Coating Cutting Tools with Hard Substance Lowers Friction Co-efficient and Improves Tool Life - A Review

Titus .B. Watmon and Anthony .C. Ijeh, *Member, IAENG*

***Abstract*—Many papers have been presented before which show coating of cutting tools often yield decreased wear rates and reduced coefficients of friction. Although different theories are proposed in those literatures covering areas such as; hardness theory, diffusion barrier theory, thermal barrier theory, reduced friction theory, most have not dealt with the question of how and why coating of tool substrates with hard material such as Titanium Nitride (TiN), Titanium Carbide (TiC) and Aluminium Oxide (AL_20_3) transforms the performance of cutting tools. The paper discusses the complex interrelationship that encompasses the thermal barrier function and the relatively low sliding friction coefficient of TiN. It concludes by saying that, the coating on tools lowers the friction coefficient and increase wear resistance long after the original coating-substrate interface, has been penetrated.**

***Index Terms*—Friction Coefficients, Coating, Wear Resistance**

I. Introduction

Hard coatings if applied by physical vapour deposition (PVD) are principally known to have the ability to reduce tool wear of high speed steel (HSS) and carbide metal cutting tools. Among the commercially available coatings, PVD TiN is today probably the most commonly used. TiN coatings according to their high hardness, corrosion and wear resistance as well as gold-like appearance, are widely used in industrial applications for a range of different applications including machining tools to decorative items [1]). Many scholars and researchers have published several works showing the successful use of TiN coatings both to improve wear resistance in sliding wear tests and to increase tool life in metal cutting. Several explanations to this valuable influence of TiN coatings resulted in abundance of more or less interconnected theories. This paper sets out to explain how and why TiN coatings really improve the performance of cutting tools by organizing previously published results on the properties of TiN and tool substrates fusion. Sue and Troue [2] stated that TiN and TiAlN PVD coatings could reduce friction in tribological contacts and increase the abrasive wear resistance. Schulz et al [3] stated that ‘cutting edges of cemented carbide tools coated with TiC, TiN or (Ti, Al)N by chemical vapour deposition (CVD) and or by physical vapour deposition (PVD) processes can show an increase of the service lifetime of tools by a factor of ten compared to uncoated tools. This paper, therefore; looks at the coating relevance, inherent properties of the coating and adhesion of the coating to substrates.

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T .B. Watmon is with the University of East London, 4 – 6 University Way, London, E16 2RD, UK (Corresponding authors phone: +44(0)208-223-7778; e-mail: bt.watmon@gmail.com)
A .C. Ijeh is with the University of East London, 4 – 6 University Way, London, E16 2RD, UK (e-mail: ijehanthony@yahoo.co.uk)

II. Coating Relevance

Overall, the main aim of applying a TiN coating to a metal cutting tool is a cost-cutting measure to reduce tool replacement costs and produce good surface finish. Many authors have discussed the performance of turning, drilling, and tapping HSS tools coated with thin layers of titanium nitride by PVD method. TiN coatings were found to be most beneficial when turning at high speed but of little value on taps which cannot be operated at speeds high enough to take advantage of this coating [4]. Obviously, all these depend on the fundamental requirement of sufficient adhesion to the substrate in order that the tool can be able to have enhanced wear resistance.

III. Have Enhanced Wear Resistance

The requisite of high wear resistance tools is usually essential in a metal machining environment to help keep replacement and changeover costs low. Most metal cutting people know that it is the wear resistance of the substrate, and not the inherent wear resistance of the coatings that matters. Consequently, the coating should be able to yield maximum protection at the critical contact point between the tool and work piece in order to enhance the wear resistance capability.

IV. Increased Productivity

The capability to cut at much higher speeds has generated more interest to metal machining industry than reduced tool wear that is associated with the tool cost and the tool change time, which normally amounts to less than 3% of the total machining cost [5]. Cutting edges of coated tools have improved properties with the ability to increase the cutting speed, the feed, and the depth of cut or any combination of these parameters. The ability to increase productivity makes more sense than reduced tool wear

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V. Reduced Power Requirements

The cutting performances of tools depend on cutting force and thrust force. These have a lot of bearing on the chip appearance and the resulting surface finish. A reduced cutting force is beneficial, primarily because it demands less motor power of the cutting machine while a reduced thrust force helps by lowering the demands for machine stability. Many authors have shown that a TiN-coated tool yields lower forces than the conventional uncoated HSS tool. A number of papers have also reported an improved surface finish of the chips ("shiny chips"). However, this is of minor importance for the cutting performance, but is an indication of changed in the contact conditions between chip and tool. 'While TiC and Al_20_3 appear to provide the most chemically stable screening layer between chip and tool, TiN appears to offer the lowest tool friction. This has been attributed to a lower chip surface strengthening action of nitrogen than carbon when the coating materials is decomposed in the presence of the austenitic surface of the chip'[6]. According to Shaw (2005), 'although Al_20_3 should be the most effective diffusion barrier, it is much more difficult to bond to the substrate than either TiN or TiC [7]. Bond strength is probably the overriding attribute of coating and, in this regard, TiC excels' concluded Shaw. TiN and TiC coated tools give good surface finish on the work piece because the contact conditions between the tool and work piece cause smaller or fewer built-up edge (BUE) fragments which could be deposited on the cut surface, and also partly by the fact that the lower forces obtained do reduce tool vibrations, which lead to deterioration in the surface finish in the case of using conventional tools.

TIN INHERENT IN COATING PROPERTIES

VII. Physical Properties

The physical properties of TiN coating of HSS and carbide tools, is probably the most interesting because TiN is often considered to play the role of a thermal barrier, by protecting the heat-sensitive tool substrate from thermal softening. The protection the substrates receive depends on the quality of the fusion between the coating and the tool. TiN and TiC are known for their ability to bond with the substrates well. The resulting surface finish of the work piece may be improved by the presence of a TiN coating on the tool [8], [9]. The explanation to this is that there is an improved contact condition because a cutting edge is vital for the resulting cutting and thrust forces. They also determine the chip shape and the appearance of the cut surface.

About 100% of cutting tool insets these days comes with some sort of coating. The principal coating materials and reasons for their use according to Shaw are as follows:-

- TiN, to lower friction and build-up
- TiC, to increase hardness
- Al_20_3 to provide a thermal barrier

VIII. Chemical Properties

Titanium Nitride has been proven to have excellent chemical stability, because of this it is used mostly as diffusion barrier on high temperature resistant alloys. TiN also has good resistance properties to oxidation. Many cutting tests reveal that even when the coating has been partially removed by edge wear, prolonged tool life is still obtained [10]. To explain this fact Kassman [11] tried to prove the presence of a "smearing mechanism" and assumed that TiN material was continuously transferred from the coated region of the edge on to the uncoated, thereby modifying the contact conditions by atomistic wear process and hence reducing the wear rate.

IX. Analysis and Discussion

The cutting performance of tools includes cutting and thrust forces, chip appearance and the resulting surface finish. Improvement in the innovative properties allows the cutting speed to be increased and the feed too, this leads to increased productivity. The whole idea is to increase production to a higher rate rather than to obtain an increased tool life [12]. The basic requirement for the efficient rough machining of steel is a tool material that exhibits the toughness of the tungsten carbide while giving the superior wear resistance of titanium nitride. For this reason, much interest is being shown in the coating of cemented carbides with a thin layer of harder material. These coatings are between 5 and 8 μm thick and are found to practically eliminate inter-diffusion between the chip and the tool [13]. Eventually, when the coating is worn off by abrasion, the tool wear rate becomes the same as that for the uncoated conventional tool. Successes have been reported with coatings of titanium carbide [14], titanium dioxide [15], and titanium nitride [16]. Although not demonstrated, it was assumed the best results would be obtained with a TiN coating on a solid tool. The TiN coating significantly reduces the wear rate of cutting tools when sliding against a work piece. The PVD techniques make it possible to extend by 50 – 100% the life of tools made from hot work steels [17], [18], and [19]

X. Conclusion

In early 1980s, coating of Tungsten tools with TiC by PVD process was introduced, while TiN coatings about 1985 and both types of coatings enabled higher cutting speeds. There is conclusive evidence to say that coating with hard substances like TiN, TiC and Al_20_3 improves cutting tool capabilities. Hence, the tools can therefore, cut at higher speeds for improved productivity with reduced power requirements. The most important mechanisms by which a coating can protect a substrate material are the following though not limited to these areas specifically:-

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a) The wear resistance of the coating itself should be superior to that of the substrate

b) The coating lowers the friction coefficient and thereby the contact temperature. A decrease in friction also reduces the tendency for severe adhesive wear.
The coating acts as a heat barrier owing to the lower thermal conductivity compared with that of the substrate. Thus, the proportion of frictional heat which dissipates into the substrate is reduced which, in turn, lowers the substrate temperature.

c) The coating has lubricating properties because it can generate secondary layers in the wear surface,

d) Elements of the coating material can diffuse into the substrate and thereby increase its wear resistance long after the original coating-substrate interface has been penetrated.

XII. RECOMMENDATION

All these coatings were done on plain tool inserts. It is therefore suggested that inserts with crater-like surface topography be coated for testing. It is hypothesised that the coatings will stick in the valleys and may retain the coating longer thereby improving the resistance to wear.

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