Influence of pretreatment on surface behavior of duplex plasma treated AISI H13 tool steel

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ABSTRACT

The purpose of duplex surface engineering involves a sequential application of two surface technologies in order to develop a surface with combined properties. Duplex treatments consisting of plasma nitriding (PN) and physical vapor deposition (PVD) have been proven to be successful in improving wear, corrosion resistance and the load-carrying capability of steel substrates. In the present study, an attempt has been made to investigate the role of pretreatment on initial surface condition on duplex treated surface properties after PN in three different time durations 6, 12, and 24 h, followed by PVD coating on as-received and heat treated AISI H13 tool steel. After duplex treatment, samples were characterized by XRD and SEM. Surface roughness was evaluated by the surface profilometer, microhardness by Vickers microhardness tester and wear resistance properties by tribometer. Surface roughness and hardness values are higher for heat treated conditions compared to the as-received conditions in three different time durations. It has been observed that the initial surface condition and thickness of the white compound layer, play important roles in governing the final properties of the coating material. Wear resistance is also better in heat treated condition for duplex treated samples compared to the as-received condition.

1. Introduction

Nowadays mechanical systems operate under severe conditions sustaining high applied loads, higher temperatures, greater sliding speeds and much more dangerous environments [1]. Surface treatment achieves the combination of all conflicting desired properties. Among various methods of surface treatments, PN is considered as one of the promising methods as this process provides of high surface hardness, fatigue strength, corrosion and wear resistance along with the low coefficient of friction. Such improvement in properties facilitated due to the introduction of nitrogen ions into the surface in plasma state leading to a formation of a thick nitrogen diffused layer. However, in the case of very strong surface attack by wear and corrosion, the nitrided layer does not exhibit sufficient resistance [2]. Similar to PN, PAPVD techniques deposits coatings with very high hardness and are well known for providing surfaces with enhanced tribological properties in terms of low friction and high wear resistance. However, their tribological performance is often limited when they deposited on soft substrate because plastic deformation is prone to occur with high loads which will lead to the film decohesion because the soft material may not be able to provide adequate support for the hard coating [3].

Considering the advantages of both these processes if PN is done before the hard coating it can improve the hardness of substrate as well as the coating substrate adhesion [4]. A process where a hard coating is followed by PN process is called a duplex treatment. With the duplex treatment the load-bearing capacity can also be further improved [5].

AISI H13 is one of the universal hot-working tool steels due to its high-temperature strength and ductility and is mostly used for die manufacturing, forging and aluminium injection applications. However, the AISI H13 tool steel shows a high coefficient of friction and suffers poor resistance to sliding wear. The interest has grown by using surface engineering techniques to improve the tribological properties of the hot work tool steel. Usually, thermo-chemical surface treatments such as PN applied to this steel in order to increase the lifetime of tools and dies [6–9]. Unlike, plain carbon steels, the presence of alloying elements like chromium, vanadium and molybdenum in this steel precipitate to nitrides during PN thereby contributing to the higher surface hardness when treated at temperatures higher than 450 °C [10]. And this also attributes to the improved tensile strength and wear resistance after PN treatment [11]. Fox-Rabinovich et al. reported that a duplex treatment consisting of PN followed by PVD coatings improved the wear resistance by 1.5 times compared to the untreated M2, high speed

Table 1
Chemical composition of AISI H13 steel in weight %.

C	Cr	V	Mo	Si	Mn	Cu	P	S	Ni	Fe
0.38	5.0	1.0	1.4	1.0	0.35	0.25	0.03	0.03	0.3	Balance

Table 2
Heat treatment details.

Hardening			Tempering		
Austenitizing Temperature (°C)	Soaking time (min)	Quenching medium	Temperature (°C)	Soaking time (min)	Cooling medium
1020	30	Oil	550	60	Air

steel (HSS) component [12]. However, at present, duplex surface treatments of PVD TiN coating on plasma nitrided AISI H13 have not yet been extensively studied [13–15].

In the present study, the influence of initial material condition and PN treatment time on the microstructure of the AISI H13 substrate and on the subsequent mechanical properties of plasma nitrided and TiN coating structure is explored. In order to quantify if the wear resistance of the duplex coating is dependent of the final microstructure of the substrate, the duplex treatment was carried out on as-received AISI H13 and hardened and tempered AISI H13 tool steel.

2. Materials and methods

The present study deals with AISI H13 tool steel and its chemical composition is given in Table 1. Two varieties of samples were considered for the present investigation namely a) As received b) Hardened and tempered (details are given in Table 2) AISI H13 tool steel. Samples of 24 mm in diameter and 5 mm in thickness were cut from as received and hardened and tempered cylindrical bar of AISI H13 having a diameter of 25 mm for the present study. These disc shaped samples were

prepared by standard metallographic methods to a final average surface roughness value of Ra = 0.02 μm.

PN and TiN coating were performed in two separate types of equipment. PN was used as the first process in the duplex treatment for AISI H13 tool steel. The schematic diagram of the PN system and its details are given elsewhere [16]. AISI H13 samples were initially cleaned with acetone and then subsequently sputter cleaned at around 250 °C in 80%H_2 + 20%N_2 gas mixture at 1 mbar pressure for 1 h to remove the oxide layer and any foreign contamination so as to expose the fresh surface for nitrogen diffusion during PN process. PN was carried out in pulsed DC glow discharge mode for three different time durations 6, 12 and 24 h at 500 °C. The other processing parameters include 480–530 V DC voltage, 80% duty cycle, 80%N_2 + 20%H_2 gas mixture and 500 Pa pressure with 6–8 A current. The temperature of the samples was monitored by Fe-Constantan-Fe thermocouple (J-type) with an accuracy of ± 10 °C. All samples were cooled inside the chamber in the N_2 and H_2 gaseous mixture atmosphere to avoid oxidation.

PVD TiN coating was performed by magnetron sputtering process. Ti (99.99% pure) material was the target material and N_2 in the form of gas was introduced into the chamber for formation of TiN deposited coating onto the sample surface. A schematic diagram of the PVD system is given in Fig. 1. The system chamber was evacuated by the rotary pump and diffusion pump to maintain the base pressure 5×10^{-5} mbar. The samples were etched inside the PVD chamber for 25 min in Argon (Ar) inert gaseous atmosphere through the needle valve with substrate bias voltage 800 V_{p-p} and operating pressure 5×10^{-2} mbar. At the time of deposition, the Argon gas was used for the plasma ignition, and the operating pressure was held at 4.5×10^{-3} mbar for an hour. Discharge current of 0.72 A, cathode voltage of 600 V, substrate bias current of 15 mA, bias voltage of −60 V and nitrogen flow rate of 2.5 sccm through mass flow controller for 1 h deposition time.

Phases of the duplex treated samples was obtained from X-ray analysis (Bruker D8 DISCOVER) as a function of nitriding time using Bragg-Brentano geometry x-ray diffractometer operated at 40 kV and 30 mA with a filter of CuKα monochromatic beam with the wavelength
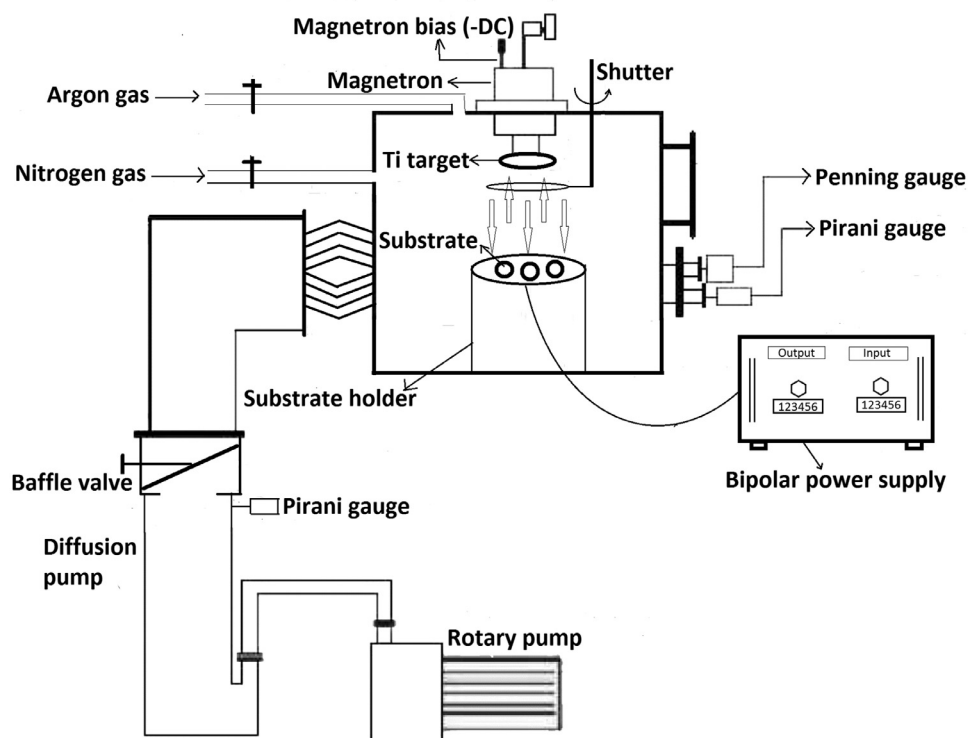
Fig. 1. Schematic diagram of PVD system.