

High temperature wear and frictional properties of duplex-treated tool steel sliding against a two phase brass

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Abstract

Improvement of die life in the hot forging of brass alloys is considered vital from both technical and economical points of view. In this research, pin-on-disc tests were carried out at a range of temperatures to evaluate the influence of plasma nitriding and duplex nitriding-physical vapour deposition (PVD), including TiN–TiAlN and TiN–TiAlN–CrAlN coatings, on the tribological properties of AISI H13 steel. PVD coatings were deposited by a cathodic arc technique on the surface of the steel pins. The mechanical properties, surface roughness and composition of the coatings were determined by microhardness, nanoindentation, Scanning Electron microscopy (SEM) equipped with energy-dispersive X-ray spectroscopy (EDS) and X-ray diffraction (XRD). Performance tests were conducted under real working conditions by hot forging of a two phase brass alloy. The results of pin-on-disc tests at 250 °C revealed the minor adhesion of brass alloy on the surface of duplex TiN–TiAlN coating. At 700 °C, this coating was relatively more resistant to oxidation and thus, it performed better than other coatings. The performance tests indicated improvement of 200% in die life compared to H13 hot work tool steel dies.

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1. Introduction

Metalworking industries have shown a growing interest in improving the die life. The die life is defined as the number of outputs that can be produced with the same die, especially in hot forging operations. The die life is reduced by wear, mechanical fatigue, plastic deformation and thermal fatigue, in order of importance [1–3]. It is known that the die cost is about 30% of the total cost for a closed die forging process. Hence, an increase of 100% in the die life may reduce the total cost of the product by about 15% [4]. Surface engineering methods are used in metal forming processes to increase the die life. The common techniques used for forging dies are thermochemical treatments as well as reactive and deposited coatings [5]. The last generation of these coatings is duplex treatment: a combined process of plasma nitriding and

subsequent PVD coatings [6]. Among different methods of PVD coatings, both anodic and cathodic arc vaporizations are widely used to deposit hard and wear resistant coatings for functional applications [7,8]. Cathodic arc deposition is the most widely used arc technique when vaporizing alloy electrodes such as Ti–Al in industrial applications [9].

In the field of forging copper alloys, Sato et al. [10] studied wear and tribological properties of PVD coatings rubbed against copper. The wear rate of CrN rubbed was very low, but the wear rate of TiN, TiC and TiCN was high compared to hot work tool steel. The main reason for the more wear rates of Ti-based coatings has been suggested to be the catalytic action of copper in the oxidation of the coatings. The investigation of oxidation and high-temperature properties has only been predicated by heat treatment of coating materials and copper powder.

In the field of steel forging, the existence of a single layer of PVD coating, without pre-nitriding, has been found to increase wear rate compared with the uncoated conditions [11].

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In duplex treatments, plasma nitriding process prior to PVD coating deposition increases the load-bearing capacity of the substrate as well as the adhesion of the coating to the substrate [12,13], thereby exhibiting higher critical loads than their non-duplex counterparts in the scratch test [14]. The addition of aluminum to TiN and CrN coatings, forming ternary thin layers, is particularly attractive in terms of oxidation resistance [15–18].

In the last two decades, much research has been done to improve the die life in the field of hot forging steel alloys by surface engineering methods. However, in the case of copper-based alloys, there are few studies regarding the role of die coatings. This is despite the fact that brass alloys and H13 hot work tool steel are typically used in hot forging materials for workpiece and tool material respectively, for the production of such parts as gas valves [19–21].

The main idea in the present research was to consider the coated steel die and forging brass as the two components of a tribo-system in order to study the tribological properties of duplex-PVD coated die sliding against a two phase brass alloy in high-temperature pin-on-disc tests. The PVD coatings included TiN–TiN–TiAlN and TiAlN–CrAlN deposited by a cathodic arc process and wear tests carried out at 250 and 700 °C.

2. Material and methods

2.1. Test Materials

The materials used in this study were AISI H13 hot work tool steel (0.4%C, 1.03%Si, 0.38%Mn, 4%Cr, 1.23%Mo, 0.2%Ni, 0.14%Cu, 0.92%V and balanced Fe in wt%) and CuZn38Pb2 hot-extruded alloy (38.9%Zn, 1.87%Pb, 0.31%Fe, 0.13%Al, 0.08%Sn and balanced Cu in wt%), which is known as the forging brass with a wide variety of applications in industry [22]. Pins were prepared from H13 steel ($\varnothing 0.5 \times 50 \text{ mm}^2$ and the radius curvature of 3.5 mm) austenitized at 980 °C, oil quenched and tempered at 590 °C, plasma nitrided and PVD coated. Discs were made of CuZn38Pb2 alloy ($\varnothing 3.6 \times 5 \text{ mm}$).

2.2. Preparation of duplex coatings

A duplex process was carried out on the pins in two steps: plasma nitriding followed by a PVD coating of either TiN–TiAlN

or TiN–TiAlN–CrAlN. The following DC-pulsed plasma nitriding parameters were selected: gas composition $\text{N}_2:\text{H}_2$ 10:90 (Vt.%), pressure 300 Pa, process temperature of 480 °C and treatment time of 8 h. After plasma nitriding, the pins were polished with 1 μm diamond paste. The pins were cleaned by ultrasonic with acetone and ethanol for 10 min respectively, and then dried and stored prior to the coating process.

Details related to the deposition parameters of multilayer coatings are listed in Table 1. The chamber was evacuated to approximately 10^{-3} Pa before sputter cleaning. After the samples were cleaned by argon sputtering, high-purity nitrogen gas was added as the reactive gas. TiN monolayer was deposited as an interlayer followed by the formation of TiAlN coating and then the chamber was cooled down and vented. Some pins were coated by TiN–TiAlN–CrAlN using TiAl and CrAl targets.

2.3. Evaluation of the coatings

Microhardness measurements and optical microscopy examinations were carried out on the cross sections of the plasma nitrided pins. In addition, the hardness and Young's modulus of plasma nitrided and PVD coatings were determined by nanoindentation testing (CSM NHTX). Evaluation of the measured results was based on equations developed by Oliver and Pharr [23]. Poisson's ratios of plasma nitrided H13 steel, TiAlN and CrAlN coatings were assumed to be 0.33 [24], 0.21 [25] and 0.25 [26], respectively. Field-emission scanning electron microscope (MIRA\TESCAN-IROST) equipped with energy dispersive X-ray detector was used to determine the thickness and surface morphology of the coatings before and after pin-on-disc tests and the concentrations of the elements in the coatings. The phases present on the surface of the pins and wear tracks were determined by XRD measurements (Philips) using $\text{Cu K}\alpha$ radiation and step size of 0.05°.

2.4. Pin-on-disc wear tests

The specimens were tested by a custom designed high-temperature pin on disc wear test machine (Fig. 1). Pin on disc tests were carried out at 250 and 700 °C at a sliding speed of 0.03 m/s, under 5 N load for 500 m. The temperatures selected were 250 and 700 °C based on the previous measurements indicating that the maximum temperature at the surface of the

Table 1
Parameters for the deposition of TiN–TiAlN and TiN–TiAlN–CrAlN duplex coatings.

Step	Process	Parameter
1	Workpiece cleaning	preheating temperature of 200 °C, chamber pressure of 1 Pa, Ar^+ bombardment, bias voltage of 2 KV, and cleaning time of 20 min
2	TiN interlayer	target composition of 100%Ti, cathode current of 150 A, chamber pressure of 0.1 Pa, and coating time of 20 min
3	TiAlN interlayer or top layer	target composition of 40%Ti–60%Al wt%, cathode current of 110 A, chamber pressure of 0.1 Pa, and coating time of 80 min
4	CrAlN top layer	target composition of 30%Cr–70%Al wt%, cathode current of 110 A, chamber pressure of 0.1 Pa, coating time of 40 min
5	Cooling down and venting	Ar flow, sample temperature < 200 °C

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