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A CRITICAL STUDY OF MICRO-SOLID LUBRICANT COATING BY THE USING OF CUTTING TOOLS

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ABSTRACTS

Conventional methods for metal cutting require significant energy consumption where the particular cutting energy is normally high. A large division of this energy is converted into heat that causes adverse effects on the wear of the cutting tool, the life of the tool and the surface quality of the machined work material. While cutting fluids are successful in coercing this energy transfer, coolant machining is increasingly challenging manufacturers to restrict the use of cutting fluids to cope with the environmental and health aspects. The goal of the current research work, as an alternative to cutting fluid applications, is to establish the idea of an approach to product manufacturing in the development of novel coatings. In view of this the present work presents an electrostatic micro-solid lubricant (EMSL) coating as a solid lubricant on a carbide instrument with molybdenum disulfide (MoS2). Efficiencies of coatings have been studied in tribological as well as machining applications to discover the extent of performance of this novel coating. Machining with EMSL coated cutting tools results in lower tool-work interface friction values that contribute to relatively lower cutting forces than those in uncoated cutting tool machining. In addition, in EMSL coated cutting tools, tool flank wear is very minimal compared to that of the uncoated cutting tool. Shear deformation to shape chips was assessed and positive tool-chip contact was observed while machining with EMSL coated equipment. When machining with EMSL coated cutting tools, the surface quality of machined work material showed a much better improvement compared to that of machining with uncoated cutting tools.

Key words : coating, machining tests, cutting parameters, crystalline solids

INTRODUCTION

In order to extract unnecessary material and attain the ideal surface finish of engineering parts, metal cutting processes are commonly used. The unwanted material is extracted in metal cutting processes by the cutting tool, which is considerably harder than the workpiece. The cutting temperatures and forces on a cutting tool are usually high during metal cutting operations, which dramatically decreases the life of the tool and affects the quality of the products made. In order to ensure simultaneous improvement of efficiency and product quality, effective countermeasures for the control of heat generation in the cutting zone are strongly needed. Therefore in machining processes, the use of a proper lubrication method is important for changing contact conditions as a means of better regulating frictional interaction between tool-chip contact and machining mechanics, thus affecting contact temperatures, tool life, cutting forces and energy consumption. Several technologies have been developed in recent years for temperature control in the cutting zone and tool-chip touch frictional effects, such as flood cooling, minimum quantity lubrication/near dry machining, cryogenic cooling and solid lubricant assisted machining. In the past, cutting fluids and solid lubricants have been used by researchers and producers for their ability to monitor the above parameters in order to maximise the efficiency of the machining operation.

Cutting fluids are historically used in cutting processes to monitor the high temperatures produced. Cutting fluids are often used to decrease energy and energy consumption, to regulate the coefficient of friction between the instrument and the chip, to wash away the chips, and to protect the machined surfaces from environmental corrosion. However, the use of cutting fluids produces a variety of techno-environmental issues such as environmental pollution due to chemical disassociation of high-temperature cutting fluids, biological problems for operators, water pollution and soil contamination during disposal[3-5]. Growing global understanding of green production and customer attention on environmentally sustainable goods has placed increased pressure on producers and scientists to eliminate or reduce the use of cutting fluids. Therefore, as an alternative to cutting fluids, researchers experimented with the use of solid lubricants with various techniques, such as dispersing solid lubricants into the touch of the tool-work material, forming a lubricating oxide film on the tool-chip interface by in-situ reaction through elevated cutting temperature and isolating the tool from the workpiece with a lubricating layer on the face of the cutting tool[Among these potential methods, the use of solid lubricant-containing self-lubricant layer/coating as one of the alternative materials on contact surfaces has come a long way in recent years[9-12].

Self-lubricant layers/coatings containing solid lubricant on cutting tools are now capable of managing high heat generation during cutting processes and can provide excellent anti-friction and fair tool efficiency. A variety of solid lubricant materials such as molybdenum disulfide (MoS2), polytetrafluoroethylene (PTFE), calcium floride (CaF2), diamond-like carbon (DLC), graphite, tungsten disulfide (WS2), etc have been found in advanced modern tribology[13]. It is very important to find an efficient approach to manufacturing self-lubricant coatings for any industrial application. Awareness of the coatings used in a wide range of machining and tribological applications and factors affecting the performance of coating material, such as coating thickness, substrate material, surface preparation, etc., are important when choosing a solid lubricant coating deposition method.

Flotation phase, electrochemical deposition, dispersion (dipping, brushing), burnishing, bonding, particulate deposition (thermal spray) and physical or chemical vapour deposition (PVD/CVD)[14] are the typical deposition techniques used in tribological coatings. Each method has its unique advantages and its own application region, but because of its poor bonding power, deposition rate, achievable coating thickness, cost, etc., not all of them are suitable for tribological as well as machining applications. These methods of deposition allow us to prepare different adhesive solid lubricant coatings for cutting instruments from soft metal laminar solids such as MoS2 and WS2 to hard metals such as cubic boron nitride (CBN), titanium nitride (TiN) and DLC. The PVD coatings of the first generation featured TiN as the hard coating and were used in metal cutting processes. It is well understood, however that hard coatings retain a high friction coefficient and require lubricants. Often when machining advanced engineering products, these properties make the hard coatings non acceptable. In addition, even though the diversified solid lubricant coatings can be accomplished using the above techniques, there are still some difficulties associated with the deposition of solid lubricant particles of micron-size/nano-size as they have an extremely high surface area to volume ratio, leading to diffusion at high temperatures, often resulting in aggregates and agglomerates rather than a single primary pa

In order to address the above-mentioned disadvantages, there is therefore a need to focus efforts in this direction and to explore new coating material and deposition methods to achieve a sustainable machining system. Researchers investigated the application of the electrostatic charging principle in the deposition of polymer and ceramic powders on various substrates to extend their wear and corrosive resistance due to its economical and simple in-house configuration, high transfer performance, and particularly easy deposition on large and complex geometric surfaces with high deposition rate and coating thickness. The use of this technique in the use of various solid lubricants such as MoS2, Graphite, ZnO, etc. in machining applications in nearly recent years makes researchers highly attractive [16-18]. The researchers of the above research are effective in using the theory of electrostatic charging either in depositing solid lubricant coating on cutting tools or in dispersing solid lubricant mixture to the touch interface of the tool-chip.

In understanding their performance in machining applications, the study of tribological properties (friction and wear) of coatings plays a vital role. Tribology seeks to mitigate the loss of components used in the tribo-mechanical system caused by friction and wear. In practise due to the sliding movement and the limited contact areas involved, direct measurement of the friction effect and temperature at the sliding contact interfaces is very difficult. Laboratory-based tribological tests, on the other hand, can provide a rapid and accurate prediction of sliding tribological component interactions[19]. Within the surface engineering research group, accelerated laboratory wear tests using test machinery are popular. Pin-on-disc, block-on-ring, micro-abrasion, ballon-plate effect and reciprocating-sliding wear tests[20] are various devices that can be used to understand the tribological behaviour of material pairs. These techniques are capable of providing accurate information on how materials or coatings behave under various conditions, and material pairs used in a wide variety of industrial applications including construction, automotive, aerospace, positioning devices, and very strict motion control needed by the like.

It is important to model and simulate the metal cutting process using the finite element method to improve the efficiency and consistency of the machining process before resorting to expensive and time-consuming experimental trials (FEM). FEM uses a science-based approach in which the complete machining process can be simulated and optimised in order to understand the variables of the actual cutting process, such as cutting power, cutting temperature, wear of the instrument, and to relate the same to practical machining process conditions. The performance and reliability of FE modelling of machining processes rely heavily on the following characteristics: I the workmaterial flow stress model - should fairly denote elastic, plastic and thermo-mechanical workmaterial deformation behaviour observed during the cutting process, (ii) the FE model should not require requirements for chip separation - continuous remeshing and consistency of the workmaterial deformation observed during the cutting process, (ii)

RESEARCH METHODOLOGY

The role of solid lubricant-based coatings in improving process efficiency in current industrial applications seeks more advanced machining processes and methods for researchers and manufacturers to develop new and more reliable coated cutting tools, which can take sustainability into account as an essential parameter of machining processes. To our knowledge, this technique is new in machining applications and the level of detail offered in machining applications is not adequate to understand the benefits of such a concept in the deposition of micron/nano-sized solid lubricant particles on cutting tools. The literature review stressed that the concept of electrostatic charging and its significance exist in some industrial applications. To this date, a literature search on the use of the concept of electrostatic charging in solid lubricant-assisted machining results in a limited amount of work, although to our knowledge there is no information in the open literature on deposition of electrostatic solid lubricant coatings on cutting tools, in particular to understand the tribological performance of electrostatic solid lubricant coatings and their There is a motivation to explore the electrostatically deposited solid lubricant coatings with good machining as well as tribological efficiency due to the restricted work in the field of electrostatically deposited solid lubricant coated tools that could be used in machining processes.

The current research work therefore contributes to the production of a new solid lubricant coated cutting tool, namely electrostatic micro-solid lubricant (EMSL) coated carbide tool with molybdenum disulfide, to concentrate on this direction and to explore the feasibility of new coating materials and methods less costly than the existing deposition techniques and thus make the machining sustainable. Coating strength was tested with the aid of the scratch tester by measuring the critical load needed to remove the coating from the substrate in order to see the ability of coating adhesion to the substrate. Using the ASTM G99 standard pin-on-disc tribological test system, the tribological behaviour of EMSL coatings under dry sliding conditions is evaluated under different sliding speeds and loads. In order to assess the efficiency during the machining phase of the developed coated cutting tools, extensive machining studies have been carried out. In addition, relative comparison of the output of the process in terms of cutting temperature, cutting power, chip thickness and shear angle is provided while machining with and without a coated tool. In addition to the above, FE machining process modelling was performed to understand the variables of the physical cutting process, such as cutting temperature, cutting power, chip thickness and shear angle, and to relate the same to practical conditions when machining with and without coated cutting tools. With the assistance of numerical code, DEFORMTMTM, FE modelling of the machining process by taking into account the frictional effects based on the combination of shear friction and Coulomb friction and material flow behaviour through formulated constitutive models was demonstrated.

Material and tool substrate

Dow Corning Corp., U.K. obtained MoS_2 solid lubricant material used in the EMSL coating deposition process. The physical characteristics of MoS_2 are as follows: mean particle size is 0.7 µm, theoretical density is 4.8 g/cc, and purity is around 98 percent. The solely modified micron-sized phenolic novolac resin powder was used as a binding agent in the formulation of the solid lubricant to strengthen the coating adhesion to the cutting tool substrate. The resin's physical properties are as follows: the mean particle size is 2 µm and the density is approximately 0.36 g/cc. The substrates to be coated are as follows: I cemented tungsten carbide-cobalt alloy (WC-Co) pins with 94% WC and 6% Co composition, and (ii) inserts for carbide cutting equipment. In tribological and machining experiments, the coated pin and coated instrument insert are used respectively.

RESULTS AND DISCUSSION

Plan of EMSL coating experiments

In achieving the desired degree of coating thickness and transfer efficiency of the coating method, the parameters of the coating deposition process, air pressure, electrical potential and nozzle tip to substrate distance play a vital role. Therefore, Taguchi design method and Study of Variance (ANOVA) are used in the experimental plan to analyse the optimum deposition process parameters and to understand their significance on their overall thickness of the coatings. The Taguchi design approach and ANOVA allow the data to be optimised and analysed before and after the experiments in a controlled manner. The findings obtained were analysed using statistical analysis software, Minitab-16. The number of test tests performed with the three levels of solid lubricant powder feed pressure, electrical potential and distance between nozzle tip and substrate for each defined control factors are shown in Table-1.

Table 1. Assignment of levels to the factors used in experiments

Control factors	Levels		
	1	2	3
Electric potential (kV)	50	70	90
Solid lubricant powder feed pressure (bar)	0.5	1.0	1.5
Distance between nozzle tip to substrate (mm)	140	160	180

Each experiment was replicated three times to ensure repeatability and minimal error. As shown in Figure-1, the deposited samples were characterised by the tool maker's microscope (Olympus, STM6) for coating thickness. In Figure-2, photographs of EMSL coated tool substrates are presented. The extensive studies are explained in tribological and machining applications on EMSL coated instruments.

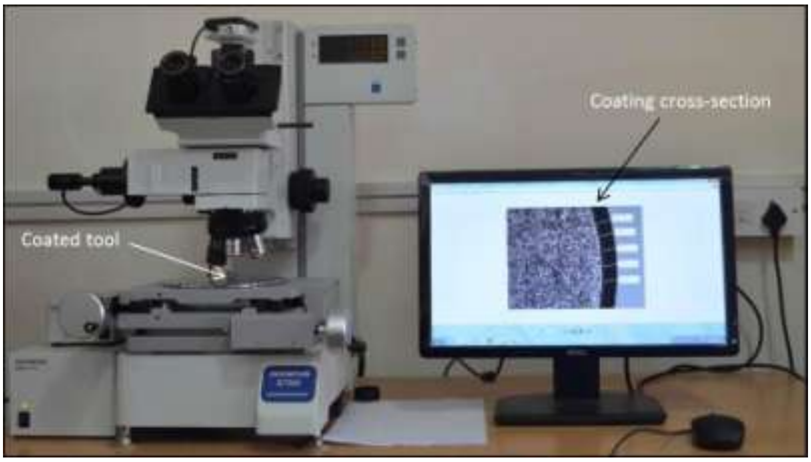

Figure-1. Coating thickness measurement using tool measuring microscope (Olympus STM6).

Table -2. Selected electrostatic coating deposition process parameters and measured coating thickness.

Exp. No.	Electric potential	Powder feed pressure	Distance between nozzle tip to substrate	Coating thickness (μm)	S/N ratio
1	1	1	1	12.23	21.7485
2	1	1	2	14.2	23.0458
3	1	1	3	15.6	23.8625
4	1	2	1	13.07	22.3255
5	1	2	2	15.2	23.6369
6	1	2	3	16.45	24.3233
7	1	3	1	12.79	22.1374
8	1	3	2	13.77	22.7787
9	1	3	3	14.08	22.9721
10	2	1	1	16.4	24.2969
11	2	1	2	15.3	23.6938
12	2	1	3	14.9	23.4637
13	2	2	1	17.9	25.0571
14	2	2	2	19	25.5751

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15	2	2	3	20.1	26.0639
16	2	3	1	17	24.6090
17	2	3	2	18.21	25.2062
18	2	3	3	18.86	25.5108
19	3	1	1	14.5	23.2274
20	3	1	2	16.12	24.1473
21	3	1	3	14.76	23.3817
22	3	2	1	15.8	23.9731
23	3	2	2	17.12	24.6701
24	3	2	3	18.24	25.2205
25	3	3	1	15.1	23.5795
26	3	3	2	16.4	24.2969
27	3	3	3	17.2	24.7106

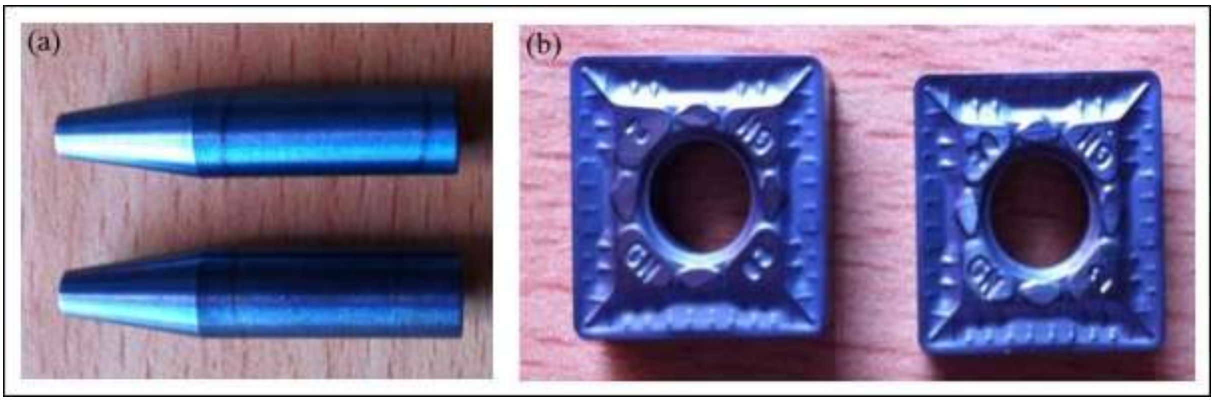

Figure-2 Photographs of EMSL coated carbide substrates: **(a)** pin specimens used in tribological pin-on-disc tests, and **(b)** cutting tool inserts used in machining experiments.

Results of the coating thickness are shown in Table-2. In achieving uniform coatings, the relationship between deposition parameters such as electrical potential, solid lubricant powder feed pressure and distance between the nozzle tip and the substrate plays an important role. Fig. Fig. 3.8 displays the SEM and microscopic images of the coated surfaces at different conditions of the coating process. The ANOVA findings for the coating thickness are shown in Table 3.4. For a 95% level of trust, this study is carried out. The last column of the ANOVA table shows the percentage of the contribution (P) of each process parameter to the total variation, showing the degree of impact of the coatings on their response. From the Table-2 study, we can note that the electrical potential factor has a major effect on the variation in coating thickness, followed by the pressure of the powder feed and the distance between the tip of the nozzle and the substrate. Each factor's percent contribution to the overall coating thickness is as follows: electrical potential factors (50.33%), pressure factors for powder feed (17.73%) and distance between nozzle tip and substrate factors (13.81 percent).

CONCLUSIONS

The driving forces behind advances in today's cutting technology are demands on goods and manufacturing processes. Innovations such as the introduction of advanced workmaterial principles, along with the need for sustainable machining methods, increased flexibility and enhanced cost-effectiveness, cause high-performance processes and placed greater stress on the production of new cutting tools. Coating technology is one way to achieve a critical increase in instrument efficiency in this direction. There is however, such a huge variety of available coating materials, coating structures and coating processes that it is important to carefully choose an acceptable coating system for the development of coated tools. The application of the electrostatic charging principle in coating deposition know-how in the present research work may lead to the creation of the first solid lubricant coatings ever bonded for machining operations.

REFERENCES

- S.P.F.C. Jaspers, J.H. Dautzenberg, Material behaviour in metal cutting: strains, strain rates and temperatures in chip formation, Journal of Materials Processing Technology, 121 (2002), 123-135.
- N. Fang, A new Quantitative Sensitivity Analysis of the Flow Stress of 18 Engineering Materials in Machining, Journal of Engineering Materials and Technology, 127 (2) (2005), 192-196.
- Y.C. Lin, Xiao-Min Chen, Ge Liu, A modified Johnson–Cook model for tensile behaviors of typical high-strength alloy steel, Materials Science and Engineering A, 527 (2010), 6980-6986.
- T. Ozel, Taylan Altan, Determination of workpiece flow stress and friction at the chip–tool contact for high-speed cutting, International Journal of Machine Tools & Manufacture, 40 (2000), 133-152.
- T. Ozel, Erol Zeren, Determination of work material flow stress and friction for FEA of machining using orthogonal cutting tests, Journal of Materials Processing Technology, 153-154 (2004), 1019-1023.

- Shuhui Li, Bo Hou, Material Behavior Modeling in Machining Simulation of 7075-T651 Aluminum Alloy, Journal of Engineering Materials and Technology, 136 (2014), 11001-14.
- T. Ozel, The Influence of Friction Models On Finite Element Simulations of Machining, International Journal of Machine Tools & Manufacturing, 46 (2006), 518-530.
- T. Ozel, and E. Zeren, Finite Element Modelling the Influence of Edge Roundness on the Stress and Temperature Fields Induced by High Speed Machining, International Journal of Advanced Manufacturing Technology, 35 (2007), 255-267.
- Attanasio, E. Ceretti, S. Rizzuti, D. Umbrello, F. Micari, 3D finite element analysis of tool wear in machining, CIRP Annals-Manufacturing Technology, 57 (2008), 61-64.
- J.P. Davim, and C. Maranhao, A Study of Plastic Strain and Plastic Strain Rate in Machining of Steel AISI 1045 Using Fem Analysis, Materials and Design, 30 (2009), 160-165.
- Guoqin Shi, Xiaomin Deng, Chandrakanth Shet, A finite element study of the effect of friction in orthogonal metal cutting, Finite Elements in Analysis and Design, 38 (2002), 863–883.
- Chandrakanth Shet, Xiaomin Deng, Finite element analysis of the orthogonal metal cutting process, Journal of Materials Processing Technology, 105 (2000), 95-109.
- P.J. Arrazola, D. Ugarte, J. Montoya, A. Villar, S. Marya, Finite element modelling of chip formation process with Abaqus/explicit™ 6.3, VIII International Conference on Computational Plasticity COMPLAS VIII , Barcelona, 2005.
- Maranhao, J. Paulo Davim, Finite element modelling of machining of AISI 316 steel: Numerical simulation and experimental validation, Simulation Modelling Practice and Theory, 18 (2010), 139-156.