RECENT DEVELOPMENTS ON COATING TECHNOLOGIES FOR ALUMINUM & TITANIUM ALLOY AS SUBSTRATE-A BRIEF REVIEW

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Abstract

Recent developments in the field of coating technologies for aerospace applications have reviewed in this paper. The improved performances along with the environmental safety norms are the main reason in the advancement of material and coatings technologies. There are many areas which require improvements but here in this review work traditional areas, or the areas require much attention like corrosion/oxidation protection, wear protection, increasing fatigue strength are still under primary focus. This paper investigated the commonly used titanium alloy that uses in aircraft industries and check is characteristics followed by the different coatings processes and enhances its suitability for the aircraft industry.

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Keywords: *Titanium Alloy, Ti-6Al-4V, Coatings, Wear Resistance, Corrosion Resistance, fretting fatigue*

1. Introduction

An advanced research effort to find the new and improved version of coating technology in aerospace industry is continuously increasing due to advancement of the material being used. In the process of developments of alternatives that must comprises of the fulfillment of the challenging conditions rigorous effort is being given by the aerospace industry. Driven by the emerging demands from the industry several works have been done toward enhancing the property. The new alloy chemistry along with the advanced coating processes have been investigated. The property of titanium and the magnesium that makes it a suitable candidate after some modification in aircraft industry is discussed by the Siobhan Fleming [1] in his work. A further view of investigating alloys like aluminum, titanium, magnesium [2,3] and the composites is the trend toward enhancing the various property. Titanium is the new choice of the aircraft industry for the manufacturing components due to its special characteristics that is reflected in the review work of Anuwar et al. [4]. Khanna N, Davim [5] suggested how It is desirable to provide aero components made-up of titanium alloys with superior strength without sacrificing machining performance the optimum control parameters have been obtained for getting minimum cutting force, feed force and cutting tool temperature. Armstrong [6] in his review looked forwards the coating technology and the fields where researchers have to look for enhancing the composites property in order to make it a best industrial choice. The two-fold requirement of the industry that is the economical material and the desirable property cannot solely be full filed by the alloying chemistry alone, a parallel advance process in coating technology is also needed for this. Ongoing developments included the complete removal of chromium (with higher oxidation state in coating Cr^{6+} followed by the lower oxidation state Cr^{3+} due to the environmental issue. Aguero et al [7], describe the use of an Al slurry coating on AISI 4340 steel as a replacement for Cd, banned in Europe for most industrial applications apart from the aerospace sector. The coating is shown to be an excellent alternative to Cd as evidenced by corrosion and materials testing in coatings technology, improvement is corrosion and wear protection, enhanced fatigue strength is achieved to make product stability longer in the harsh environment. The new step is also taken in the direction of toxic-free pigments, additives that being added in coat to retard flame in adverse situations. A wide range of alloy aluminum, titanium and magnesium along with the composites have been tried by the manufacturer. In this review, the important points of carefully selected papers of coating technology on aerospace parts and aircraft structural material, in the recent years, is presented. The primary focus of coating is to resist the corrosion, wear along with the aim of enhancing the fatigue strength and hardness. The further requirement is the specialism like the infrared transmittance, emissivity, thermal barrier and the pressure sensitivity. It can be seen that in the recent years the development in field of coating technologies for the traditional fields of corrosion/oxidation resistance [8–15], wear resistance [16–21] and the fatigue protection [22-27] for the alloy used in different parts of the aircraft. In addition of this the emergence of the specialty of the coating according to the industry demands such as the infrared transmittance, emissivity and the pressure and thermal sensitivity are also a vast field of research.

2. literature review

CORROSION AND OXIDATION RESISTANCE

Humidity, a great concern for the aircraft parts (like the blades of the turbine which has to handle large masses of air containing moisture) which is made of alloy of titanium. Humidity having the very harmful influences on the corrosion protection mechanism of the titanium alloy (Ti-6Al-4V). Motte [8] and co-workers found in his work that, on the specimen of the alloy the two layers of titanium oxide (rutile) scale is formed and it is separated by another layer of alumna. The layers forms generally contain the defects such as pores/and of whiskers for the outer part, which is the typical presence of water vapor. The existence of different oxygen dissolution depth different mechanism of oxidation due to the presence of moist air reflected in the morphology difference of the alloy before and after subjected to continuous moist air supply. In fact, Pérez [9] in his investigation on titanium, found that after being treated at 973 ◦K for 150 h, the samples of pure titanium exposed to air in laboratory and due to the moisture content of the air .the two layer of oxides having thickness 15mm and 17 mm respectively formed on the titanium samples. There is an enlargement of the oxygen dissolution area thickness (30mm to 40mm). The size of the hydroxyl ion (OH^-) is relatively smaller and having less charge compared to O^{2-} . which results faster diffusion of OH- ion in the larger oxygen dissolution depth. The hydroxyl ion (OH-) coming from the dissociation followed by adsorption of the water molecule at the interface. The review work by Ochonogor O. F [10] showed that the effect of creep for the Ti6Al4V alloy used for the aircraft turbine under the elevated temperature. The internal microstructural changes have been shown by the optical micrograph, that presence of the α –phase having lamellar structure formed heterogeneously in the phase transition (β→α). the formation of lamellar structure is due to the cooling from β field, has also been seen to be an important contributing factor in the formation of secondary alpha and beta phases. Recent research works have been done on the manufacturing processes (additive), which is seen as a potential route to enhance the creep properties of titanium alloy under very high temperature. The microstructure of the Ti alloy tends to change as the condition of heat treatment varies forming the β and α phases. Zunqi Xiaoa et.al [11] studied the oxidation resistance of the alloy at high temperature by applying a coat of novel-glass (amorphous) silica prepared by the slurry method. At high temperature thick oxides layer composed of titanium oxides (rutile) and some granular alpha-aluminum oxides formed on the Ti–6Al–4V surface, while the quartz, diopside and cristobalite were observed in the composite coating. These were helps in slowing down the inwards diffusion of the o_2 molecule into the substrate. Experimental data reveals that solids solution in the alloy with the coating helps in increases the oxidation resistance. A fewer effective oxides layer of titanium and aluminum oxides mixtures can also develop on the surface, which leads to the decrement in the oxidation resistance and thus limits the use of the alloy at high temperature. The main reason behind this limitation is all goes to its porous nature. These alloys also develop a sub-layer (oxygen rich) beneath the oxide scale, which leads to its solubility for the oxygen molecule during high temperature exposure, thus reducing the plasticity of the alloy reflected in the work of Li et al. [12]. However, despite the good oxidation resistance of the alloy provided by the coatings (aluminide) against high-temperature oxidation, it has not been demonstrated to protect and enhance the life span of the titanium-based alloys Ti-6Al-4V as studied by Alam and Das [13]. The extreme brittleness of the aluminum oxide (Al_2O_3) scale provided by these coatings make it prone to cracking, when it is subjected to u cyclic thermal stresses due to mismatch of coefficient of thermal expansion. Shiang-Cheng Jeng [14] in his studies found that the alloy Ti-6Al-4V after hot-dipping in the molten aluminium bath (800 °C) for a time period of three minutes, the microstructure obtained by XRD data shows that it is free from cracks and also has a good adhesion at the interface. In addition to that, coated microstructure of the coatings was found to be a three layer and a reaction zone. These were in the sequence of an outer layer and a reaction zone followed by the two different layers. Fig (01) shows the weight gain of oxidation and time taken followed a parabolic kinetic oxidation law for coated Ti-6Al-4V specimens at 800 °C. However, the uncoated Ti-6Al-4V show a two-step oxidation kinetic at the same temperature. The first step, $\Delta m1 = 1.018\ t^{1/2}$ (parabolic), $\Delta m2 = 0.106\ t + 3.075$ (linear) at a temperature of 800 °C from 24 h to 96 hr.

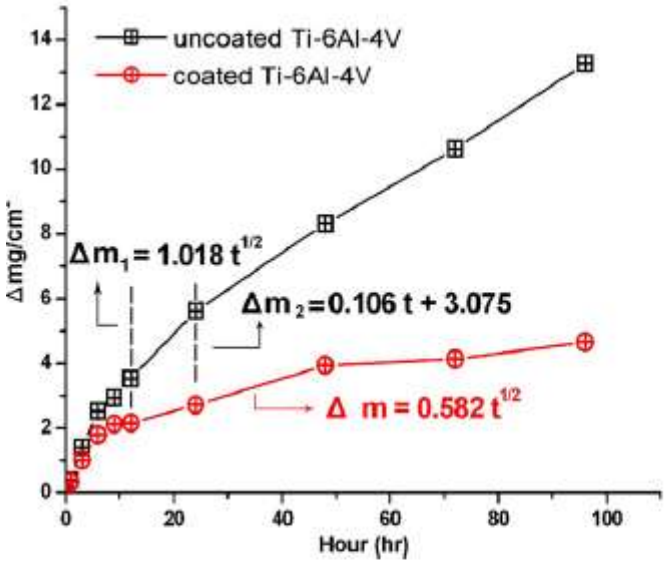

Fig.01; Weight change curves obtained for uncoated and coated Ti-6Al-4V specimens during oxidation at constant temperature of 800 °C in air. Shiang-Cheng [14]

Chaur Jeng Wang [15] checked the consequences of the plasma spray and hot-dip coatings after high-temperature oxidation (cyclic) were investigated in dry and moist air conditions

at a temperature of 750°C. Aluminide coatings prepared on Ti-6Al-4V alloy substrate were able to increase the oxidation resistance of the
alloy under cyclic oxidation at a temperature 750°C. This increment in the resistance is due to aluminide's ability to develop a stable alumina oxides layer on the substrate. These coatings were degraded due to spallation, cracking and internal oxidation with increased cyclic oxidation causes reduction in the lifespan of the coatings and the surface underneath the substrate. The mechanism of failure of the coating is different in both the coating processes, for the hot-dip process it is fragmentation mode and delamination mode are attributed to the plasma spray coating process. The coating provide by the hot-dip process shows greater resistance to high-temperature cyclic oxidation with a little change in mass, few spallation and fewer cracks on the coating when it is compared to plasma spray coating.

WEAR RESISTANCE;

The main cause of the poor tribological properties of the titanium alloy is consisting of two factors. The first is the titanium has very low resistance to the plastic shearing properties and very low work-hardening rate. The mechanical properties that affected by this is the abrasion, adhesion, delamination. Another factor is the it has low protection exerted by the upper titanium oxide (which is formed due to the high flash temperature exposure, this high temperature is due to the energy released during the dry sliding. The oxide layer is (TiO_2) is rutile in nature and easily rubbed away by the micro-fragmentation/ spalling that results poor protection of sub-surface layer of material against the wear. In addition to that oxygen presence in the atmosphere attack the material causes embrittlement of the matrix, which is reflected in the lowering the mechanical resistance property of the material as discussed in [16].
Molinari A. [17] and team studied the wear mechanism of the Ti6Al4V during dry sliding test. The parameters were the variable speed and the different load conditions. The results showed that the alloy have low resistance towards plastic deformation even at low load conditions. This is the consequences of the formation of oxides layer on the material due to the high temperature. This oxide layer enhances the mechanical instability caused by the plastic deformation resulting worse condition of the alloy during dry sliding condition. The graph plotted in the figure (02) depicted a combination of the load and the speed condition, which is the kinetic limit under which the surface oxidation is minimum and hence resulting better wear resistance.

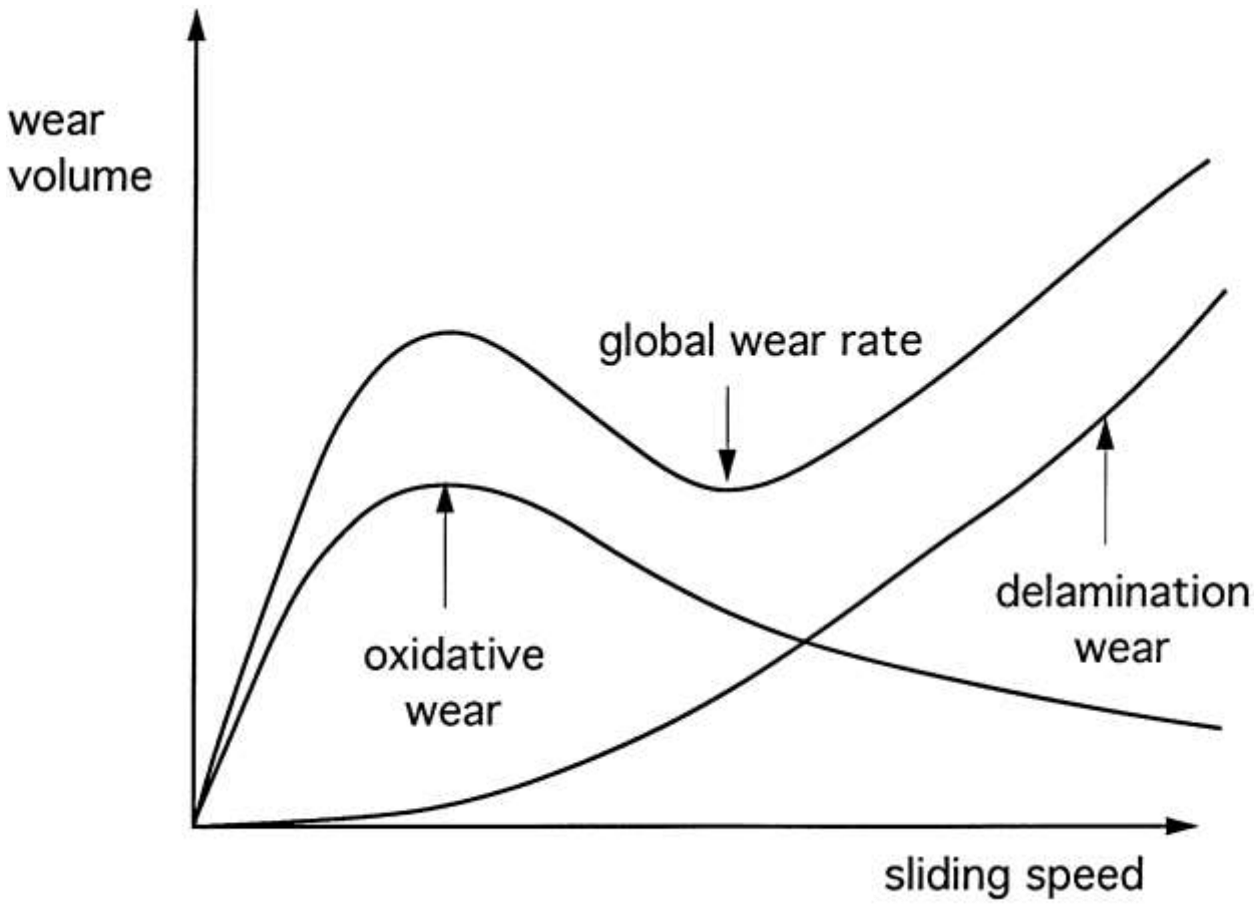

fig (02); The qualitative representation of sliding wear VS sliding speed (Molinari [17]))

The wear resistance of Ti–6Al–4V subjected to plasma nitriding is tested using ball-on-disc- wear tester instrument by the S. Taktak [18] and team.
He carried out the plasma nitriding process in three different temperature 700,800,900 degree centigrade for the time period of 3,6,9,12 hrs. The samples were pre-treated with the explosives shock and then plasma nitriding enables it to enhancing the wear resistance by an amount of two-fold in magnitude. Nitriding over the sample (Ti–6Al–4V) improves the resistance towards wear against WC-Co ball. The wear tester data suggest it is found that increasing the plasma nitriding temperature and time increases the wear resistance of the untreated Ti–6Al–4V alloy increases. The wear resistance property of the alloy (Ti6Al4V) is investigated by L. Ceschini [19]. In his work he compared the wear behaviour of the plasma electrolytic oxidation and of physical vapour deposition of the Ti, Al) N and Cr-N/Nb-N super-lattice Ti-N on the same alloy. The samples coated by the physical vapour significantly decreases the wear and the friction of the alloy, but the life time of this physically vapour coating is a strong function of the applied loads. The plasma electrolytic coat also enhances the tribological property, reducing both friction and wear of the alloy, even at a high loading situation. Quiana Feng, [20] uses the slurry sintering process to provide an enamel coat over the surface of the alloy Ti–6Al–4V (extra low interstitial EIL). The 3-D morphologies, micro-hardness and the wear track morphologies, these all testing are performed on alloy with and without the coat. The adhesion strength was tested by the atomic force microscopy, SEM, hardness test, results leads to the fact that the alloy with the enamel coat shows greater resistance towards wear, but the improvement of the wear resistance costs the alloy losing is surface smoothness. The increasing surface roughness is due to the enamel coating is sintered by the enamel powder on the alloy. Hardness test on the coated samples shows a two time increment in hardness that of the base alloy. The

probability of the wear by abrasion decreases, and the plough created by the wear track looks like shallow.
Shi-hang Kang,[21] used a combined method to improve the wear resistance of the titanium alloy (). The data obtained in the tests revealed that the when a 13-micron layer of aluminium first applied on the alloy by the magnetron sputtering coating process followed by the plasma electrolytic oxidation as a second treatment of aluminium coated alloy increases the wear resistance. On the second treatment the aluminium coated alloy PEO coatings has been formed on the duplex system of aluminium and Ti6Al4V alloy (as shown in fig (03)) in silicate and aluminate electrolytic bath.

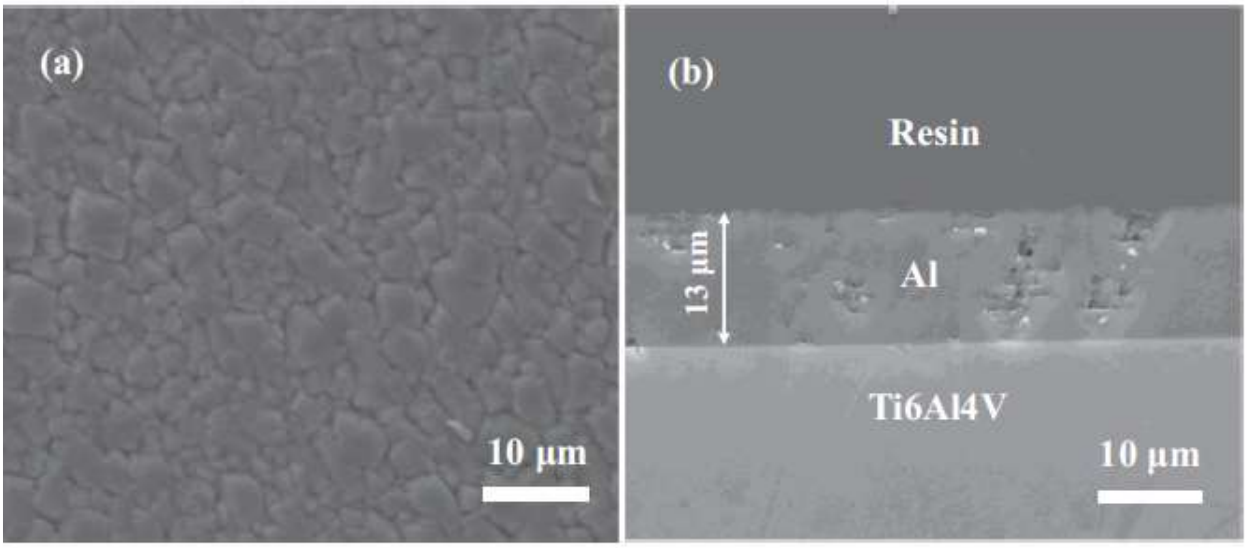

Fig *(03); cross section morphology of magnetron sputtered Al layer on Ti6Al4V* (Shi-hang Kang [21]

Duplex Al/Ti6Al4V alloy system is the most desirable candidate for wear protection. The single layer formation during the magnetron sputtered aluminium coating, shows a growth rate of ~3.8 µm·min−1.

Fatigue resistance

The effect of contact pressure on the fracture surface of Ti6Al4V titanium alloy and the fatigue source region was studied by ZY. Li (22)
The fretting fatigue strength of the alloy is 271 N/mm^2 under 10 MPa contact pressure, which is forty percent less than that of plain fatigue strength. The depth of the source region in the alloy fretting fatigue is a strong function of the contacts pressure implies rapidly increment in the depth when the contact pressure in increases to a value of 10 Mpa, after that a stable region of about 250 µm depth of fretting fatigue is maintained in spite of increasing the contact pressure. The damage in the fretting zone is mainly fatigue delamination. The composition varies from source region to propagation region. O and Fe contents decreases very sharply and the titanium content increases. Fuping Li,[23] studied the compression-compression fatigue behaviour, in which porous titanium alloy Ti6Al4V were fabricated by diffusion bonding of meshes. Results data showed that enhancement in the fatigue strength of the porous titanium alloy, which is in the range of 0.5-.55 at 10^6 cycles. The porosity of the alloy has minor effects on the normalised S-N curves, but considerable effects on the absolute S-N curves.
As the fig (04) show the relationship of strain and the numbers of cycles consisting of the three stages.

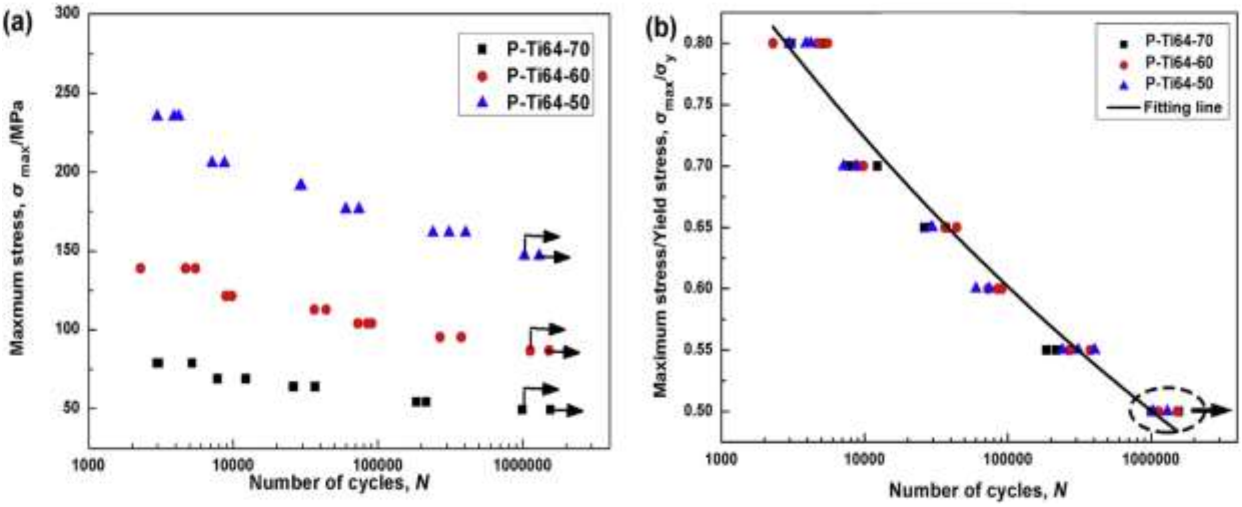

Fig (04); The *S–N curves of porous alloys (Ti6Al4V) using absolute (a) and normalized (b) Stress values. The arrows represent porous samples that did not fail.* Fuping Li.[23]

In this letter, Ti6Al4V alloy fabricated by diffusion bonding was studied for the fatigue behaviour. Result data concluded that the absolute S–N curves of porous alloys having lower porosity are higher than those with higher porosity, but the features obtained for normalized S–N curves are almost the same for different porosity. S. Ganesh Sundara Raman,[24] In his work, The Cu-Ni coating were formulated on two substrate materials—the first is Ti-alloy (Ti-6Al-4V) and another alloy of aluminium. The coating was provided by the detonation gun spray. Cu-Ni-In coating on Ti-6Al-4V alloy shows the lesser mismatch in the properties compare to the aluminium (AA 6063) alloy. The effect of life reduction found to be relatively larger in Al alloy compared to that of the alloy of titanium due to the fretting. So, the Cu-Ni coating is found to be beneficial for the titanium alloy. M. S. RAHMAN_ [25] conducted an experimental investigation to examine the fretting fatigue behaviour of Cr-N film deposited on Ti-6Al-4V specimens by physical vapour deposition. The fretting fatigue strength up to 10^7 characterises the behaviour of the Cr-N coated specimen. The main attribution for enhanced fretting fatigue is the hardness of the Cr-N film due to change of bias voltage during the film deposition. There is small influence of bias voltage on the fatigue strength up to the stress cycle $10^{6,}$ after that fatigue strength is changes with the bias voltage for both the contacts loads. Daisuke Yonekura [26]In this work provide multi-layer coatings of Cr/CrN with different number of bilayers on Ti–6Al–4V alloy substrates by an arc ion plating method and pin-on-disk wear tests and Tension–tension fatigue tests were performed in order to found the effect of Cr/CrN bilayers on the fatigue and wear properties. The hardness increased with increasing number of Cr/CrN bilayers following the Hall–Petch relation, however the magnitude of this increment is marginal. Fatigue strength greatly improved by the multi-layer CrN Coatings compared to the single layer. A better wear resistance also offered by the three bilayer coatings Cr/CrN. However, multi-layer (4-5 bilayers) severely damaged by the wear. QI YANG [27] has chosen the Dovetail joints made up of titanium alloy that are commonly used to attach blades and discs in gas turbine engines. These joints are always subjected to large centrifugal loading and high frequency vibration during the engine running time. The severe stress and small relative movement (fretting) situation arises in the surfaces between the blade's roots and the fan discs. The Cu-Ni coating modified the local stress distribution under the fretting condition and mitigated the degree of stress concentration of the contact edge. Graph in the fig (05) shows that the short peening treatment induced the compressive residual stress, which promoted the fatigue resistance of the alloy under the fretting fatigue condition.

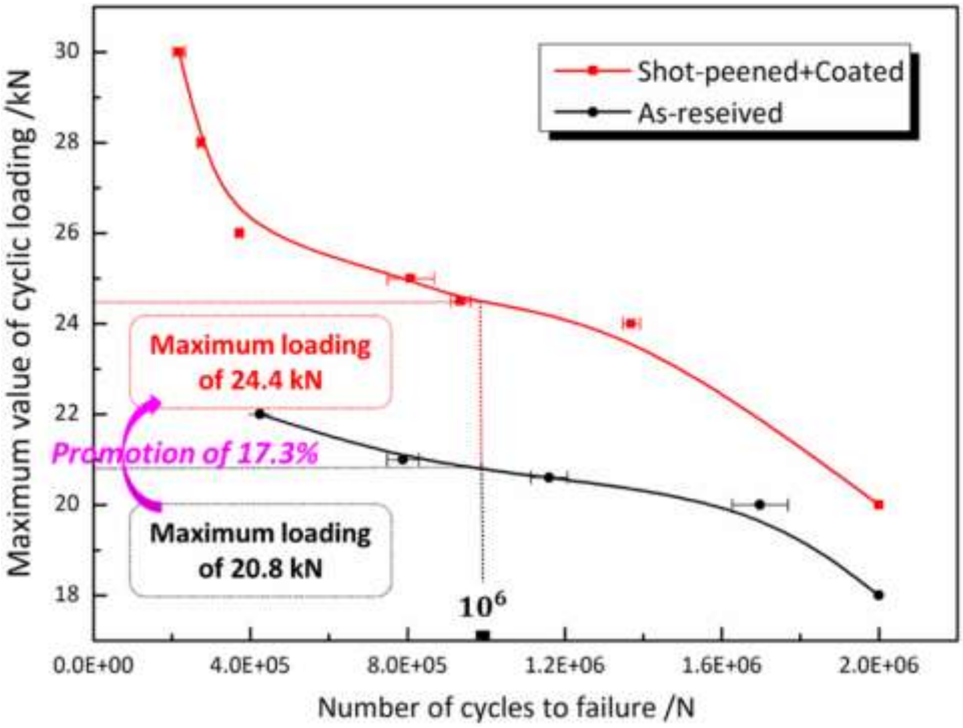

Fig (05); F*retting fatigue lives of the AS and SC specimens under different loading conditions* (QI YANG [27]

A better plasticity nature shown by the CuNiIn coating titanium alloy under the fretting condition. This enabled the CuNiIn coating to have great adaptation and co-operation capacity for the plastic deformation. The CuNiIn coating could effectively limit the nucleation risk of the fretting fatigue cracks and alleviate the stress concentration of the contact area. The CuNiIn coating played a significant role in protecting the Ti-6Al-4V alloy from fretting damages, such as subsurface cracks and surface inclined cracks.

3. CONCLUSION

Intensive research efforts continue to be directed in the way to find and develop new coating materials along with the coating processes for aerospace bodies and structures. The various aspects of material properties corrosion, wear resistance, oxidation at high temperature, fatigue at reversal/ vibrating load application has been investigated. The discussion of improvement of such properties with examined alloy and different coating materials shows promising results.

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