ELIMINATION OF LUBRICANTS IN INDUSTRIES IN USING SELF-LUBRICATING WEAR RESISTANT COATINGS BASED ON MOS_2

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Abstract The problem that has been haunting for long manufacturing industries (automotive, aerospace, domestic appliance and electronics) is the lubrication. Most processes are impossible without lubrication, otherwise wear and galling will occur. On the other hand, many lubricants are toxic and some lubricants are even flammable, and therefore the use of lubricants is a big environment, safety and health concern.

This paper demonstrates how innovative self-lubricated coating such as MoS_2 / Titanium composite coatings can be used to solve these problems and are suitable for the specific requirements with characteristics such as low frictional coefficient, high wear resistance and low cost.

For example, demand coatings such as MoS_2/Titanium composite coatings is increasing, therefore forming and cutting process can be performed "dry" without use additional lubricants, that is, the oil based lubricants can be eliminated from processes. The benefits of MoS_2/Titanium composite coatings are both ecological and economical. The ecological side is obvious. The economical benefits can be obtained from the elimination of the direct costs of lubricants and the application apparatus, from longer tool life and less tool maintenance, from improved quality of machined parts as well as from the indirect costs of parts cleaning and waste disposal. Industrial results from forming and cutting processes will be presented and understanding analysis will be performed. Parameters such as life-time, cutting force, surface finishing… will be correlated to laboratory friction and wear tests as well as microstructure observations.

Keywords: MoS_2/material composite coatings, Low friction, Solid lubricant, Elimination of Lubricants

1. Introduction

Traditionally, cutting fluids are used to reduce cutting temperatures and prevent excessive heating of the tool/workpiece. It also assists to removal of chips from the cutting zone. Forming fluids are used to prevent galling or sticking and reducing friction during processing. Fluids are also applied on to the workpiece material during sheet metal forming to prevent corrosion during the manufacturing process. However, the costs involved in purchase and disposal of cutting and forming fluids are excessive. In addition, the use and disposal have led to environmental concern [1]. Therefore, there is a trend for manufacturers to opt for dry machining or the use of minimal quantity of fluid by using systems such as spray mist. Another possibility for reducing the amount of cutting fluids is to use a so-called "solid lubricant" coating applied on cutting or forming tools. They have low coefficient of friction (0.02–0.1) and low shear strength characteristic. Such "solid lubricant" coatings act as a solid film lubricant. One example is molybdenum disulphide (MoS_2).

Composite coatings of MoS_2 and metals deposited by Closed Field Unbalanced Magnetron Sputtering (MoST™) have been shown to have remarkable tribological properties [2]. Although MoS_2 and MoST™have been used in some machining applications they have not yet found wide spread use [3, 4]. This paper demonstrates how innovative self-lubricated coating such as MoS_2/Titanium composite coatings can be used to solve these problems and are suitable for the specific requirements with characteristics such as low frictional coefficient, high wear resistance and low cost.

2. Dry Drilling operations

Dormer AISI M35 high speed steel (HSCo) 8 mm diameter stub drills were used for the drilling tests [5]. Drills were coated with commercial TiAlN, MoST and TiAlN + MoST by means of 2 industrial PVD processes, cathodic arc [6, 7] for TiAlN (3.5 µm, Critical load > 60 N, Oxidation resistance up to 500 ℃) and magnetron sputtering for MoST (1.2 µm, Critical load > 90 N, Oxidation resistance up to 900 ℃). Bright drawn mild steel (BS 970-070-M20) plate, with a hardness of 143 HB was used as the workpiece material ($450 \times 150 \times$ 20 mm). The drilling tests were performed on the Hayes numericon CNC 850 vertical milling machine with a maximum spindle speed of 2550 rpm. Tool wear/life, cutting force, workpiece surface roughness and hole accuracy data were obtained using Teer Coatings MoST™ coating when drilling. The feed rate was 0.2 mm/rev. where the hole depth was 20 mm (through holes). Tests have been carried out at several cutting speeds; 25, 40 and 60 [m/min]. The test was stopped after 500 holes or failures. When a maximum flank wear criterion 0.6 mm has been reached, the tool is classified as failed. Uncoated and coated

TiAlN drills have been tested wet (semi-synthetic cutting fluid 5% concentration in water), whereas MoST™and TiAlN + MoST™have been tested dry.

The results obtained for roundness and cylindricity of the holes produced were inconsistent. This was due to the coarse nature of the peak-to valley height index, which can be greatly affected by debris welded onto the surface of the hole. All holes were drilled oversize. However, the holes produced by TiAlN and TiAlN+MoST™coated drills had hole sizes with lesser variance and were relatively close to the nominal hole size. There was a signifi cant improvement in surface roughness (R_a) value with TiAlN and TiAlN + MoST coated drill. This was due to the good thermal and chemical stability of the TiAlN coating and the low coeffi cient of friction properties of MoST coating that provided smooth evacuation of the swarf from the cutting area. This prevented the swarf being pressed into the surface and causing a deterioration in surface roughness. At 25 m/min all tools reached the criterion of 500 holes. There was no signifi cant difference in the progression of maximum flank wear between the uncoated and MoST coated tools, and the TiAlN and TiAlN+ MoST tools (Fig. 1 (e)), indicating that the substitution of cutting fluid by MoST does not dramatically affect the flank wear rate. The flank wear at the end of the test is reported in brackets on Figs. 1 (a)-(d).

Workpiece material build up was observed on all drills after 500 holes, mostly around the chisel edge and cutting edge corner. The uncoated drill had a larger build up of material around the chisel edge than the other three drills, whilst the TiAlN + MoST drill had a minimal amount of build up.

At 40 m/min The uncoated drill failed after 185 holes by reaching the 0.6mm flank wear criterion, whilst the MoST coated drill failed catastrophically after 54 holes (Fig. 2(a)-(b)). TiAlN and TiAlN + MoST coated drills both reached the criterion of 500 holes with relatively little flank wear.

Figure 2 (c)-(f) show the flank wear on one of the cutting lips of the four drills used at 40 m/min at the end of each test. The fi gure in brackets is the maximum flank wear value recorded. A build up of workpiece material is clearly visible on the uncoated tool at the cutting edge corner in Fig. 2 (c). A built up edge on the corner and along the cutting edge is present on the TiAlN drill in Fig. 2 (e) and Fig. 2 (f) shows the TiAlN+ MoST coated drill to have a slight build up on the corner and near the chisel edge.

At 60 m/min, all drills failed catastrophically before reaching the criterion. The uncoated and MoST coated drills failed after drilling 2 and 7 holes, respectively. The mode of failure was a result of poor chip evacuation causing a build up of chips in the drill flutes due to softened of the tool. The TiAlN and TiAlN + MoST coated drills produced signifi cantly more holes, drilling 329 and 238 holes.

A summary of the number of holes drilled for the different cutting speeds is shown in Fig. 3.

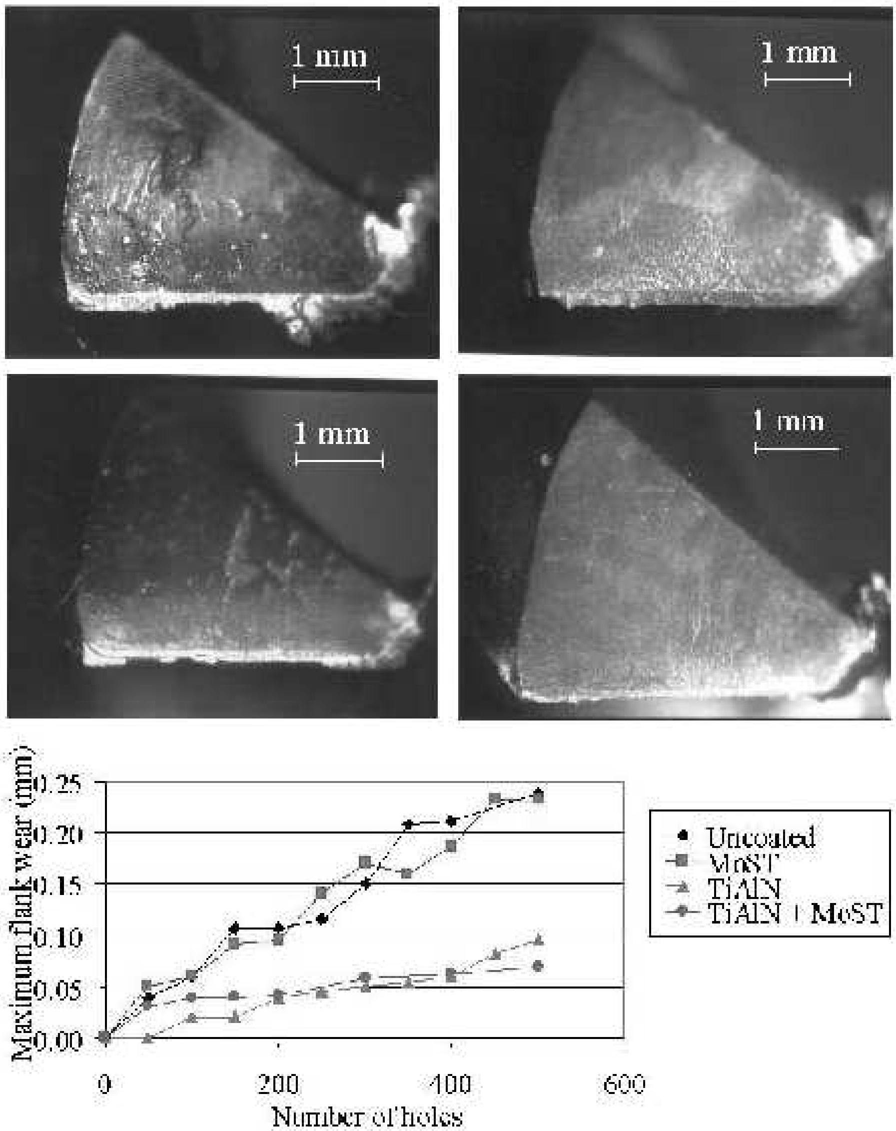

Figure 1. (a) Uncoated (0.238 mm), (b) MoST (0.231 mm), (c) TiAlN (0.095 mm) and (d) TiAlN + MoST (0.069 mm). (d) Flank wear against number of holes drilled at 25 m/min.

3. Conclusions

At average recommended cutting speeds for HSCo 8mm stub drills on mild steel workpiece material, i.e. 25 m/min, tool life was maintained when replacing cutting fluid with the use of MoST coated drills in dry instead of lubricated

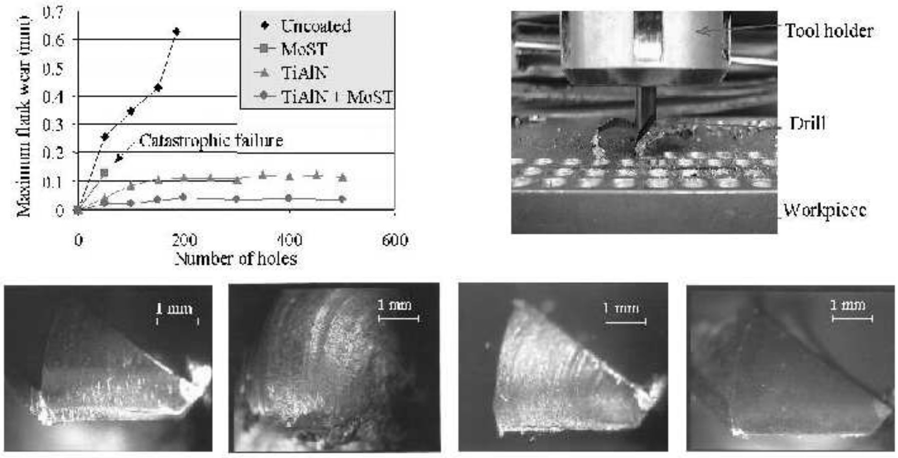

Figure 2. (a) Flank wear against number of holes at 40 m/min. (b) MoST coated drill failure at 40 m/min. (c) Uncoated (0.627 mm) after 185 holes, (d) MoST (catastrophic failure) after 54 holes, (e) TiAlN (0.116mm) after 500 holes and (f) TiAlN + MoST (0.036 mm) after 500 holes.

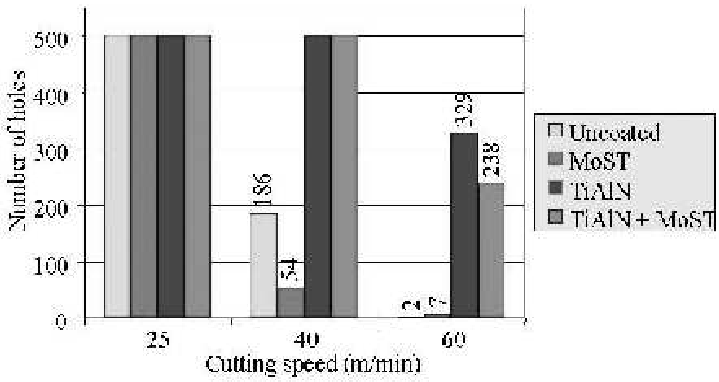

Figure 3. Tool life for all drills and cutting speeds.

conditions. The addition of an underlayer such as TiAlN coating signifi cantly improved the tool life at all cutting speeds. At 60 m/min (an extreme cutting speed for uncoated HSCo), the mode of failure was a result of poor chip evacuation causing a build up of chips in the drill flutes due to softened of the tool, TiAlN and TiAlN + MoST were both able to drill more than 200 holes. TiAlN and TiAlN+ MoST drills performed well at both 25 and 40 m/min, showing low levels of flank wear after 500 holes. At 60 m/min. MoST was shown to be a suitable replacement for cutting fluid at the three cutting speeds when used on top of a TiAlN. The occurrence of the built up edges during drilling with

TiAlN + MoST coated drill was low in comparison with the uncoated, MoST and TiAlN coated tools. MoST coated drill alone was not effective in preventing built up edge (due to softened of the tool) and resistance to tool wear.

The cutting force and torque value obtained for TiAlN and TiAlN + MoST coated drill revealed that drilling at higher cutting speed was just as effective as at lower cutting speed. There was a significant improvement in surface roughness (R_a) value with TiAlN and TiAlN + MoST coated drill. This was due to the good thermal and chemical stability of the TiAlN coating and the low coefficient of friction properties of MoST coating that provided smooth evacuation of the swarf from the cutting area. This prevented the swarf being pressed into the surface and causing a deterioration in surface roughness.

Acknowledgments

The Authors would like to thanks the following people: Dr Aspiwall, Dr R. Dewes and H. Codwell of Birmingham University (U.K.)

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