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Sliding wear characteristics of solid lubricant coating on titanium alloy surface modified by laser texturing and ternary hard coatings

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Abstract: Titanium alloys are poor in wear resistance and it is not suitable under sliding conditions even with lubrication because of its severe adhesive wear tendency. The surface modifications through texturing and surface coating were used to enhance the surface properties of the titanium alloy substrate. Hard and wear resistant coatings such as TiAlN and AlCrN were applied over textured titanium alloy surfaces with chromium as interlayer. To improve the friction and wear resisting performance of hard coatings further, solid lubricant, molybdenum disulphide (MoS2), was deposited on dimples made over hard coatings. Unidirectional sliding wear tests were performed with pin on disc contact geometry, to evaluate the tribological performance of coated substrates. The tests were performed under three different normal loads for a period of 40 min at sliding velocity of 2 m/s. The tribological behaviours of multi-layer coatings such as coating structure, friction coefficient and specific wear rate were investigated and analyzed. The lower friction coefficient of approximately 0.1 was found at the early sliding stage, which reduces the material transfer and increases the wear life. Although, the friction coefficient increased to high values after MoS_2 coating was partially removed, substrate was still protected against wear by underlying hard composite layer.
Key words: surface texturing; chromium interlayer; hard coating; molybdenum disulphide; dry sliding

1 Introduction

The attractive properties such as lower modulus, superior biocompatibility and better corrosion resistance possessed by Ti−6Al−4V, $\alpha+\beta$ alloy, lead to its higher usage in structural and automobile field. More than 50% of all titanium alloys in use today are of this composition [1]. Ti−6Al−4V presently is the most widely used, high-strength titanium alloy. It finds a large application in aerospace, automotive, marine and chemical industries. Many research papers focused on the tribological improvement of titanium alloy surfaces only through the surface treatments and surface coatings [2−7]. The surface is the most important part of any engineering component. It is well known that most of the components fail from surface initiated defects such as wear, corrosion, fatigue or fracture. There is a constant demand for surfaces with improved tribological performance. Surface engineering, as opposed to bulk alloying, provides an opportunity to improve the wear resistance of engineering materials while leaving the bulk characteristics relatively unchanged. The substrate material can be designed for strength and toughness while the coating is responsible for the resistance to wear, corrosion and thermal loads, and the achievement of the required frictional characteristics [8].

Surface texturing involves modifications of surface topography by creating an identical micro-relief with commonly shaped asperities or dimples. It helps to improve adhesion of the coating and to enhance the tribological properties of substrate materials. Among the various texturing techniques, laser surface texturing is one of the emerging techniques, which involves fabrication of artificial, regularly patterned micro-dimples over the substrate surface by a material ablation process with a pulsating laser beam, and thus it was employed to pattern substrate surfaces [9,10]. The use of surface coatings opens up the possibility for a material design in which the specific properties are located where they are most needed.

TiN and CrN are the most extensively investigated hard coatings due to their ability to provide high wear and corrosion resistance. The tribological performance of

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TiN and CrN coatings can be improved by the addition of a third element such as Al, thus forming the TiAlN and AlCrN phases. Addition of aluminum results in the formation of oxides, which is very stable and prevents any form of erosion to the inner layers of these compounds and improves the elastic modulus, nano hardness and anti spalling of the coating [11]. The use of multi-layers has often been cited as the way forward to improve the mechanical, tribological and chemical properties of coatings. The metallic chromium interlayer can effectively improve the interface adhesion, wear resistance and reduce friction of hard coatings on soft substrates [12].

The surface modifications through texturing and surface coating were used to enhance the surface properties of the titanium alloy substrate. Further, to improve the friction and wear resisting performance of hard coatings, solid lubricant molybdenum disulphide (MoS_2), was deposited on dimples made over hard coatings. The lamellar structure of MoS_2 reduced the coefficient of friction and the underlying hard coating can successfully increase the load supporting capacity and improve the wear resistance [12−14]. The present investigation deals with the wear improvement of titanium-based alloy through surface modification by texturing followed by coating. The deposition of friction reduction coating on laser textured hard coating surfaces is a unique diversification in the current sliding wear analysis for effective wear resisting performance. This will meet the functional requirement of titanium alloy used in structural and automotive applications.

2 Experimental

2.1 Substrate material preparation and laser surface texturing

Mild annealed Ti−6Al−4V was chosen as the substrate material, which consists of 3.5%−4.5% V, 5.5%−6.75% Al, 0.4% Fe, 0.1% C (mass fraction), and balance titanium. Titanium alloy flats and cylindrical pins were procured from Noble Engineering Private Limited, Chennai, India, and machined to suitable sizes for tribological testing. Cylindrical pins made from mild annealed Ti−6Al−4V were first machined to a uniform diameter of 8 mm for a length of 40 mm. Further, the diameter of one end of the specimen was reduced to (4±0.05) mm for a length of (5±0.05) mm and preferred as the target end for the pin on disc experiment. Figure 1 shows the schematic diagram of the stepped cylindrical pin made from Ti−6Al−4V alloy.

The pin and flat specimens were mechanically polished by 1200 and 2000 mesh grit abrasive paper followed by polishing with 3 μm diamond paste. The polished specimens with a final surface roughness of the order of 0.05−0.07 μm were cleaned ultrasonically in acetone to remove the burr and surface contaminants. Surface texturing was done on the polished specimens by using a commercial pulse Nd:YAG® laser beam. Among the various texturing techniques, laser surface texturing, which is one of the emerging techniques, involves fabrication of artificial, regularly patterned micro-dimples over the substrate surface by a material ablation process with a pulsating laser beam, and thus it was exploited to pattern titanium alloy surfaces. The surface texturing with laser beam is extremely fast, which requires short processing time and environment friendly. This provides excellent control of shape and size of the micro dimples, which allows realization of optimum designs. The laser beam operating parameters were 1.5 kHz pulsating beam, 1064 nm wavelength with a power of 11 kW and engraving speed of 50 mm/s. The texturing pattern was rectangular array and its schematic diagram is shown in Fig. 2.

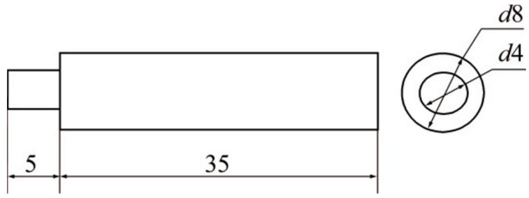

Fig. 1 Schematic diagram of cylindrical specimen used in pin on disc experiment (unit: mm)

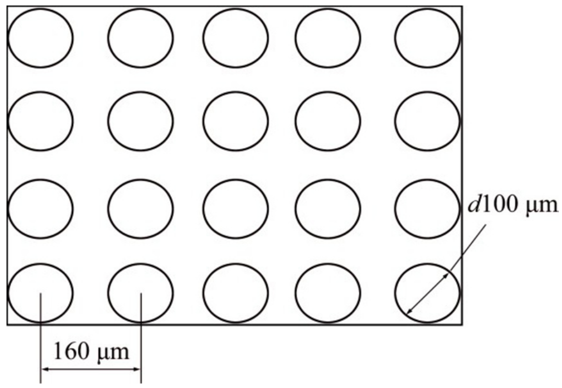

Fig. 2 Schematic diagram of rectangular array texturing pattern

The laser texturing was carried out over the target end surface for the following specifications based on the earlier research in Ref. [9]. The surface was processed to attain the texturing pattern as dimple density of 35%−45%, dimple diameter of 100−110 μm, dimple depth of 2.25−2.75 μm and distance between dimples of 150−160 μm. Figure 3(a) confirms the dimple arrangement and its dimensions on the polished titanium alloy surface. The close up view at the single dimple region clearly reveals the geometry of the dimple (Fig. 3 (b)).