The Use of Digital Microscopy for the Forensic Examination of Footwear

by

Olivia Holden

A thesis submitted in partial fulfilment for the requirements for the degree of MSc (by Research) at the University of Central Lancashire

November 2024

RESEARCH STUDENT DECLARATION FORM

Type of Award **Masters by Research**

School **School of Law and Policing**

*Sections marked * delete as appropriate*

1. Concurrent registration for two or more academic awards

Either *I declare that while registered as a candidate for the research degree, I have not been a registered candidate or enrolled student for another award of the University or other academic or professional institution

or ~~*I declare that while registered for the research degree, I was with the University's specific permission, a *registered candidate/*enrolled student for the following award:~~

2. Material submitted for another award

Either *****I declare that no material contained in the thesis has been used in any other submission for an academic award and is solely my own work

or ~~*I declare that the following material contained in the thesis formed part of a submission for the award of:~~

(state award and awarding body and list the material below):

3. Collaboration

Where a candidate's research programme is part of a collaborative project, the thesis must indicate in addition clearly the candidate's individual contribution and the extent of the collaboration. Please state below:

4. Use of a Proof-reader

Either ~~*The following third party proof-reading service was used for this thesis____________________________ in accordance with the Policy on Proof-reading for Research Degree Programmes and the Research Element of Professional Doctorate Programmes.~~
~~A copy of the confirmatory statement of acceptance from that service has been lodged with the Academic Registry.~~

or *No proof-reading service was used in the compilation of this thesis.

Signature of Candidate

Print name: OLIVIA HOLDEN

ABSTRACT

Olivia Holden: The Use of Digital Microscopy for the Forensic Examination of Footwear.

(Under the direction of Dr Catherine Tennick and Adam Baines)

During the forensic examination of footwear evidence, test impressions are taken from shoes and compared with footwear marks from crime scenes. Currently, enlargement of footwear marks is only conducted if there is visible detail at 1:1. This thesis uses a Keyence VHX 7000 digital microscope to examine 3 pairs of Nike Air Max 270 shoes for detail that could be used for comparison. Test impressions were taken to see if Schallamach were visible between replicates. Results indicate that when there is no visible detail in static test impressions at a 1:1 scale, the use of magnification at 50x and 200x exposes detail that can also be identified in three replicated impressions and the outsole that created them. Without conducting a deeper examination with the use of a Keyence VHX 7000 digital microscope, this level of detail would not have been located. In practice, this could mean that there have been instances that detail has been missed during the forensic examination of crime, and therefore, exposes a potential risk of missed convictions.

Due to a lack of research exploring footwear evidence, the understanding that static test impressions are more favourable for recording fine detail is based on anecdotal means, and not through published validation. By experimenting with and discontinuing the use of dynamic test impressions (oil and magna with black and red fluorescent powder and Printscan) within this thesis as there was no recorded detail within these test impression methods, this thesis provides data to support the anecdotal practice.

X^2 tests were conducted to enable a deeper understanding of the relationship between the detail seen in footwear test impressions and the outsole by using correspondence scores. Ultimately, there is a significant relationship supporting the view that if a 1:1 footwear impression does not show detail, that this does not mean that there is no detail to be seen; the introduction of microscopy may be required to reveal it.

Moreover, the works within this thesis have revealed that poor quality test impressions require a higher level of magnification (200x) than those that are considered a good quality, with only requiring a magnification of 50x. A finding like this can support the forensic examiner when attempting to examine a challenging print. Although further work has been suggested to continuously improve this novel method, the author proposes that with the suggested work, this method has the potential to be used by forensic science providers.

Key Terms:

Forensic Science; Forensic Footwear Comparisons; Footwear Test Impressions; Digital Microscopic Examination; Keyence VHX-7000; Schallamach; Replication; Correspondence Score.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

This thesis would not have been possible without my two incredible supervisors: Dr Catherine Tennick and Adam Baines.

I couldn't choose any two better supervisors for this project. You have both been incredibly patient and helpful. You were supportive when I needed to interrupt my studies, ultimately causing a 12-month project into a 21-month project! Despite this, you have been patient and still stuck with me to see this research through. There have been many tears shed, which ultimately turned back into laughs after your support and chocolate! Thank you for every meeting, message, caramel latte, and supporting me throughout the entirety of this research. You haven't just trained me to become a researcher, and the forensic scientist that I am today (eekk!), but you have also taught me to be kind to myself and made me into a confident, resilient, and committed individual, thank you.

I would also like to thank my examiners Dr Helen Tidy and Dr Tina Gornall for reading my thesis and for providing valuable feedback.

Jennifer Jones – Thank you for your advice and time when assisting me throughout this research and being a great RDT!

Rachael Cunliffe - Thank you for all your time, assistance, and suggestions on statistics. You made a scary part of my research not so scary with your wisdom, and I appreciate all your help in trying to make sense of my data.

Paul Langton – Thank you for sharing advice and help throughout this project and reminding me why I am doing this almost every time I bumped into you in the corridors!

To the wonderful technicians: Natalie, Irene, Amy, Clare – Thank you for always being on hand to assist with equipment, advice, and training of the Keyence, especially with a lack of notice in some cases! Thank you for your patience with me throughout this research, and for taking the time to fix the Keyence to allow me to finish this project. Your help has been undoubtedly appreciated, thank you.

> Irene – Thank you for always picking me up and supporting me throughout my lab work with your advice and laughs. Thank you for encouraging me to continue!
>
> Clare Bedford – Thank you for all your assistance and teaching me tips and tricks of the Keyence.

My family – Thank you for your encouragement and keeping me going when at times I couldn't see the end. Your belief has been such a powerful force in me completing this research.

Ethan - This research would not be possible if it was not for you. For picking up the slack of housework during my long days and late nights of writing, for encouraging me to continue, for shining a light on the end goal and reminding me that I can do this. You know this research in-and-out and have never gotten tired of hearing all about it, I can never thank you enough.

LIST OF TABLES

LIST OF FIGURES

GLOSSARY OF TERMS

1:1 – No magnification, what is seen by eye alone.

CLASS CHARACTERISTIC – A feature that is shared amongst a group of things.

FEATHERING – See *SCHALLAMACH*.

GENERIC RAC's - Used to describe damage characteristics on the outsole caused by random events such as cuts and scratches.

INDIVIDUAL / INDIVIDUALISING CHARACTERISTIC – A feature that makes something unique.

OUTSOLE – Underside of a shoe that contacts the ground.

REPLICATED / REPLICATION - Used to describe the same detail visible in another test impression.

REPLICATES / REPEATS – Used to describe the multiple test impressions created from the same source and the multiple pairs of footwear.

SCHALLAMACH – A wear characteristic on a footwear outsole that resembles the pattern of a fingerprint.

CORROSPONDENCE SCORE – Used to describe how test impression replicates and the outsole correspond in terms of features.

TEST IMPRESSION – A footwear impression created from a known shoe source.

TEST IMPRESSION-OUTSOLE – A comparison when a test impression transparent overlay is compared with an image of the outsole printed onto paper.

TEST IMPRESSION-TEST IMPRESSION – A comparison when a test impression transparent overlay is compared with a test impression printed onto paper.

ABBREVIATIONS

BGL – Black gel lift

C – Control Area

CS(s) – Correspondence score(s)

DF – Degrees of freedom

FW1L – Footwear 1, left shoe

FW1R – Footwear 1, right shoe

FW2L – Footwear 2, left shoe

FW2R – Footwear 2, right shoe

FW3L – Footwear 3, left shoe

FW3R – Footwear 3, right shoe

ISO - International Organisation for Standardisation

NFRC – National Footwear Reference Collection

RAC(s) - Randomly acquired characteristic(s)

S1 – Section 1

S2 – Section 2

S3 – Section 3

S4 – Section 4

SB1 – Static black 1

SB2 – Static black 2

SB3 – Static black 3

X^2 – Chi-square

α - Significance level

CHAPTER 1 – INTRODUCTION

1.1. Research Context:

Within forensic science, footwear evidence can be used to help determine a potential match between a footwear mark found at a crime scene and that of a suspect's footwear to assist with the investigation of crime. To do so, a forensic specialist is required to examine the pattern, size, wear, and individual damage features of the footwear (Larsen and Bennet, 2021). The pattern of footwear is established by comparing the outsole pattern to those on The National Footwear Reference Collection (NFRC); the biggest police-owned footwear reference collection in the world (Budka *et al.*, 2021). During a footwear comparison, a test impression created from seized footwear (known) is photocopied onto a clear acetate sheet and overlayed with a crime scene mark (unknown) at 1:1 as the forensic specialist compares the characteristics (Baines, 2024). If a known and unknown footwear mark matches in terms of pattern, size, and wear, observed individualising features can be used for a positive identification if one or more individualising feature share the same feature and placement on each mark, and this could produce a *hit* between an item of footwear and a footwear mark (Bodziak, 2000). However, individual features can vary in size, and the analysis of small features can pose challenges to the examiner completing a footwear comparison (Shor *et al.* 2018). Currently, it is not a routine practice to examine all footwear evidence with microscopy, whereas microscopy is often used in other forensic evidence types such as: tools and tool marks (Baldwin *et al.,* 2013), ballistics (Kumar and Sharma, 2022), and fibres (Agarwal and Chang, 2022), and it is thought that critical evidence is missed without microscopic examination of footwear evidence. Therefore, this research explicitly analyses microscopic features of the footwear outsole and test impressions created from the shoe to explore if there is additional detail that cannot be seen by the naked eye, and therefore if microscopic examinations should routinely be conducted on footwear evidence. Taking this further, the replication of the microscopic features directly from the outsole and test impressions is also addressed to understand the significance of the findings.

The relationship between footwear evidence and microscopic analysis, primarily regarding the replication of microscopic features has not been heavily researched. In contrast, microscopic analysis of footwear outsoles in association with forensic botany has been more extensively researched. Specifically, the retention of very small particles (Stoney *et al.,* 2019), loss and replacement of particles (Stoney *et al.,* 2016), and the usability of plant material (Virtanen *et al.,* 2007). However, it is important to note that these studies' primary focus surrounds evidence *on* the outsole, and not individual features as *part* of the outsole itself. However, the area of microscopy and footwear evidence is sparse. High-powered microscopic analysis of footwear evidence within a forensic context is currently not routinely practiced in forensic Standing Operating Procedures (Lancashire Constabulary, 2020), and there has been no substantial academic research exploring this area. An exploration of existing studies will be discussed in more detail in Chapter 2: Literature review.

When considering that an offender has been in contact with the floor or other surfaces during a crime, footwear evidence has the potential to be found at every crime scene; following the universally accepted rule of Locard's exchange principle: "every contact leaves a trace" (Locard, 1920). Footwear marks can be positive or negative: negative footwear marks occur when the outsole removes a contaminant from a surface, such as a clean shoe encountering a dirty surface; positive footwear marks occur when the outsole deposits a contaminant onto a surface, such as a bloody footwear mark depositing a footwear mark in blood (National Policing Improvement Agency, 2009). However, chemical or physical enhancement may be necessary to reveal a latent print (Cellmark, 2021). Footwear marks found at a crime scene require a level of interpretation as a footwear mark created by walking, kicking, and climbing, for example, can change the morphology of the impression (Baines, 2024), causing marked differences to the footwear that created it. However, to the skilled examiner, these differences can be overcome by reproducing the conditions of how the footwear mark was likely deposited. In spite of challenges, the examination of footwear evidence is possible and can make useful contribution to forensic investigation.

When considering the unique properties embedded into the outsole such as distinctive wear, cuts and defects (Naples and Miller, 2004), and the fact that criminals often do not consider to destroy their footwear marks (Bisbing, 2006), and the commonality of suspects wearing the same shoes between offences (Srihari and Tang, 2014), footwear evidence holds a large significance and has a great evidential value, potentially resulting in a smaller group of suspects and a possible link between multiple crime scenes and victims (Richetelli *et al.*, 2017b; Speir *et al.,* 2016).

Despite the evidential value of footwear evidence, there is a lack of research within forensic science, and this has been recognised within the House of Lords who state, “almost every forensic science sub-discipline has areas that evidence suggests would benefit from further research" (Parliament. House of Lords, 2019: 173), and this "should be a research priority" (Parliament. House of Lords, 2019: 169). The current methods used to examine footwear evidence does not seem to have changed for some time, however, this research intends to explore possibilities for adaptation of current methods. The absence of research in relation to footwear and microscopy needs further investigation. Considering the current research, future studies may find that potential *hits* between suspected footwear and crimes have gone unnoticed by not using microscopic examination on all footwear evidence in forensic cases.

This thesis considers that there may be detail within footwear marks currently going unnoticed to the forensic specialist who routinely conducts footwear comparison work by eye alone. Currently, photographic enlargement of footwear evidence is only practiced if there is fine detail within a test impression visible at 1:1 that may share similarities with a crime scene mark (Lancashire Constabulary, 2020). This raises a question about whether microscopy should be introduced into the footwear Standing Operating Procedures on all handled footwear evidence.

1.2. Research Aims:

To ensure this thesis benefits those in the forensic sector and future research, a thorough review of the literature is required. Considering previous similar research within the subject area can assist when producing a methodology and will allow for successful research when noting any area of limitations discovered. The following aims and objectives have been set:

- Discuss how individualising features of footwear occur and if there are variables that can affect the placement of features on an outsole that should be considered.
- Review literature regarding individualising features of footwear, highlighting the authors choice of method when creating impressions of footwear, considering their findings when observing individualising features.
- Obtain a sample of footwear and identify if there are additional features that can only be seen with microscopy.
- Explore if any microscopic features observed replicate those from the outsole.
- Quantitatively report the results by a combination of figures, tables, and statistics for clarity.

1.3. Thesis Outline:

The following chapters are structured accordingly to allow for a complete understanding of the subject area.

Chapter 2 – Literature Review.

Chapter 3 – Methodology.

Chapter 4 – Results.

Chapter 5 – Discussion.

Chapter 6 – Conclusion.

Chapter 7 – Appendix.

CHAPTER 2 - LITERATURE REVIEW

This literature review will draw together existing work relating to the current topic area, such as a background of class and individualising characteristics, an evaluation of using new/worn shoes in footwear research, the assignation of subjects, methods of test impression creation, an evaluation of subsections of an outsole, and a forensic case where enlargement of a footwear mark was paramount.

2.1. Background of Class and Individualising Characteristics:

In footwear evidence, the features comprising the footwear can be divided into two groups: *class characteristics* and *individualising characteristics* (Bodziak, 2000). Class characteristics are the "intentional or unavoidable characteristics that repeat during the manufacturing process and are shared by one or more shoes" (Bodziak, 2000: p329), such as the pattern design and size of the footwear (Cassidy, 1980). In contrast, individualising characteristics are features that are "randomly added to or taken away from a shoe outsole" (Bodziak, 2000: p.335), obtained through random events of wear and tear, making the outsole unique (Tuthill, 1994). Further, randomly acquired characteristics (RACs) are individualising characteristics used to describe random markings on a shoe outsole such as cuts, scratches, or holes (Kaplan-Damary *et al.,* 2018), that can appear due to environmental conditions such as stepping onto glass **(Figure 1)**. Conversely, Schallamach, also referred to as *feathering*, was originally discovered on tyres by Adolph Schallamach, and is an individualising characteristic on the rubber outsole of footwear appearing as a ridge-like abrasion pattern like seen in fingerprints (Smith, 2009), occurring due to continuous abrasion during wear (Davis and Keeley, 2000) **(Figure 2)**. A diagram showing the breakdown of footwear characteristics can be seen in **Figure 3**. To allow for a clear differentiation between the two types of individualising characteristics, the term 'generic RACs' will be used going forward to describe damage characteristics on the outsole caused by random events such as cuts and scratches, and Schallamach will be used to refer to the abrasion pattern.

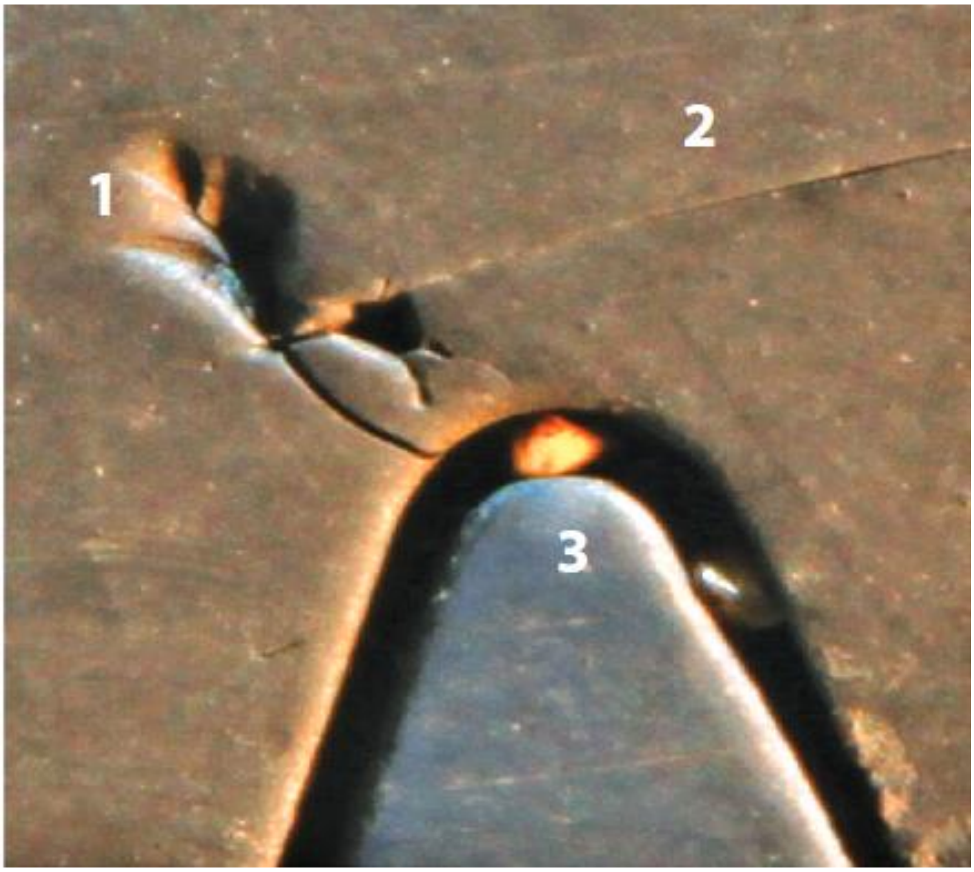


Figure 1: *An image of different types of generic RACs on the outsole of footwear, highlighted with numbers. 1: puncture, 2: fine scratch, 3: stone hold. Adapted from a collage of images from Bodziak (2000)*

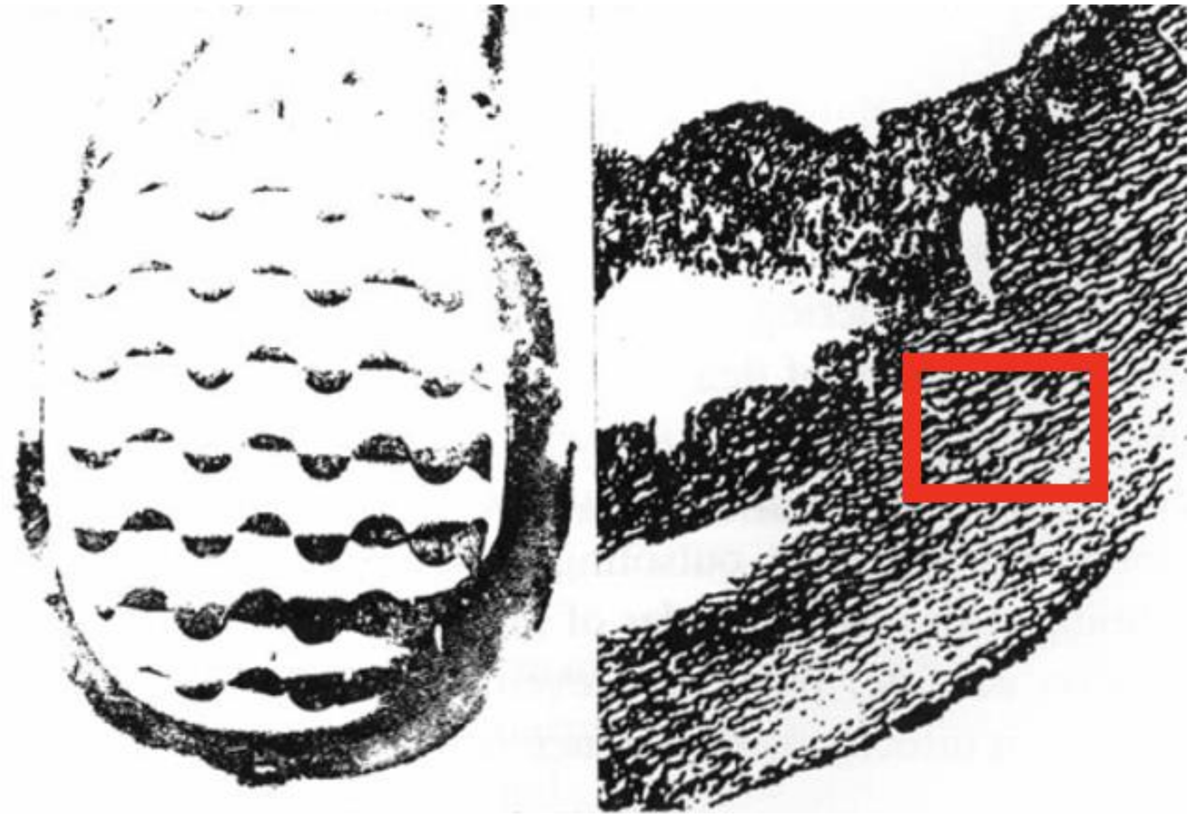


Figure 2: *The Schallamach pattern on the heel of a Reebok outsole (left) and at 3.5x magnification (right), highlighted by a red box. Taken from Davis and Keeley (2000)*

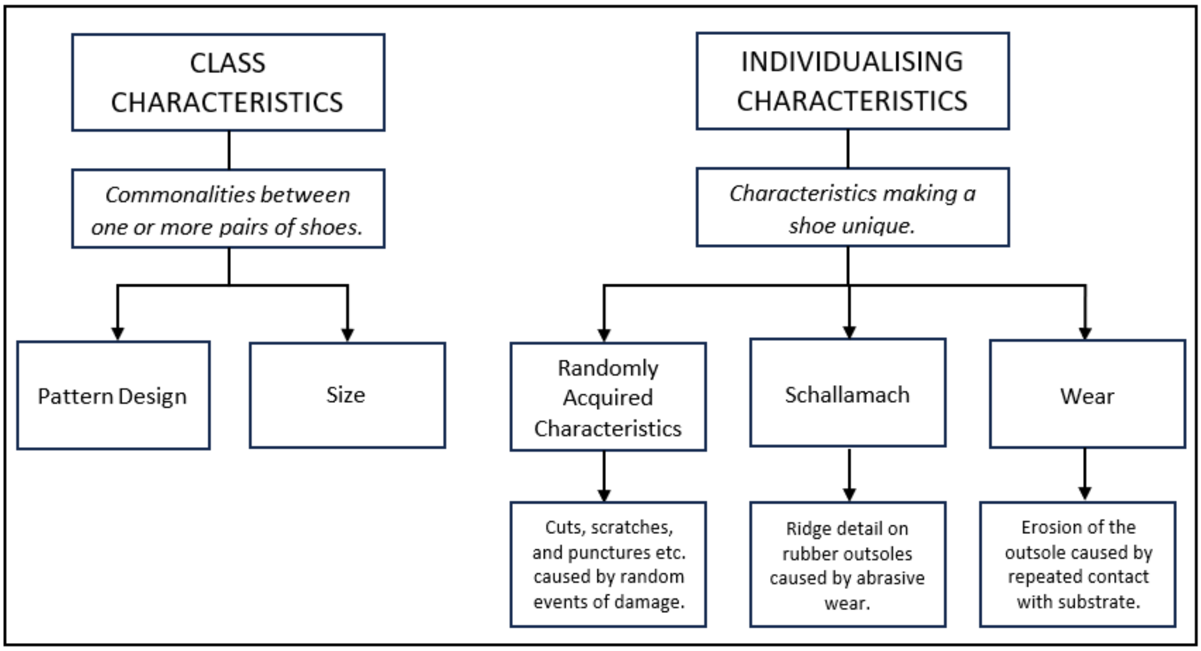


Figure 3: *A diagram highlighting class and individualising characteristics in footwear*

2.2. Previous Research:

To obtain sufficient knowledge regarding previous methodology and data sets used in footwear research, researchers focusing primarily on generic RACs in footwear are included in this literature review due to the vast research exploring these characteristics. Namely, the stability (Moorthy and Chelliah, 2013); quantification (Speir *et al.,* 2016); similarity (Richetelli *et al.,* 2017a); classification (Richetelli *et al.,* 2017b); relationship and dependence (Kaplan-Damary *et al.,* 2018); retention and loss of foreign objects (Liu *et al.,* 2019), reproducibility (Liu *et al.,* 2020); rarity (Wiesner *et al.,* 2020); and the location distribution (Kaplan-Damary *et al.,* 2022) of RACs has been discussed in published literature. On the contrary, there is limited research where the Schallamach pattern in footwear is the sole purpose of research, with only discovering papers studying the changes (Davis and Keeley, 2000); and specificity and reproducibility (Zhang *et al.,* 2021) of Schallamach.

To gain a more detailed understanding of footwear mark examination and suitable methodologies, it is important to discuss both generic RAC's and Schallamach patterns.

2.2.1. New vs. Worn Shoes

The presence of Schallamach is reliant on deformations of the rubber outsole during wear (Zhang *et al*., 2021), and therefore is not present on new shoes and does not occur as part of the manufacturing process. As Davis and Keeley (2000) observed the changes of Schallamach over time, they opted to examine each pair of footwear from new. However, many researchers examined shoes that were already exposed to wear (Zhang *et al.*, 2021; Richetelli *et al*., 2017a; Richetelli *et al.,* 2017b; Speir *et al.,* 2016;

Kaplan-Damary *et al.,* 2018; Kaplan-Damary *et al.,* 2022; Wiesner *et al*., 2020). In contrast, Moorthy and Chelliah (2013), Liu *et al*. (2019), and Liu *et al.* (2020) do not state whether shoes were new or worn at the start of the research. Therefore, comparing the data from these studies does not seem appropriate as this variable cannot be established. It is possible that new and worn shoes behave differently, for example, a new shoe may have a tougher rubber outsole than a worn shoe, and this differentiation could be a critical variable when observing how the outsole retains and loses foreign objects in the outsole. For example, Hemler *et al.* (2021) completed a study on the relationship between gait and the shoe outsole wear rate and found that the rate at which shoes wear out is dependent on an individuals' gait and the force used during wear. Similarly, Verma *et al.* (2014) reported that slip-resistant shoes are less effective after six months than those worn for under six months. As shoes are typically manufactured from elastomeric material, the wear of outsoles is consistent with the fatigue failure wear theory of elastomeric outsole wear and the tearing energy of the outsole contributes to elastomer fatigue and failure (Hemler *et al.,* 2021). Seemingly supporting the view that the greater degree of outsole wear corresponds with quicker elastomeric failure, and potentially causing a weaker outsole that is more susceptible to random events of damage. Supporting this, Kaplan-Damary *et al.* (2018) also found that being a wear characteristic, Schallamach was less prone on heavy duty outsoles due to the stronger material of the outsole. However, further research on this area may be required for a deeper understanding.

With the aim to understand the causes of the Schallamach pattern, Davis and Keeley (2000) created footwear impressions with new shoes and examined the impressions over time to approximate when Schallamach appears, changes, and erodes completely. They found that Schallamach appears in as little as 9 hours of wear, began to change after 31 to 32 hours of wear, and were completely different after a further 6 to 16 hours of wear (Davis and Keeley, 2000). Although the current study does not observe the changes of Schallamach, it demonstrates that it is essential to examine the shoes from new, despite the expected absence of Schallamach. Often, shoes bought from online retailers are returned, and it remains unknown if the shoes purchased for the current study have been previously returned to the retailer after brief wear. Therefore, due to the quick nature that Schallamach appears (Davis and Keeley, 2000; Bodziak, 2000), examining the shoes from new demonstrates that the Schallamach observed is in fact Schallamach and can define potential characteristics to assist with creating a robust and reliable research project.

Similarly, Richetelli *et al.* (2017a), Richetelli *et al.* (2017b), Speir *et al.* (2016) and Wiesner *et al*. (2020) created footwear impressions that were created by worn shoes. Importantly, these were obtained from thrift stores, personal and corporate donations (Richetelli *et al.,* 2017a; Richetelli *et al.,* 2017b; Speir *et al.,* 2016), and shoes confiscated by suspects from previous criminal cases (Wiesner *et al.,* 2020). However, Richetelli *et al.* (2017a), Richetelli *et al.* (2017b) and Speir *et al.* (2016) used the footwear impressions to observe how well RACs replicate, contrary to Wiesner *et al*. (2020) who studied the rarity of RACs. It is hypothesised that a RAC rarity score cannot be applied to a shoe without understanding the wear history. Without making their own footwear impressions, Kaplan-Damary *et al.* (2018), and Kaplan-Damary *et al.* (2022) obtained worn impressions from the Israeli Police Division of Identification and Forensic Science to observe the relationship and dependence (Kaplan-Damary *et al.,* 2018) and location distribution (Kaplan-Damary *et al.,* 2022) of RACs. Whereas the worn footwear impressions used in Zhang *et al.* (2021) were obtained from the published work of Liu *et al.* (2020) to explore the specificity and reproducibility of Schallamach.

Obtaining worn shoes in footwear research regarding the observations of the outsoles could cause unavoidable variables and potentially lead to subjective assessments. For instance, an absence of data discussing the previous shoe owners' walking habits, or if the shoes have been worn by various people each with different walking habits, can cause characteristics to appear in various locations. Due to RACs occurring due to random events causing damage, the location of RACs can be altered and further influenced by the type of substrate walked upon and by the gait: the manner a person walks (Bodziak, 2017). During walking, the foot pronates and supinates - in pronation, the foot is flexible and rolls inward as weight is distributed throughout the foot; in supination, the foot is rigid as it pushes off the surface; some people may pronate or supinate more than others, thus having differing gaits and wear patterns (Bodziak, 2000). Like RACs, there is also a correlation between gait and Schallamach, but Schallamach is created differently: as the rubber outsole bends due to external pressure, the molecular chains within the rubber that were once in a fixed position, distanced from neighbouring chains alter position, and the rubber outsole deforms as the molecular chains move with Brownian motion (Zhang *et al.,* 2021), further shown in **Figure 4**. It is the repeat deformations of the outsole due to continued wear which eventually lead the molecular chains to break, thus creating Schallamach patterns (Zhang *et al.,* 2021). As Schallamach is created with Brownian motion (Zhang *et al.,* 2021), it is possible that Schallamach could potentially appear in areas of the outsole that do not receive excessive pressure due to the movement of the molecular chains within a high-pressure point of an outsole effecting neighbouring chains. Unfortunately, there are no suitable examples of an outsole with and without Schallamach as seen under magnification, and future studies should publish visual examples. After reviewing the ways in which RACs and Schallamach form, the importance of understanding the history of each footwear used in footwear research, such as if a shoe was new or worn or worn by two or more people with differing gait, has been understood. The rarity of RACs in various locations as observed in Wiesner *et al*. (2020) could potentially be unreliable without understanding the footwear history information due to the likelihood of observing individualising characteristics in unexpected locations which could skew the data. To fully quantify (Speir *et al.,* 2016) the similarity (Richetelli *et al*., 2017a), the relationship and dependence (Kaplan-Damary *et al*., 2018), location distribution (Kaplan-Damary *et al*., 2022) and rarity (Wiesner *et al*., 2020) of RACs, results may be better understood with controlled variables, and understanding the history of each footwear.

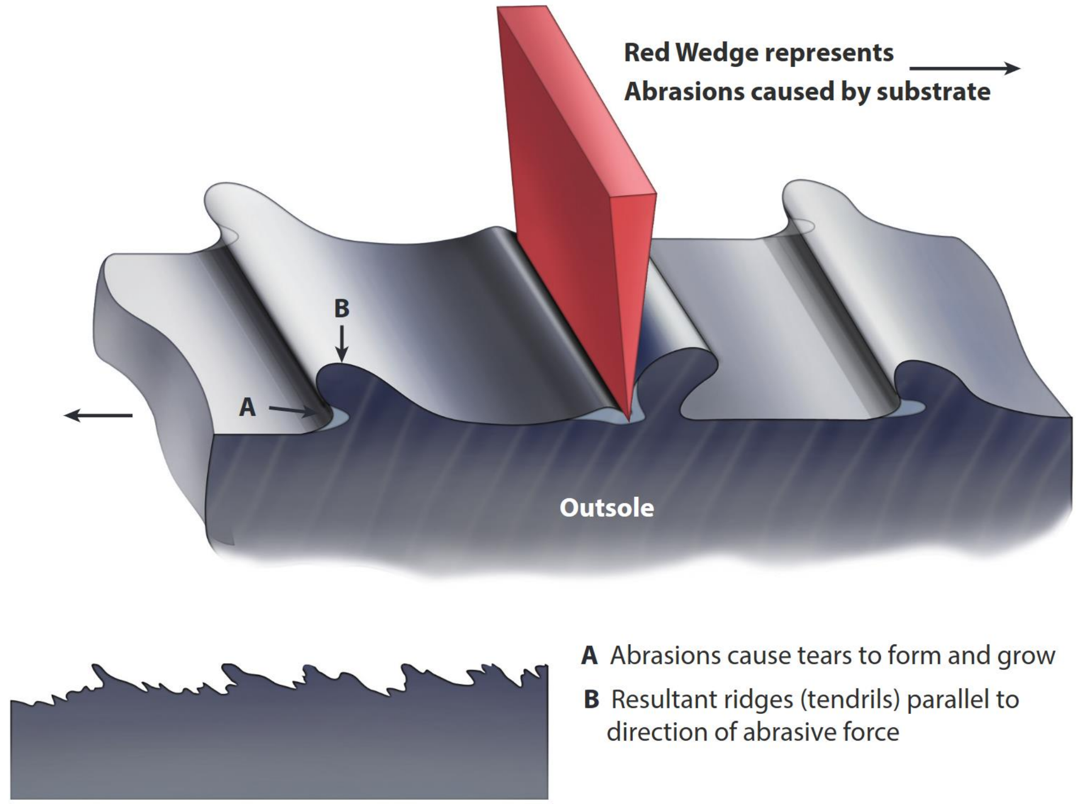


Figure 4: *An image to show the creation of Schallamach from Bodziak (2017); the red wedge representing the substrate causing abrasion as the outsole scruffs across it, the randomly created ridges then connect to form Schallamach patterns.*

2.2.2. Assigning Participants

Recognising that the wearer of the footwear can alter how the outsole displays characteristics, Liu *et al.* (2020) took careful consideration when obtaining participants and samples. They chose 42 students with the same timetables and shoes, causing their shoes to receive similar exposures in terms of route and surface considerations. Similarly, Davis and Keeley (2000) assigned one individual to wear all the new shoes in the sample (4 pairs), to control the variables.

The assigned participant wearing the footwear in the study should also be assigned to create test impressions or crime scene marks where the footwear must be worn, to exclude pressure variations. Replica crime scene marks were created in few studies observing generic RAC's (Richetelli *et al.,* 2017a; Richetelli *et al.,* 2017b). However, five to six analysts of differing weight and shoe size were assigned shoes from a random sample of footwear. In their research, Richetelli *et al*. (2017a) proposed RAC replication between crime scene marks, test impressions, and the shoe source is rarely an exact replica. However, without understanding the dependant variables of each analyst and shoe wear history, it becomes clear that pressure variation was not accounted for in this study. Surprisingly, it was not mentioned if the analysts were assigned shoes that match their own shoe size, which could potentially cause pressure variation and an absence of RACs in areas where their feet would not fill out the shoes. Supporting this defence, the current policy at Lancashire Constabulary is to assign an analyst with the same as or +1 or -1 size of the shoe being examined, and if known, a similar weight as the individual who the shoes have been seized from to ensure a true like for like comparison, (Baines, 2024). Speir *et al.* (2020) conducted a study on the reliability of footwear examiner agreement and acknowledged that their study may have had limitations as the individual who created the footwear impressions had a smaller shoe size than the outsole used in their study; supporting the view that shoe size could be a critical variable to consider. Contradictory, Bodziak (2000) states that it is not necessary for the analyst to share the same shoe size or weight as the person who the shoes were seized from. However, the author proposes that if the shoes worn by the analysts were too large or if there is a large difference in body weight, that this could potentially cause a differentiation of pressure that may influence the quality of the mark being made, and this could be a reason for finding a low RAC replication in the research by Richetelli *et al*. (2017a). However, more work needs to be published in this area for a deeper understanding. Although Schallamach was not directly observed in the above study, acknowledging the limitation of a differentiation of pressure, one analyst will create all impressions in the current research. Microscopically examining Schallamach and other microscopic detail whilst controlling the variables, it is hoped that replication would be higher due to being able to view each characteristic in higher detail.

2.2.3. Method of Taking Test Impressions

With various methods of taking test impressions of footwear, it is hypothesised that there will be a more favoured method when observing the replication of Schallamach and other microscopic detail microscopically, and the method used is thought to have a crucial effect on observations.

After trial and error of other methods, Davis and Keeley (2000: p.273) opted for a method they say to be the "easiest and most reliable"; loading a 12.5mm brush with carbon black powder, making an impression on self-adhesive film and sealing with clear non-adhesive film. Although it is not directly stated, the method described shares similarities with the static/powdered method of creating test impressions. Although no discussion on why this method was the most reliable or if the footwear was worn during the process, this paper was published 24 years ago, and attempting other methods of taking test impressions may assist with updating the literature on the most appropriate method when analysing Schallamach microscopically.

Richetelli *et al.* (2017a), Richetelli *et al.* (2017b), Zhang *et al*. (2021), and Liu *et al.* (2020) opted for the Handiprint method of creating test impressions as detailed in Speir *et al.* (2016) **(Figure 5)**. Handiprint impressions were created by applying black powder to the outsole and brushed with a Zephyr brush in at least three directions to ensure full coverage, removing excess powder with three to four taps and placed onto the Handiprint sheet, and pressed onto the outsole before removing the Handiprint and applying a clear polyester cover (Speir *et al.,* 2016). Although this is not specified, it is thought that Handiprint Lifter Material is an American version of Avery Dennison or Fablon lifters, which are used during static/powdered test impression creation in the United Kingdom. The method is detailed and the application of powder in three directions and tapping off excess powder implies that the method could be repeatable with consistent results. Once the Handiprint impressions were made, they were digitalised and background subtracted by initially tracing the perimeter of the outsole with the computer cursor, primarily mapping and labelling each pixel as “belonging to the outsole or belonging to the background” (Speir *et al.,* 2016). This ‘map’ was then mathematically multiplied to the other Handiprint digitalised images. An analyst examined each RAC present on both the outsole and impression using oblique light and 4x magnification (Speir *et al.,* 2016). Using Photoshop, each RAC was outlined at 200x magnification to result in a RAC map, highlighting the location and geometry of each RAC.

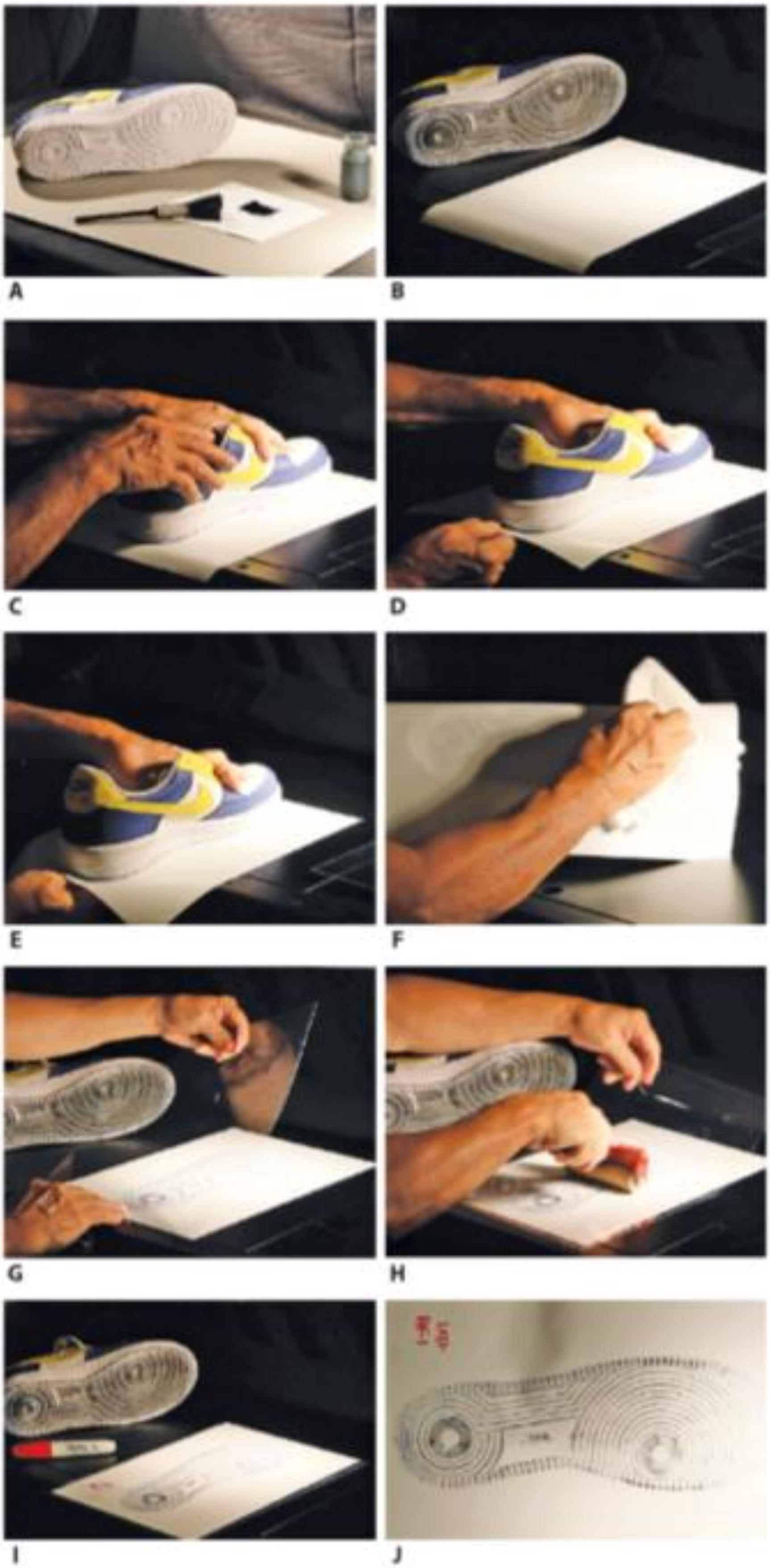


Figure 5: *Fingerprint powder and white or transparent adhesive (static) test impressions (Bodziak, 2000)*

Zhang *et al*. (2021) specifically addressed the reproducibility of Schallamach on the heel of rubber outsoles, and due to the similar topic area of the current research, their chosen method provides interest. To make their test impressions, the method of using Handiprint lifters were used (Zhang *et al.*, 2021; Speir *et al*., 2016). The authors used Photoshop CS6 to conduct their examinations by inserting a grid over the footwear marks and examining each grid in turn (Zhang *et al.* 2021). Although the outsole was not divided into specific subsections like other researchers (Kaplan-Damary *et al*., 2018; Kaplan-Damary *et al.,* 2022; Speir *et al.,* 2016; Liu *et al*., 2019), their examination of a smaller 5mm x 5mm region is expected to make examinations easier due to the smaller area. Due to the distinct pattern of Schallamach, they concluded that the Schallamach pattern can be distinguished without knowing the presence/absence, angle, and density of Schallamach patterns (Zhang *et al.* (2021). After their study observed an ability to distinguish Schallamach without this additional information, the current research hopes to generate additional knowledge regarding detail within Schallamach with a high-power microscope, whilst considering the replication of this pattern amongst other test impression methods and the outsole.

All authors opted to create powdered test impressions without attempting other methods, and there is no discussion into why this was the preferred method. It may be beneficial to attempt different methods of creating test impressions and conduct a validation on the preferred method.

2.2.4. Outsole Subsection(s) Examined

Researchers have been intrigued by the location RACs or Schallamach are found on an outsole. Most researchers examined the whole outsoles, split into various subsections (Kaplan-Damary *et al*., 2018; Kaplan-Damary *et al.,* 2022; Speir *et al.,* 2016; Liu *et al*., 2019) to identify and discuss potential causes of the most populated subsections. In this subchapter, the focus will be on the researchers highlighted above to discuss the subsections selected; including the works by Davis and Keeley (2000) and Zhang *et al.* (2021) who did not use subsections, but did focus on the Schallamach pattern, similar to the current research.

Kaplan-Damary *et al.* (2018) and Kaplan-Damary *et al.* (2022) examined the entire outsole divided into 14 subsections, **Figure 6**, "according to expert knowledge". However, it is not disclosed who the experts are, what field they are experts in, how long they have been experts, and if they have been wrong is not discussed, and should therefore be used with caution. Within the seven categories of RACs used, shown in **Figure 7**, 6.88% of RACs observed were Schallamach; the most (185) found medially in subsection 6 and the least (13) found in subsection 8 (Kaplan-Damary *et al.,* 2018). However, it is unknown how each Schallamach was counted, as like a fingerprint, Schallamach often has bifurcations, **Figure 8**, thus causing potential complications when attempting to count the features.

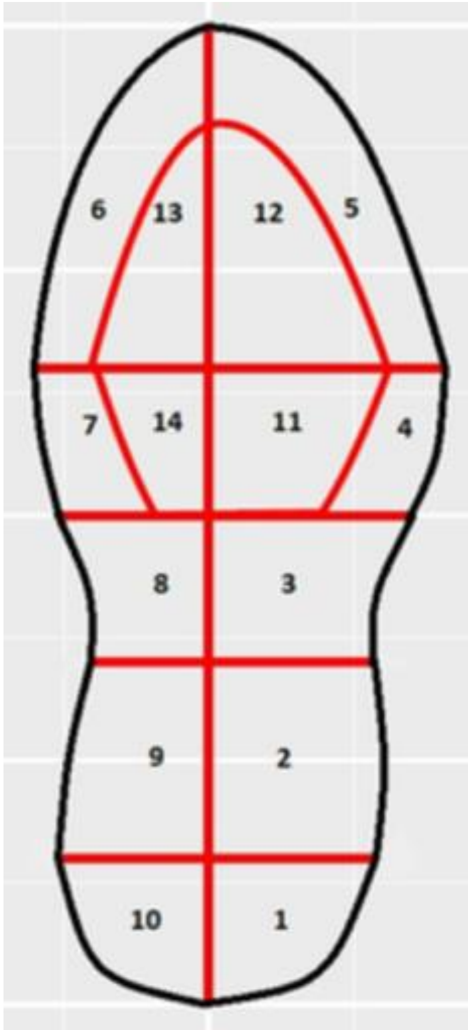
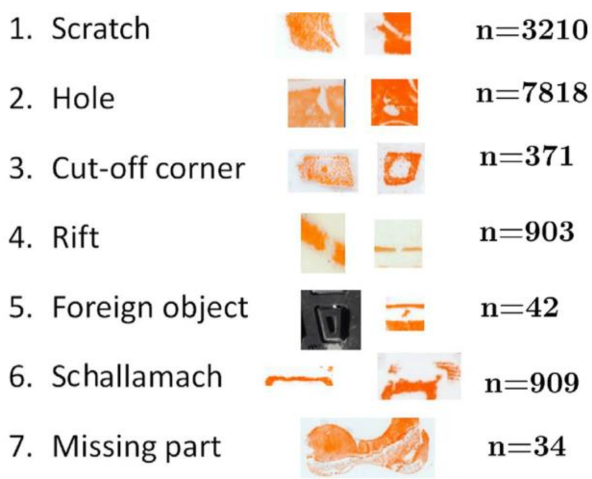


Figure 6: *Outsole divided into 14 subsections (Kaplan-Damary et al., 2018; Kaplan-Damary et al., 2022)*



Shape type	1 (Scratch)	2 (Hole)	3 (Cut-off corner)	4 (Rift)	6 (Shcallamach)	Total
Sub area						
1	203	445	7	29	38	722
2	372	965	34	122	77	1570
3	92	336	12	77	33	550
4	169	372	22	11	37	611
5	306	710	34	55	100	1205
6	401	944	64	81	185	1675
7	74	191	13	30	37	345
8	36	119	13	31	13	212
9	368	904	24	105	56	1457
10	193	464	11	37	37	742
11	233	554	37	111	62	997
12	361	852	47	80	104	1444
13	290	679	30	68	97	1164
14	112	283	23	66	33	517
Total	3210	7818	371	903	909	13211

Figure 7: *The seven categories of RACs from Kaplan-Damary et al. (2016), taken from Yekutieli et al. (2016) [top], and the occurrence of each type of RAC in each sub area of the shoe taken from Kaplan-Damary et al. (2018) [bottom]*

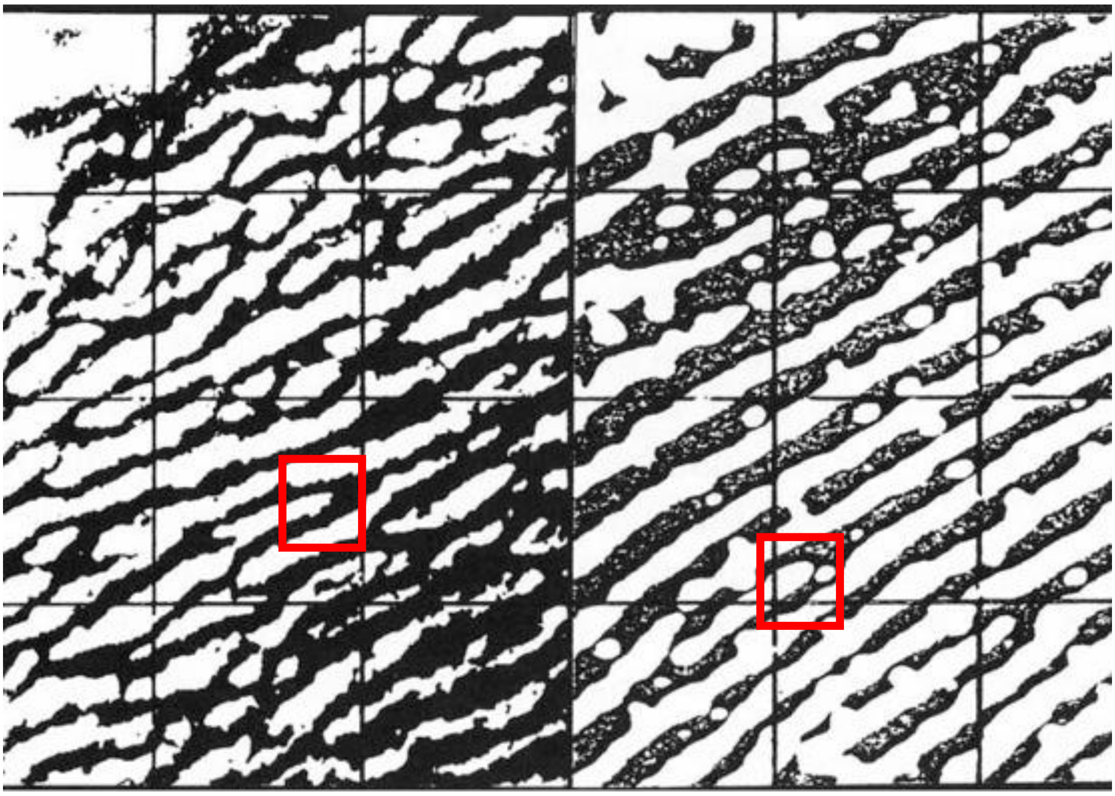


Figure 8: *Schallamach on an outsole [left] and a fingerprint [right], with similar bifurcations highlighted with a red square, taken from Davis and Keeley (2000)*

Although not specifying Schallamach in Kaplan-Damary *et al.* (2022), they found the most generic RACs in the stepping circle: subsections 11 and 14; and the least in the lateral heel: subsection 1. The subsections selected are rigorous, the divide between section 6/13, and 5/12 allows for specific identification of characteristics around the front of the toe area and metatarsals where pressure may be different for individuals who under-pronate or over-pronate their feet when walking, as illustrated in **Figure 9**. Creating a similar divide around the outer edges of sections 10 and 1 may provide additional specific characteristics because of potential pressure variation around the heel.

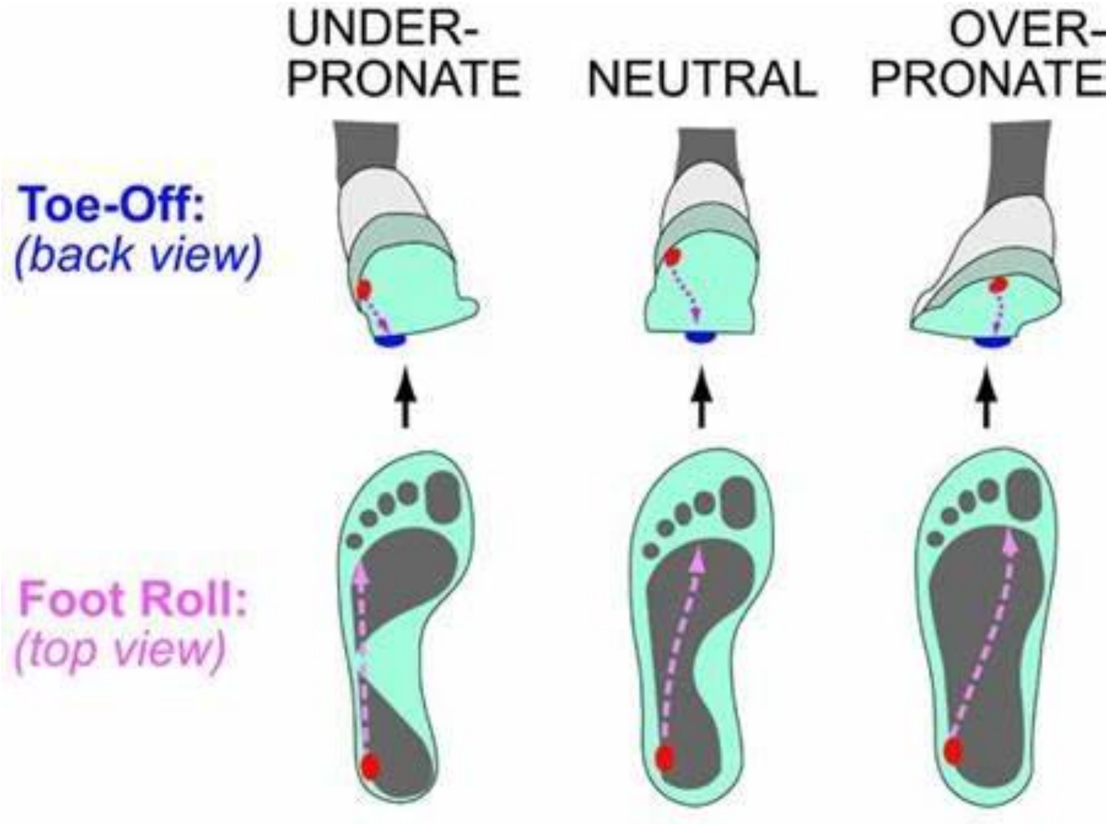
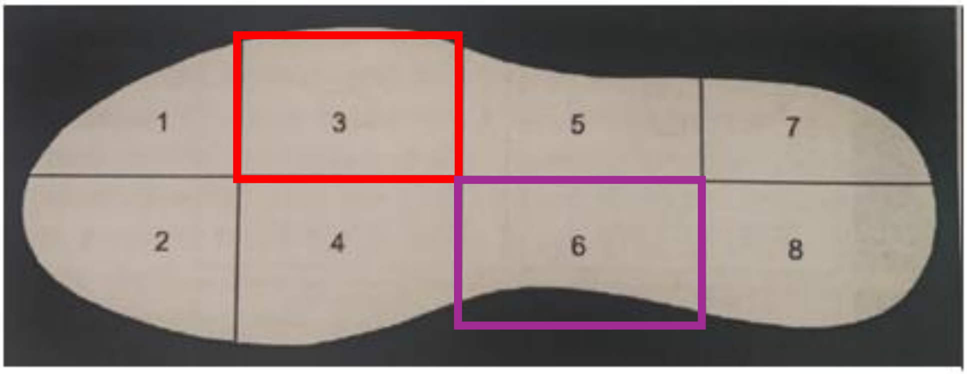
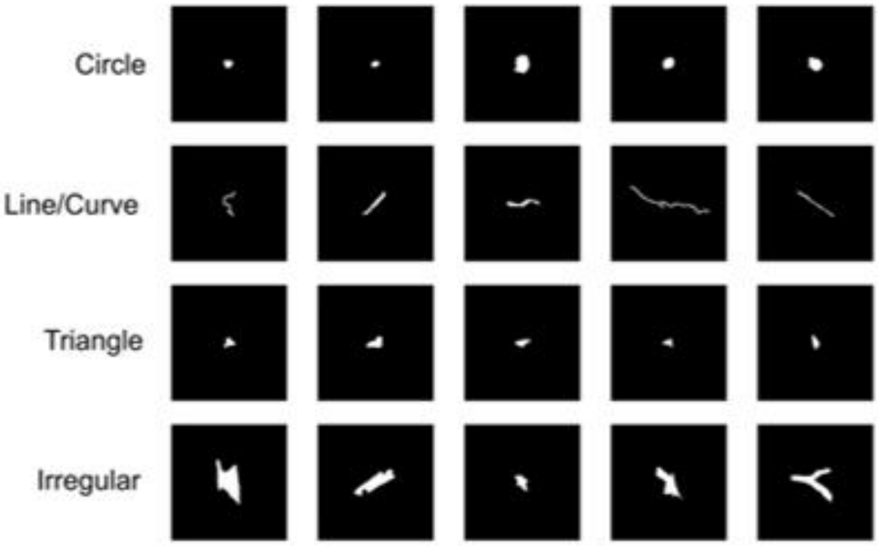


Figure 9: *An illustration to show when the foot under-pronates (left), is neutral (centre), and over-pronates (right). Adapted from an image from Douglass and Miller (2015).*

Speir *et al.* (2016) examined the entire outsole divided into 8 subsections, **Figure 10**. Although the research did not specifically explore Schallamach, they briefly noted 74.3% of the shoes examined had Schallamach present (Speir *et al*., 2016). However, as Schallamach was not the focus of their research, it is unknown in which areas Schallamach was most common. In terms of generic RACs, 4 categories were used, and they observed the most RACs in the lateral toe area, section 3 (10,377), and the least in the medial upper heel, section 6 (3,886). Contrasting the results by Kaplan-Damary *et al.,* (2018) who found the most RACs within the medial toe area. However, it would not be reliable to compare the results between the two studies without reiterating that the outsole sections are different; in Speir *et al.,* (2016) their section containing the most RACs is much larger than in Kaplan-Damary *et al.,* (2018) and the categories and definitions of RACs are different. Moreover, the difference of results could be explained by the type of shoes used. Although Speir *et al.,* (2016) do list all the varying brands of footwear examined, Kaplan-Damary *et al.,* (2018) do not, and the author proposes that the outsole design has an impact on the location of RACs. Furthermore, despite Speir *et al.* (2016) listing the footwear brand examined, they do not separate their RAC results into brand-specific tables to allow for a deeper understanding on this variable. A table containing the brands of footwear used can be seen in **Figure 11**. The subsections allocated for this research would not be detailed enough for the current microscopic details the current research seeks to observe due to the microscopic examination exploring small areas.





Metric	All RACs	Irregulars	Circles	Triangles	Lines/curves
Total	10,377	4002	1170	568	4637
Minimum number in a cell	0	0	0	0	0
Maximum number in a cell	124	46	19	14	72
Mean number in a cell	69	27	8	4	31
Median number in a cell	68	27	8	4	31

Metric	All RACs	Irregulars	Circles	Triangles	Lines/curves
Total	3886	1610	425	184	1667
Minimum number in a cell	0	0	0	0	0
Maximum number in a cell	99	32	17	6	48
Mean number in a cell	34	14	4	2	15
Median number in a cell	33	14	3	1	12

Figure 10: *Outsole divided into 8 subsections (top); categories of RACs (centre), the occurrence of each type of RAC in subsection 3 (centre) [highlighted with a red box], and subsection 6 (bottom) [highlighted with a purple box]. Adapted from Speir et al. (2016)*

Manufacturer/brand	Number
Adidas	28
Asics	30
Brooks	10
Converse	30
Hoka	36
New balance	20
Nike	294
Puma	14
Reebok	160
Skechers	12
Under armour	60
Unknown	26
Other (fewer than 10 shoes)	280
Total	1000

Figure 11: *A figure taken from Speir et al. (2016) listing the footwear brand and quantity used in their research*

In Liu *et al.* (2019) research, 19 subsections were used, and they found the most likely areas for a foreign object to remain held in the outsole were sections 9, 12, 13, 14, and 15 **(Figure 12)**. Although the current research does not observe foreign objects in the outsole, it may inadvertently imply that these areas have the most pressure and contact with the ground. Therefore, showing which areas may be worn quicker in a shorter time which is helpful for the current research due to the time restrictions the research has. The subsections allocated for this research are the most detailed, and there are further subsections around the heel, that Kaplan-Damary *et al.* (2018) and Kaplan-Damary *et al.* (2022) excluded.

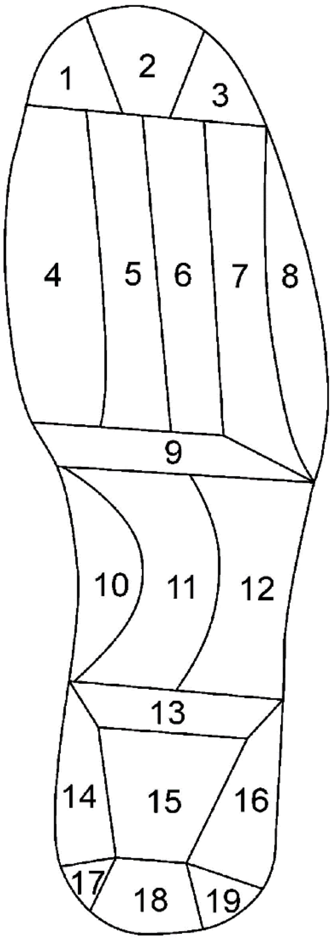


Figure 12: *Outsole divided into 19 subsections (Liu et al., 2019)*

Davis and Keeley (2000) examined the whole outsole and found Schallamach on all worn areas but found extensive Schallamach at 3.5x magnification within the heel and toe region. Although there is no information or images regarding Schallamach appearing on the medial or lateral toe region, it is presumed that by stating Schallamach was found on “all the worn areas of the outsole, but mainly around the heel and toe” suggests this is both medially and laterally (Davis and Keeley, 2000: p. 273). It is neither mentioned if the medial or lateral heel receives the most Schallamach, but **Figure 13 (*right*)** shows the centre and lateral heel with Schallamach at 3.5x magnification. However, there is no magnified image of

Schallamach at the medial heel. This could be explained by the outsole style; there are few ground level blocks where Schallamach could appear, **Figure 13 (*left*)**. Further supporting the view that the outsole design has a large impact on the formation of individualising features. It is hypothesised that with high microscopy and examining the outsole, that Schallamach will be present in the medial heel.

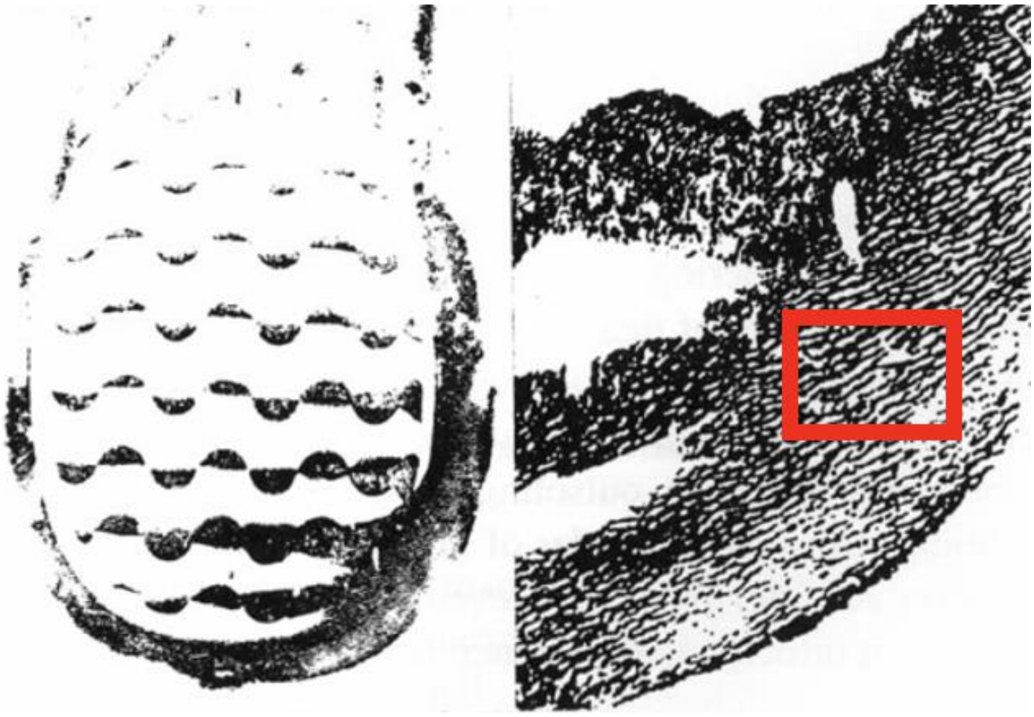


Figure 13: *The Schallamach pattern on the heel of a Reebok outsole (left) and at 3.5x magnification (right), highlighted by a red box. Adapted from Davis and Keeley (2000)*

Recognising that Schallamach appears the most at the heel, Zhang *et al.* (2021) focused their research examining this area and found similar results to Davis and Keeley (2000), when considering Schallamach within the lateral heel, **Figure 14**.

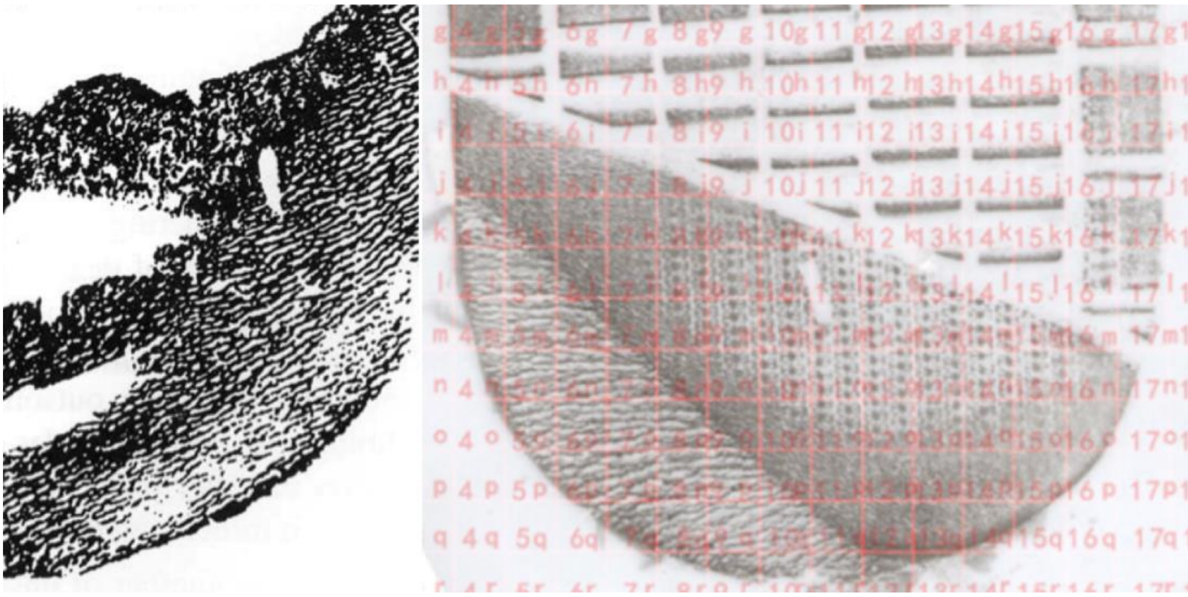


Figure 14: *Schallamach patterns in the heel region of an outsole. Left (Davis and Keeley, 2000) and Right (Zhang et al., 2021)*

Considering weight and pressure placement when walking and standing, it is expected for an outsole to wear more in the heel region, subsequently resulting in an increase of Schallamach in this area. However, focusing just on the heel region should be used with caution as very worn outsoles can erase Schallamach due to becoming "very fine and fragmented or the outsole being worn smooth" (Davis and Keeley, 2000: p.273). This point remaining true from 23 years earlier as Davis and DeHaan (1977) stated continuous wear in this region erased the occurring RACs, causing the opposite effect. Suggesting that there may be a limit to focussing on Schallamach within the heel after extensive wear, therefore, the current research hopes to observe and see replication of Schallamach between the outsole and test impressions on various areas of the outsole as well as the heel, that may benefit forensic science providers in the future.

It has been previously suggested that Schallamach may be able to contribute to forensic identification (Zhang *et al.,* 2021), and that these patterns are unique: Davis and Keeley (2000) concluded that a 2mm x 3mm area of Schallamach will be enough to conclude a match and Zhang *et al.* (2021) discussing that the Schallamach pattern on different outsoles were significantly different. Despite it being previously mentioned that Schallamach patterns change quickly, Davis and Keeley (2000) were still able to conclude a Schallamach match from impressions taken before and after the wearer ran one mile **(Figure 15)**. Although similarities were discovered after wear, Zhang *et al*. (2021: p.1945) stated that the "accuracy decreased with an increase in the number of days wearing". However, Zhang *et al.* (2019) only examined the heel region, which supports the statements made by Davis and Keeley (2000) and Davis and DeHaan (1977). By using high microscopy and examining multiple small and precise areas, it is hypothesised that the current research will see Schallamach replication between the outsole and test impressions and be of use in forensic identifications.

Figure 15: *The Schallamach pattern on the same outsole before (top) and after (bottom) the wearer ran one mile (Davis and Keeley, 2000)*

Seemingly, there is conflicting information regarding expected areas of outsole wear and the presence of Schallamach and RACs. This is potentially due to skewed data in the studies involving Schallamach and generic RACs. It is apparent that these two characteristics behave differently, and although Schallamach is an individualising characteristic, it may be beneficial to consider these characteristics separately. Although the works by Davis and Keeley (2000) share similarities with the current research and is a great introduction to Schallamach in footwear, their paper is relatively short, and going into further depth discussing the application and results of using various test impression methods and experimenting with the use of microscopy and Schallamach could be of great benefit. Expanding on the works by Zhang *et al.* (2019) by including additional areas of the shoe would give a better understanding of the replication of Schallamach and other microscopic detail.

2.3. Lancashire Constabulary Case:

This section is dedicated to an important case submitted to Lancashire Constabulary discussing the photographic enlargement of a footwear mark, including the findings and what was learnt as a result.

Two black gel lifts (BGL) were recovered from a crime scene, along with the footwear worn by the suspect upon arrest. From the initial examination, the forensic specialist noted that there were extensive background textures present in the crime scene marks which made a reliable comparison of features not possible. The forensic specialist decided to enlarge one area of the BGL at 4:1 for further examination, an examination not known to be carried out regularly. An image of the BGL prior to and after enlargement of the highlighted section can be seen in **Figure 16**.

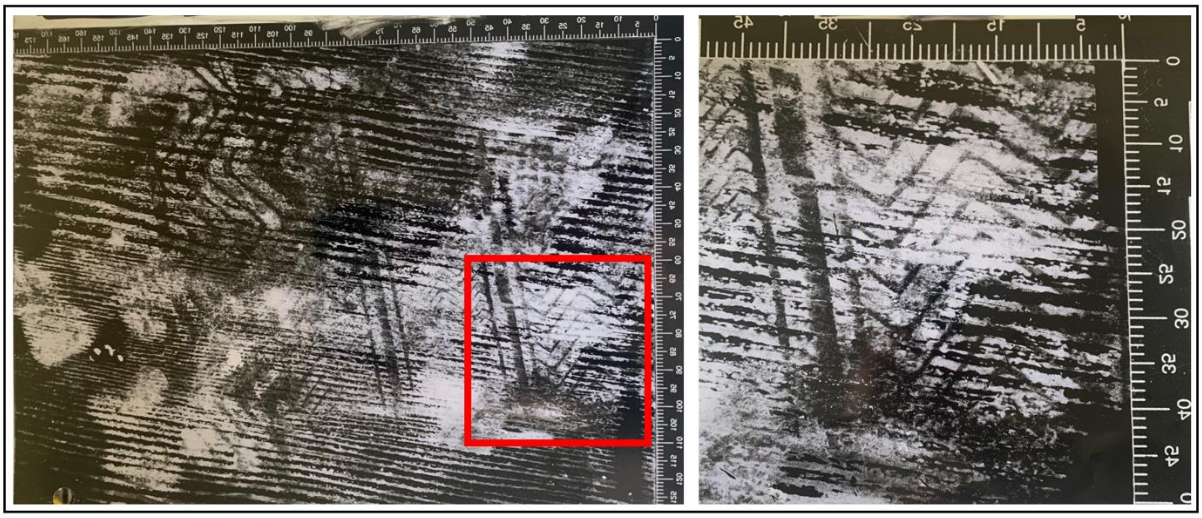


Figure 16: *BGL prior to enlargement (left) and after enlargement of the highlighted specific section (right)*

The highlighted section of the BGL showed a visible partial footwear mark that matched the test impression created with the suspects' shoes in terms of pattern, size, and wear. The specific areas of interest from the corresponding test impression can be seen in **Figure 17**.

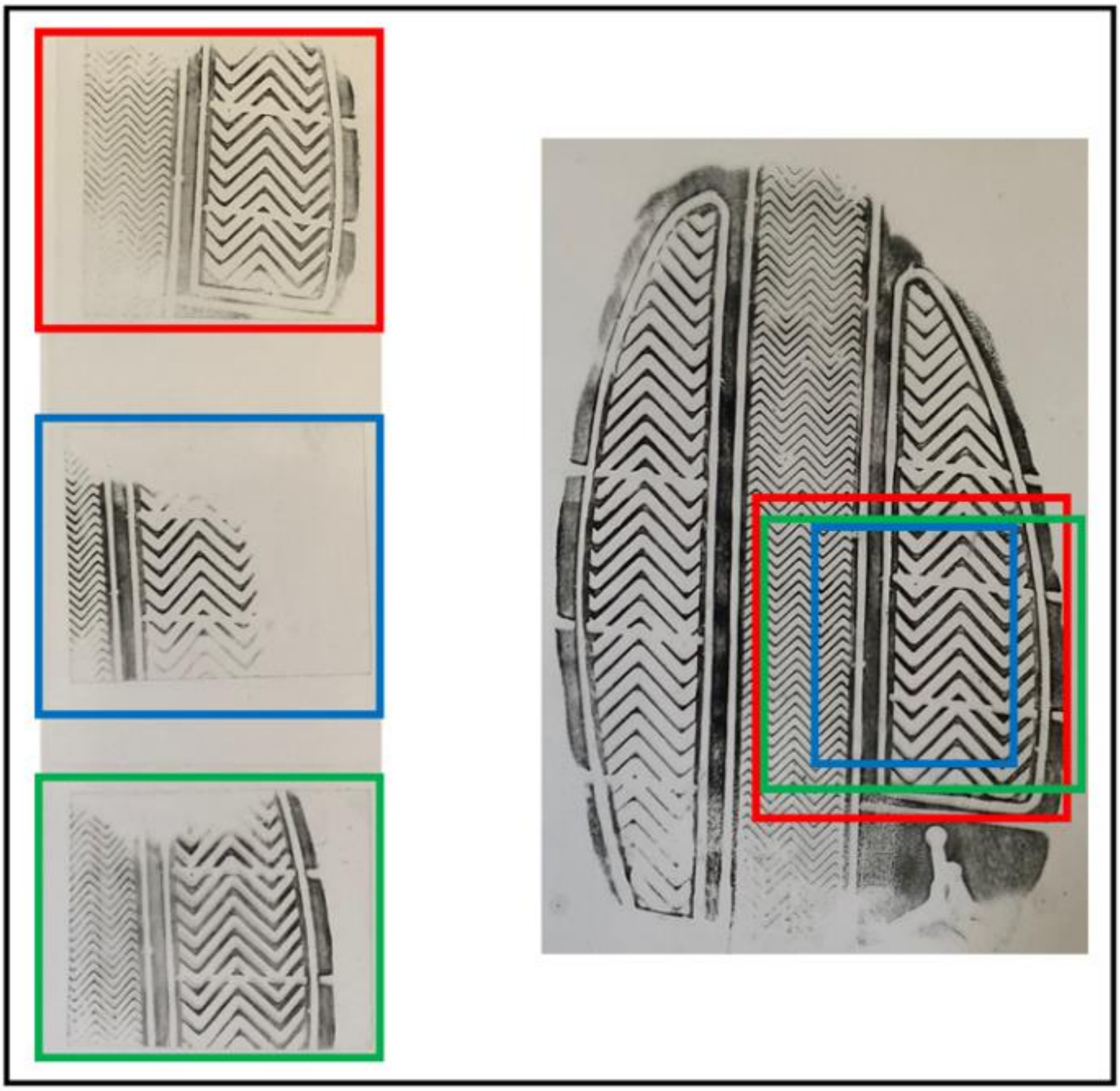


Figure 17: *Right Jordan Air test impression alongside specific sections with coloured annotations*

As the test impression shared the same class characteristics of those on the BGL, the specific area of the test impression was enlarged to enable a further comparison. After enlargement of the test impression, it was clear that there was correspondence of Schallamach between the test impression and the BGL. Corresponding features observed can be seen in **Figure 18**.

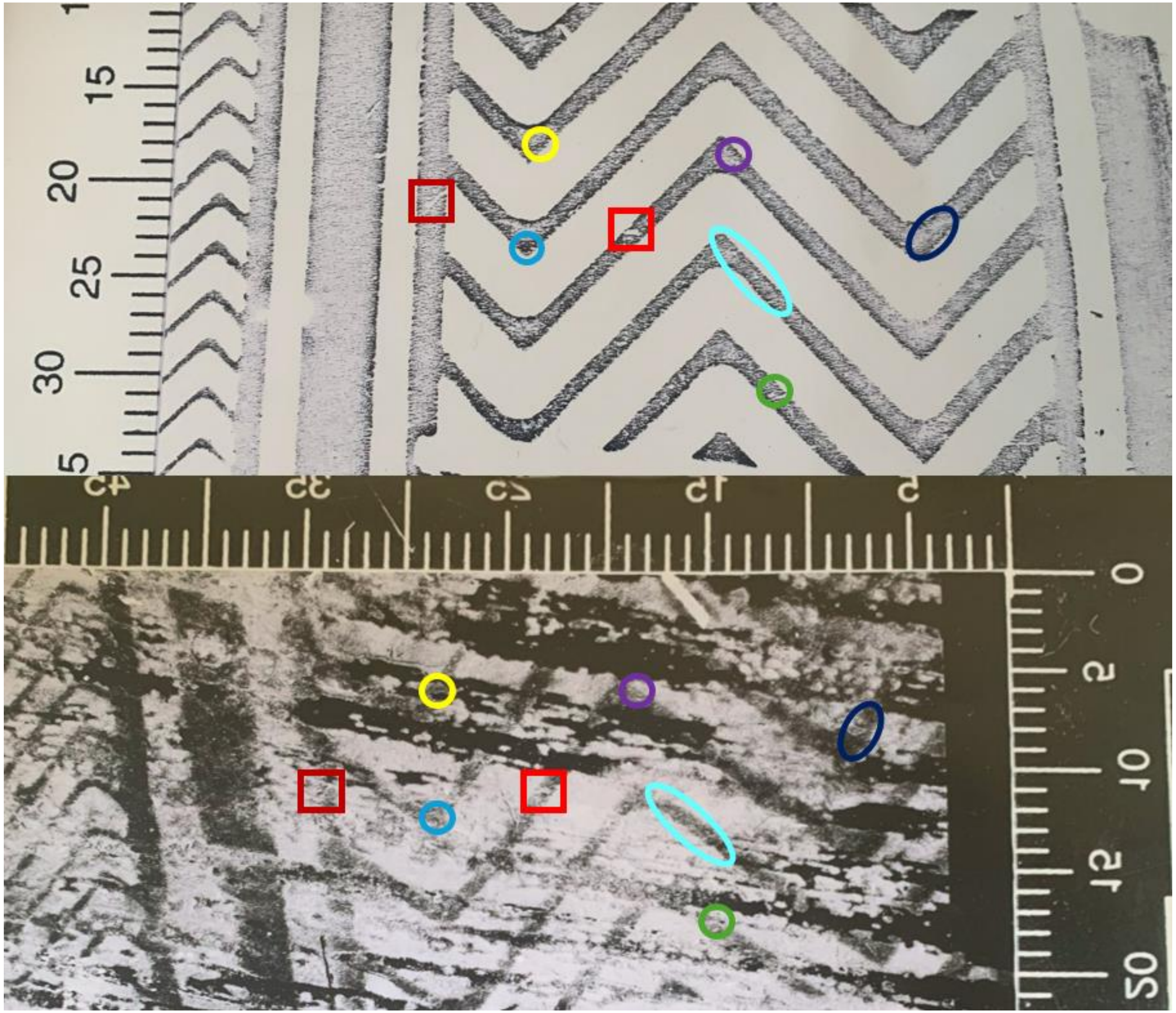


Figure 18: *Enlarged test impression (top) and enlarged BGL (bottom) with annotations of replication. Square shapes = RACs used as anchor points and circle shapes = Schallamach replication*

As shown, there are multiple areas where Schallamach within the test impression replicates the Schallamach within the crime scene mark, which would have been missed if this examination were not to occur. It was through this examination that gave the forensic specialist the confidence to determine that there was conclusive evidence that the considered footwear mark was made by the seized footwear. It was this case that inspired the works within this thesis, it has been proven that Schallamach has the potential to be a forensically relevant feature, and this should be studied further to answer the question if all footwear evidence should be enlarged during examinations to expose replicated detail that is not seen by eye alone.

2.4. Microscopy within Forensic Mark Evidence:

To enable utmost clarity and precision, a digital microscope will be used within this project. A Keyence digital microscope, specifically the VHX-7000 series, can capture 4K images with optimal balance of brightness and clarity (Keyence, 2022), and the built-in measure function can measure the roughness and grain size.

Most forensic mark evidence such as tool marks, ballistics, and bite marks or considerations of same source samples such as hair and fibres are examined via a comparison microscope (Baldwin *et al.* 2013; Houck and Siegel, 2015). Comparison microscopes are joined by an optical bridge (Houck and Siegel, 2015), allowing the observer to view two samples side-by-side to analyse similarities or differences within trace evidence (Saadat *et al.*, 2020). Microscopes are used within tool mark examinations to enable a view of the submitted tool and a casting of a tool mark to confirm or eliminate the tool from having made the mark by observing similarities or differences of features (Baldwin *et al.* 2013).

Footwear within forensics is a type of mark evidence, and this evidence type is known to be compared by overlaying test impressions on crime scene marks, and not with microscopy. Unfortunately, it is thought that the examination of footwear evidence has not developed due to the misconception that this evidence type is not as useful as others. However, footwear evidence has the potential to be found at every crime scene when considering that each offender has been in contact with the floor or other surfaces (Williams, 2009), and along with the substantial result from the case submitted to Lancashire Constabulary, the results gained from this thesis hopes to change this ideology.

2.5. Literature Summary:

After a review of the literature, the area of microscopically analysing Schallamach in footwear, considering the microscopic replication of features in various types of test impressions is non-existent. Important considerations on the sections of the outsoles to examine have been addressed. Moreover, with the introduction in Chapter 1, extensive knowledge regarding the process of examining footwear evidence and how footwear evidence can assist with an investigation has been discussed, and from this, it is understood why microscopic examinations of footwear evidence is required.

2.6. Research Questions:

After a thorough analysis of the literature, the following research questions have been generated:

- “Should footwear examiners routinely use microscopy in footwear comparisons?”
- “Is there a favoured method of creating test impressions when considering the consistent replication of Schallamach and/or other microscopic detail?”
- “Does detail revealed under magnification consistently replicate between test impressions?”
- "Is there a limit to the magnification when examining Schallamach and/or other microscopic detail in footwear evidence?”
- “What are the benefits of using a microscope during forensic footwear examinations?”

2.7. Research Hypotheses:

The following hypothesis and competing hypothesis for this research are as follows:

- **Null hypothesis:** There is no detail visible with magnification that was not seen at a 1:1 scale.
- **Alternative hypothesis:** There is visible detail seen with magnification that was not seen at a 1:1 scale.

- **Null hypothesis:** No visible detail at 1:1 would not result in visible detail during microscopic examination.
- **Alternative hypothesis:** No visible detail at 1:1 would result in visible detail during microscopic examination.

CHAPTER 3 - METHODOLOGY

Reviewing academic literature has shown the limited research between the relationship of footwear evidence and the microscopic examination of Schallamach and the replication of other microscopic detail from the outsole to different types of test impression methods.

3.1. Research Design:

The scope of the method warranted an examination of the outsoles and test impressions by a VHX-7000 series Keyence digital microscope for areas where Schallamach is likely to appear. The Keyence has a magnification range of 20x-200x, and has built-in software to view, capture and measure magnified features with the large digital screen (Keyence, 2022), making this microscope the most suitable equipment for this project, **Figure 19-Figure 20.**

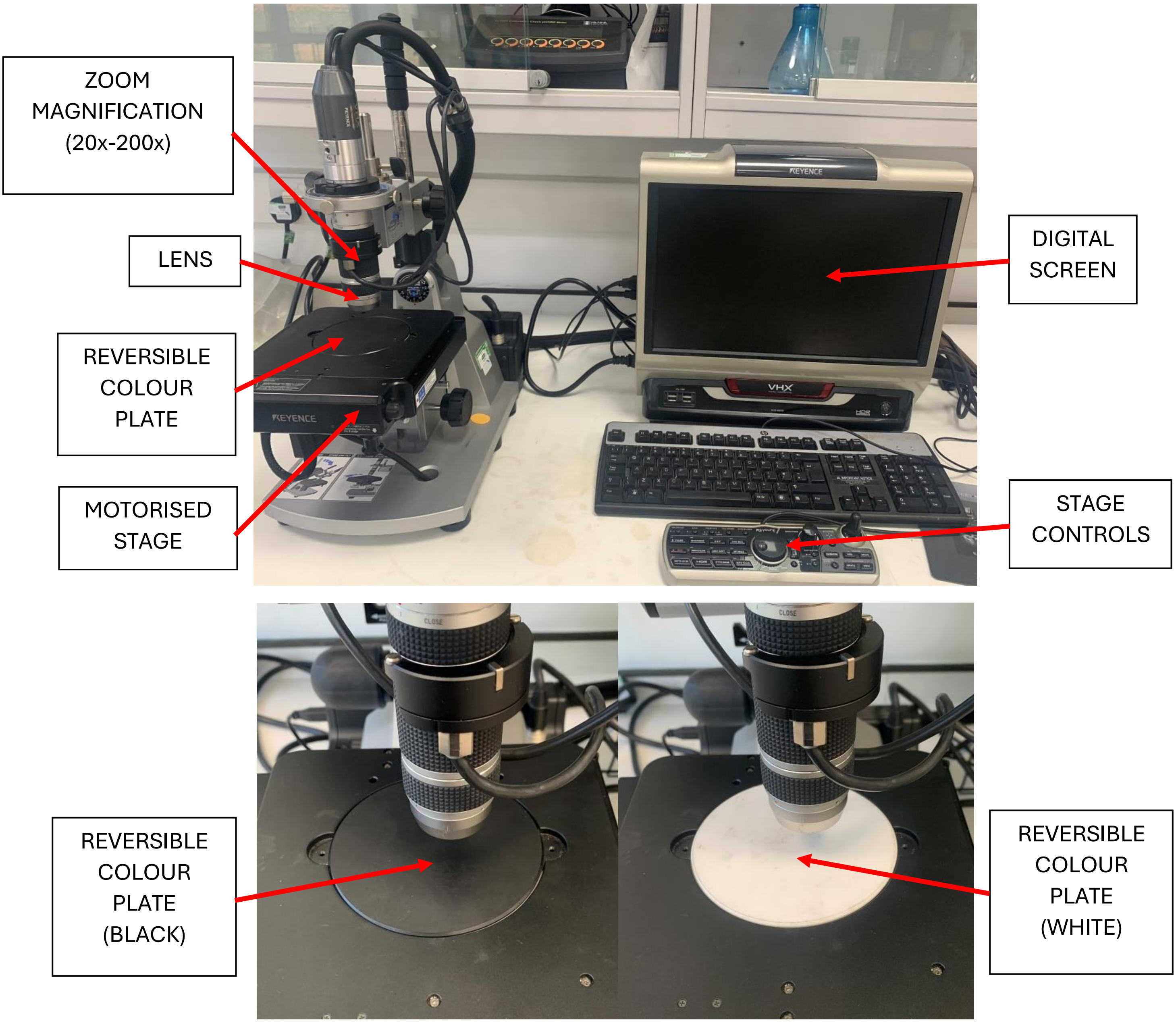


Figure 19: *An image of the VHX-7000 series Keyence microscope*

Figure 20: *An image of the VHX-7000 series Keyence controls*

3.1.1. Footwear Sample

Three new pairs of Nike Air Max 270 training shoes were selected as the footwear in this project. Primarily due to the commonality of Nike footwear (Baines, 2022), demonstrated by Nike's footwear, apparel, and accessories sales reaching over $51.5 billion dollars in the United States of America in 2023; largely outperforming sales with their competitors: Adidas and PUMA **(Figure 21)** (Smith, 2024). The popularity of Nike training shoes is also expressed in R v T, where at the time of the court hearing in 2010, there were "1,200 different sole patterns of Nike trainers" (R v T, 2010: h:42), and approximately 786,000 pairs of trainers were distributed by Nike between 1996-2006 (R v T, 2010). Selecting a popular footwear brand was important as it is likely that the popularity is also true when considering Nike footwear being worn during crime, and therefore, developing a methodology examining a Nike shoe could generate accurate and relevant results that could be used within forensic examinations.

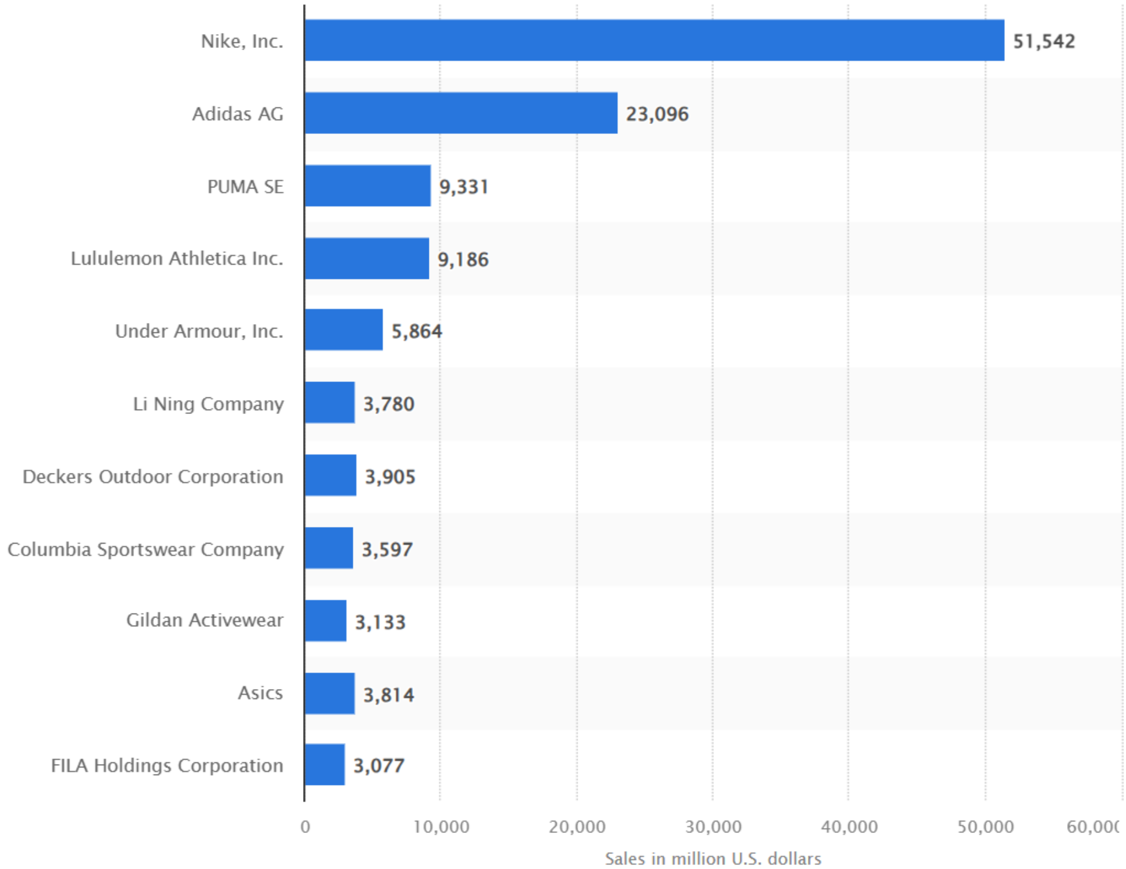


Figure 21: *A figure of the biggest athletic apparel, accessories, and footwear companies and their sales in million dollars, taken from Smith (2024)*

The shoe designs had outsoles with clearly defined sections **(Figure 22)**, which made this footwear a sensible choice during method development to assist with the selection of subsections to examine. A sample of three was chosen to enable a repetition of the method, whilst exposing any outliers.

Figure 22: *An image of the Nike Air Max 270 outsole*

3.1.2. Test Impressions

There are many ways in which *known impressions*, referred to in this thesis as ‘test impressions’, of footwear are created. The intent of creating test impressions is to provide a replicated footwear mark from suspected footwear to compare with crime scene marks to exclude or conclude that the footwear did or did not create a footwear mark found at a crime scene (Shor *et al.,* 2018; Bodziak, 2017). It is therefore essential that the method chosen provides the best replication of the microscopic detail to ensure a detailed and accurate examination.

3.1.2.1. Dynamic: Printscans

One method of test impression creation is an inkless system and involves stepping onto a pad containing a chemical solution, then stepping onto chemically treated paper to generate an instant black footwear mark (Bodziak, 2000; ASB, 2019) (**Figure 23**). Bodziak (2000) refers to this method as “Identicator Pad and Paper”, this is however referred to as a “Printscan” in the United Kingdom (Baines, 2024). Due to the “very quick and convenient” method of producing test impressions (Bodziak, 2000: p.350), this method is often favoured in UK constabularies (Baines, 2024) for standard non-microscopic examination and as such, will be used within this research to establish the value of microscopic examination for Printscan replication of footwear.

Figure 23: *Identicator Pad and Paper (Printscan) test impressions (Bodziak, 2000). The shoe is placed on the yellow "inkless" pad, and placed on the reactive white paper to create a replica of the print*

3.1.2.2. Dynamic: Oil and Magna Impressions

Another popular method of creating test impressions involves stepping onto an oily substance and dusting the impression with magnetic fingerprint powder (Bodziak, 2000) (**Figure 24**), referred to as oil and magna impressions in this thesis. Magnetic powder must be used as once the footwear mark has been developed, the surrounding area is cleaned up with a magnetic wand and can be re-used in future test impression creation. There are various substances available to create the oiled impression, such as petroleum jelly, WD-40, or oils (Bodziak, 2000). A 50:50 mixture of petroleum ether and paraffin oil is a common substance used within the United Kingdom (Baines, 2024), and this is the substance that this thesis will use. Again, black powder is commonly used, but to discuss the better powder when creating and examining the test impressions, red fluorescent powder was used as red may provide a good contrast when completing the comparisons (ASB, 2019; Baines, 2024).

Figure 24: *Oily substance and fingerprint powder on paper (dynamic) test impressions (Bodziak, 2000)*

3.1.2.3. Static/Handiprint Impressions

As mentioned in Chapter 2, this common method involves fine fingerprint powder and white/transparent adhesive **(Figure 25)**, referred to as static impressions in the United Kingdom. The shoes can be worn whilst creating static impressions (SWGTREAD, 2005; ASB, 2019), however, as people wear their shoes differently, not wearing the shoes could offer a full, more detailed impression by pressing the adhesive into the outsole, which would likely create contact with the outsole in areas that may not during wear. Black powder is commonly used when creating test impressions; however, aluminium powder was used to observe if the lighter colour could provide an increase of contrast to assist during the comparisons.

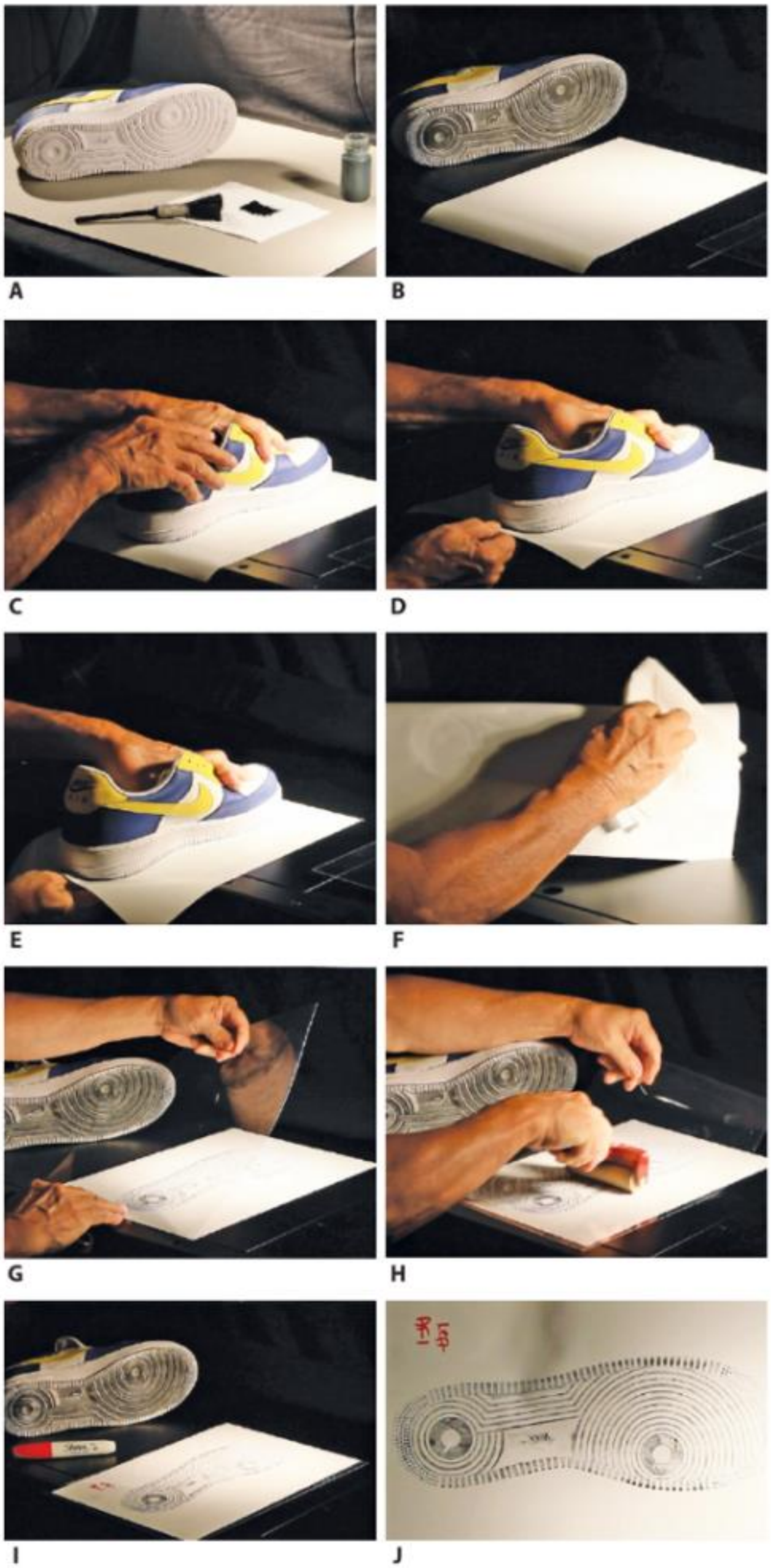


Figure 25: *Fingerprint powder and white or transparent adhesive (static) test impressions (Bodziak, 2000)*

3.1.2.4. *Test Impression Summary*

Despite selecting the most appropriate method of creating test impressions, discrepancies between the same methods still apply (Shor *et al.,* 2018). Though each method is intended to replicate the outsole, it is recommended to take several test impressions of the footwear to account for slight differences amongst the impressions (Shor *et al.,* 2018) as variables such as a differentiation of pressure, weight shift, substrate, amount of ink/powder can alter the detail revealed in the impression (Bodziak, 2000). In asking if footwear examiners should use microscopy on all footwear evidence to expose potential missed detail, it is important to consider the best test impression creation method for consistent replication of Schallamach and microscopic detail - this thesis will see each test impression created three times, to account for slight differences between impressions.

3.1.3. Subsections of the Outsole

After reviewing the published literature in Chapter 2, the current study initially sought to examine the lateral heel, medial toe region, and stepping circle as authors observed the most individualising features within these areas (Davis and Keeley, 2000; Zhang *et al.,* 2019; Kaplan-Damary *et al.,* 2018; Kaplan-Damary *et al.,* 2022); sections 1, 6, 11, and 14 in the outsole map from Kaplan-Damary *et al.* (2018) and Kaplan-Damary *et al.,* (2022), **(Figure 26)**. However, it became clear when creating the dynamic test impressions that section 1 was not compatible with Nike Air Max 270 due to the depth variability of the outsole, and a lack of consistent contact with the ground in these areas due to the authors walking habits. An example of dynamic test impressions can be viewed in **Figure 27-Figure 29**, and it is shown that there are inconsistencies of ground contact between the initial sought sections to examine, but areas that create contact are consistent between all dynamic impressions.

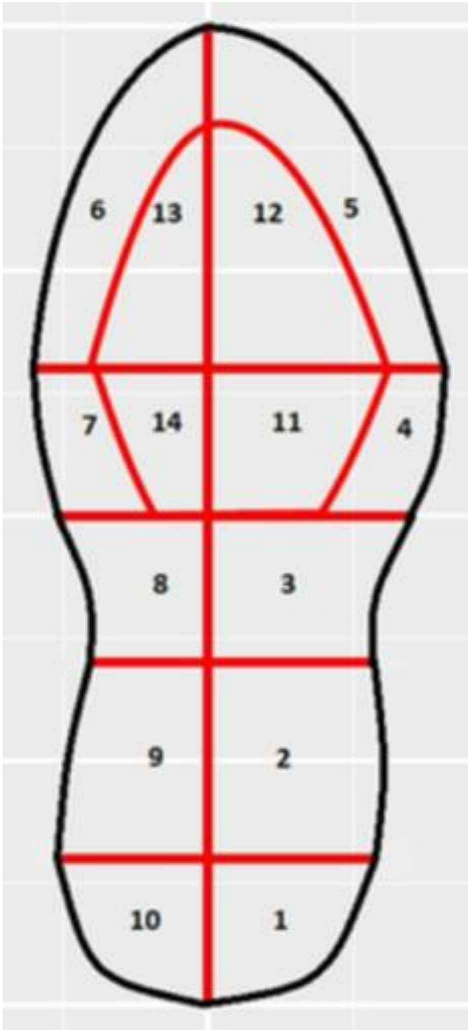


Figure 26: *An image to show the subsections of footwear (Kaplan-Damary et al., 2022)*

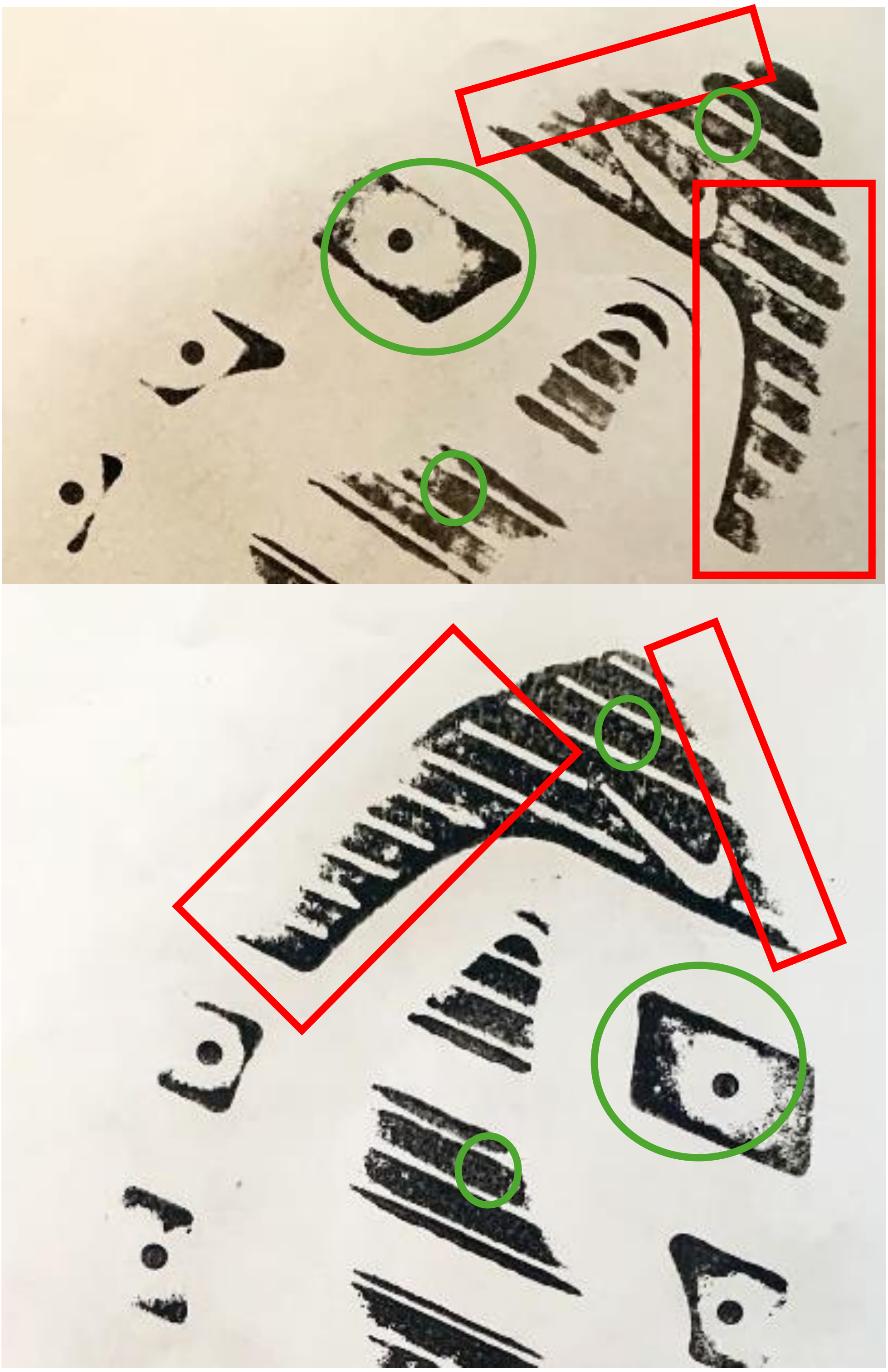


Figure 27: *Dynamic: Oil and Magna test impressions with black powder. Left shoe [top], right shoe [bottom]. A lack of contact highlighted with a red box, and consistent ground-contacted areas highlighted with a green circle*

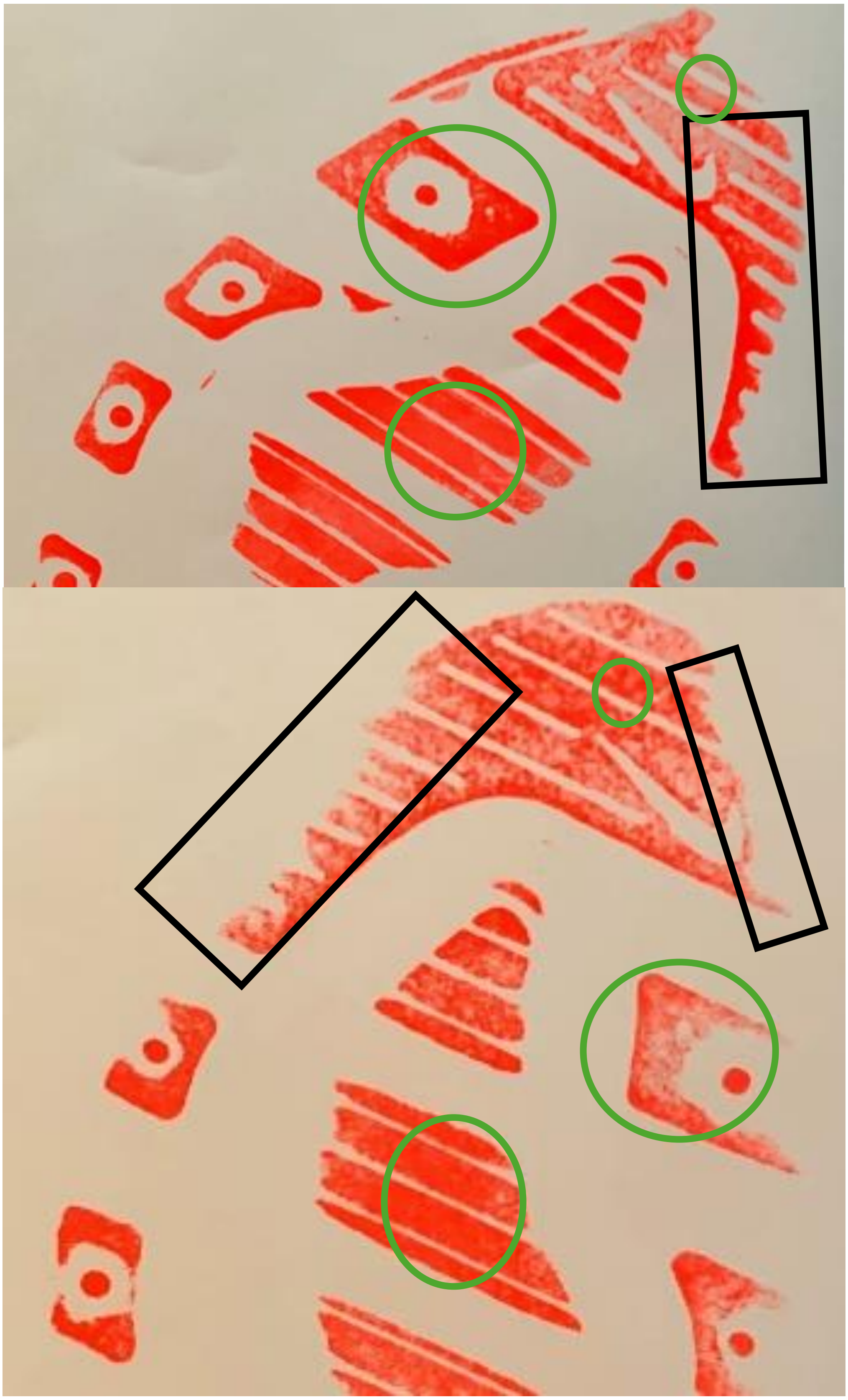


Figure 28: *Dynamic: Oil and Magna test impressions with red fluorescent powder. Left shoe [top], right shoe [bottom]. A lack of contact highlighted with a black box, and consistent ground-contacted areas highlighted with a green circle*

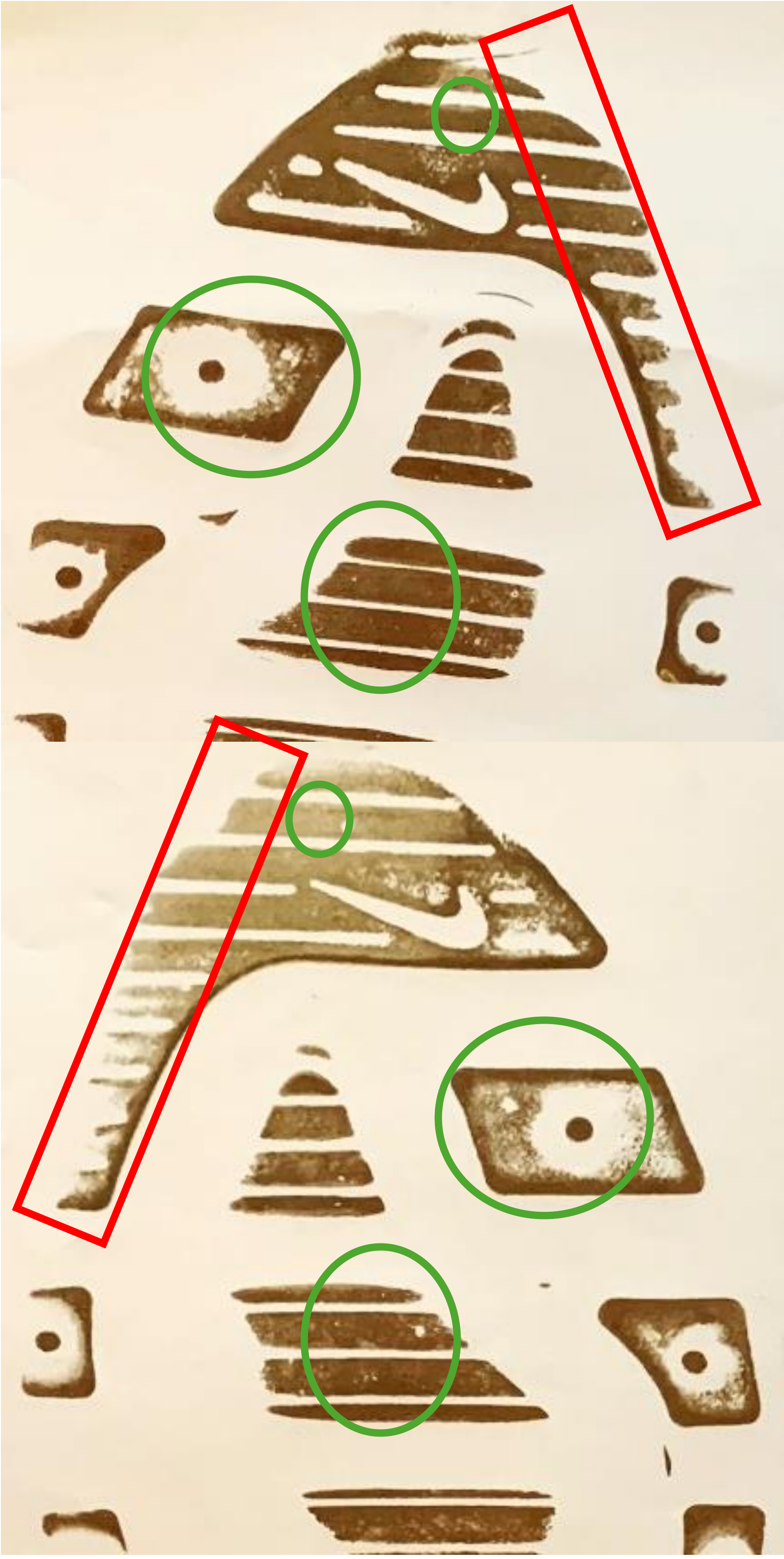


Figure 29: *Dynamic: Printscan test impressions. Left shoe [top], right shoe [bottom]. A lack of contact highlighted with a red box, and consistent ground-contacted areas highlighted with a green circle*

As dynamic test impressions are created whilst wearing the shoes and walking over treated paper, areas that are not present in a test impression of these types suggest that there would not be frequent contact with the ground in these areas during daily wear, and therefore, would potentially not see a higher degree of wear as opposed to the areas that did appear in these test impressions. Due to time constraints, it is essential that the selected areas consistently contact the ground to ensure that wear is established within a short period of time.

Upon re-thinking the figure highlighting the subsections of footwear and re-examining the Nike Air Max 270 outsole for areas creating contact with the ground, new subsections (1-4) were derived along with a control area (C), **Figure 30**. As Schallamach is created due to Brownian motion during wear, it was important that an area that does not contact the ground was selected to observe a potential formation of Schallamach within this area. The author proposes that Schallamach patterns could potentially occur within an area that does not contact the ground as the breakage of molecular chains due to Brownian motion within outsole areas that do have direct ground contact could affect the neighbouring chains within a control area, thus resulting in Schallamach patterns despite a lack of direct abrasive wear. The extent of Schallamach formation within this area was observed to open a discussion for future research.

Figure 30: *The Nike Air Max 270 outsole and the revised subsections (1-4) and control area (C) for examination*

A breakdown of the selected outsole sections, and the justification for selection are as follows:

- [1] Section 1 *(centre toe)*: When creating the three types of dynamic test impressions, the centre uppermost edge of the toe was consistently present between the left and right feet. As Davis and Keeley (2000) found extensive Schallamach within the toe area and Kaplan-Damary *et al.* (2018) found the most RACs within the medial toe region, this research included a suitable toe area due to the likelihood of finding observable features in this area for the research project.

- [2] Section 2 *(lateral toe – 5th metatarsal head)*: Continuing taking inspiration from Davis and Keeley (2000) when considering the presence of Schallamach within the toe region, the large rectangular feature on the lateral edge of a Nike Air Max 270 was consistently present when creating dynamic test impressions between the left and right feet, when the medial area of the 1st metatarsal head was inconsistently present. This was possibly due to the outsole design of a large rectangular feature supporting weight. Speir *et al.* (2016) also found the most RACs within the lateral toe, and so it was likely to observe wear features here when considering the contact with the ground within this area. The only consistently present toe areas (section 1 and 2) were selected due to literature inspiration and adapting this to the chosen footwear used within this project.
- [3] Section 3 (*stepping circle*): Kaplan-Damary (2022) found the most RACs within the stepping circle, and this area (section 3) was consistently present on all dynamic test impressions. The author proposes that as the stepping circle is comprised of a series of bar features, selecting section 3 to be slightly off centred and closer to the border edge of the bar features will be more prone to abrasive wear due to a potential increase of micro-tears within this region. Moreover, due to the large sections used in Speir *et al.* (2016), section 3 in this thesis also includes their section which contained the highest number of RACs.
- [4] Section 4 (*medial heel*): Although published research regarding Schallamach within the heel demonstrates Schallamach formation within the lateral heel (Davis and Keeley, 2000; Zhang *et al.* 2019), since the lateral toe

was examined in the current research, the opposing area of the foot, the medial heel was selected due to the natural distribution of weight across the shoe providing equal pressure to the two areas, and this was shown in the dynamic test impressions. However, the outsole has a natural curve going upwards to the back of the heel, meaning the medial heel as seen on a test impression is slightly central on the outsole.

Although slightly differing to original subsections explored by other authors, (Davis and Keeley., 2000; Zhang *et al.,* 2021; Kaplan-Damary *et al.,* 2018; and Kaplan-Damary *et al.,* 2022), the current areas are tailored to the chosen footwear. As these characteristics are dependent on pressure variation and specific shoe moulds (Kaplan-Damary *et al.*, 2018), selecting areas which are more prone to wear for the specific wearer, whilst using the published literature as guidance, would be more beneficial. Moreover, the revised areas selected have a variation of colouration which provides a variety of contrasts that may be present on shoe soles for examination.

3.1.4. New Shoes

Contrary to Zhang *et al.* (2021), Richetelli *et al*. (2017a), Richetelli *et al.* (2017b), Speir *et al.* (2016), Kaplan-Damary *et al.* (2018), Kaplan-Damary *et al.* (2022) and Wiesner *et al*. (2020) and like Davis and Keeley (2000), the outsoles are examined as new and are then re-examined after wear to define Schallamach. Earlier researchers observed the changes of Schallamach/RACs by subsequently re-examining the outsoles after specific timings of wear (Davis and Keeley, 2000; Zhang *et al.* 2021; Moorthy and

Chelliah, 2013). However, as this research does not address the changes of observed microscopic detail, the shoes were worn for two weeks before re-examination when Schallamach was expected to be present. The length of wear was based on data from David and Keeley (2000), who found that new shoes develop Schallamach after 9 hours of wear and changed completely after a further 6-16 hours.

3.2. Method Development:

When beginning the practical work, it was apparent that there were aspects of the initial methodology that was not suitable for this project. The following subchapter highlights the adaptations to the method.

3.2.1. Test Impressions

It became apparent that the static test impressions created with aluminium powder were difficult to examine microscopically. It was found that the particles were too coarse to reveal small details, and the aluminium powder reflected against the microscope light **Figure 31**. For these reasons, it was decided to discontinue the use of aluminium static test impressions from the research.

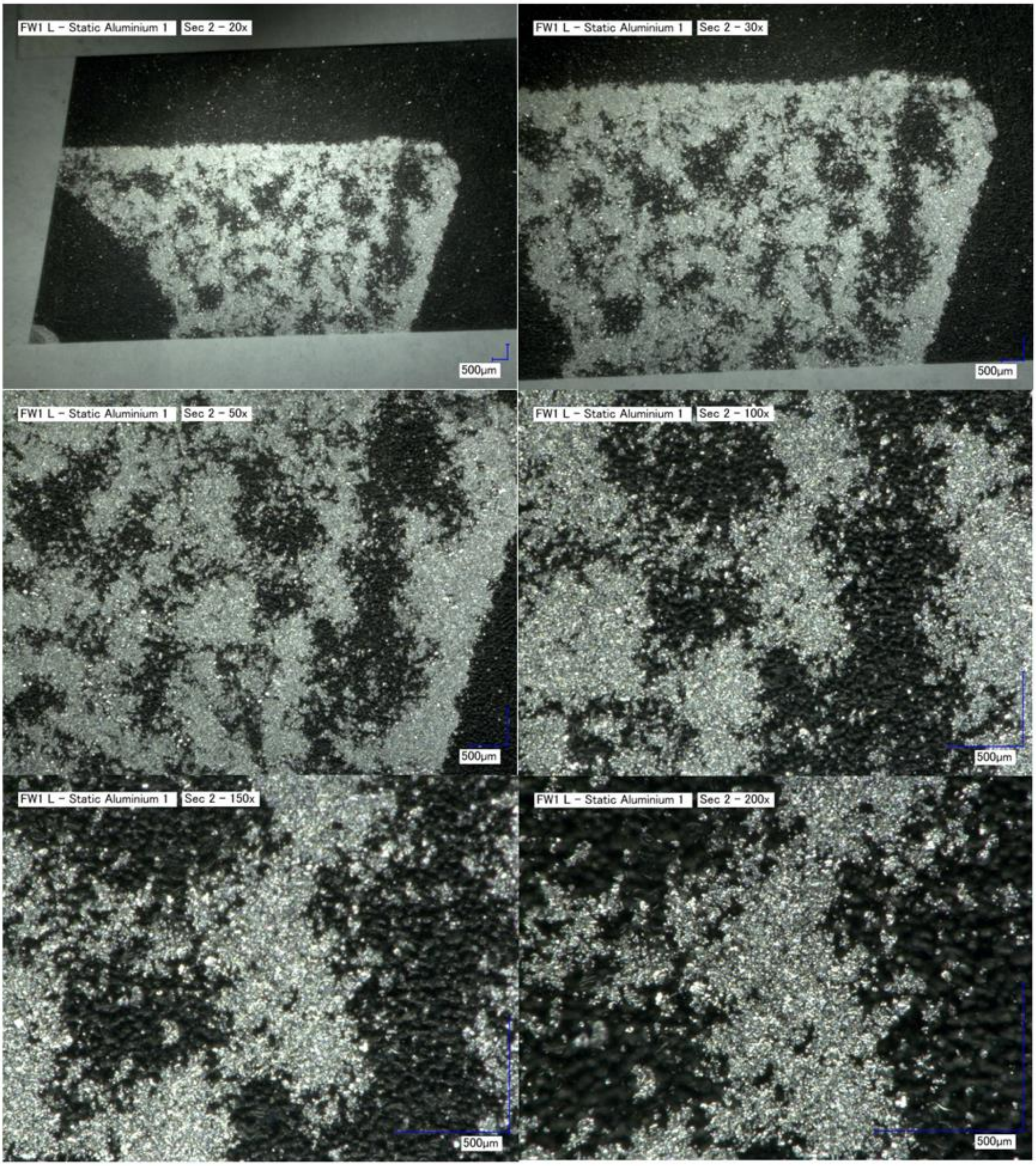


Figure 31: *Images of the static aluminium test impressions taken with the Keyence microscope at 20x-200x magnification. (20x [top left], 30x [top right], 50x [centre left], 100x [centre right], 150x [bottom left], 200x [bottom right])*

Moreover, irrespective of wearing the shoes, dynamic test impressions: oil and magna test impressions created with black and red fluorescent powder and printscan impressions showed a lack of detail. Therefore, it was also decided to remove these methods from the research. Examples of each eliminated test impression listed can be viewed in **Figure 32-Figure 34**.

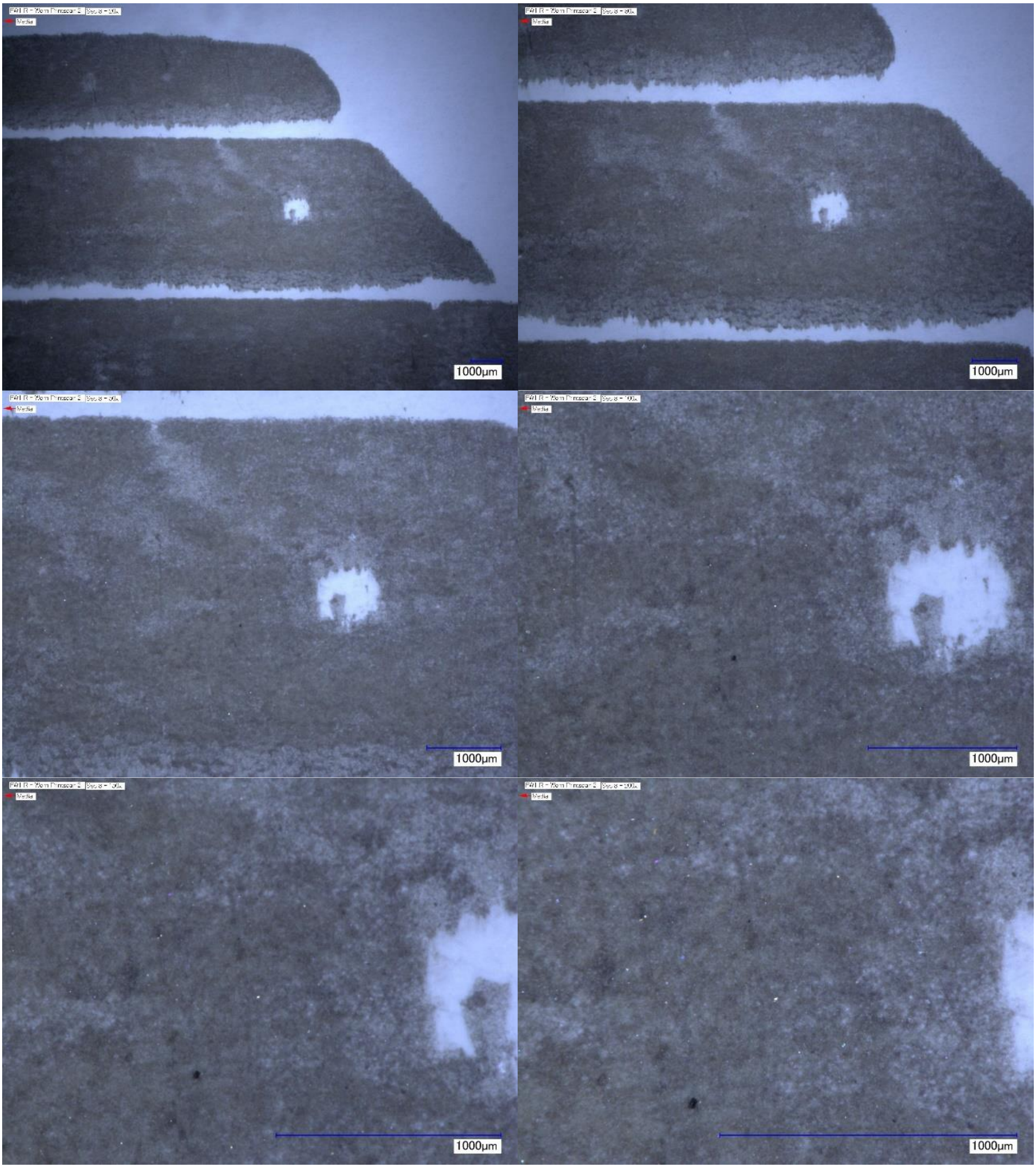


Figure 32: *Images of the printscan test impressions taken with the Keyence microscope at 20x-200x magnification. (20x [top left], 30x [top right], 50x [centre left], 100x [centre right], 150x [bottom left], 200x [bottom right])*

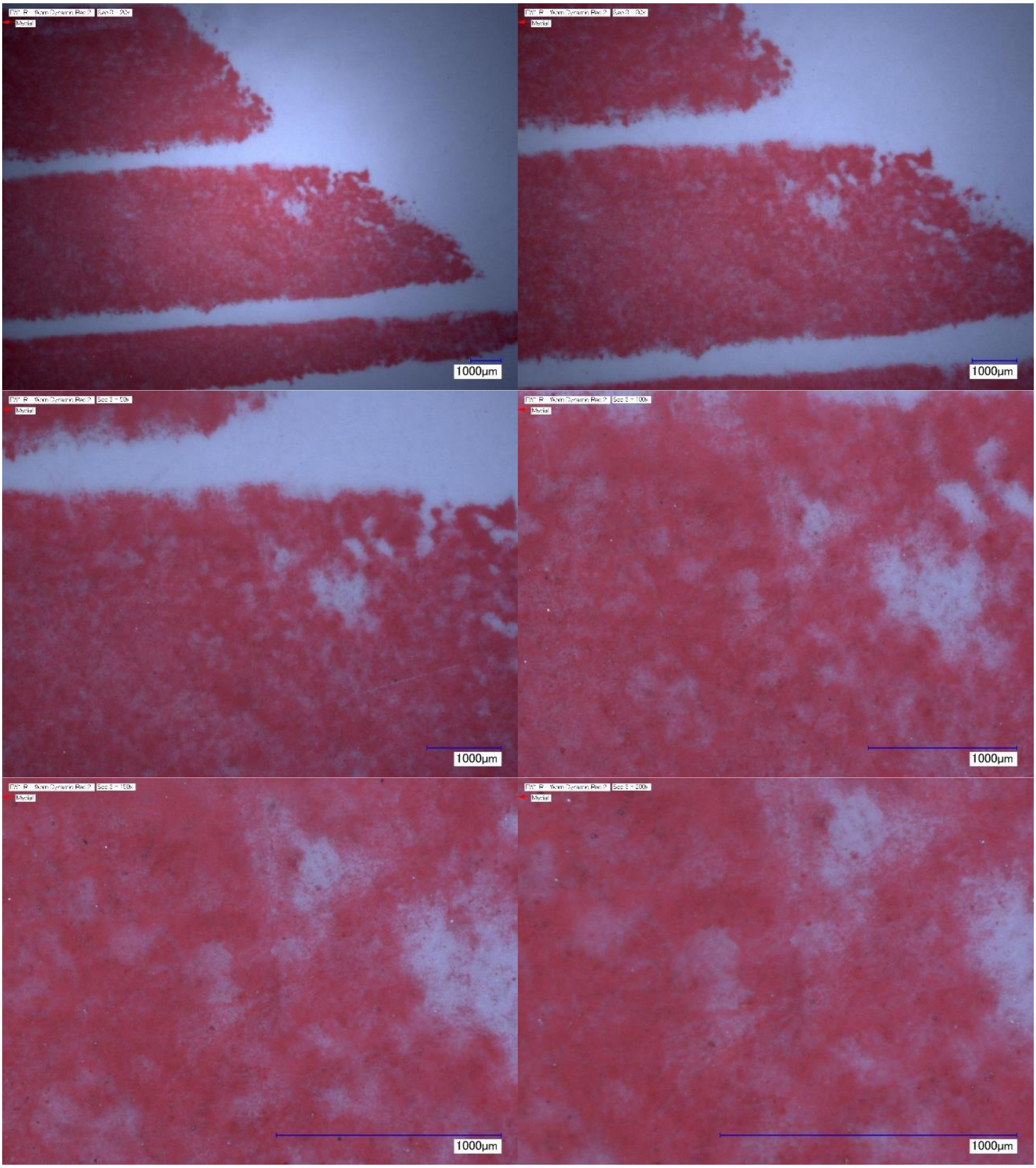


Figure 33: *Images of the dynamic red test impressions taken with the Keyence microscope at 20x-200x magnification. (20x [top left], 30x [top right], 50x [centre left], 100x [centre right], 150x [bottom left], 200x [bottom right])*

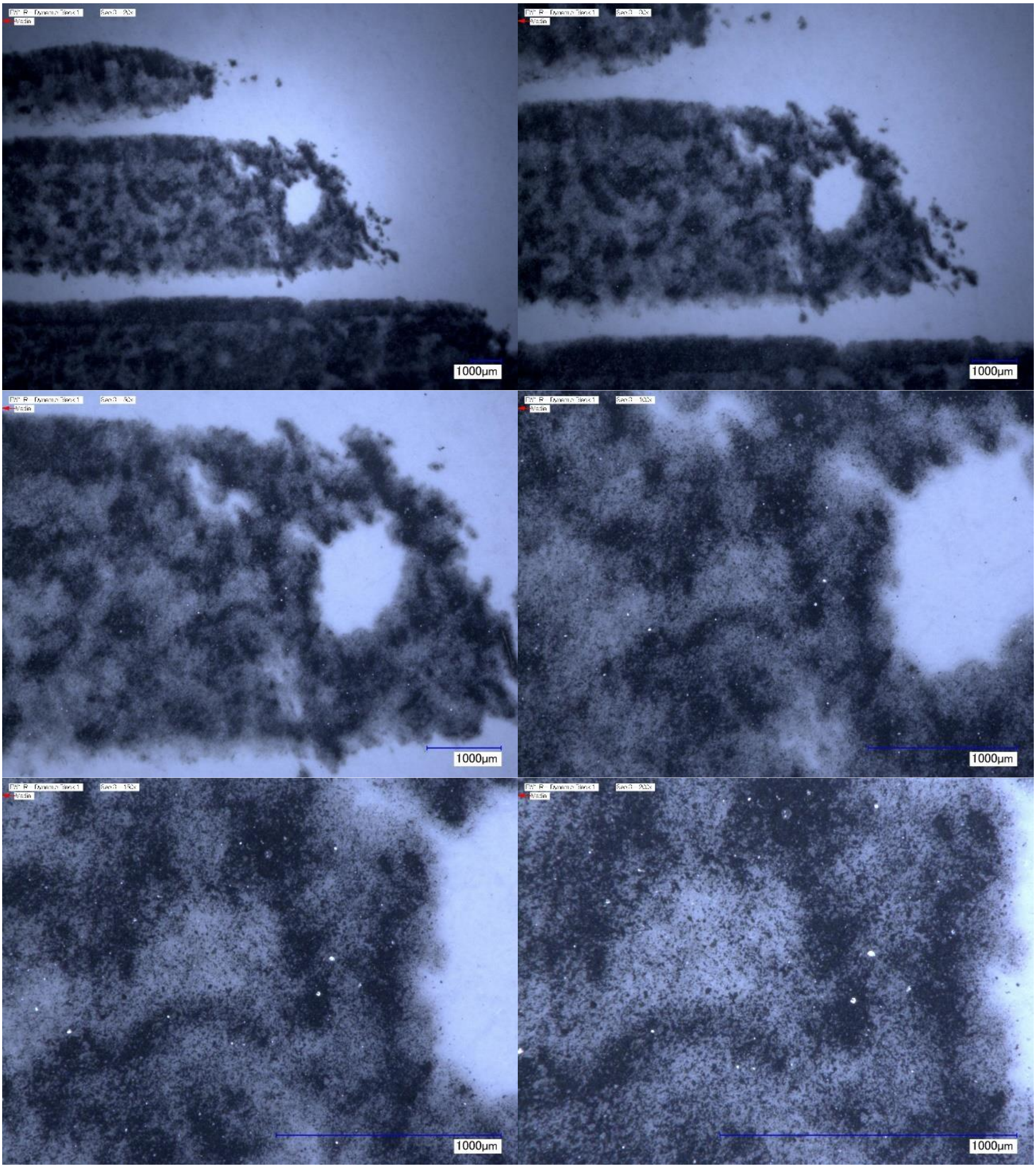


Figure 34: *Images of the dynamic black test impressions taken with the Keyence microscope at 20x-200x magnification. (20x [top left], 30x [top right], 50x [centre left], 100x [centre right], 150x [bottom left], 200x [bottom right])*

After discontinuing the dynamic and static test impressions with aluminium powder, only black powdered static test impressions remained, allowing a deeper, more thorough examination into the consistent replication of Schallamach and microscopic detail between black static test impressions and the outsole. Images of this preferred and suitable method can be viewed in **Figure 35**.

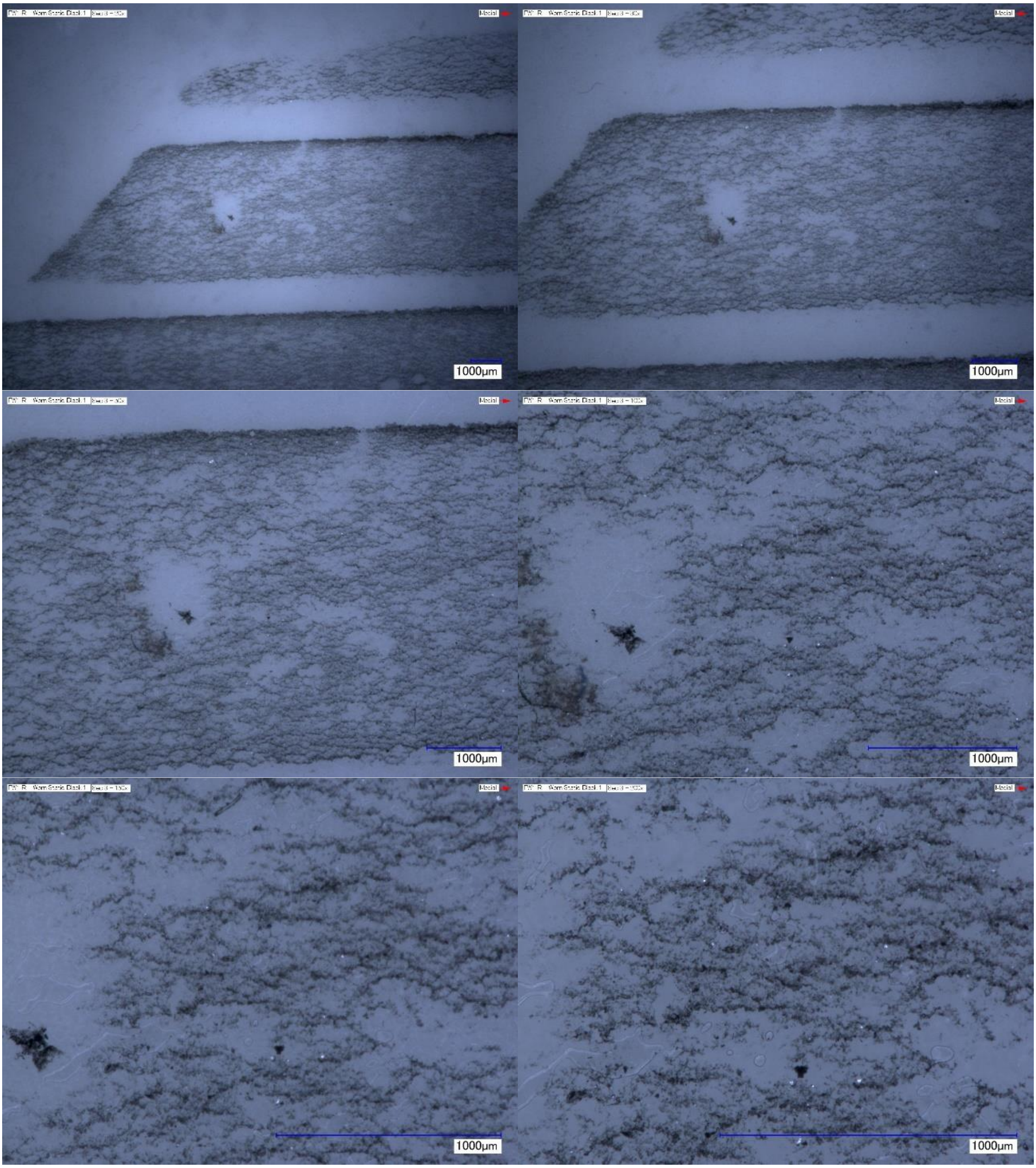


Figure 35: *Images of the static test impressions created with black powder taken with the Keyence microscope at 20x-200x magnification. (20x [top left], 30x [top right], 50x [centre left], 100x [centre right], 150x [bottom left], 200x [bottom right])*

3.2.2. Defining the Subsections

For clarity when using magnification, a border of tape distinguished the four subsections **(Figure 36)**. However, it became apparent that the subsections were too large, and there was uncertainty of locating the exact microscopic location between the outsole and test impressions. To counter this, a drawing pin was inserted 3530µm (3.53mm) into each of the four subsections and control area to create a distinctive hole that would not wear away, as an ink mark likely would, and would be clear when viewed under the microscope **(Figure 37)**. The pin was inserted into the outsole until resistance was overcome and the remaining exposed pin was marked using a permanent marker; assisting with ensuring the pin was consistently inserted the same depth into the remaining subsections. The depth the pin was inserted was measured by using the measure feature on the Keyence software. However, during the examinations, it was found that a drawing pin was too thick and created much distortion to the surrounding outsole, causing a difference of detail from the outsoles to the previously created test impressions. Subsequently, test impressions were retaken to account for the new features.

Figure 36: *An image of the tape borders on the outsole (left) and test impression (right), prior to creating pinholes*

Figure 37: *An image of the pinholes created in the subsections 1-3 of the outsole, highlighted by an illustrated circle. (Section 1 [top], section 2 [centre], section 3 [bottom])*

Completing Keyence examinations with pinholes placed in the outsoles gave the examiner a point of reference to improve consistency and ensure the same areas are examined between the outsole and test impressions. The pinhole was consistently in view at each magnification, and the same side of the pinhole was examined (lateral side of subsection 1's pin hole, lateral side of subsection 2's pinhole, medial side of subsection 3's pinhole, medial side of subsection 4's pinhole, and the medial side of the control area).

3.2.3. Setting up the Outsole Examinations

The test impressions were taken prior to the outsole examinations, and although this was not problematic in viewing the microscopic detail, the aluminium powder stained the outsole. To avoid disturbing the outsole or creating 'wear', it was decided to not rub the outsole clean.

Challenges arose early during the microscopic outsole examinations; the microscope has a stage intended for objects to be placed onto. However, to examine the outsole the shoe must be placed upside down, and it was a challenge to keep the shoe in a steady position. Instead, a clamp was used to support the shoe, and the microscope lens was rotated away from the stage, **Figure 38**

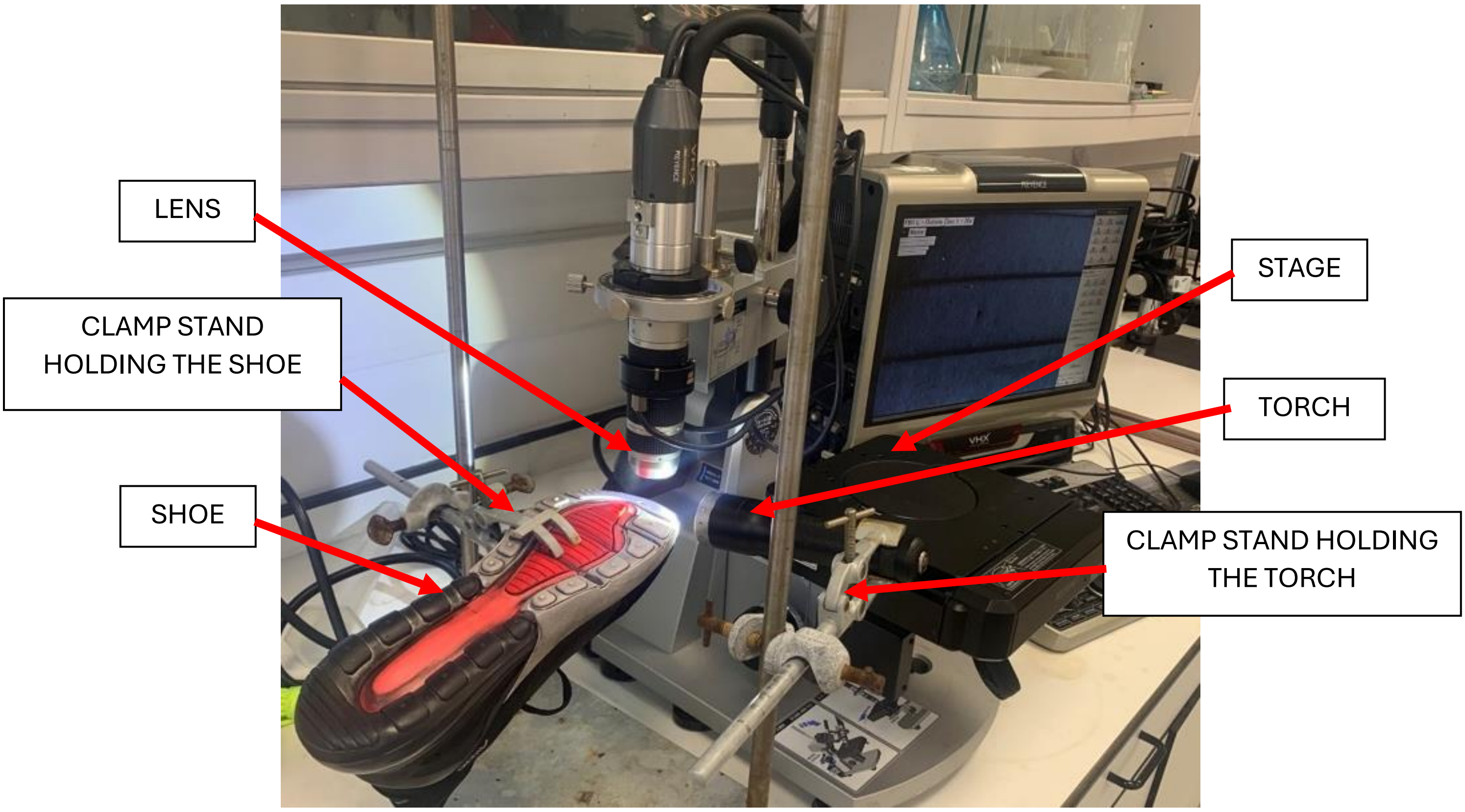


Figure 38: *An image showing the setup of outsole examinations using the VHX-7000 series Keyence microscope*

3.2.4. Oblique Lighting: Light Sources

With distinctive areas for examination recorded into the outsoles and new test impressions due to the pinholes, the pre-worn outsoles were re-examined with the Keyence to allow for a definition of Schallamach later in the project. To assist with this, oblique lighting was used during the outsole examinations to expose additional details. **Figure 39** shows section 2 at 30x without oblique lighting, and **Figure 40** shows the same section of the outsole with oblique lighting from three different light sources. It was found that each light source provided different results, the best being the rechargeable LED Lenser M7R (400 Lumens) torch, and therefore was used throughout the examinations.

Figure 39: *Section 2 without oblique lighting*

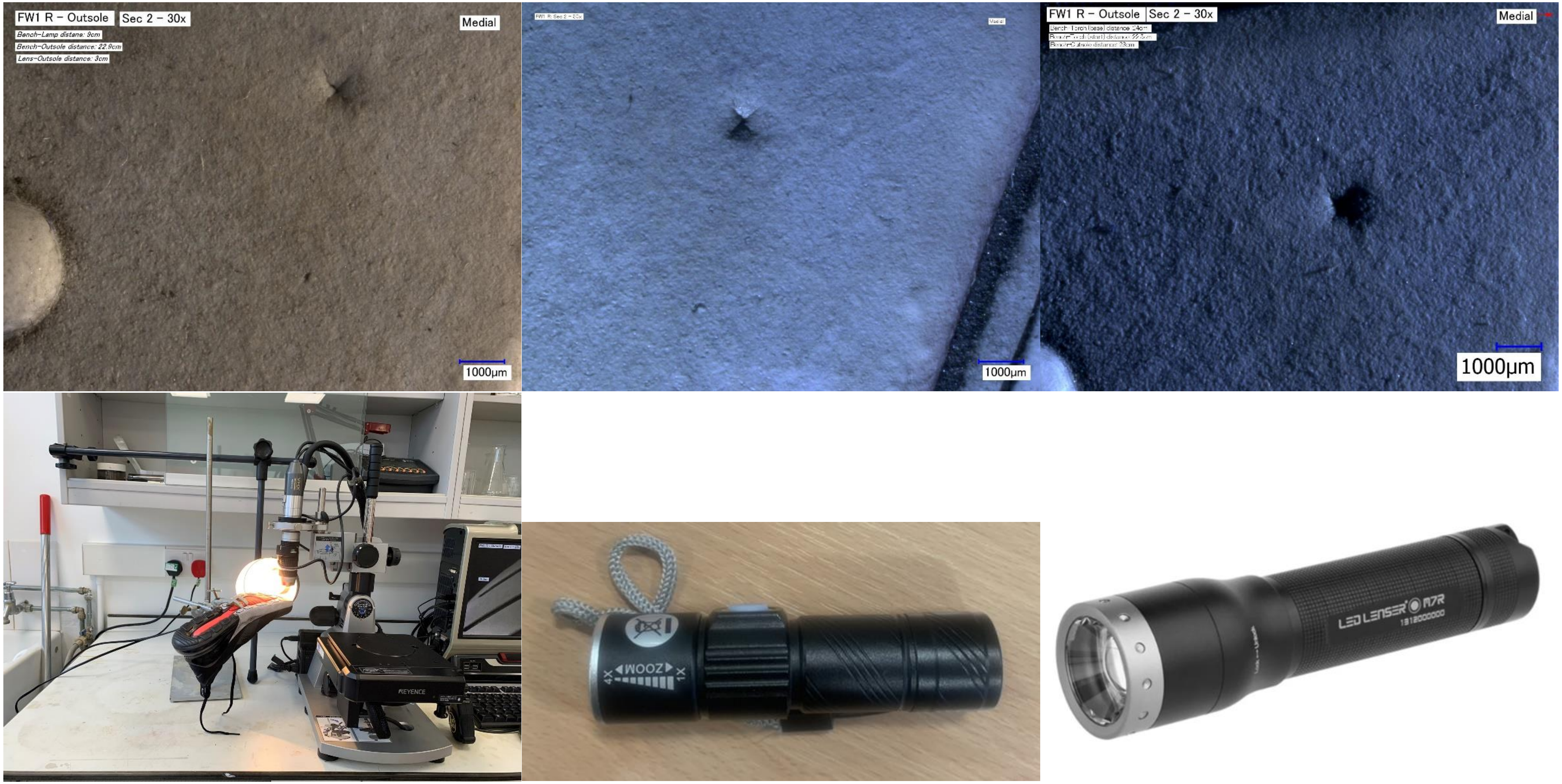


Figure 40: *Section 2 with oblique lighting via a lamp [left]; via a Trixes LED torch [centre]; via a LED Lenser M7R (400 Lumens) [right*

Figure 41-Figure 42 shows each magnification without and with oblique lighting using the LED Lenser torch.

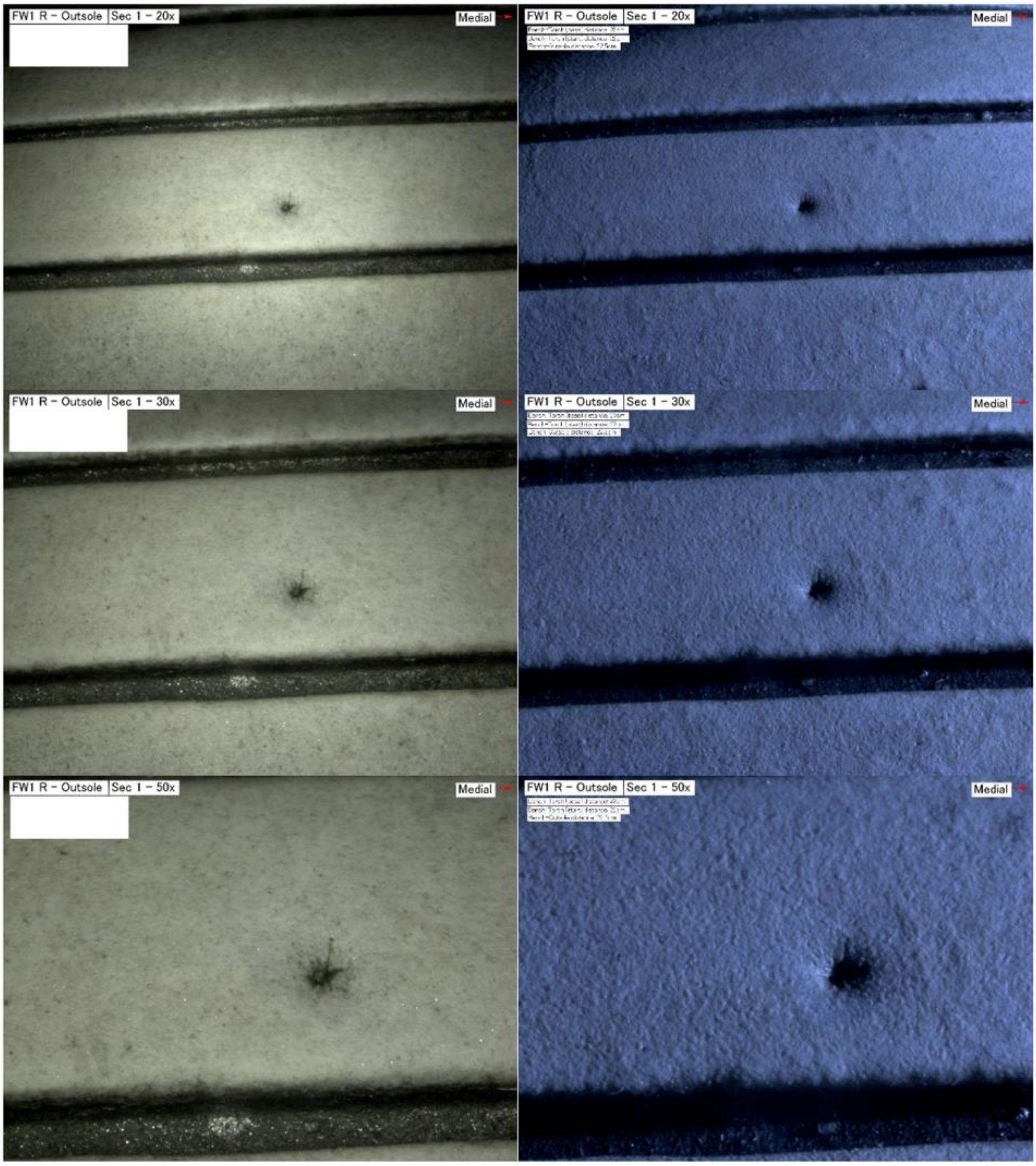


Figure 41: *Images showing the detail seen in each magnification (20x [top], 30x [centre], and 50x [bottom]) with the Keyence microscope light (left) and with oblique lighting using the LED Lenser (right)*

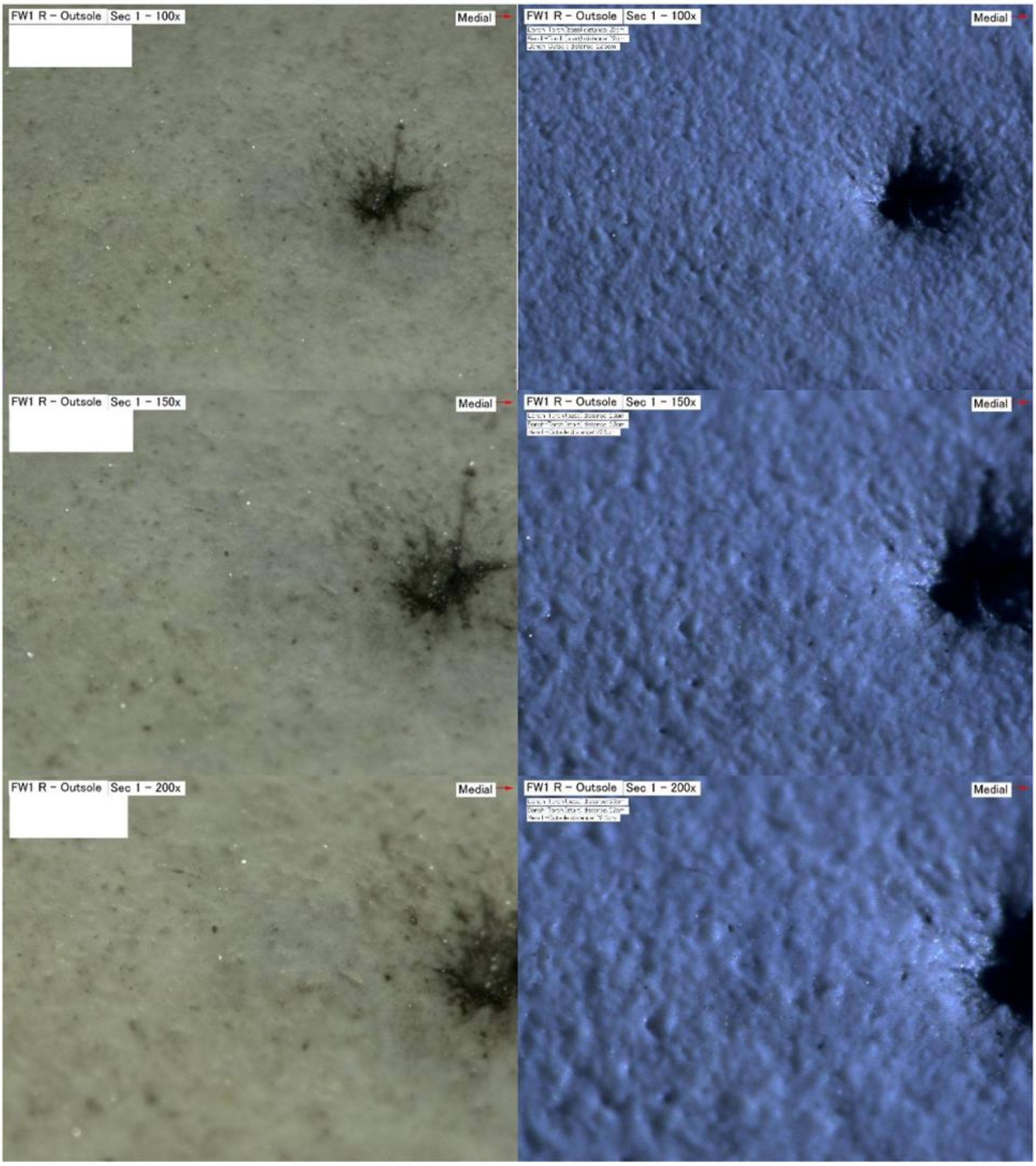


Figure 42: *Continued - Images showing the detail seen in each magnification (100x [top], 150x [centre], and 200x [bottom]) with the Keyence microscope light (left) and with oblique lighting using the LED Lenser (right)*

3.2.5. Oblique Lighting: The Inversion Effect

When photographing three-dimensional objects, oblique lighting is used to achieve illumination of 'high' areas, and shadows on the 'low areas' (Bodziak, 2000). Initially, the Keyence examinations of the outsole were completed with natural sunlight and the overhead microscopic light, however, it was found that the features appearing raised were in fact indented due to the lack of illumination and shadows. Within Bodziak's (2000) book, this is referred to as an inversion effect often due to strong natural oblique light. **Figure 43** shows an example of the inversion effect with the same footwear, section, and magnification, but with artificial oblique light [A] and with natural sunlight and the overhead microscope light [B].

Figure 43: *A figure to show an example of artificial oblique lighting [A] and using natural sunlight and the overhead microscope light [B]*

Although this does not interfere with the examination (Bodziak, 2000), it must be highlighted to avoid confusion, and awareness of this effect is beneficial when recognising which features on the outsole are raised when comparing this to features found within a test impression.

3.2.6. Increasing Magnification

Starting with the lowest magnification of 20x and reaching a maximum of 200x, the magnification was increased in stages of 20x, 30x, 50x, 100x, 150x, and 200x, utilizing the available magnification lens on the Keyence. Images were taken ensuring that the pin hole remains visible at each magnification to maintain consistency. **Figure 44** shows the differences of features at each magnification, and from this, each microscopic image was examined for clear features not observed with the naked eye. It was found that 50x and 200x were the more favoured magnifications for this, thus focusing on these two magnifications going forward.

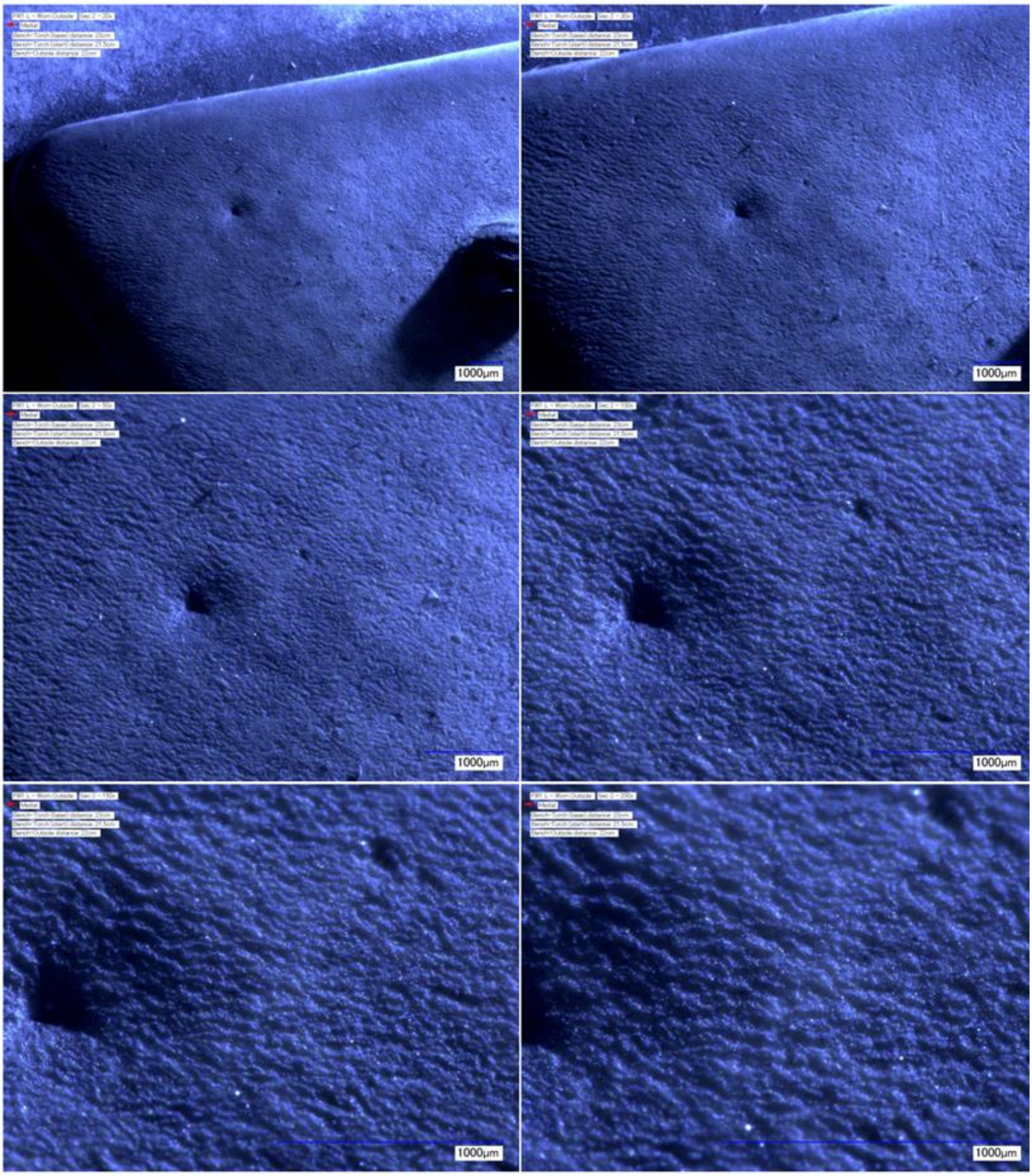


Figure 44: *Images of Worn FW1 L (footwear 1 left) taken with the Keyence microscope at 20x-200x magnification. (20x [top left], 30x [top right], 50x [centre left], 100x [centre right], 150x [bottom left], 200x [bottom right])*

3.3. Data Collection Method:

To observe if there was correspondence of microscopic detail between replicated test impressions, it was important to compare the test impressions with each other before comparing a test impression to the outsole. To assess the correspondence, a correspondence score (CS) was assigned to each comparison. The results are collated via a combination of tables, figures, and statistics. An example table of results can be seen in **Table 1-Table 2**.

Table 1: *An example of the results table when comparing test impressions to the test impression replicates (FW1 L = footwear 1 left; S1 = section 1; S2 = section 2; S3 = section 3; S4 = section 4; Mag total = Magnification total)*

FW1 L Worn		*(Acetate Copy)*																																			
		Static Black 1												*Static Black 2*												*Static Black 3*											
		1:1				*50x*				*200x*				*1:1*				*50x*				*200x*				*1:1*				*50x*				*200x*			
		S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
(Paper Copy)	*Static Black 1*																																				
	Static Black 2																																				
	Static Black 3																																				
Section Total																																					
Scale/Mag Total																																					

Table 2: *An example of the results table when comparing test impressions to the outsole*

FW1 L Worn		*(Acetate Copy)*																							
		Static Black 1								*Static Black 2*								*Static Black 3*							
		50x				*200x*				*50x*				*200x*				*50x*				*200x*			
		S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
(Paper Copy)	*FW1L Worn Outsole*																								
Total																									

Each test impression is compared at a 1:1 scale, followed by at 50x and 200x magnification to avoid bias during the comparisons. Comparing a full static black footwear impression to the physical outsole at 1:1 was not possible due to the fiddly nature of a comparison of this type. As shown in subchapters 3.3.4 and 3.3.5, oblique lighting is required to reveal the fine detail used during the comparisons. It would be difficult to avoid inconsistencies during a comparison of this type, as controlling variables such as ensuring that the torch, outsole position and distance is the same throughout the comparisons would not be possible. It is important to consider these variables, as shown in subchapter 3.3.5, a change to the light source can cause major differences in the level of detail shown, which could affect the comparisons. It was for these reasons that comparisons between static black test impressions and the physical outsole at 1:1 were not completed.

At each magnification specific questions were considered to help assist with assigning scores of correspondence to the comparisons; an example of the questions and scoring system can be found in **Figure 45** and **Table 3**. The higher the score, the more each comparison corresponds to one another.

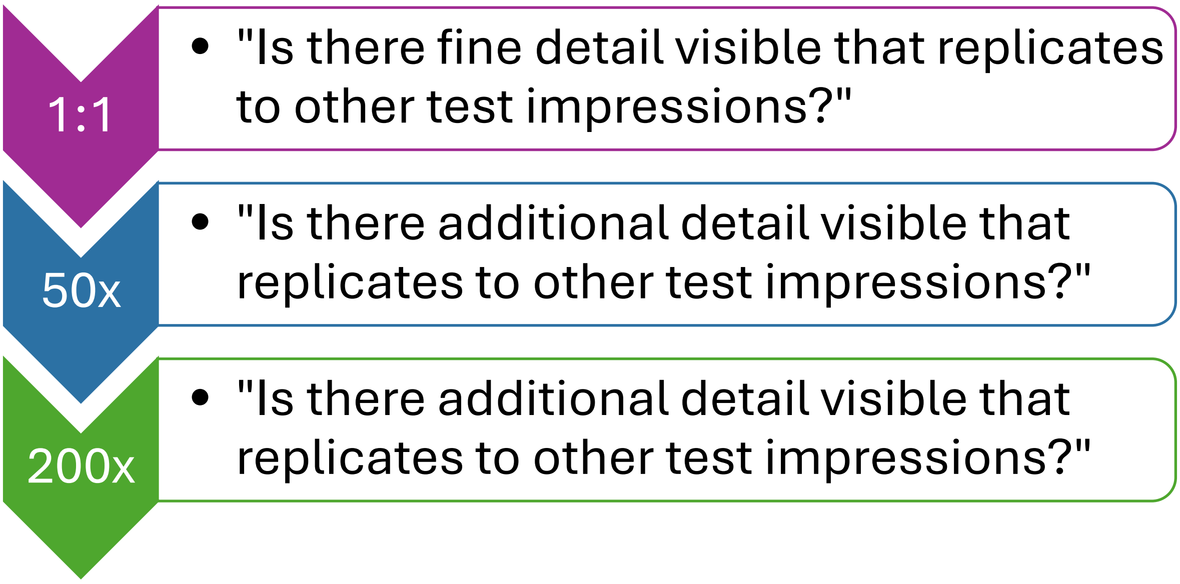


Figure 45: *An example of the questions asked when conducting the comparisons*

Table 3: *The scores given to comparisons at each magnification with definitions*

Magnification	Symbol	Definition	Notes
1:1	0	NO replication observed	There is no visible detail.
	3	YES, there is replication	There is detail visible.
50x and 200x	0	NO correspondence observed	There is no visible detail.
	0	NO correspondence observed	(Affected by test impression quality)
	1	GOOD correspondence	(Affected by test impression quality)
	2	GOOD correspondence	(A lot of features correspond)
	3	VERY GOOD correspondence	(All features correspond)

As shown, comparisons at a 1:1 scale have a different question and scoring system as it became clear that fine features seen at a 1:1 scale were difficult to see, and it was not reasonable to attempt to score the correspondence of replication. As such, there are only two scores for 1:1 scale, either 0 or 3 to determine whether there is observable correspondence. Alternatively, there are five different scores for comparisons at 50x and 200x as it is important to provide insight into why the scores were low, for example, poor test impression quality: resulting with two separate definitions for scores 0 and 1. A poor quality test impression describes an impression with a lack of detail due to a potential lack of pressure applied when sticking the lifter onto the outsole; this could lead to sections missing on the test impression, air bubbles; due to not taking care when rolling the acetate cover onto the static lifter; and creating ghosted features; occurring due to re-sticking the static lifter onto a different part of the outsole. An example of a poor-quality test impression can be found in **Figure 46** and an example of the scores applied to the comparisons can be viewed in **Table 4**.

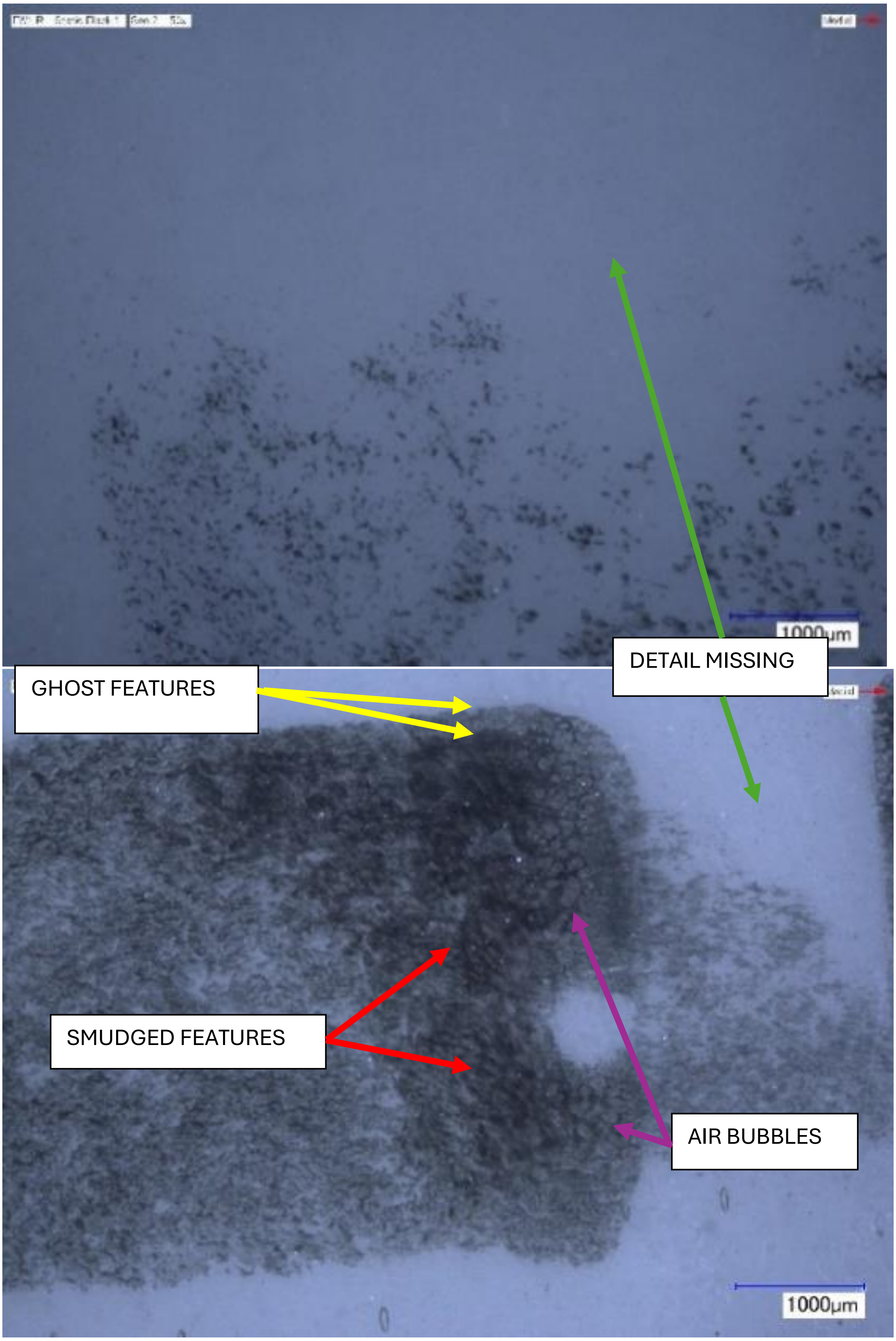
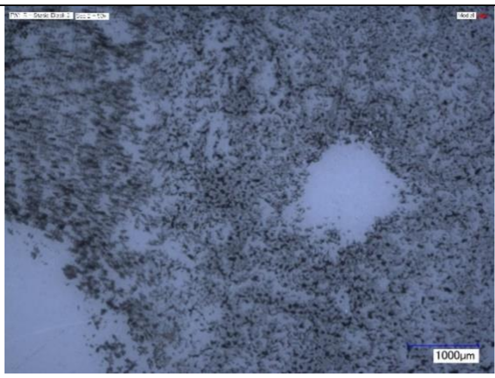
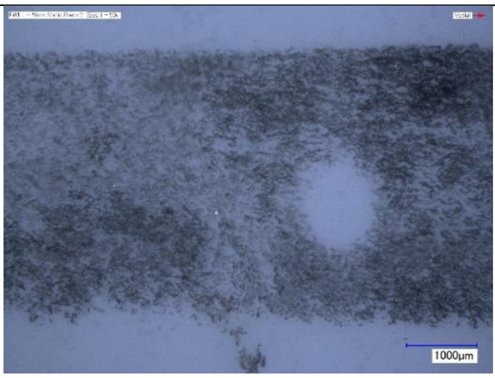
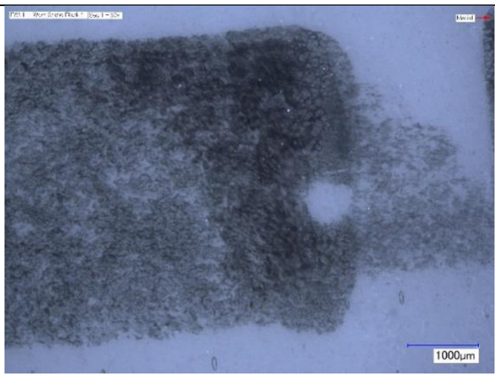
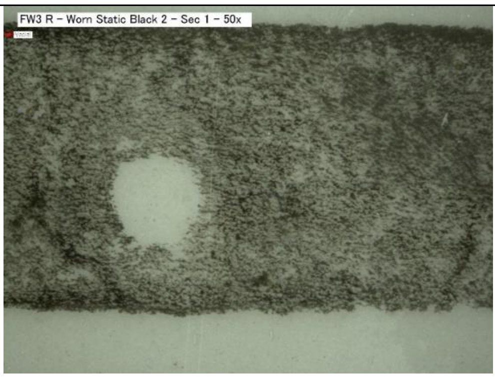
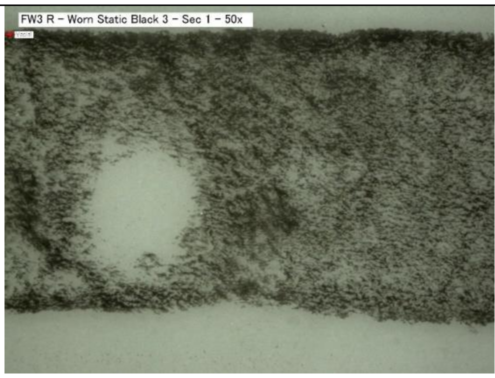
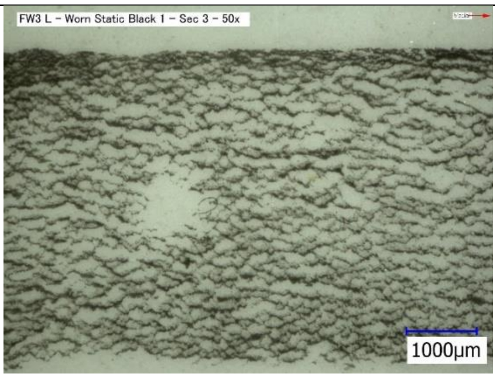
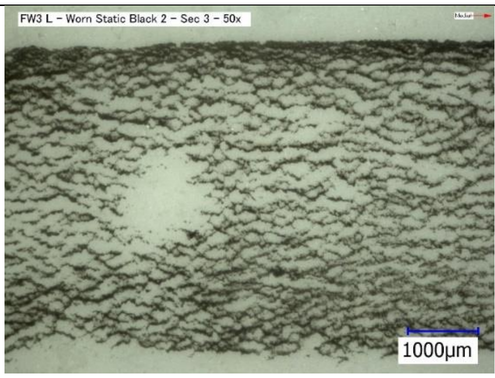


Figure 46: *Examples of poor-quality test impressions with annotated examples*

Table 4: *Examples of the correspondence scores (0, 0, 1, 2, 3) given to static black test impression-test impression comparisons with photographic examples*

0	*No examples*	*No examples*
0		
1		
2		
3		

3.4. Method of Examinations, Comparisons, and Keyence Software:

This subchapter demonstrates the method used to complete the practical aspect of this project as a whole; to set up the Keyence microscope for the examinations of the outsoles and test impressions; the order of comparisons; and the method used for the comparisons between test impressions and outsoles. Moreover, due to a practical-based project, an equipment list is essential and can be found in the **Appendix (A. Resources)**.

3.4.1. Method of Footwear Examinations:

For a true replication of the method, begin the steps with new shoes, following the steps in **Figure 47**.

Figure 47: *A flow chart showing the method of the practical aspect of the project*

3.4.2. Setting up the Keyence Microscope for the Outsole Examinations:

1. Turn on the Keyence microscope and ensure the microscopic light is switched on.
2. Rotate the lens away from the stage by rotating the dial in **Figure 48**.

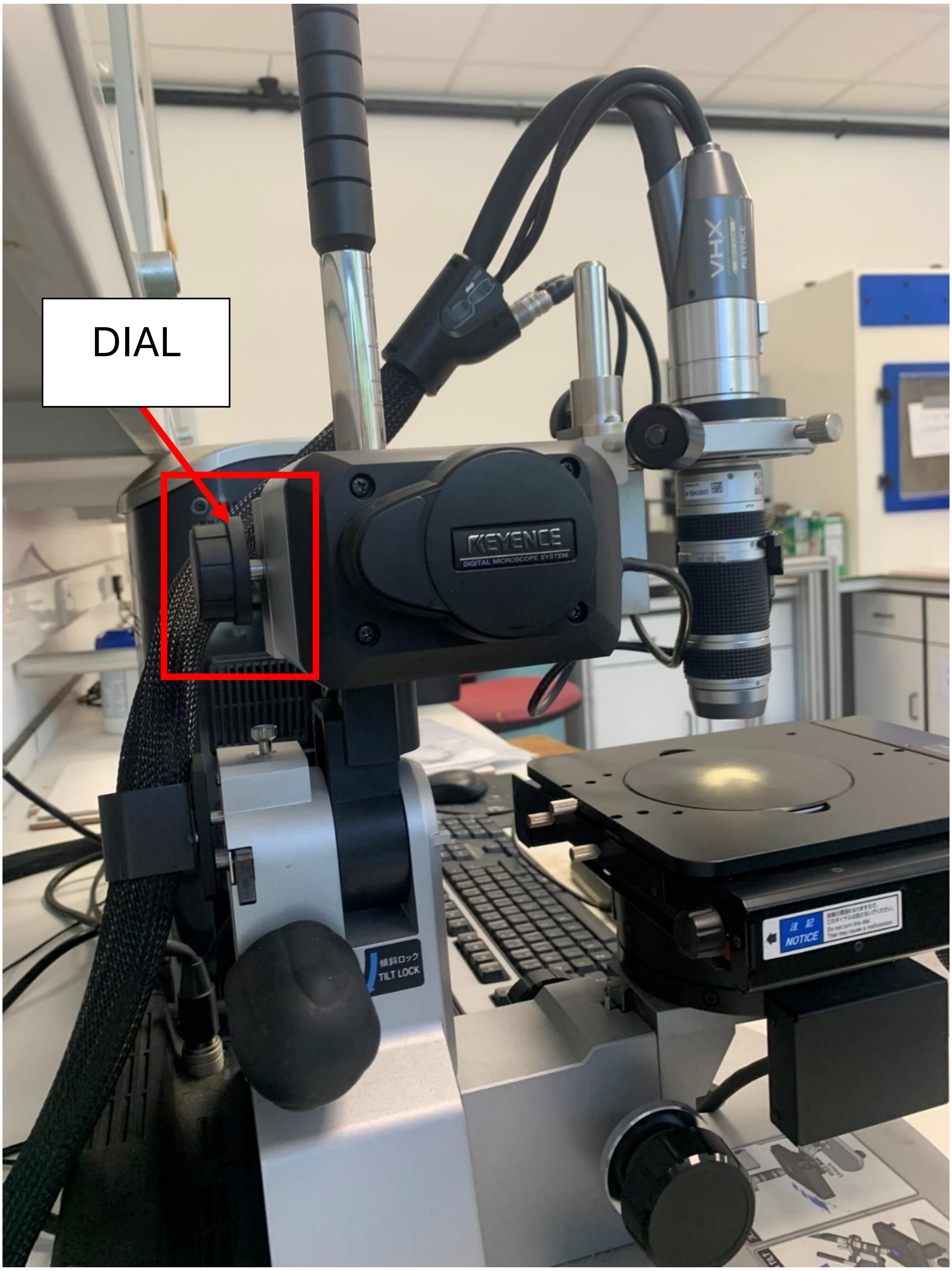


Figure 48: *The side view of the VHX-7000 series Keyence microscope, a red box highlighting the lens rotating dial*

3. Clamp the outsole onto the stand, ensuring that the arms of the clamp do not interfere with any pin holes and place under the microscope lens, focusing on a desired section **(Figure 49)**.

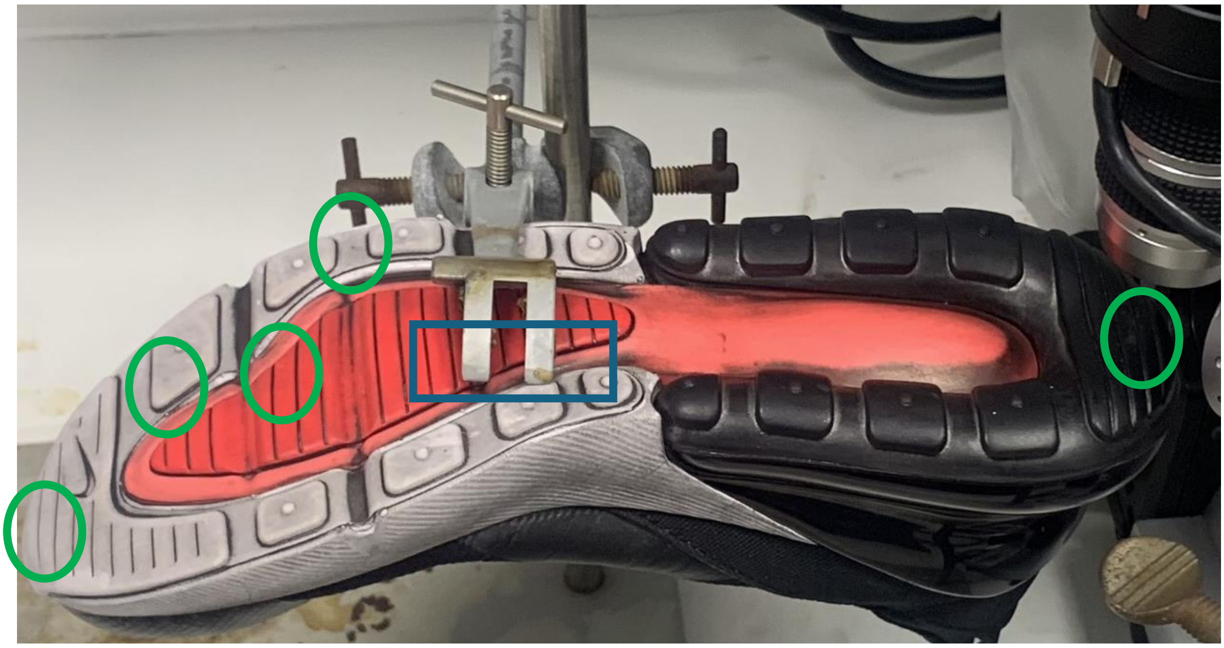


Figure 49: *Nike Air Max 270 secured on the clamp stand. The clamp arms highlighted with a blue rectangle, and the pin holes highlighted with green circles*

4. Increase the magnification from 20x-200x and ensure that the pin hole is consistently in view, without needing to alter the position of the lens/clamp.
5. Once the pin hole is consistently in view, tighten the Keyence dial and turn off the microscope light and with a torch, slowly shine the light around the shoe to determine the position which offers the best clarity.
6. With the best torch position determined, clamp the torch into position.
7. With a tape measure, take measurements for repeatability **(Figure 50)**.

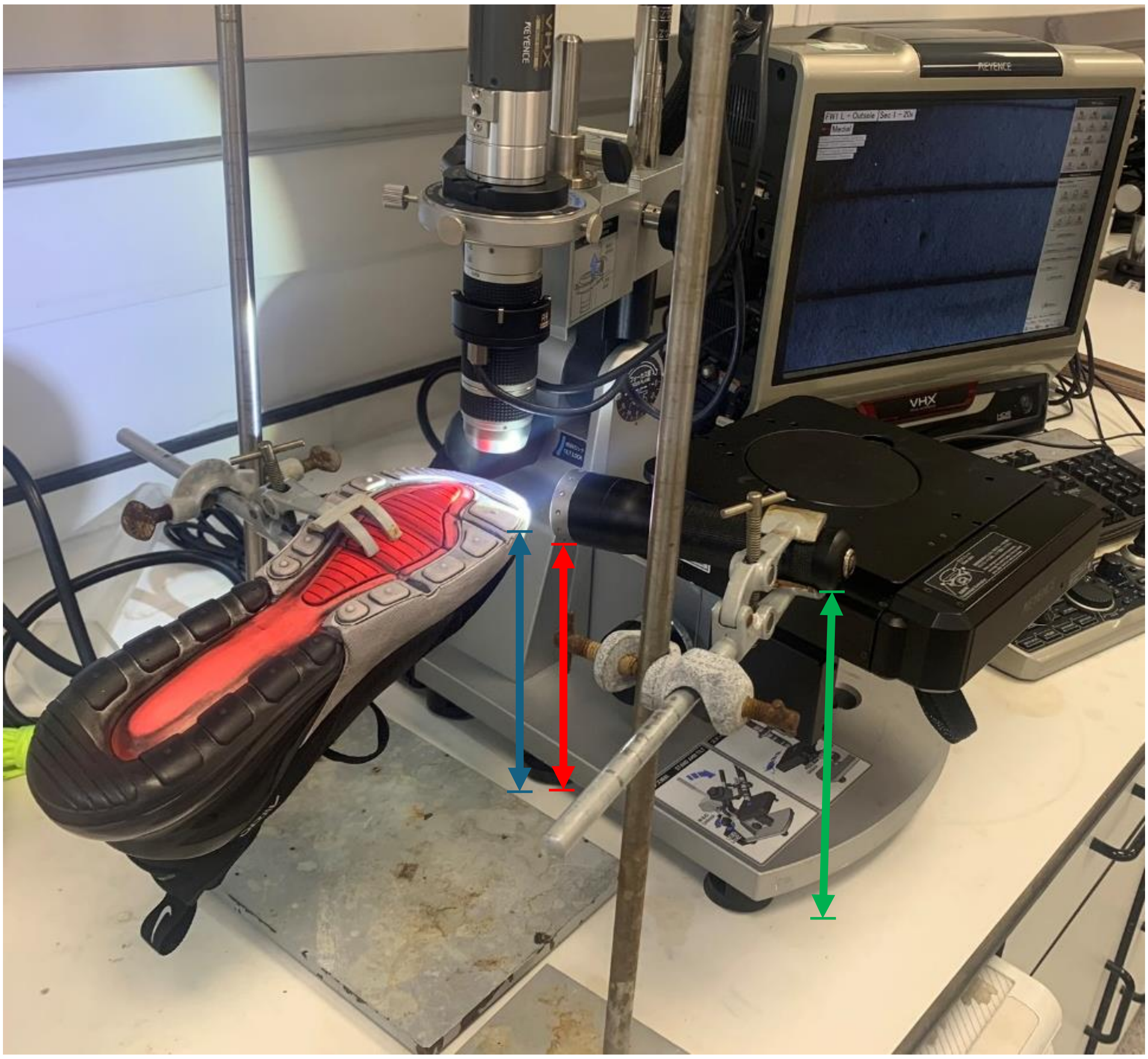


Figure 50: *Nike Air Max 270 and torch secured on the clamp stands. The measurements taken highlighted by coloured arrows: outsole-bench distance [blue arrow]; torch start-outsole distance [red arrow]; torch base-bench distance [green arrow]*

8. Using the 'Measure' function on the Keyence, annotate the examination information (footwear number, left/right shoe, medial arrow, measurements, and the magnification used) **(Figure 51)**.

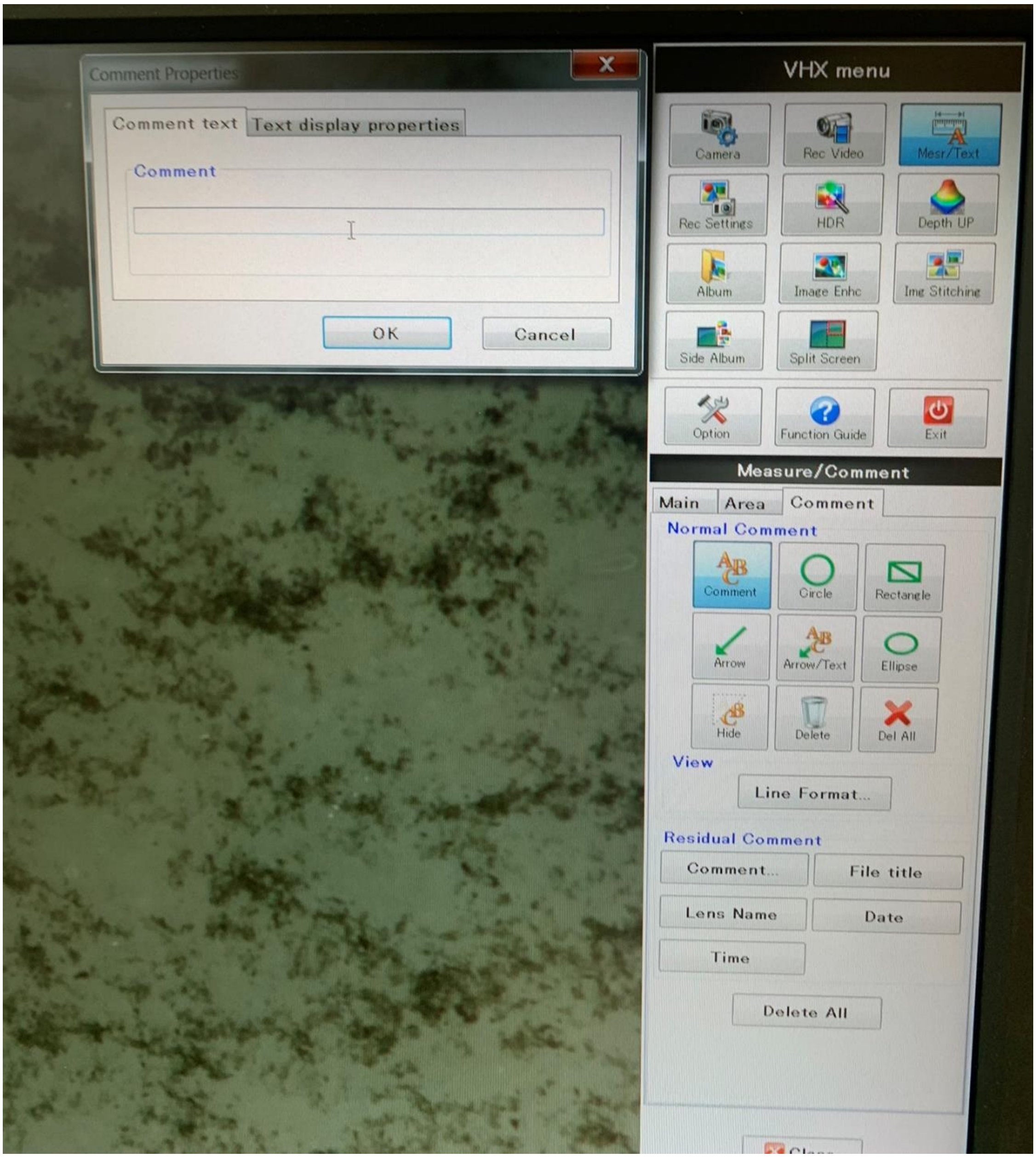


Figure 51: *The measure/comment function on the Keyence, allowing for on-screen annotation*

9. Capture images at each magnification.

3.4.3. Setting up the Keyence Microscope for the Test Impression Examinations:

1. Turn on the Keyence microscope and ensure the microscopic light is switched on.
2. Rotate the reversible colour plate on the Keyence stage to white to provide contrast against the black impression.
3. Place the transparent 1:1 static test impression onto the stage, using weights to keep the impression in position **(Figure 52)**.

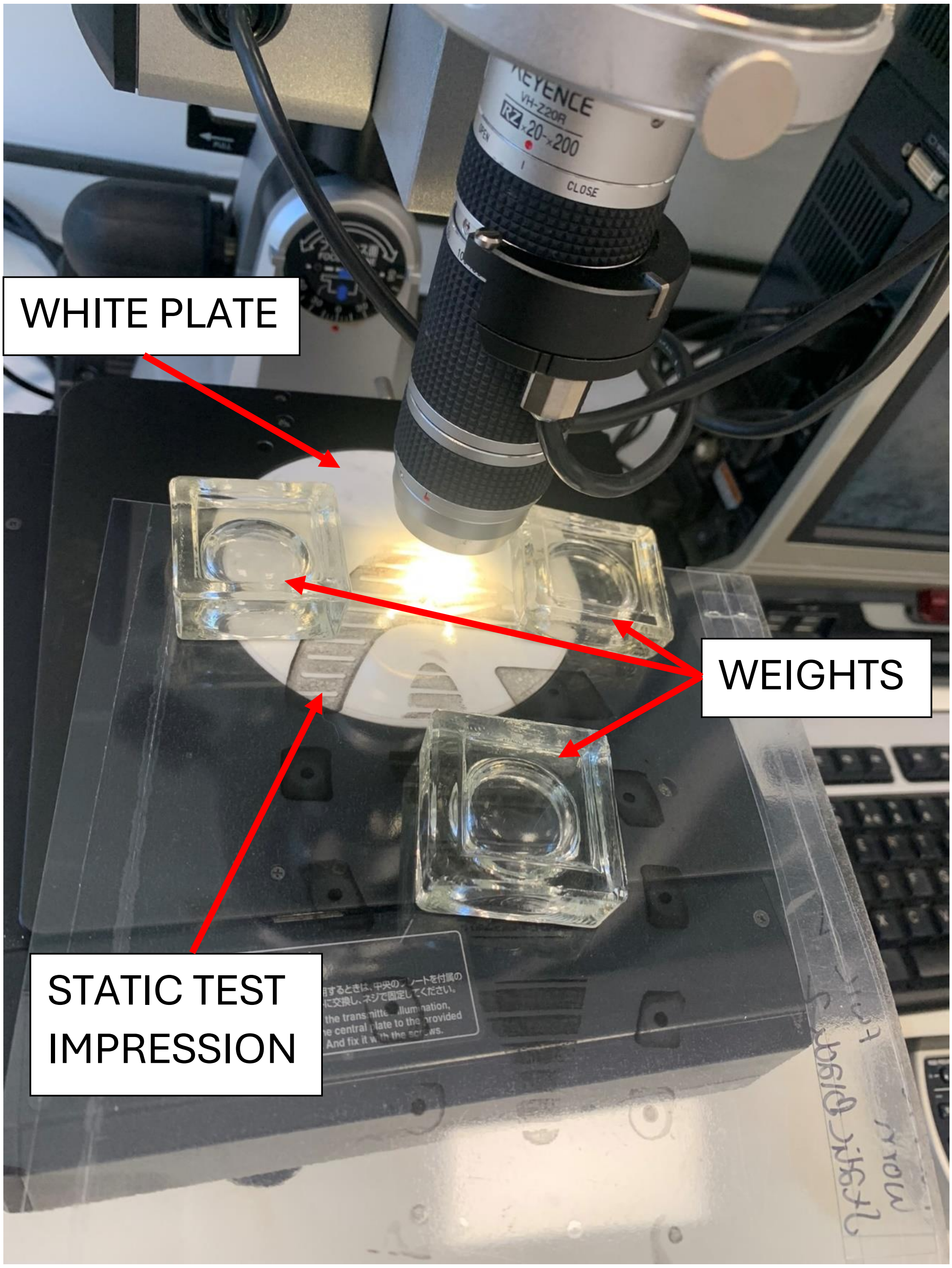


Figure 52: *Keyence test impression examination, utilising the white reversible colour plate and weights to maintain the position of the impression*

4. Using Keyence stage controls highlighted in **Figure 53**, adjust position of the stage so the pin hole within the test impression is consistently in view at each magnification.

Figure 53: *Keyence controls, the stage control highlighted with a red box*

5. Using the 'Measure' function, annotate the examination information (footwear number, left/right, medial arrow, and magnification).
6. Capture images at each magnification.

3.4.4. Order of Comparisons:

To avoid creating bias during the comparisons, it is important to consider the order of comparisons. To do this, the comparisons are first completed at a 1:1 scale, followed by comparisons at 50x and finishing with the comparisons at the highest magnification of 200x. If the comparisons were completed at the highest magnification first, the result may be biased as if detail was visible at 200x, the observer may be inclined to report that there was visible detail at 1:1, even if this is not accurate.

A full breakdown of the order of comparisons can be viewed in the flow chart in **Figure 54**.

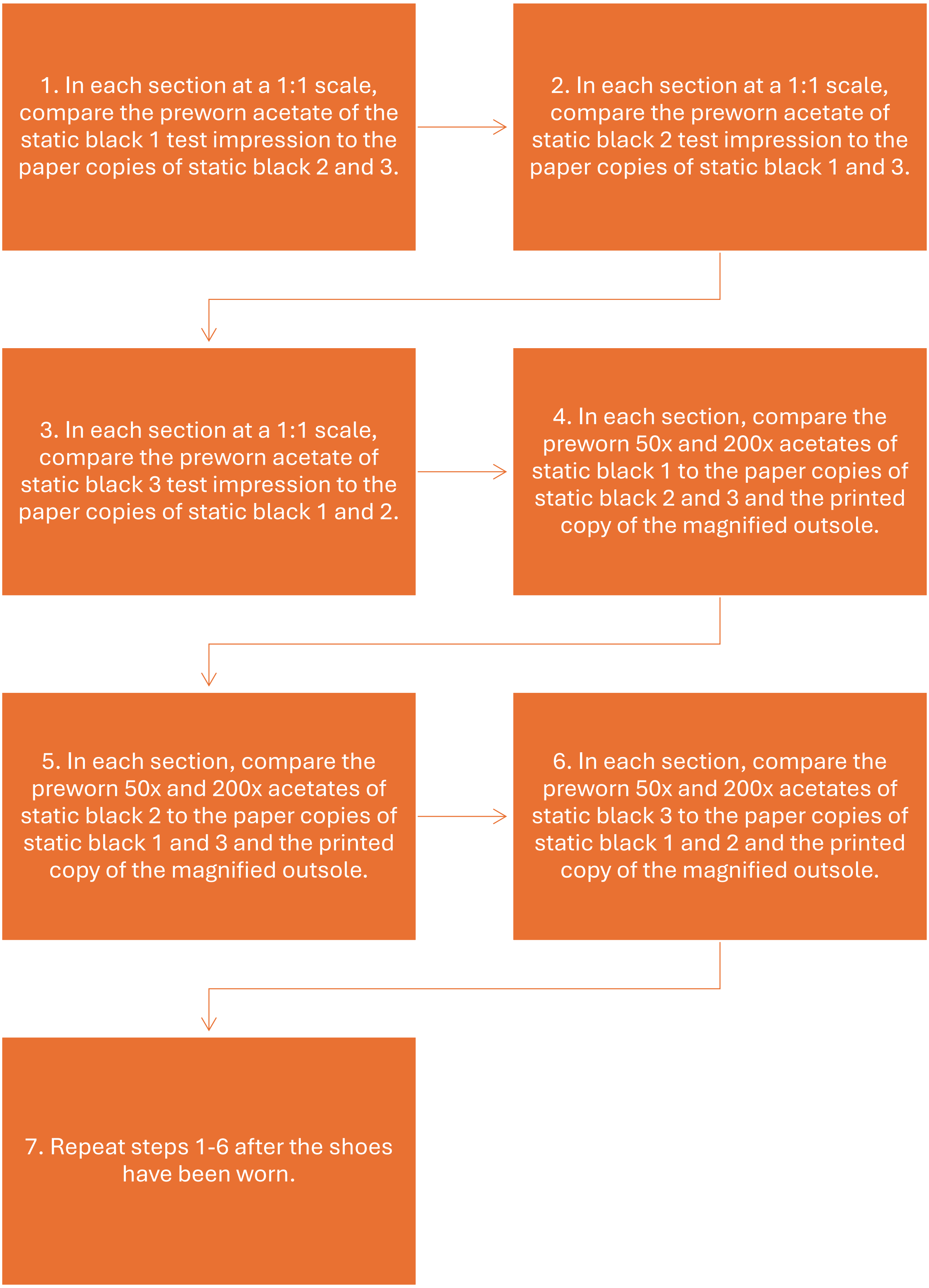


Figure 54: *A flow chart showing the order of footwear comparisons*

With brief breakdown of the order of comparisons understood, a more detailed breakdown of comparisons at each scale and magnifications and within each section can be viewed in the diagrams in **Figure 55**-**Figure 63**.

Each colour (blue, orange, green, pink) represents a section of the outsole (sections 1-4). The first box details which acetate was being overlayed onto the paper copies detailed in the two boxes underneath.

Although the examples only cover FW1L Worn, it is important to note that the same steps are completed with all footwear used in the sample.

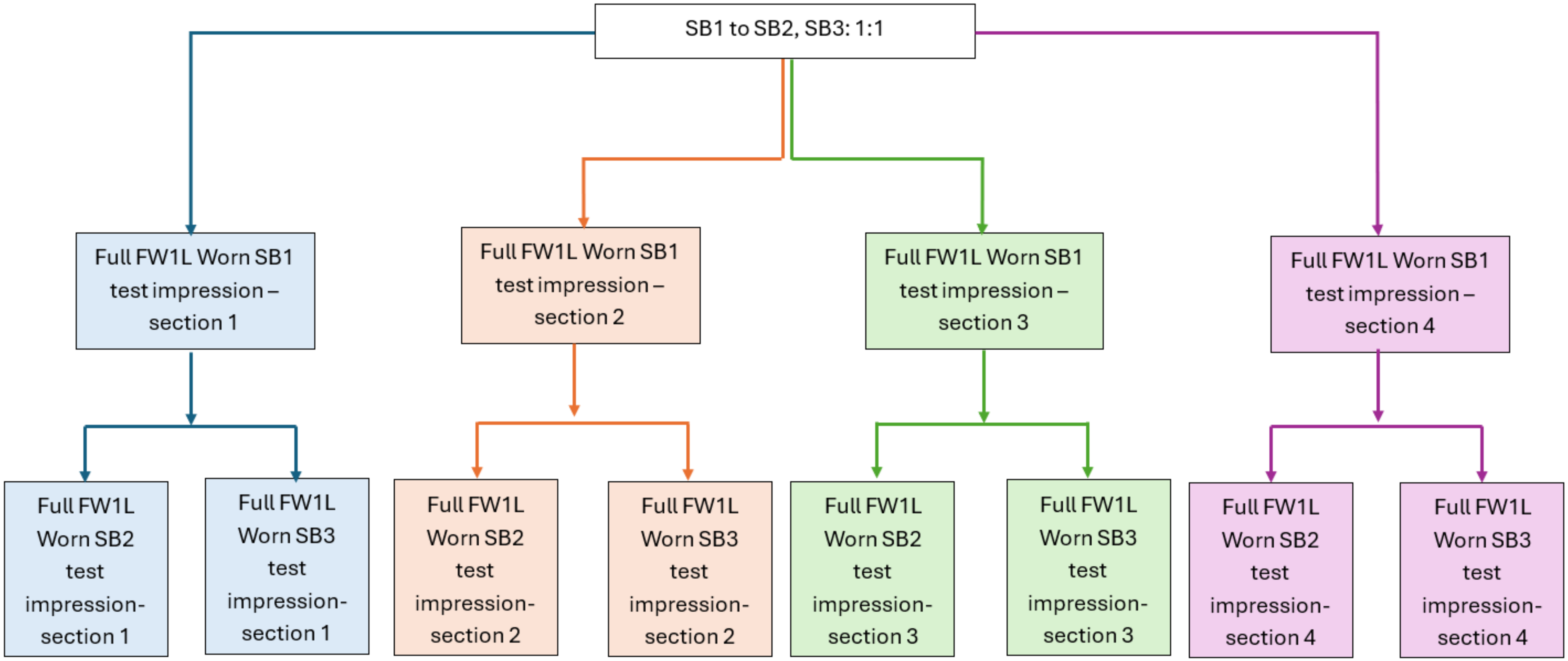


Figure 55: *The order of comparisons when comparing the SB1 test impression with SB2 and SB3 at each section at 1:1*

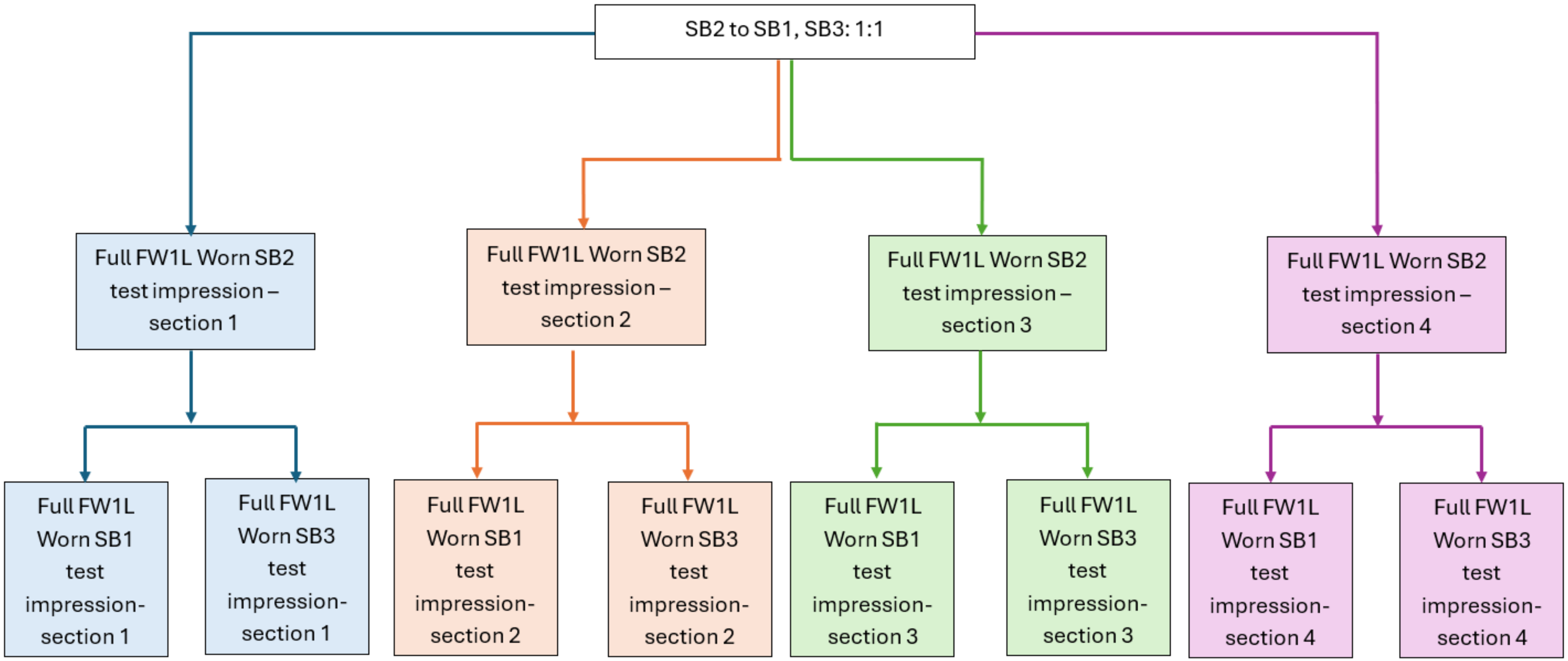


Figure 56: *The order of comparisons when comparing the SB2 test impression with SB1 and SB3 at each section at 1:1*

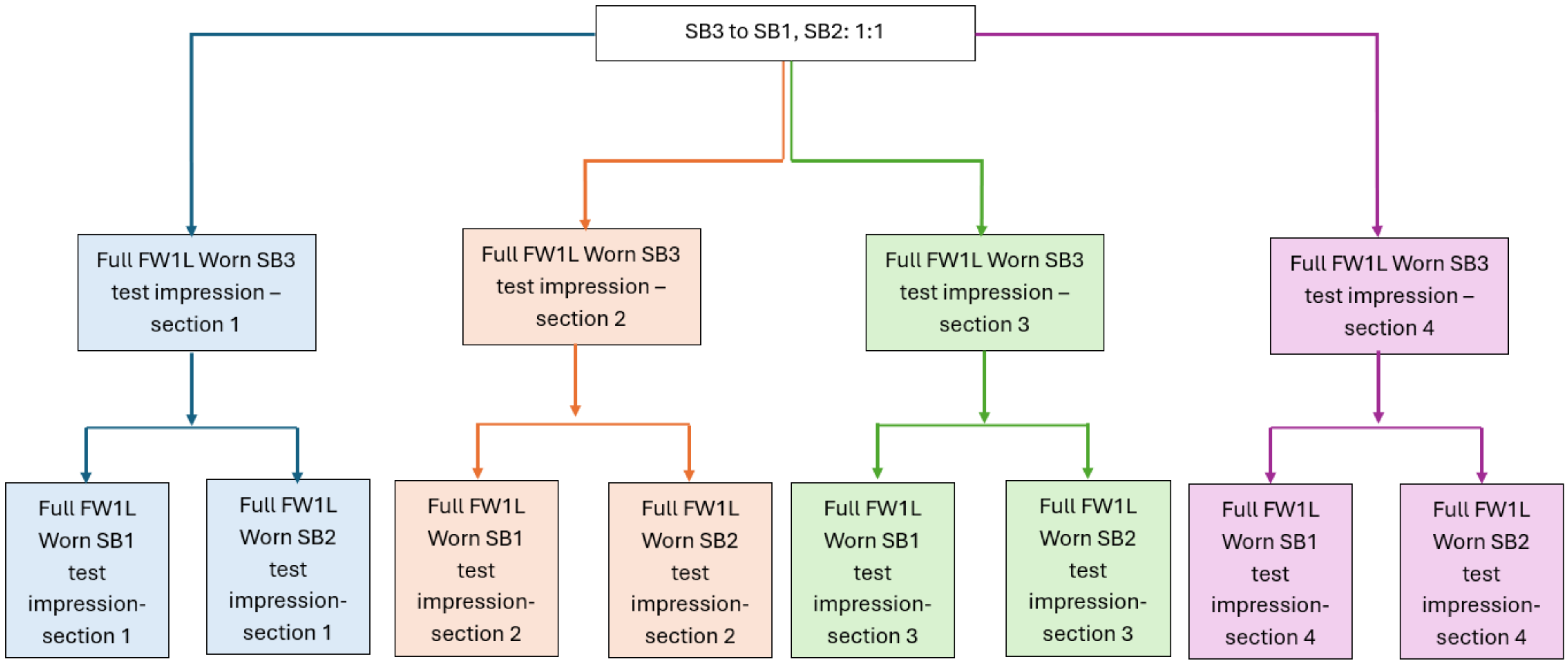


Figure 57: *The order of comparisons when comparing the SB3 test impression with SB1 and SB2 at each section at 1:1*

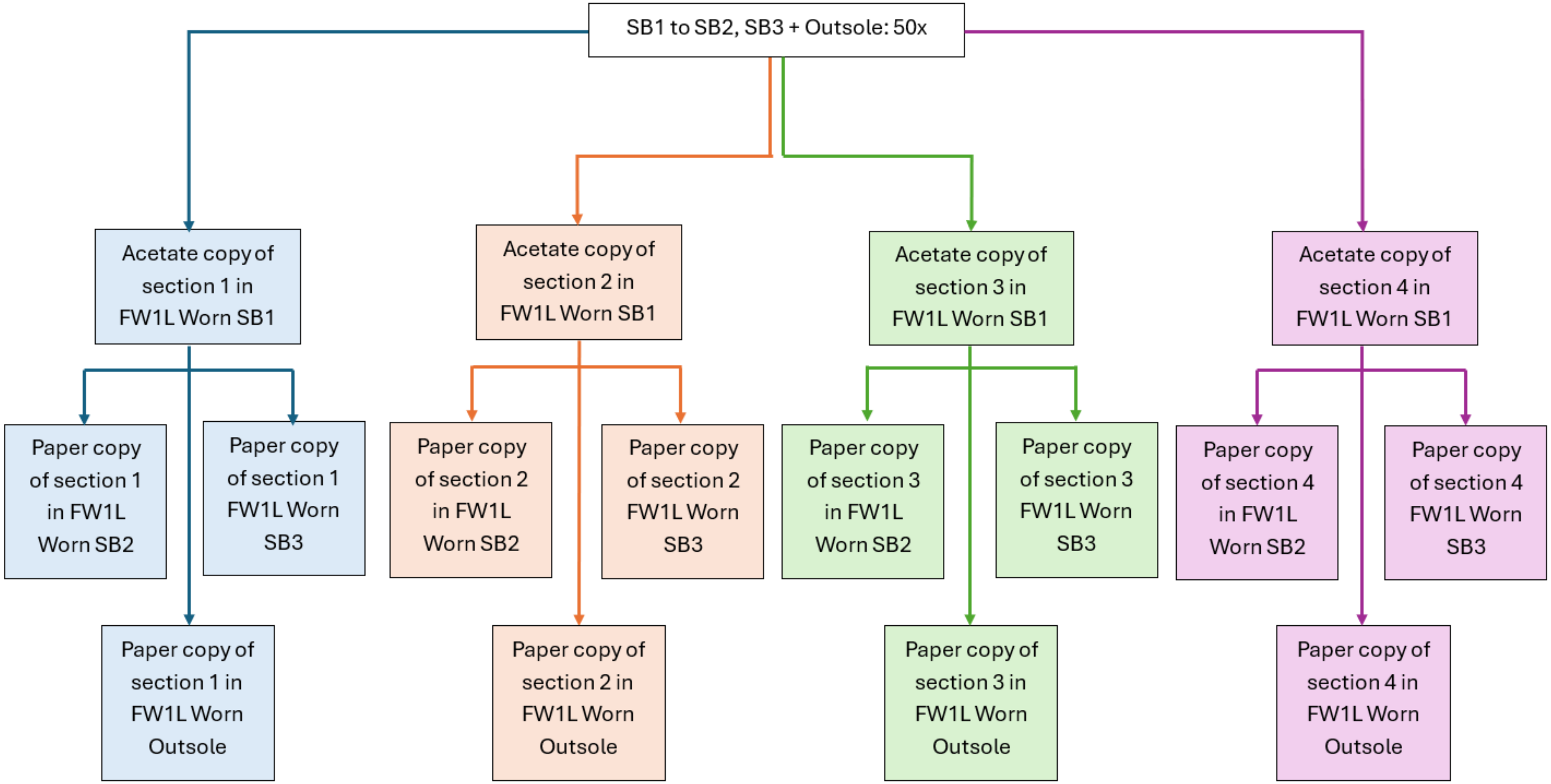


Figure 58: *The order of comparisons when comparing the SB1 test impression with SB2 and SB3 at each section at 50x*

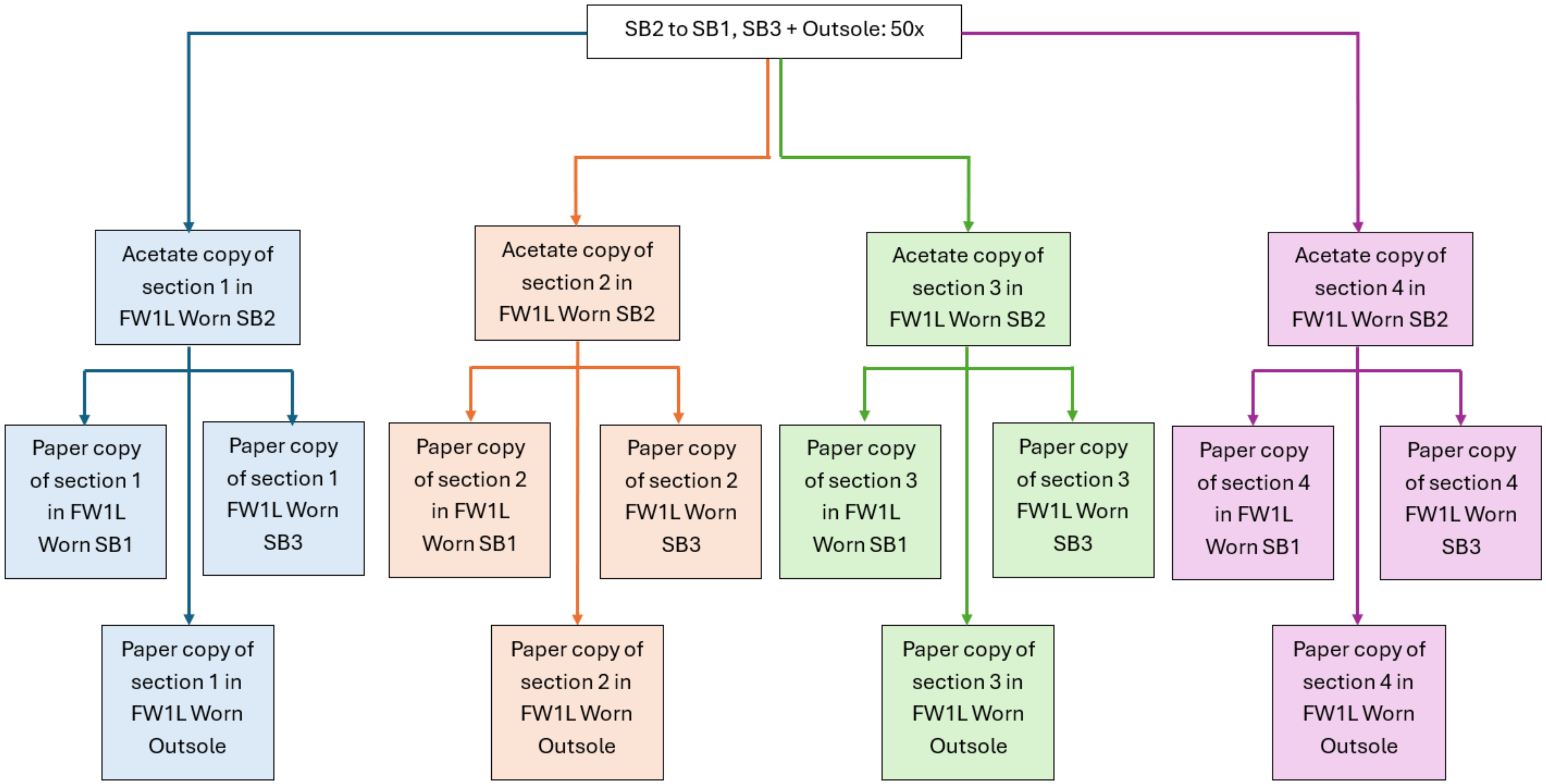


Figure 59: *The order of comparisons when comparing the SB2 test impression with SB1 and SB3 at each section at 50x*

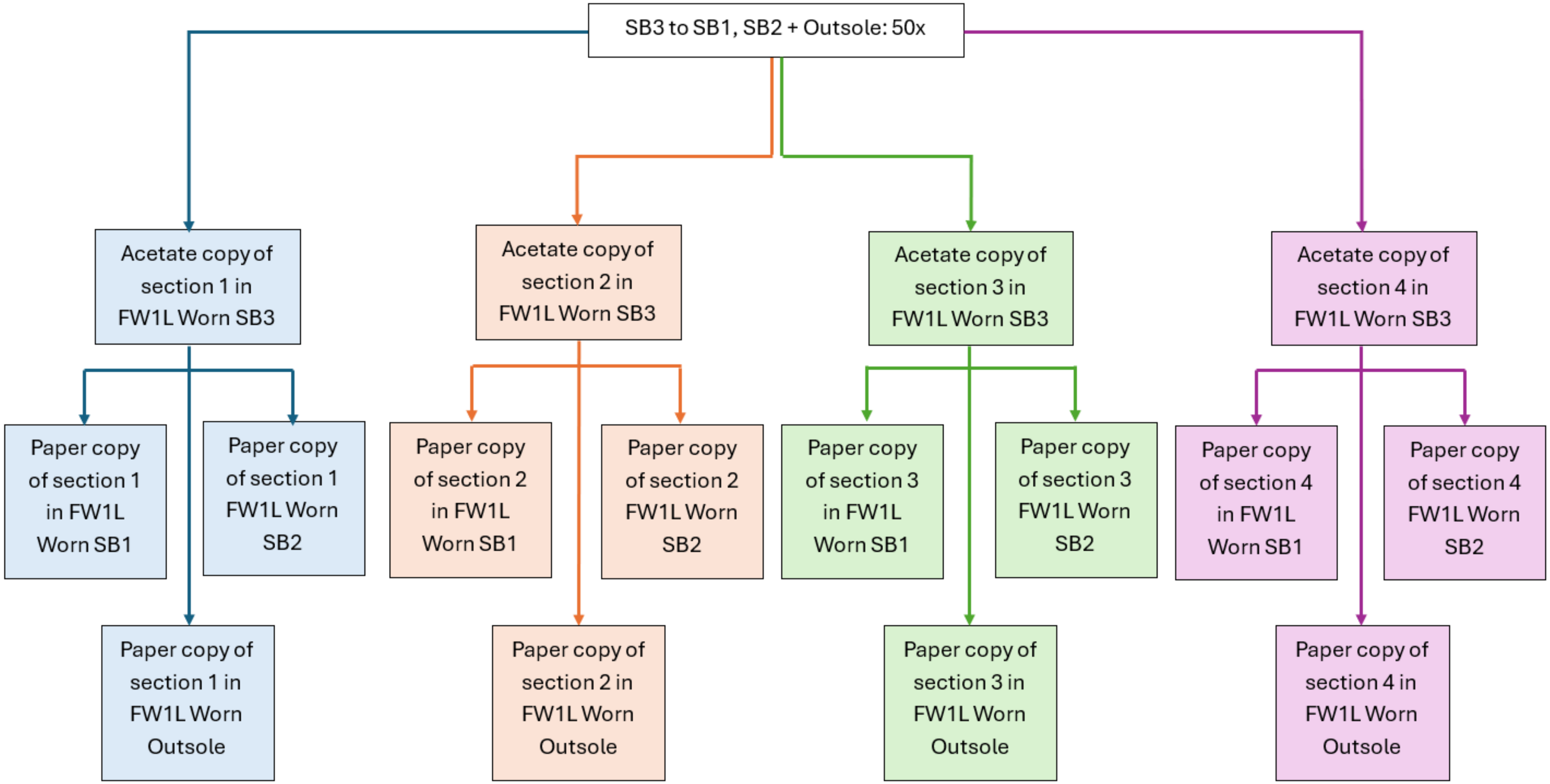


Figure 60: *The order of comparisons when comparing the SB3 test impression with SB1 and SB3 at each section at 50x*

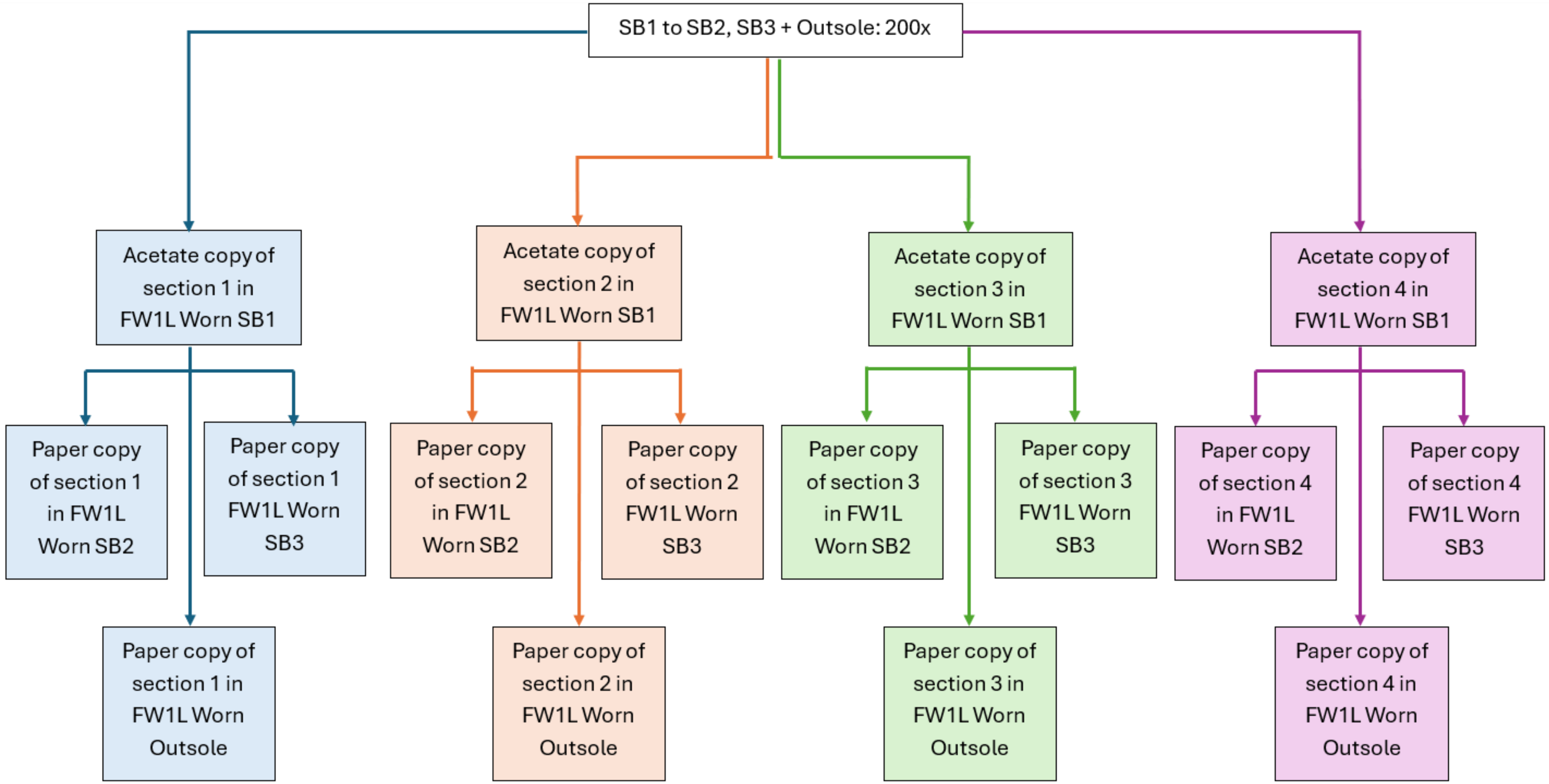


Figure 61: *The order of comparisons when comparing the SB1 test impression with SB2 and SB3 at each section at 200x*

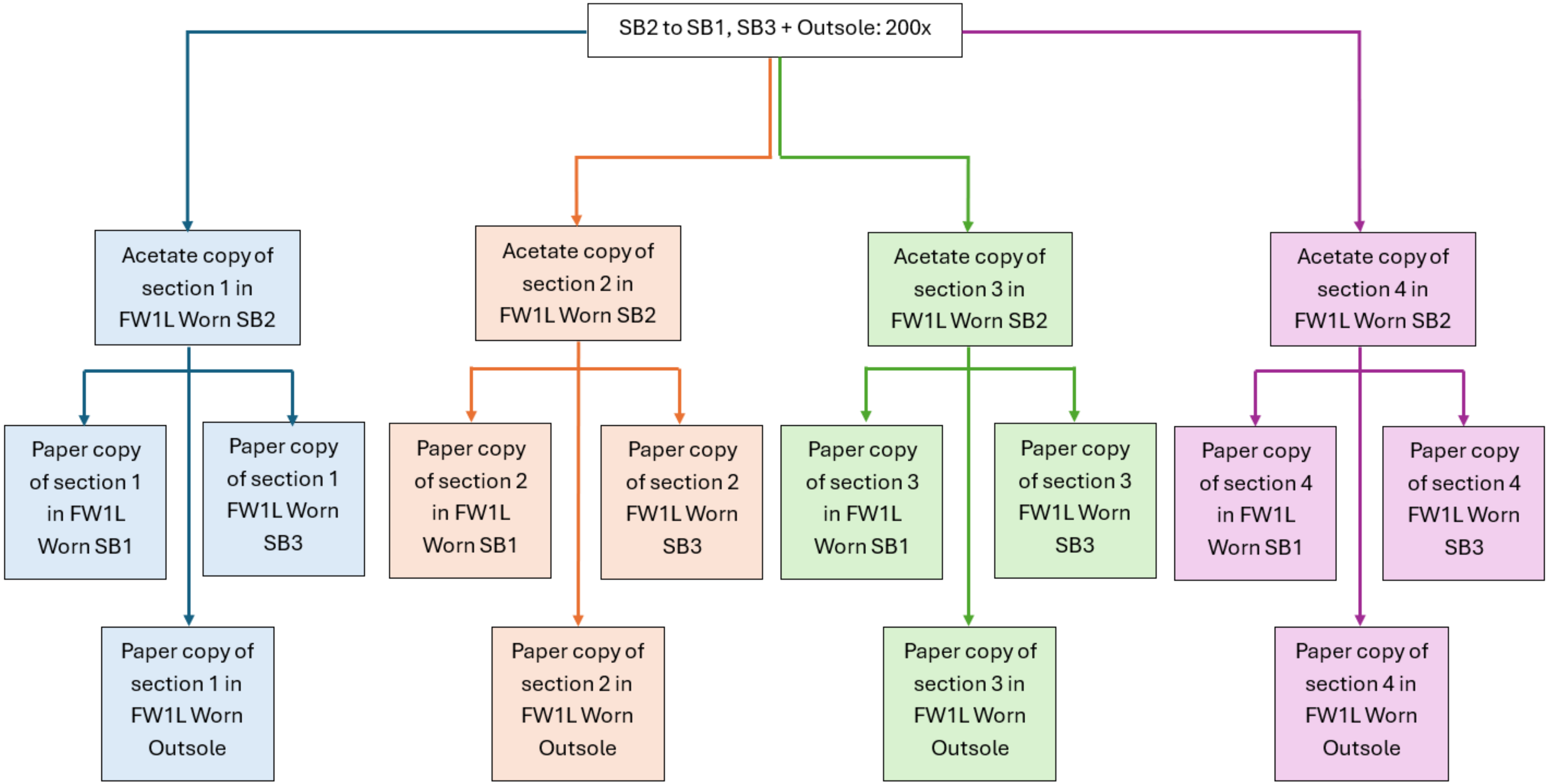


Figure 62: *The order of comparisons when comparing the SB2 test impression with SB1 and SB3 at each section at 200x*

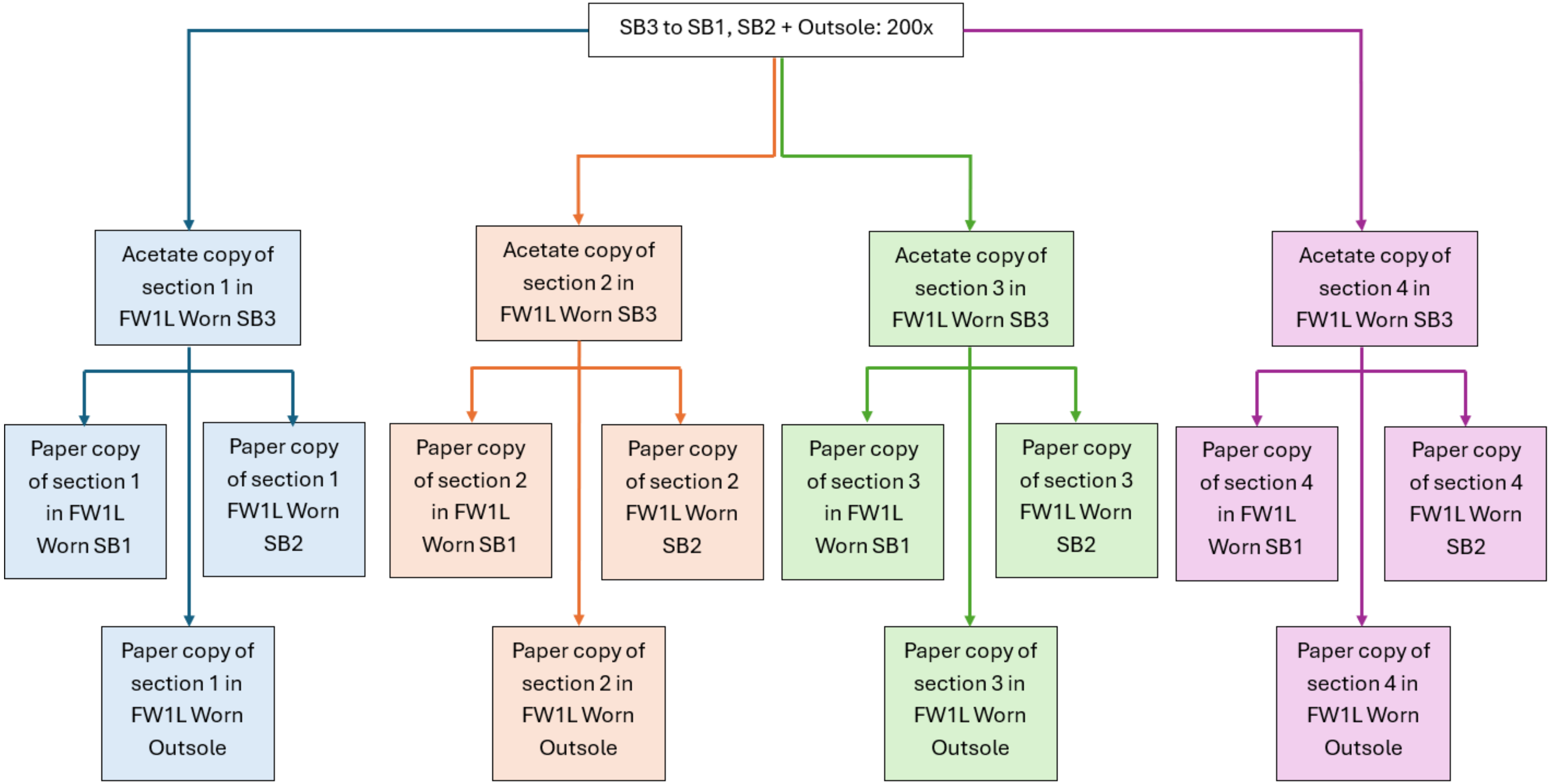


Figure 63: *The order of comparisons when comparing the SB3 test impression with SB1 and SB2 at each section at 200x*

3.4.5. Method of Comparisons:

The comparison method was based on comparison methods used in an ISO17025 accredited Forensic Footwear Laboratory. Complete footwear static test impression acetates were photocopied onto plain white A4 paper on a *HP E87750 - MB116 copier*. Magnified images of the static test impressions were printed onto plain white A4 paper and then photocopied onto Q-Connect A4 Universal Laser and Copier Transparency Film clear acetates, and finally magnified images of the outsole were then printed onto plain white A4 paper.

The acetates were placed on top of the printed images and moved around to check the alignment with key features; the pin hole was used as a key comparison point in all sections of the outsole and test impressions. Once the images were aligned, the acetate was moved rapidly over the image by pulling back and repositioning the acetate, as the observer looks for similarities and differences.

Figure 64-**Figure 68** show examples of test impression-test impression comparisons at 1:1, 50x, and 200x and test impression-outsole comparisons at 50x and 200x using the method of comparisons detailed here.

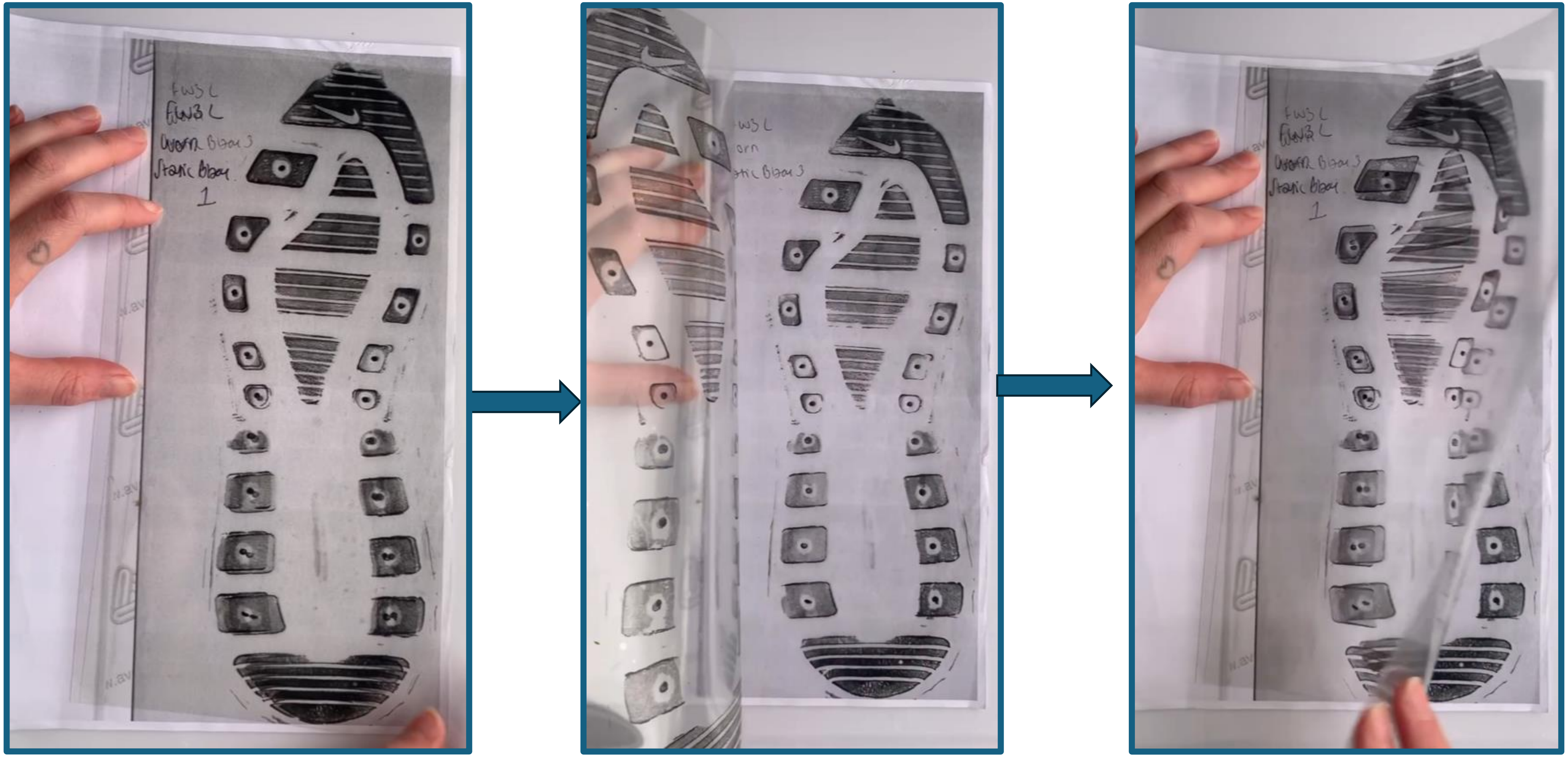


Figure 64: *A flow chart showing the method of 1:1 test impression-test impression comparisons*

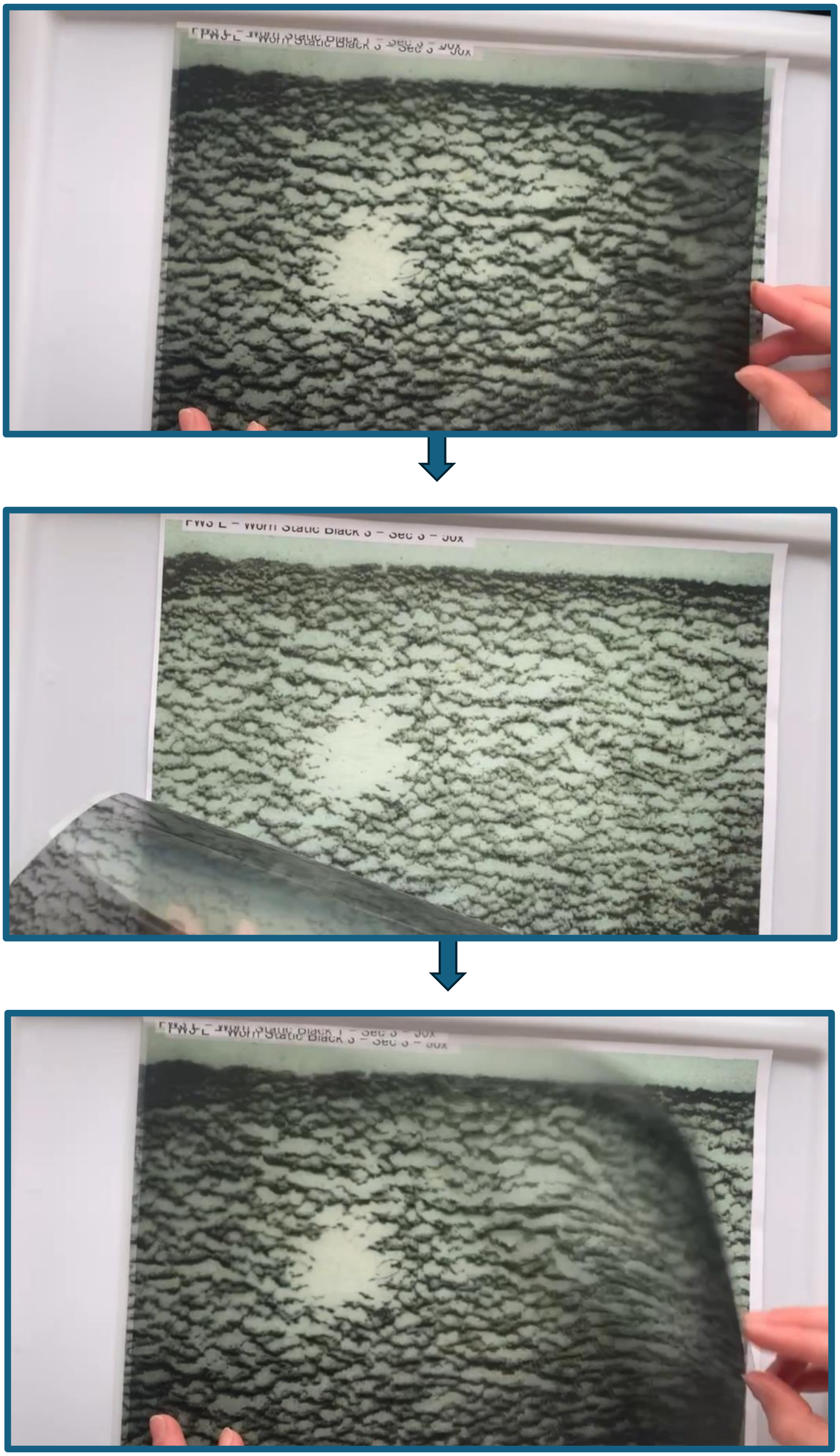


Figure 65: *A flow chart showing the method of 50x test impression-test impression comparisons*

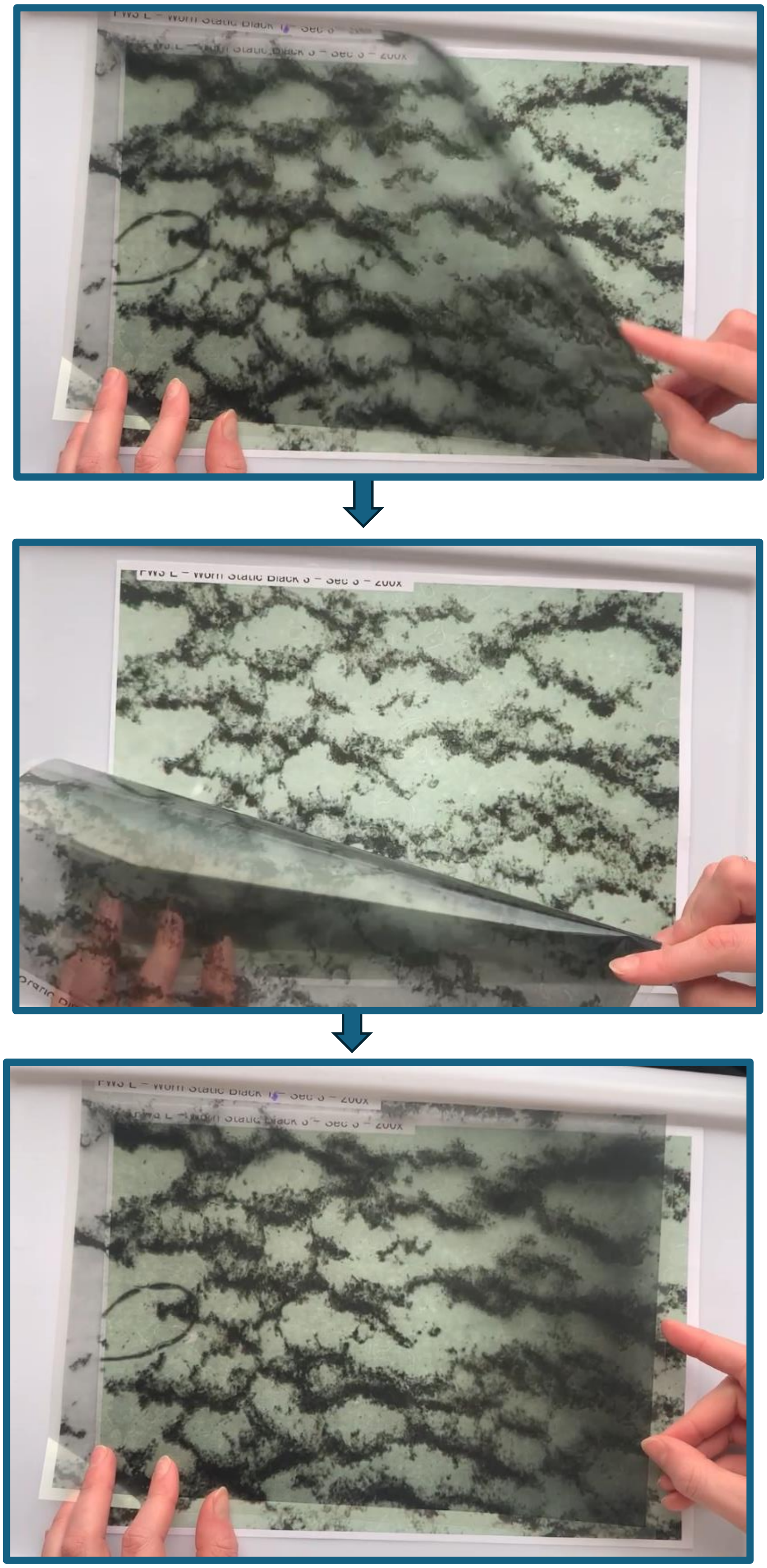


Figure 66: *A flow chart showing the method of 200x test impression-test impression comparisons*

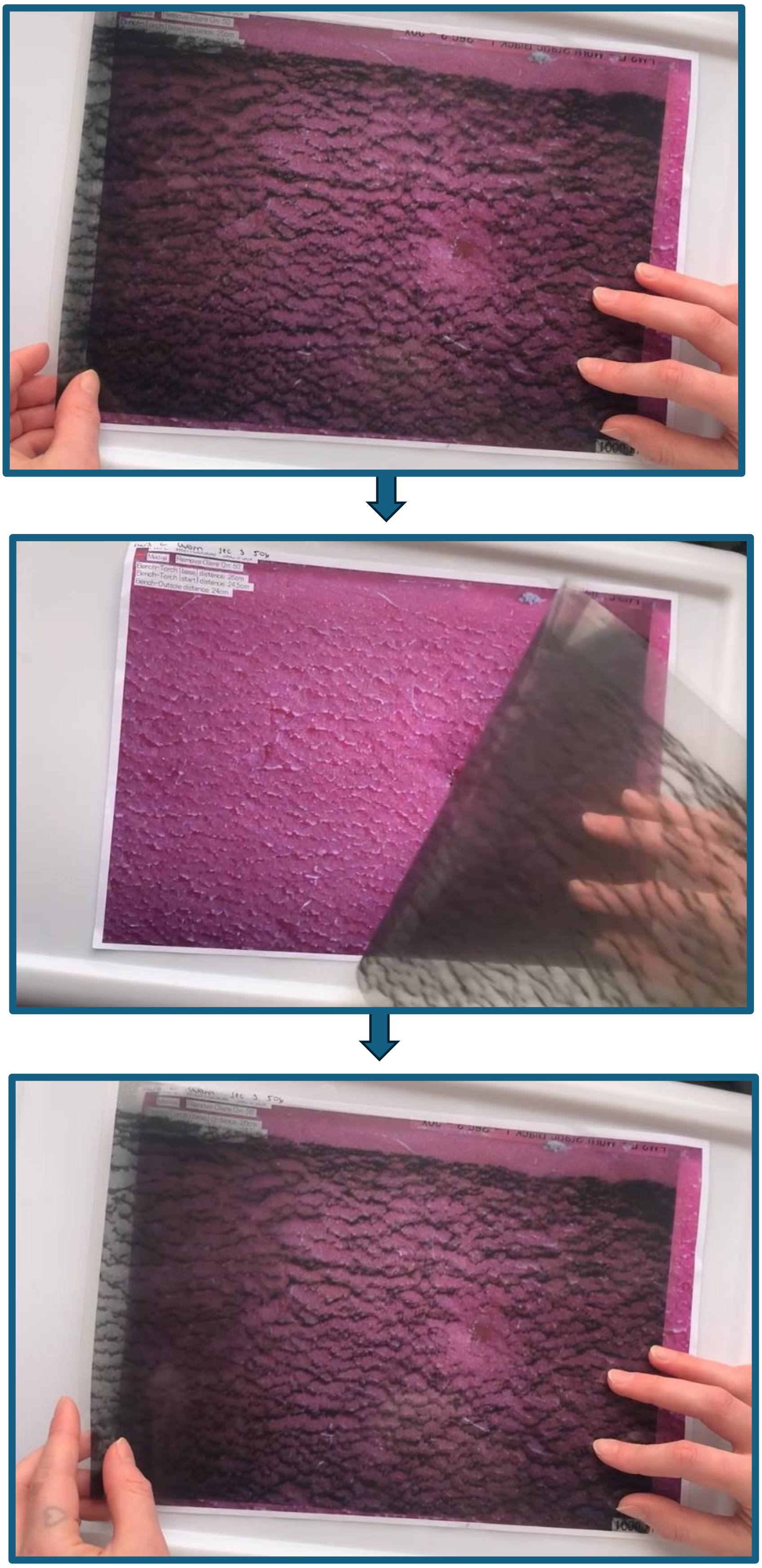


Figure 67: *A flow chart showing the method of 50x test impression-outsole comparisons*

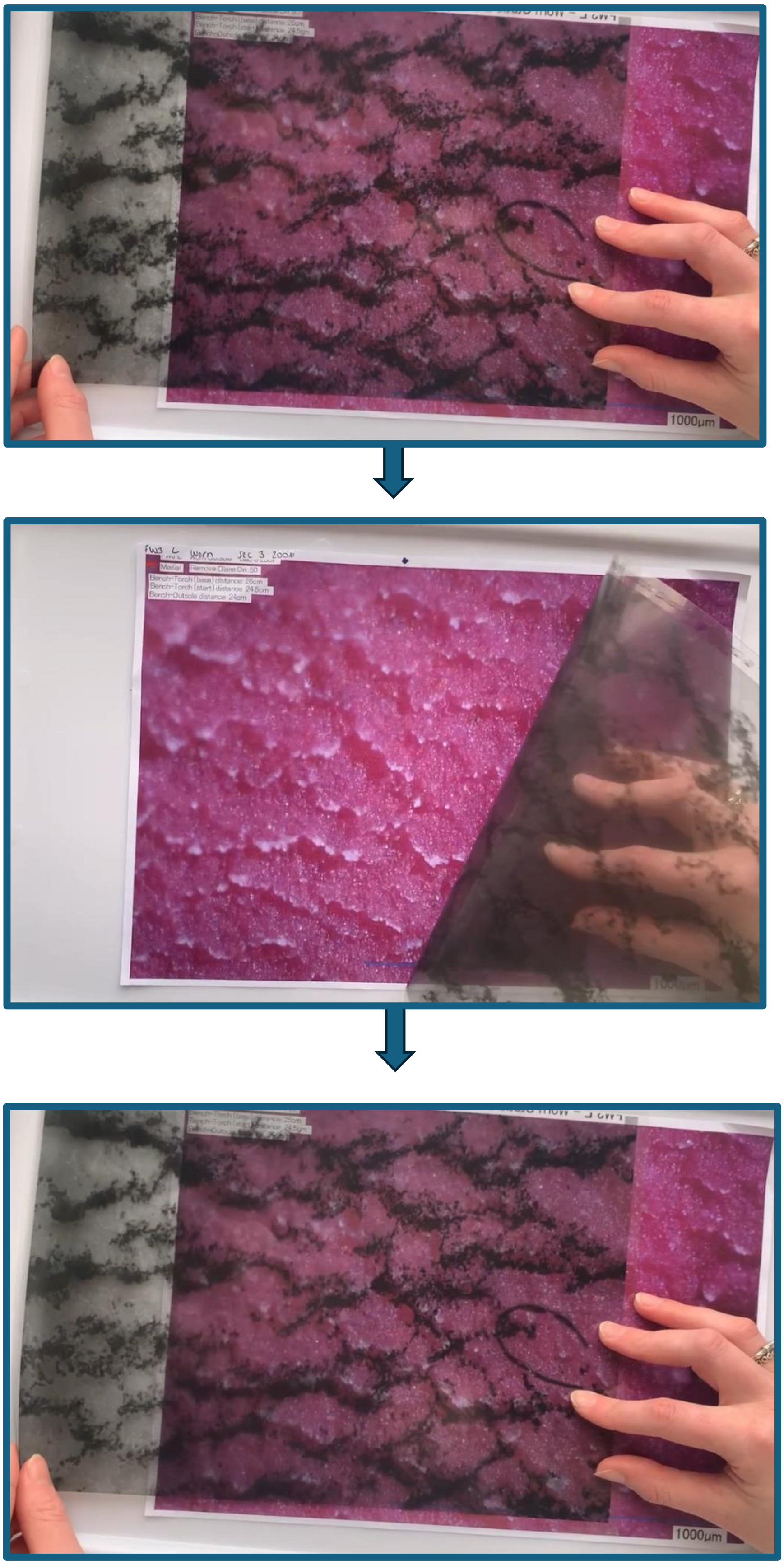


Figure 68: *A flow chart showing the method of 200x test impression-outsole comparisons*

3.5. Method of Test Impression Preparation:

This subchapter demonstrates the method used to create the test impressions used within this project **(Figure 69-Figure 71)**. Although dynamic test impressions were discontinued, the methods used are illustrated for a discussion. For a more extensive illustration of the test impression preparation with visual examples, refer to the **Appendix**

B. **Test** Impressions.

3.5.1. Dynamic Test Impression Preparation:

1. Lightly spray a 50:50 mixture of Petroleum Ether and Paraffin Oil onto a sponge pad.

2. Whilst wearing the shoes, step onto the oiled sponge, ensuring the entire outsole is covered.

3. Diagonally step from heel to toe onto a sheet of plain white A4 Xerox Colotech+ Coated paper, ensuring the entire shoe fits onto the paper.

4. Using a magnetic wand, add one application of magnetic powder (black or red fluorescence) onto the oiled footwear impression, release the powder by pulling the lever.

5. Apply a second application of powder without releasing the powder. Avoiding contact with the paper, use the magnetic wand to dust over the impression.

6. After enhancing the footwear mark, remove the excess powder by hovering the magnetic wand over the impression and releasing the collected powder back into the pot.

7. Carefully lift and flick the back of the paper to remove the excess powder.

8. Seal the footwear impression with hairsray.

Figure 69: *A flow chart showing the preparation of dynamic test impressions*

3.5.2. Static Test Impression Preparation:

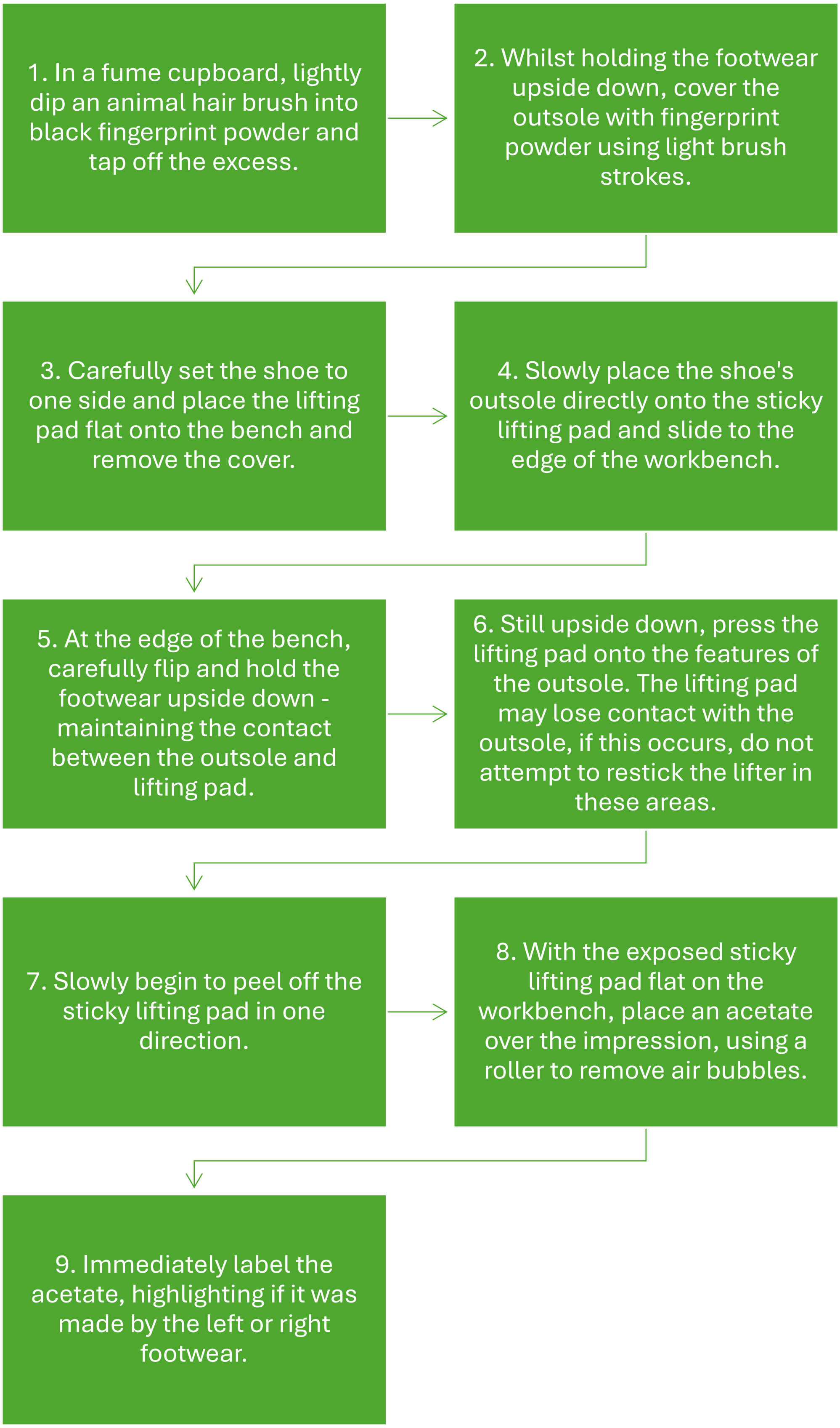


Figure 70: *A flow chart showing the preparation of static test impressions*

3.5.3. Print-scan Test Impressions Preparation:

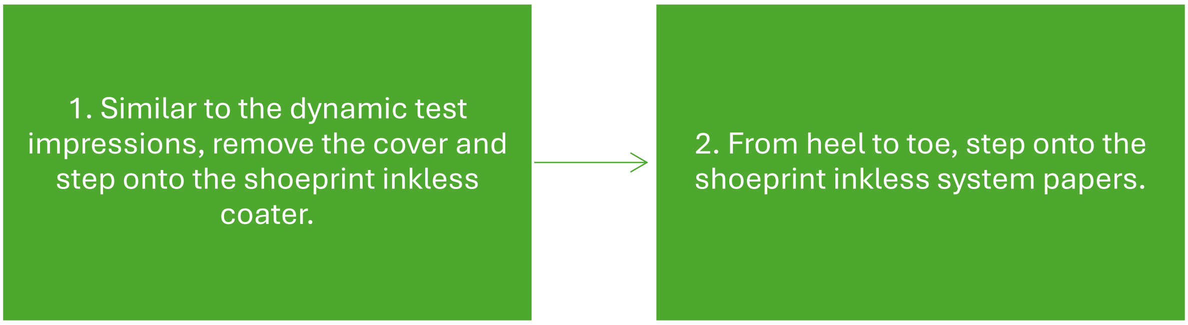


Figure 71: *A flow chart showing the preparation of printscan test impressions*

CHAPTER 4 - RESULTS

The purpose of this project is to discuss if microscopes should be routinely used in all forensic footwear examinations by analysing fine detail at three different scale and magnifications (1:1, 50x, and 200x) and observing if there is replicable detail that was initially not seen by eye alone. To score the replication observed, each comparison was given a correspondence score between 0-3, **Table 5**, as stated in the previous chapter. As the test impressions replicates are compared with each other at three scale and magnifications (1:1, 50x, 200x), and the test impressions are compared with the outsole at two magnifications (50x and 200x), the results are collated in two separate tables.

Table 5: *The scores given to comparisons at each magnification with definitions*

Magnification	Symbol	Definition	Notes
1:1	0	NO replication observed	There is no visible detail.
	3	YES, there is replication	There is detail visible.
50x and 200x	0	NO correspondence observed	There is no visible detail.
	0	NO correspondence observed	(Affected by test impression quality)
	1	GOOD correspondence	(Affected by test impression quality)
	2	GOOD correspondence	(A lot of features correspond)
	3	VERY GOOD correspondence	(All features correspond)

By collating the frequency of correspondence scores within each magnification, the Chi-Square test (X^2) was used to observe if there is a relationship between correspondence scores and the scale/magnification used, using the following hypotheses:

- **Null Hypothesis (H_0):** There is no association between correspondence scores and the scale/magnification used.
- **Alternative Hypothesis (H_1):** There is an association between correspondence scores and the scale/magnification used.

Moreover, to gain a deeper understanding on the relationship between correspondence scores and magnification, X^2 was also used between correspondence scores given at 1:1 and correspondence scores given at magnification (50x and 200x combined), using the following hypotheses:

- **Null Hypothesis (H_0):** There is no association between correspondence scores at 1:1 and correspondence scores when using magnification.
- **Alternative Hypothesis (H_1):** There is an association between correspondence scores at 1:1 and correspondence scores when using magnification.

To understand if there is a limit to the magnification, X^2 was also used to understand if there is a relationship between correspondence scores at 50x and correspondence scores at 200x, using the following hypotheses:

- **Null Hypothesis (H_0):** There is no association between correspondence scores at 50x and correspondence scores at 200x.

- **Alternative Hypothesis (*H_1*):** There is an association between correspondence scores at 50x and correspondence scores at 200x.

The subsequent subchapters show the X^2 formulas, comparison correspondence scores, and the X^2 results from: worn test impression-test impression comparisons, worn test impression-outsole comparisons, pre-wear test impression-test impression comparisons, and pre-wear test impression-outsole comparisons.

4.1. X^2 Formulas

Once a contingency table of observed results is complete, expected frequencies are calculated with the following formula:

$$\frac{(row\ total * column\ total)}{total}$$

With *O* = observed frequencies and *E* = Expected frequencies, X^2 was calculated with the following equation:

$$X^2 = \sum \frac{(O - E)^2}{E}$$

The X^2 probability-value (p-value) was then calculated to observe the likelihood of a result if the null hypothesis was true. To find the p-value, the degrees of freedom (*df*) is required, by using the following formula:

$$df = (number\ of\ variable\ 1\ groups - 1) * (number\ of\ variable\ 2\ groups - 1)$$

The X^2 p-value was calculated using the following formula in Excel:

$$CHISQ.DIST.RT(X^2, df)$$

To observe when to reject the null hypothesis, the p-value is compared with a chosen significance level (α). In this project, α = 0.05 (5%) by convention; meaning the results must have 5% or lower chance of occurring under H_0 to be considered statistically significant (Bhandari, 2023). If the p-value< α, the null hypothesis can be rejected.

4.2. Worn Test Impression-Test Impression Comparison

The following subchapter shows the results from worn test impression-test impression comparisons from the left and right static black test impressions from FW1, FW2, and FW3.

4.2.1. FW1L Worn

FW1 endured approximately 73,206 steps (roughly 14 hours of wear when considering 5,000 steps were taken in a one-hour period). Comparisons at a 1:1 scale shows consistently high correspondence scores (CSs) within section 4 (S4), however, sections 1, 2, and 3 (S1-S3) have a CS of 0; indicating that there is no fine replicable detail visible between the test impressions. Yet magnified comparisons show markedly higher CSs for all test impressions, S2-S4 particularly sharing correspondence with all features, scoring the maximum CS of 3. Although the CSs given at S1 do not reach the maximum of 3, CSs fluctuate between 1 and 2 at 50x, CSs at 200x have consistent scores of 2; indicating that a lot of features correspond.

The results from the test impression-test impression comparisons with the worn FW1L can be viewed in **Table 6**.

Table 6: *Correspondence scores for comparisons with FW1 L Worn static test impressions*

FW1 L Worn	Static Black 1												Static Black 2												Static Black 3											
	1:1				50x				200x				1:1				50x				200x				1:1				50x				200x			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
Static Black 1													0	0	0	3	1	3	3	3	2	3	3	3	0	0	0	3	1	3	3	3	2	3	3	3
Static Black 2	0	0	0	3	1	3	3	3	2	3	3	3													0	0	0	3	2	3	3	3	2	3	3	3
Static Black 3	0	0	0	3	1	3	3	3	2	3	3	3	0	0	0	3	2	3	3	3	2	3	3	3												
Section Total	0	0	0	6	2	6	6	6	4	6	6	6	0	0	0	6	3	6	6	6	4	6	6	6	0	0	0	6	3	6	6	6	4	6	6	6
Scale/Mag Total	6				20				22				6				21				22				6				21				22			

4.2.1.1. FW1L Worn: Correspondence Sores and The Scale/Magnification Used

Supporting H_1, there is a significant relationship between CSs and the scale/magnification used when $\alpha = 0.05$: X^2 (6, N = 72) = 57.85714, p = 0.000000000122492, **Table 7**.

Table 7: *Frequency table of observed [top], expected [centre] and (O-E)²/E [bottom] when comparing FW1 L Worn test impression replicates with each other at 1:1, 50x, and 200x*

Observed Frequencies	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
1:1	18	0	0	6	24
50x	0	4	2	18	24
200x	0	0	6	18	24
Column Total	18	4	8	42	72

Expected Frequencies	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	6	1.333333	2.666667	14
50x	6	1.333333	2.666667	14
200x	6	1.333333	2.666667	14

$(O-E)^2/E$	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	24	1.333333	2.666667	4.571429
50x	6	5.333333	0.166667	1.142857
200x	6	1.333333	4.166667	1.142857
	X^2 = 57.85714			

4.2.1.2. FW1L Worn: Correspondence Scores at 1:1 and When Using Magnification

Supporting H_1, there is a significant relationship between CSs at 1:1 and when using magnification when $\alpha = 0.05$: X^2 (3, N = 72) = 48.85714286, p = 0.000000000139908, **Table 8**.

Table 8: *Frequency table of observed [top], expected [right] and (O-E)²/E [centre] when comparing FW1 L Worn test impression replicates with each other at 1:1 and magnified*

Observed Frequencies	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
1:1	18	0	0	6	24
Magnified (50x and 200x)	0	4	8	36	48
Column Total	18	4	8	42	72

Expected Frequencies	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	6	1.333333	2.666667	14
Magnified (50x and 200x)	12	2.666667	5.333333	28

$(O-E)^2/E$	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	24	1.333333	2.666667	4.571429
Magnified (50x and 200x)	12	0.666667	1.333333	2.285714
	X^2 = 48.85714			

4.2.1.3. FW1L Worn: Correspondence Scores at 50x and 200x

Supporting H_0, there is no significant relationship between CSs at 50x and 200x when α = 0.05: X^2 (3, N = 48) = 6, p = 0.111610225, **Table 9**.

Table 9: *Frequency table of observed [top], expected [right] and (O-E)²/E [centre] when comparing FW1 L Worn test impression replicates with each other at 50x and 200x*

Observed	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
50x	0	4	2	18	24
200x	0	0	6	18	24
Column Total	0	4	8	36	48

Expected	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	2	4	18
200x	0	2	4	18

(O-E)²/E	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	2	1	0
200x	0	2	1	0
	X^2 = 6			

4.2.2. FW1R Worn

FW1 endured approximately 73,206 steps (roughly 14 hours of wear when considering 5,000 steps were taken in a one-hour period). Comparisons at a 1:1 scale shows consistently high CSs within S4, however, S1-S3 have a CS of 0; indicating that there is no fine replicable detail visible between the test impressions. Yet magnified comparisons show markedly higher CSs for all test impressions, S2-S4 particularly sharing correspondence with all features, scoring the maximum CS of 3. S1 have consistent CSs of 2 when using magnification; indicating that a lot of features correspond.

The results from the test impression-test impression comparisons with the worn FW1R can be viewed in **Table 10**.

Table 10: *Correspondence scores for comparisons with FW1 R Worn static test impressions*

FW1 R Worn	Static Black 1												Static Black 2												Static Black 3											
	1:1				50x				200x				1:1				50x				200x				1:1				50x				200x			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
Static Black 1													0	0	0	3	2	3	3	3	2	3	3	3	0	0	0	3	2	3	3	3	2	3	3	3
Static Black 2	0	0	0	3	2	3	3	3	2	3	3	3													0	0	0	3	2	3	3	3	2	3	3	3
Static Black 3	0	0	0	3	2	3	3	3	2	3	3	3	0	0	0	3	2	3	3	3	2	3	3	3												
Section Total	0	0	0	6	4	6	6	6	4	6	6	6	0	0	0	6	4	6	6	6	4	6	6	6	0	0	0	6	4	6	6	6	4	6	6	6
Scale/Mag Total	6				22				22				6				22				22				6				22				22			

4.2.2.1. FW1R Worn: Correspondence Scores and The Scale/Magnification Used

Supporting H_1, there is a significant relationship between CSs and the scale/magnification used when α = 0.05: X^2 (6, N = 72) = 48.85714286, p = 0.00000000796327, **Table 11**.

Table 11: *Frequency table of observed [top], expected [centre] and (O-E)^2/E [bottom] when comparing FW1 R Worn test impression replicates with each other at 1:1, 50x, and 200x*

Observed Frequencies	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
1:1	18	0	0	6	24
50x	0	0	6	18	24
200x	0	0	6	18	24
Column Total	18	0	12	42	72

Expected Frequencies	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	6	0	4	14
50x	6	0	4	14
200x	6	0	4	14

(O-E)^2/E	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	24	0	4	4.571428571
50x	6	0	1	1.142857143
200x	6	0	1	1.142857143
	X^2 = 48.85714286			

4.2.2.2. *FW1R Worn: Correspondence Scores at 1:1 and When Using Magnification*

Supporting H_1, there is a significant relationship between CSs at 1:1 and when using magnification when $\alpha = 0.05$: X^2 (3, N = 72) = 48.85714286, p = 0.000000000139908, **Table 12**.

Table 12: *Frequency table of observed [top], expected [centre] and (O-E)^2/E [bottom] when comparing FW1 R Worn test impression replicates with each other at 1:1 and magnified*

Observed	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
1:1	18	0	0	6	24
Magnified (50 and 200)	0	0	12	36	48
Column Total	18	0	12	42	72

Expected	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	6	0	4	14
Magnified (50 and 200)	12	0	8	28

(O-E)^2/E	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	24	0	4	4.571428571
Magnified (50x and 200x)	12	0	2	2.285714286
	X^2 = 48.85714286			

4.2.2.3. FW1R Worn: Correspondence Scores at 50x and 200x

Supporting H_0, there is no significant relationship between CSs at 50x and 200x when $\alpha = 0.05$: X^2 (3, N = 48) = 0, p = 1, **Table 13**

Table 13: *Frequency table of observed [top], expected [centre] and (O-E)²/E [bottom] when comparing FW1 R Worn test impression replicates with each other at 50x and 200x*

Observed	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
50x	0	0	6	18	24
200x	0	0	6	18	24
Column Total	0	0	12	36	48

Expected	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	0	6	18
200x	0	0	6	18

$(O-E)^2/E$	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	0	0	0
200x	0	0	0	0
	$X^2 = 0$			

4.2.3. FW2L Worn

FW2 endured approximately 63,813 steps (roughly 12 hours of wear when considering 5,000 steps were taken in a one-hour period). The CSs given for comparisons with FW2L worn test impressions are the same as CSs given for FW1R comparisons. Comparisons at a 1:1 scale shows consistently high CSs within S4, however, S1-S3 have a CS of 0; indicating that there is no fine replicable detail visible between the test impressions. Yet magnified comparisons show markedly higher CSs for all test impressions, S2-S4 particularly sharing correspondence with all features, scoring the maximum SS of 3. S1 have consistent CSs of 2 when using magnification; indicating that a lot of features correspond.

The results from the test impression-test impression comparisons with the worn FW2L can be viewed in **Table 14**.

Table 14: *Correspondence scores for comparisons with FW2 L Worn static test impressions*

FW2 L Worn	***Static Black 1***												***Static Black 2***												***Static Black 3***											
	1:1				***50x***				***200x***				***1:1***				***50x***				***200x***				***1:1***				***50x***				***200x***			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
Static Black 1													0	0	0	3	2	3	3	3	2	3	3	3	0	0	0	3	2	3	3	3	2	3	3	3
Static Black 2	0	0	0	3	2	3	3	3	2	3	3	3													0	0	0	3	2	3	3	3	2	3	3	3
Static Black 3	0	0	0	3	2	3	3	3	2	3	3	3	0	0	0	3	2	3	3	3	2	3	3	3												
Section Total	0	0	0	6	4	6	6	6	4	6	6	6	0	0	0	6	4	6	6	6	4	6	6	6	0	0	0	6	4	6	6	6	4	6	6	6
Scale/Mag Total	6				22				22				6				22				22				6				22				22			

4.2.3.1. *FW2L Worn: Correspondence Scores and The Scale/Magnification Used*

Supporting H_1, there is a significant relationship between CSs and the scale/magnification used when $\alpha = 0.05$: X^2 (6, N = 72) = 48.85714, p = 0.00000000796327, **Table 15**.

Table 15: *Frequency table of observed [top], expected [centre] and (O-E)²/E [bottom] when comparing FW2 L Worn test impression replicates with each other at 1:1, 50x, and 200x*

Observed Frequencies	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
1:1	18	0	0	6	24
50x	0	0	6	18	24
200x	0	0	6	18	24
Column Total	18	0	12	42	72

Expected Frequencies	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	6	0	4	14
50x	6	0	4	14
200x	6	0	4	14

(O-E)²/E	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	24	0	4	4.571429
50x	6	0	1	1.142857
200x	6	0	1	1.142857
	X^2 = 48.85714			

4.2.3.2. FW2L Worn: *Correspondence* Scores at 1:1 and When Using Magnification

Supporting H_1, there is a significant relationship between CSs at 1:1 and when using magnification when $\alpha = 0.05$: X^2 (3, N = 72) = 48.85714286, p = 0.000000000139908, **Table 16**.

Table 16: *Frequency table of observed [top], expected [centre] and (O-E)^2/E [bottom] when comparing FW2 L Worn test impression replicates with each other at 1:1 and magnified*

Observed	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
1:1	18	0	0	6	24
Magnified (50x and 200x)	0	0	12	36	48
Column Total	18	0	12	42	72

Expected	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	6	0	4	14
Magnified (50x and 200x)	12	0	8	28

(O-E)^2/E	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	24	0	4	4.571429
Magnified (50x and 200x)	12	0	2	2.285714
	X^2 = 48.85714			

4.2.3.3. *FW2L Worn: Correspondence Scores at 50x and 200x*

Supporting H_0, there is no significant relationship between CSs at 50x and 200x when α = 0.05: X^2 (3, N = 48) = 0, p = 1, **Table 17**.

Table 17: *Frequency table of observed [top], expected [centre] and $(O-E)^2/E$ [bottom] when comparing FW2 L Worn test impression replicates with each other at 50x and 200x*

Observed	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
50x	0	0	6	18	24
200x	0	0	6	18	24
Column Total	0	0	12	36	48

Expected	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	0	6	18
200x	0	0	6	18

$(O-E)^2/E$	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	0	0	0
200x	0	0	0	0
	$X^2 = 0$			

4.2.4. FW2R Worn

FW2 endured approximately 63,813 steps (roughly 12 hours of wear when considering 5,000 steps were taken in a one-hour period). Comparisons at a 1:1 scale shows consistent low CSs between all outsole sections, with scores of 0; indicating that there is no fine replicable detail visible between the test impressions. Yet magnified comparisons show markedly higher CSs for all test impressions: S1-S2 have consistent CSs of 2 at 50x and 200x indicating that a lot of features correspond, and S3-S4 have consistent maximum CSs of 3 at 50x and 200x; indicating that all features correspond.

The results from the test impression-test impression comparisons with the worn FW2R can be viewed in **Table 18**.

Table 18: *Correspondence scores for comparisons with FW2 R Worn static test impressions*

FW2 R Worn	Static Black 1												Static Black 2												Static Black 3											
	1:1				50x				200x				1:1				50x				200x				1:1				50x				200x			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
Static Black 1													0	0	0	0	2	2	3	3	2	2	3	3	0	0	0	0	2	2	3	3	2	2	3	3
Static Black 2	0	0	0	0	2	2	3	3	2	2	3	3													0	0	0	0	2	2	3	3	2	2	3	3
Static Black 3	0	0	0	0	2	2	3	3	2	2	3	3	0	0	0	0	2	2	3	3	2	2	3	3												
Section Total	0	0	0	0	4	4	6	6	4	4	6	6	0	0	0	0	4	4	6	6	4	4	6	6	0	0	0	0	4	4	6	6	4	4	6	6
Scale/Mag Total	0				20				20				0				20				20				0				20				20			

4.2.4.1. FW2R Worn: Correspondence Scores and The Scale/Magnification Used

Supporting H_1, there is a significant relationship between CSs and the scale/magnification used when $\alpha = 0.05$: X^2 (6, N = 72) = 72, p = 0.000000000000158887, **Table 19**.

Table 19: *Frequency table of observed [top], expected [centre] and (O-E)^2/E [bottom] when comparing FW2 R Worn test impression replicates with each other at 1:1, 50x, and 200x*

Observed Frequencies	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
1:1	24	0	0	0	24
50x	0	0	12	12	24
200x	0	0	12	12	24
Column Total	24	0	24	24	72

Expected Frequencies	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	8	0	8	8
50x	8	0	8	8
200x	8	0	8	8

(O-E)^2/E	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	32	0	8	8
50x	8	0	2	2
200x	8	0	2	2
	X^2 = 72.5035			

4.2.4.2. FW2R Worn: *Correspondence* Scores at 1:1 and When Using Magnification

Supporting H_1, there is a significant relationship between CSs at 1:1 and when using magnification when $\alpha = 0.05$: X^2 (3, N = 72) = 72, p = 0.000000000000015919, **Table 20**.

Table 20: *Frequency table of observed [top], expected [centre] and $(O-E)^2/E$ [bottom] when comparing FW2 R Worn test impression replicates with each other at 1:1 and magnified*

Observed	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
1:1	24	0	0	0	24
Magnified (50x and 200x)	0	0	24	24	48
Column Total	24	0	24	24	72

Expected	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	8	0	8	8
Magnified (50x and 200x)	16	0	16	16

$(O-E)^2/E$	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	32	0	8	8
Magnified (50x and 200x)	16	0	4	4
	$X^2 = 72$			

4.2.4.3. FW2R Worn: Correspondence Scores at 50x and 200x

Supporting H_0, there is no significant relationship between CSs at 50x and 200x when α = 0.05: X^2 (3, N = 48) = 0, p = 1, **Table 21**.

Table 21: *Frequency table of observed [top], expected [centre] and (O-E)²/E [bottom] when comparing FW2 R Worn test impression replicates with each other at 50x and 200x*

Observed	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
50x	0	0	12	12	24
200x	0	0	12	12	24
Column Total	0	0	24	24	48

Expected	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	0	12	12
200x	0	0	12	12

$(O-E)^2/E$	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	0	0	0
200x	0	0	0	0
	$X^2 = 0$			

4.2.5. FW3L Worn

FW3 endured approximately 55,863 (approximately 11 hours of wear when considering 5,000 steps were taken in a one-hour period). Comparisons at a 1:1 scale within S1 have CSs of 0; indicating that there is no fine replicable detail visible. However, comparisons at 1:1 show consistently high CSs within S2-S3 with scores of 3, and CSs within S4 have a range of CSs from 0 and 3. Although magnified comparisons have score variations within S4 with scores of 3 and 2, all other outsole sections remain consistent with CSs of 2 within S1 and 3 within S2 and S3.

The results from the test impression-test impression comparisons with the worn FW3L can be viewed in **Table 22**

Table 22: *Correspondence scores for comparisons with FW3 L Worn static test impressions*

FW3 L Worn	Static Black 1												Static Black 2												Static Black 3											
	1:1				50x				200x				1:1				50x				200x				1:1				50x				200x			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
Static Black 1													0	3	3	3	2	3	3	3	2	3	3	3	0	3	3	0	2	3	3	2	2	3	3	2
Static Black 2	0	3	3	3	2	3	3	3	2	3	3	3													0	3	3	3	2	3	3	2	2	3	3	2
Static Black 3	0	3	3	0	2	3	3	2	2	3	3	3	0	3	3	3	2	3	3	2	2	3	3	2												
Section Total	0	6	6	3	4	6	6	5	4	6	6	6	0	6	6	6	4	6	6	5	4	6	6	5	0	6	6	3	4	6	6	4	4	6	6	4
Scale/Mag Total	15				21				22				18				21				21				15				20				20			

4.2.5.1. *FW3L Worn: Correspondence Scores and The Scale/Magnification Used*

Supporting H_1, there is a significant relationship between CSs and the scale/magnification used when $\alpha = 0.05$: X^2 $(6, N = 72) = 25.71228$, $p = 0.00025186$, **Table 23**.

Table 23: *Frequency table of observed [top], expected [centre] and (O-E)^2/E [bottom] when comparing FW3 L Worn test impression replicates with each other at 1:1, 50x, and 200x*

Observed Frequencies	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
1:1	8	0	0	16	24
50x	0	0	10	14	24
200x	0	0	9	15	24
Column Total	8	0	19	45	72

Expected Frequencies	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	2.666667	0	6.333333	15
50x	2.666667	0	6.333333	15
200x	2.666667	0	6.333333	15

(O-E)^2/E	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	10.66667	0	6.333333	0.066667
50x	2.666667	0	2.122807	0.066667
200x	2.666667	0	1.122807	0
	X^2 = 25.71228			

4.2.5.2. FW3L Worn: *Correspondence* Scores at 1:1 and When Using Magnification

Supporting H_1, there is a significant relationship between CSs at 1:1 and when using magnification when $\alpha = 0.05$: X^2 (3, N = 72) = 25.6, p = 0.0000115653, **Table 24**.

Table 24: *Frequency table of observed [top], expected [centre] and (O-E)²/E [bottom] when comparing FW3 L Worn test impression replicates with each other at 1:1 and magnified*

Observed	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
1:1	8	0	0	16	24
Magnified (50x and 200x)	0	0	19	29	48
Column Total	8	0	19	45	72

Expected	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	2.666667	0	6.333333	15
Magnified (50x and 200x)	5.333333	0	12.66667	30

$(O-E)^2/E$	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	10.66667	0	6.333333	0.066667
Magnified (50x and 200x)	5.333333	0	3.166667	0.033333
	$X^2 = 25.6$			

4.2.5.3. FW3L Worn: Correspondence Scores at 50x and 200x

Supporting H_0, there is no significant relationship between CSs at 50x and 200x when α = 0.05: X^2 (3, N = 48) = 0.087114338, p = 0.993337587, **Table 25**.

Table 25: *Frequency table of observed [top], expected [centre] and (O-E)²/E [bottom] when comparing FW3 L Worn test impression replicates with each other at 50x and 200x*

Observed	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
50x	0	0	10	14	24
200x	0	0	9	15	24
Column Total	0	0	19	29	48

Expected	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	0	9.5	14.5
200x	0	0	9.5	14.5

$(O-E)^2/E$	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	0	0.026316	0.017241
200x	0	0	0.026316	0.017241
	$X^2 = 0.087114$			

4.2.6. FW3R Worn

FW3 endured approximately 55,863 (approximately 11 hours of wear when considering 5,000 steps were taken in a one-hour period). Comparisons at a 1:1 scale shows consistently high CSs within S2 and S4 with maximum scores of 3, however, all other sections (S1 and S3) have CSs of 0. Magnified comparisons show markedly higher CSs for all test impressions, S2-S4 particularly sharing correspondence with all features, scoring the maximum SS of 3. Although the CSs given at S1 do not reach the maximum of 3, scores indicate that a lot of features correspond, with scores of 2.

The results from the test impression-test impression comparisons with the worn FW3R can be viewed in **Table 26**.

Table 26: *Correspondence scores for comparisons with FW3 R Worn static test impressions*

FW3 R Worn	Static Black 1												Static Black 2												Static Black 3											
	1:1				50x				200x				1:1				50x				200x				1:1				50x				200x			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
Static Black 1													0	3	0	3	2	3	3	3	2	3	3	3	0	3	0	3	2	3	3	3	2	3	3	3
Static Black 2	0	3	0	3	2	3	3	3	2	3	3	3													0	3	0	3	2	3	3	3	2	3	3	3
Static Black 3	0	3	0	3	2	3	3	3	2	3	3	3	0	3	0	3	2	3	3	3	2	3	3	3												
Section Total	0	6	0	6	4	6	6	6	4	6	6	6	0	6	0	6	4	6	6	6	4	6	6	6	0	6	0	6	4	6	6	6	4	6	6	6
Scale/Mag Total	12				22				22				12				22				22				12				22				22			

4.2.6.1. FW3R Worn: Correspondence Scores and The Scale/Magnification Used

Supporting H_1, there is a significant relationship between CSs and the scale/magnification used when $\alpha = 0.05$: X^2 (6, $N = 72$) = 31.5, $p = 0.0000203426$, **Table 27**.

Table 27: *Frequency table of observed [top], expected [centre] and $(O-E)^2/E$ [bottom] when comparing FW3 R Worn test impression replicates with each other at 1:1, 50x, and 200x*

Observed Frequencies	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
1:1	12	0	0	12	24
50x	0	0	6	18	24
200x	0	0	6	18	24
Column Total	12	0	12	48	72

Expected Frequencies	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	4	0	4	16
50x	4	0	4	16
200x	4	0	4	16

$(O-E)^2/E$	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	16	0	4	1
50x	4	0	1	0.25
200x	4	0	1	0.25
	$X^2 = 31.5$			

4.2.6.2. FW3R Worn: *Correspondence* Scores at 1:1 and When Using Magnification

Supporting H_1, there is a significant relationship between CSs at 1:1 and when using magnification when $\alpha = 0.05$: X^2 (3, N = 72) = 31.5, p = 0.000000667023, **Table 28**.

Table 28: *Frequency table of observed [top], expected [centre] and (O-E)^2/E [bottom] when comparing FW3 R Worn test impression replicates with each other at 1:1 and magnified*

Observed	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
1:1	12	0	0	12	24
Magnified (50x and 200x)	0	0	12	36	48
Column Total	12	0	12	48	72

Expected	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	4	0	4	16
Magnified (50x and 200x)	8	0	8	32

(O-E)^2/E	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	16	0	4	1
Magnified (50x and 200x)	8	0	2	0.5
	X^2 = 31.5			

4.2.6.3. *FW3R Worn: Correspondence Scores at 50x and 200x*

Supporting H_0, there is no significant relationship between CSs at 50x and 200x when α = 0.05: X^2 (3, N = 48) = 0, p = 1, **Table 29**.

Table 29: *Frequency table of observed [top], expected [centre] and $(O-E)^2/E$ [bottom] when comparing FW3 R Worn test impression replicates with each other at 50x and 200x*

Observed	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
50x	0	0	6	18	24
200x	0	0	6	18	24
Column Total	0	0	12	36	48

Expected	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	0	6	18
200x	0	0	6	18

$(O-E)^2/E$	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	0	0	0
200x	0	0	0	0
	$X^2 = 0$			

4.3. Worn Test Impression-Outsole Comparison

The following subchapter shows the results from worn test impression-outsole comparisons from the left and right impressions from FW1, FW2, and FW3.

4.3.1. FW1L Worn

Comparisons at a 50x scale show consistently high CSs within S2-S4 with maximum scores of 3, and CSs within S1 fluctuate between scores of 1 and 2. A score of 1 indicates that the test impression was of poor quality. However, at 200x, the comparisons with the poor-quality test impression increases to 2 at 200x, and other test impression comparisons at S1 maintain the score of 2. CSs maintain a score of 3 within S3-S4 and decrease to 2 within S2 at 200x.

The results from the test impression-outsole comparisons with the worn FW1L can be viewed in **Table 30**.

Table 30: *Correspondence scores for comparisons with FW1 L Worn static test impressions-outsole*

FW1 L Worn	***Static Black 1***								***Static Black 2***								***Static Black 3***							
	50x				***200x***				***50x***				***200x***				***50x***				***200x***			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
FW1L Worn Outsole	1	3	3	3	2	2	3	3	2	3	3	3	2	2	3	3	2	3	3	3	2	2	3	3
Mag Total	10				10				11				10				11				10			

4.3.1.1. FW1L Worn: Correspondence Scores at 50x and 200x

Supporting H_0, there is no significant relationship between CSs at 50x and 200x when α = 0.05: X^2 (3, N = 24) = 3.6, p = 0.308022172, **Table 31**.

Table 31: *Frequency table of observed [top], expected [centre] and (O-E)²/E [bottom] when comparing FW1 L Worn test impression replicates with the outsole at 50x and 200x*

Observed Frequencies	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
50x	0	1	2	9	12
200x	0	0	6	6	12
Column Total	0	1	8	15	24

Expected Frequencies	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	0.5	4	7.5
200x	0	0.5	4	7.5

$(O-E)^2/E$	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	0.5	1	0.3
200x	0	0.5	1	0.3
	$X^2 = 3.6$			

4.3.2. FW1R Worn

Comparisons at 50x scale have the same CSs as comparisons at 200x with consistent scores of 2 within S1-S2; indicating that a lot of features correspond, and consistent scores of 3 within S3-S4; indicating that the comparisons share correspondence with all features.

The results from the test impression-outsole comparisons with the worn FW1R can be viewed in **Table 32**.

Table 32: *Correspondence scores for comparisons with FW1 R Worn static test impressions-outsole*

FW1 R Worn	Static Black 1								Static Black 2								Static Black 3							
	50x				200x				50x				200x				50x				200x			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
FW1R Worn Outsole	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3
Mag Total	10				10				10				10				10				10			

4.3.2.1. FW1R Worn: Correspondence Scores at 50x and 200x

Supporting H_0, there is no significant relationship between CSs at 50x and 200x when α = 0.05: X^2 (3, N = 24) = 0, p = 1, **Table 33**.

Table 33: *Frequency table of observed [top], expected [right] and $(O\text{-}E)^2/E$ [centre] when comparing FW1 R Worn test impression replicates with the outsole at 50x and 200x*

Observed Frequencies	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
50x	0	0	6	6	12
200x	0	0	6	6	12
Column Total	0	0	12	12	24

Expected Frequencies	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	0	6	6
200x	0	0	6	6

$(O\text{-}E)^2/E$	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	0	0	0
200x	0	0	0	0
	$X^2 = 0$			

4.3.3. FW2L Worn

Comparisons at 50x scale have the same CSs as comparisons at 200x with consistent scores of 2 within S1-S3; indicating that a lot of features correspond, and consistent scores of 3 within S4; indicating that the comparisons share correspondence with all features.

The results from the test impression-outsole comparisons with the worn FW2L can be viewed in **Table 34**.

Table 34: *Correspondence scores for comparisons with FW2 L Worn static test impressions-outsole*

FW2 L Worn	Static Black 1								Static Black 2								Static Black 2							
	50x				200x				50x				200x				50x				200x			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
FW2L Worn Outsole	2	2	2	3	2	2	2	3	2	2	2	3	2	2	2	3	2	2	2	3	2	2	2	3
Mag Total	9				9				9				9				9				9			

4.3.3.1. *FW2L Worn: Correspondence Scores at 50x and 200x*

Supporting H_0, there is no significant relationship between CSs at 50x and 200x when α = 0.05: X^2 (3, N = 24) = 0, p = 1, **Table 35**.

Table 35: *Frequency table of observed [top], expected [centre] and $(O\text{-}E)^2/E$ [bottom] when comparing FW2 L Worn test impression replicates with the outsole at 50x and 200x*

Observed Frequencies	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
50x	0	0	9	3	12
200x	0	0	9	3	12
Column Total	0	0	18	6	24

Expected Frequencies	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	0	9	3
200x	0	0	9	3

$(O\text{-}E)^2/E$	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	0	0	0
200x	0	0	0	0
	$X^2 = 0$			

4.3.4. FW2R Worn

Comparisons with FW2R test impressions to the outsole are the same as comparison CSs with FW1R test impressions to the outsole with the same CSs at a 50x scale and at a 200x. CSs have consistent scores of 2 within S1-S2, and consistent scores of 3 within S3-S4.

The results from the test impression-outsole comparisons with the worn FW2R can be viewed in **Table 36**.

Table 36: *Correspondence scores for comparisons with FW2 R Worn static test impressions-outsole*

FW2 R Worn	Static Black 1								Static Black 2								Static Black 2							
	50x				200x				50x				200x				50x				200x			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
FW2R Worn Outsole	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3	2	2	3	3
Mag Total	10				10				10				10				10				10			

4.3.4.1. FW2R Worn: Correspondence Scores at 50x and 200x

Supporting H_0, there is no significant relationship between CSs at 50x and 200x when α = 0.05: X^2 (3, N = 24) = 0, p = 1, **Table 37**.

Table 37: *Frequency table of observed [top], expected [centre] and (O-E)²/E [bottom] when comparing FW1 R Worn test impression replicates with the outsole at 50x and 200x*

Observed Frequencies	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
50x	0	0	6	6	12
200x	0	0	6	6	12
Column Total	0	0	12	12	24

Expected Frequencies	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	0	6	6
200x	0	0	6	6

$(O-E)^2/E$	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	0	0	0
200x	0	0	0	0
	$X^2 = 0$			

4.3.5. FW3L Worn

Comparisons at a 50x and 200x scale indicate that a lot of features correspond within S1, S2, and S4 at 50x, and all features correspond within S3 at 50x and 200x.

The results from the test impression-outsole comparisons with the worn FW3L can be viewed in **Table 38**.

Table 38: *Correspondence scores for comparisons with FW3 L Worn static test impressions-outsole*

FW3 L Worn	***Static Black 1***								***Static Black 2***								***Static Black 2***							
	50x				***200x***				***50x***				***200x***				***50x***				***200x***			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
FW3L Worn Outsole	2	2	3	2	2	2	3	2	2	2	3	2	2	2	3	2	2	2	3	2	2	2	3	2
Mag Total	9				9				9				9				9				9			

4.3.5.1. FW3L Worn: Correspondence Scores at 50x and 200x

Supporting H_0, there is no significant relationship between CSs at 50x and 200x when α = 0.05: X^2 (3, N = 24) = 0, p = 1, **Table 39**.

Table 39: *Frequency table of observed [top], expected [centre] and (O-E)²/E [bottom] when comparing FW3 L Worn test impression replicates with the outsole at 50x and 200x*

Observed Frequencies	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
50x	0	0	9	3	12
200x	0	0	9	3	12
Column Total	0	0	18	6	24

Expected Frequencies	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	0	9	3
200x	0	0	9	3

$(O-E)^2/E$	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	0	0	0
200x	0	0	0	0
	$X^2 = 0$			

4.3.6. FW3R Worn

Comparisons at a 50x scale show consistent scores of 2 within S1-S2, and although the CSs fluctuate between 2 and 3 within S1 at 200x, CSs maintain a score of 2 within S2 at 200x. CSs are consistently high within S3 at both magnifications with scores of 3; indicating that the comparisons share correspondence with all features. However, CSs fluctuate between scores of 2 and 3 at 50x, but all CSs at 200x in this section all share a score of 2.

The results from the test impression-outsole comparisons with the worn FW3R can be viewed in **Table 40**.

Table 40: *Correspondence scores for comparisons with FW3 R Worn static test impressions-outsole*

FW3 R Worn	Static Black 1								Static Black 2								Static Black 2							
	50x				200x				50x				200x				50x				200x			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
FW3R Worn Outsole	2	2	3	3	2	2	3	2	2	2	3	3	3	2	3	2	2	2	3	2	2	2	3	2
Mag Total	10				9				10				10				9				9			

4.3.6.1. FW3R Worn: Correspondence Scores at 50x and 200x

Supporting H_0, there is no significant relationship between CSs at 50x and 200x when α = 0.05: X^2 (3, N = 24) = 0.177778, p = 0.9810944, **Table 41**.

Table 41: *Frequency table of observed [top], expected [centre] and (O-E)²/E [bottom] when comparing FW3 R Worn test impression replicates with the outsole at 50x and 200x*

Observed Frequencies	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
50x	0	0	7	5	12
200x	0	0	8	4	12
Column Total	0	0	15	9	24

Expected Frequencies	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	0	7.5	4.5
200x	0	0	7.5	4.5

$(O-E)^2/E$	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	0	0.033333	0.055556
200x	0	0	0.033333	0.055556
	X^2 = 0.177778			

4.4. Pre-Wear Test Impression-Test Impression Comparison

The following subchapter shows the results from pre-wear test impression-test impression comparisons from the left and right impressions from FW1, FW2, and FW3.

4.4.1. FW1L Pre-Wear

Comparisons at a 1:1 scale show consistently high CSs within S3, however, S1, S2, and S3 have a SS of 0; indicating that there is no fine replicable detail visible between the test impressions. Magnified comparisons show markedly higher CSs for all test impressions: S1, S2, and S4 having scores of 2 at 50x and 200x; and S3 having CSs of 3 at 50x and 200x.

The results from the test impression-test impression comparisons with the pre-wear FW1L can be viewed in **Table 42**.

Table 42: *Correspondence scores for comparisons with FW1 L Pre-Wear static test impressions*

FW1 L Pre-Wear	Static Black 1												Static Black 2												Static Black 3											
	1:1				50x				200x				1:1				50x				200x				1:1				50x				200x			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
Static Black 1													0	0	3	0	2	3	2	2	2	3	2	2	0	0	3	0	2	3	2	2	2	3	2	2
Static Black 2	0	0	3	0	2	3	2	2	2	3	2	2													0	0	3	0	2	3	2	2	2	3	2	2
Static Black 3	0	0	3	0	2	3	2	2	2	3	2	2	0	0	3	0	2	3	2	2	2	3	2	2												
Section Total	0	0	6	0	4	6	4	4	4	6	4	4	0	0	6	0	4	6	4	4	4	6	4	4	0	0	6	0	4	6	4	4	4	6	4	4
Scale/Mag Total	6				18				18				6				18				18				6				18				18			

4.4.1.1. *FW1L Pre-Wear: Correspondence Scores and The Scale/Magnification Used*

Supporting H_1, there is a significant relationship between CSs and the scale/magnification used when $\alpha = 0.05$: X^2 (6, N =72) = 54, p = 0.000000000737715, **Table 43**.

Table 43: *Frequency table of observed [top], expected [centre] and $(O-E)^2/E$ [bottom] when comparing FW1 L pre-wear test impression replicates with the outsole at 1:1, 50x, and 200x*

Observed Frequencies	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
1:1	18	0	0	6	24
50x	0	0	18	6	24
200x	0	0	18	6	24
Column Total	18	0	36	18	72

Expected Frequencies	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	6	0	12	6
50x	6	0	12	6
200x	6	0	12	6

$(O-E)^2/E$	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	24	0	12	0
50x	6	0	3	0
200x	6	0	3	0
	$X^2 = 54$			

4.4.2. FW1R Pre-Wear

Comparisons at a 1:1 scale show consistent CSs of 0; indicating that there is no replicable fine detail visible. However, magnified comparisons at 50x show consistent CSs of 2 within S1, S3, and S4 that increase to 3 within S1 at 200x and maintain a score of 2 within S3-S4 at 200x. A score of 0 within S2 between comparisons with SB1 at 50x and 200x indicates that this test impression was of poor quality, but comparisons between SB2 and SB2 have consistent scores of 2 within the same section at both 50x and 200x.

The results from the test impression-test comparisons with the pre-wear FW1R can be viewed in **Table 44**.

Table 44: *Correspondence scores for comparisons with FW1 R Pre-Wear static test impressions*

FW1 R Pre-Wear	Static Black 1												Static Black 2												Static Black 3											
	1:1				50x				200x				1:1				50x				200x				1:1				50x				200x			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
Static Black 1													0	0	0	0	2	0	2	2	3	0	2	2	0	0	0	0	2	0	2	2	3	0	2	2
Static Black 2	0	0	0	0	2	0	2	2	3	0	2	2													0	0	0	0	2	2	2	2	3	2	2	2
Static Black 3	0	0	0	0	2	0	2	2	3	0	2	2	0	0	0	0	2	2	2	2	3	2	2	2												
Section Total	0	0	0	0	4	0	4	4	6	0	4	4	0	0	0	0	4	2	4	4	6	2	4	4	0	0	0	0	4	2	4	4	6	2	4	4
Scale/Mag Total	0				12				14				0				14				16				0				14				16			

4.4.2.1. FW1R Pre-Wear: Correspondence Scores and The Scale/Magnification Used

Supporting *H_1*, there is a significant relationship between CSs and the scale/magnification used when $\alpha = 0.05$: X^2 (6, *N* =) = 55.58823529, *p* = 0.000000000352589, **Table 45**.

Table 45: *Frequency table of observed [top], expected [centre] and (O-E)²/E [bottom] when comparing FW1 R pre-wear test impression replicates with the outsole at 1:1, 50x, and 200x*

Observed Frequencies	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
1:1	24	0	0	0	24
50x	4	0	20	0	24
200x	4	0	14	6	24
Column Total	32	0	34	6	72

Expected Frequencies	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	10.66667	0	11.33333333	2
50x	10.66667	0	11.33333333	2
200x	10.66667	0	11.33333333	2

$(O-E)^2/E$	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	16.66667	0	11.33333333	2
50x	4.166667	0	6.62745098	2
200x	4.166667	0	0.62745098	8
	X^2 = 55.58823529			

4.4.3. FW2L Pre-Wear

Comparisons at a 1:1 scale shows consistently high CSs within S4, however, S1-S3 have a SS of 0; indicating that there is no fine replicable detail visible between the test impressions. Yet magnified comparisons show markedly higher CSs for all test impressions, S1 having CSs of 3 at 50x and 200x, consistent CSs of 2 within S3-S4 at 50x and 200x. The CSs show a fluctuation of scores of 1 and 3 within 50x, and 2 and 3 within 200x. A score of 1 indicates that the SB2 test impression was of poor quality.

The results from the test impression-test comparisons with the pre-wear FW2L can be viewed in **Table 46**.

Table 46: *Correspondence scores for comparisons with FW2 L Pre-Wear static test impressions*

FW2 L Pre-Worn	Static Black 1												Static Black 2												Static Black 3											
	1:1				50x				200x				1:1				50x				200x				1:1				50x				200x			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
Static Black 1													0	0	3	0	3	1	2	2	3	2	2	2	0	0	3	0	3	3	2	2	3	3	2	2
Static Black 2	0	0	3	0	3	1	2	2	3	2	2	2													0	0	3	0	3	1	2	2	3	2	2	2
Static Black 3	0	0	3	0	3	3	2	2	3	3	2	2	0	0	3	0	3	1	2	2	3	2	2	2												
Section Total	0	0	6	0	6	4	4	4	6	5	4	4	0	0	6	0	6	2	4	4	6	4	4	4	0	0	6	0	6	4	4	4	6	5	4	4
Scale/Mag Total	6				18				19				6				16				18				6				18				19			

4.4.3.1. FW2L Pre-Wear: Correspondence Scores and The Scale/Magnification Used

Supporting H_1, there is a significant relationship between CSs and the scale/magnification used when $\alpha = 0.05$: X^2 (6, N = 72) = 51.22078, p = 0.00000000267445, **Table 47**.

Table 47: *Frequency table of observed [top], expected [centre] and (O-E)²/E [bottom] when comparing FW2 L pre-wear test impression replicates with the outsole at 1:1, 50x, and 200x*

Observed Frequencies	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
1:1	18	0	0	6	24
50x	0	4	12	8	24
200x	0	0	16	8	24
Column Total	18	4	28	22	72

Expected Frequencies	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	6	1.333333	9.333333	7.333333
50x	6	1.333333	9.333333	7.333333
200x	6	1.333333	9.333333	7.333333

$(O-E)^2/E$	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	24	0	9.333333	0.242424
50x	6	0	0.761905	0.060606
200x	6	0	4.761905	0.060606
	$X^2 = 51.22078$			

4.4.4. FW2R Pre-Wear

Comparisons at a 1:1 scale shows consistently high CSs within S2 and S3 however, S1 and S4 have a SS of 0; indicating that there is no fine replicable detail visible between the test impressions. Yet magnified comparisons show higher CSs for all test impressions indicating that a lot of features correspond with consistent scores of 2.

The results from the test impression-test comparisons with the pre-wear FW2R can be viewed in **Table 48**.

Table 48: *Correspondence scores for comparisons with FW2 R Pre-Wear static test impressions*

FW2 R Pre-Worn	Static Block 1												Static Block 2												Static Block 3											
	1:1				50x				200x				1:1				50x				200x				1:1				50x				200x			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
Static Block 1													0	3	3	0	2	2	2	2	2	2	2	2	0	3	3	0	2	2	2	2	2	2	2	2
Static Block 2	0	3	3	0	2	2	2	2	2	2	2	2													0	3	3	0	2	2	2	2	2	2	2	2
Static Block 3	0	3	3	0	2	2	2	2	2	2	2	2	0	3	3	0	2	2	2	2	2	2	2	2												
Section Total	0	6	6	0	4	4	4	4	4	4	4	4	0	6	6	0	4	4	4	4	4	4	4	4	0	6	6	0	4	4	4	4	4	4	4	4
Scale/Mag Total	12				16				16				12				16				16				12				16				16			

4.4.4.1. *FW2R Pre-Wear: Correspondence Scores and The Scale/Magnification Used*

Supporting H_1, there is a significant relationship between CSs and the scale/magnification used when $\alpha = 0.05$: X^2 (6, N = 72) = 72, p = 0.000000000000158887, **Table 49**.

Table 49: *Frequency table of observed [top], expected [centre] and (O-E)²/E [bottom] when comparing FW2 R pre-wear test impression replicates with the outsole at 1:1, 50x, and 200x*

Observed Frequencies	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
1:1	12	0	0	12	24
50x	0	0	24	0	24
200x	0	0	24	0	24
Column Total	12	0	48	12	72

Expected Frequencies	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	4	0	16	4
50x	4	0	16	4
200x	4	0	16	4

$(O-E)^2/E$	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	16	0	16	16
50x	4	0	4	4
200x	4	0	4	4
	$X^2 = 72$			

4.4.5. FW3L Pre-Wear

Comparisons at a 1:1 scale shows consistently high CSs within S2 however, S1, S3, and S4 have a SS of 0; indicating that there is no fine replicable detail visible between the test impressions. Magnified comparisons show higher CSs for all test impressions, S1 fluctuating between scores of 2 and 3 at 50x and 200x, S2 consistently showing CSs of 1 at 50x and 200x; S3 maintaining the CSs of 2 between 50x and 200x; and a fluctuation of scores of 2 and 3 within S4 at 50x and 200x.

The results from the test impression-test comparisons with the pre-wear FW3L can be viewed in **Table 50**.

Table 50: *Correspondence scores for comparisons with FW3 L Pre-Wear static test impressions*

FW3 L Pre-Wear	Static Black 1												Static Black 2												Static Black 3											
	1:1				50x				200x				1:1				50x				200x				1:1				50x				200x			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
Static Black 1													0	3	0	0	2	1	2	3	3	1	2	2	0	3	0	0	2	1	2	2	2	1	2	2
Static Black 2	0	3	0	0	2	1	2	3	3	1	2	3													0	3	0	0	2	1	2	2	2	1	2	2
Static Black 3	0	3	0	0	2	1	2	2	2	1	2	2	0	3	0	0	2	1	2	2	2	1	2	2												
Section Total	0	6	0	0	4	2	4	5	5	2	4	5	0	6	0	0	4	2	4	5	5	2	4	4	0	6	0	0	4	2	4	4	4	2	4	4
Scale/Mag Total	6				15				16				6				15				15				6				14				14			

4.4.5.1. FW3L Pre-Wear: Correspondence Scores and The Scale/Magnification Used

Supporting H_1, there is a significant relationship between CSs and the scale/magnification used when α = 0.05: X^2 (6, N = 72) = 53.91202, p = 0.000000000768473, **Table 51**.

Table 51: *Frequency table of observed [top], expected [centre] and (O-E)²/E [bottom] when comparing FW3 L pre-wear test impression replicates with the outsole at 1:1, 50x, and 200x*

Observed Frequencies	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
1:1	18	0	0	6	24
50x	0	6	16	2	24
200x	0	6	15	3	24
Column Total	18	12	31	11	72

Expected Frequencies	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	6	4	10.33333	3.666667
50x	6	4	10.33333	3.666667
200x	6	4	10.33333	3.666667

$(O-E)^2/E$	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	24	0	10.33333	1.484848
50x	6	0	3.107527	0.757576
200x	6	0	2.107527	0.121212
	X^2 = 53.91202			

4.4.6. FW3R Pre-Wear

Comparisons at a 1:1 scale shows consistently high CSs within S2-S3, however, S1 and S4 have a SS of 0; indicating that there is no fine replicable detail visible between the test impressions. Magnified comparisons show markedly higher CSs for all test impressions: S1 maintaining consistent scores of 3 and S3-S4 maintaining consistent scores of 2 when increasing the magnification from 50x and 200x. However, S2 shows a fluctuation of CSs of 2 and 3 at 50x but maintains scores of 2 at 200x.

The results from the test impression-test comparisons with the pre-wear FW3R can be viewed in **Table 52**.

Table 52: *Correspondence scores for comparisons with FW3 R Pre-Wear static test impressions*

FW3 R Pre-Wear	Static Black 1												Static Black 2												Static Black 3											
	1:1				50x				200x				1:1				50x				200x				1:1				50x				200x			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
Static Black 1													0	3	3	0	3	2	2	2	3	2	2	2	0	3	3	0	3	3	2	2	3	2	2	2
Static Black 2	0	3	3	0	3	2	2	2	3	2	2	2													0	3	3	0	3	2	2	2	3	2	2	2
Static Black 3	0	3	3	0	3	3	2	2	3	2	2	2	0	3	3	0	3	2	2	2	3	2	2	2												
Section Total	0	6	6	0	6	5	4	4	6	4	4	4	0	6	6	0	6	4	4	4	6	4	4	4	0	6	6	0	6	5	4	4	6	4	4	4
Scale/Mag Total	12				19				18				12				18				18				12				19				18			

4.4.6.1. *FW3R Pre-Wear: Correspondence Scores and The Scale/Magnification Used*

Supporting H_1, there is a significant relationship between CSs and the scale/magnification used when α = 0.05: X^2 (6, N = 72) = 43.33032, p = 0.0000001003398, **Table 53**.

Table 53: *Frequency table of observed [top], expected [centre] and (O-E)²/E [bottom] when comparing FW3 R pre-wear test impression replicates with the outsole at 1:1, 50x, and 200x*

Observed Frequencies	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
1:1	12	0	0	12	24
50x	0	0	16	8	24
200x	0	0	18	6	24
Column Total	12	0	34	26	72

Expected Frequencies	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	4	0	11.33333	8.666667
50x	4	0	11.33333	8.666667
200x	4	0	11.33333	8.666667

$(O-E)^2/E$	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
1:1	16	0	11.33333	1.282051
50x	4	0	1.921569	0.051282
200x	4	0	3.921569	0.820513
	X^2 = 43.33032			

4.5. Pre-Wear Test Impression-Outsole Comparison

The following subchapter shows the results from pre-wear test impression-outsole comparisons from the left and right impressions from FW1, FW2, and FW3.

4.5.1. FW1L Pre-Wear

Comparisons at a 50x magnification show consistent CSs within all outsole sections (S1-S4) with scores of 2. At 200x, S1, S2, and S4 maintain the scores of 2, but CSs within S3 decrease to 1 at this magnification.

The results from the test impression-outsole comparisons with the pre-wear FW1L can be viewed in **Table 54**.

Table 54: *Correspondence scores for comparisons with FW1 L Pre-Wear static test impressions-outsole*

FW1 L Pre-Wear	Static Black 1								Static Black 2								Static Black 2							
	50x				200x				50x				200x				50x				200x			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
FW1L Pre-Wear Outsole	2	2	2	2	2	2	1	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2	1	2
Mag Total	8				7				8				7				8				7			

4.5.1.1. *FW1L Pre-Wear: Correspondence Scores at 50x and 200x*

Supporting H_0, there is no significant relationship between CSs at 50x and 200x when $\alpha = 0.05$: X^2 (3, N = 24) = 3.428571, p = 0.330145011, **Table 55**.

Table 55: *Frequency table of observed [top], expected [centre] and $(O-E)^2/E$ [bottom] when comparing FW1 L pre-wear test impression replicates with the outsole at 50x and 200x*

Observed Frequencies	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
50x	0	0	12	0	12
200x	0	3	9	0	12
Column Total	0	3	21	0	24

Expected Frequencies	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	1.5	10.5	0
200x	0	1.5	10.5	0

$(O-E)^2/E$	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	1.5	0.214286	0
200x	0	1.5	0.214286	0
	X^2 = 3.428571			

4.5.2. FW1R Pre-Wear

Comparisons at a 50x magnification show consistent CSs within S1, S3 and S4 with scores of 2. Although there is a fluctuation of CSs at S2 at 50x between the test impression replicates, these scores are the same when the magnification is increased to 200x. The scores of 2 at 50x within S1, S3, and S4 CSs decrease to 1 within S1 and S3 and maintain the score of 2 within S4 at 200x.

The results from the test impression-outsole comparisons with the pre-wear FW1R can be viewed in **Table 56**.

Table 56: *Correspondence scores for comparisons with FW1 R Pre-Wear static test impressions-outsole*

FW1 R Pre-Wear	***Static Black 1***								***Static Black 2***								***Static Black 2***							
	50x				***200x***				***50x***				***200x***				***50x***				***200x***			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
FW1R Pre-Wear Outsole	2	0	2	2	1	0	1	2	2	2	2	2	1	2	1	2	2	2	2	2	1	2	1	2
Mag Total	6				4				8				6				8				6			

4.5.2.1. *FW1L Pre-Wear: Correspondence Scores at 50x and 200x*

Supporting H_1, there is a significant relationship between CSs at 50x and 200x when $\alpha = 0.05$: X^2 (3, N = 24) = 10.25, p = 0.016556321, **Table 57**.

Table 57: *Frequency table of observed [top], expected [centre] and (O-E)²/E [bottom] when comparing FW1 R pre-wear test impression replicates with the outsole at 50x and 200x*

Observed Frequencies	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
50x	1	0	11	0	12
200x	1	6	5	0	12
Column Total	2	6	16	0	24

Expected Frequencies	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	1	3	8	0
200x	1	3	8	0

$(O-E)^2/E$	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	1	3	1.125	0
200x	1	3	1.125	0
	$X^2 = 10.25$			

4.5.3. FW2L Pre-Wear

Comparisons at a 50x magnification show consistent CSs within S1, S3 and S4 with scores of 2, and a fluctuation of scores of 2 and 1 within S2. The CSs maintain a score of 2 at 200x within S1 and S4 but decrease to 1 within S2 and S3.

The results from the test impression-outsole comparisons with the pre-wear FW2L can be viewed in **Table 58**.

Table 58: *Correspondence scores for comparisons with FW2 L Pre-Wear static test impressions-outsole*

FW2 L Pre-Wear	Static Black 1								Static Black 2								Static Black 2							
	50x				200x				50x				200x				50x				200x			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
FW2L Pre-Wear Outsole	2	2	2	2	2	1	1	2	2	1	2	2	2	1	1	2	2	2	2	2	2	1	1	2
Mag Total	8				6				7				6				8				6			

4.5.3.1. FW2L Pre-Wear: Correspondence Scores at 50x and 200x

Supporting H_0, there is no significant relationship between CSs at 50x and 200x when $\alpha = 0.05$: X^2 (3, N = 24) = 5.042017, p = 0.168746195, **Table 59**.

Table 59: *Frequency table of observed [top], expected [centre] and (O-E)²/E [bottom] when comparing FW2 L pre-wear test impression replicates with the outsole at 50x and 200x*

Observed Frequencies	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
50x	0	1	11	0	12
200x	0	6	6	0	12
Column Total	0	7	17	0	24

Expected Frequencies	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	3.5	8.5	0
200x	0	3.5	8.5	0

$(O-E)^2/E$	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	1.785714	0.735294	0
200x	0	1.785714	0.735294	0
	X^2 = 5.042017			

4.5.4. FW2R Pre-Wear

Comparisons at a 50x magnification show consistent CSs within all outsole sections (S1-S4) with scores of 2. When increasing the magnification to 200x, S1, S2, and S3 show a decrease in CSs to a score of 1, but at 200x, CSs maintain a score of 2 within S3.

The results from the test impression-outsole comparisons with the pre-wear FW2R can be viewed in **Table 60**.

Table 60: *Correspondence scores for comparisons with FW2 R Pre-Wear static test impressions-outsole*

FW2 R Pre-Wear	***Static Black 1***								***Static Black 2***								***Static Black 2***							
	50x				***200x***				***50x***				***200x***				***50x***				***200x***			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
FW2R Pre-Wear Outsole	2	2	2	2	1	1	2	1	2	2	2	2	1	1	2	1	2	2	2	2	1	1	2	1
Mag Total	8				5				8				5				8				5			

4.5.4.1. *FW2R Pre-Wear: Correspondence Scores at 50x and 200x*

Supporting H_1, there is a significant relationship between CSs at 50x and 200x when $\alpha = 0.05$: X^2 (3, N = 24) = 14.4, p = 0.002408284, **Table 61**.

Table 61: *Frequency table of observed [top], expected [centre] and (O-E)^2/E [bottom] when comparing FW2 R pre-wear test impression replicates with the outsole at 50x and 200x*

Observed Frequencies	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
50x	0	0	12	0	12
200x	0	9	3	0	12
Column Total	0	9	15	0	24

Expected Frequencies	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	4.5	7.5	0
200x	0	4.5	7.5	0

(O-E)^2/E	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	4.5	2.7	0
200x	0	4.5	2.7	0
	X^2 = 14.4			

4.5.5. FW3L Pre-Wear

Comparisons at a 50x magnification have the same CSs at 200x. S1, S3, and S4 have consistent CSs of 2, and S2 show CSs of 1. The score of 1 indicates that the test impressions were of poor quality, but some correspondence could be identified.

The results from the test impression-outsole comparisons with the pre-wear FW3L can be viewed in **Table 62**.

Table 62: *Correspondence scores for comparisons with FW3 L Pre-Wear static test impressions-outsole*

FW3 L Pre-Wear	***Static Black 1***								***Static Black 2***								***Static Black 2***							
	50x				***200x***				***50x***				***200x***				***50x***				***200x***			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
FW3L Pre-Wear Outsole	2	1	2	2	2	1	2	2	2	1	2	2	2	1	2	2	2	1	2	2	2	1	2	2
Mag Total	7				7				7				7				7				7			

4.5.5.1. FW3L Pre-Wear: Correspondence Scores at 50x and 200x

Supporting H_0, there is no significant relationship between CSs at 50x and 200x when

$\alpha = 0.05$: X^2 (3, N = 24) = 0, p = 1, **Table 63**.

Table 63: *Frequency table of observed [top], expected [centre] and (O-E)²/E [bottom] when comparing FW3 L pre-wear test impression replicates with the outsole at 50x and 200x*

Observed Frequencies	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
50x	0	3	9	0	12
200x	0	3	9	0	12
Column Total	0	6	18	0	24

Expected Frequencies	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	3	9	0
200x	0	3	9	0

$(O-E)^2/E$	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	0	0	0
200x	0	0	0	0
	$X^2 = 0$			

4.5.6. FW3R Pre-Wear

Comparisons at a 50x magnification show consistent CSs within all outsole sections (S1-S4) with scores of 2. When increasing the magnification to 200x, S2, S3, and S4 show a decrease in CSs to a score of 1, but at 200x, CSs maintain a score of 2 within S1.

The results from the test impression-outsole comparisons with the pre-wear FW3R can be viewed in **Table 64**.

Table 64: *Correspondence scores for comparisons with FW3 R Pre-Wear static test impressions-outsole*

FW3 R Pre-Wear	***Static Black 1***								***Static Black 2***								***Static Black 2***							
	50x				***200x***				***50x***				***200x***				***50x***				***200x***			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
FW3R Pre-Wear Outsole	2	2	2	2	2	1	1	1	2	2	2	2	2	1	1	1	2	2	2	2	2	1	1	1
Mag Total	6				5				6				5				8				5			

4.5.6.1. FW3R Pre-Wear: Correspondence Scores at 50x and 200x

Supporting H_1, there is a significant relationship between CSs at 50x and 200x when $\alpha = 0.05$: X^2 (3, N = 24) = 14.4, p = 0.002408284, **Table 65**.

Table 65: *Frequency table of observed [top], expected [centre] and $(O-E)^2/E$ [bottom] when comparing FW3 R pre-wear test impression replicates with the outsole at 50x and 200x*

Observed Frequencies	Correspondence Score				
Magnification	**0**	**1**	**2**	**3**	*Row Total*
50x	0	0	12	0	12
200x	0	9	3	0	12
Column Total	0	9	15	0	24

Expected Frequencies	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	4.5	7.5	0
200x	0	4.5	7.5	0

$(O-E)^2/E$	Correspondence Score			
Magnification	**0**	**1**	**2**	**3**
50x	0	4.5	2.7	0
200x	0	4.5	2.7	0
	X^2 = 14.4			

CHAPTER 5 - DISCUSSION

This thesis sought to explore if it is necessary for footwear examiners to enlarge or use microscopy during footwear examinations to locate detail that is not visible to the naked eye and would therefore be missed during their forensic examinations.

During the development of the method, this thesis experimented with different types of test impression methods to create an understanding on the most appropriate method for replication of microscopic detail. It was apparent that static test impressions gave a more consistent replication of Schallamach and other microscopic detail than dynamic test impression methods. Although Printscan test impressions were discontinued due to the lack of recorded detail, (Bodziak 2000: p.293) says this method of test impression creation contains “exceptionally fine detail”; this was not found here. Upon reflection, it is thought that the quality of the Printscan test impressions created within this thesis may have been impacted due to using a new printscan pad as the impressions appeared oversaturated. Future research should reattempt the works within this thesis to understand if fine detail is recorded when using an older Printscan pad. Nonetheless, the discussion relates to static test impressions.

Although the anecdotal standard practice for forensic science providers is to initially create dynamic test impressions to make an assessment on pattern, size and wear, static test impressions are often used for an assessment of fine detail after the use of dynamic impressions when the class characteristics have been established. This anecdotal practice was consistent to the findings discovered during method development; all dynamic test impressions were discontinued as these impressions did not expose any fine detail to be used during microscopic comparisons.

Despite several recommendations from the House of Commons Science and Technology Committee stating, “forensic science should be a research priority” (Parliament. House of Lords, 2019: 169), there is a lack of research within forensic science, and it is apparent that the ‘known’ practice of the appropriate test impression methods are anecdotal and not based on published data. It is critical that there is an increase of published work to support or reject working practice to ensure that each aspect is working accordingly through validation. It is apparent that some forensic science providers only use static test impressions (Baines, 2024); and despite static impressions offering the finest detail, and this has been proven in this thesis, this method of test impression creation cannot preclude the creation of dynamic test impressions. Methods of creating test impressions are often preferable dependent on what the forensic specialist wishes to use the test impression for. For example, dynamic test impressions offer the most reliability when considering the size of a footwear; whereas static test impressions appear larger than the footwear that created it. There would not be an accurate assessment of size when limiting test impressions to only static methods. With the increase of real crime television programmes, there is an increase of criminals becoming ‘forensically aware’ (Beauregard and Bouchard, 2010), and the increase of forensic science research exploring the more beneficial and accurate methods of examination will assist with staying ahead of the criminals.

During the comparison stages of the project, it was apparent that out of the 36 test impressions created (18x pre-wear and 18x worn), 6 were deemed poor quality (S1 of SB1 in FW1L Worn; S2 of SB1 in FW1R Pre-Wear; S2 of SB2 in FW2L Pre-Wear; S2 of SB1/SB2/SB3 in FW3L Pre-Wear) when considering the visibility of features, presence of air bubbles, and overall care taken of each test impression. However, the severity of the quality was established during the microscopic examinations, and it was apparent that the whole test impressions were not considered to be poor, but individual sections. This is likely due to the small area being examined under magnification, and a large room for error when creating the test impressions; if too much powder was applied, or an abundance of air bubbles were present, this was noticeable during the magnified comparisons.

The following subchapters discuss the results from worn test impression-test impression comparisons; worn test impression-outsole comparisons; sectional breakdown of comparison results; new vs. worn shoes; and limitations and suggestions for future research.

5.1. Worn Test Impression-Test Impression Comparison

Worn test impressions were compared with each other before comparisons were made with the outsole. The main findings of the comparisons are detailed below.

5.1.1. Footwear Breakdown

5.1.1.1. *FW1L Worn:*

According to X^2, the results show a significant relationship between CSs and the scale/magnification used ($\alpha = 0.05$: X^2 (6, $N = 72$) = 57.85714, p = 0.000000000122492); a significant relationship between CSs at 1:1 and when using magnification ($\alpha = 0.05$: X^2 (3, $N = 72$) = 48.85714286, p = 0.000000000139908); and no significant relationship between CSs at 50x and 200x ($\alpha = 0.05$: X^2 (3, $N = 48$) = 6, p = 0.111610225).

Four outsole sections were examined at 1:1, however, no replicable detail was visible in S1-S3 (each had a SS of 0). In contrast, S4 showed replicable detail with a total SS of 18. This is important in practice as currently, enlargement of footwear evidence is only practiced if there is detail visible at this stage (Lancashire Constabulary, 2020), and an absence of detail at 1:1 would not result in further examination.

This research demonstrates that despite CSs of 0 at 1:1 in S1-S3, using magnification exposed additional replicable detail and overall CSs increased to 62 at 50x and 66 at 200x. Both 50x and 200x saw consistent maximum CSs of ‘3’ in S2 and S3, when at 1:1, 100% of CSs of 0 within S1-S3 indicates there is no replicable detail. The results suggest that in this instance, introducing microscopy at 50x is beneficial in obtaining higher CSs than simply comparing test impressions at 1:1. However, as the CSs neither decreased or increased at 200x within S2 and S3, increasing the magnification from 50x to 200x did not make a marked difference to CSs in these sections and therefore a 200x magnification may not be required for further examination.

Comparisons at 50x magnification in S1 with SB1 to SB2 and SB3; SB2 to SB1; and SB3 to SB1 had a correspondence score of ‘1’. This score was given as the comparisons were affected because SB1 was of poor quality. The ‘ghosting’ effect around part of the test impression could be the result of an area of the static lifter lifting from the shoe and subsequently re-stuck in a slightly different position onto part of the outsole, which could explain the smudged features surrounded by air bubbles; these can be seen in **Figure 72**. However, these scores of ‘1’ increased to ‘2’ at 200x, which suggests that a lot of the features correspond, observable due to the higher magnification, **Figure 73**. The increase of CSs suggest that a higher magnification may be able to assist with obtaining a higher SS in test impressions of poorer quality due to being able to view each feature in higher detail. The increase of CSs for this comparison is likely because at 50x the features appear smudged and it was difficult to distinguish each feature from another and it appeared that only some of the features corresponded, **Figure 74**, but increasing the magnification to 200x focused on and exposed each feature, and it was possible to see more correspondence within the test impressions compared, **Figure 75**. These findings could positively impact forensic science providers as a poor-quality test impression may dissuade them from conducting a forensic examination and often may not be used at all (Srihari, 2010). However, conducting further examination via microscopes may assist with obtaining a result and therefore save resources.

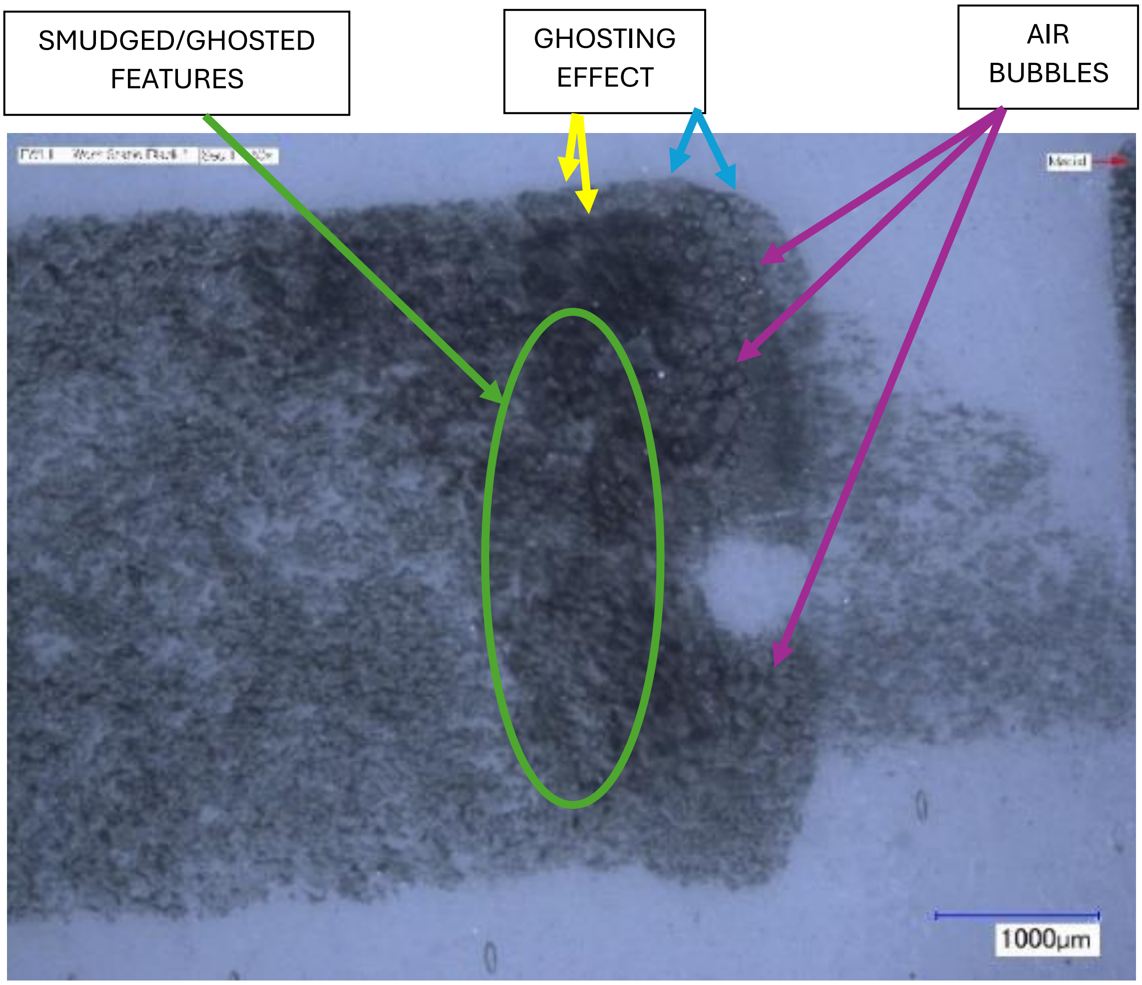


Figure 72: *Worn SB1 section 1 at 50x, highlighting areas showing a poor test impression*

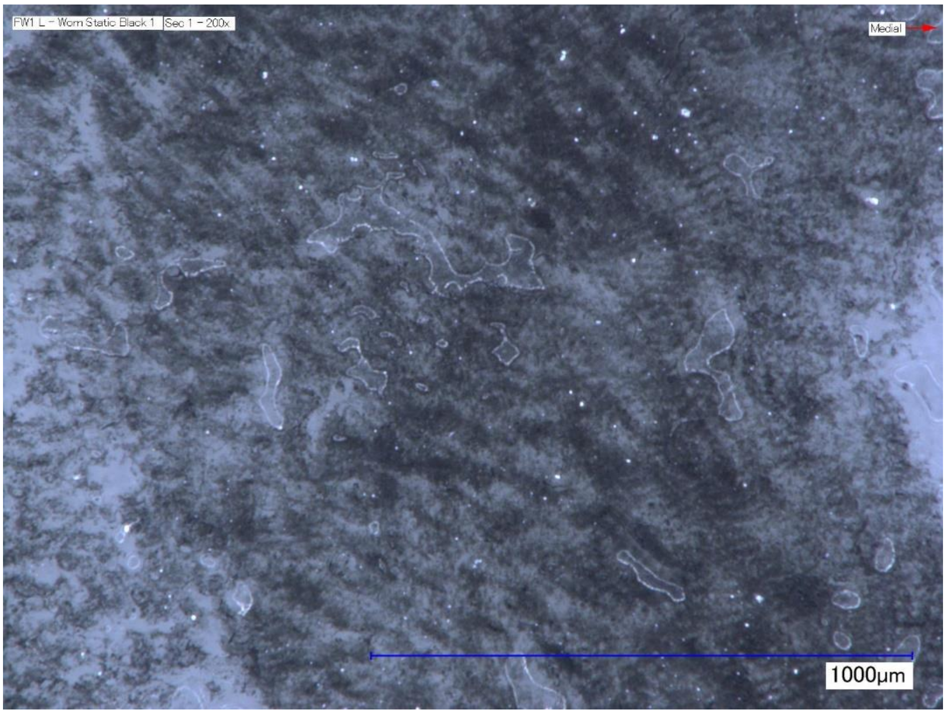


Figure 73: *Worn SB1 section 1 at 200x*

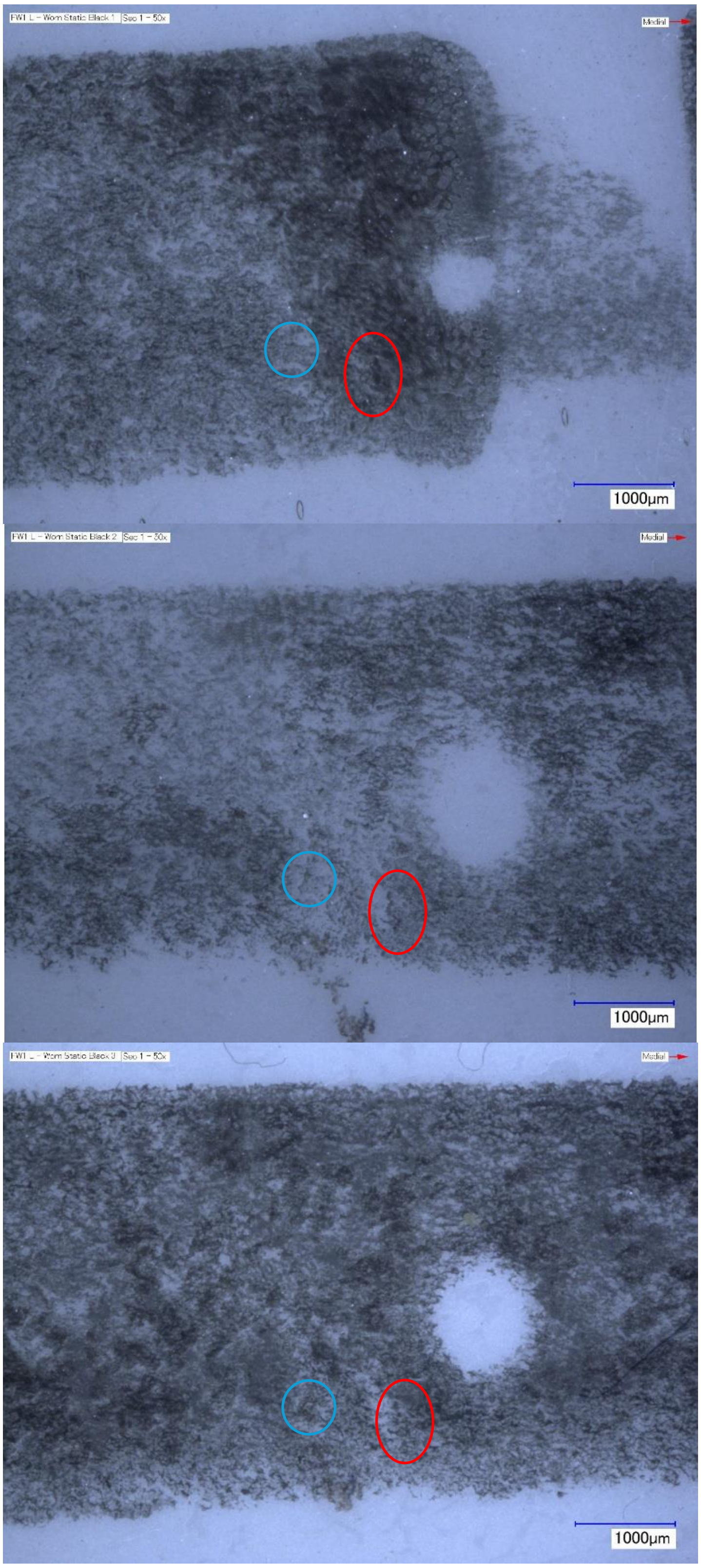


Figure 74: *Worn static black test impressions at 50x, with circles highlighting correspondence. SB1 (top) SB2 (centre) SB3 (bottom)*

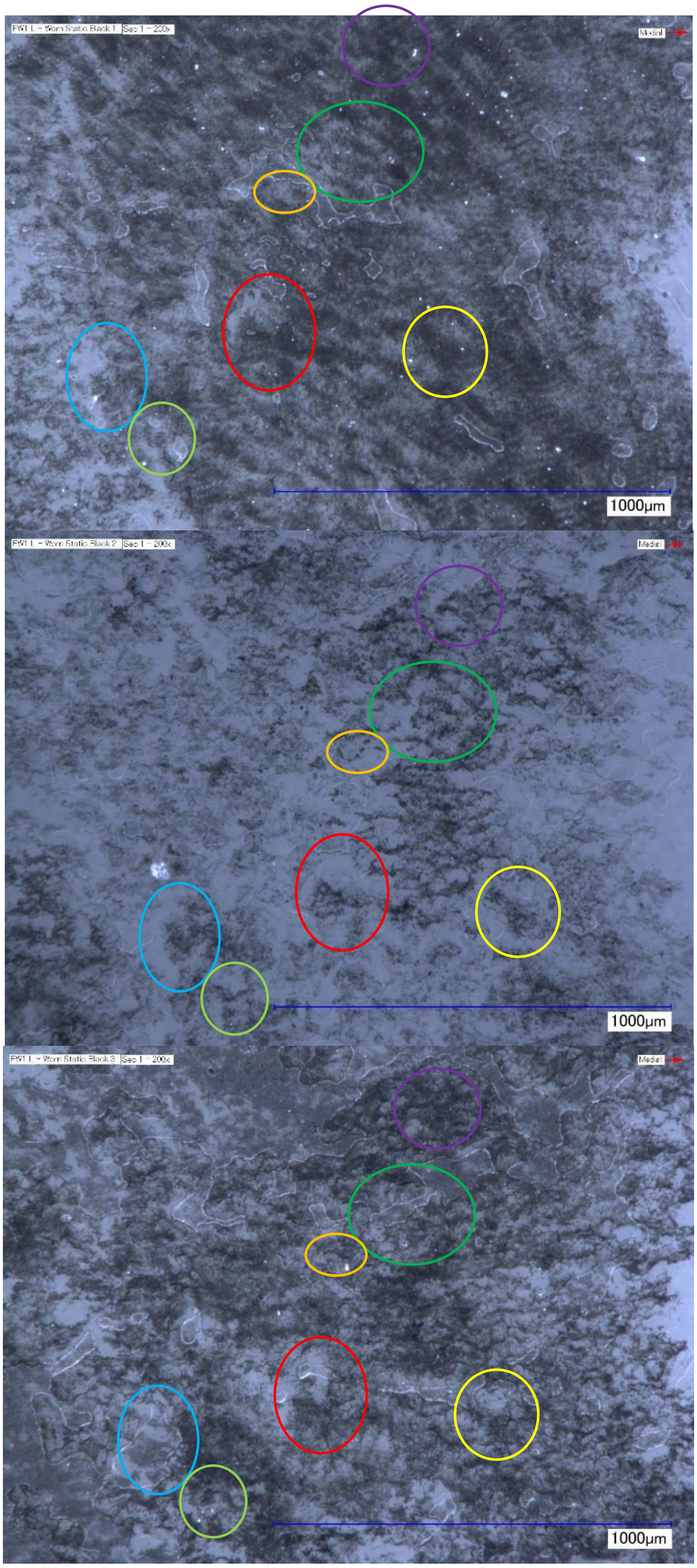


Figure 75: *Worn static black test impressions at 200x, with circles highlighting correspondence. SB1 (top) SB2 (centre) SB3 (bottom)*

By completing the comparisons at three different scales and magnifications (1:1, 50x, and 200x), the comparisons when using magnification were more beneficial in obtaining CSs. Despite only observing replicable detail at 1:1 in one out of the four sections examined (S4), the use of magnification revealed that there is replicable detail that can be used during successful comparisons with the use of microscopy. The three X^2 tests have resulted in very low p-values, suggesting that there is an extremely low chance that the results are caused by random means under H_0; providing significant findings to reiterate the importance of using microscopy despite a lack of visual detail at 1:1.

Overall, the results suggest that CSs of the FW1L test impression-test impression comparisons were more statistically significant, and CSs were higher at 200x as opposed to 1:1 and 50x. This could be due to the poor-quality test impressions requiring a higher magnification to expose the detail and correspondence. Within forensic examinations the footwear evidence available for examination may be limited, and if the only evidence available is of poor quality, this comparison has revealed that the use of magnification may be able to assist when obtaining a result. However, future research should replicate the works within this thesis to enable a deeper understanding of the microscopic replication/correspondence of crime scene footwear marks. Crime scene marks often require interpretation to examine, as there is a higher likelihood of observing background contaminants (Kortylewski *et al.,* 2015) due to substrate, or powder; if the mark was dusted prior to lift, and therefore, it may be likely that the microscopic examination of these marks will require a higher magnification to examine and compare accurately.

As this thesis aims to discuss if microscopy should be used on all footwear evidence that does not show visible detail at 1:1, this result can assist the forensic examiner when deciding if further examination should be completed with magnification and if higher magnification may be required on poorer test impressions.

5.1.1.2. FW1R Worn

FW1R produced similar findings to FW1L in terms of only observing replicable detail at 1:1 in S4 and reporting consistent scores of ‘3’ in S2-S4 at 50x and 200x. However, all test impressions were deemed good quality and comparisons in S1 were not affected, and scores of ‘2’ were given as there was evidence that a lot of features corresponded. A SS of 18 was reported at 1:1, and this increased to 66 at both 50x and 200x. Although this examination did not see a benefit of further increasing the magnification from 50x as CSs did not change at 50x and 200x, X^2 suggest that there is a significant relationship between magnification and CSs and the scale/magnification used ($\alpha = 0.05$: X^2 $(6, N = 72) = 48.85714286$, $p = 0.00000000796327$); a significant relationship between CSs at 1:1 and when using magnification ($\alpha = 0.05$: X^2 $(3, N = 72) = 48.85714286$, $p = 0.000000000139908$); and there is no significant relationship between CSs at 50x and 200x ($\alpha = 0.05$: X^2 $(3, N = 48) = 0$, $p = 1$).

The results suggest that FW1R test impression-test impression comparisons were more significant, and CSs were higher at 50x, due to an increase of CSs from 1:1 to 50x, and no change between CSs from 50x-200x. As the CSs within this comparison are similar to the CSs within the FW1L Worn, the only difference being that no test impressions were deemed poor-quality; it is interesting that the

CSs were higher at 50x here, rather than 200x in FW1L Worn. This further indicates that the poor-quality test impression was a crucial factor in requiring to reach magnification of 200x. This result can be used to assist forensic science providers, as providing guidance on the most beneficial magnification for different variations of test impressions could save the examiner time during their companions if they wish to replicate these methods.

5.1.1.3. *FW2L Worn*

FW2L worn saw the same results and CSs as FW1R worn. Again, the CS of 66 at 50x did not differ at 200x, highlighting that increasing magnification higher than 50x may not be required. Due to the increase of CSs from 1:1 to 50x, X^2 report of a significant relationship between CSs and the scale used (α = 0.05: X^2 (6, N = 72) = 48.85714, p = 0.00000000796327); a significant relationship between CSs at 1:1 and when using magnification (α = 0.05: X^2 (3, N = 72) = 48.85714286, p = 0.000000000139908); and there is no significant relationship between 50x and 200x CSs (α = 0.05: X^2 (3, N = 48) = 0, p = 1).

The results suggest that FW2L test impression-test impression comparisons were more significant at 50x, due to an increase of CSs from 1:1 to 50x, and no change between CSs from 50x-200x.

5.1.1.4. *FW2R Worn*

The results have shown that there is a significant relationship between CSs and the scale/magnification used (α = 0.05: X^2 (6, N = 72) = 72.5035, p = 0.000000000000158887); a significant relationship between CSs at 1:1 and when using magnification (α = 0.05: X^2 (3, N = 72) = 72, 0.0000000000000015919);

and there is no significant relationship between CSs at 50x and 200x ($\alpha = 0.05$: X^2 (3, N = 48) = 0, p = 1) as CSs increased from 1:1 to 50x, but did not differ at 200x. The results suggest that 50x is the most significant magnification used in terms of the highest CSs.

The 1:1 comparison of the four sections resulted in consecutive CSs of 0 as there was no observable detail that replicated with other test impressions. Importantly, CSs increased to 60 at 50x and 200x when initially there was no observable detail. Throughout all comparisons, S1 and S2 saw CSs of ‘2’ at 50x and 200x, and S3 and S4 had CSs of ‘3’ at both 50x and 200x, despite not observing replicable detail at 1:1.

This comparison is important as there was no visible detail at 1:1, and during forensic footwear examinations, if there is no observable replicable detail visible by eye when comparing a test impression with a crime scene mark, no further examination would be completed (Lancashire Constabulary, 2020), and this result would have been missed. However, this result has highlighted the value of using microscopy for revealing hidden features that was not visible at 1:1; and provides potential for successful comparison results on all footwear evidence when considering that fine detail is only visible when microscopy is used. However, conducting microscopic examinations of this type in practice could be a time consuming and costly investment. It therefore is recommended that if a known and unknown footwear mark share the same class characteristics (pattern and size), and there are no visible identifying features, such as Schallamach at 1:1, that microscopy should be used to potentially reveal hidden features.

5.1.1.5. FW3L Worn

The results show that there is a significant relationship between CSs and the scale/magnification used ($\alpha = 0.05$: X^2 (6, $N = 72$) = 25.71228, $p = 0.00025186$); a significant relationship between CSs at 1:1 and when using magnification ($\alpha = 0.05$: X^2 (3, $N = 72$) = 25.6, $p = 0.0000115653$); and no significant relationship between 50x and 200x ($\alpha = 0.05$: X^2 (3, $N = 48$) = 0.087114338, $p = 0.993337587$). S1 was especially significant as this section revealed more significant replication at magnification compared to what was visible at 1:1. Despite FW3L worn having a variation of CSs within the test impressions at 1:1. Importantly, there was no visible detail at 1:1 in S1, but the CSs increased to '2' at 50x and 200x in this section, further highlighting that microscopy exposes detail not initially seen, and supporting the view that if a 1:1 footwear impression does not show detail, that this does not mean that there is no detail to be seen; microscopy may be required to reveal it.

There was visible detail at 1:1 in S2 and S3, and CSs remained at the maximum of '3' throughout the comparisons at 50x and 200x. Although consistent CSs of '3' appears to be valuable, this detail was already observed at 1:1 and so the findings are not as significant as the replicable detail was already known. However, consistent scores of '3' within these sections at 50x and 200x demonstrate that the CS scoring system robustly recognises features that share correspondence of all features, if this detail was seen at 1:1.

There was no visible detail at 1:1 between SB1 to SB3; and SB3 to SB1 comparisons in S4, but the scores increased to '2' at 50x. There was a variation here as the comparison at 200x between SB1 to SB3 saw an increase of SS of

‘3’, whereas the 200x comparison between SB3 to SB1 maintained the SS of ‘2’. This variation can be explained by the features within SB3 appearing *dense* due to an increase of background noise likely due to the application of too much powder, that when overlayed on top of SB1 where there is less background noise and powder, the features are obscured giving the illusion that there is less correspondence, the test impressions can be seen in **Figure 76** and **Figure 77**. However, there was no complications when observing correspondence when overlaying SB1 onto SB3, as there was no background noise obscuring the features. In practice, this could cause implications if multiple test impressions were not created, or if all test impressions created were of poorer quality, as the background noise could potentially hide corresponding detail when overlayed with a crime scene mark. However, this could potentially be overcome in practice if the acetate was printed in a different colour to allow for contrast of features.

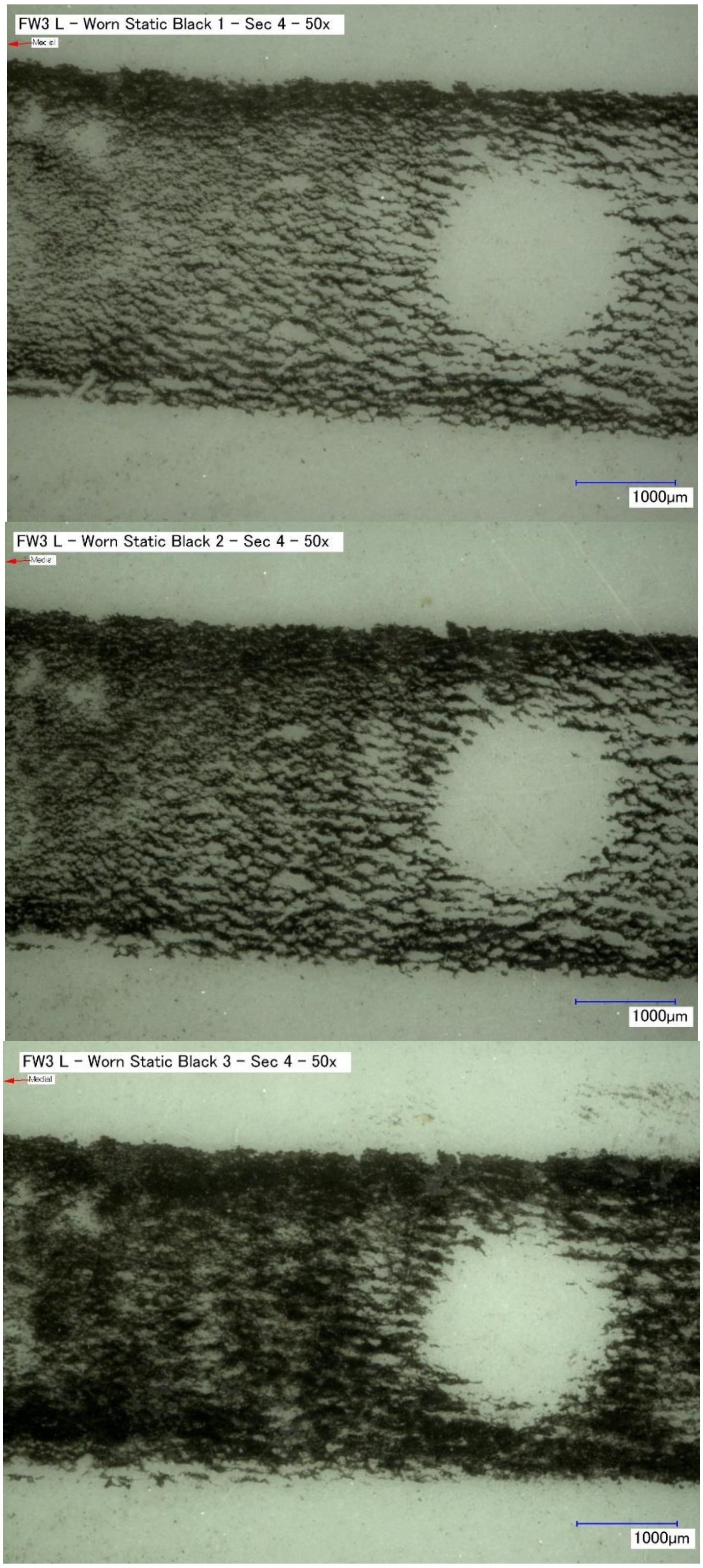


Figure 76: *Worn static black test impressions at 50x. SB1 (top) SB2 (centre) SB3 (bottom)*

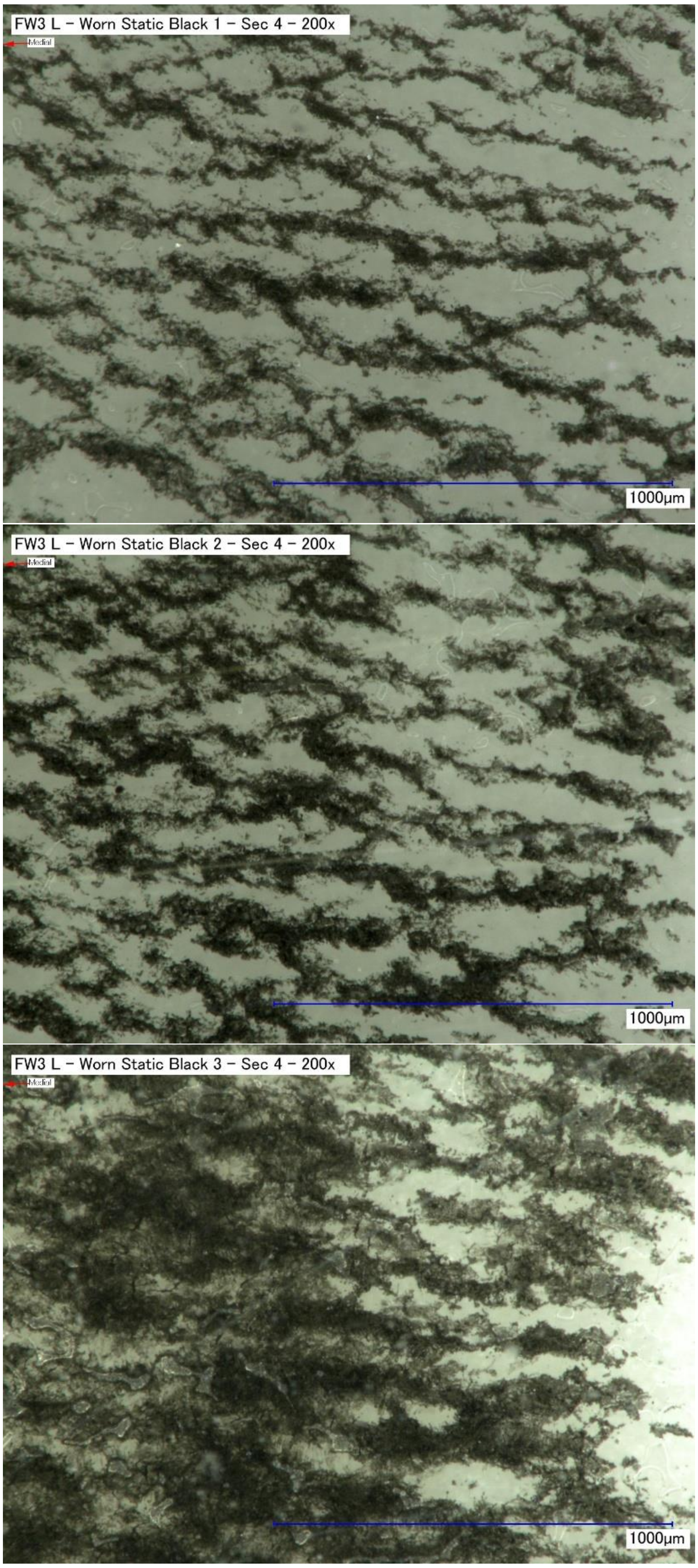


Figure 77: *Worn static black test impressions at 200x. SB1 (top) SB2 (centre) SB3 (bottom)*

5.1.1.6. FW3R Worn

The X^2 results show that there is a significant relationship between CSs and the scale/magnification used ($\alpha = 0.05$: X^2 (6, $N = 72$) = 31.5, $p = 0.0000203426$); a significant relationship between CSs at 1:1 and when using magnification ($\alpha = 0.05$: X^2 (3, $N = 72$) = 31.5, $p = 0.000000667023$); and there is no significant relationship between CSs at 50x and 200x ($\alpha = 0.05$: X^2 (3, $N = 48$) = 0, $p = 1$). The results have likely occurred due to the increase of SS between section 1 of 3 from 1:1 to 50x, but no change from 50x and 200x.

There was no visible detail at 1:1 in S1 and S3. Scores in S1 increased to ‘2’ at 50x and 200x, whereas scores in S3 increased to ‘3’ at 50x and 200x. This is likely due to the presence of more Schallamach in S3, as areas with more extensive Schallamach seemed to have greater replication. Although there are consistent CSs of ‘3’ at 50x and 200x in S2 and S4, there was already detail visible at 1:1, making these findings less significant in terms of only being able to obtain high CSs with the use of magnification. Reiterating that the SS scoring system may be beneficial in accurately identifying detail that is visible at 1:1.

5.1.2. Worn Test Impression-Test Impression Comparison Summary

In worn static black test impression-test impression comparisons, it was found that there were 0% of instances where there was fine, replicable detail in S1, 33.3% in S2, 16.7% in S3, and 77.8% in S4 visible at 1:1. However, whether detail was observed at 1:1 or not, there was a 100% success rate of observing replicable detail at 50x and 200x, further supporting the view that when the footwear impression does not indicate that there is visible detail by eye, the impression should be examined for microscopic detail within forensic footwear examinations to result in a successful comparison.

When concluding on a potential limit to the magnification in terms of higher CSs, there was only two instances (FW1L Worn and FW3L Worn) where the CSs given at 200x were higher than those given at 50x. However, SB1 in the FW1L Worn comparison has been discussed regarding the poor quality of the impression, that has thought to have an impact on CSs. Similarly, out of all magnified test impression-test impression comparisons for FW3L Worn (48), just one impression saw an increase of CSs from 50x and 200x (2.08%). However, this test impression (SB1-SB3 within S4) had been discussed regarding a possible heavy application of powder due to the dense features out of all magnified test impressions, that has likely impacted the overall CSs statistics. Although there were two footwear comparisons that suggest that 200x is a more beneficial magnification in terms of higher CSs, this was just 33.33% of the sample, and both were subject to a decrease of static test impression quality. This result further supports the view that a higher magnification (200x) may be beneficial for forensic specialists when examining or comparing poor quality test impressions. Moreover, 66.66% of test impression-test impression comparisons did not see a difference in CSs at 50x and 200x, giving the indication that reaching 200x does not provide additional benefits and may not be required when static test impressions are of good quality. Recommending a suitable magnification can save time for the forensic specialist who may conduct an examination of this type. However, only 50x and 200x magnification were explored, and therefore, the works within this thesis acknowledge that although 50x was deemed to be the best starting magnification during the development of the method, it is unknown whether 20x or 30x could obtain the same results. Future studies may wish to replicate this method, considering all available magnifications for method validation.

For a visual representation of the data, **Figure 78** shows the accumulation of all CSs at each magnification, using the data from **Table 66**.

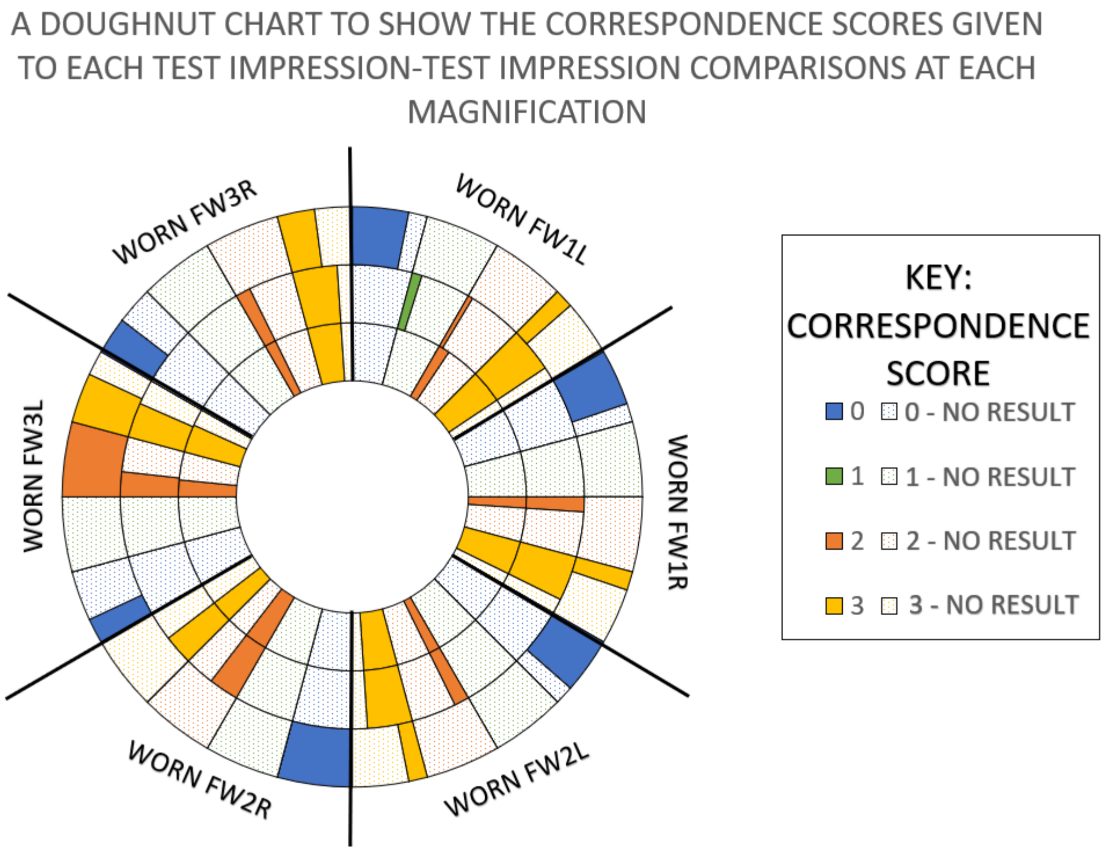


Figure 78: *A doughnut chart of the accumulation of CSs at each magnification between test impression-test impression comparisons. 1:1 [outer ring], 50x [centre ring], and 200x [inner ring]*

Table 66: *A table of the accumulation of CSs at each magnification for each test impression-test impression comparison*

	SS	200x	50x	1:1
FW1 L	***0***	0	0	18
	1	0	4	0
	2	6	2	0
	3	18	18	6
FW1 R	***0***	0	0	18
	1	0	0	0
	2	6	6	0
	3	18	18	6
FW2 L	***0***	0	0	18
	1	0	0	0
	2	6	6	0
	3	18	18	6
FW2 R	***0***	0	0	24
	1	0	0	0
	2	12	12	0
	3	12	12	0
FW3 L	***0***	0	0	8
	1	0	0	0
	2	9	10	0
	3	15	14	16
FW3 R	***0***	0	0	12
	1	0	0	0
	2	6	6	0
	3	18	18	12

5.2. Worn Test Impression-Outsole Comparisons

After comparing the test impressions with each other, they were then compared directly to the magnified images of the outsole. The following subchapter discusses the main findings of the comparisons.

5.2.1. Footwear Breakdown

5.2.1.1. FW1L Worn

FW1L worn showed statistically significant results. X^2 results indicate that there is no significant relationship between CSs at 50x and 200x ($\alpha = 0.05$: X^2 (3, N = 24) = 3.6, p = 0.308022172). However, the CSs differ and suggest that there is a difference to the most beneficial magnification depending on the section.

33.33% of CSs within S1 increased at 200x, but 66.66% of CSs do not differ when the magnification is increased; meaning 66.66% of the comparisons suggest that 50x could be the more beneficial magnification in obtaining higher CSs. However, this test impression (SB1) has been discussed regarding the poor quality, **Figure 79**. When comparing SB1 directly with the outsole at 50x, it was difficult to determine the outline of each feature to enable a reliable comparison. Although the test impression at 200x still shows evidence of 'ghosting', it was possible to view each feature and interpret which features have been subject to the ghosting and enable a comparison. It was apparent that features subject to ghosting were larger. This is likely because when peeling and re-sticking the lifter on a slightly different area of the outsole when creating the test impression, that each feature that initially created contact with the lifter re-contacted the lifter, resulting in larger/thicker features. After the test impression-test impression and test impression-outsole comparisons, it is clear that care needs to be taken when creating static test impressions as there is an impact on the SS and recommended magnification. Like the test impression-test impression comparisons, poorer quality test impressions may require a higher magnification when considering higher CSs.

There was a trend of CSs of ‘3’ in S2 at 50x decreasing to ‘2’ at 200x. This result indicates that 50x could be the most beneficial magnification. This is likely due to the less extensive Schallamach in these areas, and it was more difficult to locate areas of correspondence at 200x to the outsole. Although this statement may require further research to enable a deeper understanding, it is hypothesised that when compared, established Schallamach offers higher CSs.

Although not directly statistically studied, consistent CSs of ‘3’ within S3 at 50x and 200x could have been assisted by the contrast of colours due to this sections’ pink outsole. This conclusion has been reached as although Schallamach within this section is present, the detail is not as prominent as in S4, where consistent CSs of ‘3’ were also reported. However, in practice, printing the test impression in contrasting colours could assist when obtaining high CSs in areas of an outsole without a high contrast. Both S3 and S4’s results suggest that 50x would be the most beneficial magnification when considering higher CSs.

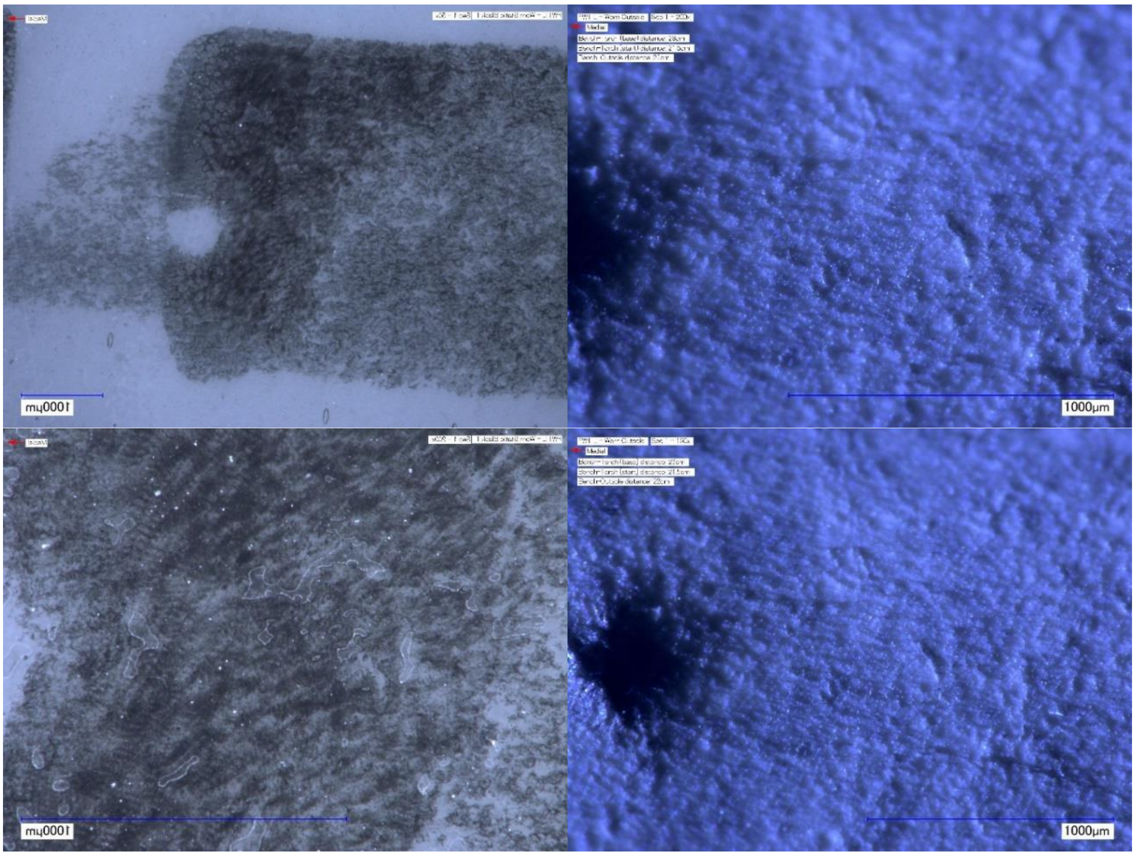


Figure 79: *Worn section 1 of SB1 at 50x (top left) and 200x (bottom left); worn section one of FW1L at 50x (top right) and 200x (bottom right). [Images of SB1 have been flipped horizontally]*

5.2.1.2. FW1R Worn

Comparisons with test impressions to FW1 R outsole did not show a significant relationship between CSs at 50x and 200x ($\alpha = 0.05$: X^2 $(3, N = 24) = 0$, $p = 1$). This is because CSs at 50x did not differ at 200x; section 1-2 had CSs of ‘2’, and section 3-4 had CSs of ‘3’. The results further support that areas with more established Schallamach result in higher CSs when compared.

The results support the view that increasing the magnification to 200x when comparing a test impression to the outsole does not provide additional detail that was already known at 50x.

5.2.1.3. FW2L Worn

Like the results for FW1R worn, the X^2 results suggested that there was not a significant relationship between CSs at 50x and 200x ($\alpha = 0.05$: X^2 (3, $N = 24$) = 0, $p = 1$). S1-S3 saw consistent CSs of ‘2’ at 50x, and these neither decreased nor increased at 200x. S4 saw a consistent SS of ‘3’ at 50x, and this did not decrease at 200x; These results suggest that 200x magnification does not provide additional information. The consistent CSs of ‘2’ are likely due to a lack of Schallamach in S1-S3, as Schallamach is more prominent in S4, and this section saw maximum CSs of ‘3’.

5.2.1.4. FW2R Worn

The X^2 results indicate that there was no significant relationship between CSs at 50x and 200x ($\alpha = 0.05$: X^2 (3, $N = 24$) = 0, $p = 1$), as the CSs did not change as magnification was increased. S1-S2 had a SS of ‘2’ at 50x and 200x, whereas S3 and S4 had a SS of ‘3’ at 50x and 200x. The differences of CSs could be due to an increase of Schallamach in S3-S4, making features more prominent and comparisons easier. The results support the view that using a 50x magnification may be the most beneficial magnification when considering higher CSs.

5.2.1.5. FW3L Worn

The X^2 results indicate that there is no significant relationship between CSs at 50x and 200x ($\alpha = 0.05$: X^2 (3, $N = 24$) = 0, $p = 1$), as scores did not differ at each magnification. CSs of ‘2’ were consistent at 50x and 200x in S1, S2, and S4; CSs of ‘3’ were consistent at 50x and 200x in S3.

S3 on a Nike Air Max 270 is flat, and it was found that it was uncomplicated when comparing a magnified test impression to the outsole. However, S4 (heel) is on an area that is slightly curved, and there was more interpretation when observing correspondence. Although Schallamach was prominent in S4, it was apparent CSs were higher at 50x. Despite the pin hole being in view in all S4 test impressions and the magnified outsole images, it was found that there were difficulties when completing the comparisons due to a possible magnification perspective. As a small area of the outsole and test impressions are examined, if this area is not accurately positioned under the microscope, when magnified, it will appear that a different area is examined, and therefore, appearing that there is less correspondence. An example of this perspective can be viewed in **Figure 80**.

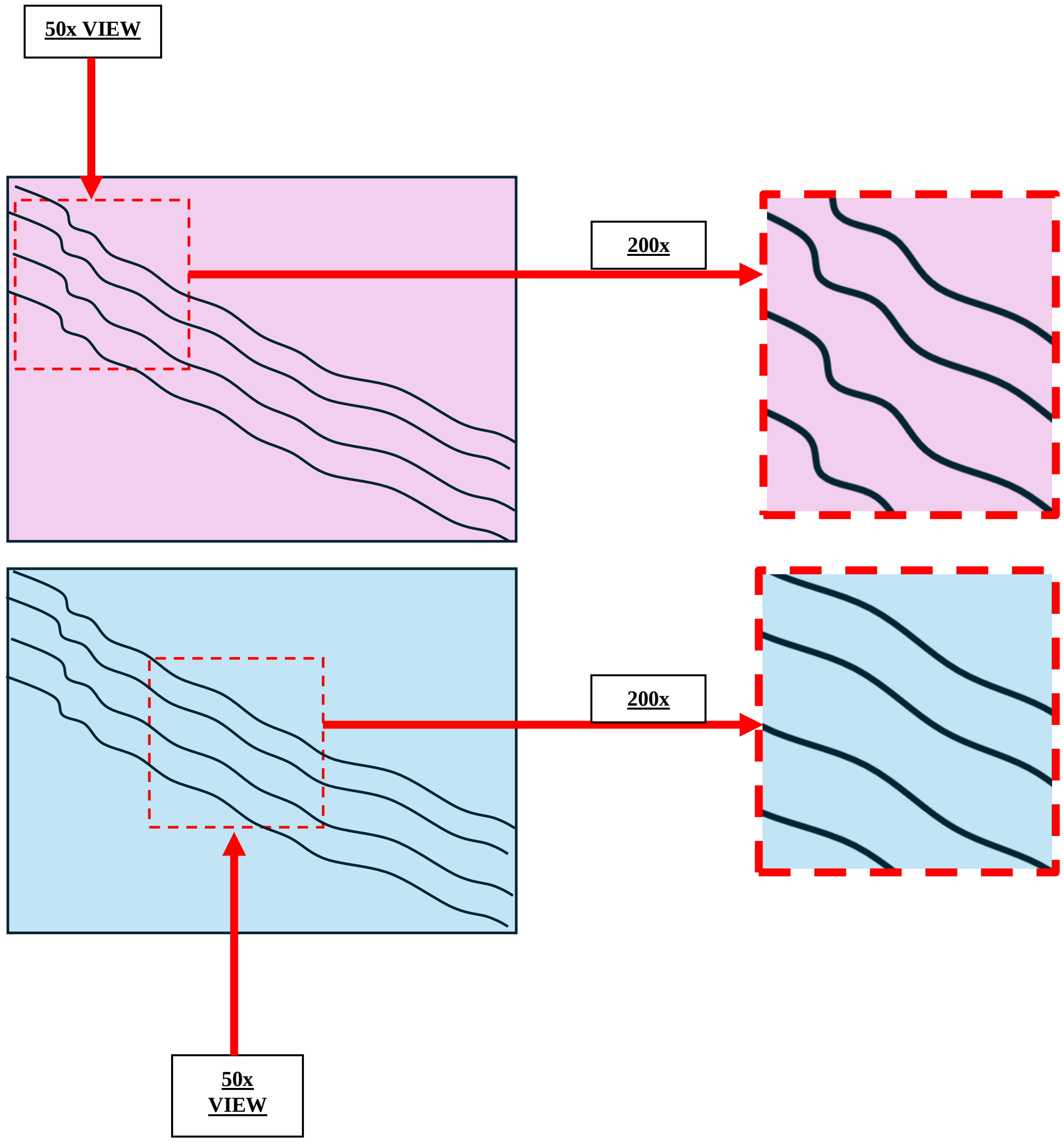


Figure 80: *An image to show a magnification effect. The view at 50x [left], when increased to 200x [right]. The diagram showing the difference to the view when positioning the object within a slightly different area*

5.2.1.6. FW3R Worn

The X^2 results showed that there is no significant relationship between CSs at 50x and 200x (α = (0.05: X^2 (3, N = 24) = 0.177778, p = 0.9810944), as there was a variation of CSs between magnifications. However, S2 and S3 was the most consistent amongst the replicates and maintained the SS of ‘2’ in S2 and ‘3’ in S3 at both 50x and 200x; supporting the view that 50x could be the more beneficial magnification. There was a variation of CSs at each magnification within S1 and S4: SB1 in S1 saw consistent CSs of ‘2’ in S2 at 50x that did not change at 200x; but the SS of ‘3’ at 50x in S4 decreased to ‘2’ at 200x. SB2 saw different CSs from 50x and 200x in S1 and S4: S1 had a SS of ‘2’ at 50x that increased to ‘3’ at 200x, and S4 had a SS of ‘3’ at 50x that decreased to ‘2’ at 200x. The CSs did not differ between magnification in SB3. The results support that the clearer and more prominent the Schallamach, the higher the SS. S4 in SB3 was not as clear as SB1 and SB2, hence the reason for allocating this test impression with ‘2’. Overall, the results suggest that 50x could be the more beneficial magnification when considering higher CSs.

5.2.2. Worn Test Impression-Outsole Comparison Summary

X^2 results of worn test impressions-outsole comparisons did not show a significant relationship between magnification and CSs. When observing the results, it becomes apparent that the CSs decreased slightly at 200x; aside from once in FW3L where S1 in SB2's score of '2' at 50x increased to '3' at 200x. This could be due to the smaller area being examined at 200x, and therefore, it often became challenging in locating the detail on the outsole. This was especially problematic on areas with less established Schallamach as the detail was more difficult to see. FW1R Worn, FW2L Worn, FW2R Worn, FW3L Worn however, showed no significant relationship between magnification and CSs as the scores given at 50x were the same as given at 200x. Suggesting that overall, when comparing test impressions to the outsole using 50x magnification may be the more beneficial magnification when considering higher CSs.

Importantly, comparing test impressions to the outsole 200x was very time consuming. It has been previously reported that the current method of footwear comparisons can be a time-consuming task (Srihari, 2010; Pavlou and Allinson, 2009). When attempting to introduce a new method, it is important to consider the length of time and cost the examination would take, as it may be a requirement to hire additional staff to complete this work, which would increase costs. Ultimately, these elements could be detrimental on the introduction of using microscopy on footwear evidence, and therefore, it is essential that further research is completed to fine tune and perfect the method during the development stage.

Despite the success of assigning CSs during magnified test impression-outsole comparisons, this took more time, which could be explained by the magnification perspective. As only 33.33% of comparisons saw an increase of CSs at 200x, and considering the length of time these examinations at 200x took to complete, it would not be worth taking the additional time to increase the magnification to 200x.

However, as in practice an impression of the outsole is compared with the outsole itself, it is important that the most beneficial magnification in terms of higher CSs correlate each other to compare like for like. When removing the anomalies of the only two comparisons that saw an increase of CSs at 200x, the X^2 results suggest that test impression-test impression and test impression-outsole comparisons CSs are higher at 50x. Overall, the results did not show a significant relationship between magnification and CSs. Between 50x and 200x, the works within this thesis suggest a recommendation of 50x magnification when conducting comparisons of this type.

Moreover, it is apparent that there is a correlation between higher CSs and more prominent Schallamach. Areas with less Schallamach, (in this case S1-S2) had lower CSs, and it is clear by observing the images of pre-worn and worn that Schallamach is not really established within S1-S2, despite two weeks of wear. A full breakdown of all images of test impressions and outsoles pre-worn and worn can be viewed in the **Appendix (C. Outsole and Test Impression Images)**.

For a visual representation of the data, **Figure 81** shows the accumulation of all CSs at each magnification, using the data from **Table 67**.

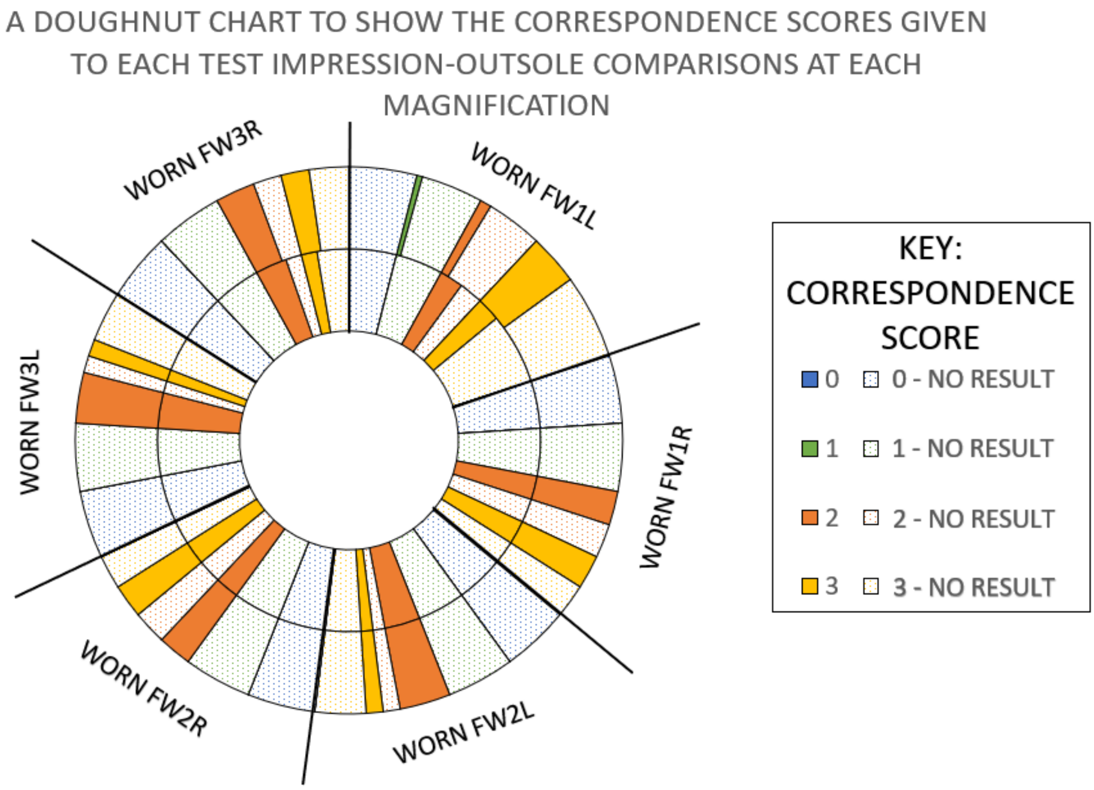


Figure 81: *A doughnut chart of the accumulation of CSs at each magnification between test impression-outsole. 50x [outer ring], and 200x [inner ring]*

Table 67: *A table of the accumulation of CSs at each magnification for each test impression-outsole*

	SS	**200x**	**50x**
FW1 L	***0***	0	0
	1	0	1
	2	6	2
	3	6	9
FW1 R	***0***	0	0
	1	0	0
	2	6	6
	3	6	6
FW2 L	***0***	0	0
	1	0	0
	2	9	9
	3	3	3
FW2 R	***0***	0	0
	1	0	0
	2	6	6
	3	6	6
FW3 L	***0***	0	0
	1	0	0
	2	9	9
	3	3	3
FW3 R	***0***	0	0
	1	0	0
	2	8	7
	3	4	5

5.3. Subsections of the Shoe

The following subchapter discusses the sections of the shoes examined and relates this to the results and published literature.

5.3.1. Sectional Breakdown

Four areas of the shoe were examined, plus a control area. Each section is discussed in turn, breaking the results up into test impression-test impression and test impression-outsole comparisons.

5.3.1.1. Section 1

Davis and Keeley (2000) state that they found extensive Schallamach within the toe region, and Kaplan-Damary *et al.* (2018) found the most Schallamach around the toe area; specifically, section 6 in their subsections. **Figure 82** overlays the subsections used in Kaplan-Damary *et al.* (2018) on the outsole used in this thesis.

Figure 82: *The subsections of the outsole used in Kaplan-Damary et al. (2018) adapted to black and white and transparent, overlayed on the sections of the outsole used in this thesis. Rectangle = the similar toe area used. Arrow = medial*

As shown, the toe area examined in this thesis (S1) fits within the toe area examined in Kaplan-Damary *et al.* (2018) (S6). However, as Davis and Keeley (2000) do not provide illustrations or an explanation as to where within the toe region they made their observations, it is difficult to compare their findings to this thesis.

Although this thesis initially set out to examine the medial toe area, the Nike Air Max 270 used in this thesis has a slight curve around the toe, which caused a lack of contact with the ground in this area due to the authors walking habits. As the centre toe consistently created ground contact, this area was selected to adapt the published findings to the outsole used. Despite ensuring that there is ground contact in this area, this research found the least Schallamach and observed the least correspondence score in S1. As these findings are similar amongst the three footwear replicates, this could be due to Schallamach not yet being established after the two weeks at which the shoes were worn. As well as the outsole design, variables such as weight and type of substrate walked upon would likely alter the formation of Schallamach if another person repeats this study with the same model of shoes. However, more research should be completed on different outsole shapes and the differences of Schallamach formation in different areas to enable a complete understanding.

A summary of the test impression-test impression and test impression-outsole comparisons in section 1 are detailed as follows:

Section 1 - Test Impression-Test Impression:

With a mean SS of 0 at 1:1 (*total SS / number of 1:1 test impression-test impression comparisons in S1*); 1.89 at 50x (*total SS / number of 50x test* *impression-test impression comparisons in S1*); and 2 at 200x (*total SS / number of 200x test impression-test impression comparisons in S1*), it is apparent that an absence of Schallamach as viewed at 1:1 result in low CSs but despite this, results suggest that it is possible to observe replicable correspondence at 200x.

Section 1 - Test Impression-Outsole:

Amongst all footwear replicates when comparing a test impression to the outsole, S1 was never scored a CS of ‘3’, which would indicate that the test impressions share correspondence with all features of the outsole; and S1 had the least observed Schallamach detail. Although the lower CSs within this section may be indicative due to the lack of Schallamach, a statement cannot be made regarding if these findings would be consistent amongst different wearers. Although authors have made statements regarding the areas of the outsole where RACs and Schallamach are typically found (Davis and Keeley, 2000; Kaplan-Damary et al., 2018; Kaplan-Damary et al., 2022; Speir et al., 2016), the results within this thesis have understood that with the many variables for the presence of these individualising characteristics, it is important to first conduct a validation of the impact controlled variables have on Schallamach/RAC formation before creating statements on the ‘better’ areas. Although in real criminal investigations the controlled variables may not be known, the author believes that all footwear research should consider obtaining new pairs of footwear and controlling variables such as: individuals’ gait, weight, shoe size, substrate walked upon/terrain, number of steps taken etc. and only reporting results concluding on typically populated Schallamach/RAC sections when this background information is known. Footwear specialists may refer to published footwear research when making decisions, and the author proposes that it is important to generate controlled, accurate results. Footwear specialists in practice attempt to reproduce the conditions in which the footwear mark was made; either by creating test impressions with the same as or -1/+1 of the shoe size and being a similar weight as the suspected individual to reduce the number of variables (Lancashire Constabulary, 2020). If the level of precision is used in practice, the author believes that footwear research should follow in the footsteps of this precise practice.

S1 saw a mean SS of 1.94 at 50x (*total SS / number of 50x test impression-outsole comparisons in S1*); and 2.06 at 200x (*total SS / number of 200x test impression-outsole comparisons in S1*). Like test impression-test impression comparisons, CSs are higher at 200x, suggesting that despite lower levels of Schallamach, it is possible to observe correspondence with the assistance of high magnification. Although published works discuss the replication of and appearance of Schallamach and RACs (Moorthy and Chelliah, 2013; Speir *et al.,* 2016; Richetelli *et al.,* 2017a; Richetelli *et al.,*2017b; Kaplan-Damary *et al.,* 2018; Liu *et al.,* 2019; Liu *et al.,* 2020; Wiesner *et al.,* 2020; Kaplan-Damary *et al.,* 2022; Davis and Keeley, 2000; Zhang *et al.,* 2019), this thesis has shown that even after wear, there are areas of a shoe outsole that can contact the ground and see little change in terms of wear, and CSs can be generated; therefore, it is important that future studies also consider the uniqueness of detail on shoe outsoles that have a lack of wear characteristics. Interestingly, despite less visible detail at 1:1, the use of magnification can assist with revealing replicable detail; supporting the view that microscopic examinations should be introduced in the routine examination of forensic footwear evidence to avoid missing detail and results leading to potential convictions.

5.3.1.2. Section 2

S2 was selected as it was apparent during method development that this area consistently created contact with the ground, likely due to the author's walking habits walking on the lateral toes. However, Schallamach was only apparent in FW1 L+R, despite wearing all three replicate shoes for the same length of time. The difference in Schallamach formation is likely due to the type of substrate walked upon, as FW2+3 was mainly worn indoors. With the understanding that Schallamach occurs due to abrasive wear (Davis and Keeley, 2000; Bodziak, 2017), the smooth surface present indoors likely did not cause enough abrasion to result in Schallamach patterns around the front of the toes. However, it was apparent that despite this finding, there was Schallamach within S3 and S4. Differing to S1 and S2, the stepping circle and heel area were common areas of the foot that the author scruffs across the floor during wear, resulting in Schallamach in this area despite a lack of outdoor wear. To enable a full understanding of the formation and changes of Schallamach, future authors should observe changes on different substrates and shoes to understand if there are specific variables that can alter results.

Section 2 - Test Impression-Test Impression:

Despite a difference in the appearance and formation of Schallamach across the three shoes replicates, S2 (lateral toe) had significant CSs. At 1:1 in FW1L+R and FW2L there was no observable detail, but at 50x and 200x there were consistent CSs of ‘3’. FW2R Worn saw no observable detail at 1:1, but CSs of ‘2’ were reported at 50x and 200x. FW3L+R also saw consistent CSs of ‘3’ at 50x and 200x, but it was reported that there was already visible detail at 1:1. At 1:1, the mean SS was 1; 2.83 at 50x; and 2.83 at 200x. The mean CSs indicate that 50x could be the most beneficial magnification when conducting microscopic examinations in this section. Just 33.33% of comparisons revealed visible detail at 1:1, and when using magnification, there was a 100% success rate of observable replicable detail. Further reiterating the importance microscopes can bring to footwear examinations; especially when there is no visible detail at 1:1.

Section 2 - Test Impression-Outsole:

When comparing the test impressions to the outsole, it was apparent that the most replicable detail occurred on the medial side of the pin hole in the 50x images. This is likely due to the medial side appearing closer to the border of the rectangular feature, as Schallamach has been mentioned as a micro-tear of the border of an element (Kaplan-Damary *et al.,* 2018), potentially experiencing the most abrasive wear on this edge. Despite specially examining and comparing the lateral side of the pin hole, CSs were still high within this section, with a mean CSs between test impressions to the outsole of 2.17 at 50x and 2 at 200x. Like test impression-test impression comparisons, the results indicate that 50x would be an efficient magnification when observing detail of a test impression directly to the outsole.

5.3.1.3. Section 3

Kaplan-Damary *et al.* (2022) observed the most generic RACs in the stepping circle, and although the same section was not examined in this study as their sections were not compatible with the outsole and authors walking habits, the equivalent section (section 3) in this thesis deemed to have significant results. Speir *et al.* (2019) also found the most generic RACs within the lateral section of an outsole. **Figure 83** shows an overlay of the above authors' subsections of an outsole compared to the subsections used here.

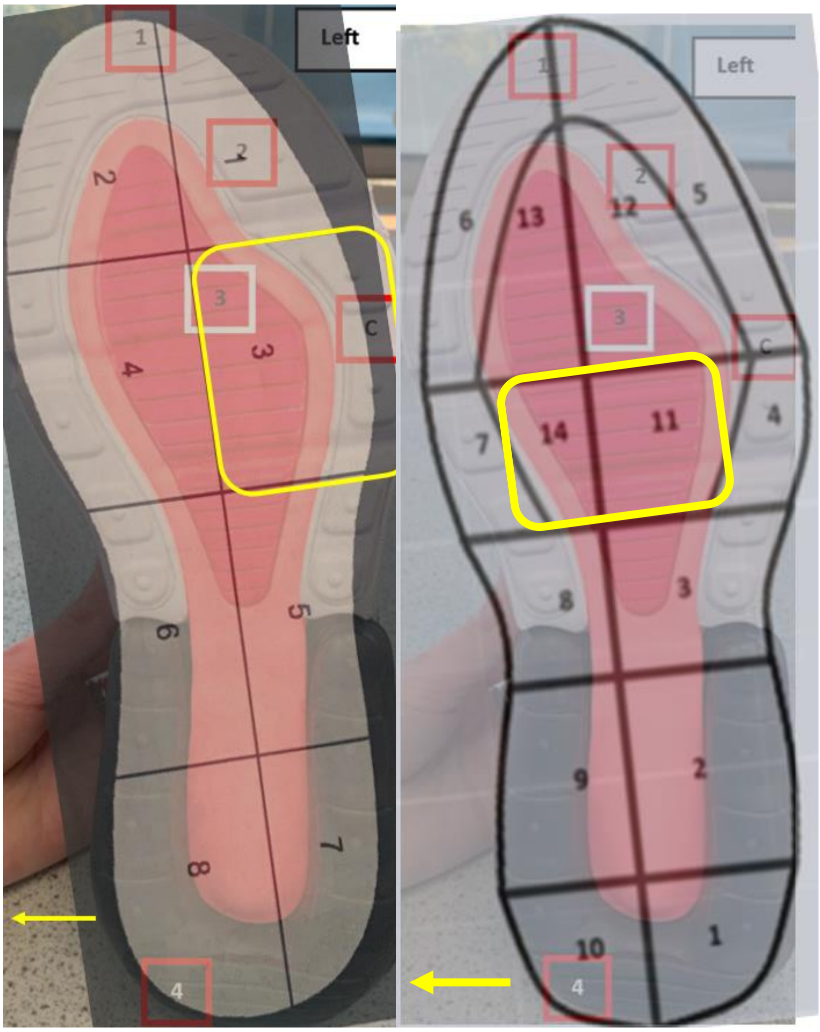


Figure 83: *The subsections of the outsole used in Speir et al. (2019) [left] and Kaplan-Damary et al. (2018) [right] adapted to black and white and transparent, overlayed with the sections of the outsole used in this thesis. Arrow = medial*

S3 on a Nike Air Max 270 is relatively flat, and it is thought that this enabled an increased level of contact with the ground at this high-pressure point location of a shoe, thus resulting in extensive Schallamach. This finding is not surprising as it has previously been mentioned that Schallamach appears on the flat part of the outsole (Smith, 2009). S3 on the Nike Air Max 270 was also pink, and this colouration assisted with the comparisons as the black static test impression provided a great contrast against the pink outsole. SWGTREAD (2005) recommend that footwear test impressions should be of good contrast to be suitable for comparisons. If the outsole to be examined does not offer different areas of colouration to allow for a contrast, the test impressions can be printed in various colours to overcome this.

Section 3 - Test Impression-Test Impression:

CSs in S3 from test impression-test impression comparisons were consistently significant; the mean SS at 1:1 was 0.5; 3 at 50x; and 3 at 200x. The differing results between S1 and S2 and S3 further supports the possibility that this is due to the extensive presence of Schallamach in this area. As Schallamach occurs due to extended abrasion to the outsole causing the molecular chains within the rubber to break (Zhang *et al.,* 2019); the extent of Schallamach within this area suggest that this is a high-contact area of the outsole and therefore, leads to higher CSs. However, it remains unknown if the results would replicate with all shoes or all wearers, as the area of prolonged ground contact on the outsole may be bespoke for everyone. Future studies should explore this area, experimenting with various variables to enable a deeper understanding of Schallamach formation and CSs. Moreover, the Schallamach seen on the static test impressions was prominent and made comparisons straight forward.

Section 3 - Test Impression-Outsole:

The mean CSs of comparisons between test impressions-outsole were 2.83 at 50x and 2.83 at 200x. Like the test impression-test impression comparisons within S3, the Schallamach stood out on the outsole, and this is likely the reason why the mean SS result was the same at 50x and 200x. The author proposes that the extent of Schallamach is paired with more disturbance to the molecular chains within the rubber, and the more disturbance leads to more prominent features; and therefore, potentially large enough to not require magnification to reach 200x. As it would not be reliable to recommend that this area would provide the same results to another person, it is reliable to recommend that areas of prominent Schallamach could result in high CSs. However, selecting this area may require interpretation into the lesser obvious outsole location, as it was found that the heel; an area that is known for the presence of Schallamach, reveals this detail at 1:1 in this area and is therefore less likely to be subject to microscopic examination.

5.3.1.4. Section 4

Davis and Keeley (2000) state there was extensive Schallamach in the heel region, and Zhang *et al.* (2021) specifically researched the replication of Schallamach within the heel. Despite Davis and Keeley (2000) not disclosing which side of the heel they saw the extensive Schallamach and Zhang *et al.* (2019) examining the lateral heel, this research compared the medial heel due to the authors walking habits and a consistent contact with the ground in this area. However, in practice the walking habits of the offender may not be known. This research has explored the replication of Schallamach and other microscopic detail between test impressions and the outsole to ultimately gain a deeper understanding on possible reasonings for successful or unsuccessful replication. It was important to select a heel area in this project as it is known that Schallamach is often found in this location (Davis and Keeley, 2000; Zhang *et al.,* 2019), and this thesis needed to obtain evidence of Schallamach within a short period of time to explore the replication. Although only 16.6% of test impressions at 1:1 did not show visible detail, there was a 100% success rate of viewing correspondence with the aid of magnification. Importantly, if a crime scene mark is only a partial footwear mark of the heel and there is no detail visible despite this area being known for extensive wear features, the use of magnification may be able to result in a successful comparison. However, future research should explore the replication of microscopic features in crime scene marks.

It was found that despite a lack of Schallamach in S1 and S2, there was extensive Schallamach in S4.

Kaplan-Damary *et al*. (2018) found “37” Schallamach at the medial heel, however, it is unknown how they successfully counted each Schallamach, and as this was not completed here, it would be unreliable to attempt to compare the findings here to their research. As Schallamach was not their sole research focus, there are no images to enable a comparison of results.

Although replicable Schallamach was present within the heel, and this has been observed by Zhang *et al.* (2019), it is known that Schallamach can quickly erase in this area due to extensive wear erasing the Schallamach (Davis and Keeley, 2000; Davis and DeHaan, 1977). Therefore, although comparisons of S4 resulted in high CSs, this detail may not replicate as well if there is a time delay between the deposition of a footwear mark and seizing the footwear that created it; further research in this area would be beneficial for forensic interpretation of this evidence. In the current study, each pair of shoes were worn for two weeks, and the test impressions were created, and the outsoles were examined immediately after wear. Davis and Keeley (2000) have previously discussed how quickly Schallamach changes and if matches can be made after wear, however, further research should expand on this and introduce high microscopy to observe if CSs can be achieved in this scenario.

Section 4 - Test Impression-Test Impression:

Due to the extent of Schallamach within S4, it was found that the Schallamach detail was pronounced in this section, and this is likely to account for observing higher CSs at 1:1. The mean SS was 2.33 at 1:1; 2.89 at 50x; and 2.92 at 200x. Although the replicable detail was visible at 1:1, the results show that the CSs increased at each magnification. Importantly, in the FW2R comparisons where there was no visible detail observed, magnification was able to increase the CSs to the maximum of ‘3’. The current practice of footwear examination would have missed this replicable detail without this method, supporting the view that magnification should be used on all footwear evidence where there is no visible detail at 1:1. Whilst completing this project, no similar studies were found regarding the use of microscopes to potentially reduce the amount of missed detail in footwear evidence. Along with the recommendation for future research from Parliament: House of Commons (2019), this research supports an urgency in developing methods to improve the science. With an increase of criminals becoming aware of the multiple forensic evidence types, it is critical that more thorough techniques are introduced to increase the potential of all forensic evidence. Although the works within this project have obtained significant results, the methodology would still require a skilled individual to accurately conduct the examinations, and due to human error, it is possible that mistakes could be made. To counter this, obtaining an International Organisation for Standardisation (ISO) accreditation to this method may help with reducing the risk of false positives to a minimum, and having formal structured policy in place can assist with how to correct mistakes.

Section 4 - Test Impression-Outsole:

As Schallamach was visible at 1:1 in all test impressions except in FW2R comparisons, the Schallamach was very prominent when viewed under magnification, and this showed in the CSs. With a mean CS of 2.78 at 50x and 2.67 at 200x, the results suggest that 50x magnification would offer higher CSs. As this detail was visible in 83.33% 1:1 test impressions, this finding is less significant. However, it reinforces that if there is no detail at 1:1, that magnification may be able to assist with obtaining CSs.

5.3.1.5. Control Area

Before the shoes were worn, a control area was selected that does not contact the ground to observe if Schallamach would appear due to Brownian motion. The following images in **Figure 84-Figure 89** show the control areas pre and post wear.

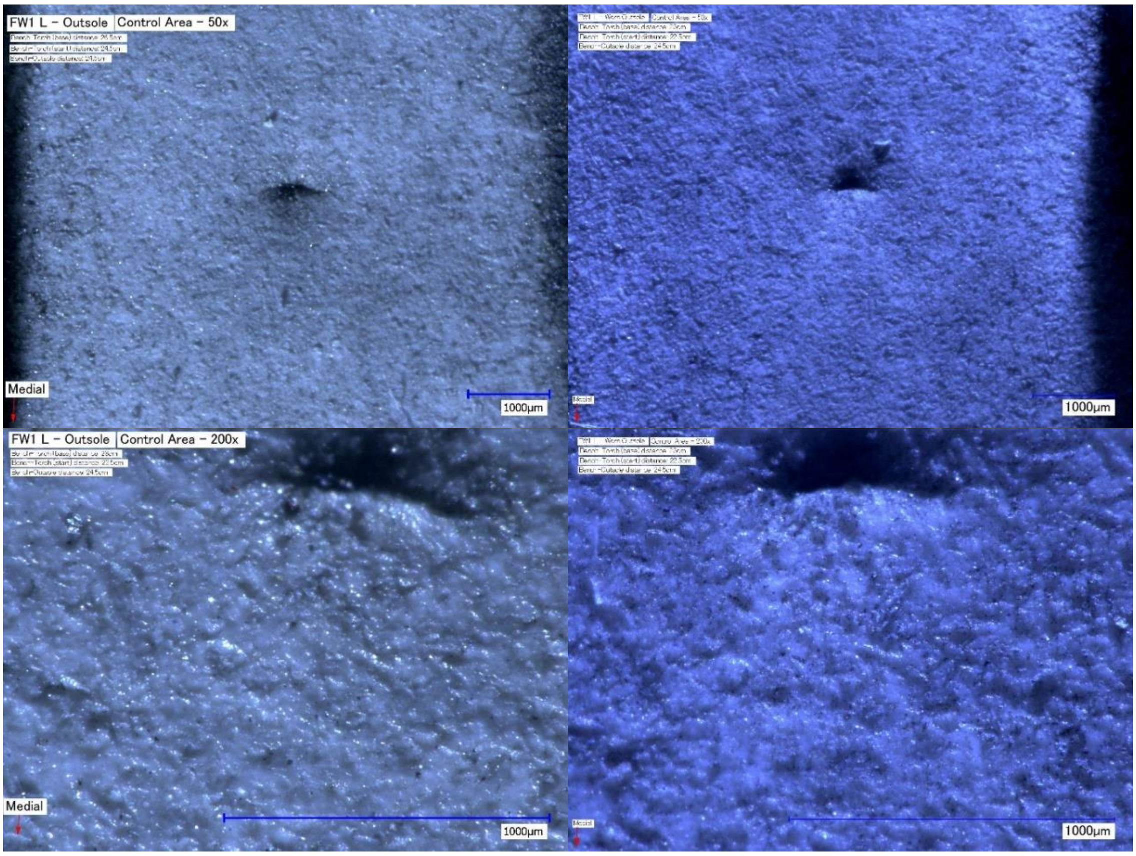


Figure 84: *FW1L control area pre-wear (left) and post wear (right) at 50x (top) and 200x (bottom)*

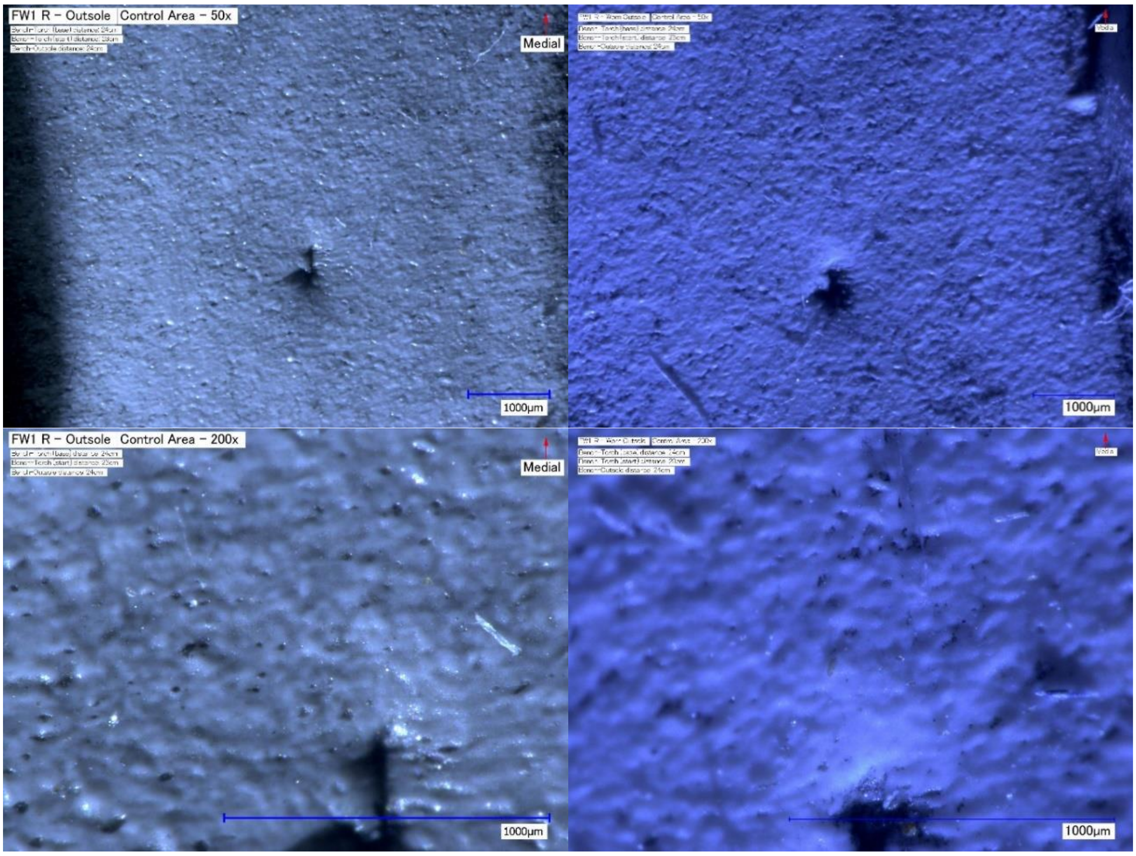


Figure 85: *FW1R control area pre-wear (left) and post wear (right) at 50x (top) and 200x (bottom)*

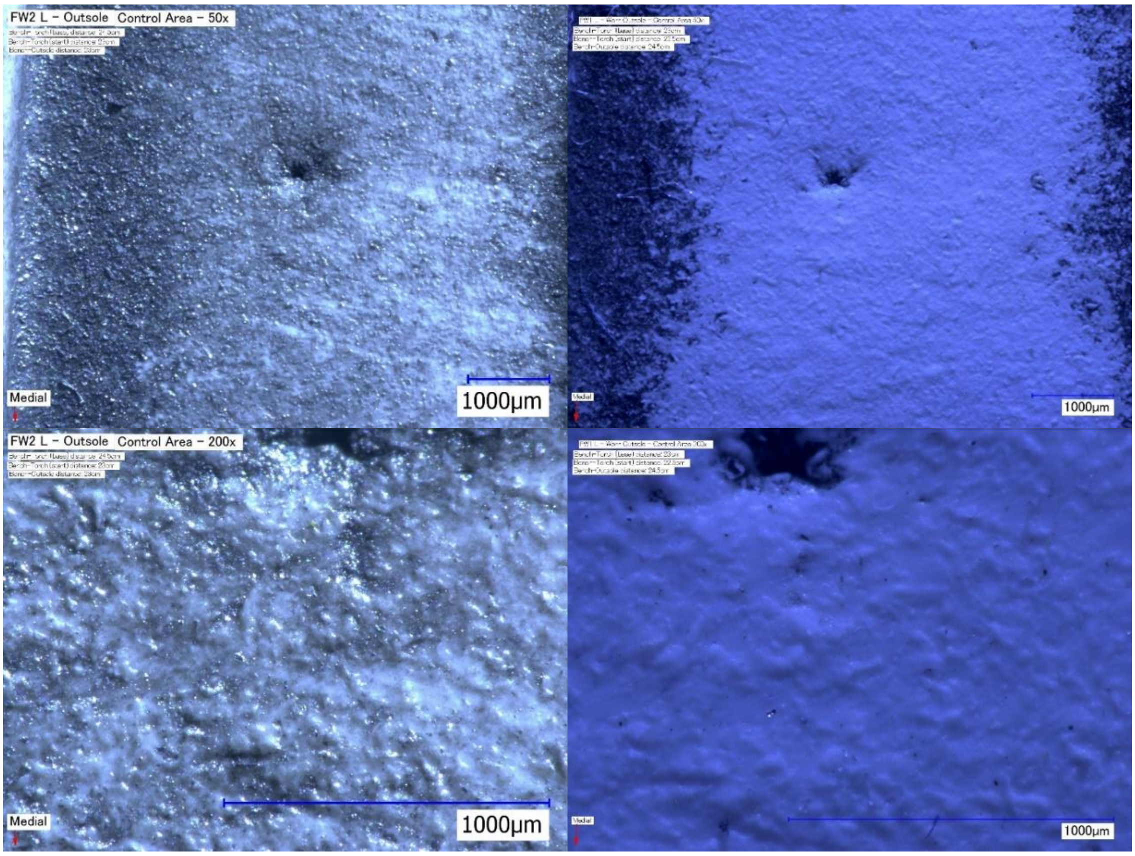


Figure 86: *FW2L control area pre-wear (left) and post wear (right) at 50x (top) and 200x (bottom)*

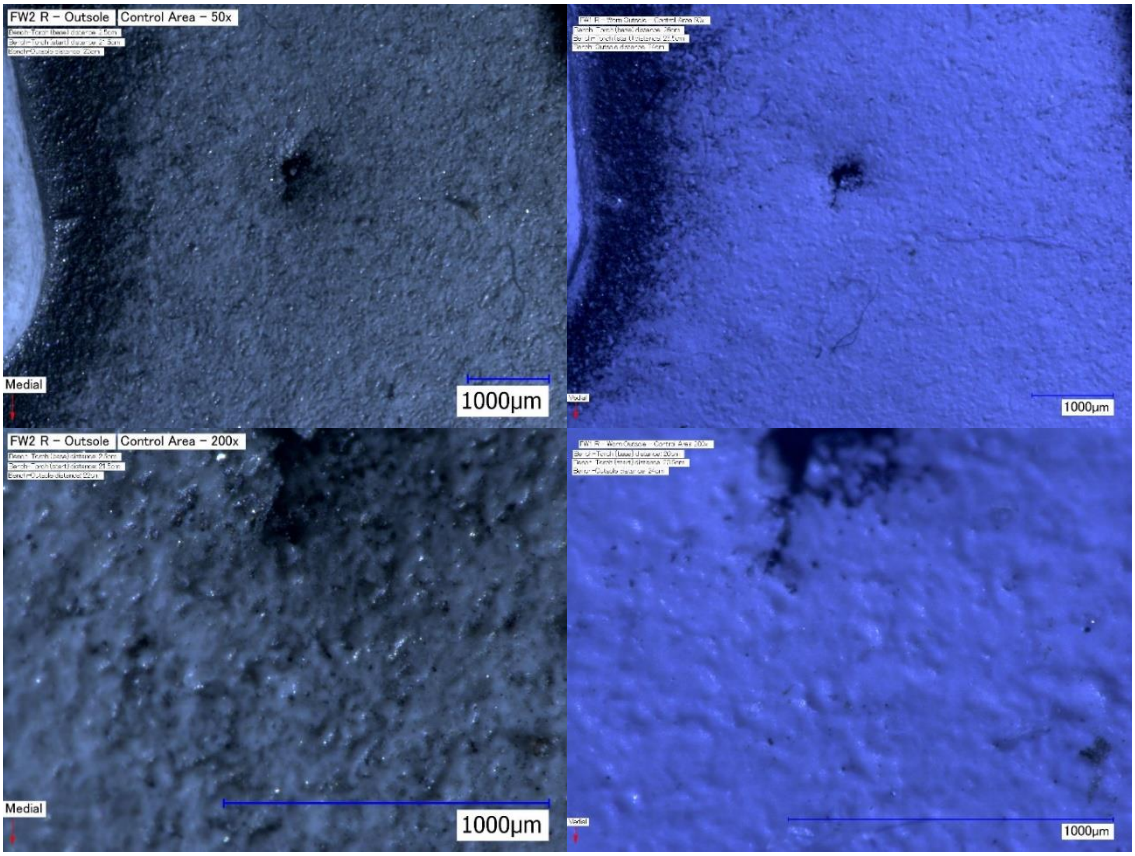


Figure 87: *FW2R control area pre-wear (left) and post wear (right) at 50x (top) and 200x (bottom)*

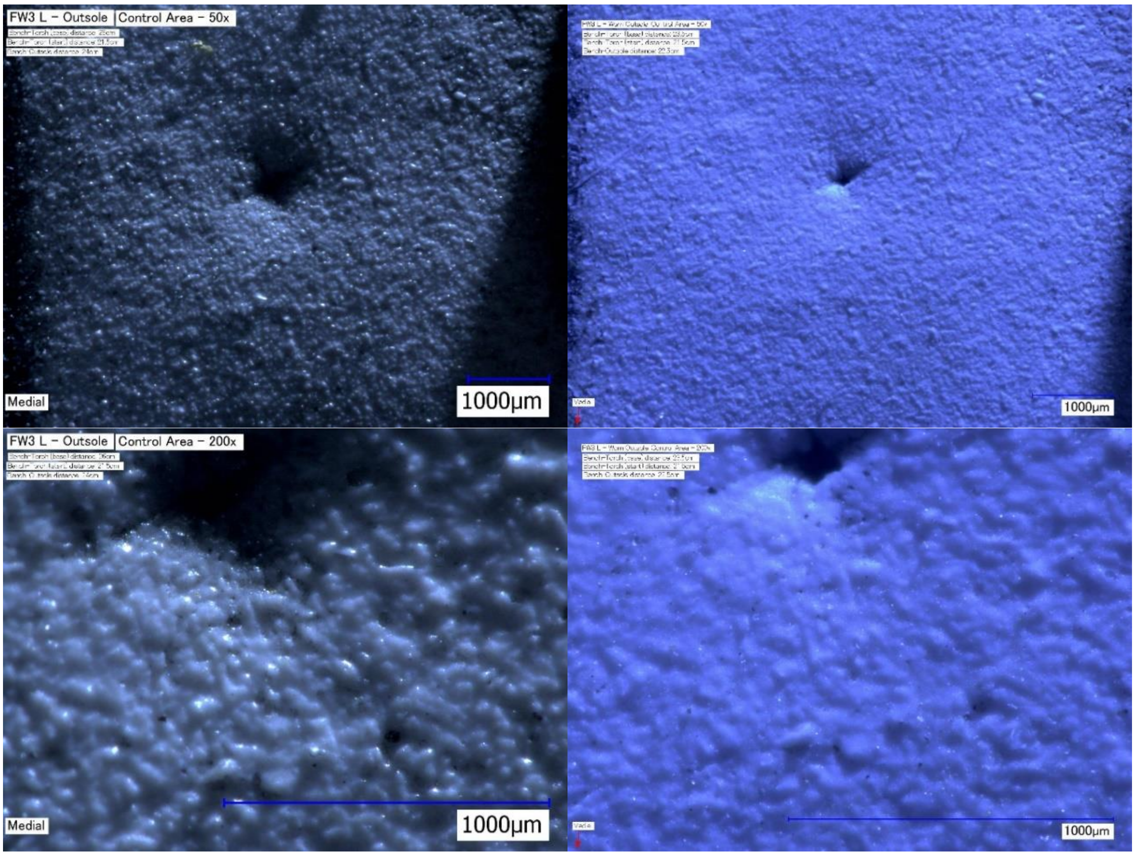


Figure 88: *FW3L control area pre-wear (left) and post wear (right) at 50x (top) and 200x (bottom)*

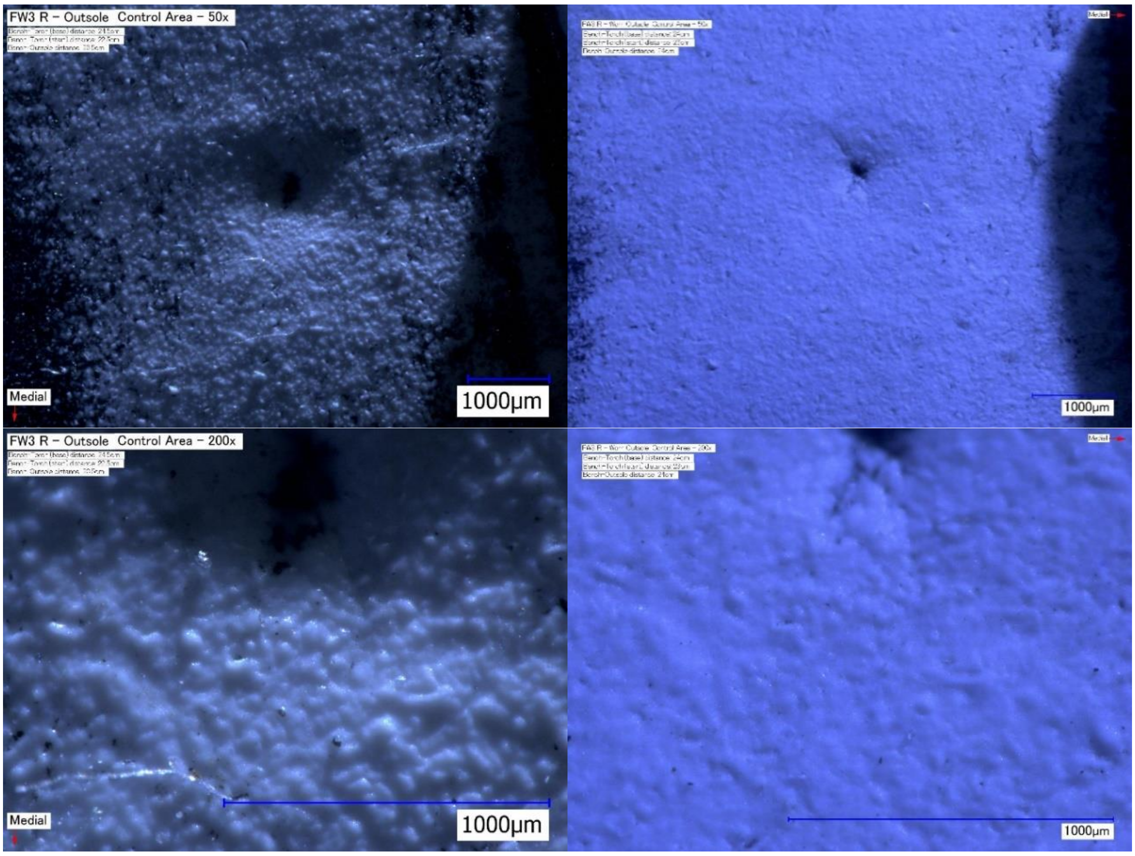


Figure 89: *FW3R control area pre-wear (left) and post wear (right) at 50x (top) and 200x (bottom)*

As shown, Schallamach was not present after wear. This is likely due to the lack of movement in this area on the centre lateral outsole, **Figure 90**. However, FW1 only endured approximately 73,206 steps; FW2 approximately 63,813 steps; and FW3 approximately 55,863 steps over the course of two weeks. Like S1, an area that did contact the ground, the lack of Schallamach within the control area is understandable. Although if Schallamach was to occur in this area, it is unknown how this detail would be used during a footwear examination. If the control area does not contact the ground, it would neither appear in a two-dimensional footwear mark; but may appear in a three-dimensional footwear mark. Future research should observe the development on Schallamach on areas of an outsole that do not contact the ground after longer intervals of wear in two- and three-dimensional footwear marks for a deeper understanding.

Figure 90: *The subsections of the outsole, with the control area highlighted by 'C'*

5.3.2. Sectional Breakdown Summary

Despite researchers suggesting that Schallamach is prominent within the toe region (Davis and Keeley, 2000), this was not found here. However, the results indicate that the outsole design is an important variable in the formation of Schallamach and needs to be considered when examiners are selecting areas to examine and interpreting observations. An understanding of these variables needs to be understood before favouring one section over another. Although the model is unknown, Davis and Keeley (2000) used Reebok shoes and as they found extensive Schallamach within the toe area, and as Schallamach is formed due to abrasive wear, it is likely that the toe section likely contacts the ground better than a Nike Air Max 270. However, this should be studied with participants of varying weights to enable a true understanding.

Despite the lack of Schallamach in S1-S2, magnification still exposed additional replicable details to enable a SS, that was not seen at 1:1. Therefore, microscopic detail that is not Schallamach could be used for comparisons during forensic examinations as this thesis has shown a positive success rate during magnified comparisons. However, future studies should explore the uniqueness of microscopic detail on the outsole to enable reliable conclusions. Although Schallamach and general wear to the outsole can appear quickly (Davis and Keeley, 2000), the shoes in this study were worn for two weeks and there were areas where Schallamach did not appear. Therefore, it is likely that a real crime could see similar findings, and it is essential to explore if these features could be unique. Although there were three identical replicates of Nike 270 in this project, the uniqueness of features cannot be explored as it is not known if the areas examined were in the *exact* location on each shoe.

S3 proved to be an excellent subsection for observations and comparisons of Schallamach with Nike 270. The contrast of colours with the pink outsole proved to be beneficial during static comparisons. The Schallamach was prominent and easy to see. More research should explore the area of the stepping circle on different shoes to allow for a deeper understanding on if this area is consistently resulting in high CSs, or if this is of particular benefit for this shoe.

As expected, S4 was an excellent area for Schallamach, supporting earlier work by Davis and Keeley (2000) and Zhang *et al.* (2019). Although this area was challenging during test impression to pre-worn outsole comparisons due to the full black outsole, there was no difficulties after wear when Schallamach developed. This is because the Schallamach was very prominent and contrast with oblique lighting was more easily observed after wear, **Figure 91**.

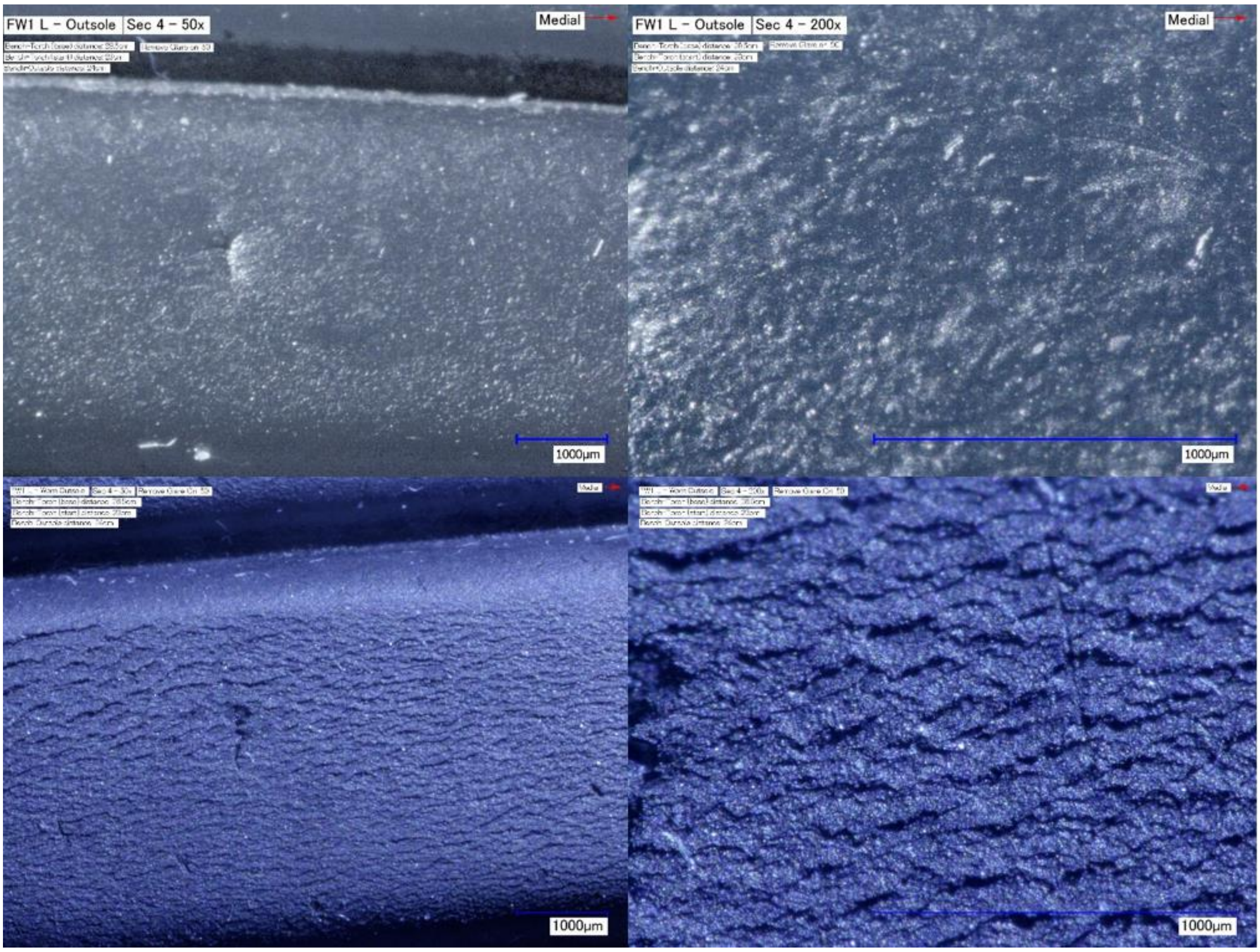


Figure 91: *FW1L pre-worn outsole (top) and worn outsole (bottom) and 50x (left) and 200x (right)*

Although this area provided excellent results, future studies need to explore if with high microscopy, are CSs still high after varying intervals of wear, due to the rate at which features within this area erase (Davis and Keeley, 2000; Davis and DeHaan, 1977).

This research has shown a differentiation of CSs between magnification when comparing test impressions-test impressions or test impressions-outsole. A summary of the best magnification based on the mean CSs in each footwear section can be found in **Table 68**.

Table 68: *A summary of the best magnification in terms of higher CSs between test impression-test impression and test impression-outsole comparisons at each section of the outsole*

Section	**Comparison Type**	
	Test Impression-Test Impression	*Test Impression-Outsole*
Sec 1	200x	200x
Sec 2	50x = 200x	50x
Sec 3	50x = 200x	50x
Sec 4	200x	50x

S2-S3 saw the same CSs at 50x as 200x, therefore, it can be concluded that 50x is a suitable limit to the magnification when conducting comparisons of this type. This is essential to know as further increasing the magnification takes time and therefore would increase costs in forensic examinations. S1 had the least Schallamach present, and in both test impression-test impression and test impression-outsole comparisons, 200x was more favoured. Consequently, it is apparent that the least Schallamach present, the higher the magnification required to obtain the higher SS.

Although a pin hole was created in the outsole to assist with the examination of the same area in the outsole and test impressions, it was found that after wear this did erode. However, with the use of oblique lighting and magnification, it was possible to observe a marking of the original pin hole. This was cross referenced with the images of the pin hole pre-wear before re-pinning each section. Like pinning the holes prior to wear, the same pin was used and inserted the same depth. However, the original marking of the pin hole may not be present if the shoes were worn for longer. Therefore, future studies may wish to create a new technique of identifying such precise and small areas successfully.

5.4. New vs. Worn Shoes

Pre-worn shoes were examined to define Schallamach, and in doing so, the research has shown in which areas Schallamach is the most extensive within a short period of time. All images of pre-wear and worn test impressions and outsoles can be viewed in the **Appendix (C. Outsole and Test Impression Images)**.

New shoes were difficult to examine microscopically as it was found that there may be a coating on the outsoles that caused the outsole to appear shiny despite utilising the 'Remove Glare' function on the Keyence. This likely effected the examinations of pre-wear test impression-outsole as it was difficult to observe small features through the distortion. However, during wear, this coating wore away and examinations post-wear were easier.

By completing the comparisons with new shoes as well as worn shoes, it became apparent that new and worn shoes may behave differently. Despite X^2 suggesting that there is a significant relationship between CSs and the scale/magnification used between all comparisons with new and pre-worn shoes, the average CS was less in pre-wear comparisons than worn comparisons. This could be due to the larger features of the pre-wear outsole distorting the static test impressions, averages of the correspondence scores can be viewed in **Table 69**.

Table 69: *The accumulation of correspondence scores with pre-wear test impression-test impression, pre-wear test impression-outsole, worn test impression-test impression, and worn test impression-outsole comparisons*

Correspondence Score	Pre-Wear Test Impression-Test Impression Comparison	Pre-Wear Test Impression-Outsole Comparison	Worn Test Impression-Test Impression Comparison	Worn Test Impression-Outsole Comparison
0	110	2	98	0
1	16	40	4	1
2	211	102	87	83
3	95	0	261	60

5.5. Limitations

There were several limitations which are essential to address if future authors wish to replicate or modify this research.

5.5.1. Microscopic Examination Lighting

The built-in microscopic light was not used during the Keyence examinations of the outsoles and instead oblique lighting was used with a LED Lenser M7R (400

Lumens) torch. However, despite maintaining the measurements of the torch and outsole placement within each section from pre and post wear, it is likely that the lighting was different depending on when the microscopic examinations were completed. This is because the Keyence microscope is situated by a window and the natural sunlight likely had an impact on the examinations, despite keeping the set-up placement and measurements consistent.

It was discussed in chapter 3.2.4. and 3.2.5. that lighting has a crucial effect on the level of detail present. Although comparisons between test impressions and the outsole could be completed, it is important to consider that a differentiation in lighting could have had an impact on CSs given. Future research should take considerations into lighting if they wish to reattempt the works within this thesis.

5.5.2. Time

Time constraints was a strict contender to the limitations; time was lost due to equipment failure which caused practical work to come to a halt. The interruption of practical work caused a domino effect of all work to be pushed back, including causing complications when wearing the shoes.

5.5.3. Wearing the Shoes:

After reviewing the literature and considering the research time constraints, it was decided to wear each pair of shoes for 2 weeks as this would be enough time for Schallamach to appear after constant wear whilst ensuring the research was completed in time. In hindsight, it would have been more efficient to calculate number of steps, and specifically dedicating the shoes to be worn outdoors. Unfortunately, this was not initially considered as the development of Schallamach was not the research focus point, and the shoes were only worn to acquire Schallamach to be used for an examination of replication. Therefore, a detailed breakdown of steps taken, and substrate walked upon was not generated. However, due to the researcher wearing an Apple Watch, an approximation of steps taken were available to view. Footwear 1 had the most Schallamach present, with an approximate 73,206 steps taken (roughly 14 hours of wear when considering 5,000 steps were taken in a one-hour period). Footwear 2 endured approximately 63,813 steps (roughly 12 hours), and Footwear 3 55,863 (approximately 11 hours).

Due to time constraints as discussed in the previous subchapter, the newly created timetable for this research project caused Footwear 1 to be examined whilst Footwear 2 was being worn, and Footwear 2 to be examined whilst Footwear 3 was being worn. This is important to note as this means that Footwear 2 and Footwear 3 were mainly worn indoors, potentially slowing down the production of Schallamach due to the smoother ground surfaces indoors. Although Footwear 2 and 3 were worn for approximately 2-3 hours less than Footwear 1, there was enough Schallamach present to analyse the replication of features. Critically, the examination of Footwear 2 and 3 revealed less Schallamach despite an approximation of 11-12 hours wear. The decline in wear can be explained by the time constraints due to pushing back practical work and mainly wearing the shoes indoors.

If future authors wish to use the data generated by this thesis, it is important to not rely on the number of steps documented here. Apple Watches may not effectively count the number of steps accurately, and there may have been days when the battery depleted or was not worn until late afternoon. Future research may find it more beneficial to allocate an alternative person aside from the author to wear the shoes to enable a deeper understanding.

5.5.4. Schallamach Formation

Importantly, this thesis does not recommend if the presence or absence of Schallamach within the sections of the outsole examined here would be the same as another study created by another person. Upon completing this research, the author has understood that Schallamach is largely dependent on many variables, such as, gait, substrate walked upon as found by Kaplan-Damary *et al.* (2018), as well as the length of time worn, and the outsole design; and these variables combined could create bespoke Schallamach patterns in various sections for different people. To be able to recommend areas for Schallamach formation, future studies need to complete a thorough research project with multiple different people with differing gaits

However, to fully understand the relationship between controlled variables and Schallamach formation, future studies should complete thorough research exploring this topic before recommending that sections of the outsole are better or worse for Schallamach formation. For example, assigning multiple groups of participants with differing gaits to wear the same brand/model of shoes and walk the same route would give a deeper understanding on potential differences of Schallamach formation. From there, the more populated Schallamach areas would be understood; importantly, all variables would be known and would therefore generate reliable and accurate results to inform future interpretation of forensic footwear evidence.

5.5.5. Sample Size

Although the sample of three Nike Air Max 270 training shoes were used in this research due to the commonality of Nike shoes and the design of the outsole having clearly defined sections, this small sample size may supply limited research of the presence/absence of replication of Schallamach or microscopic detail with other footwear types/brands. The smaller sample size was selected to initially introduce and develop a suitable methodology for examinations of this type, and a wider sample range should be considered in future research.

5.5.6. 1:1 Comparisons with The Outsole

This project did not complete comparisons of the static test impressions and the outsole at 1:1 due to the fiddly nature of this task, as discussed in chapter 3.3. Although this project has identified replicable features within test impressions that was not seen at 1:1, it is unknown if there was visible detail on the outsole itself at 1:1. However, static black test impressions have proven to be very detailed, shown in this project with high correspondence scores between the magnified test impressions and images of the magnified outsole. It is thought that if the static test impression did not reveal fine detail at 1:1, that the outsole that created the impression would also not show visible detail to compare. However, future research should explore this area with a suitable methodology to make the comparisons possible.

5.5.7. Subjective Assessment

Despite completing the comparisons at 1:1, then 50x, then 200x to avoid bias, having one person to score each comparison was an unavoidable subjective assessment; based on subjective opinion and eyesight. Unfortunately, it was not possible to receive a blind comparison from another person to observe if the same CSs would be given. However, within the Forensic Science Regulators Codes of Practice, it is a requirement to have a procedure in place to check findings are correct by conducting a blind check, for example, which involves another competent induvial to review the findings in isolation of the original opinion (Forensic Science Regulator, 2023). Having a second person review the findings is a forensic science requirement and without this stage, the results are subjective to opinion. Although the comparisons were completed twice by the author on separate occasions and the same CSs were given, this is still a subjective opinion. Therefore, the works within this thesis are acknowledged to be a limitation without implementing a checking stage by a competent individual.

5.5.8. Cost

As the works within this thesis recommends that comparisons of this type should be used in all footwear evidence, the increase of cost if this was to occur cannot be ignored. Forensic science providers are under pressure and may not have sufficient time to introduce more thorough examinations of this type. This may require hiring multiple individuals to specifically conduct the microscopic examinations and quality check findings with blind checks. With an average salary for a forensic scientist of £26,524 (Indeed, 2024) and the purchasing of specialist equipment, this could be a costly investment. However, forensic science providers should deliberate if the investment is worth having the potential of uncovering an increase of convictions or seeing a decrease of wrongful convictions due to viewing all footwear evidence in higher detail.

5.6. Suggestions for Future Research:

As this thesis identified that there is replicated detail that is not visible at 1:1 in footwear test impressions and the outsole, but is visible and replicable with microscopy, future research should focus on expanding this. Namely:

- The examination and replication of Schallamach and microscopic detail after intervals of wear to observe if it is still possible to observe replication.
    - Although a similar study was conducted by Davis and Keeley (2000), this was over 20 years ago, and it would be interesting to reattempt this with higher magnifications.
- The examination and replication of Schallamach and microscopic detail in crime scene marks created on different surfaces.
- The examination and replication of Schallamach and microscopic detail in different 3-dimensional substrates.
- The uniqueness of microscopic Schallamach.
    - Although it has briefly been stated that Schallamach is unique in published literature (Davis and Keeley, 2000; Zhang *et al.,* 2021), it would be interesting to test this further amongst a variety of different footwear brands.
- The uniqueness of non-Schallamach detail.

- The development of Schallamach on areas of the outsole that do not contact the ground.
- Assigning participants with varying weights and shoe sizes to create test impressions with the same shoe to observe if there are differences to replication.
- The formation of Schallamach on sections of the outsole with groups of participants and controlled variables.
- Compare static test impressions to the outsole at 1:1 with a suitable methodology.
- Is 50x the best magnification, could the same results be achieved with 20x and 30x?
- The use of an older Printscan pad when considering recordable fine detail in test impressions.

Moreover, during the method development stage of this project, a method of creating "highly detailed test impressions" that provides a "complete representation of the Schallamach pattern" called the roller transport film method (Bodziak, 2000: p. 353) was learnt, **Figure 92**. However, this method was not attempted within the works of this thesis as this method is rarely used as the products required are no longer available, and Bodziak (2000) proposes that there is not another method that produces similar results. The method involves applying fingerprint powder to the outsole and stepping onto a wet, and therefore softened sheet of roller transport film to create a powdered test impression, that remains permanent when the film hardens (Bodziak, 2000). It is important to mention this method, as future studies may attempt to reproduce the results of this research with a re-make of the roller transport film method and complete a validation study, comparing the results when using the static test impression method.

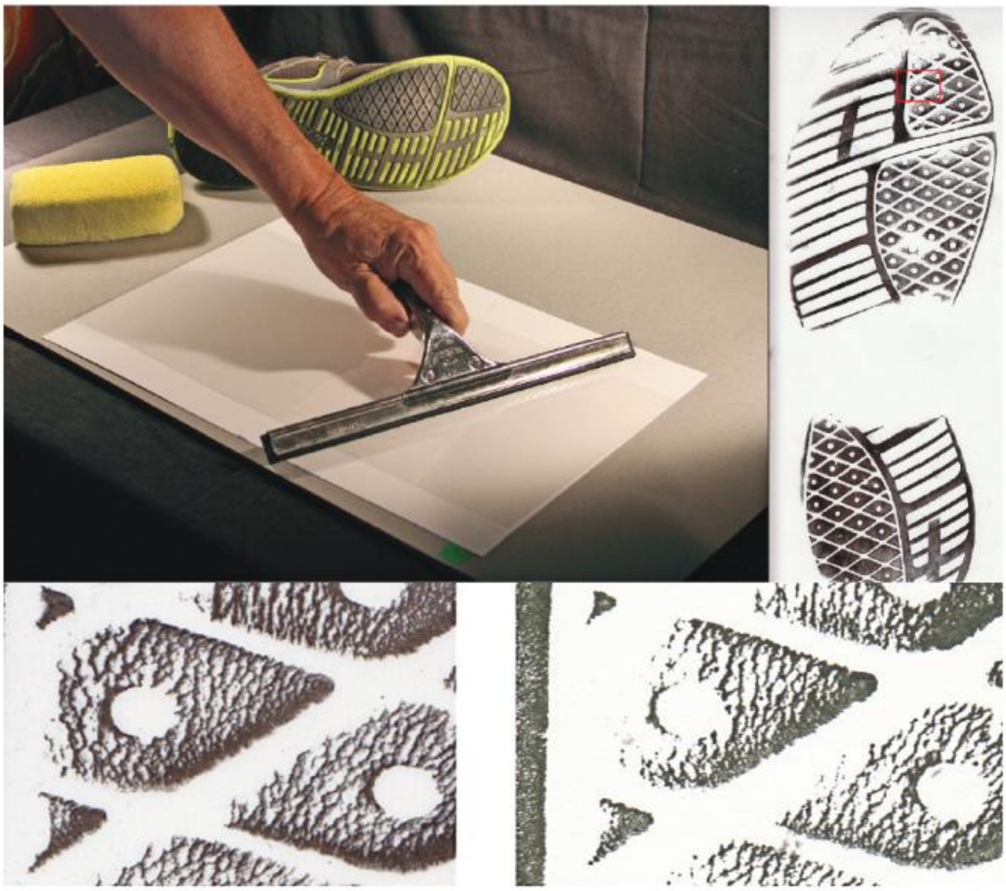


Figure 92: Roller transport film test impressions. Bottom right being the Printscan method, highlighting the differences (Bodziak, 2000)

Additionally, oil-based inked test impressions are often used in footwear casework as they provide "excellent detail and contrast" (Bodziak, 2000: p. 288). To create an inked test impression, a layer of ink is applied to the shoe with a fingerprint roller, and an adhesive lift can be placed onto the outsole, as shown in **Figure 93**, or the wearer can take several steps onto white card stock (Bodziak, 2000). However, this method was not attempted in this thesis due to the time constraints of the research. Inked impressions require 1-4 hours to dry prior to further examination, (Bodziak, 2000), and it was therefore not possible to consider this method. Moreover, the ink is often impossible to clean from the outsole (Bodziak, 2000), and there was a risk of depositing inked footwear marks on the university floors. Future studies should attempt the use of inked test impressions and compare the results when using the static test impression method.

Figure 93: *Inked test impressions created by applying an adhesive lift to the outsole (Bodziak, 2017)*

CHAPTER 6 - CONCLUSION

This thesis has addressed the following aims and objectives:

- Discussed how individualising features of footwear occur, including generic RACs (cuts and scratches) and Schallamach (abrasion pattern) and the variables that can affect the placement of features such as: an individual's gait, weight, and shoe size; the outsole design, and the substrate walked upon. However, for a complete understanding on the variables of the placement and occurrence of Schallamach and RACs, assigning groups of participants with differing weights, shoe size, and gait to walk the same route in the same brand/model of shoes to observe if there are similarities or differences in terms of Schallamach and RAC placement has been suggested for further research.

- Reviewed literature regarding the individualising features of footwear, including generic RACs and Schallamach and discussed their choice of method when creating footwear test impressions. All authors used the Handiprint/Static test impression method, and this thesis also found that this method is favourable when observing fine features, after observing a lack of detail when using dynamic test impressions (oil and magna with black and red fluorescence, and Printscan).

- Obtained three pairs of Nike Air Max 270 and successfully identified that there are additional features that can only be seen with microscopy when considering examining a static test impression at 1:1 and comparing the test impressions and the outsoles with 50x and 200x magnification.

- Explored that the microscopic features seen within static test impressions replicate the outsole at 50x and 200x magnification, despite viewing no replicable detail in test impressions at 1:1.

- Reported results by a combination of figures, showing examples of the microscopic detail and areas of a poor-quality test impression; tables, showing the CSs assigned to each comparison and the X^2 results; and statistics, using X^2 to understand if the results have or do not have a significant relationship to observe if there is a more preferred magnification when using the method.

This thesis set out and answered the following research questions:

- “Should footwear examiners routinely use microscopy in footwear comparisons?”
    - Currently, forensic examiners are only known to enlarge footwear evidence if they observe detail visible at 1:1. However, it was found that even when there is no observable detail at 1:1, there is replicable detail seen using microscopy at 50x and 200x that consistently repeats in multiple static, black powdered test impressions created from the same shoe and the outsole itself. Without the use of high-powered microscopy, this detail would have been missed, and therefore, the works within this thesis support the use of microscopy when there is no visible detail at 1:1.

- “Is there a favoured method of creating test impressions when considering the consistent replication of Schallamach and/or other microscopic detail”
    - After trialling dynamic test impressions (black and red fluorescence powder, and Printscan), these methods were discontinued as there was no recorded fine detail to be used during comparisons. The works within this thesis support the use of static test impressions when observing fine replicable detail from the outsole.

- “Does detail revealed under magnification consistently replicate between test impressions?”
    - Amongst three replicate test impressions from each of the three pairs of shoes, it was found that the microscopic detail does consistently replicate between test impressions. However, future research should consider if this is true with a variety of different footwear brands.

- “Is there a limit to the magnification when examining Schallamach and/or other microscopic detail in footwear evidence?”
    - When considering correspondence scores, overall scores indicated that 50x could be a preferable magnification as opposed to 200x. Comparisons at 200x took more time, likely due to a magnification effect as reaching a magnification of 200x was found to be disorientating. However, it was found that a poor-quality test impression may need the assistance of 200x to view the features in higher detail.

- “What are the benefits of using a microscope during forensic footwear examinations?”
    - By comparing test impressions at 1:1 and test impressions and the outsole at 50x and 200x, there is detail that is not visible at 1:1 and required microscopy to reveal it. The use of microscopy has successfully proved that microscopes are a requirement when it is thought that there is no detail. This observation has the potential to significantly change the way that footwear evidence is examined and may see an increase in matches for footwear evidence due to viewing replication under magnification. The examination of evidence using microscopy is well established in other areas of forensic investigation; the findings of this thesis provide support for the view that microscopy should also be a routine and important part of the forensic footwear examination process through X^2 tests.

Along with the suggestions for further research, this topic area has the potential to prove that action must be taken to introduce microscopy to all footwear evidence with a lack of visible detail at 1:1. Although the works within this thesis have been successful, mistakes could be made without fine-tuning the method prior to use within forensic science institutions. To overcome this, an ISO accreditation and clear Standing Operating Procedures could assist with implementing a robust method whilst having a system in place to correct mistakes. However, the implementation of this method could see a rise in costs with the purchase of new equipment and/or by hiring additional competent staff. It would need to be discussed if spending additional time and resources into this method would be worth obtaining a thorough result. Ultimately, if forensic science providers introduce microscopy on footwear evidence going forward, would there be an increase of successful convictions? The author proposes that if microscopy is introduced to footwear evidence, that there would be more confidence when making statements concluding if the suspected shoe did or did not create the questioned footwear mark.

REFERENCE LIST

Agarwal, R and Chang, A (2022) ‘Forensic Applications of Comparison Microscope*’,* in Shukla, R.K., Kapoor, N., Badiye, A. (ed.) *Forensic Microscopy: Truth Under the* Lenses. Boca Raton: CRC Press. pp. 191-200

ASB (2019) *ANSI/ASB Best practice recommendation 021, First Edition: Best practices for the preparation of test impressions from footwear and tires.* Available at: https://www.aafs.org/sites/default/files/media/documents/021_BPR_e1.pdf (Accessed: May 2024)

Baines, A. (2022) Conversations with Adam Baines, 21 November

Baines, A. (2024) Conversations with Adam Baines, 7 May

Baldwin, D., Birkett, J., Facey, O., Rabey, G. (2013) *The Forensic Examination and Interpretation of Tool Marks. West Sussex:* John Wiley & Sons.

Beauregard, E and Bouchard, M. (2010) ‘Cleaning up your act: Forensic awareness as a detection avoidance strategy’, *Journal of Criminal Justice*, 38(6), pp. 1160-1166

Bhandari, P. (2023) *Descriptive Statistics: Definitions, Types, Examples*. Available at: https://www.scribbr.com/statistics/descriptive-statistics/ (Accessed: May 2024)

Bisbing R. (2006) ‘Trace evidence in the real crime laboratory’, in Mozayani, A and Noziglia, C. (ed.) *The Forensic Laboratory Handbook: Procedures and Practice.* Totowa: Humana Press Inc, pp 265-290.

Bodziak, W.J. (2000) *Footwear Impression Evidence: Detection, Recovery, and Examination.* Second Edition. Florida: CRC Press.

Bodziak, W.J. (2017) *Forensic Footwear Evidence*. Florida: CRC Press

Budka, M., Ashraf, A.W.U., Bennett, M., Neville, S., Mackrill, A. (2021) 'Deep multilabel CNN for forensic footwear impression descriptor identification', *Applied Soft Computing,* 109, 107496.

Cassidy, M.J. (1980) *Footwear Identification*. Canada: Public Relations Branch of the Royal Canadian Mounted Police

Cellmark. (2021) *Forensic Footwear Analysis.* Available at: https://www.cellmarkforensics.co.uk/services/forensic-casework/footwear/ (Accessed: 01/06/2024)

Davis, R.J., and DeHaan, J.D. (1977) 'A survey of men's footwear', *Journal of the Forensic Science Society*, 17(4), p. 271-285.

Davis, R.J., and Keeley, A. (2000) 'Feathering of footwear', *Science & Justice*, 40(4), pp. 273-276

Douglass, E and Miller, C. (2015) *How does pronation affect running? Practically Science. Available at:* https://www.practicallyscience.com/what-is-foot-pronation-and-why-does-it-matter/ (Accessed: 30 April 2024)

Forensic Science Regulator (2023) Code of Practice, Version 1, Crown Copyright. Available at https://assets.publishing.service.gov.uk/media/64da431cc8dee4000d7f1c1e/FINAL_2023.1.18_Code_of_Practice.pdf (Accessed: 15 May 2024)

Hemler, S.L., Sider, J.R., Redfern, M.S., Beschorner, K.E. (2021) 'Gait kinetics impact shoe tread wear rate', *Gait & Posture*, 86, pp. 157-161.

Houck, M.M., and Siegel, J.A. (2015) *Fundamentals of Forensic Science*, Third Edition, Nikki Levy: United Kingdom.

Indeed (2024) *Forensic scientist salary in the United Kingdom.* Available at: https://uk.indeed.com/career/forensic-scientist/salaries (Accessed: May 2024)

Kaplan-Damary, N., Mandel, M., Wiesner, S., Yekutieli, Y., Shor, Y., Spiegelman, C. (2018) 'Dependence among randomly acquired characteristics on shoeprints and their features', *Forensic Science International*, 283, p. 173-179.

Kaplan-Damary, N., Mandel, M., Yekutieli, Y., Shor, Y., Wiesner, S. (2022), 'Location distribution of randomly acquired characteristics on a shoe sole', *Journal of Forensic Sciences,* 67(5), p. 1801-1809

Keyence (2022) Digital Microscope: VHX-7000 Series. Available at: https://www.keyence.co.uk/products/microscope/digital-microscope/vhx-7000/ (Accessed: 04/11/2022)

Kortylewski, A., Albrecht, T., Vetter, T. (2015). Unsupervised Footwear Impression Analysis and Retrieval from Crime Scene Data. In: Jawahar, C., Shan, S. (eds) Computer Vision - ACCV 2014 Workshops. ACCV 2014. Lecture Notes in Computer Science, 9008. Springer: Cham. https://doi.org/10.1007/978-3-319-16628-5_46

Kumar, K and Sharma, P. (2022) 'Forensic Applications of Comparison Microscope*',* in Shukla, R.K., Kapoor, N., Badiye, A. (ed.) *Forensic Microscopy: Truth Under the* Lenses. Boca Raton: CRC Press. pp. 117-122

Lancashire Constabulary (2020) *Scientific Support Department Quality Management System: Footwear Mark Comparisons*

Larsen, H.J and Bennett, M.R (2021) 'Recovery of 3D footwear impressions using a range of different techniques', *Journal of Forensic Sciences,* 66(3), pp. 1056-1064.

Liu, L., Wang, W., Luo, Y. (2019) 'Foreign object held in recessed areas of a shoe outsole as an acquired characteristic in footwear examination: A preliminary study', *Forensic Science International,* 304, pp. 1-10

Liu, L., Wu, J., Luo, Y., Lin, S. (2020) 'Reproducibility of artificial cut on heel area of rubber outsole', *Journal of Forensic Sciences*, 65(1), pp. 229-237

Locard, E. (1920) *Criminal investigation and scientific methods.* E Flammarion: Paris

Moorthy, N.T., and Chelliah, S. (2013) 'Study on stability of individualising characteristics on footwear impression as aging of footwear for forensic investigation', *Journal for Bloomers of Research*, 6(1), pp. 757-763

Naples, V and Miller, S. (2004) ‘Making tracks: The forensic analysis of footprints and footwear impressions’, *The Anatomical Record*, 279(1), pp. 9-15

National Policing Improvement Agency. (2009). *Footwear Marks Recovery* Manual. Available at: https://library.college.police.uk/docs/appref/NPIA-(2007)-Footwear-Marks-Recovery-Manual.pdf (Accessed: 01/06/2024)

Parliament. House of Lords (2019) Science and Technology Select Committee. *Forensic Science and the criminal justice system: a blueprint for change* (333). Available at: https://publications.parliament.uk/pa/ld201719/ldselect/ldsctech/333/33302.htm (Accessed: 31/05/2024)

Pavlou, M and Allinson, N.M. (2009) ‘Automated encoding of footwear patterns for fast indexing’, *Image and Vision Computing,* 27(4), pp. 402-409.

'R v T' (2010) England and Wales Court of Appeal (Criminal Division), EWCA Crim 2439. *Westlaw*. Available at: https://uk.westlaw.com/Document/IA61097E033D911E08E6E960452C500D3/View/FullText.html (Accessed: 14/10/2024).

Richetelli, N., Lee, M.C., Lasky, C.A., Gump, M.E., Speir, J.A. (2017b) ‘Classification of footwear outsole patterns using Fourier transform and local interest points’, *Forensic Science International,* 275, p. 102-109.

Richetelli, N., Nobel, M., Bodziak, W.J., Speir., J.A. (2017a) ‘Quantitative assessment of similarity between randomly acquired characteristics on high quality exemplars and crime scene impressions via analysis of feature size and shape’, *Forensic Science International*, 270, pp. 211-222.

Right-Light (2024) *LED Lenser M7R Rechargeable Torch (400 Lumens).* Available at: https://www.right-light.co.uk/products/led-lenser-m7r-rechargeable-led-torch-400-lumens?variant=34808258461845 Accessed: (February 2024)

Saadat, S., Pandeym G., Tharmavaram, M. (2020) ‘Microscopy for forensic investigations’, in Rawtani, D., Hussain, C.M (ed.) *Technology in Forensic Science: Sampling, Analysis, Data and Regulations.* Boschstr: Wiley, pp. 101-127

Shor, Y., Wiesner, S., Tsach, T., Gurel, R., Yekutieli, Y. (2018) 'Inherent Variation in Multiple Shoe-Sole Test Impressions', *Forensic Science International,* 285, pp. 189-203.

Smith, M.B. (2009) 'The Forensic Analysis of Footwear Impression Evidence', *Forensic Science Communications,* 11(3)

Smith, P (2024) *Global sales of the top performance apparel, accessories, and footwear companies 2023*. Available at: https://www.statista.com/statistics/900271/leading-sportswear-and-performance-wear-companies-by-sales-worldwide/ (Accessed: 28th May 2024)

Speir, J.A., Richetelli, N., Fagert, M., Hite, M., Bodziak, W.J. (2016) 'Quantifying randomly acquired characteristics on outsoles in terms of shape and position', *Forensic Science International*, 266, p. 399-411.

Speir, J.A., Richetelli, N., Hammer, L. (2020) 'Forensic footwear reliability: Part 1 – Participant demographics and examiner agreement', *Journal of Forensic Sciences*, 65(6), pp. 1852-1870

Srihari, S. (2010) *Analysis of Footwear Impression Evidence*. Available at: https://www.ojp.gov/pdffiles1/nij/grants/233981.pdf (Accessed: 1/6/2024)

Srihari, S and Tang, Y. (2014) 'Computational Methods for the Analysis of Footwear Impression Evidence', In Muda, A., Choo Y.H., Abraham, A., Srihari, S.N. (ed.) *Computational Intelligence in Digital Forensics: Forensic Investigation and Applications.* London: Springer, pp. 333-383.

Stoney, D.A., Bowen, A.M., Ausdemore, M.A., Stoney, P.L., Neumann, C., Stoney F.P. (2019) 'Differential analysis of very small particles (VSP) from the contact surfaces and recessed areas of footwear', *Forensic Science International,* 298, pp. 106-114.

Stoney, D.A., Bowen, A.M., Stoney, P.L. (2016) 'Loss and replacement of small particles on the contact surfaces of footwear during successive exposures', *Forensic Science International,* 269, pp. 78-88.

SWGTREAD (2005) *Guide for the preparation of test impression from footwear and tires (03/2005).* Available at: swgtread_05_test_impressions_200503.pdf (treadforensics.com) (Accessed: 01/06/2024)

Tuthill, H. (1994) *Individualization: Principles and Procedures in Criminalistics.* Second Edition. Salem: Lightning Powder Company

Verma, S.K., Zhao, Z., Courtney T.K., Chang, W.R., Lombardi, D.A., Huang, Y.H., Brennan, M.J., Perry, M.J. (2014) ‘Duration of slip-resistant shoe usage and the rate of slipping in limited-service restaurants: results from a prospective and crossover study’, *Ergonomics,* 57(12), pp. 1919-192

Virtanen, V., Korpelainen, H., Kostamo, K. (2007) ‘Forensic botany: Usability of bryophyte material in forensic studies’, *Forensic Science International,* 172(2-3), pp. 161-163.

Wiesner, S., Shor, Y., Tsach, T., Kaplan-Damary, N., Yukutieli, Y. (2020) ‘Dataset of digitalised RACs and their rarity score analysis for strengthening shoeprint evidence, *Journal of Forensic Sciences,* 65(3), pp. 762-774

Williams, C. (2009) *Physical Evidence’,* in Sutton, R., Truman, K. (ed.) *Crime Scene Management: Scene Specific Methods.* West Sussex: Wiley. pp. 181-208

Yekutieli, Y., Shor, Y., Wiesner, S., Tsach, T. (2016) ‘Expert assisting computerized system for evaluating the degree of certainty in 2D shoeprints: Final technical report’, NIJ Task Plan 3211.

Zhang, H.E., Liu, L., Quan, Y., Lou, Y. (2021) ‘The specificity and reproducibility of general Schallamach pattern on heel part of rubber outsole’, *Journal of Forensic Sciences*, 66(5), pp. 1937-1947

APPENDIX

A. Resources

To achieve a repeatable method, an equipment list is essential. The required equipment are as follows:

- Footwear.
    - For use during the observations.
- Keyence microscope.
    - To use during the microscopic examination.
- Torch.
    - For oblique lighting during the examinations.
- Tape measure.
    - For use during the microscopic examinations.
- Clamp.
    - To secure the shoe during the microscopic examination.
- Universal Serial bus (USB).
    - For storing images captured with the microscope.
- Gloves.
    - To be worn during the handling of powders.
- Magnetic wand.
    - For use during the dynamic oil and magna test impressions.
- Hairspray.
    - For use during the dynamic oil and magna test impressions.

- Jet black magnetic powder.
    - For use when creating the dynamic oil and magna test impressions.
- Red fluorescence magnetic powder.
    - For use when creating the dynamic oil and magna test impressions.
- Plain white A4 Xerox Colotech+ Coated paper.
    - For use when creating the dynamic oil and magna test impressions.
- Latent black powder.
    - For use when creating the static test impressions.
- Roller.
    - For use when creating the static test impressions.
- Clear acetate.
    - For use when creating the static test impressions.
- Avery Dennison lifters.
    - For use when creating the static test impressions.
- Animal-hair brush.
    - For use when creating the static test impressions.
- Zephar brush.
    - For use when creating the static test impressions.
- Fume cupboard.
    - For use when creating the static test impressions.
- Shoeprint inkless coater.
    - For use when creating the Printscans.
- Shoeprint inkless system (papers).

- For use when creating the Printscans.

B. Test Impressions

B.1. Method of Dynamic Test Impression Preparation:

1. Whilst wearing the shoes, step onto an oiled pad, ensuring the entire outsole is covered. See **Figure 94**.

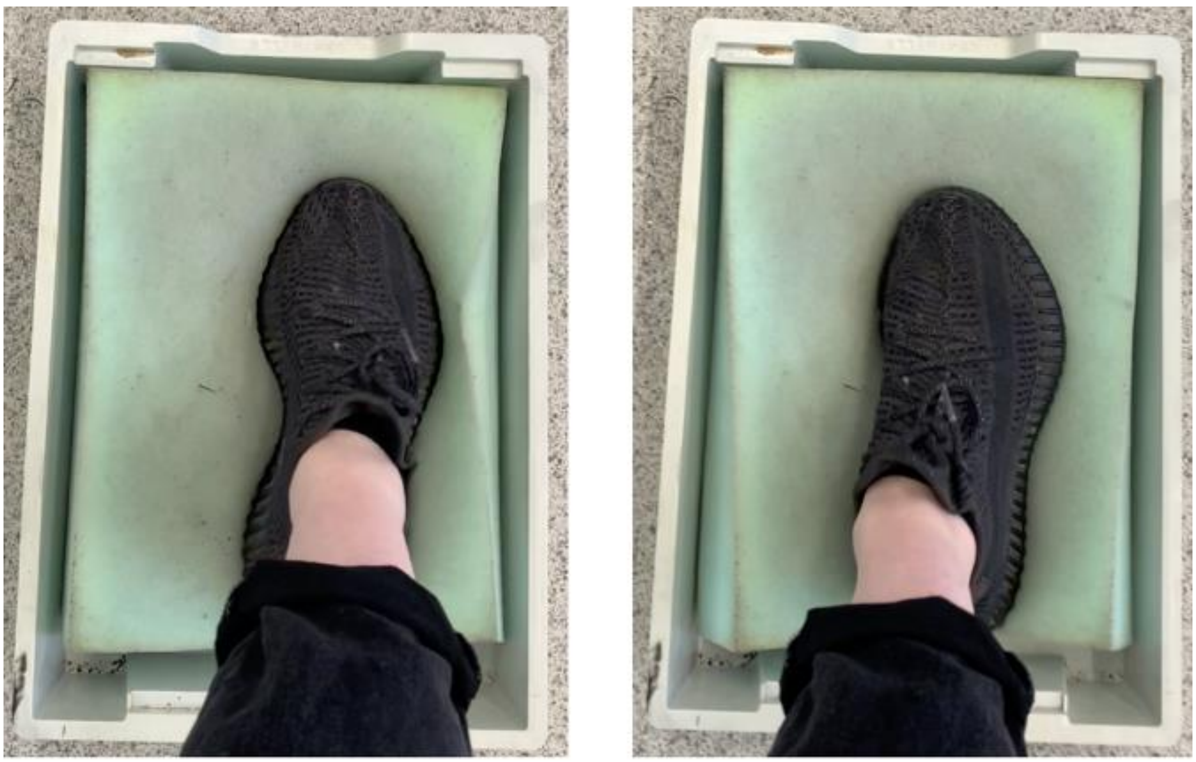


Figure 94: *An image to show the process of oiling footwear outsoles for dynamic test impressions*

2. Step from heel to toe onto a sheet of Plain white A4 Xerox Colotech+ Coated paper diagonally to ensure the entire shoe fits onto the paper. Immediately step off the paper, as if walking. See **Figure 95**.

Figure 95: *An image to show the process of footwear placement during oil and magna test impression creation. Starting with the heel (left) and shifting the weight to the toes (right)*

3. Using a magnetic wand, add one application of magnetic powder (black or red fluorescence) onto the oiled footwear impression, release the powder by pulling the lever. See **Figure 96**.

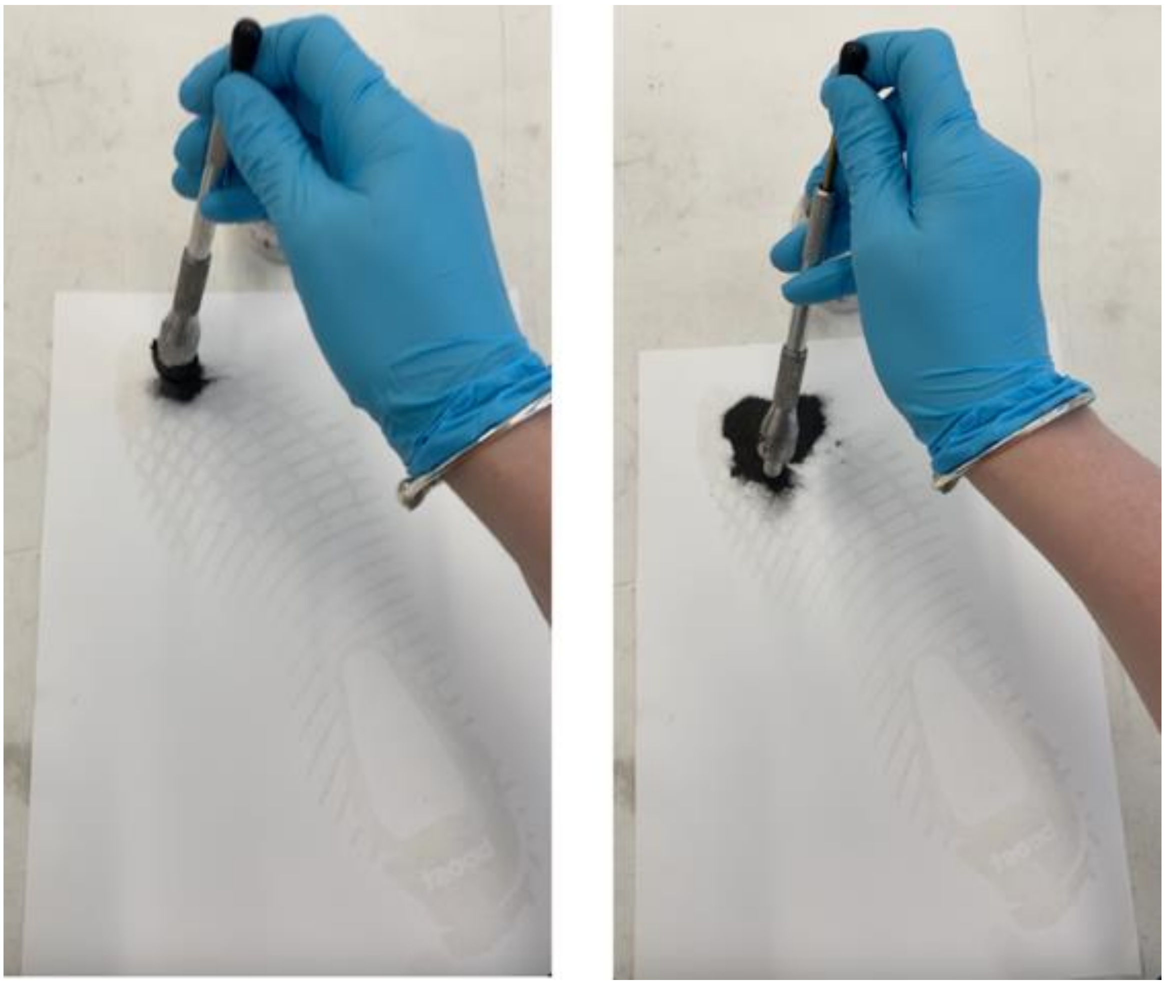


Figure 96: *An image to show the application of black magnetic powder (left) and release by pulling the leaver (right)*

4. Apply a second application of magnetic powder without releasing the powder. Begin to slowly rub over the impression, without making contact between the magnetic wand and the paper. See **Figure 97**.

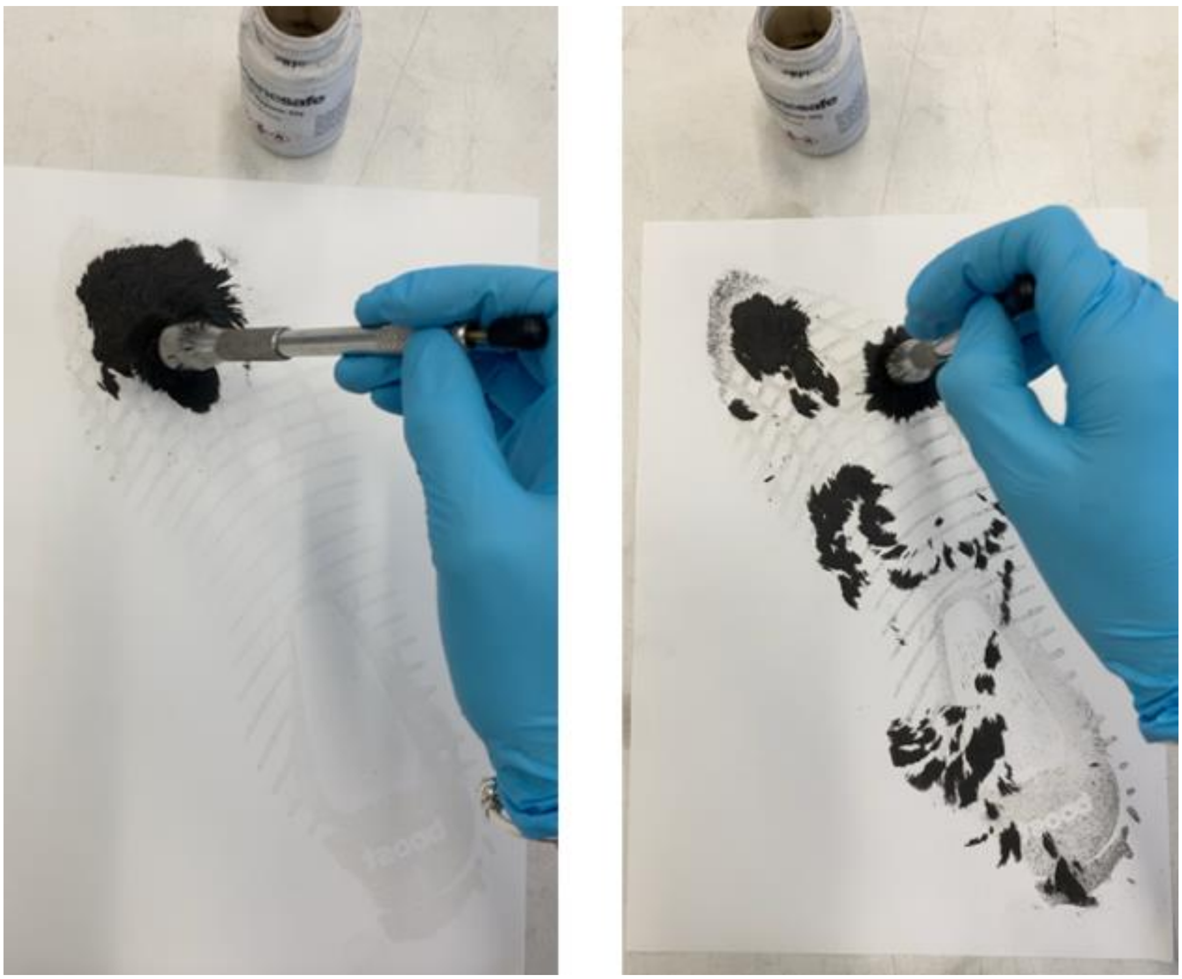


Figure 97: *An image to show the application of black magnetic powder (left) and the process of rubbing the powder over the impression (right)*

5. Once the footwear impression is enhanced, begin to remove the excess powder by hovering the magnetic wand over the impression and releasing the collected powder into the pot. See **Figure 98**.

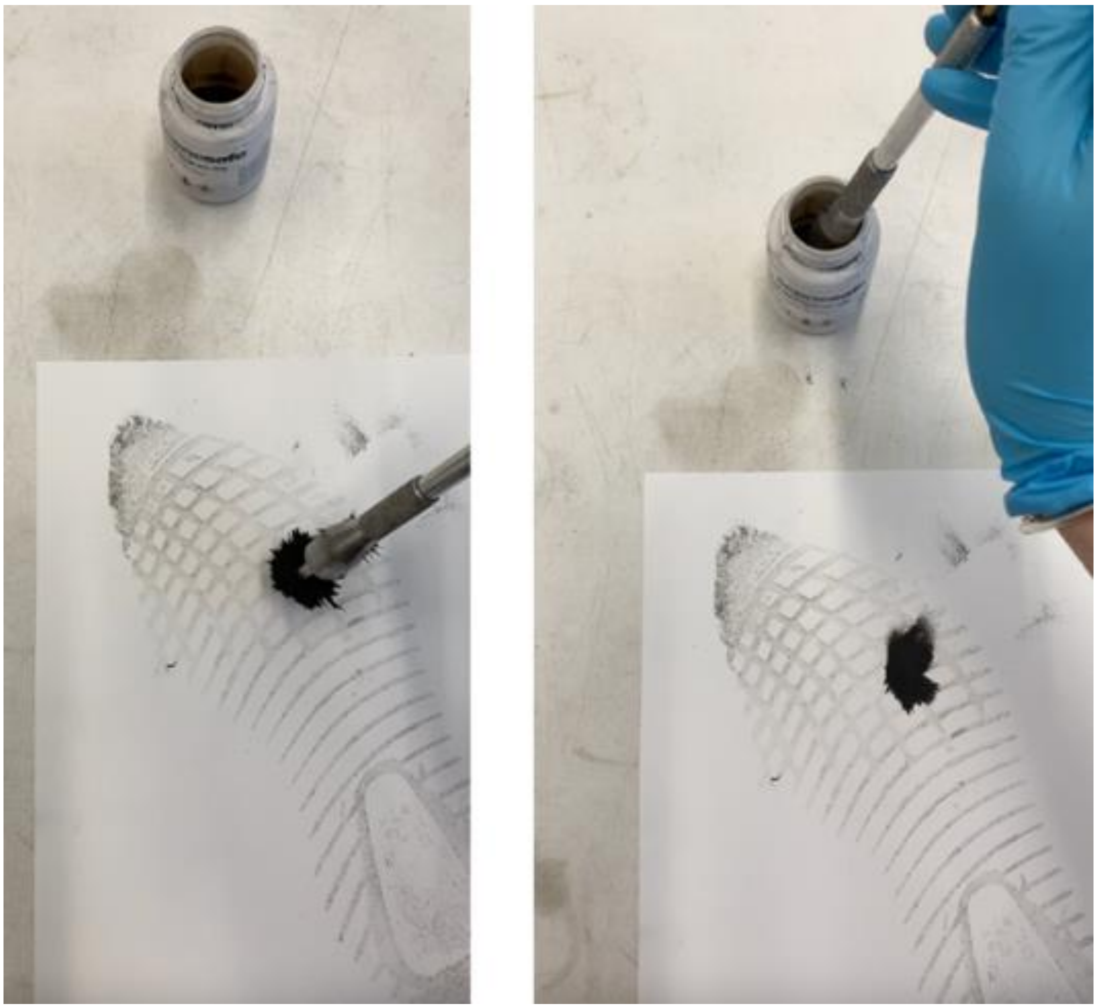


Figure 98: *An image to show the removal of excess black magnetic powder (left) and adding this back into the pot by pulling the lever (right)*

6. Finally, seal the footwear impression with hairspray. See **Figure 99**

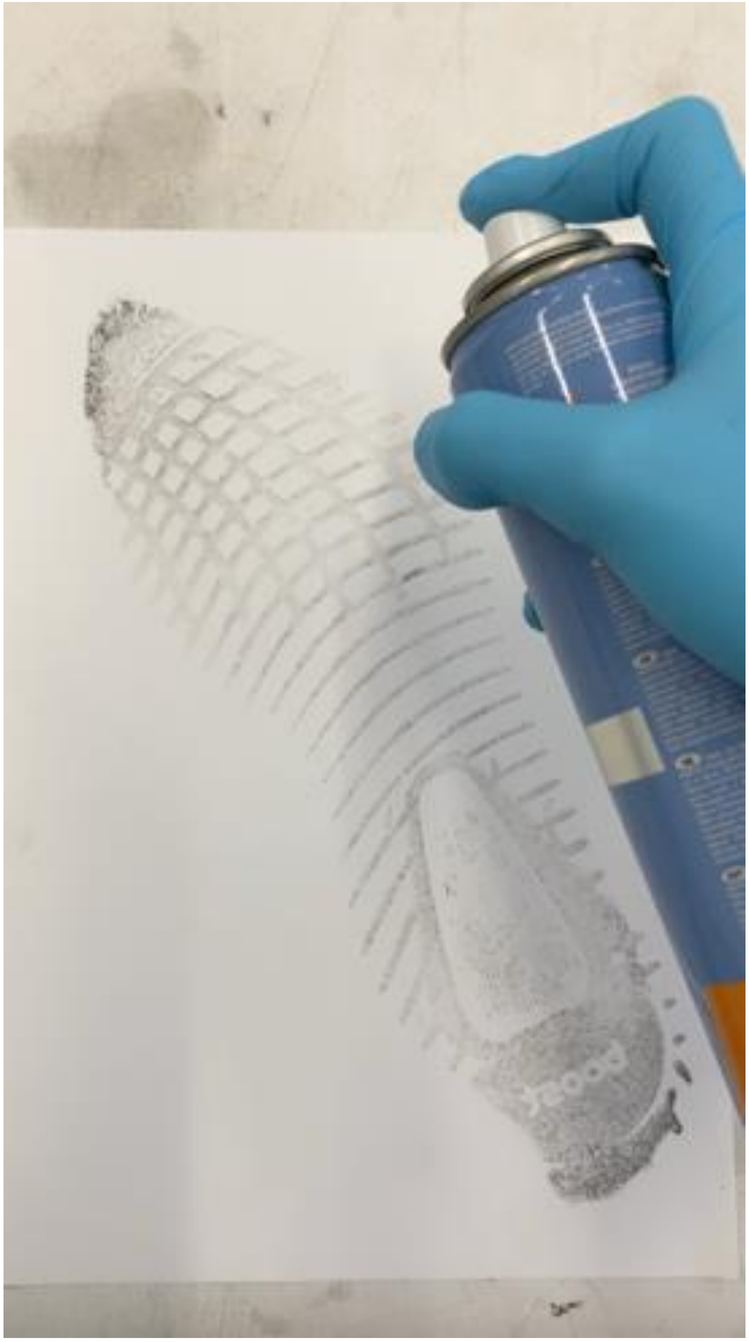


Figure 99: *An image to show the application of hairspray*

B.2. Method of Static Test Impression Creation:

1. In a fume cupboard, dip the animal-hair brush into the powder and tap off the excess.

See **Figure 100**.

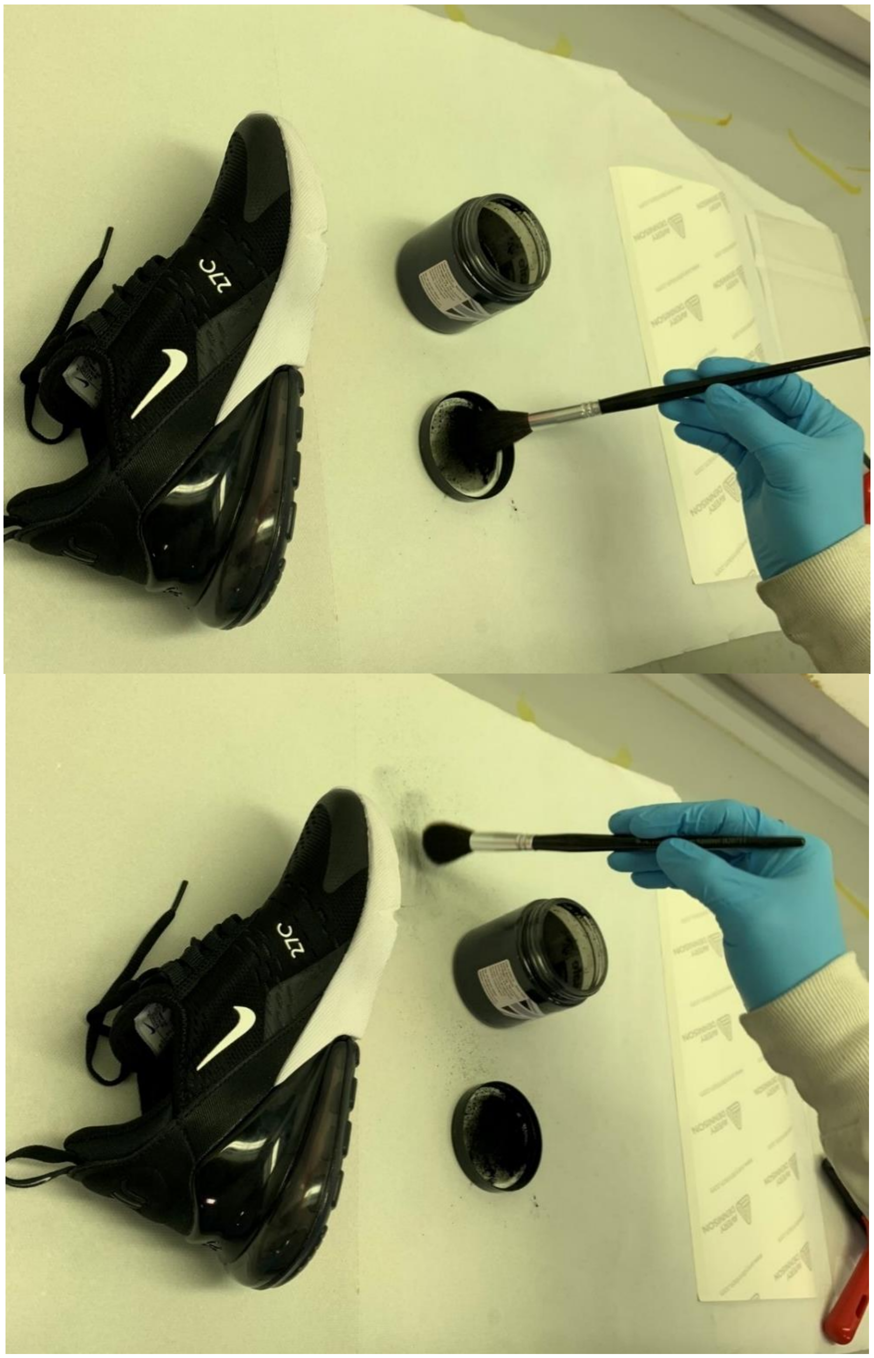


Figure 100: *An image to show the application of powder onto the animal-hair brush*

2. Whilst holding the footwear, cover the outsole with powder using light brush strokes. See **Figure 101**.

Figure 101: *An image to show the application of powder onto the outsole*

3. Stop the application of powder once the outsole is covered. See **Figure 102**.

Figure 102: *An image to show the application of powder onto the outsole*

4. Place the lifting pad flat onto the bench and remove the cover. See **Figure 103**.

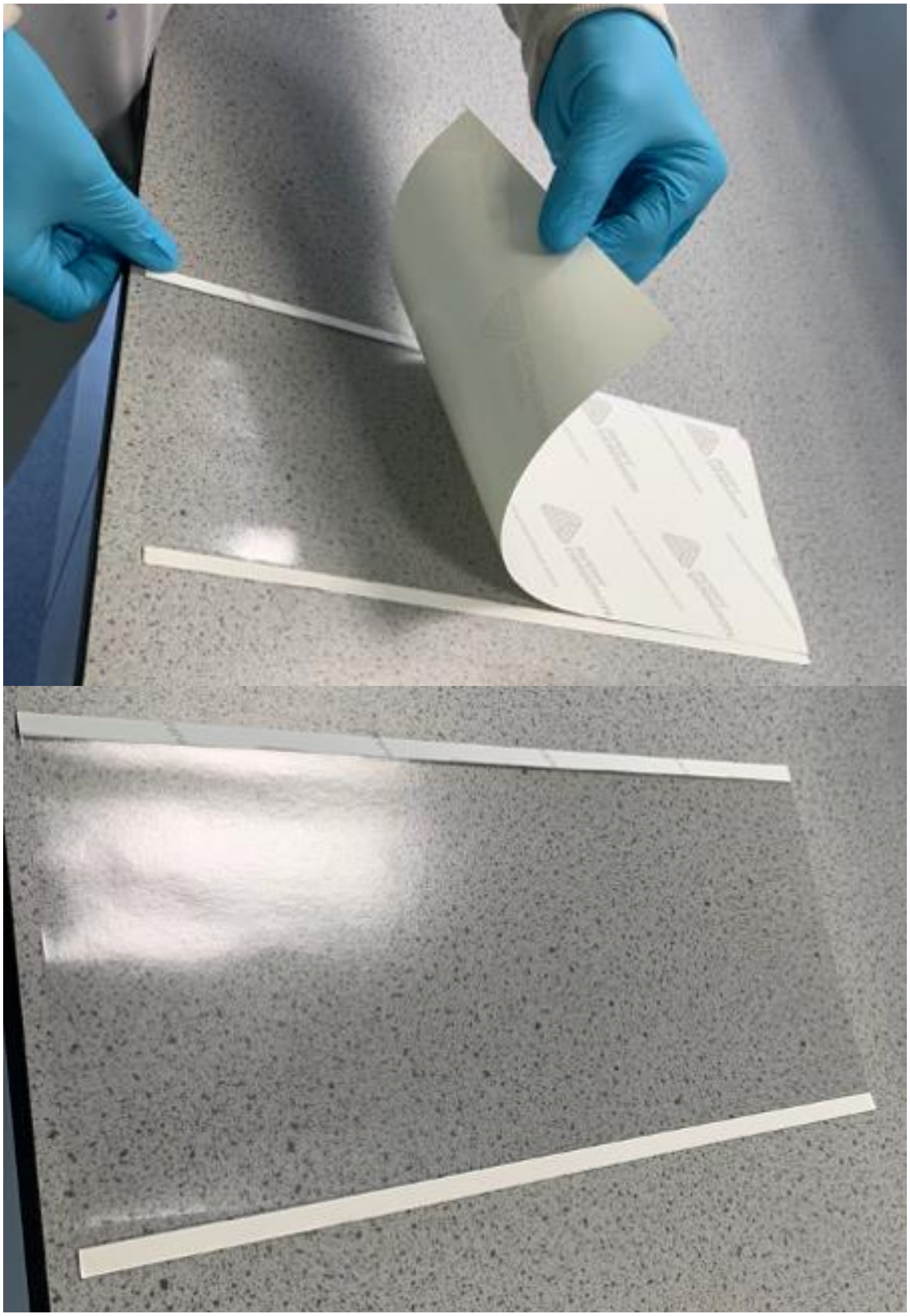


Figure 103: *An image to show the cover removal of the lifting pad*

5. Slowly place the footwear directly onto the sticky lifting pad and slide to the edge of the workbench. Once at the edge of the bench, carefully flip and hold the outsole upside down – maintaining the contact between the outsole and lifting pad. See **Figure 104**.

Figure 104: *An image to show the footwear in contact with the sticky lifting pad, and the beginning of the removal from the bench*

6. Whilst the footwear is upside down, begin to slowly press the lifting pad onto the features of the outsole. The lifting pad may not remain stuck down during this stage, if this is to occur, do not attempt to manipulate the lifter in these areas. See **Figure 105**.

Figure 105: *An image to show the pressing down of the lifting pad, and the finished result*

7. Slowly begin to peel off the sticky lifting pad. See **Figure 106**.

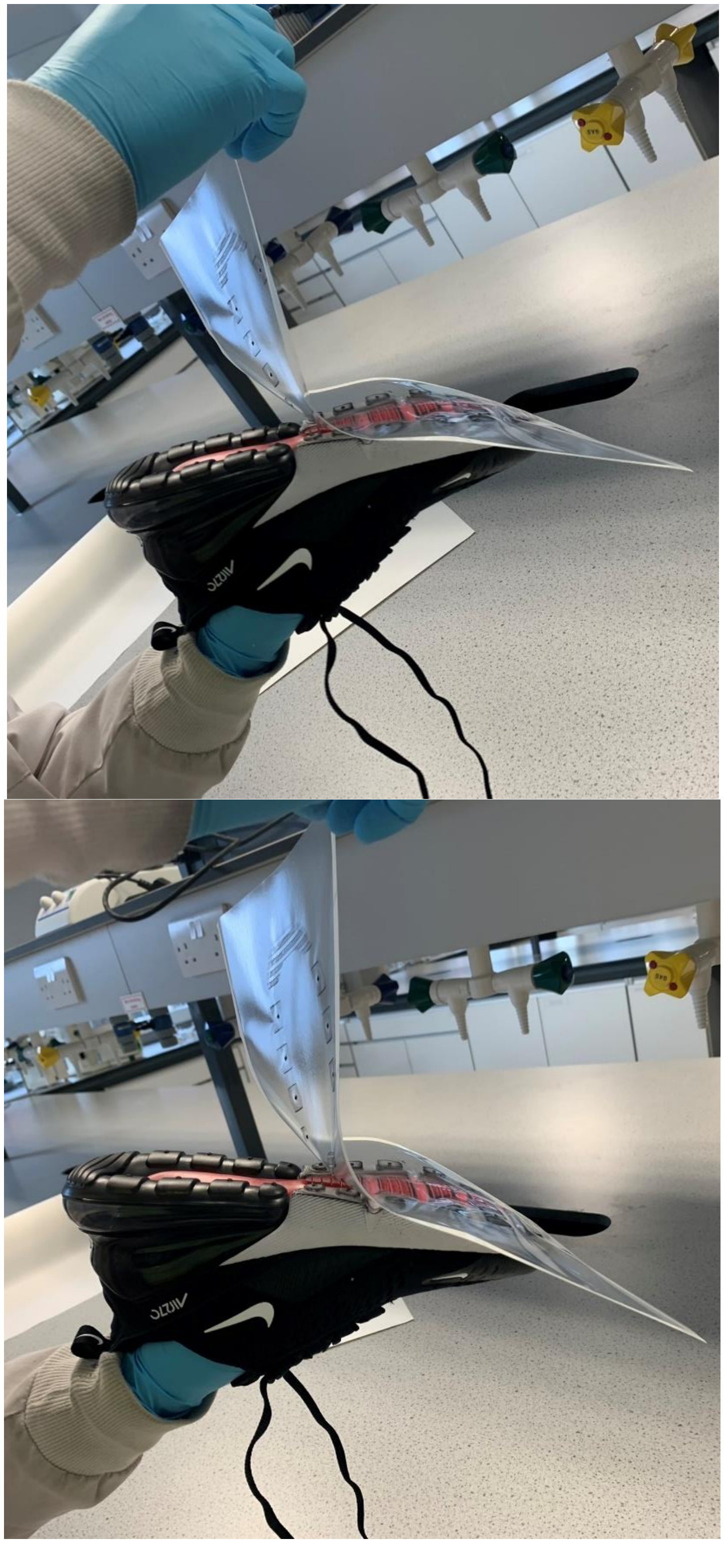


Figure 106: *An image to show the removal of the sticky lifting pad*

8. With the sticky lifting pad flat on the workbench, place an acetate over the impression, using a roller to remove air bubbles. See **Figure 107**.

Figure 107: *An image to show the process of rolling on the acetate*

B.3. Method of Print-Scan Test Impression Preparation:

1. Like the dynamic test impressions, remove the cover and step onto the shoeprint inkless coater. See **Figure 108**.

Figure 108: *An image to show stepping onto the shoeprint inkless coater*

2. From heel to toe, step onto the shoeprint inkless system papers. Printscan test impressions do not require sealing. See **Figure 109**.

Figure 109: *An image to show stepping onto the shoeprint inkless system papers. And the finished result*

C. Outsole and Test Impression Images

C.1. FW1 L

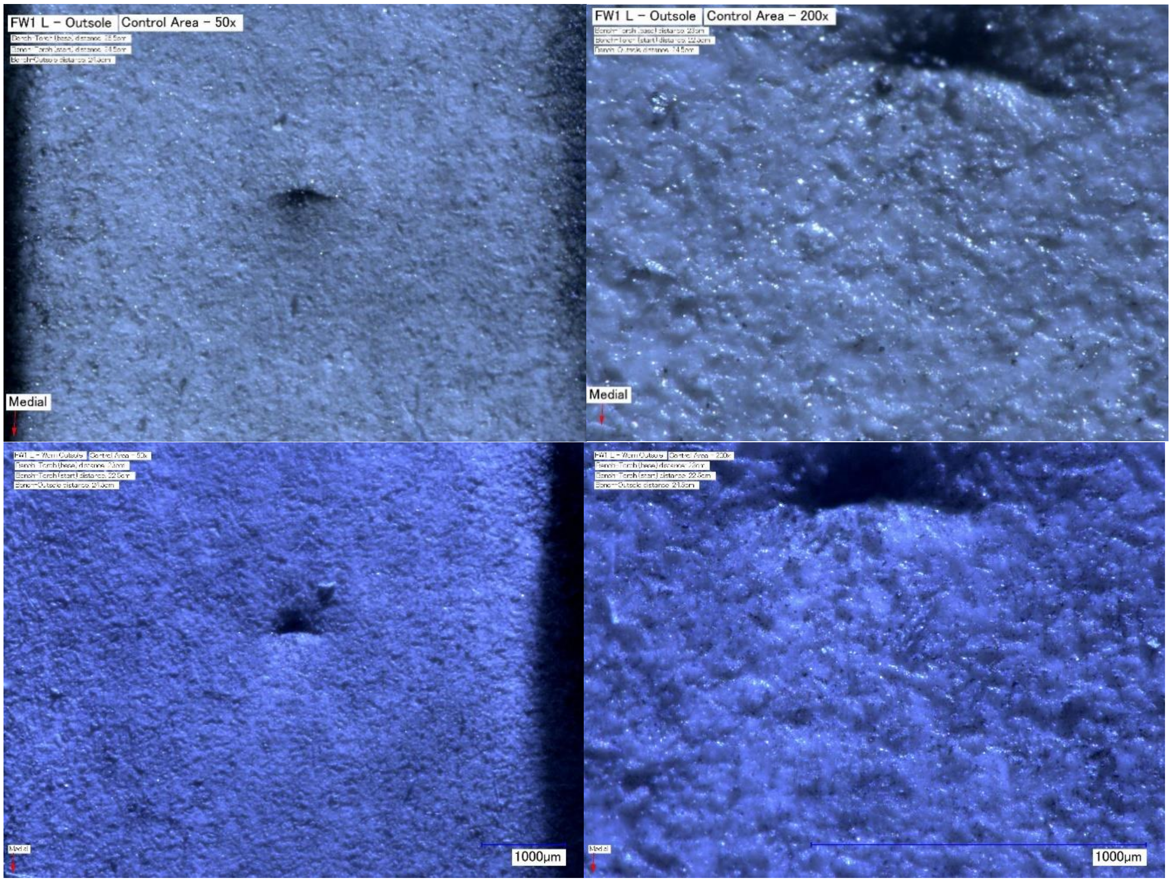


Figure 110: *Pre-wear magnified images of FW1 L control area [top] and worn [bottom], at 50x [left] and 200x [right]*

[1]

[2]

[3]

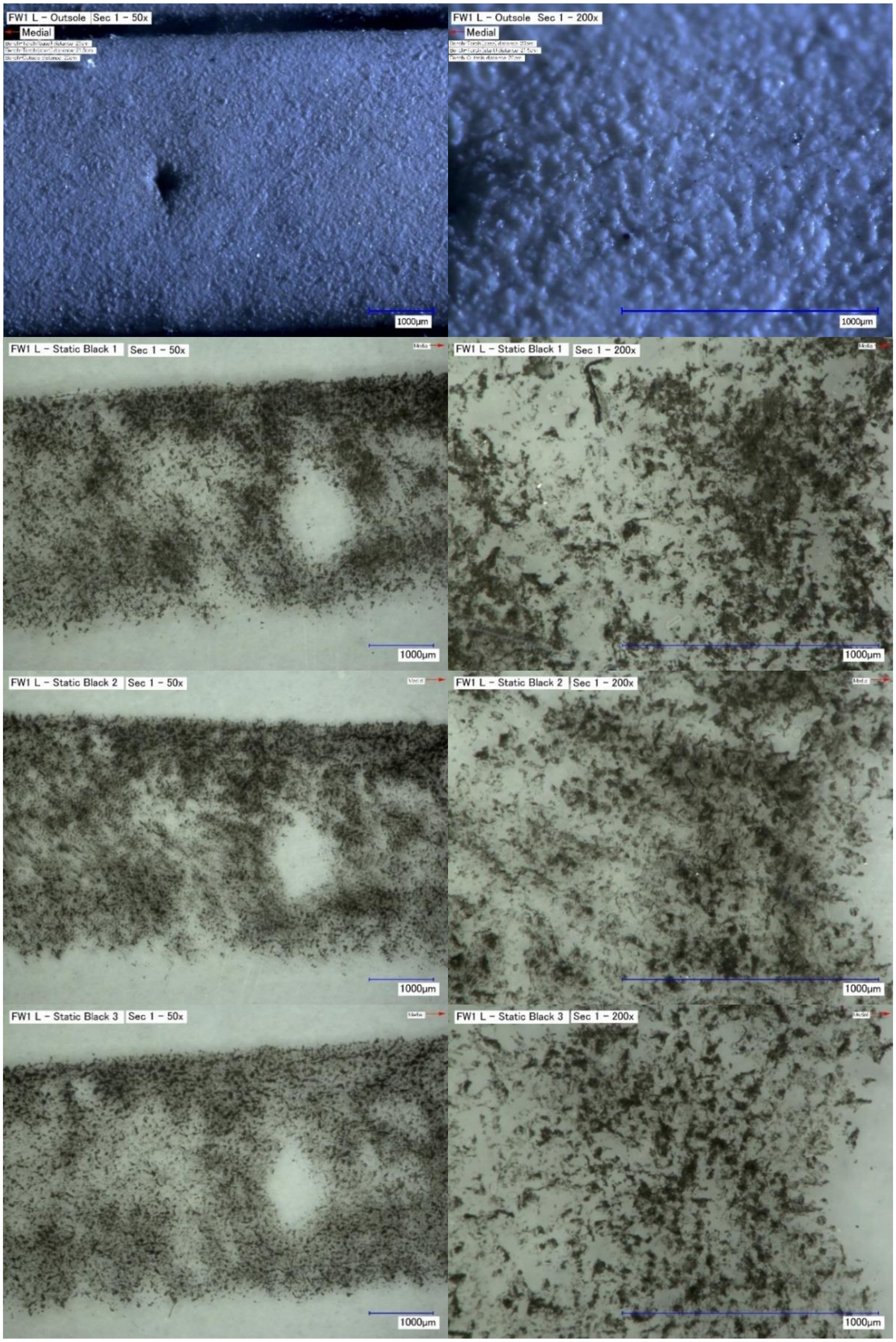


Figure 111: *Pre-wear magnified images of FW1 L section 1 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

[1]

[2]

[3]

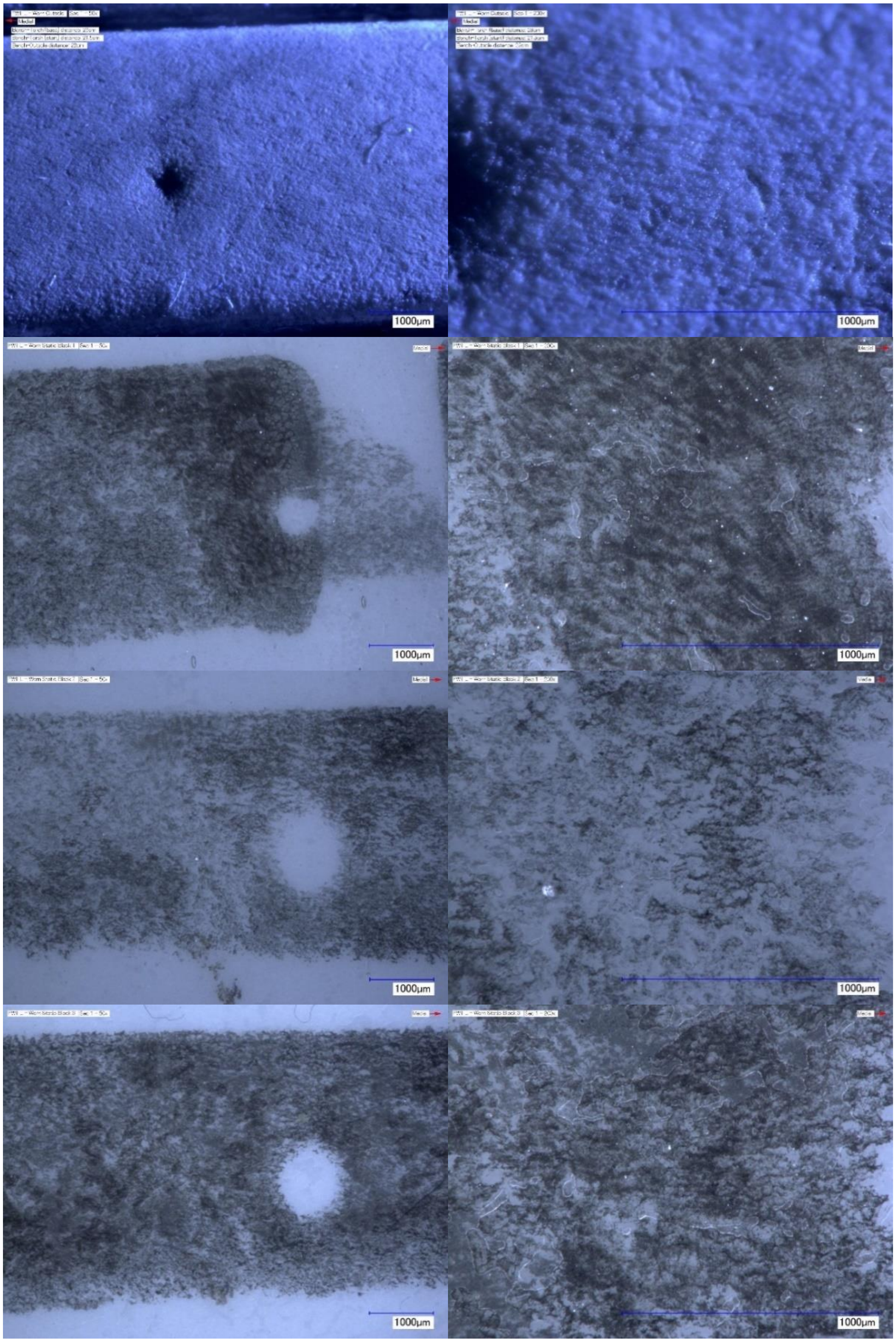


__Figure 112:__ Worn magnified images of FW1 L section 1 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]

[1]

[2]

[3]

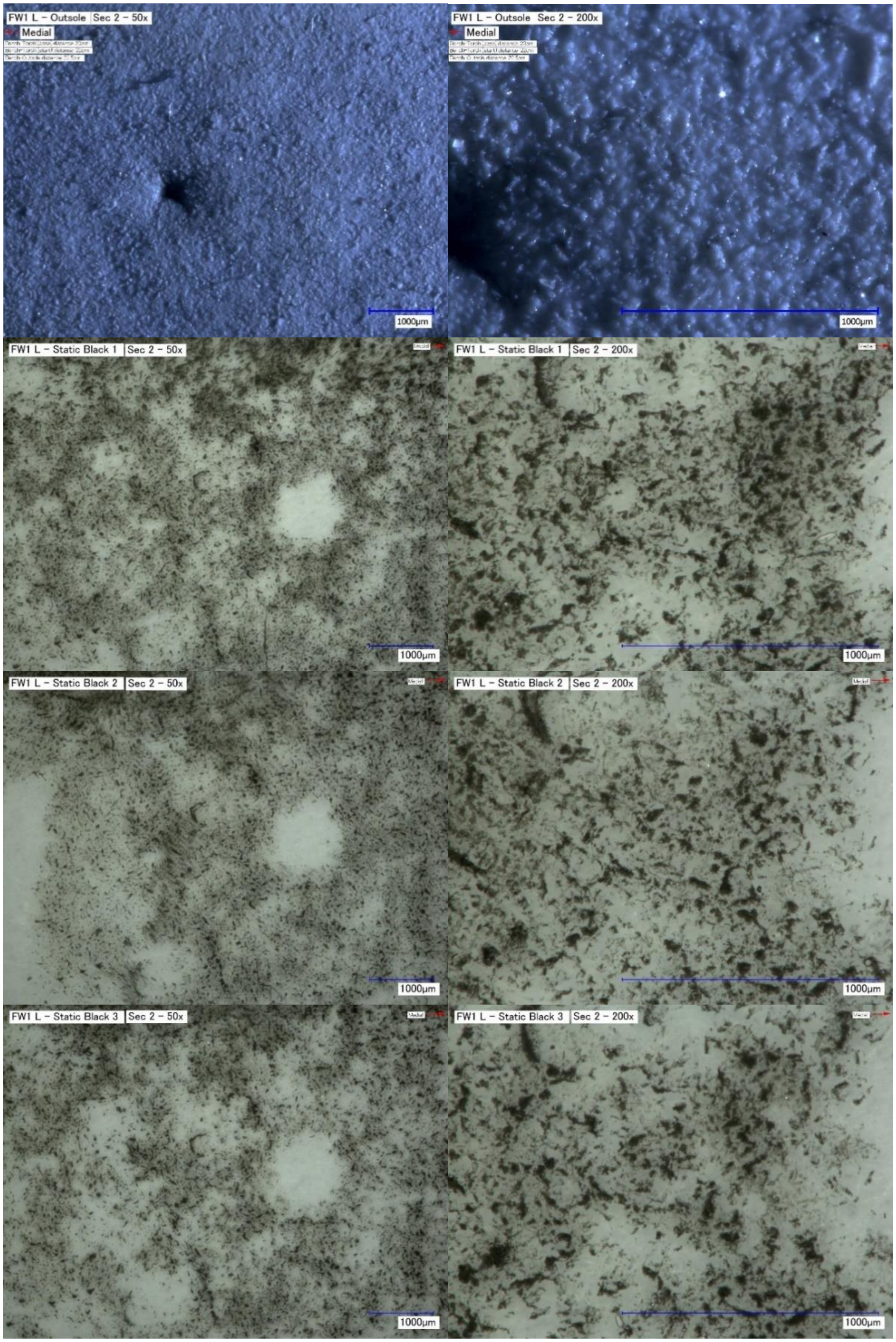


Figure 113: *Pre-wear magnified images of FW1 L section 2 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

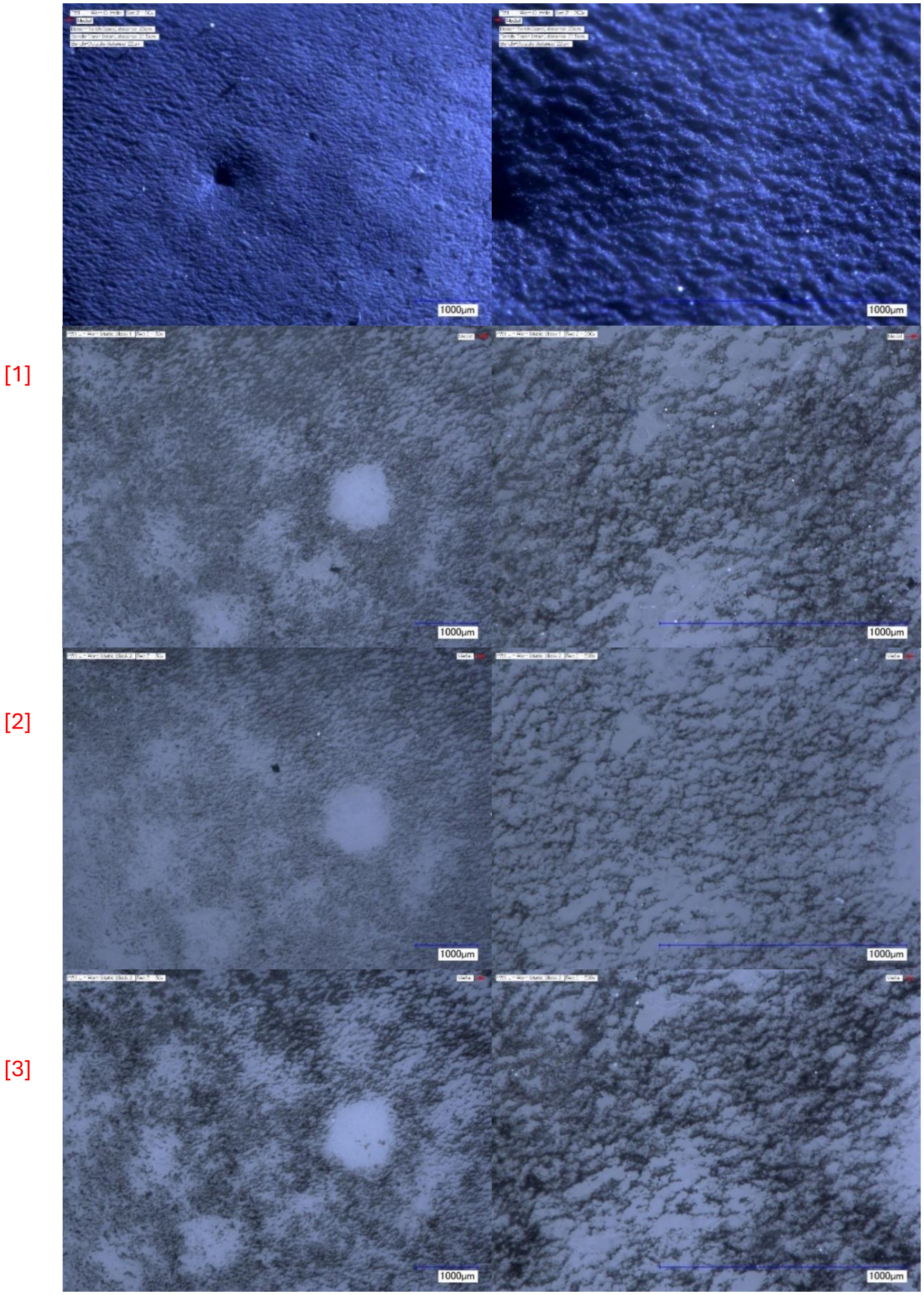


Figure 114: *Worn magnified images of FW1 L section 2 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

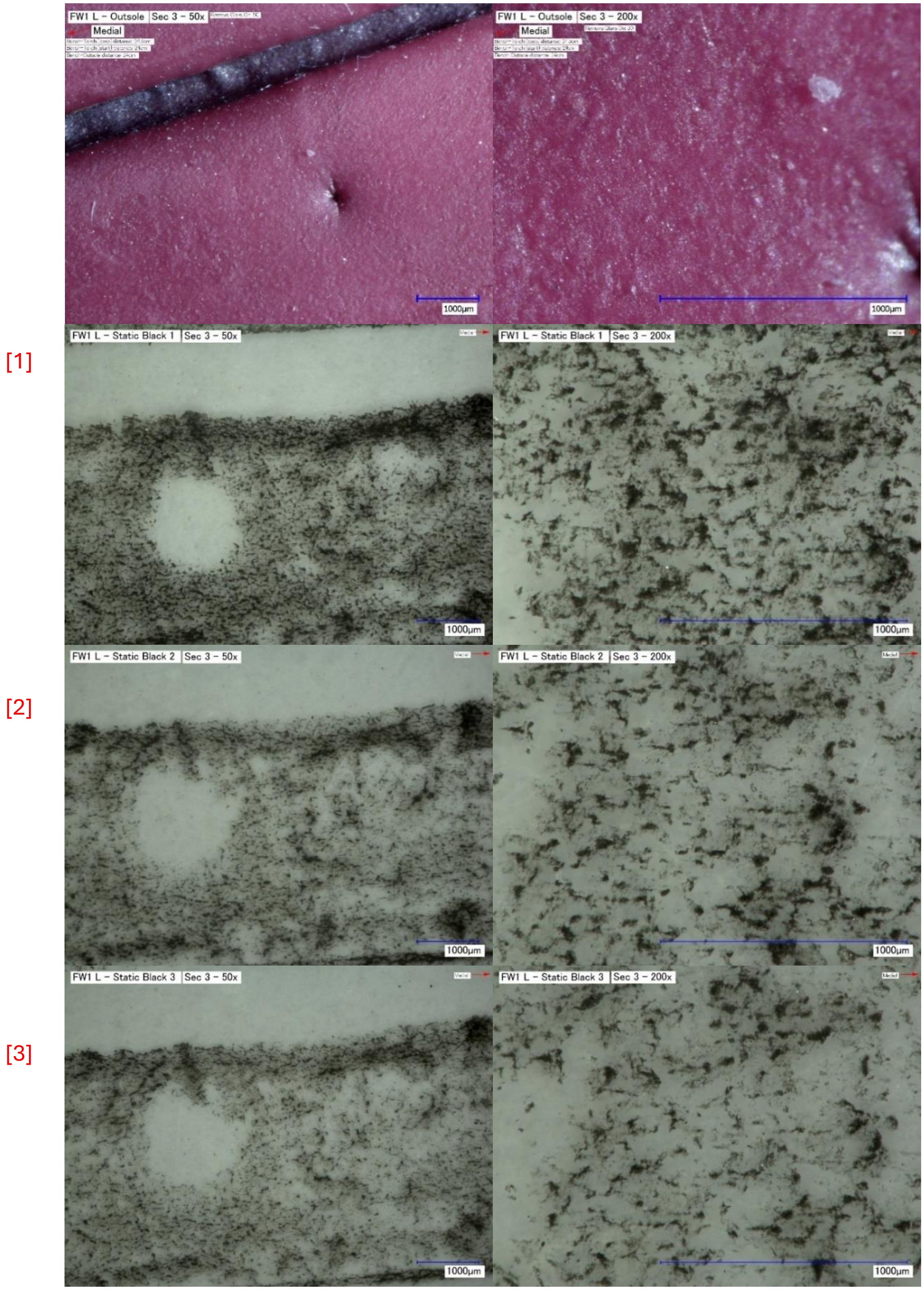


Figure 115: *Pre-wear magnified images of FW1 L section 3 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

[1]

[2]

[3]

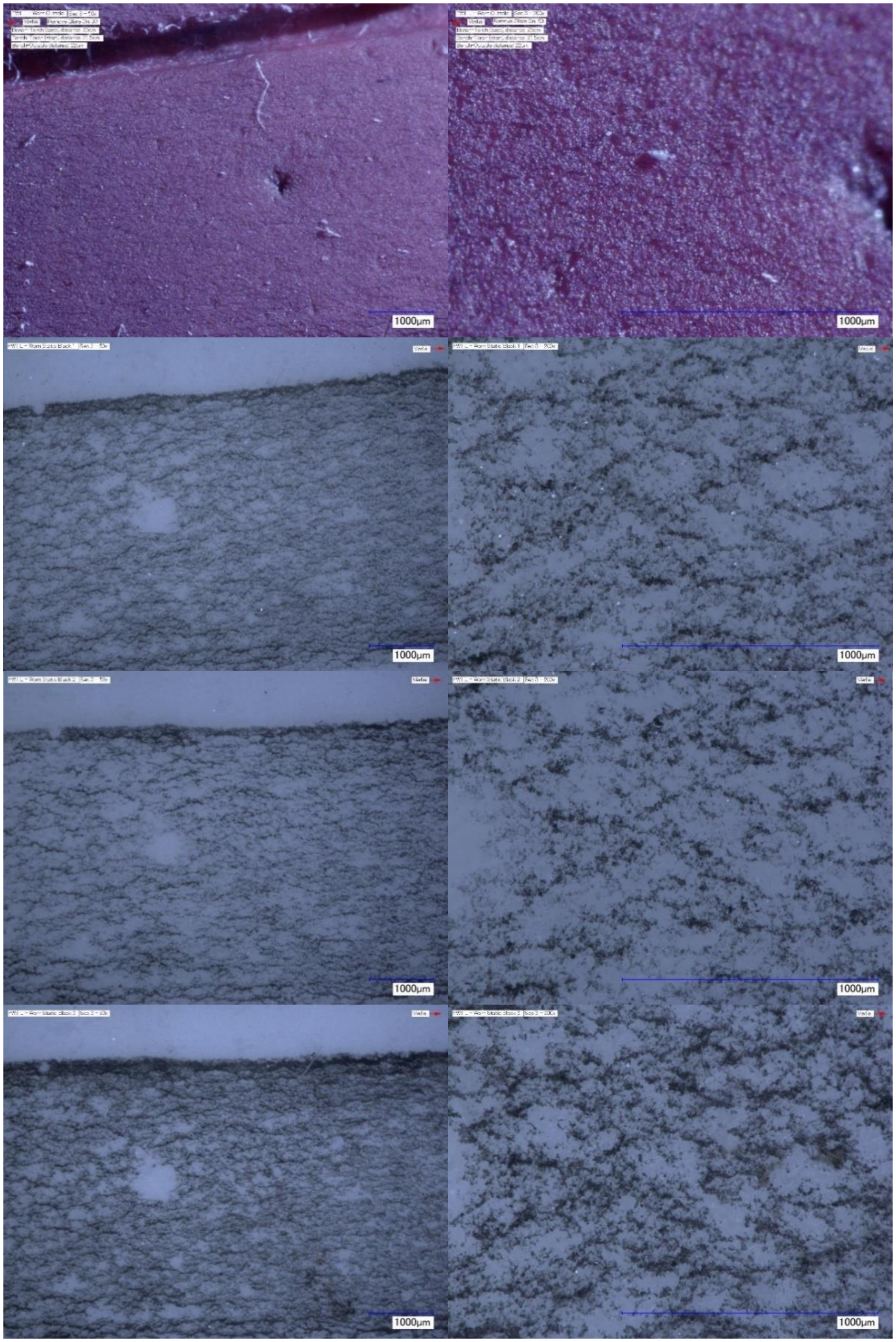
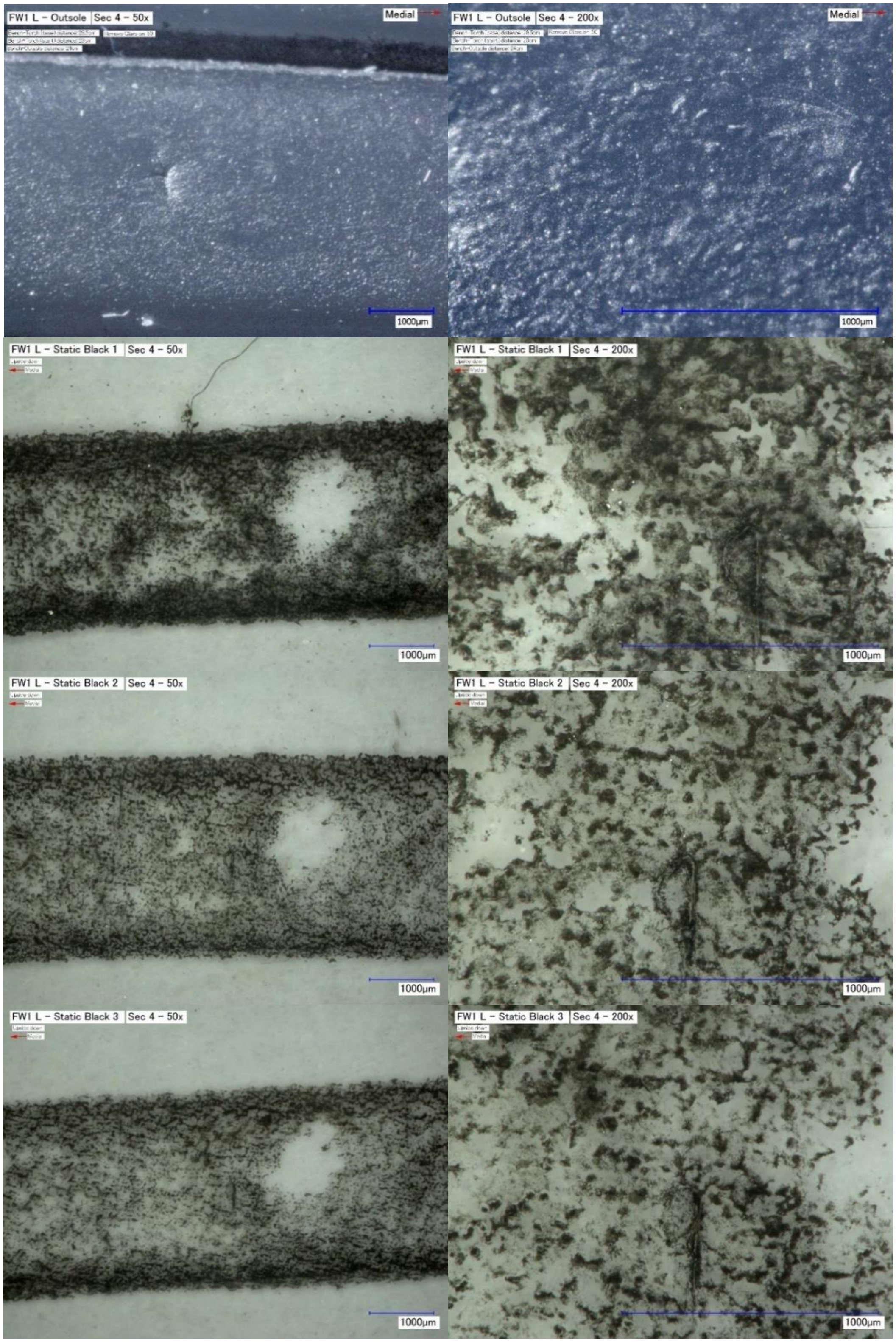


Figure 116: *Worn magnified images of FW1 L section 3 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*



[1]

[2]

[3]

Figure 117: *Pre-wear magnified images of FW1 L section 4 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

[1]

[2]

[3]

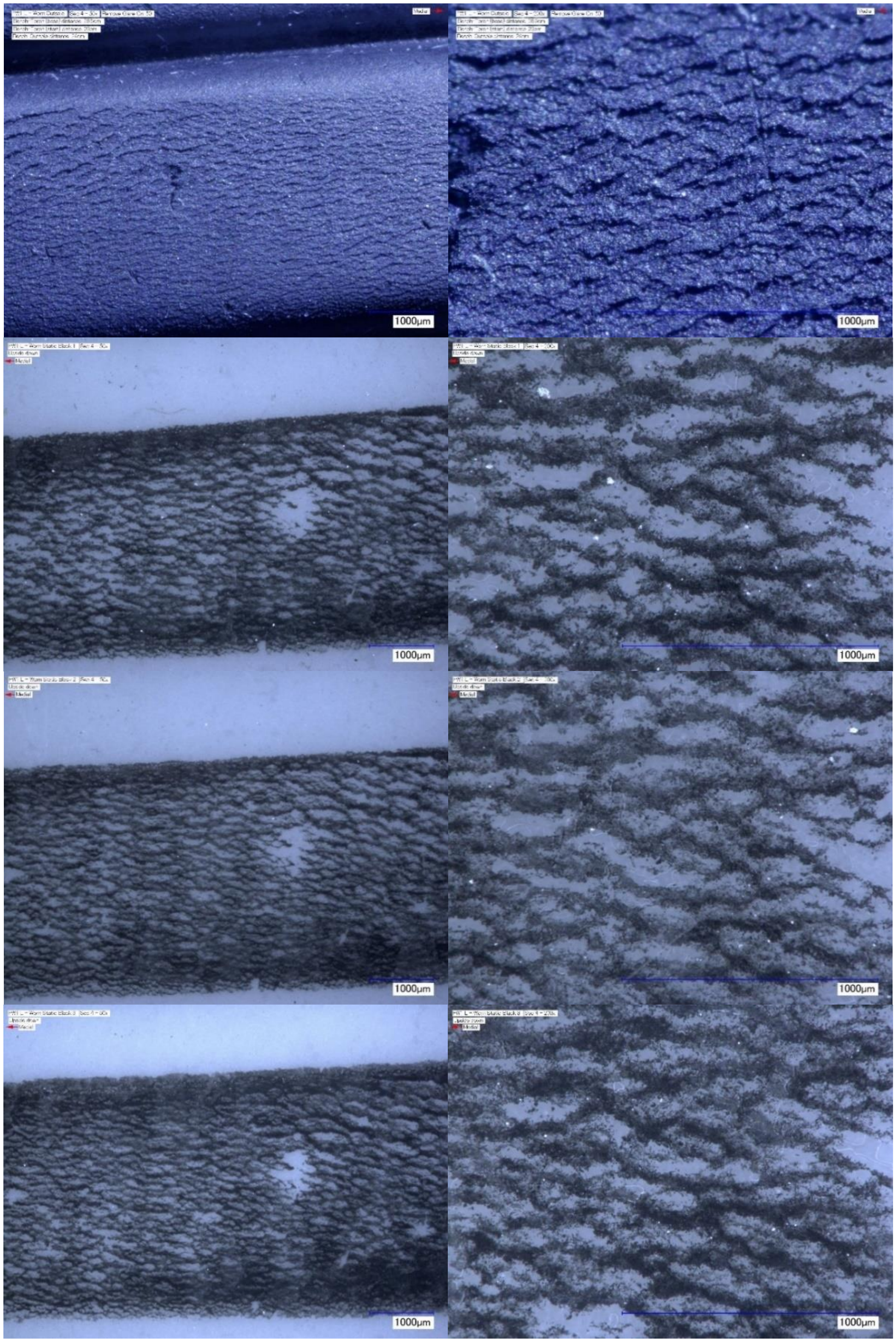


Figure 118: *Worn magnified images of FW1 L section 4 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

C.2. FW1 R

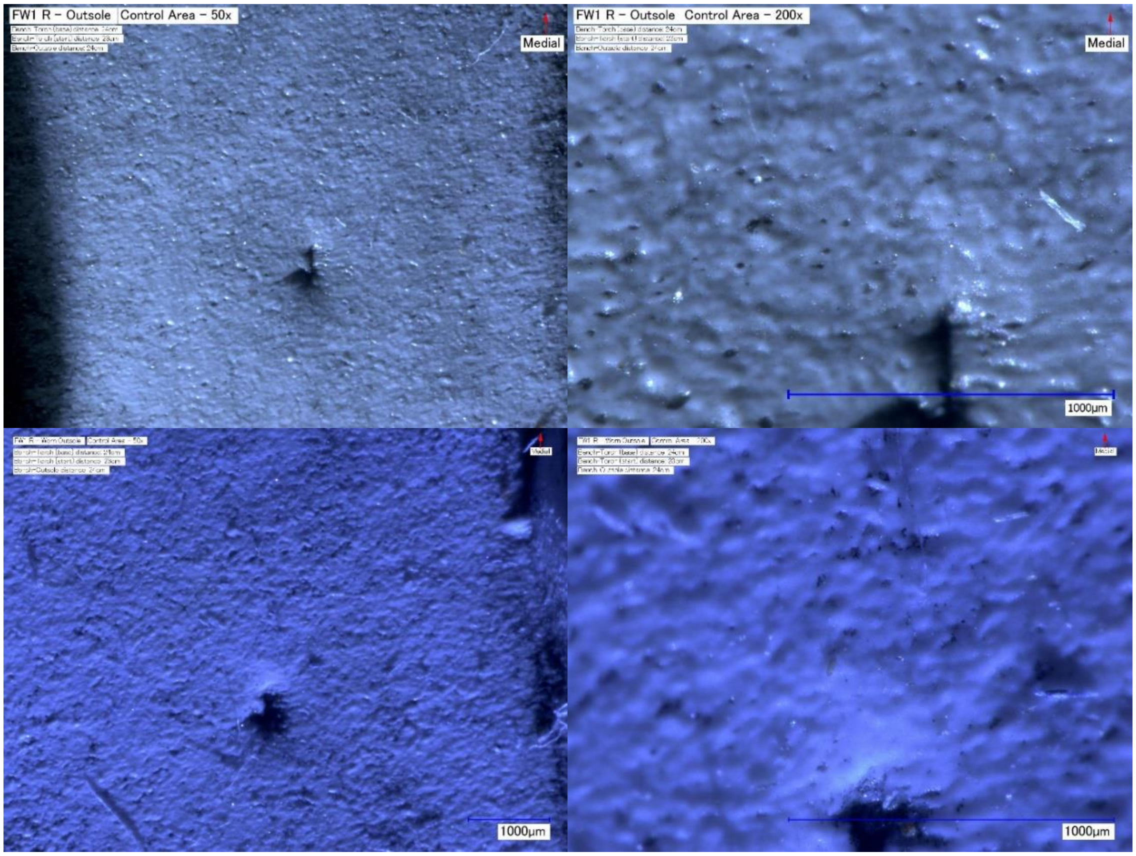
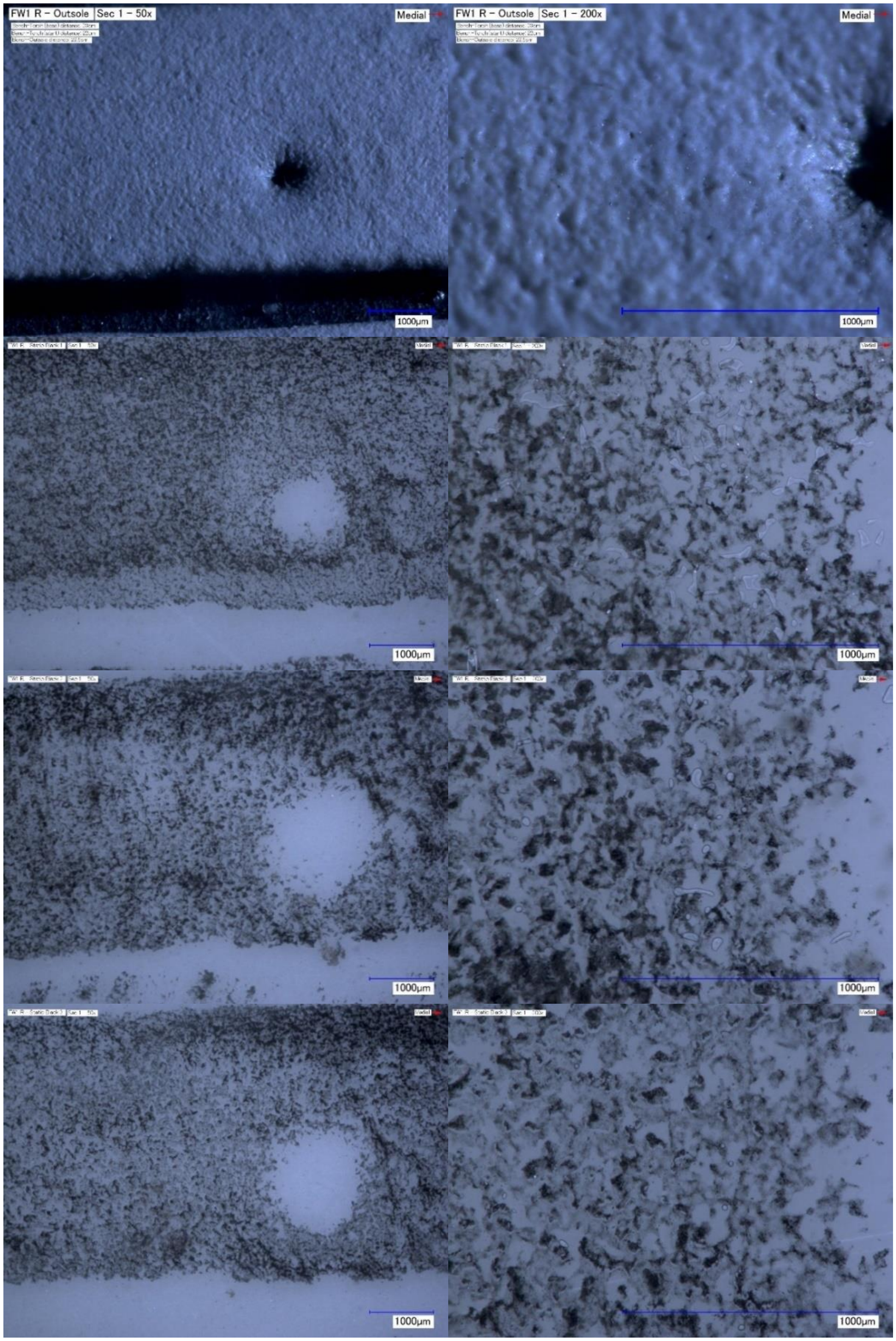


Figure 119: *Pre-wear magnified images of FW1 R control area [top] and worn [bottom], at 50x [left] and 200x [right]*



[1]

[2]

[3]

Figure 120: *Pre-wear magnified images of FW1 R section 1 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

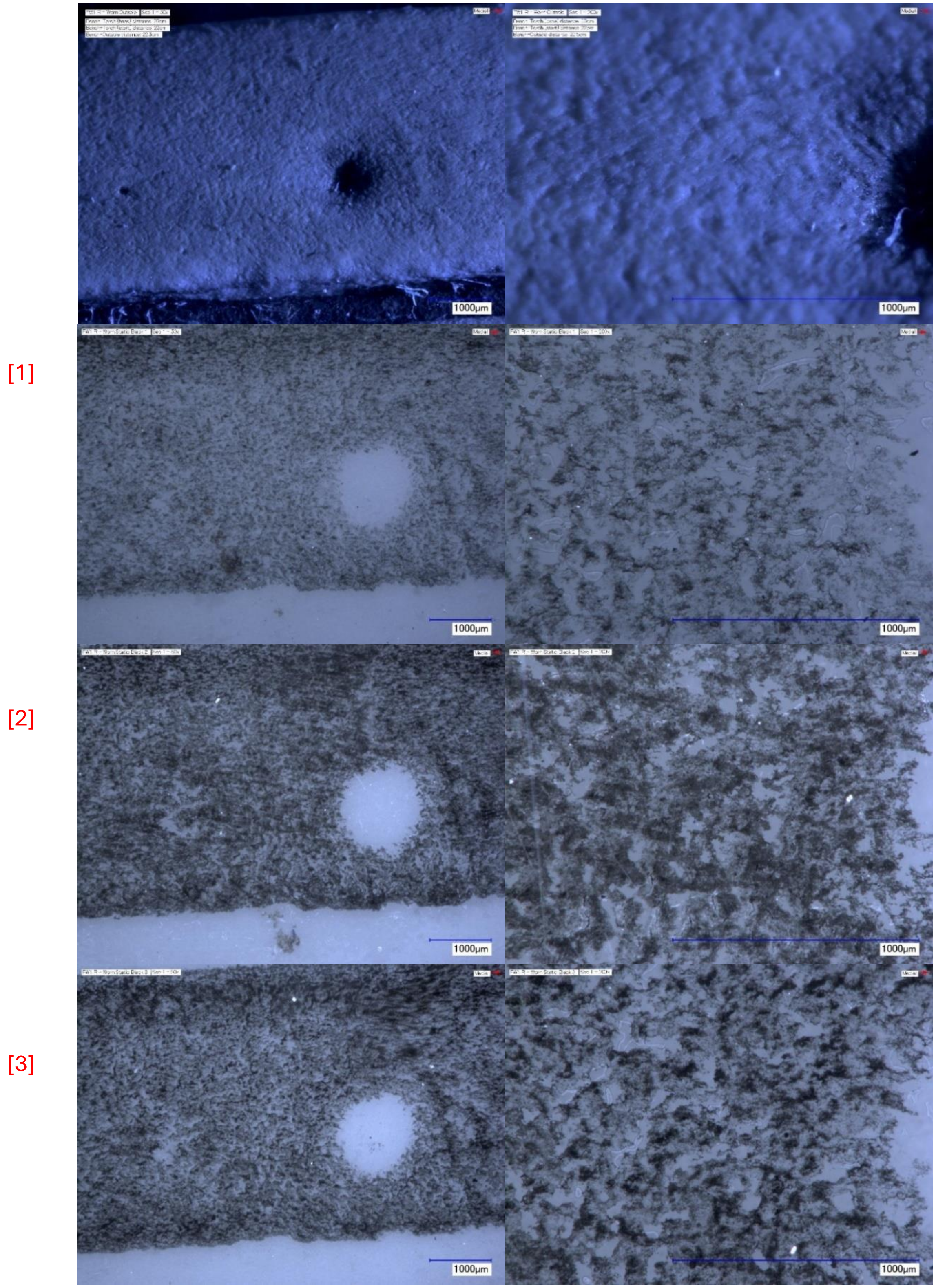
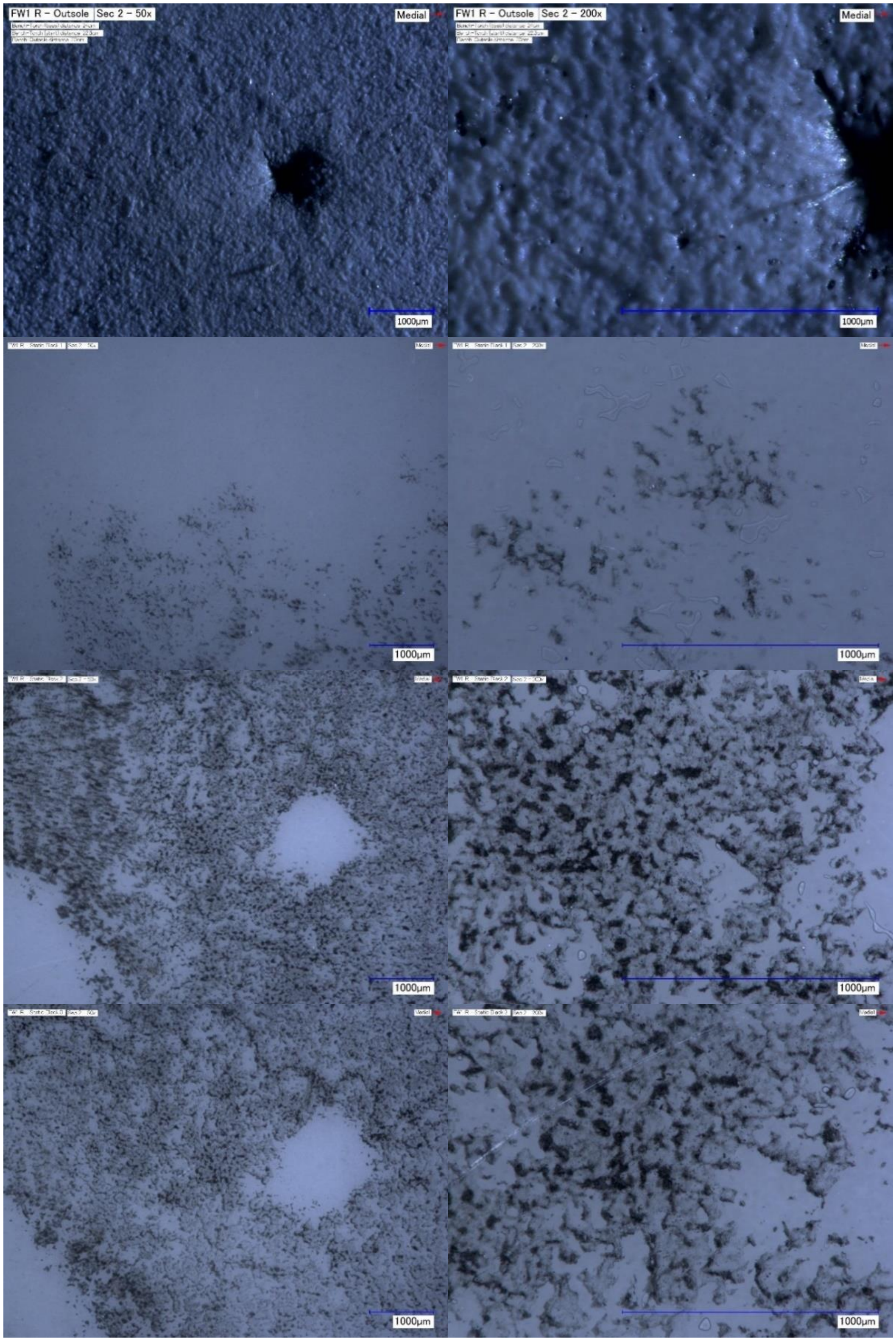


Figure 121: *Worn magnified images of FW1 R section 1 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*



[1]

[2]

[3]

Figure 122: *Pre-wear magnified images of FW1 R section 2 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

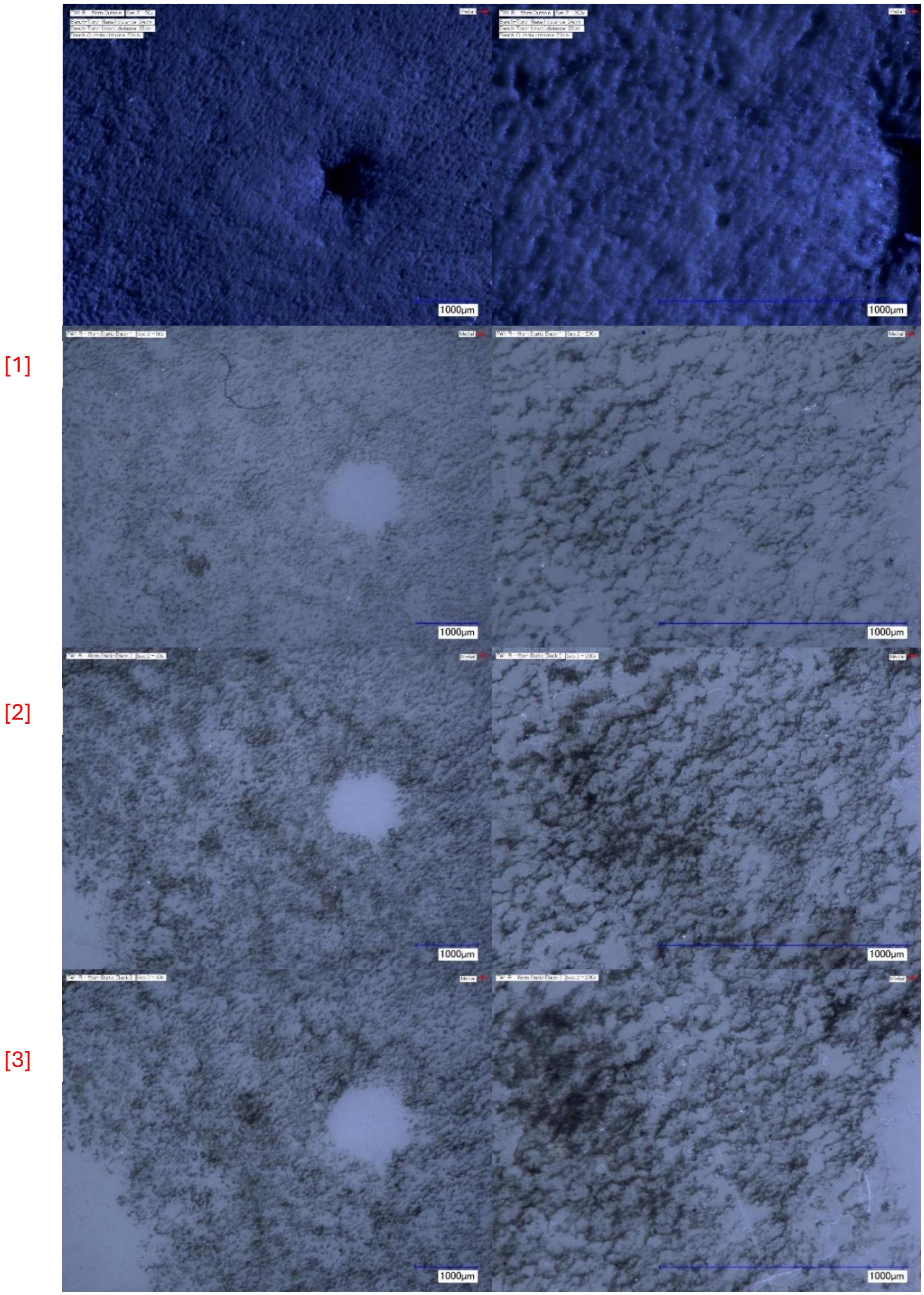
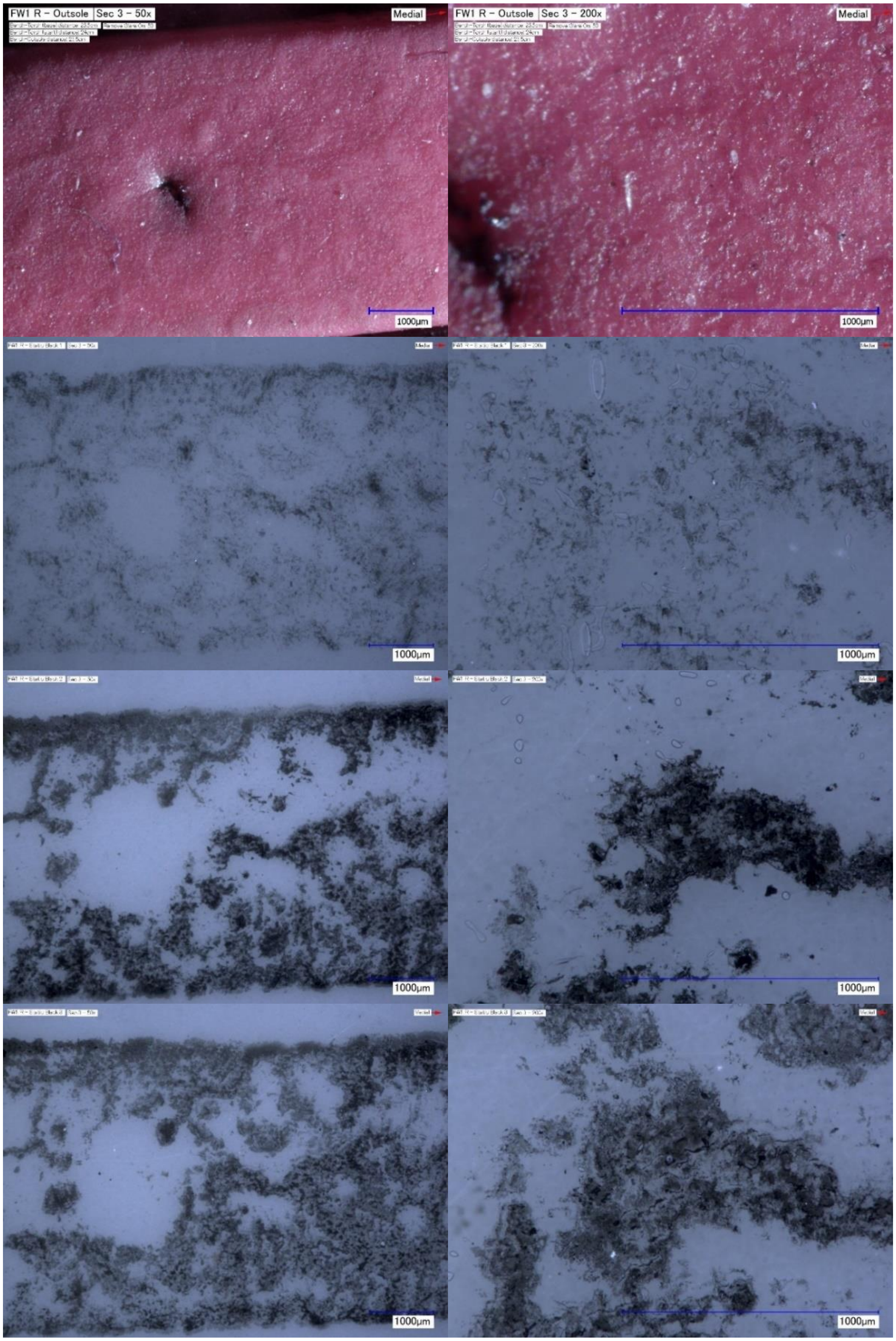


Figure 123: *Worn magnified images of FW1 R section 2 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*



[1]

[2]

[3]

Figure 124: *Pre-wear magnified images of FW1 R section 3 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

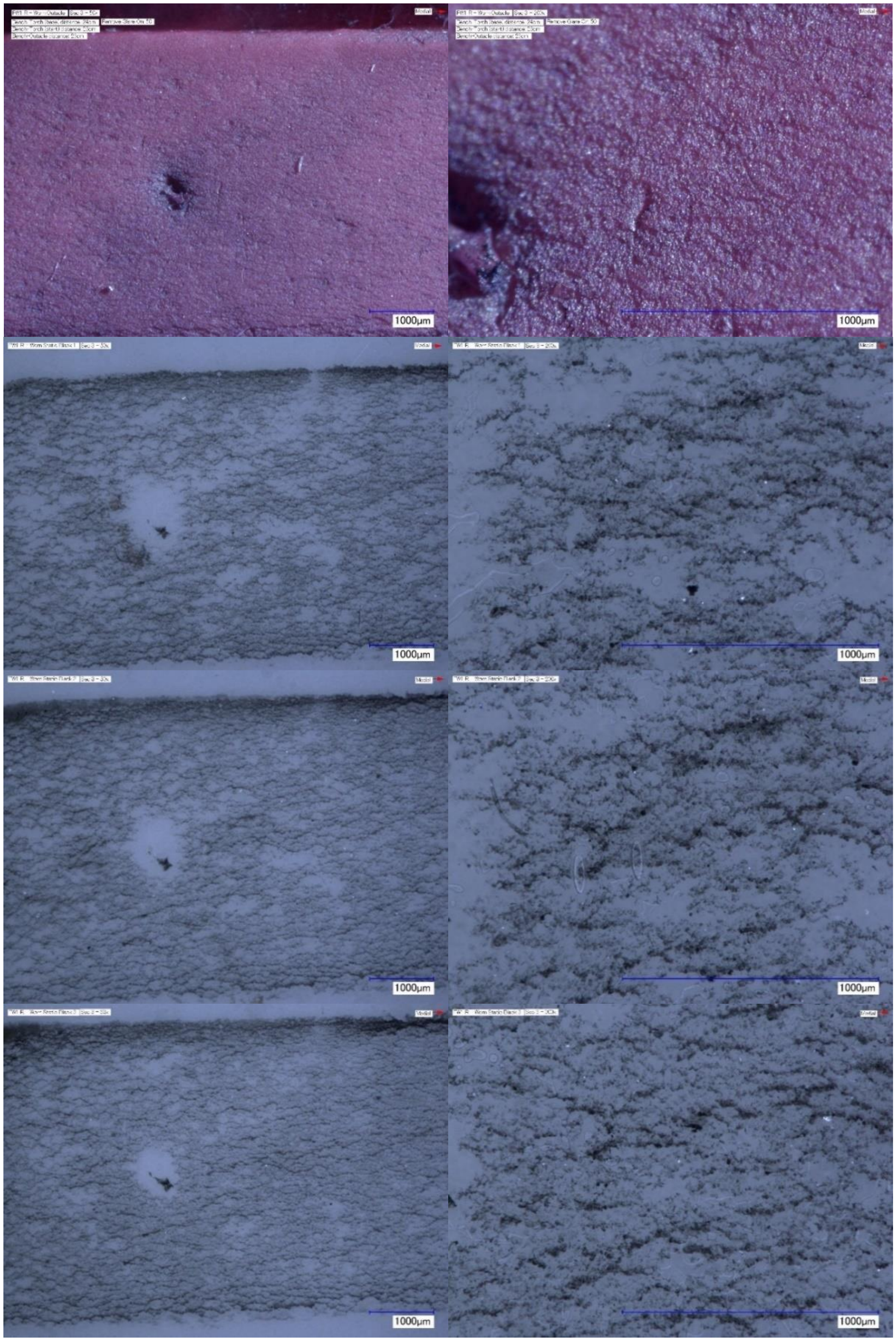
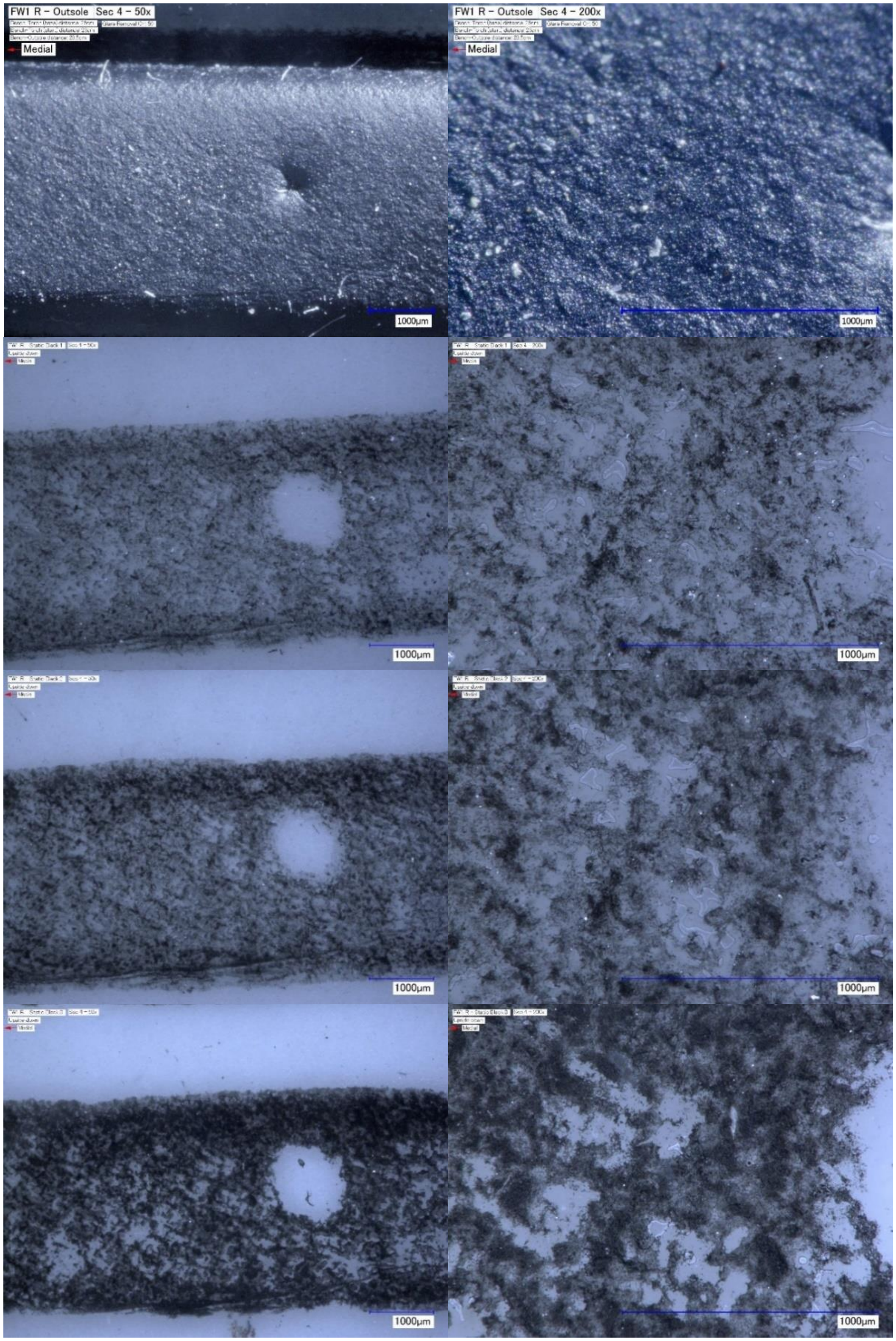


Figure 125: *Worn magnified images of FW1 R section 3 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*



[1]

[2]

[3]

Figure 126: *Pre-wear magnified images of FW1 R section 4 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

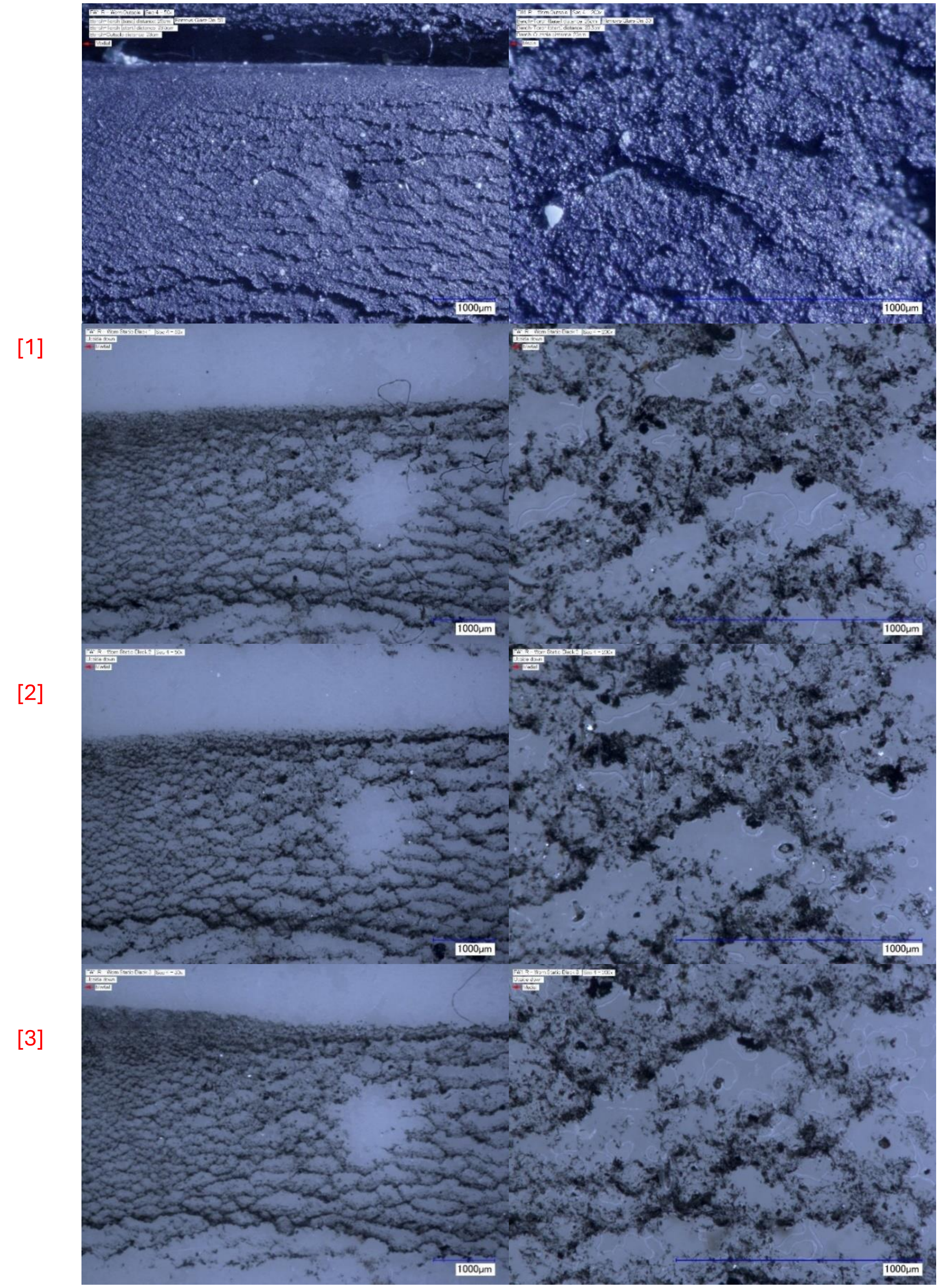


Figure 127: *Worn magnified images of FW1 R section 4 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

C.3. FW2 L

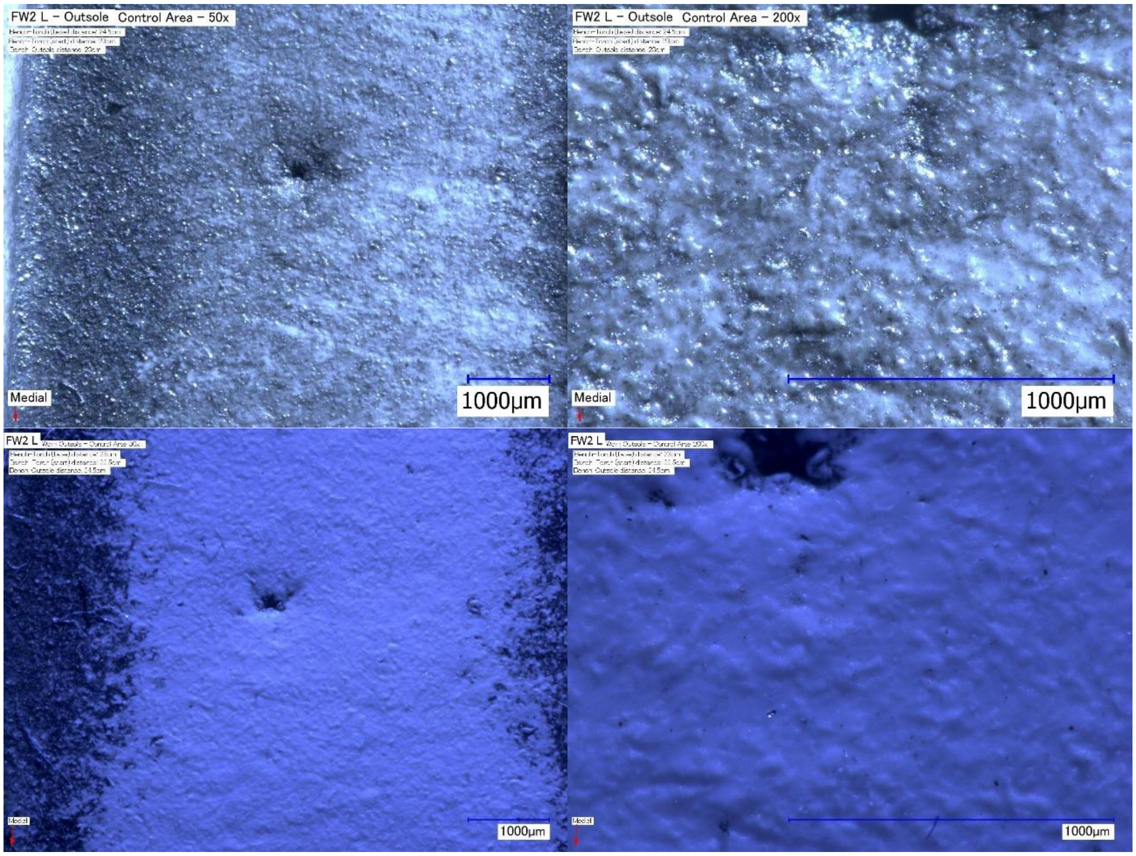


Figure 128: *Pre-wear magnified images of FW2 L control area [top] and worn [bottom], at 50x [left] and 200x [right]*

[1]

[2]

[3]

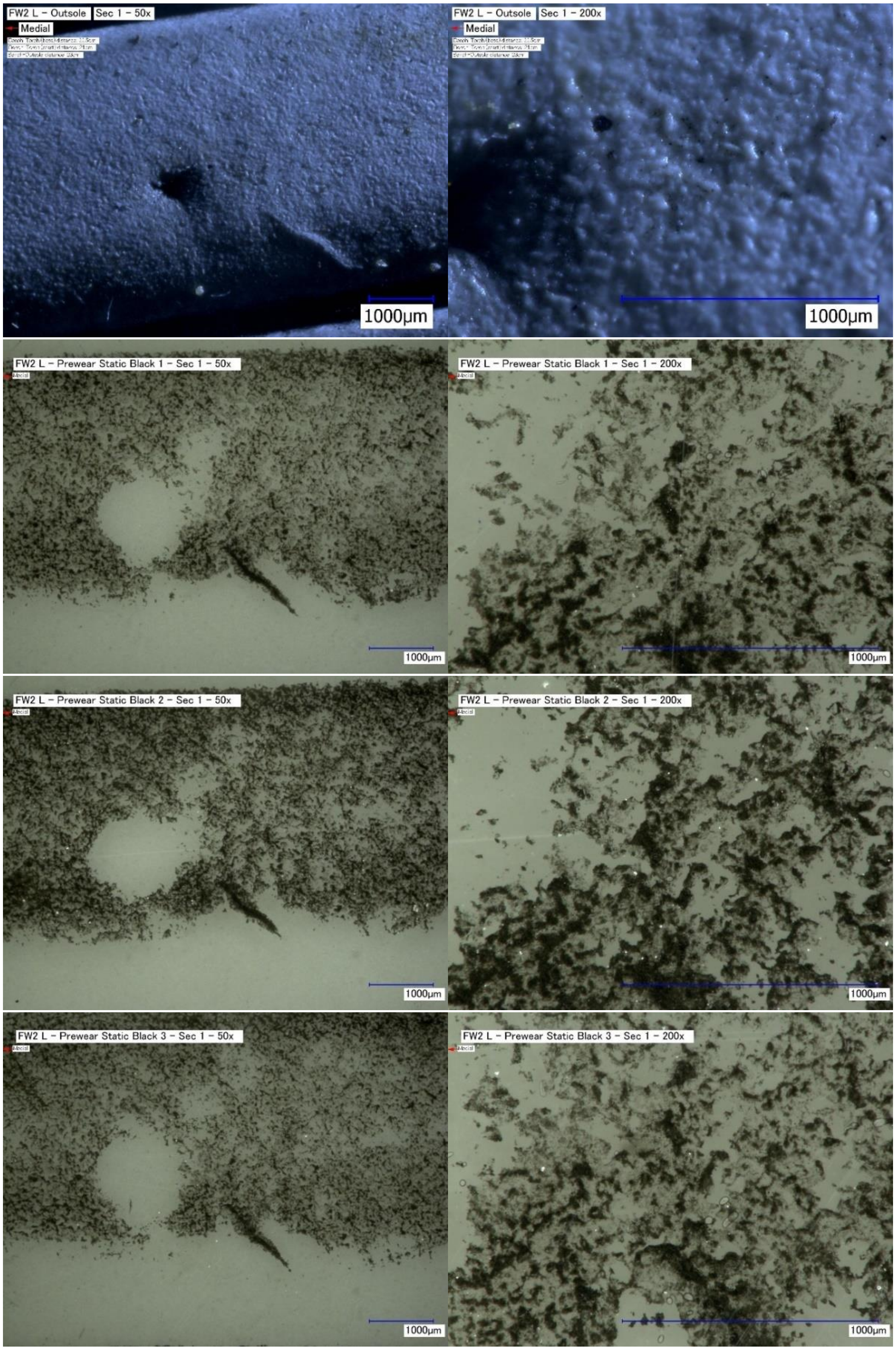


Figure 129: *Pre-wear magnified images of FW2 L section 1 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

[1]

[2]

[3]

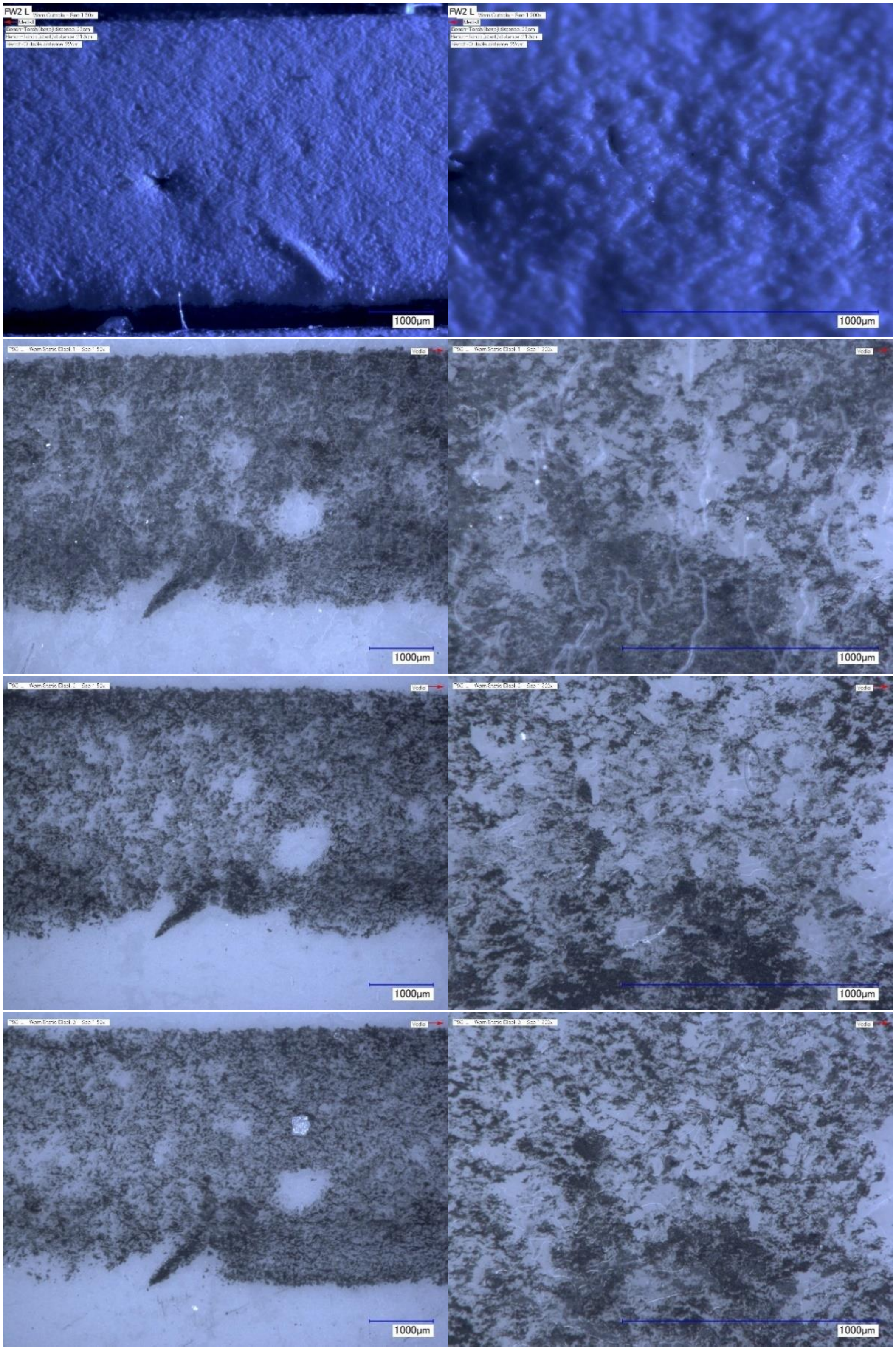
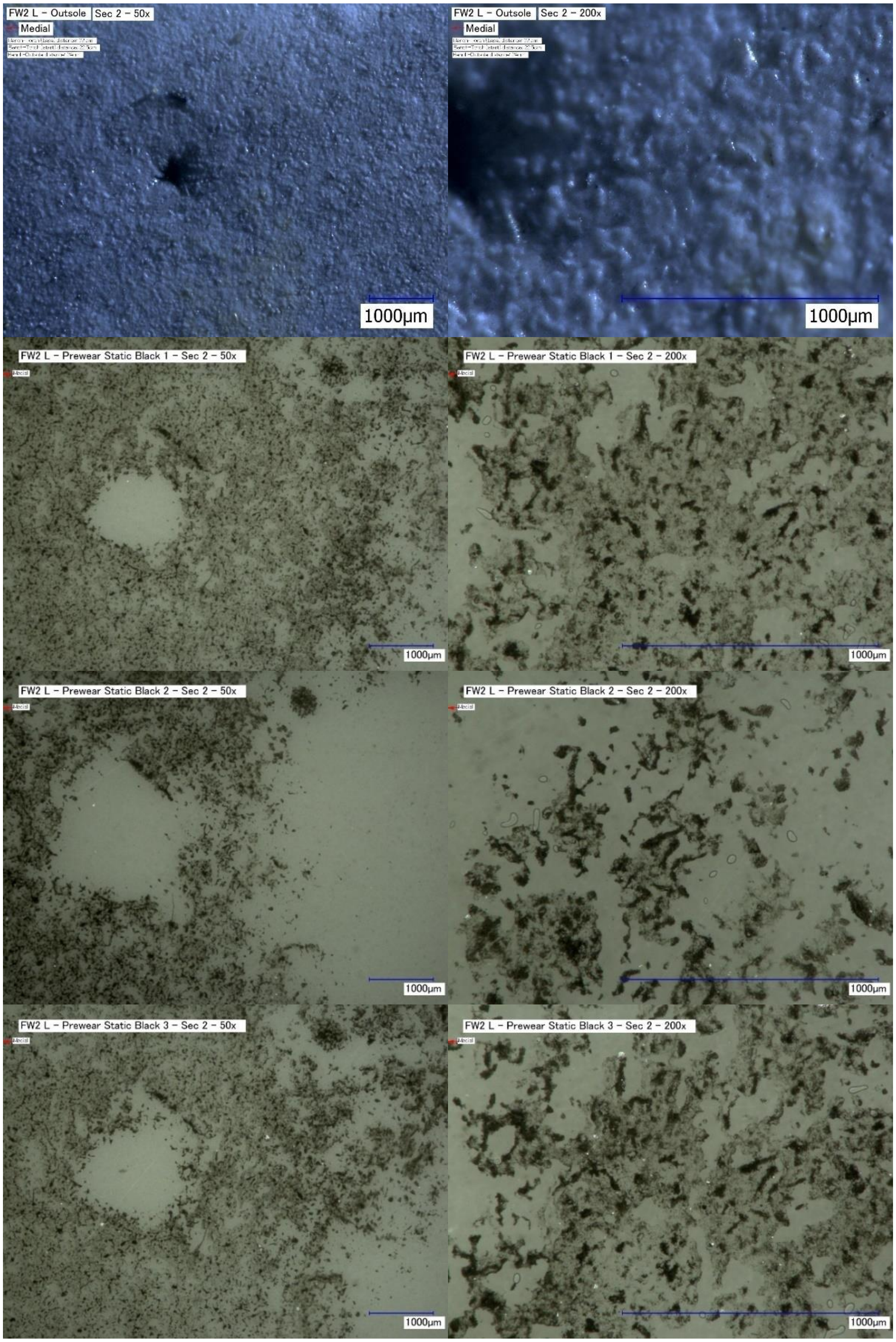


Figure 130: *Worn magnified images of FW2 L section 1 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*



[1]

[2]

[3]

Figure 131: *Pre-wear magnified images of FW2 L section 2 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

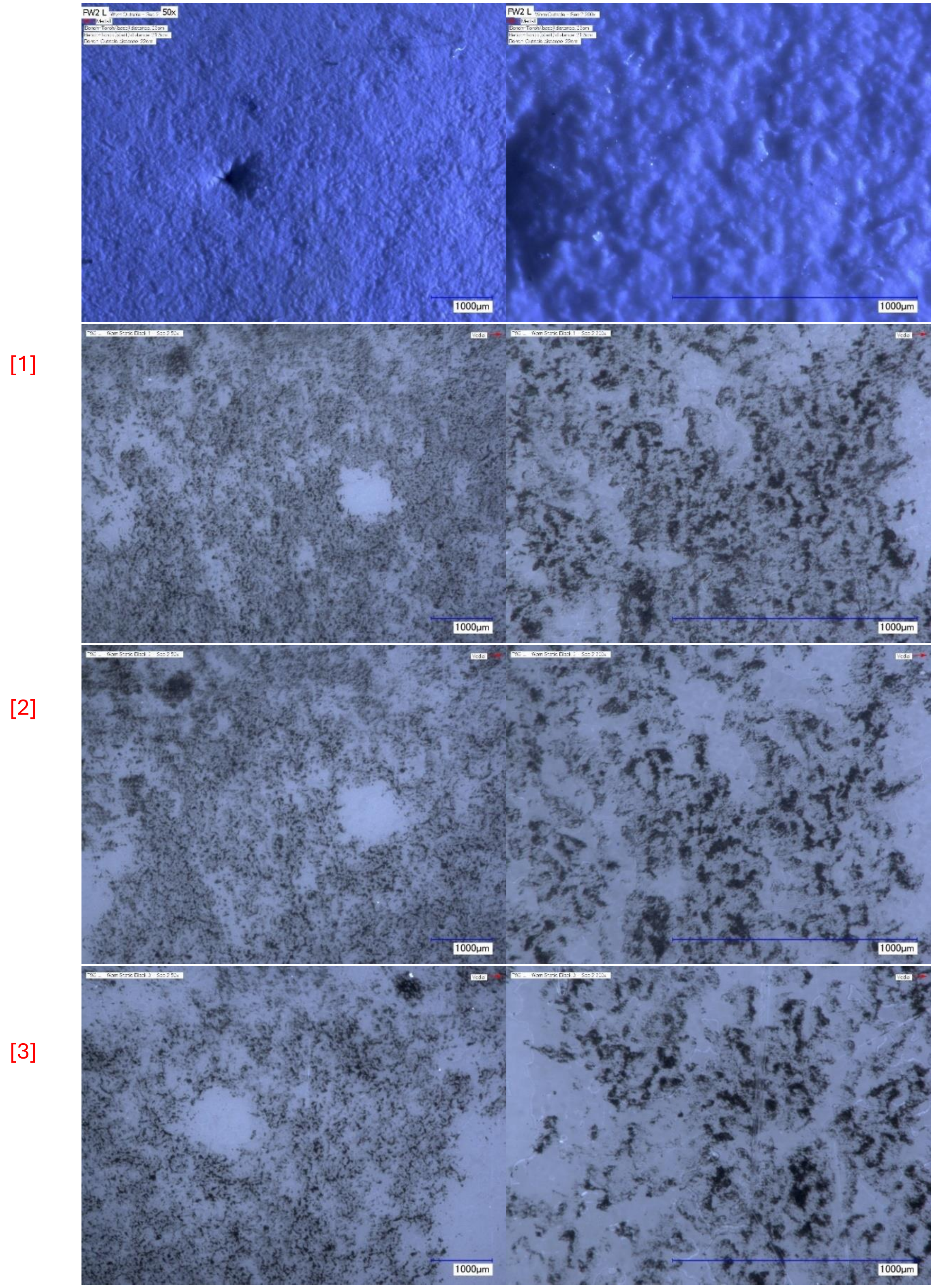


Figure 132: *Worn magnified images of FW2 L section 2 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

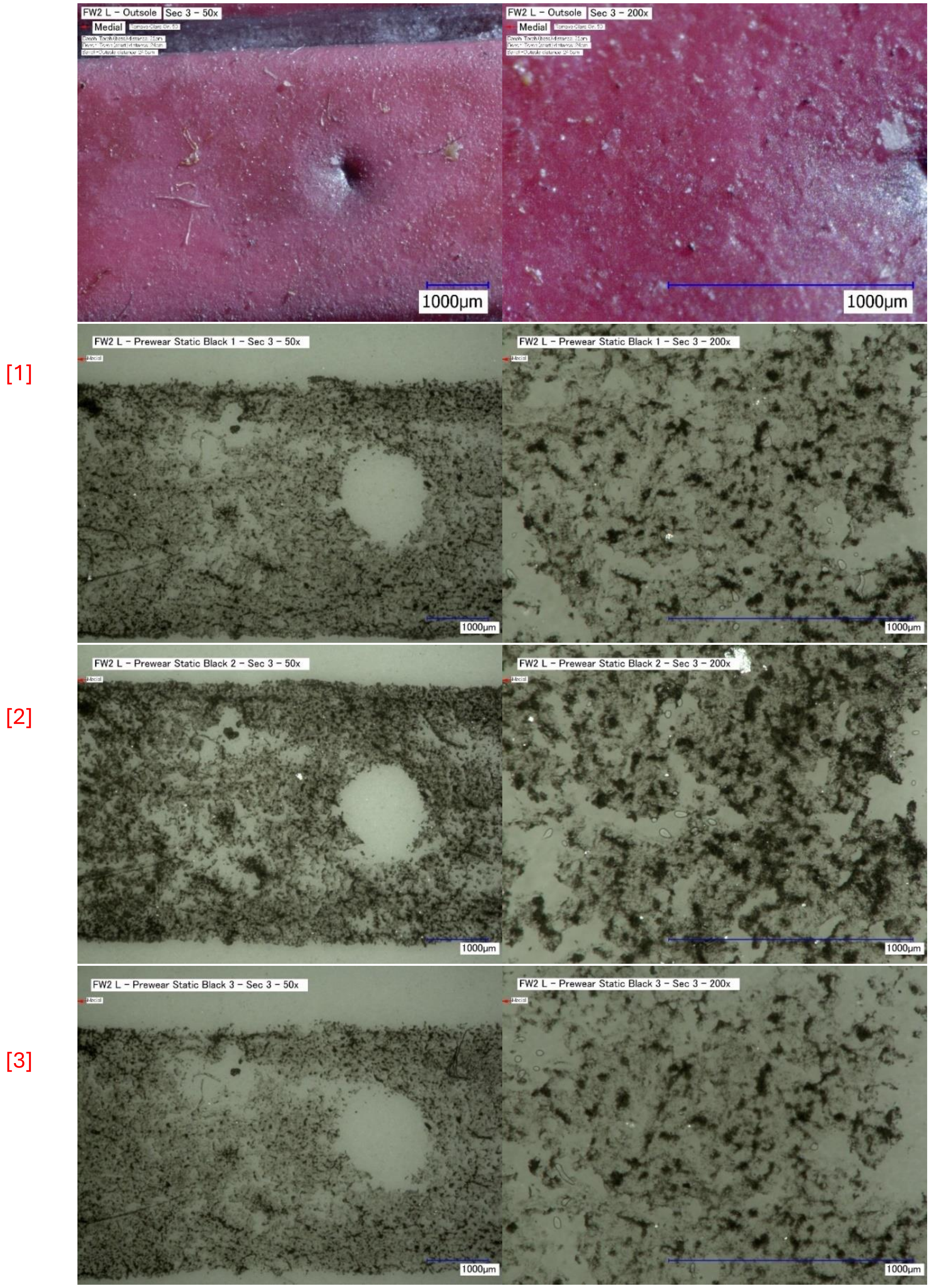
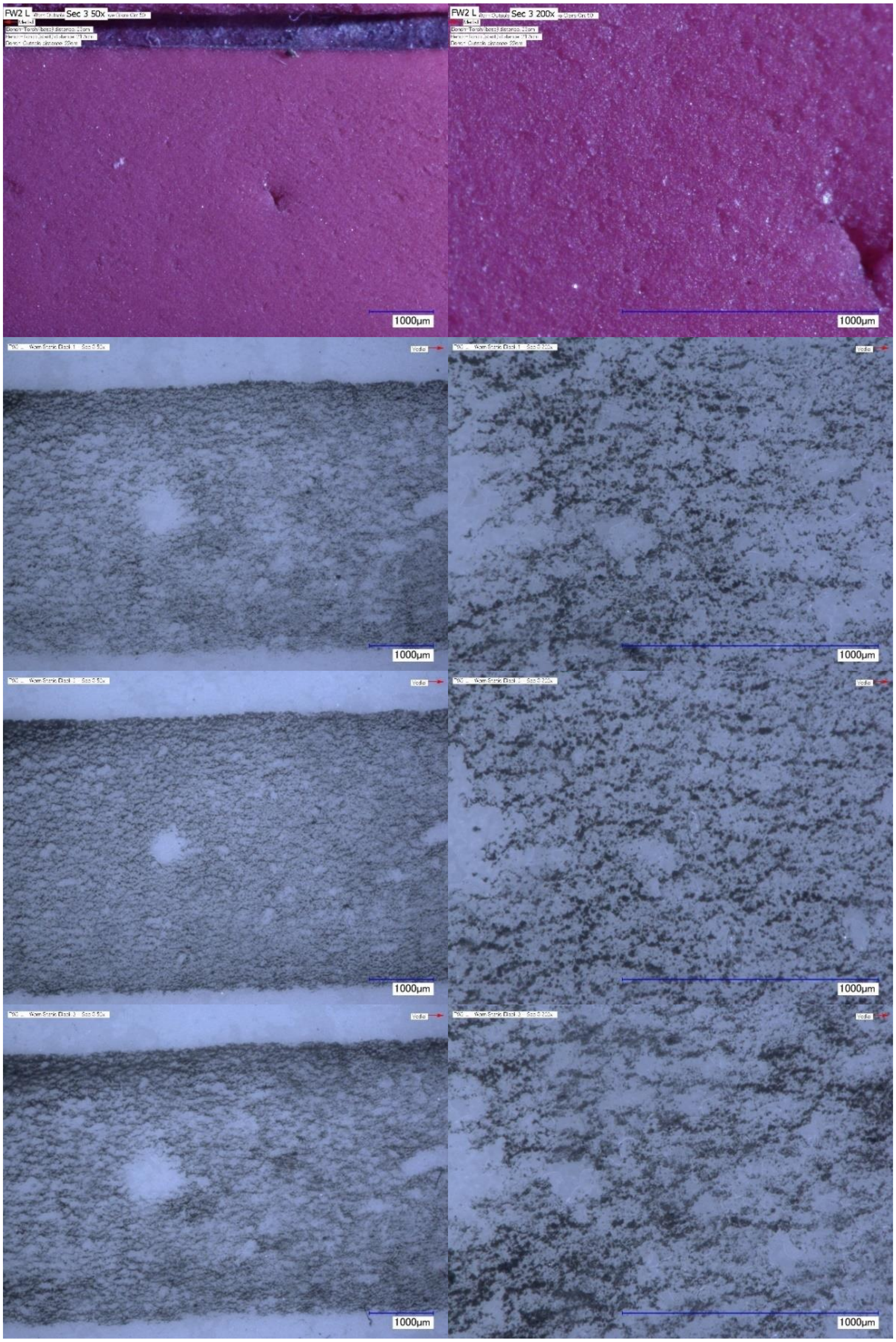


Figure 133: *Pre-wear magnified images of FW2 L section 3 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*



[1]

[2]

[3]

Figure 134: *Worn magnified images of FW2 L section 3 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

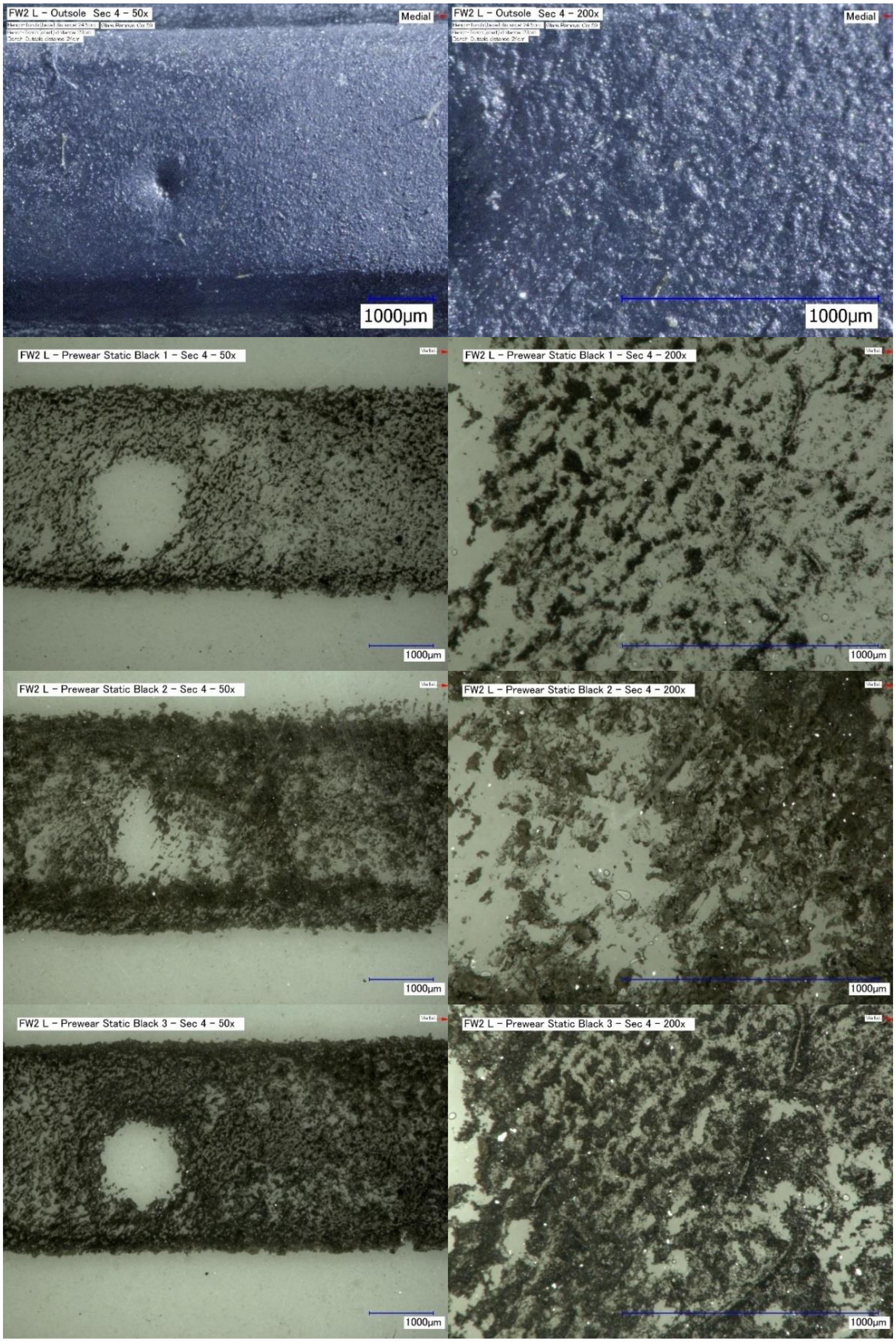
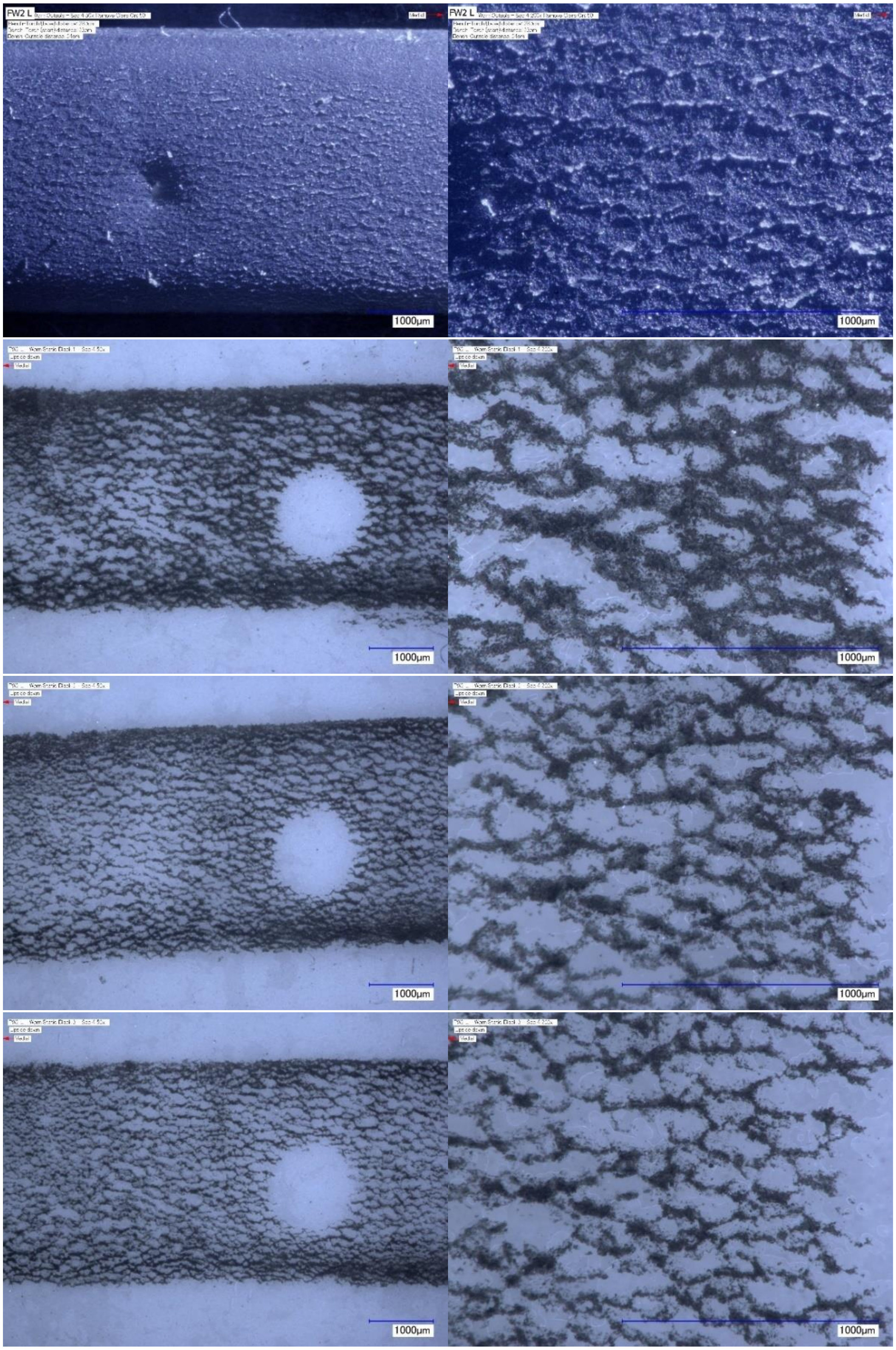


Figure 135: *Pre-wear magnified images of FW2 L section 4 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*



[1]

[2]

[3]

Figure 136: *Worn magnified images of FW2 L section 4 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

C.4. FW2 R

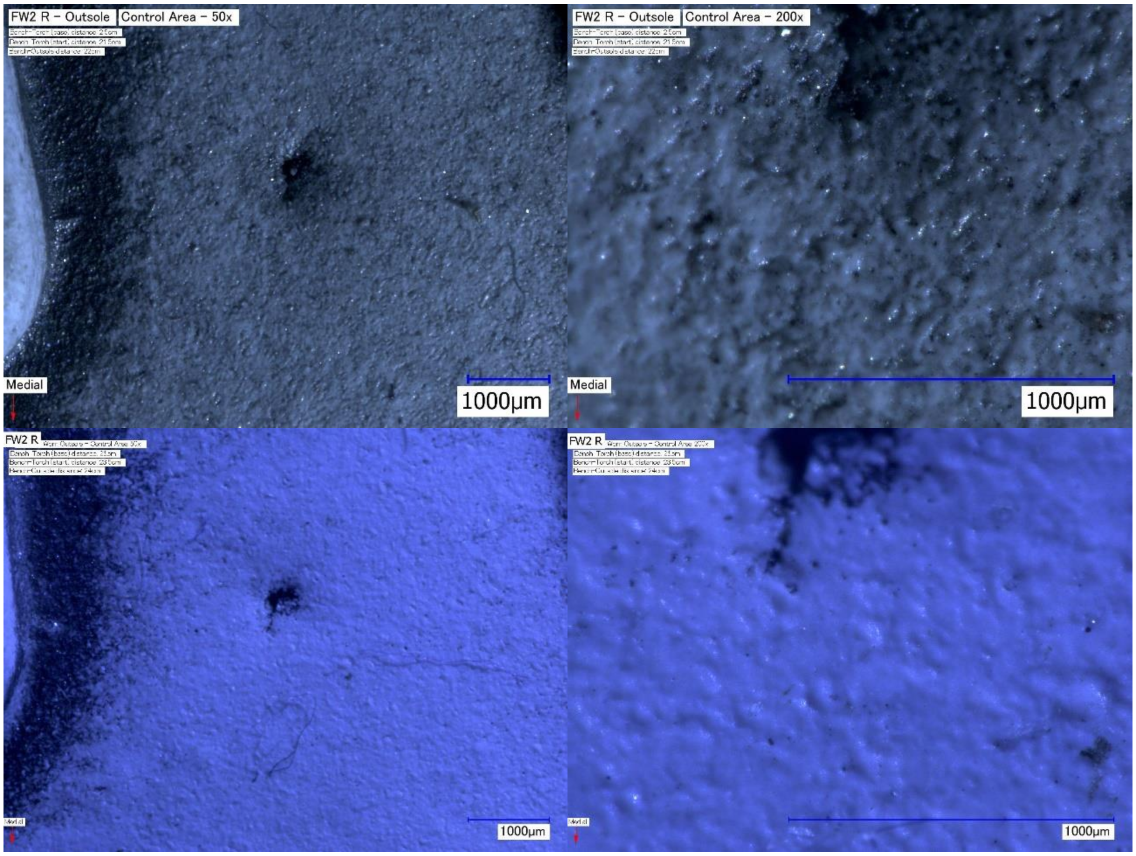


Figure 137: *Pre-wear magnified images of FW2 R control area [top] and worn [bottom], at 50x [left] and 200x [right]*

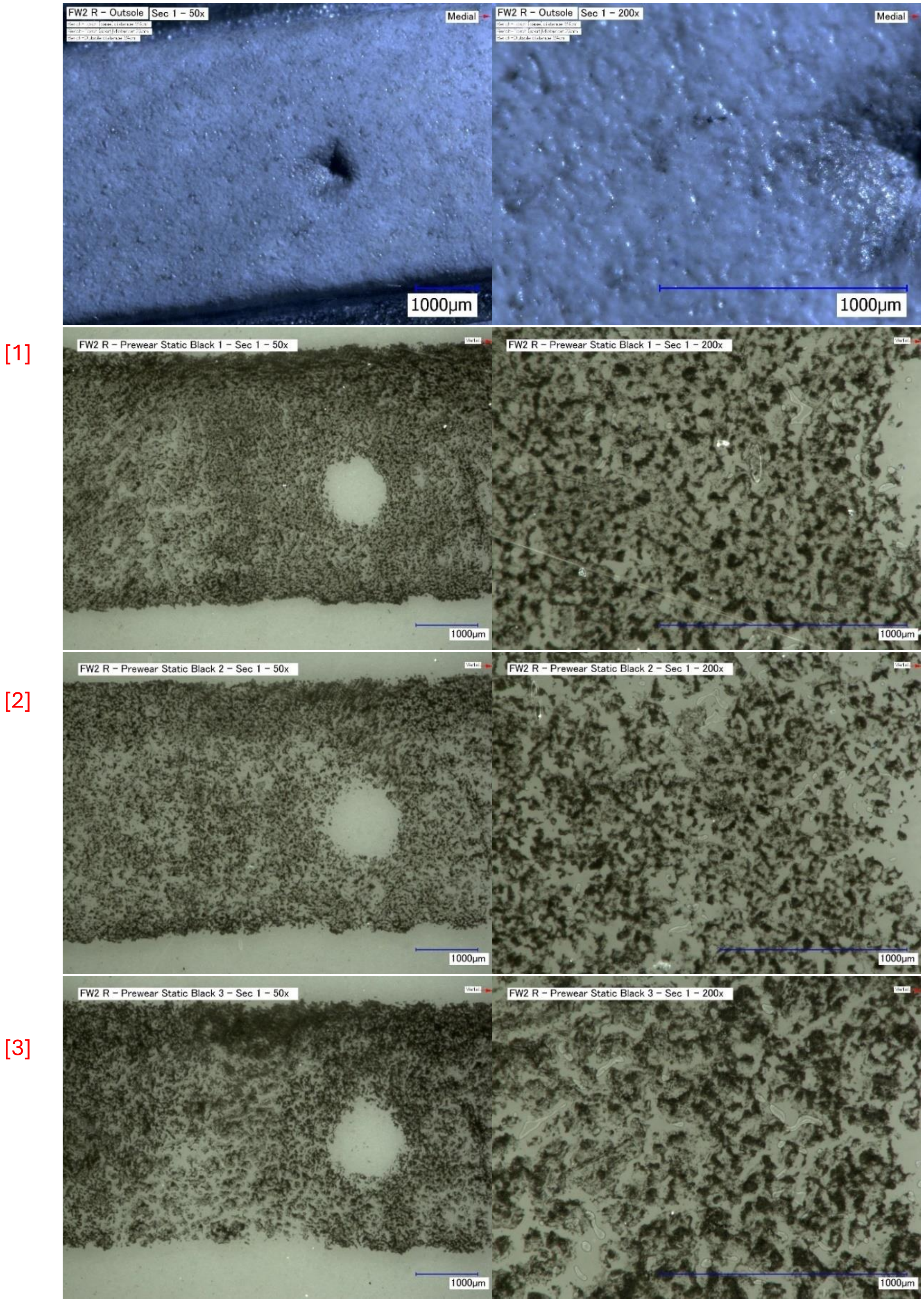


Figure 138: *Pre-wear magnified images of FW2 R section 1 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

[1]

[2]

[3]

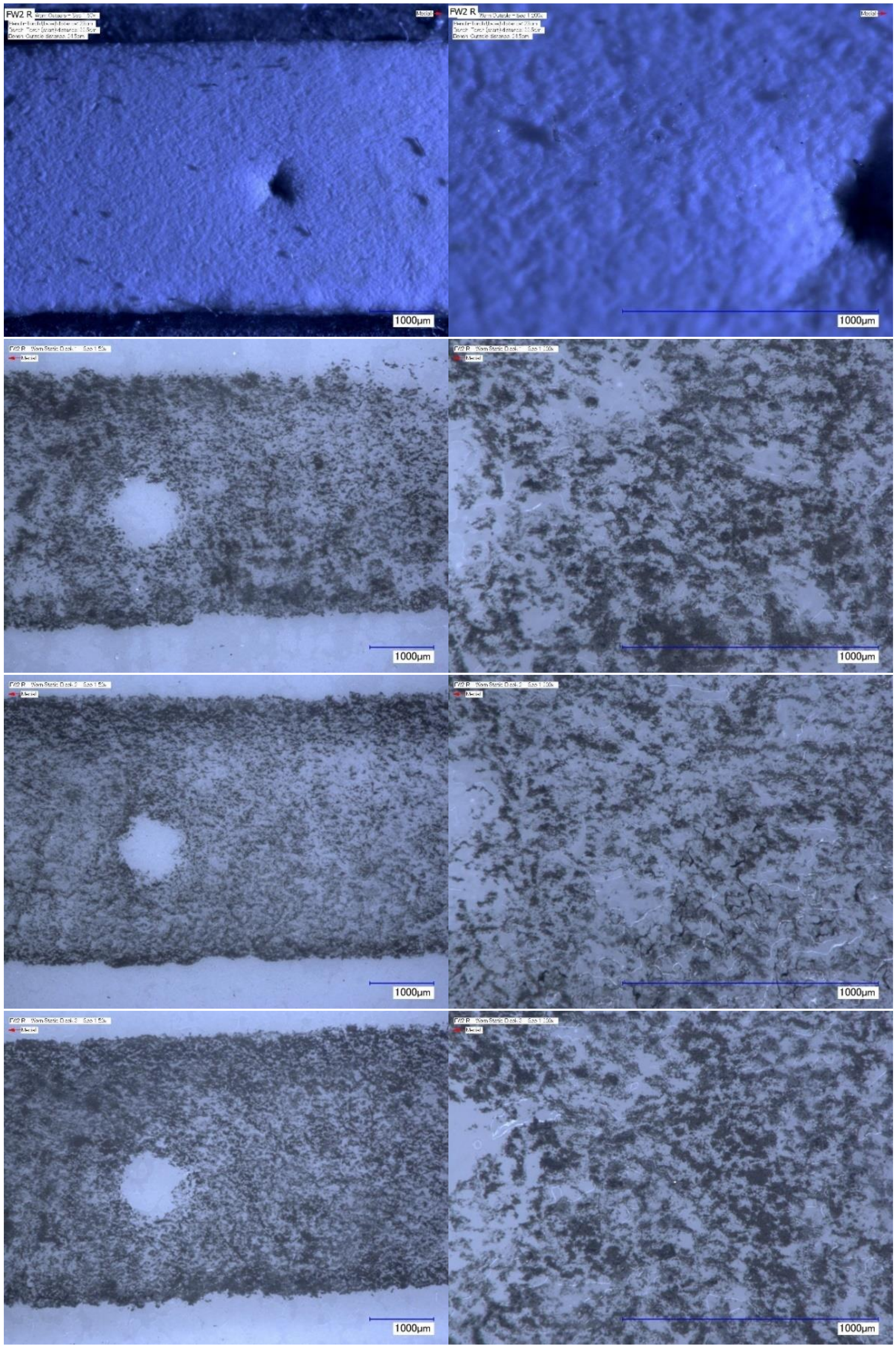


Figure 139: *Worn magnified images of FW2 R section 1 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

[1]

[2]

[3]

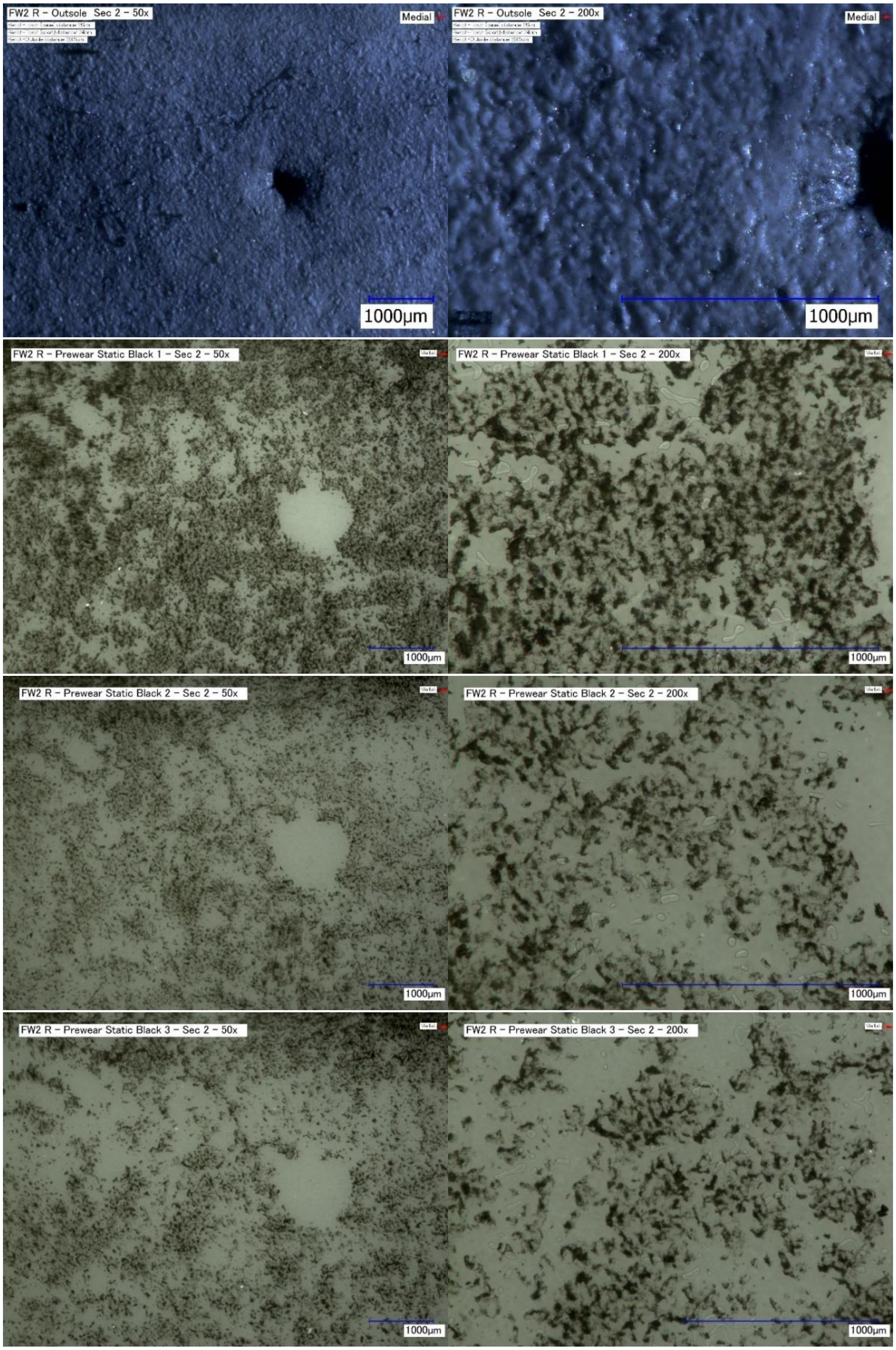


Figure 140: *Pre-wear magnified images of FW2 R section 2 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

[1]

[2]

[3]

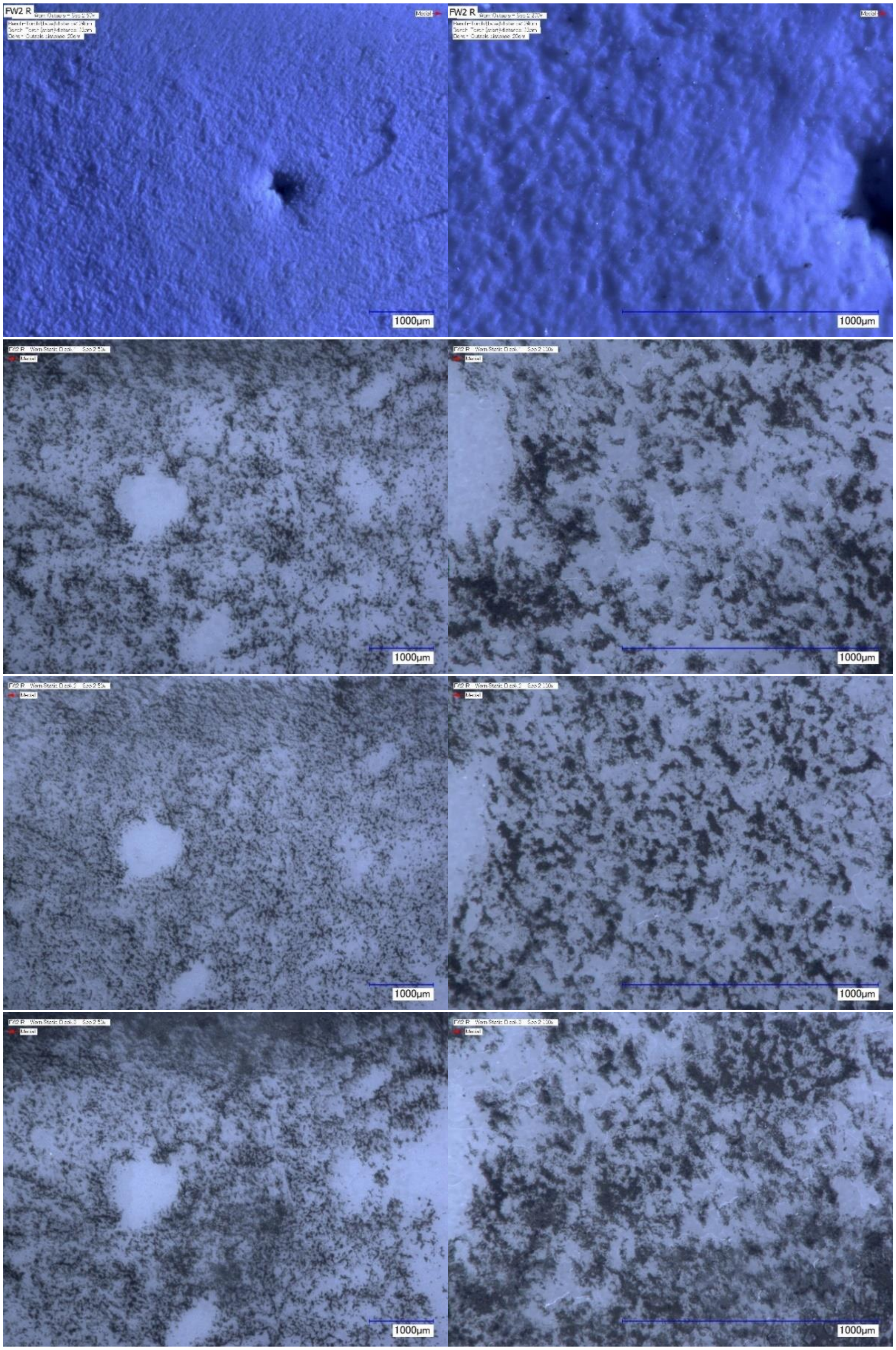


Figure 141: *Worn magnified images of FW2 R section 2 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

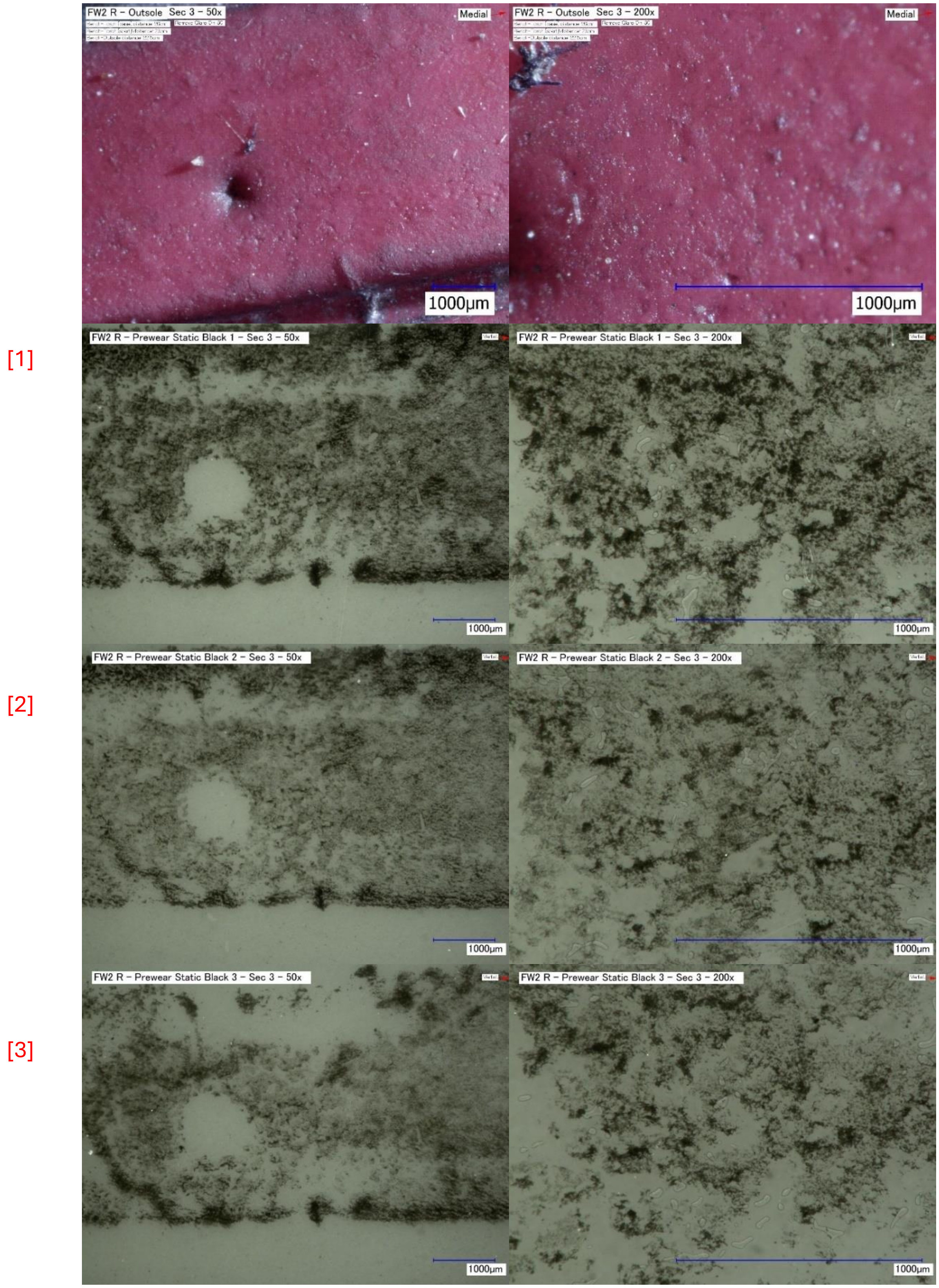
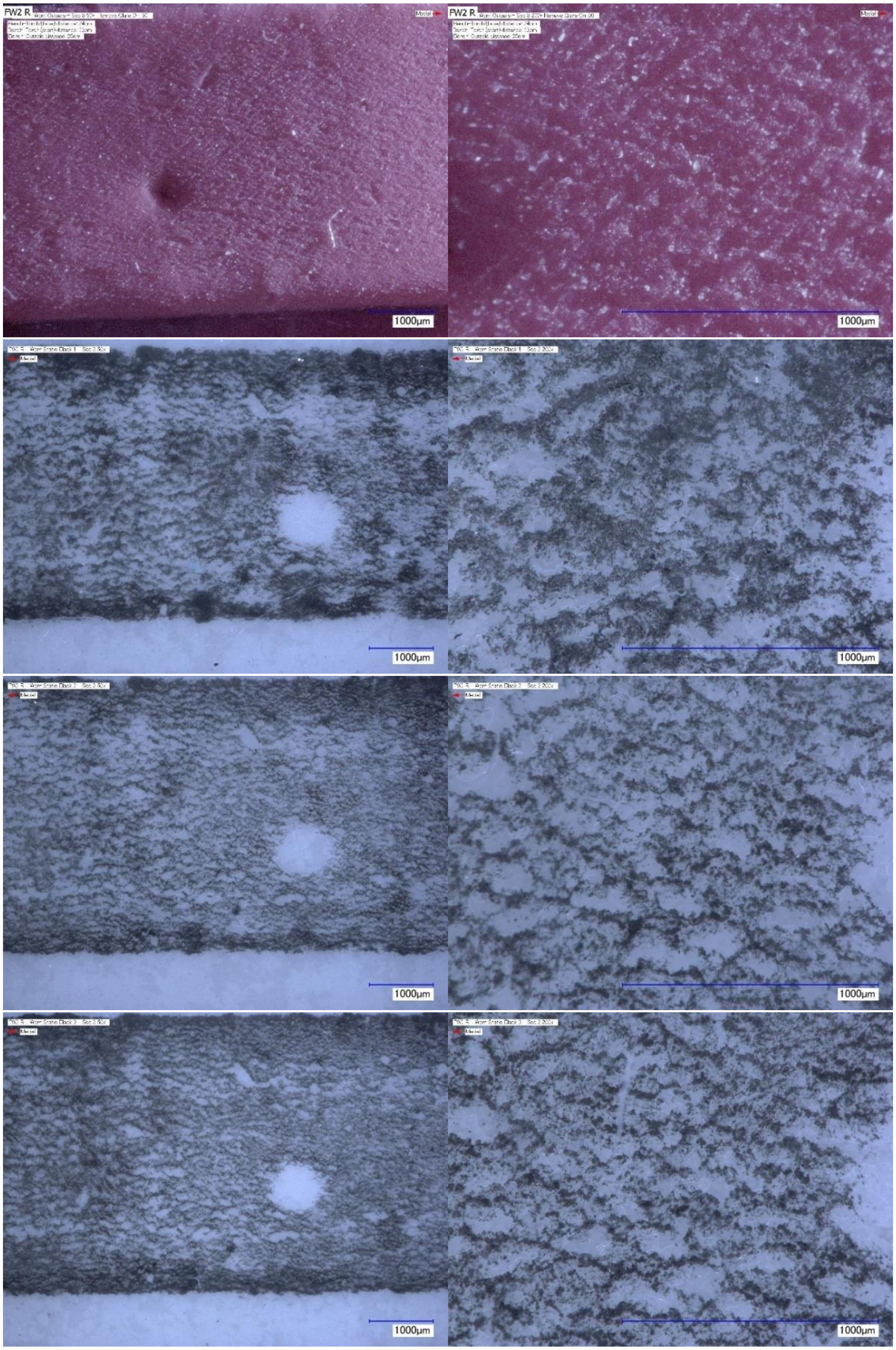


Figure 142: *Pre-wear magnified images of FW2 R section 3 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*



[1]

[2]

[3]

Figure 143: *Worn magnified images of FW2 R section 3 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

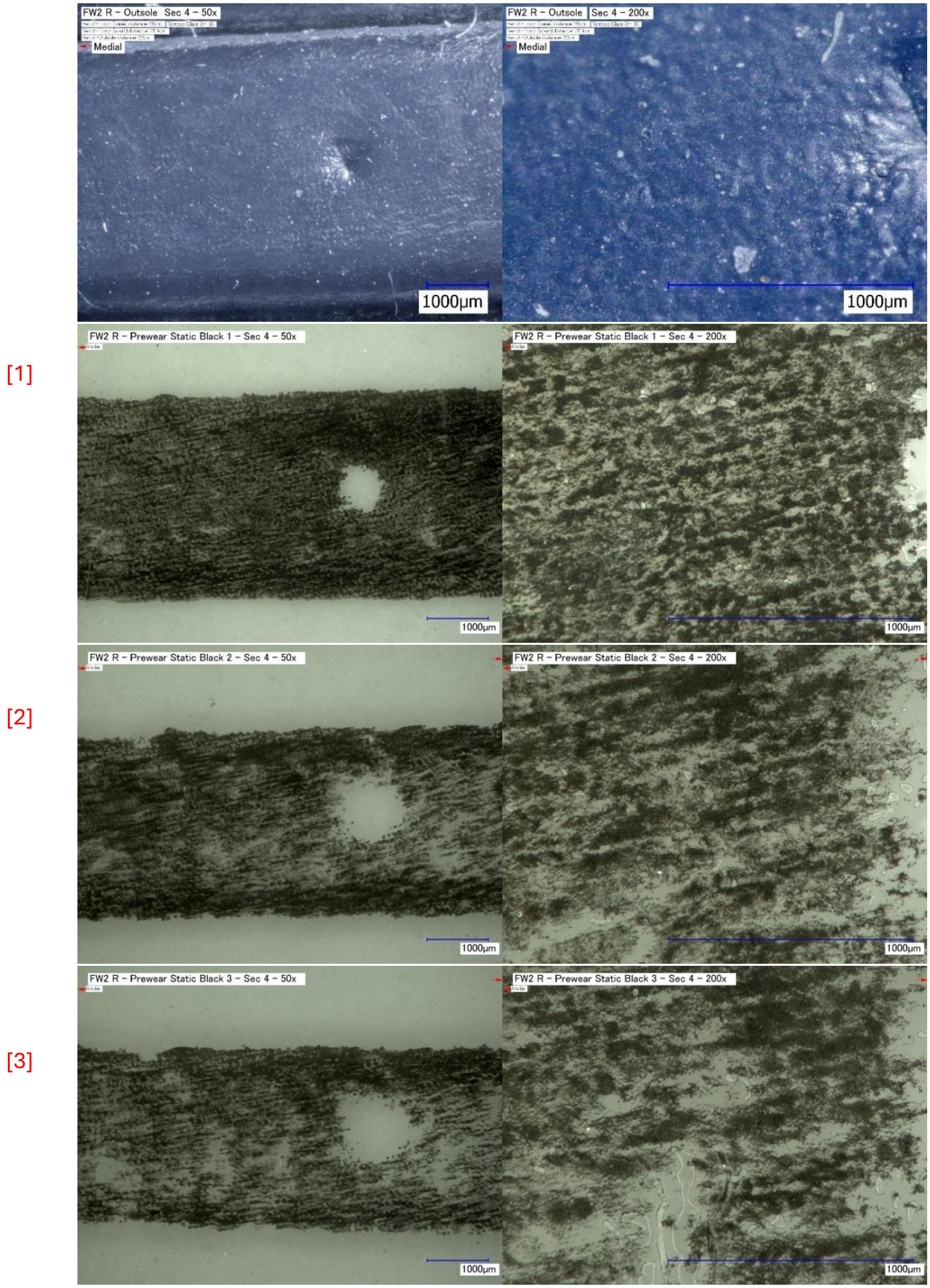


Figure 144: *Pre-wear magnified images of FW2 R section 4 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

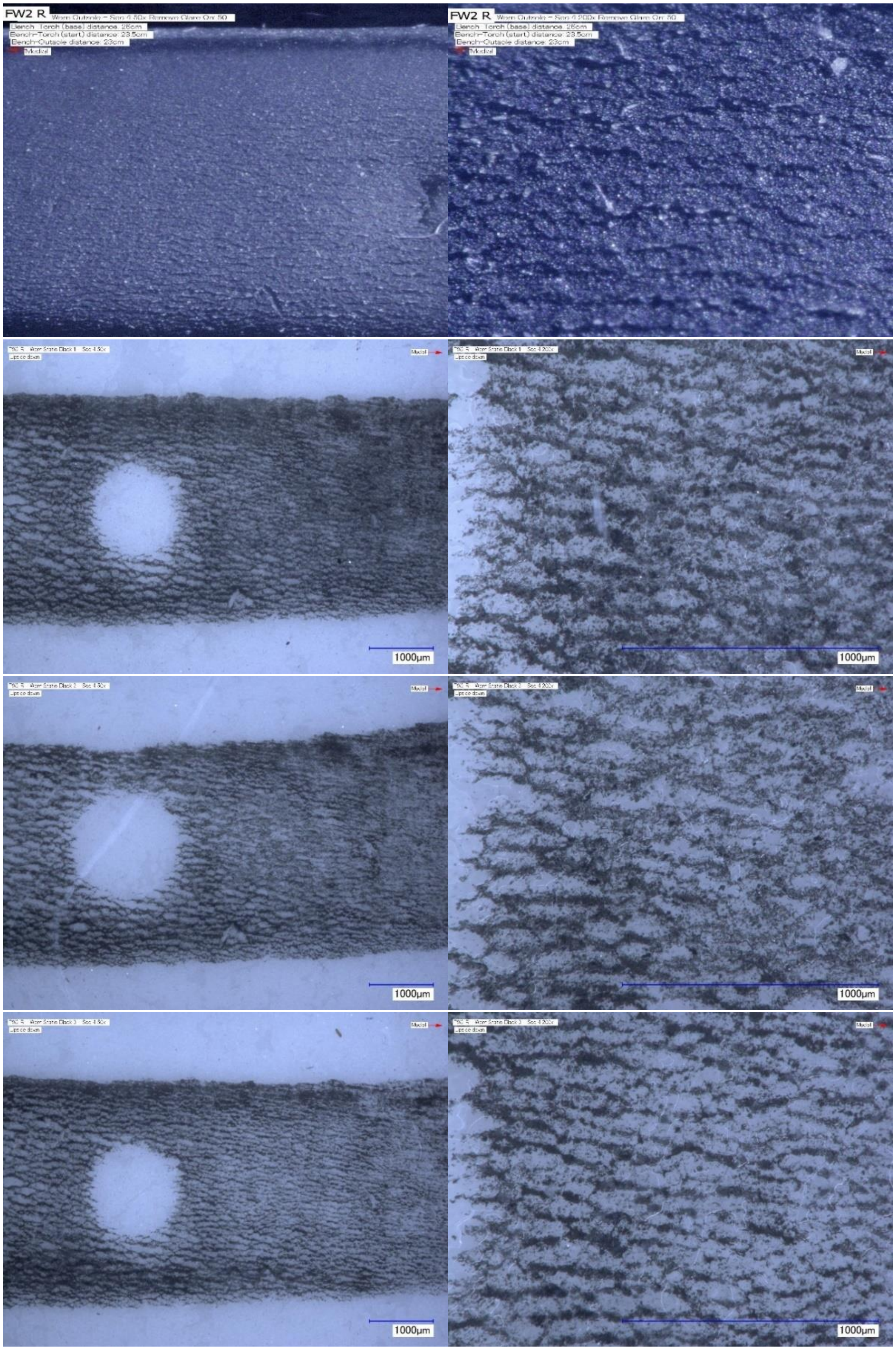


Figure 145: *Worn magnified images of FW2 R section 4 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

C.5. FW3 L

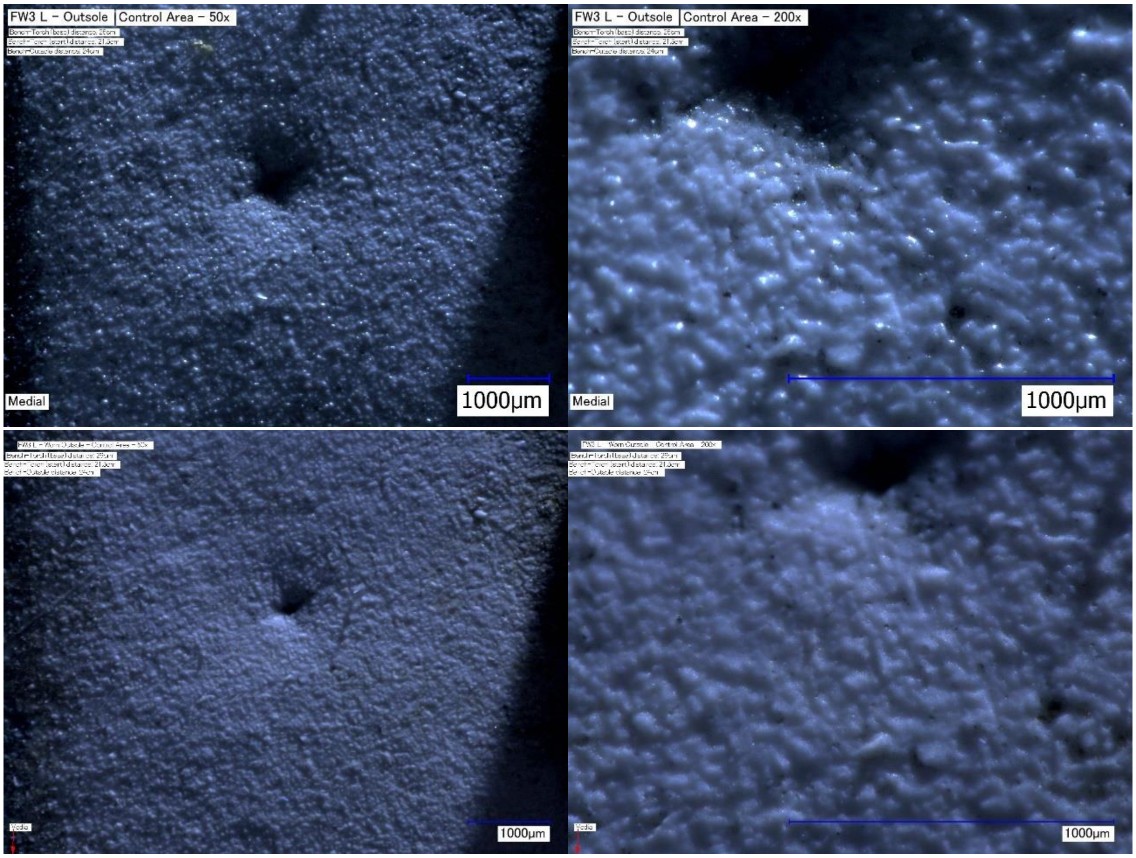


Figure 146: *Pre-wear magnified images of FW3 L control area [top] and worn [bottom], at 50x [left] and 200x [right]*

[1]

[2]

[3]

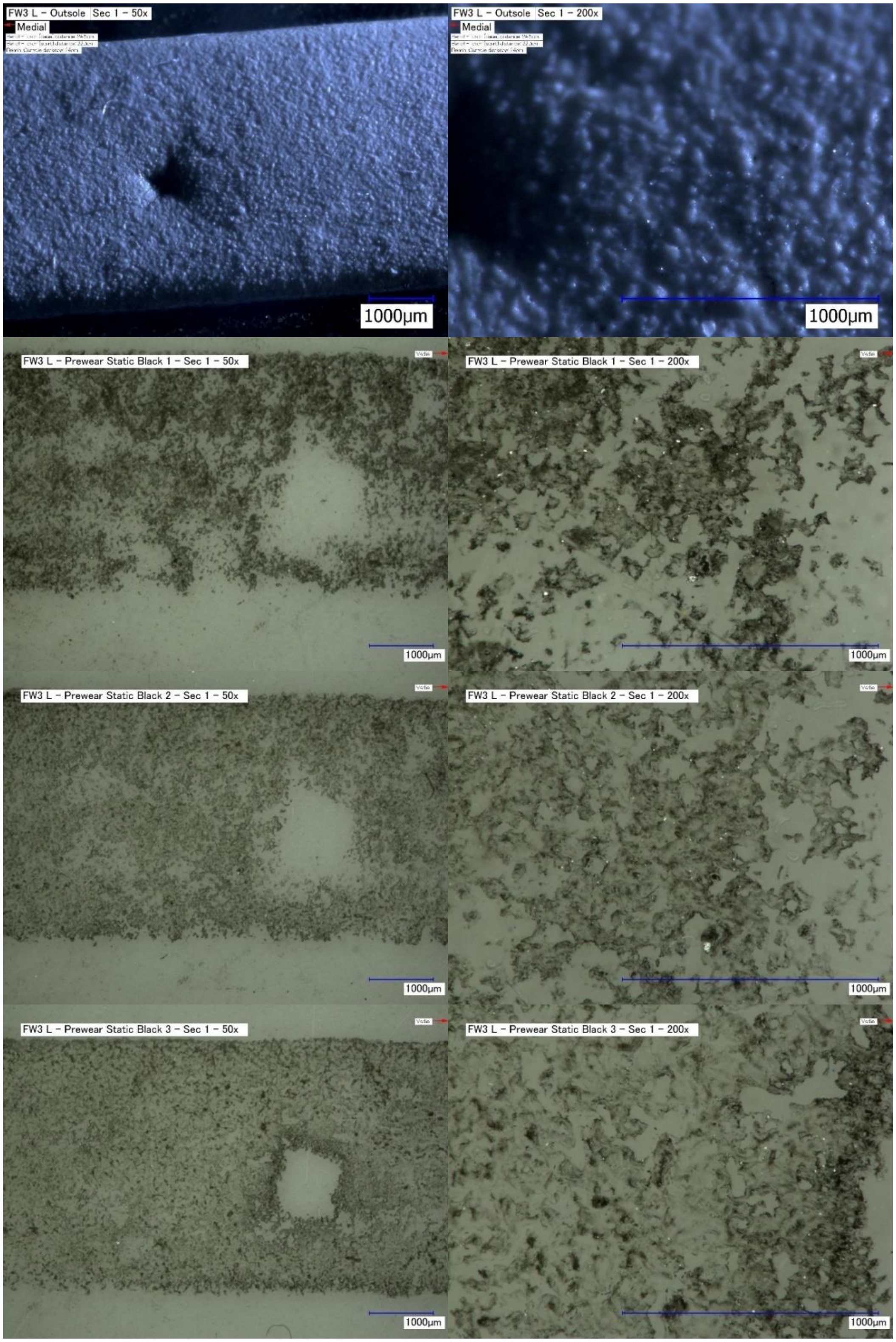


Figure 147: *Pre-wear magnified images of FW3 L section 1 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

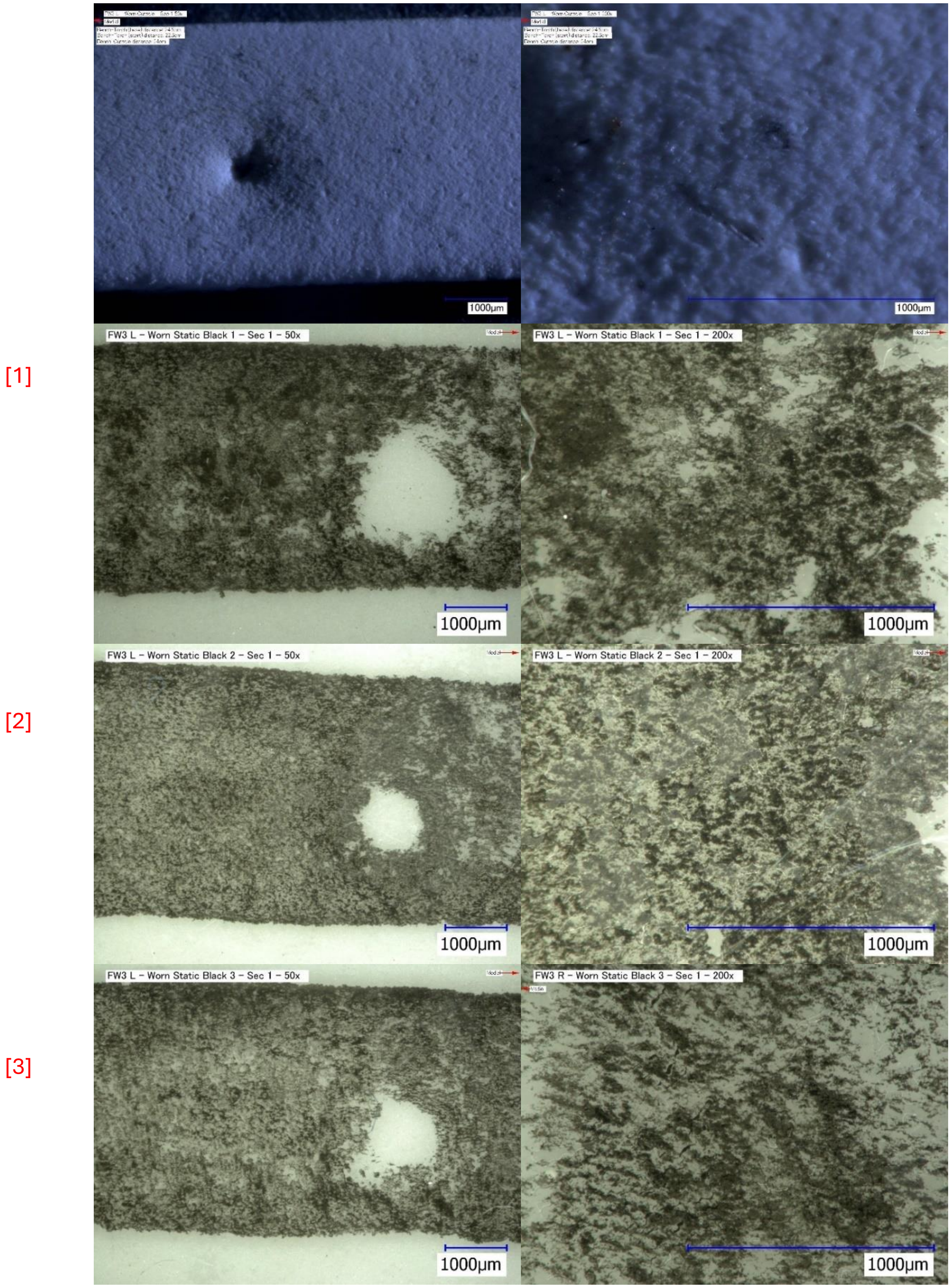


Figure 148: *Worn magnified images of FW3 L section 1 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

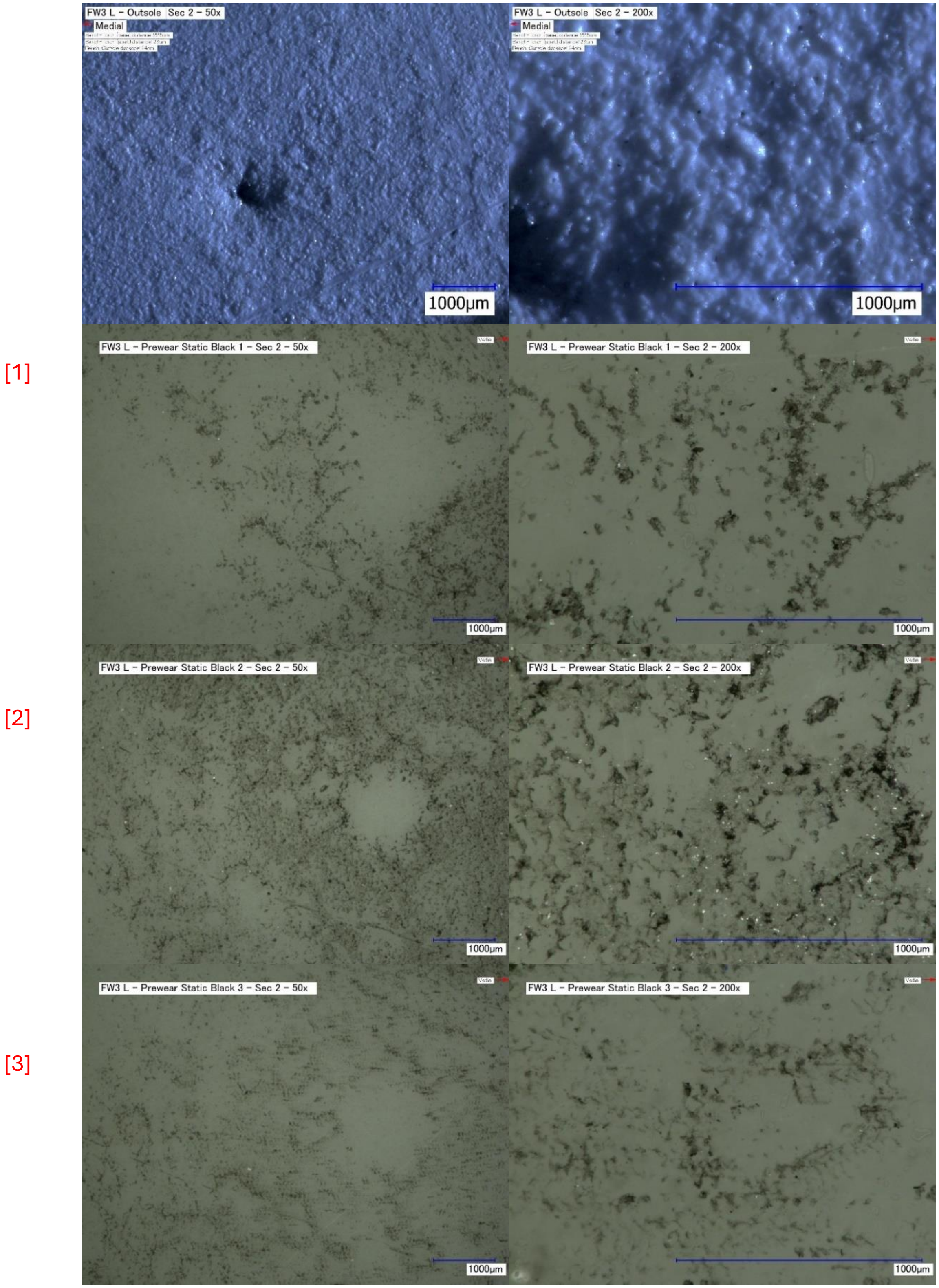
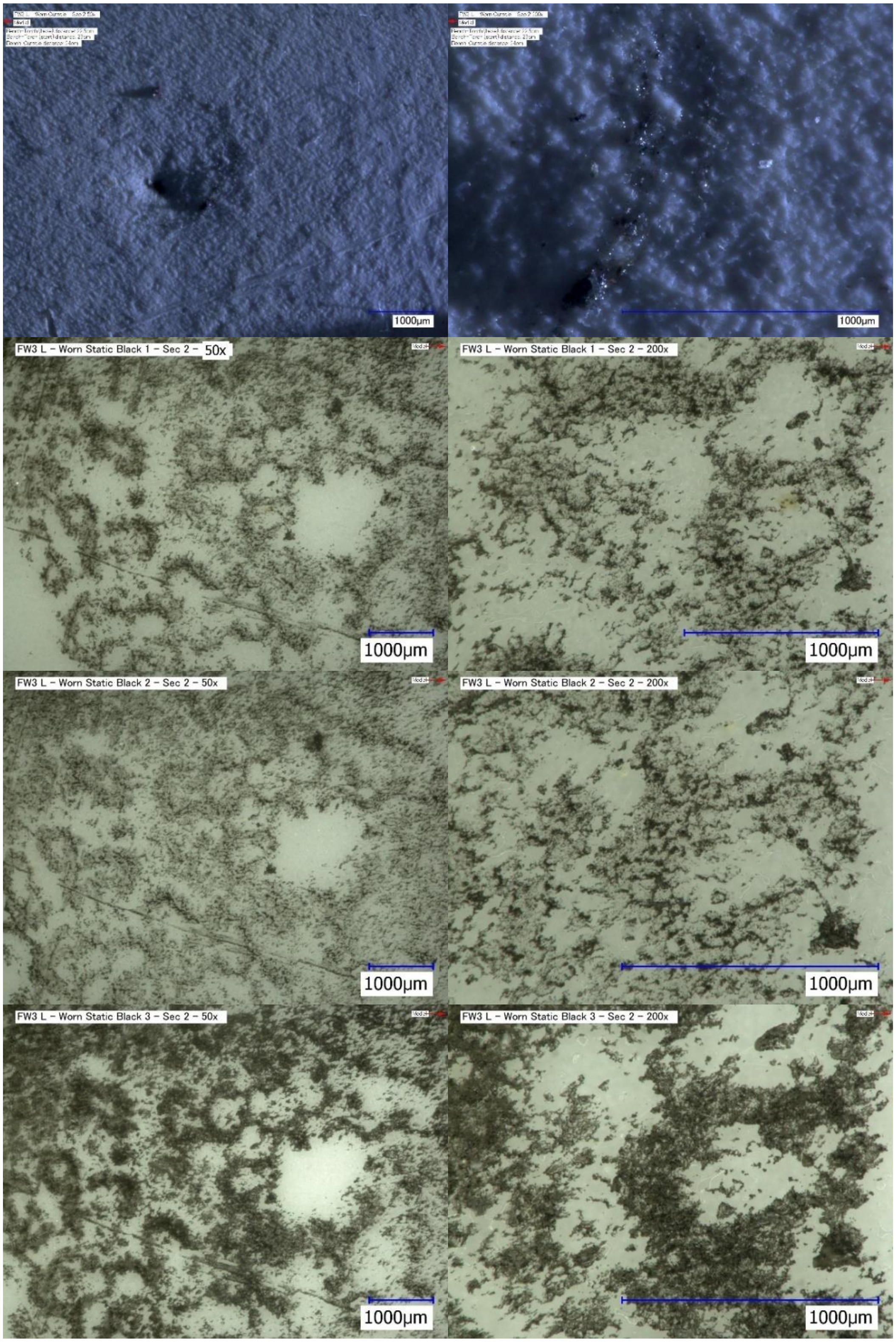


Figure 149: *Pre-wear magnified images of FW3 L section 2 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*



[1]

[2]

[3]

Figure 150: *Worn magnified images of FW3 L section 2 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

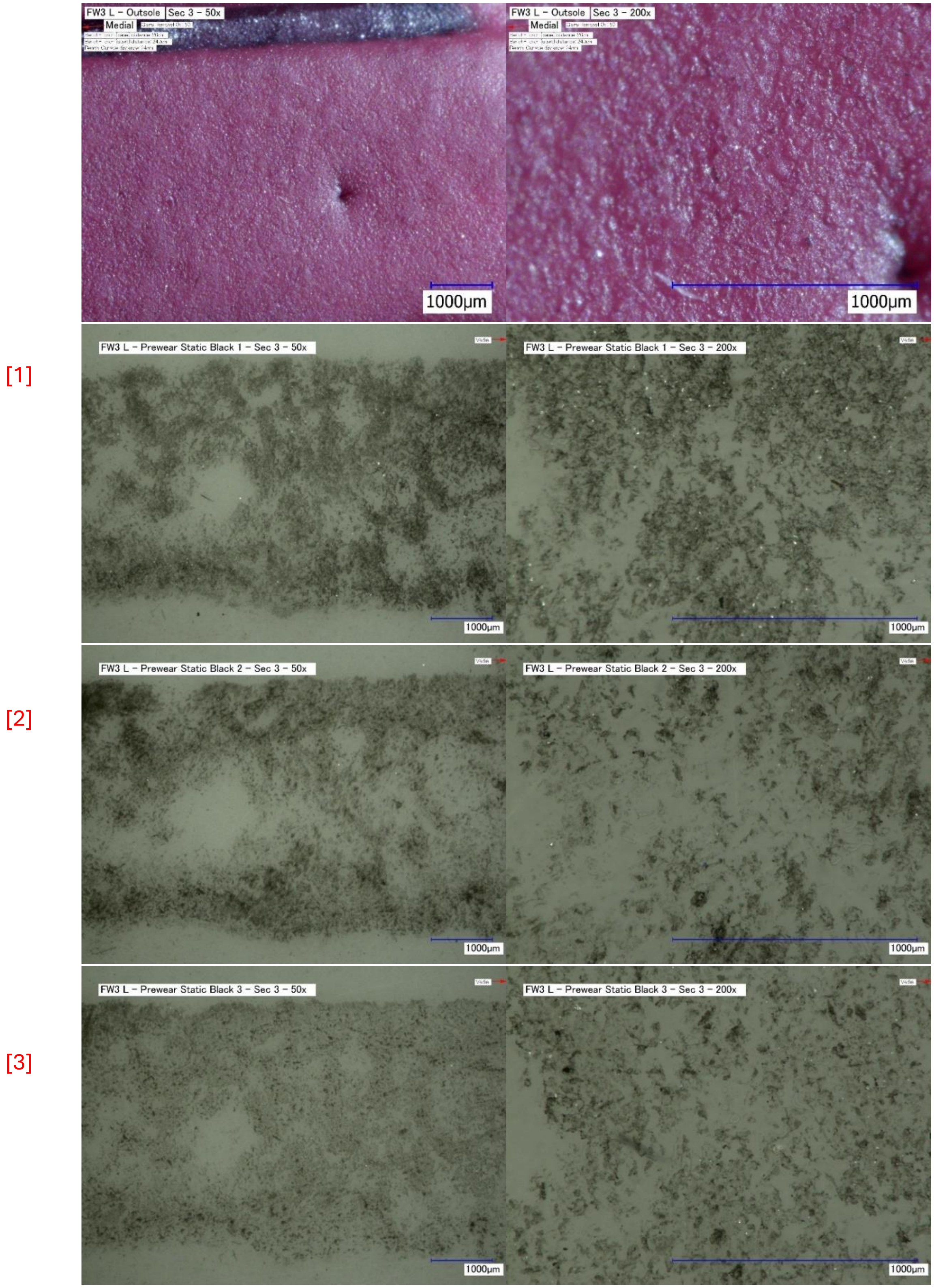


Figure 151: *Pre-wear magnified images of FW3 L section 3 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

[1]

[2]

[3]

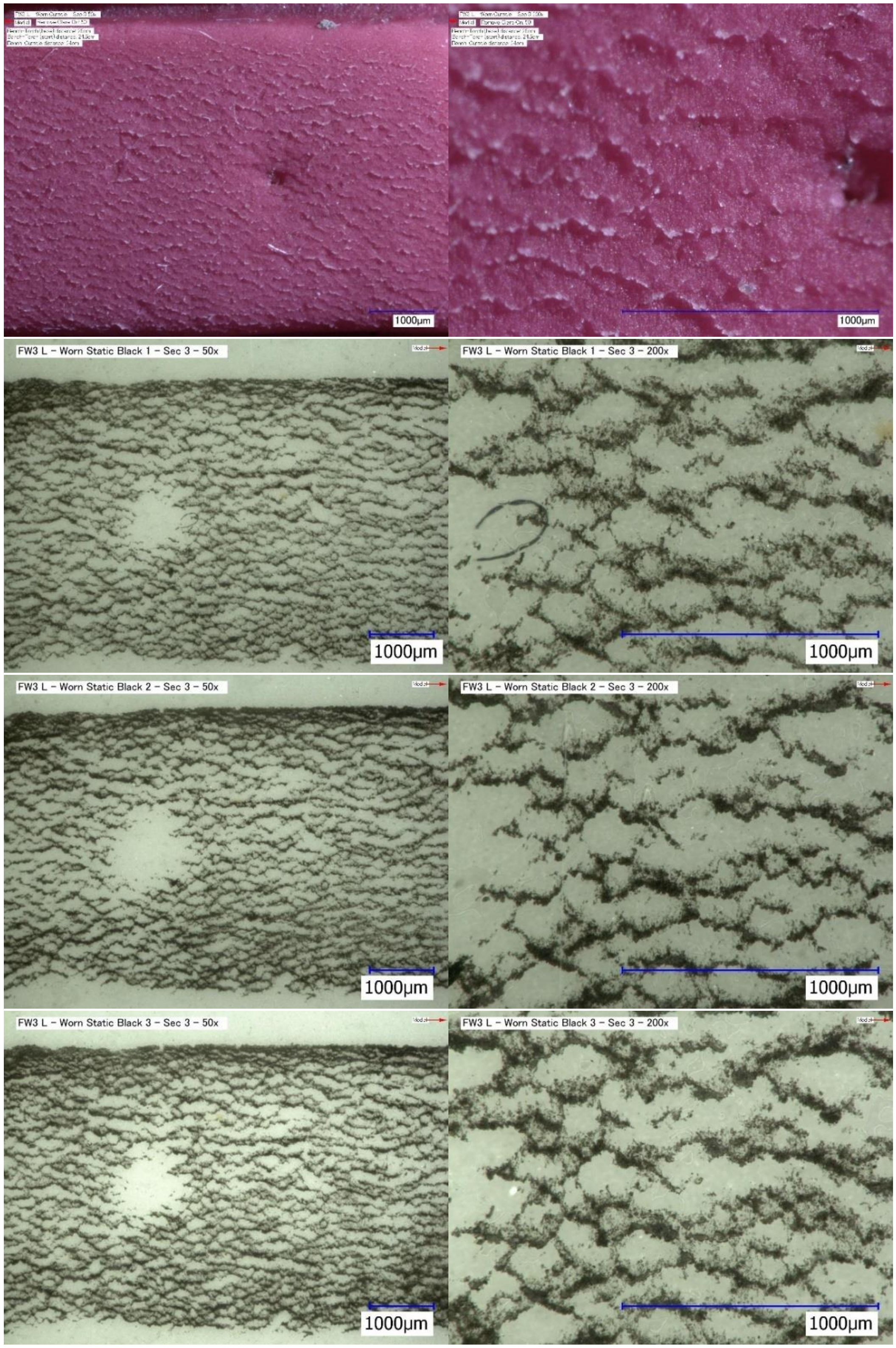


Figure 152: *Worn magnified images of FW3 L section 3 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

[1]

[2]

[3]

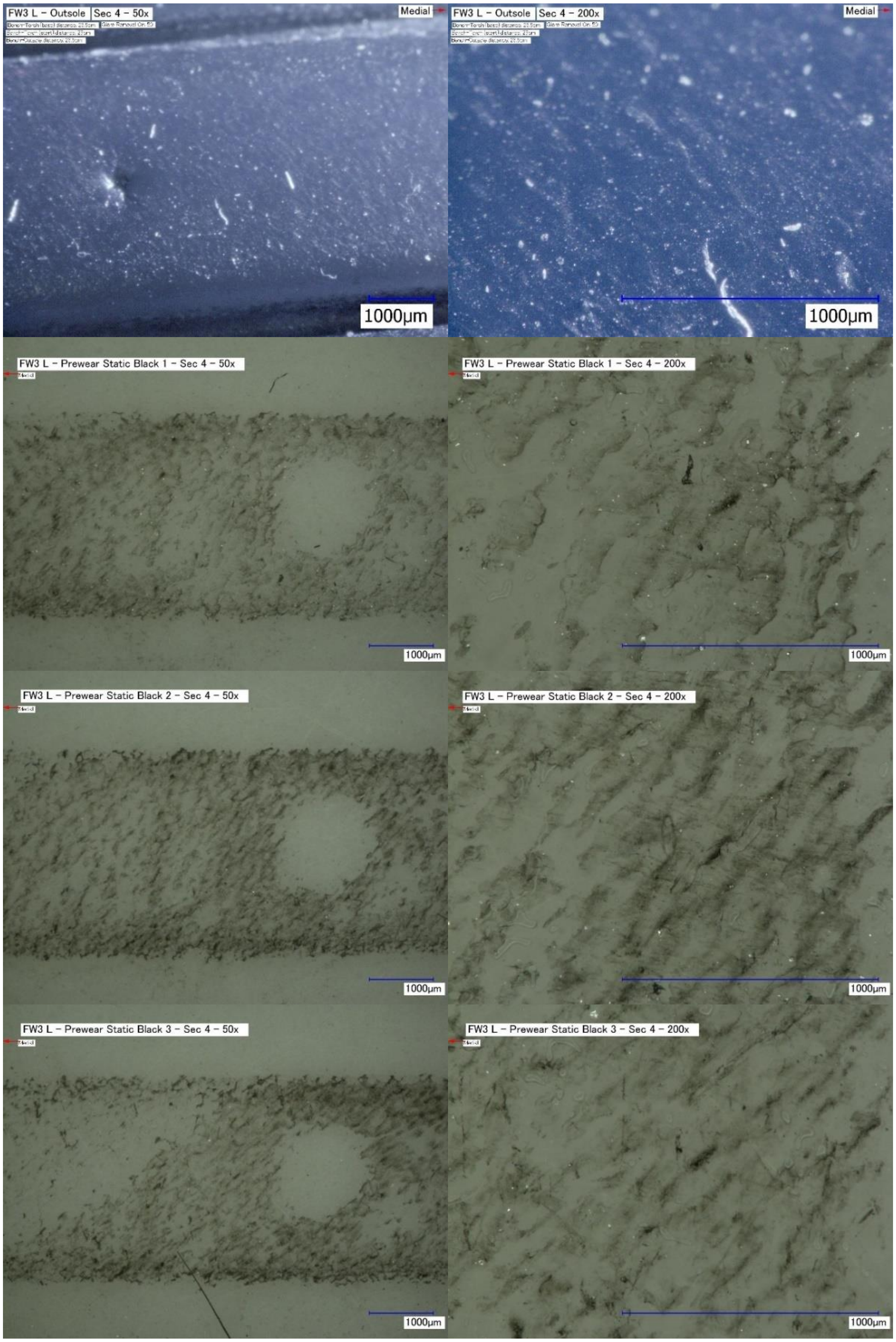
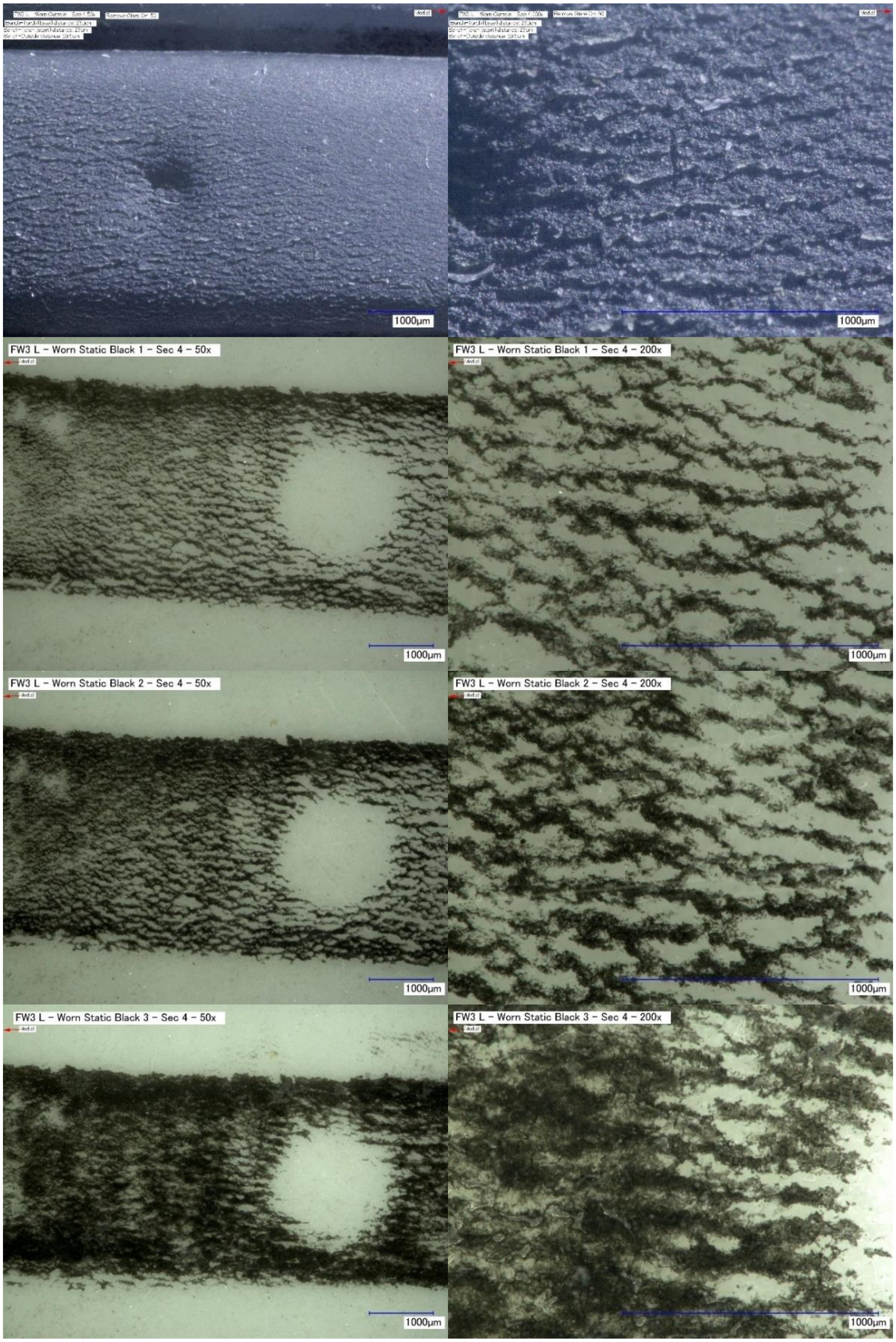


Figure 153: *Pre-wear magnified images of FW3 L section 4 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*



[1]

[2]

[3]

Figure 154: *Worn magnified images of FW3 L section 4 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

C.6. FW3 R

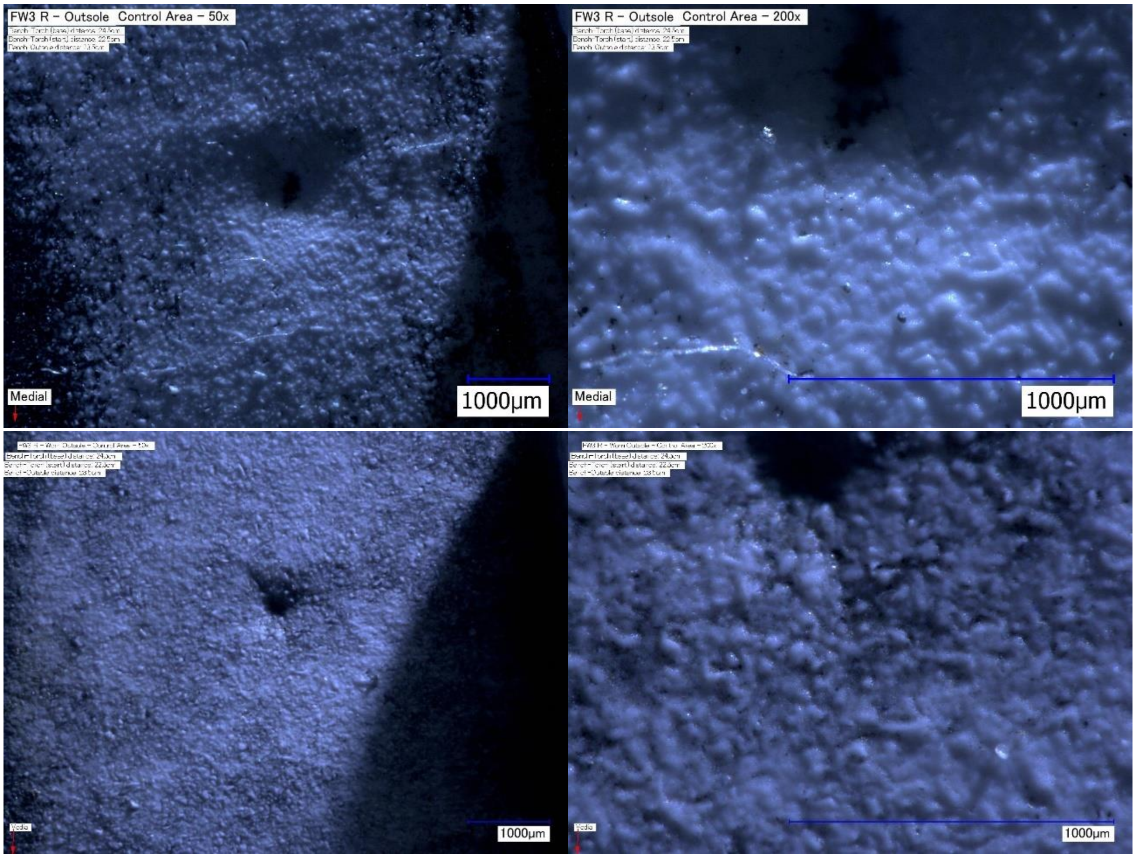
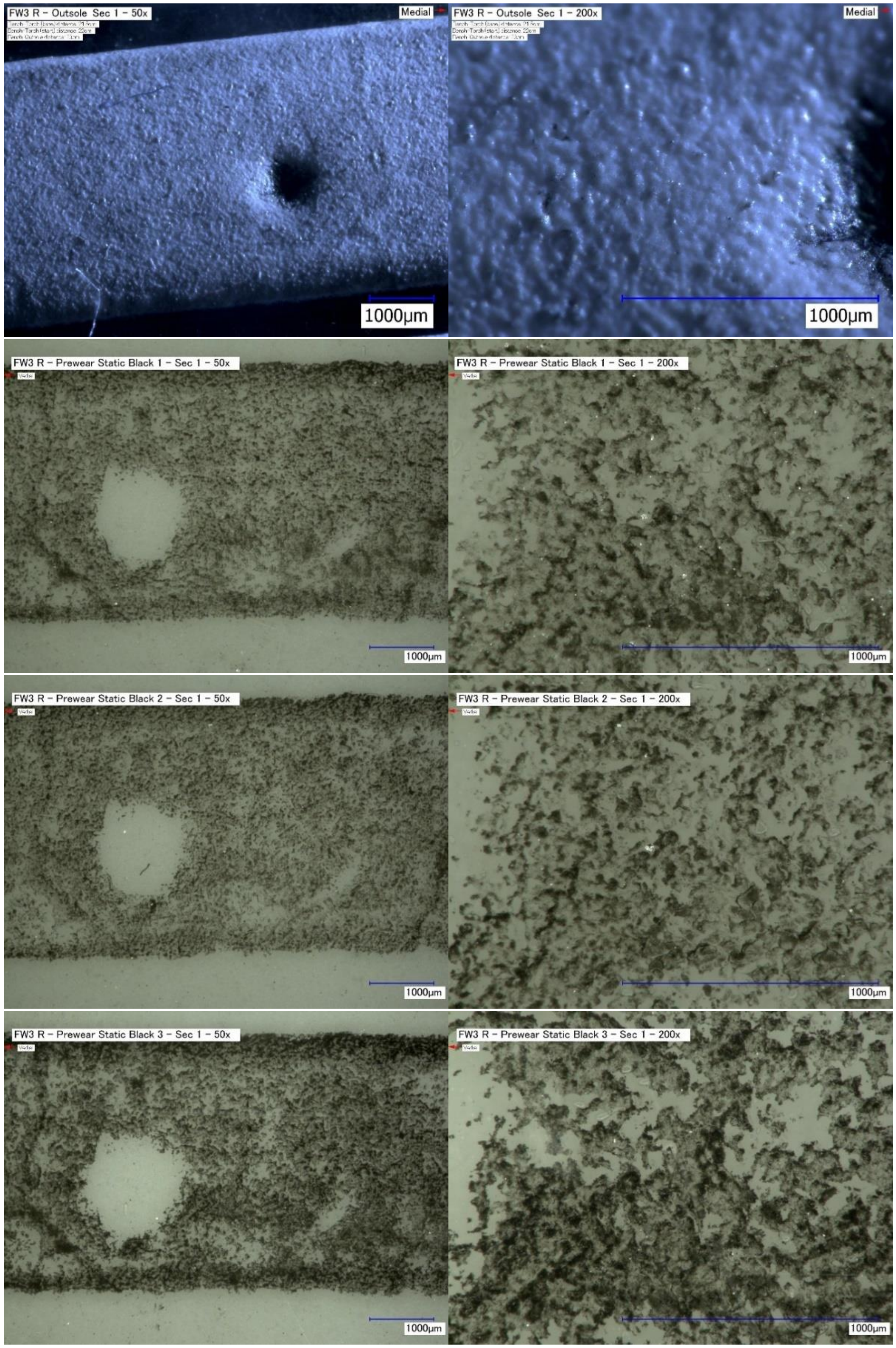


Figure 155: *Pre-wear magnified images of FW3 R control area [top] and worn [bottom], at 50x [left] and 200x [right]*



[1]

[2]

[3]

Figure 156: *Pre-wear magnified images of FW3 R section 1 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

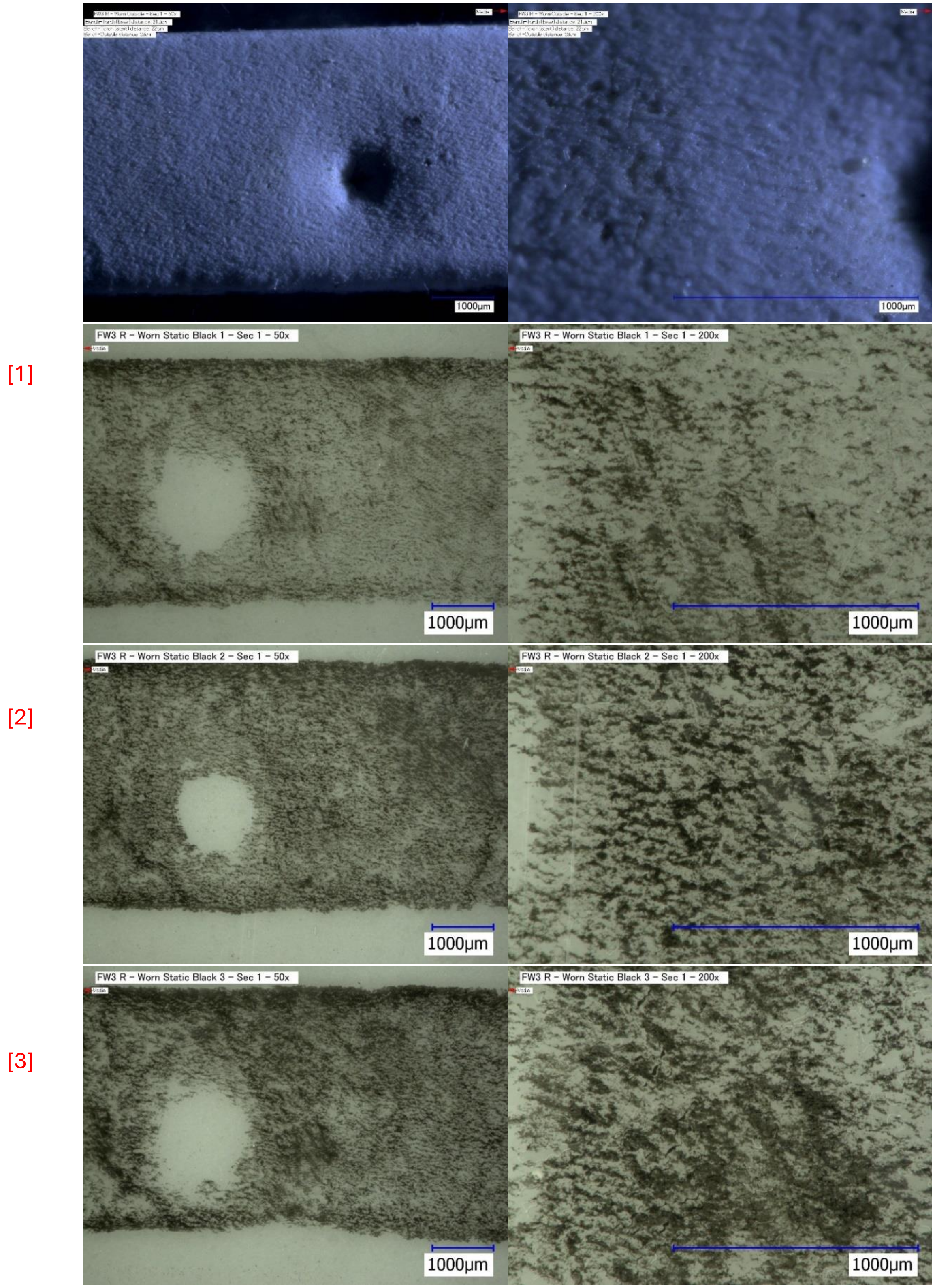


Figure 157: *Worn magnified images of FW3 R section 1 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

[1]

[2]

[3]

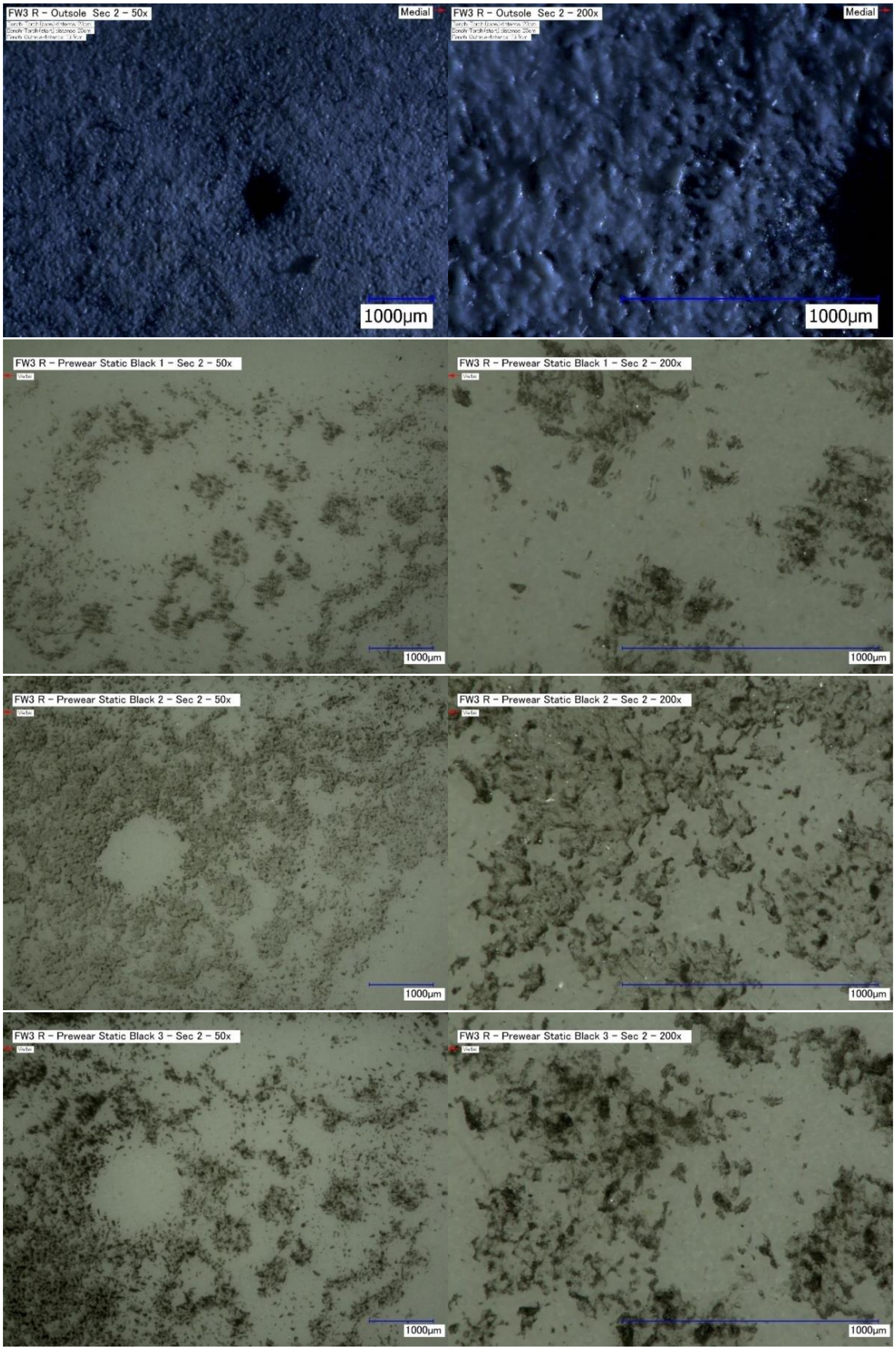


Figure 158: *Pre-wear magnified images of FW3 R section 2 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

[1]

[2]

[3]

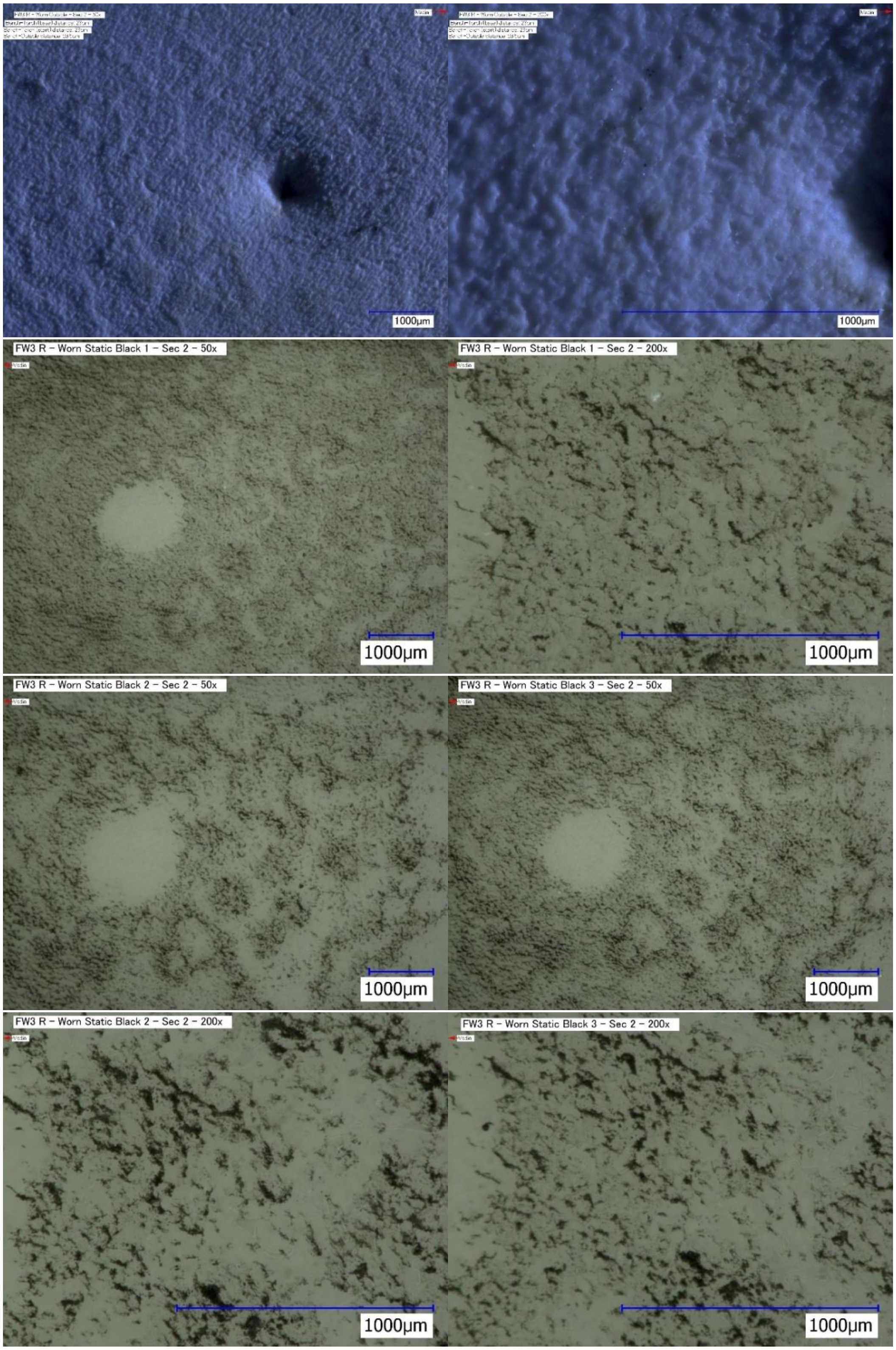


Figure 159: *Worn magnified images of FW3 R section 2 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

[1]

[2]

[3]

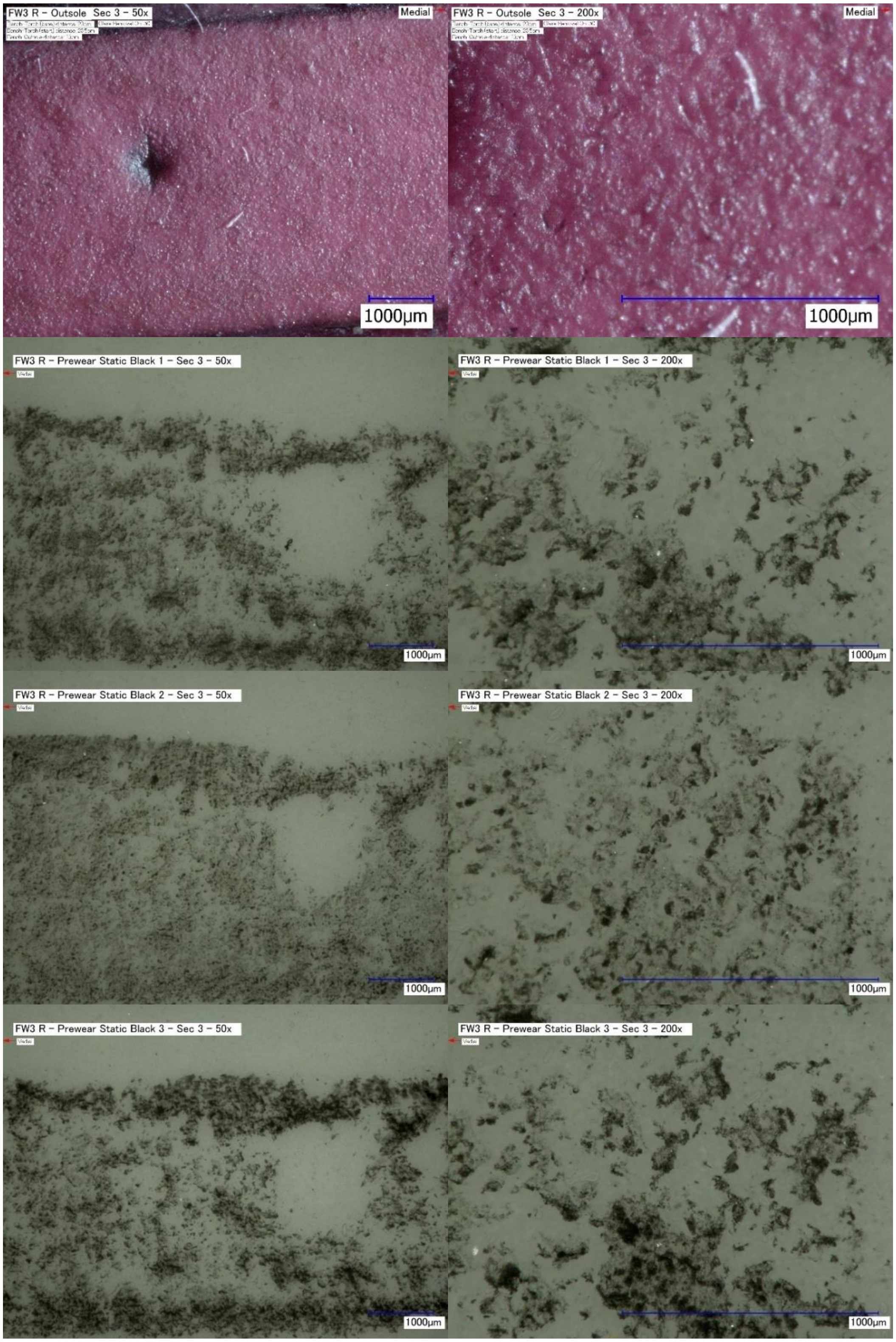


Figure 160: *Pre-wear magnified images of FW3 R section 3 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

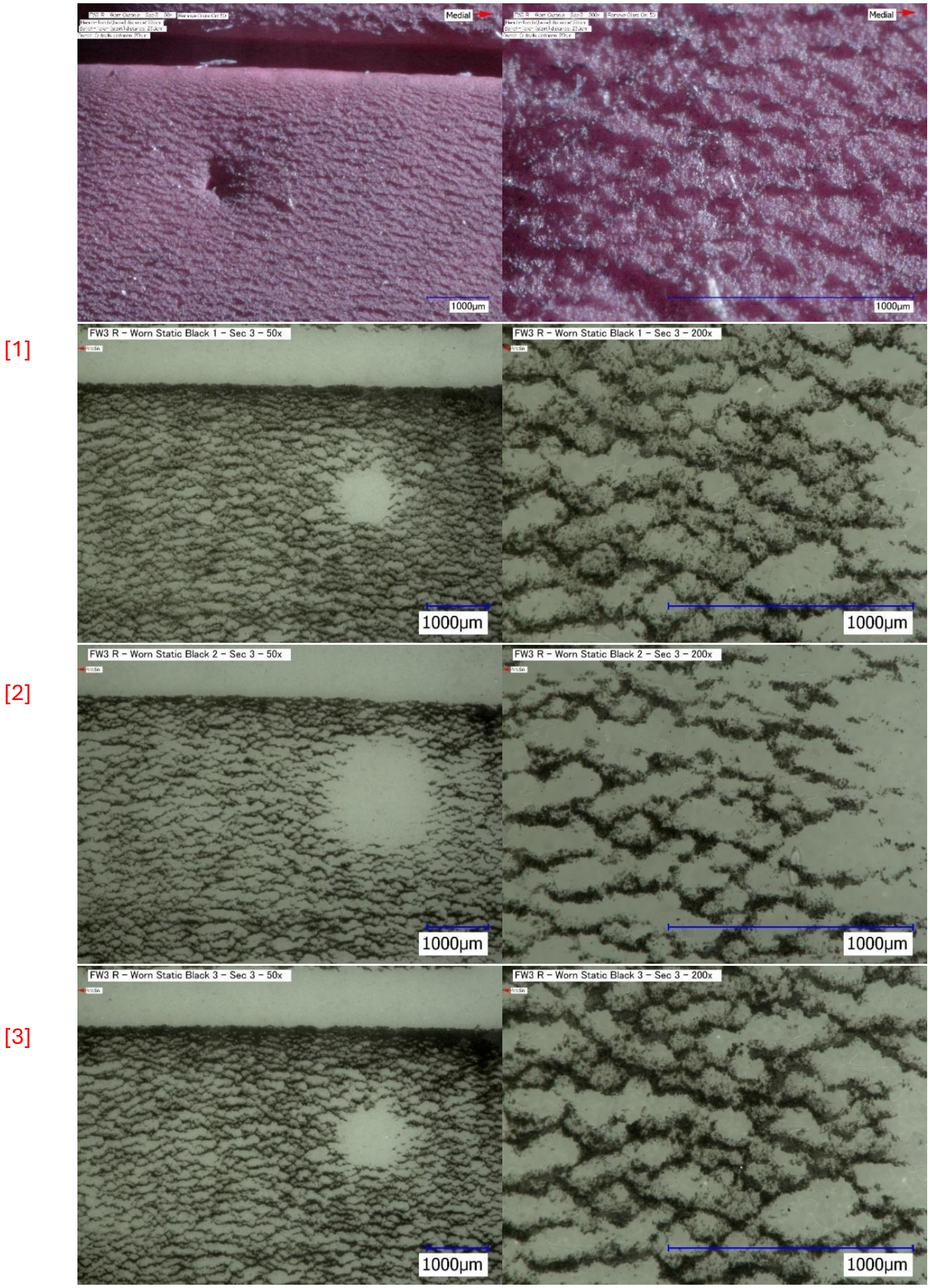


Figure 161: *Worn magnified images of FW3 R section 3 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

[1]

[2]

[3]

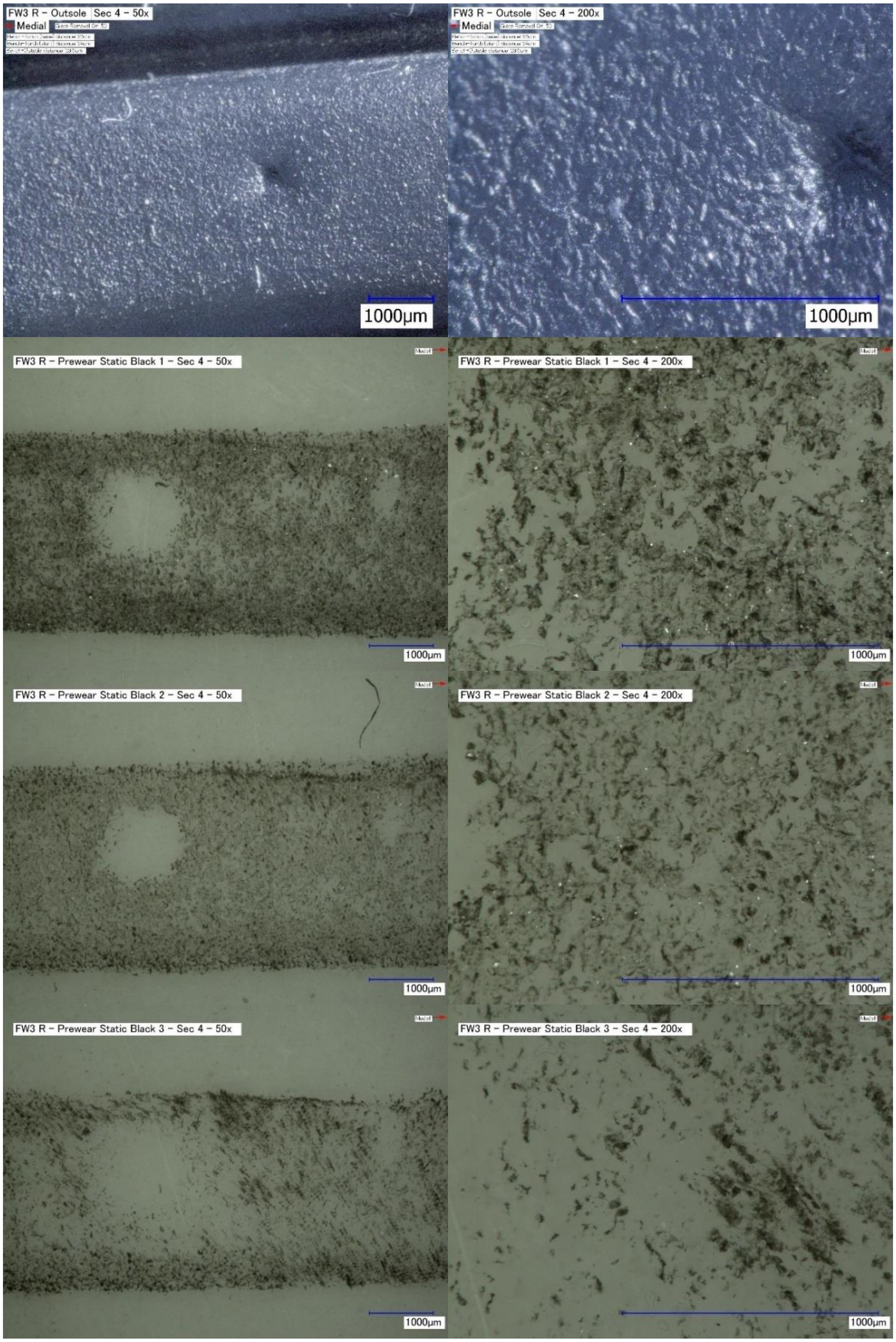


Figure 162: *Pre-wear magnified images of FW3 R section 4 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*

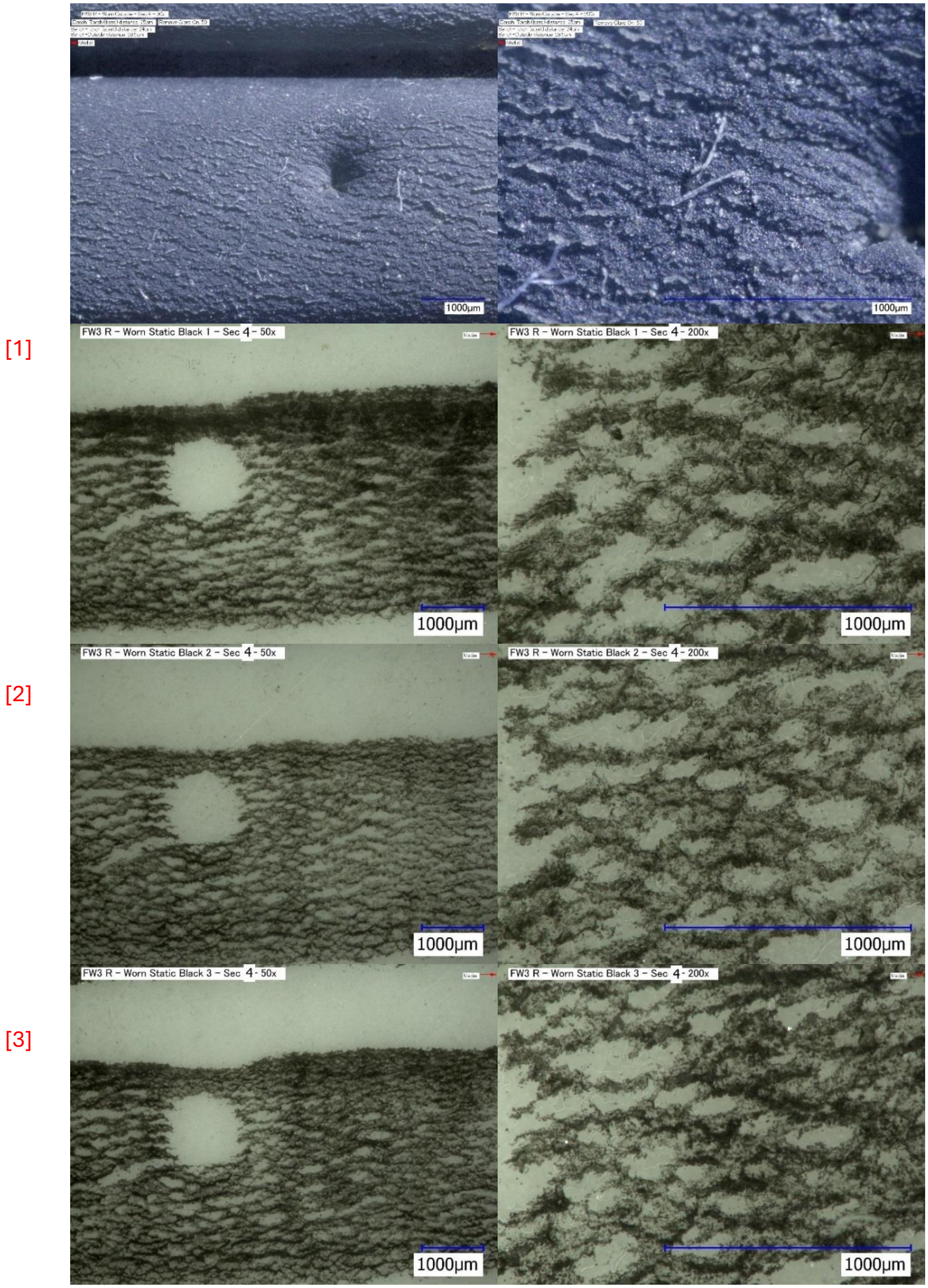


Figure 163: *Worn magnified images of FW3 R section 4 outsole [top] and SB1 [1], SB2 [2], SB3 [3] at 50x [left] and 200x [right]*