A Review on Enhancement of Wear Resistance Properties of Titanium Alloy using Nano-Composite Coating

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Abstract: The most commonly used material for aerospace application is titanium alloy due to its high strength to weight ratio, corrosion resistance properties. The wear resistance properties matters for longevity of the component and avoids failure. In the present study, different types of methodology are discussed, analyzed and compared. The Nanostructured coating found to be fruitful in infusing new properties and also improves existing properties of titanium alloy.

Key words: Methodology, Nanostructured, Nano-composite coatings, Laser peening

1. Introduction:

Titanium alloys are workhorse and abundantly available structural metal. Three major categories of titanium alloys are α alloy, β alloy and (α+β) alloy. Microstructure of these alloys defines their properties. Pure Titanium is not as strong as its different alloys. The high strength, low weight ratio, and excellent corrosion resistance immanent to titanium and its alloys. Ti6Al4V is the commonly used titanium alloy. It features low friction coefficient, wear resistance and other improved mechanical properties has led to wide range of successful applications which demand high level of reliability in biomedical performance as well as aerospace, automobile, agricultural industries, chemical plants, power generations, sports and other major industries [1,2].

The surfaces of titanium and of all of its alloys relatively inferior wear properties, huge unstable coefficient of friction, excessive adhesive wear and tendency to seize. In particular, titanium surfaces in contact with each other or with other metals readily gall under conditions of sliding contact. Even with little relative movement under light loading, complete seizure of surfaces can occur. This situation is caused by adhesive wear in which microscopic asperities on the metal surfaces come into contact because of relative sliding and they tend to weld together forming a bond at the junction, which can have a rupture strength greater than the strength of the underlying metal. Fracture then takes place at one of the asperities causing metal to be transferred from one surface to the other. The debris so formed gives rise to the accelerated wear that occurs with titanium and its alloys [3,4]. It is essential that use be made of one of a number of ways to improve wear resistance of Ti6Al4V that are available for the material.

There are number of ways to enhance wear resistance properties of Ti alloy such as enhanced surface films including plasma coatings, flame coatings, shot peening, conversion coating etc. as well as thermal oxidation, Nano-composite coatings, ball burnishing process etc. Each process has their own advantages and limitations. In the present study, a comparative study is done to find out the enhancement of wear resistance properties of Ti6Al4V.

1.1 Mechanical Treatment of Surface

Burnishing is a post machining operation and one of the few popular mechanical surface treatment methods used to enhance wear resistance properties. The surface of material is pressed using ball or rollers, which plastically deform the irregular surface asperities. The roughness of surface obtained during machining is reduced. Burnishing produces work hardened smooth surface. This process is capable of producing hard, wear, corrosion and oxidation resistance coating as well as minimizes the friction [5].

In another well-known surface treatment method, shot peening is acknowledged for preventing crack initiation and improving fatigue resistance of titanium alloys. In shot, peening surface to be treated is bombarded with continuous flow of spherical metallic media. It was observed that shot peening has no significant effect on wear behavior of Ti6Al4V but it considerably reduces the frictional coefficient [6].

Laser peening is one of the modern and prominent mechanical surface treatment method used to improve the fretting fatigue. In this operation, a focused plasma used to generate a plasma burst, which form an intermittent shock wave. This shock wave imparted to the material where it passes through the material surface and sub-surface. Due to this, a compressive residual stress generated at surface and sub-surface in the material. Laser peening creates deeper residual stress compare to shot peening process [7].

1.2 Thermal Treatment of Surface

Thermal oxidation treatment is another method to improve hardness and poor tribological properties of Ti6Al4V. This method is easy and environment friendly. In this method material heated to high temperature in the presence of air under normal atmospheric condition. Due to high reactivity of titanium, a thick oxide sublayer formed on the surface of titanium alloy. The oxide layer later found a significant improvement in the hardness and tribological properties of alloy [8, 9].

Nitriding is a surface heat treatment process to improve hardness, wear and corrosion resistance and reduces the coefficient of friction. In this process surface of Ti6Al4V ELI substrate heated with nitrogen rich intense plasma. The electric glow discharge breaks into ions and generate nitrogen ion, which further diffuses with the surface of Ti6Al4V ELI surface. Due to these diffusion the interatomic distance might have reduced and thus improving tribological properties of the alloy [10].

In another research by A. Bloyce et.al, surface of Ti6Al4V was treated with palladium. Researchers performed a comparative study among plasma nitriding, thermal oxidation and palladium treated thermal oxidation tested in boiling HCL solution. The result was found to be promising increase in corrosion and wear resistance of the alloy [11].

Although above oxidation methods are able to enhance the tribological property of Ti alloy but at higher stresses cracking and de-bonding occurs at the modified layer. To overcome above problem Bin Tang et.al has suggested that treating the surface of Ti6Al4V with Mo-N by using plasma surface alloying method. In their research, they have reported a silver white pure Mo-N layer with mixed interface diffusion layer. The result of the experiment was like significant decrease in coefficient of friction in air, Hank's solution and Na_3PO_4 solution as well as wear and corrosion was reduced drastically [12].

The above conventional surface improvement methods have some drawbacks. They take long time to process, low coating densities and susceptibility to deformation at high temperature. Laser treatment to surface can be a solution to above problem. By incorporating a focused laser on surface of material, tribological properties can be treated in many ways like micro alloying, re-melting and cladding a layer on the surface. An oxide layer of TiO_2 forms just after the melting pool solidifies. This TiO_2 oxide layer is excellent to wear and corrosion resistance [13]. By varying the laser parameters, a variety of oxide layers like TiO, TiO_2 and Ti_2O_3 can be developed on the material surface [14].

1.3 Nano-structured Coatings

Since the coating technology exist, methods are being developed to improve the material hardness and tribological properties. Nanostructured coatings exceptionally improve material with superior properties like high hardness, high toughness, wear resistance and thermal stability at elevated temperature. Various first generation PVD coating techniques used for deposition of thin hard film on Ti6Al4V substrate materials. TiC, TiB_2 and TiN are called first generation PVD coating and still being used to develop hard and wear resistant coating. At high temperature these first generation coating possess lower fracture toughness and low oxidation resistance hence limiting their use for advance engineering application [15].

K. Gangatharan et.al have researched with effect of AlCrN and DLC (Diamond like Coating) coatings on surface of Ti6Al4V using arc evaporation method. They found that there were no agglomeration of coating material and AlCrN and DLC are uniformly distributed over the surface hence results in improved mechanical and tribological properties. They also performed comparative study of two coating and come to result that the DLC coatings are better performer in mechanical and tribological condition than AlCrN coatings [16].

Low load carrying capacity and poor tribological properties of Ti alloys have led their limited use. Surface and sub-surface hardening of these alloys by incorporating interstitial N, C or O has resulted slight improvement in tribological properties limiting advance application. In the work of B.G. Wendler et.al, the researcher has suggested for multiplex treatment of Ti6Al4V. It was found that coefficient of friction reduced and wear resistance of the surface improved [17].

Magnetron sputtered coating of TiN, TiAlN and TiCN applied to substrate of Ti6Al4V. This coated substrate is used for biomedical application. At room temperature wear resistance of coated alloys was found much superior than the uncoated. TiN coating have highest wear resistance properties among other coating [18].

The above review study shows that the Titanium being versatile material to be used in various application areas but also has some drawback as high wear loss because of sliding and fretting wear, low load carrying capacity, high corrosion losses etc. To improve mechanical as well as tribological properties researchers have experimented many methods. In each experimental technique, have their own merits and demerits. Ball burnishing, shot peening method improves wear and corrosion resistance property of Ti6Al4V up to surface of the alloy only whereas laser peening produces better properties at surface and sub-surface.

Thermal treatment of Titanium alloys shows significant improvement in surface properties but lack in strength between layers. Oxide layer formed over surface are wear and corrosion resistant. At higher stresses these modified layer fails and cracking and de-bonding of layer occur. To overcome this drawback of oxidation treatment, laser treatment has adopted. In laser treatment of alloy surface, variety of oxide layer can be obtained upon varying operating parameters. Laser treatment results better improvement in tribological properties of alloy surface and subsurface.

Nanostructured coating has capability to infuse new properties along with improvement of existing properties. Material at nanostructured level deposited over the surface using various PVD techniques. Materials surface properties has been in continuous development from first generation coating to binary, ternary followed by quaternary nano-composite coatings. These nano-size particles fuse together to from a thin layer of coating material. A uniform distribution of AlCrN results in improved mechanical and tribological properties. Duplex surface treatment further increses the tribological properties than single layer coating. Although nano-structured coating treatment has ability to form new and improved properties but these properties too fails at high temperature reducing fracture toughness and low oxidation resistance [19].

2. Conclusions

A review study on different types of coatings on titanium alloy, Ti6Al4V is carried out. The following are the conclusions made from the study:

The main wear resistance methodologies used for Titanium alloy Ti6Al 4V are:

Laser peening produces better properties at surface and sub-surface.

The Nanostructured coating infuses new properties and also improves existing properties of titanium alloy Ti6Al4V.

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