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Full Length Research Paper

Fatigue properties of ALTiN and TiN-coated high speed steels (HSS) steels

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Wear of equipments limits usage life of machine parts. For this reason, coating technologies obtained from vapour phase occupy an important place in industrial applications. Coating obtained in this way has a wide usage area because it is not related directly to property of main materials to be covered. In physical vapour deposition (PVD) method, coating material is transmitted to surface in atomic, molecular or ionic form obtained not chemically but physically from solid, liquid and gas source. This work presents the fatigue properties of AlTiN and TiN-coated (high speed steels) HSS. In present study, TiN and AlTiN coatings were deposited onto HSS steel substrates by 'physical vapour deposition' technique at approximately 650°C for 4 h. Fatigue test for AlTiN and TiN-coated HSS steel samples were performed. The obtained results were compared with uncoated HSS components. It was observed that number of cycle for failure of AlTiN and TiN-coated HSS parts is longer than uncoated HSS steels. Particularly TiN-coated HSS parts have the most valuable fatigue results.

Key words: Physical vapour deposition coating, mechanical properties, fatigue, hardness.

INTRODUCTION

New tool steels types are being developed within course of working on them over the years and the ways to increase physical life of these steels are being researched. Important developments, by ultra-hard thin films originated on tool surface have been achieved in recent years. Features of nitride, carbide, and oxides used in these coatings like hardness, lubricant and abrasion resistance have been known for long times. The fact that these materials are brittle and fragile hinders usage from full materials and so their prices are very high (Bunshah, 1980; Coll et al., 1992). By the combination of physical vapour deposition (PVD) and chemical vapour deposition (CVD) coatings, a significant improvement in strength and lifetime is obtained in comparison to conventional CVD-coatings (Schlund et al., 1999). TiN coatings have gained increasing importance in the field of cutting tools, dies, and many mechanical parts to increase their lifetime and performance due to their attractive properties such as high hardness, good wear and chemical stability (Seog-Young et al., 2002). In addition to single layer coatings (homogeneous layers of TiN, TiCN and TiAlN), a new class of coatings with multilayered structures have shown enhanced mechanical and tribological properties as compared to single layer coatings (Ducros et al., 2003). Coatings obtained in processes of the physical deposition from the gas phase PVD have established their standing in many applications, ensuring a significant improvement of the working properties of tools made from high speed steels (Dobrza'nski et al., 2004). Any coating system giving improved wear properties may drastically reduce the fatigue life of a component due to cracks starting in the coating and propagating into the substrate material (Baragettia et al., 2005). Thin hard PVD coatings are today frequently used in order to improve the tribological performance of forming tools, cutting tools and machine elements (Harlin et al., 2006). An extremely important advantage of (Ti, Al)N coatings is that it possesses a high thermal stability due to the formation of a dense, highly adhesive, protective Al_2O_3 surface film on the (Ti, Al)N coating in the process of cutting (Chen et al., 2007). Ti(C, N) and TiN/Ti(C, N) multilayer coatings exhibit approximately identical performance and different failure forms in machining carbon steel (Chen et al., 2008). Finally, the

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Table 1. Chemical compound of HSS (high-speed steel) steel.

Material	DIN	C (%)	Cr (%)	Mo (%)	V (%)	W (%)	Si (%)	Mn (%)	P≤%	S≤%	Co (%)	Tensile strength
High speed steel	1.3343 S 6-5-2	0.86-0.94	3.80-4.50	4.70-5.20	1.70-2.00	6.00-6.70	≤0.45	≤0.40	0.030	0.030	-	920 MPa

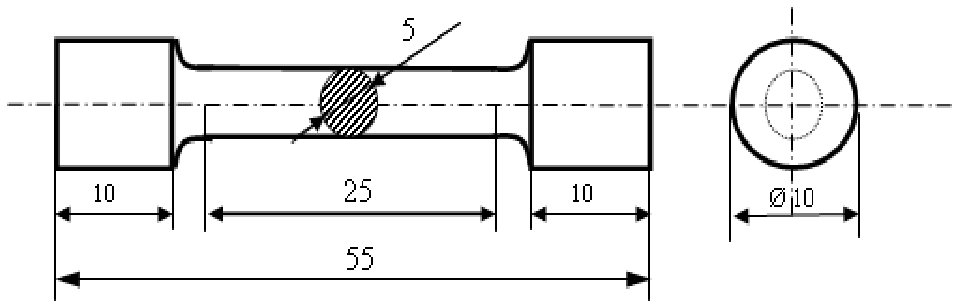

Figure 1. Tensile and fatigue experiment samples, dimensions in mm.

TiAlN film which combines good mechanical, adhesion and fatigue properties exhibited an improved cutting performance (Bouzakis et al., 2009).

PVD method is based on separating atoms from surfaces and accumulating (atomic or ionic) them to sub-material surface to be coated by evaporating or sloping materials under vacuum. PVD method is carried out by three methods called as vacuum evaporation, sputter deposition and ion plating (Dinç, 2010). Coating material in PVD method is transmitted to surface in atomic, molecular or ionic form, obtaining it not chemically but physically from solid, liquid and gas source. Chemical reactions in PVD coating can exist on main material surface too colder than CVD coating (while temperatures in CVD coating are 1000 to 2000°C, PVD coating needs temperatures between 50 to 500°C); however such a reaction formation is no necessary. It is more interesting that PVD operation is performed in relatively lower temperatures. In addition, after completion of coating micro structure and properties of main material are not affected. In this study, fatigue properties of AlTiN and TiN coated HSS steels by PVD method have been examined in detail.

MATERIALS AND METHODS

HSS (high-speed steel) steel which is important for cutting tools is used in experiments. Chemical composition of HSS (high-speed steel) steel used in experiments is given in Table 1. HSS (high-speed steel) is the most important one in its category. It has resistance against water and acid. Apart from these, it is used in every area of industry as its processing is easy. HSS fatigue and tensile samples are processed by machining operation as given in Figure 1. It is aimed to provide increase in fatigue properties and therefore low wearing value when AlTiN and TiN-coated high-speed steels are used as cutting tool. Moreover, AlTiN and TiN coating applied to HSS steels consists of process as heating, etching, coating, etching, coating and cooling. These processes take about 4 h at 650°C and then cooling process. For this reason in this study, coated HSS parts and uncoated ones are compared to have a better understanding on their fatigue and tensile properties. Steel samples, before coating were grinded with 80, 200 and 400 grit and cleaned with acetone. Thus, hazardous effect of oxide, contamination and grease on sample surface was hindered. Then, AlTiN and TiN coating was applied to samples in CemeCOM AG CC800 apparatus.

Parameters of AlTiN and TiN coating operation on samples are given in Table 2. Moreover, image of apparatus in which PVD method is applied is given in Figure 2. In addition, picture of HSS sample coated with PVD is given in Figure 3.

RESULTS

Fatigue test is carried out with Instron 8501 dynamic test device (Figure 4). The specimen to be tested is clamped at its two ends by two grips. In the current setting, the upper grip is fixed although its vertical position can be adjusted to accommodate specimens of different sizes. A powerful hydraulic actuator drives the lower grip.

Table 2. Parameters of AlTiN and TiN coating operation on samples.

Sample	Main tension (V)	Temperature (°C)	Pressure (MPa)	Arc current (A)
AlTiN and TiN -coated HSS for 4 h	200	650	10^{-6}	50

Figure 2. PVD apparatus used in the experiments.

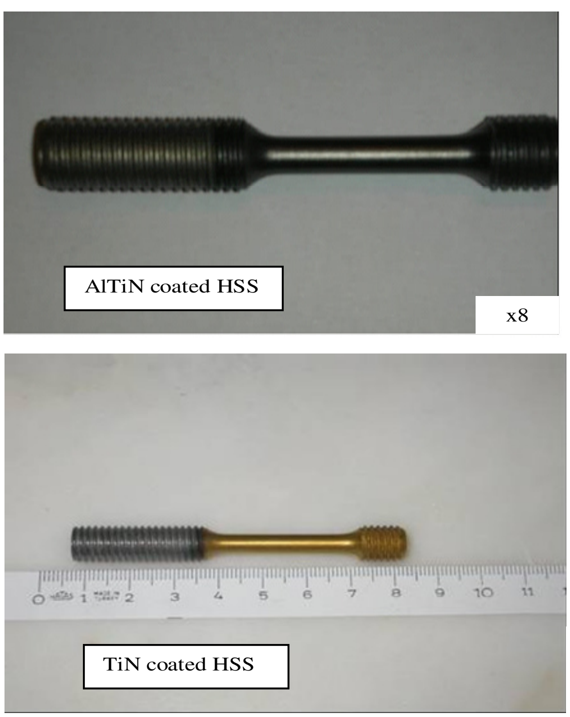

Figure 3. HSS sample coated with PVD.

Once the specimen has been attached to the grips, the vertical movement of the lower grip generates the desired loading on the specimen. In the course of experiment, load application frequency is taken as 20 Hz. Device automatically stops when there is damage (breaking) on samples fatigue tests and are carried out adding variable loads onto constant pre-stress. Constant pre-stress was 400 MPa and stress amplitude was applied between 250 to 350 MPa. Fatigue resistance and values (number of cycles) of AlTiN and TiN-coated HSS parts were compared. Three specimens were tested in each condition in the experiments and the average of three measurements was presented. Fatigue tests were conducted superimposing fluctuating tensile loads on a constant tensile load. Constant tensile load produced tensile stresses of 400 MPa. Fluctuating tensile stress amplitudes varied between 250 and 350 MPa, and numbers of cycles up to fracture were recorded. Three specimens were tested in each condition in the experiments.

Fatigue results of AlTiN and TiN-coated HSS parts and uncoated ones are given in same graph. In addition, fatigue results of AlTiN and TiN coated HSS parts were compared with those of uncoated HSS parts (Figure 5).

DISCUSSION

It was observed that fatigue resistance and cycle values of coated HSS steels are higher when operating under dynamic loads. Moreover, surface roughness of fatigue samples may cause notch effect. For this reason, surface roughness of coated HSS parts is compared with those of uncoated ones. While the average surface roughness ‘Ra’ of the uncoated samples was in the range of 0.40 µm, those of the AlTiN and TiN coated samples was in the range of 0.60 and 0.80 µm, respectively. As a result of this, it is claimed that this does not cause the strength of coated parts to decrease because there is no difference between surface roughness of coated and uncoated parts. Then, micro-hardness of samples was obtained as HV (Vickers hardness), on Instron Testor 2100 series micro-hardness tester under 500 g loads and for 10 s. Micro-hardness value of coated sample surface was measured five times under 500 g loads and for 10 s and their average was taken. However, it was found that surface hardness of AlTiN and TiN-coated HSS parts are approximately 364 and 443 HV, respectively while surface hardness of uncoated HSS parts is 250 HV. The fact that surface hardness is high on coated parts and surface roughness of coated layer is well indicates that it

Figure 4. Instron 8501 dynamic test device.

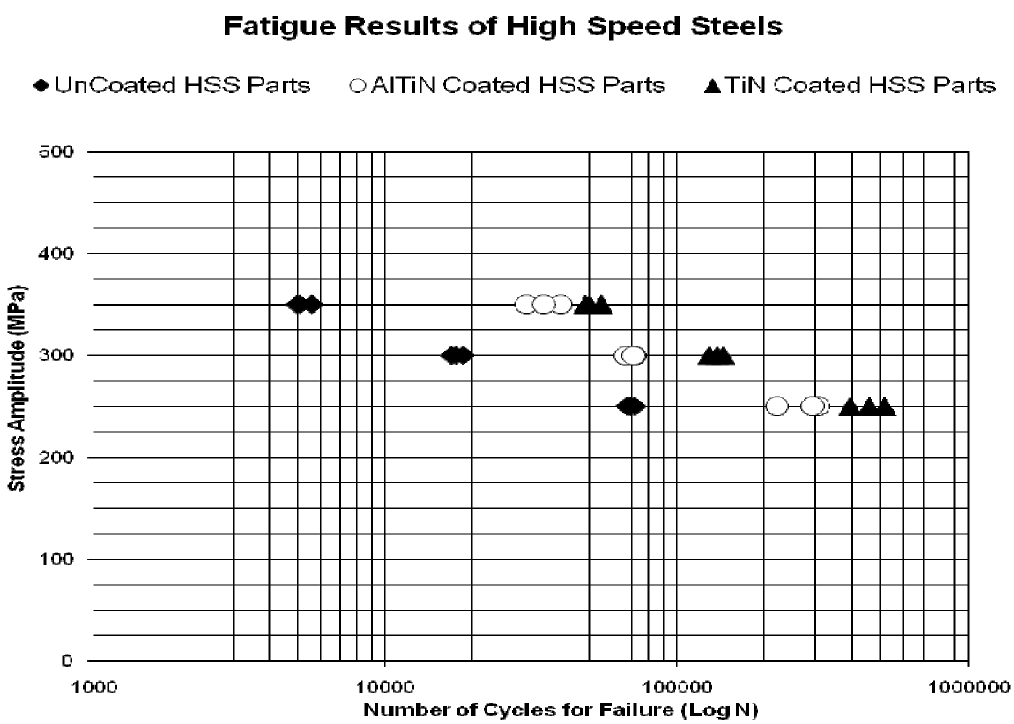

Figure 5. Fatigue results of high speed steels.

would not easily be wearing when used as cutting tool.

Conclusions

In this study, fatigue properties of PVD coated HSS steels were investigated. PVD coated parts were subjected to fatigue test. The following conclusions can be derived from the aforementioned results and discussions:

i) Coatings considerably improve tool life and boost the performance of HSS tools in high productivity.

ii) Although AlTiN and TiN-coating of HSS steels examined in this study by PVD method is a very rough method, it is carried out with technological devices in appropriate operation environment.

iii) The coating layer had dominating effect on the fatigue behaviour of coated specimens. The fact that tensile strength and fatigue time of AlTiN and TiN-coated HSS steels are higher than uncoated ones exposes that coated samples will have more resistance under static and dynamic stress.

iv) Micro-hardness results indicate that the desired surface hardness results for the test samples were achieved.

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