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APPLICATION METHODS AND PERFORMANCE STUDY OF COATINGS ON TOOLS USED IN DRY MACHINING

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Abstract - The paper is aimed at studying the performance of various coatings used on tools and their corresponding deposition techniques in reducing the tool wear and expedite the use of these tools at higher cutting speeds without the aid of liquid lubricant in machining steel and aluminum under DRY condition. It proceeds with the introduction to dry machining and its importance in the industry and why it's the preferred choice of machining. Advancements in methods of application of these coatings are then discussed. The performance of these coatings is studied in relation to certain types of tool wear. Dry machining can be defined as a machining process which makes no use of liquid/wet lubricant or uses MQL (Minimum Quantity Lubrication) in special cases. Tools used for dry machining use lubricant in the form of a coating deposited on the tool which contributes in reducing the coefficient of friction and improve tool wear. The cutting tools are currently coated with a hard coating to improve MRR. But these coated tools when subjected to high cutting speeds, a requirement for many applications these days experience increased friction and weld to the part. A solid lubricant coated on top of hard coatings is a solution to solve this problem. Problems are seen in the application of coatings and also the concentration of coatings on the tools, as the coated layers wear off too fast. Recent developments in form of double layer coatings help to solve this problem by increasing the adhesion of coating to the substrate thereby increasing life of the coating and thereby the tool life.

Key Words: *Dry machining, Tool coatings, Deposition techniques, Coating performance.*

1. INTRODUCTION

Dry machining refers to the machining of materials under no influence of wet/liquid lubricant. This method has extended beyond the boundaries of laboratory use and has seen an increase in the number of applications that make use of dry machining. This technique of machining has been widely adopted across Europe since the cost of machining with lubricant can often offset the cost of the tooling as shown in Fig 1. There has also been concern on the disposal of the lubricants and a lot of money is spent in disposing the used coolants which is harmful to the environment. Health hazards are an after effect related with the use of coolants as some coolants can emit fumes with increased temperature. The factors listed are some of the many that has paved way for the advancement in dry machining. Since the cooling lubricants serve a multitude of purposes from reducing the co-efficient of friction, cooling the work-tool interface, a carrier of chips form the area of machining and also a promoter for a good quality surface finish. In the absence of a conventional cooling technique, alternates have to be provided to compensate the loss. The introduction of hard lubricants (coatings with lubricants) is seen to be the answer to overcome this problem

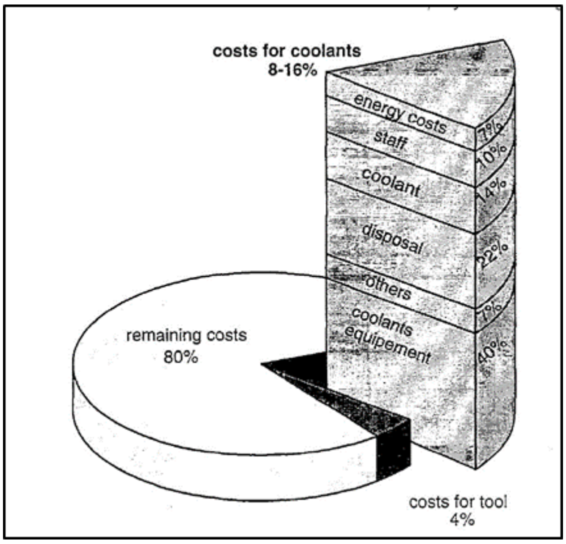

Fig -1: Breakdown of costs for cutting fluids in production.

1.1 TYPES OF COATINGS USED

The coatings for cutting tools have made huge leaps in advancement over the period of time. The most common type of coatings are single layer/single phase, multilayer/multiphase, dispersion, nanoscale and composite coatings. Single layer coatings are hard coatings consisting of binary compounds such as TiN, TiC. Based on the specific tribological reasons addressed multiphase coatings consist of a two layer system which is used to improve the adhesion of the final hard coating by depositing an interlayer below the hard coating. Dispersion coatings can be identified by the presence of small particles embedded in the coating matrix. The main advantage of such a coating method would be better

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lubrication properties due to presence of greater amount of lubricating compound in the machining period. As the name implies nanoscale coatings make of use of coating layers whose thicknesses are in nm. When there is a need for specific improvements in a cutting zone these coatings are preferred. These coatings are deposited by a means of a hybrid process consisting of various vapor deposition processes. Composite coatings consist of a metal addition such as titanium to already existing coatings. These coatings can be used in situations where increased resistance to water vapor is required. They are deposited by means of DC magnetron sputtering method.

1.2 DEPOSITION TECHNIQUES

Physical Vapor Deposition (PVD) Technique and Chemical Vapor Deposition (CVD) Technique are the most widely used deposition techniques for tools with hard coatings Fig 2

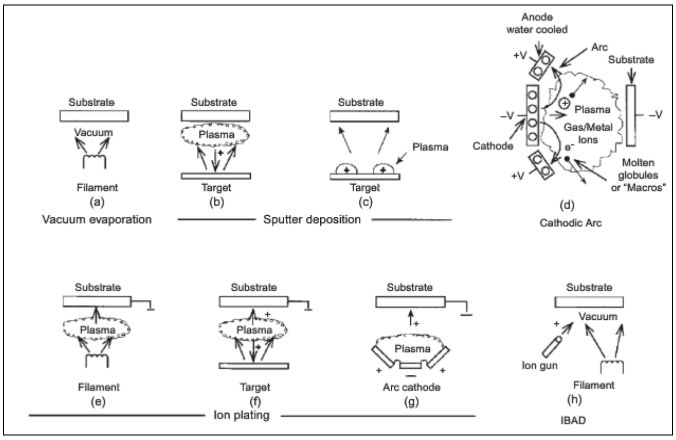

Fig -2: Various PVD Processing Techniques.

PVD also known as thin film process consists of evaporating material from a solid or a liquid and transporting this in the form of vapor through vacuum and condensing it on the substrate. PVD is gaining importance due to its ability to provide a better cohesion between the substrate and coating hence avoiding the brittle nature of the coating that's seen on the CVD method. This is possible because of the reactive deposition process. In this process compounds are formed due to the reaction of the depositing material with the ambient gas such as nitrogen for a TiN coating. The CVD process makes use of source gasses to form a deposit by bombarding it with various forms of energy such as light, heat and plasma in the CVD reactor as shown in Fig 3.

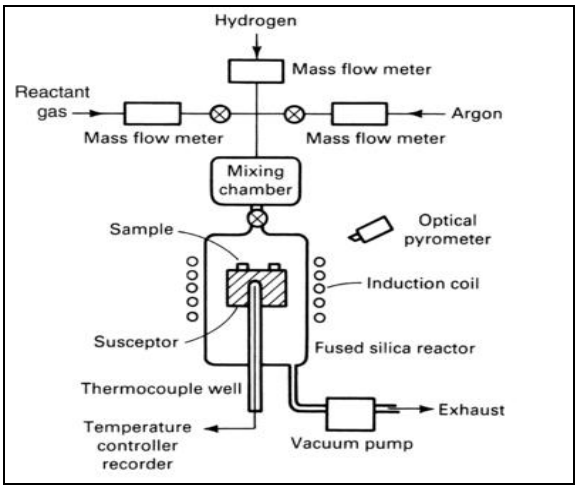

Fig -3: Construction of a CVD Reactor

Once the gases are mixed up they are deposited on the heated substrate. The reaction at the surface of the substrate causes the deposition to occur. Developments in deposition technology arise for coatings that require specific morphological or tribological properties as in the case of MOST coating. The current deposition technique of MoS_2 which is RF sputtering produces a two layer coating one consisting of a dense coating and the other a loose powdery coating that's easily removed. Due to this reason the coatings were suitable only in 0% humidity and vacuum situations. In order to improve the quality of the coatings applied, DC magnetron sputtering is tested as means for deposition by applying a negative potential to the substrate and electrons are bombarded on to the substrate thereby increasing the thickness of the coating since the properties of MoS_2 degrade with presence of water vapor. Sputtering of titanium was done to produce a gettering effect before the actual coating takes place. An interlayer consisting of titanium was then deposited to increase the coating adhesion. These coatings have shown good performance at situations where humidity exceeds 50% [CHECK]. The coatings have been deposited by DC Magnetron sputtering using standard Teer CFUBMSIP equipment. The work piece is rotated in between three MoS_2 targets and one Titanium target as shown in Fig 4.

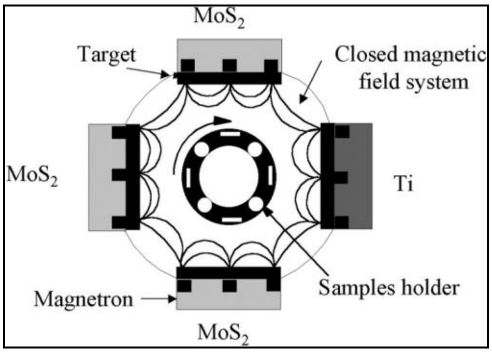

Fig -4: Schematic representation of DC sputtering Magnetron equipment.

The metal deposited is directly proportional to the power passed through these targets. Likewise the deposition of Indium as a solid lubricant requires a new method of deposition where in the process commences by spraying ceramic beads in high purity ethanol (solvent) on to the surface. This process ensures that the ceramic beads are randomly distributed on the surface. The next process would be coating it with TiN to a thickness of 1-2 μm. The beads are then removed by Sonification there by leaving small holes as micro reservoirs. Cemented carbides are the choice of the substrates for this application. A modified dipping process is used to increase the density of the coatings. In this method the substrates are dipped into a homogeneous mixed bead-ethanol solution by means of a perforated container allowing the mixture to flow in and out. When ethanol is evaporated out, it leaves behind the beads fixed on the tool rake surface. Likewise coatings such as TiAlN which are iteration to existing TiN coatings that provide greater oxidation resistance require increased adhesion capacity for the lubricant. This is achieved by using a plug and play hybrid design of an existing arc production machine which is developed for a new type of TiAlN coating on top of a WC/C lubricant layer. This machine has the ability to develop a graded layer from a cathodic arc to magnetron sputter evaporation.

2. PERFORMANCE OF COATINGS USED IN DRY MACHINING OF STEEL

Introduction of MoS_2/Ti (MOST) coatings as an improvement to the existing MoS_2 coatings provide improved resistance to water vapor. Two forms of the coating namely 'low titanium' and 'high titanium' (self-lubricating coating) are present. High speed steel M6 tap drills coated with TiN, TiCN, TiAlN, TiN+MoS_2 and TiCN+MoS_2 were tested in drilling 5.5 mm through holes into AISI 4340 stainless steel [5].

As evident from the graph TiCN+MoST has performed exceedingly well in both wet and dry applications. However MOST coatings on hard TiN coatings have produced surprisingly different results and need to be further investigated Fig 5.

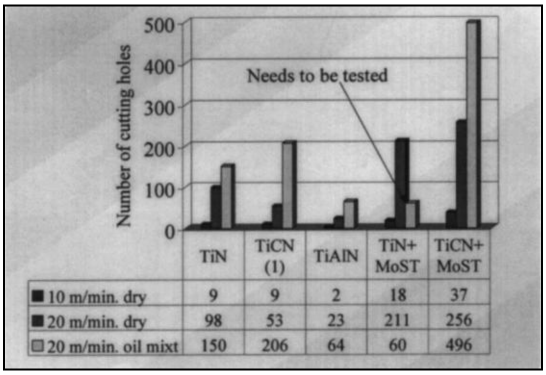

Fig -5: Plot showing performance of a coating as a factor of number of holes being cut.

In dry machining austenitic steel, validation of double layer coating system with minimal quantity lubrication is studied. Dry machining of 22Mn6 steel was done and the method of tool wear measurement was defined by the width of the wear mark at specific points on the tool.

CVD/PVD coatings were used to deposit the coatings on cemented carbide tools up to a thickness of 3-5 μm [4]. Since this method was to be used in production scenario, 720 parts were machined to determine the life of the tool. The double layer structure of TiAlN+MoS_2 was found to have the highest tool life. Though Molybdenum di sulphide seems to erode after a few parts were machined the metallurgical studies indicated that certain amount of MoS_2 was still left in the valleys of the tool surface which initiates the low friction chip flow. The double layer coating showed an increase of 15% in tool life when compared to other types of coatings [4]. Good wear behavior is seen with $TiNAlO_x$ coating where in the thick TiAlN coating provides good adhesion and the Al_2O_3 coating on top of it reduces the amount of wear induced. This is evident from Fig 6. The double layer coating also demonstrated good results for increased cutting speed (30% increase) [4].

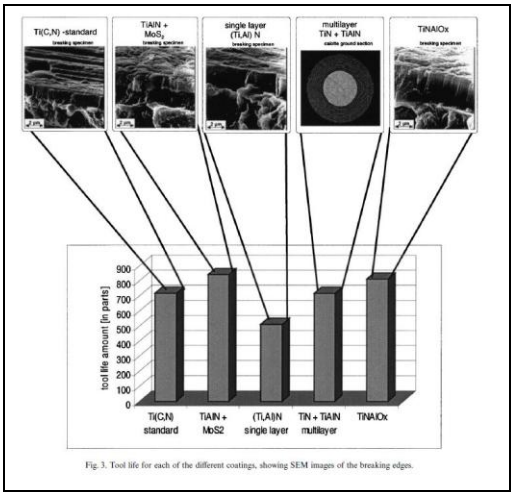

Fig -6: SEM images of breaking edges for the coatings shown along with the tool life for different possible coatings.

The increased process stability of the coatings makes them the preferred choice for machining when combined with minimal lubrication technique. However to achieve a better dry machining performance overall factors such as tool geometry, machine environment have to be considered. In machining AISI 4340 steel the role of Indium (IN) as a lubricant in reducing flank wear and the effect of temperature on the performance of the IN coating was observed. A pin on disc test where in a 6.35 mm alumina ball with a normal load of 1N was used to measure the relation between the friction coefficient and fatigue. The TiN coating with 5μm reservoirs had a lower coefficient of friction value for the same 1500 cycles' operation where the coating without the reservoirs failed to deliver better results [1]. Flank wear data measured for the turning test indicate that presence of reservoirs seemed to have no positive effect on the flank wear measurement Fig 7a. However irrespective of the fact of whether a topcoat layer of micro reservoirs was present or not the tools showed in an increase in wear life by a factor of 4. Chip morphology relates the good tribological properties of the TiN-In5L showing a smoother surface between the chip and the tool coating Fig 7b.

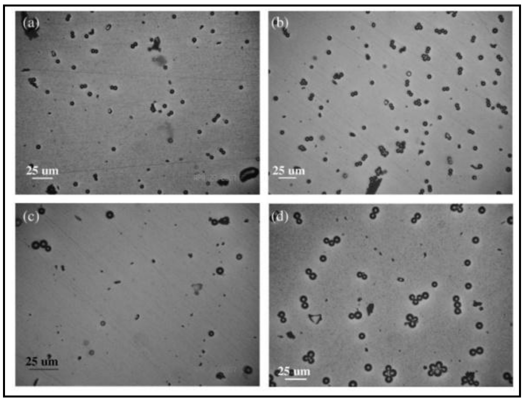

Fig -7a: Rake face of inserts after removal of microbeads revealing empty reservoirs for (Top L-R) 5μm and (Bottom L-R) 10μm spray and immersion methods.

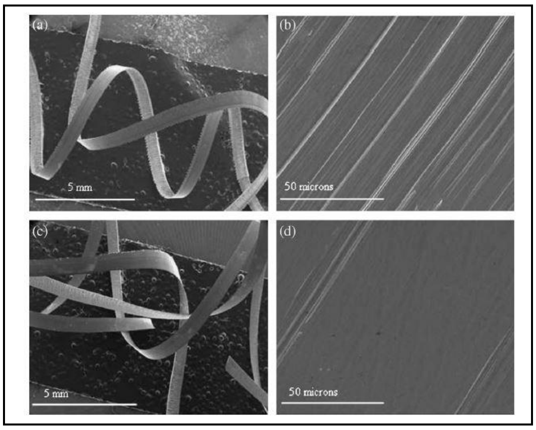

Fig -7b: SEM images of chips during early wet machining.(Top L-R) Tool with TiN coating only and (Bottom L-R) TiN coating with 5μm reservoirs.

The study evaluates the need for a lubricant to sustain heavy load conditions in order to avoid the formation of a seizure zone. Micro Reservoirs filled with solid indium do a considerable job in isolating the work piece from the tool. However the flank wear showed no substantial difference for tools with and without the micro reservoirs and this could possibly be attributed to reasons such as deposition of the beads on the rake face and not the flank and also the population of the beads on the surface which causes random areas of lubrication which could not be available in situations of high interaction.

Substantial reasoning is required as to whether the tool life is critically dependent on the presence of In or micro reservoirs. This cause of concern arises from the results where the flank wear showed no signs of improvement with the presence of reservoirs. However tools with void reservoirs can substantially decrease the life of tool due to increased stress levels at the voids. The limitation of the In coating is interlinked with temperature. For temperatures exceeding 600°C the thermal stability of the In coating decreases leading to the formation of In oxides thereby reducing the lubricity.

TiN-In coated tools in wet machining performed 4 times better than conventional tools indicating the significance of flank wear reduction due to presence of In [1]. TiN-ln5H exhibited the least amount of wear for a given test period but is still inferior to wet machining, which could possibly explain the reason for in suitability of these coatings for temperatures exceeding 450°C.

2. PERFORMANCE OF COATINGS USED IN DRY MACHINING OF ALUMINUM

Coating technology progresses towards the combination of hard/soft coating layers for machining of aluminum or steel with positive results due to the lower co efficient of friction, cutting forces and improved chip flow. The idea of developing a dual layer coating which consists of a soft low friction layer for chip removal with lower torque and a hard layer for machining operations was done [3]. Fig 8 shows the deposition of the coating on a cemented carbide tool.

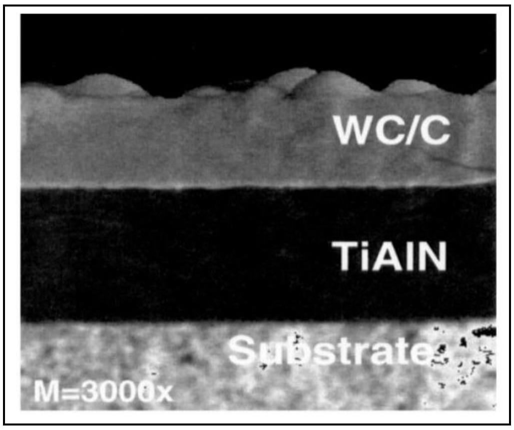

Fig -8: Deposition of Hard/Lubricant coating on a cemented carbide substrate.

The benefit of the lubrication layer can be understood by studying the graph of spindle power to the tool life. From the graph it's evident that the TiAlN coated tool had had a large number of deflections thus indicating the presence of higher stresses on the tool. On the other end the Hard/Lubricant tool has a constant curve showing lesser stress conditions on the tool. The importance of the lubricant coating can be applied with the example of the Hole No 80 in the graph [3]. With the increased depth the TiAlN coated tool lacks the ability to flush the chips out due to the absence of the lubricant layer, which in turn explains the higher power required.

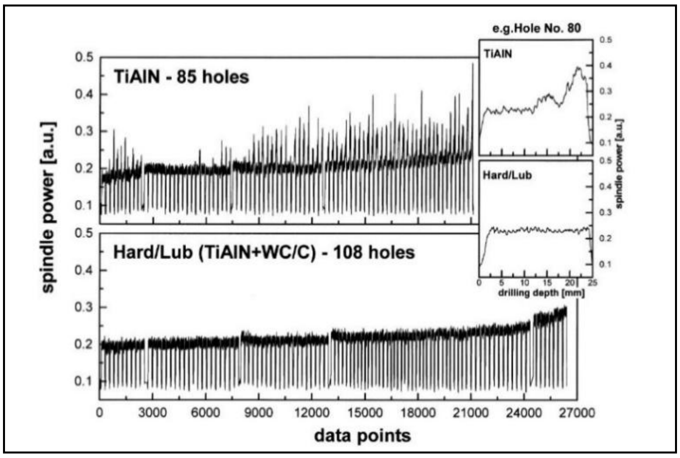

Fig -9: Comparison on performance of TiAlN coated v/s Hard/Lub coated high speed steel drill.

Another application of the Hard/Lubricant coating can be seen in emergency run situations where in minimal or no coolant is required since the coating deposited on the tool wears out during machining. This in turn causes the tool to be planed and induces lubrication grooves. These lubrication grooves along the flutes of the tool shown in the Fig 10 are able to flush out the chips thus preventing and welding of tool to the work material. Specific coating systems with a softer morphological parts or a super hard diamond coated tool have great ability to be used in dry milling operations. The presence of out breakings is directly related to the surface quality of the part. The uncoated sample showed increased presence of outbreakings when compared tools coated with α-C: H and WC/C coating. Diamond and WC/C showed very similar results when compared to one another.

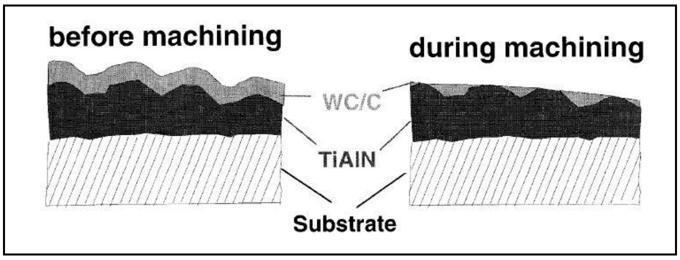

Fig -10: Possible mechanism of the low friction coating behavior during the machining operation.

Though the tools with a softer coating showed a minor built up edge formation it performed good enough than the tools used in wet milling. However significant difference in tool wear performance is seen for a tool coated with a hard (TiN) and soft (MoS_2) coating combination. The purpose of the soft coating is to provide the lubricity for chip flow and the hard coating provides considerable reduction in the tool wear. A number of coatings have the potential to dry machine Al alloys. The partially crystalline coatings discussed above with the softer morphological coating and also the super hard coatings in the likes of diamond are highly recommended.

3. CONCLUSIONS

It's seen that dry machining has seen a positive trend in its use and applications in machining the tougher materials. However the importance of lubricants is vital for overall success of a machining operation and solid lubricants need to improve more on this regard. Challenges in adhesion of the coating and distribution of the coating is seen to govern the life of the tool as shown in machining of AISI 4340 steel where the presence of lubricant reservoirs didn't show a decrease in certain categories of tool wear. Optimizing the deposition technique in providing the storage of lubricant without over deposition is crucial. Surface quality is another aspect which is a challenge to dry machining. Though most of the tools with lubricant coatings gave satisfactory surface quality for a limited period of machining time, wet lubrication is still unmatched in terms of surface finish. However a combination of hard coating and MQL is a considerable option.

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