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Effect of Vanadium Additive on Wear Behaviour of Titanium Aluminide Super Alloy

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Abstract- The impact of the vanadium addition to the coefficient of friction (COF) and wear rate was determined by examining the wear properties of titanium alloys of Ti-4.5wt%Al(Ti4.5Al) + xV (x:2,4,6,8) made by spark plasma sintering technique. A dry sliding experimental technique was used to achieve the research objectives. Normal loads of 10N and 20N were applied during the experiments, which were carried out at a linear speed of 0.06 cm/s. The titanium alloy specimens were characterized using X-ray diffraction (XRD) and scanning electron microscopy (SEM) techniques. The findings showed that as the applied normal load increases, so does the wear rate. At sliding loads of 10N and 20N, respectively, a low coefficient of friction of 0.044 and 0.120 were reported for Ti4.5Al +2wt%V. Furthermore, Ti4.5Al +4wt%V showed minimum wear rates of 1.268 x 10^{-5} (mm^3/N/M) and 3.912 x 10^{-5} (mm^3/N/M) under typical loads of 10N and 20N.

Keywords: Super alloy, Wear Rate, Friction Coefficient, Vanadium, and Phases

I.INTRODUCTION

Since titanium alloys provide an appropriate combination of most qualities, including high specific strength, superior corrosion resistance, and fatigue resistance, they are considered to be appealing materials for the majority of technical applications. They are extensively employed in the pharmaceutical and chemical sectors as well as the aircraft industry for the production of fuel tanks and engine parts due to their remarkable properties [1].Titanium alloys are desirable for the injection nuzzle production process in the aircraft sector because of their low creep and remarkable specific strength at high temperatures [1]. However, it is challenging to use titanium alloys in environments with wear and friction due to its deficient resistance to wear [2]. Low abrasive resistance, extreme adhesive wear and a high propensity to seize and a high coefficient of friction are the hallmarks of the titanium alloy Ti 6Al-4V's poor tirbological performance [3,4]. Due to these setbacks, numerous researchers [5,6,7,8], have used a variety of techniques to enhance these alloys' tribological characteristics. [7,8], various microstructures such as lamellar, martensitic etc., can be found in titanium alloys, which is pivoted on the temperature, composition and processing techniques adopted. The high demand for structural components to maximize their qualities for various applications through change in factors influencing synthesis and the microstructures that are produced necessitates extensive studies of the impact of their microstructure on the mechanical behaviour as noted by [5,6,7,8]. The following is a summary of the literature on titanium alloy wear load, wear characteristics, additive element effects, and potential phases: Lapin [9] stated that titanium alloys can be either two-phase (TiAl) + (Ti_3Al) alloys or single phase (TiAl) alloys. They [9], also pointed out that creating a single-phase alloy and the addition of third alloying elements like Nb or Ta encourages strengthening and improves resistance to oxidation. [9], reported that elements such as V, Cr, and Mn can be added to increase ductility whereas Niobium and tantalum, or their combined characteristics, can increase oxidation resistance. [9], magnesium and boron can increase hot workability whereas carbon and tungsten increase creep resistance so as oxygen decrease increases room-temperature tensile elongation. Some researchers,[10-16] reported that alloy phase structures (metastable-versus+), contact stress, sliding velocity, and cyclic count all influence the frictional characteristics of titanium alloys. [9,17], reported that frictional behaviour of a titanium alloy is characterized via surface abrasion using the production of microscopic debris. [9,17], the development of larger surface debris as a result of sticky wear and transmit between titanium and its steel part, as well as confined serious distortion and damage. Cvijovic-Alagic [18] reported that wear rate decreases as hardness increases. They [18], also stated that vanadium's presence in Ti-6Al-4V alloy resulted in a higher hardness value than that of Ti-6Al-7Nb alloy, which considerably reduces the alloy's wear rate. [19,20] reported that persistent, dense tribo-layer oxides like Fe_2O_3 present and hard carbon compounds on the Surfaces are crucial for lowering the rate of wear. Sahoo[21] stated that the dry sliding wear behaviour of Ti-6Al-4V alloy, is mostly affected by the assessment time, sliding speed, microstructural variance, and average load. Adewale [22] stated that the friction coefficient, wear depth and wear rate increased with increase in the applied load and sliding duration. Since it is known that the Al content of Ti-Al alloy can vary from 3.5 to 8%, the impact of vanadium on the wear behaviour of the super alloy of Ti4.5Al (MA) has not received much attention in the literature [21]. Therefore, the wear behaviour of Ti 4.5Al +xV (x=2, 4, 6, and 8%) will be reported for the first time in this work.

II.MATERIALS AND METHOD

Spark plasma sintering technique (SPS) was used to produce the alloy samples of Ti4.5Al as the master alloy and Ti4.5Al + xV (x; 2,4,6,8%) with vanadium as additive. The composition of vanadium was selected based on literature and preliminary studies according to [21]. Graphite dies and punches were used to produce the specimens, which have a diameter of 65 mm. The alloys were produced with a holding period of ten minutes, a heating and cooling rate of 100 degrees Celsius per minute, and a temperature of 1000 degrees Celsius and 30 MPa of pressure in maintaining vacuum at 2 torr. The chemical analyses of the alloys were studied using X-Ray Diffraction technique at grazing 2θ angles between 0 degree to 90 degrees. Scanning electron microscope at an accelerating voltage of 20KV with Energy dispersive spectroscope attachment was used to characterize the microstructural analysis and elemental analysis of the alloys. The wear characteristics of the alloys were conducted using a Tirbometer at 0.06 cm/s sliding speed, 32.59% humidity, and applied normal loads of 10N and 20N.

III. RESULTS AND DISCUSSION

3.1: X-ray diffraction examination

Figure 1 and Table 1 display the spectra and the various phases observed throughout the study. The master alloy's XRD revealed the presence of the α-Ti (titanium) and Ti_3Al (α_2 Ti_3Al) phases as shown in Table 1. After the addition of vanadium at varying compositions, novel phases like V_5Al_8(cubic), V_3Al(cubic), $Al_{45}V_7$(monoclinic) and $Al_{86}V_{14}$ were present. All alloys exhibited α-Ti, whereas the master alloy and alloys with 2, 4, and 8 weight percent V were found to exhibit Ti_3Al as a common phase. The presence of cubic V_5Al_8 and V_3Al phases in alloys with vanadium weight percentages of 2 and 4, respectively, is consistent with the findings of Shima [17] and Anioke et al. [8]. New phases $Al_{45}V_7$ and $Al_{86}V_{14}$ were found to be present as the vanadium percentage rose to 6 and 8 weight percentages respectively. In alloys containing 2, 4, and 8 weight percentages vanadium additive, the structure of the Ti4.5Al with vanadium additive showed lamellar structure of the α-Ti phase at the grain boundaries, transitioning within α_2-Ti_3Al sites. At 4.0% vanadium incorporation, a continuous change and transition of the lameller structure of Ti into an duplex equiaxed structure of α-Ti phase and hard V_3Al phase traces were found at the grain boundaries, surrounded by α_2-Ti_3Al, which accords with Anioke et. al.[8], Qungquan and Fuwan [14]. The equiaxed duplex structure α-Ti phase took over when the vanadium percentage of the Ti alloy is raised to 6%. This led to the α_2–Ti_3Al disappearance and the formation of an intermetallic phase $Al_{45}V_7$, which substituted the α_2–Ti_3Al at the grain boundaries, this is also in line with the findings of Anioke et al [8], Qungquan and Fuwan [14].

Table 1: Phases of the alloys

Ti4.5Al (MA)	Ti4.5Al + 2wt%V	Ti4.5Al + 4wt%V	Ti4.5Al) + 6wt%V	Ti4.5Al) + 8wt%V
α-Ti	α-Ti	α-Ti	α-Ti	α-Ti
Ti_3Al	α_2-Ti_3Al	α_2-Ti_3Al	$Al_{45}V_7$	α_2-Ti_3Al
	Al_8V_5	V_3Al		$Al_{86}V_{14}$

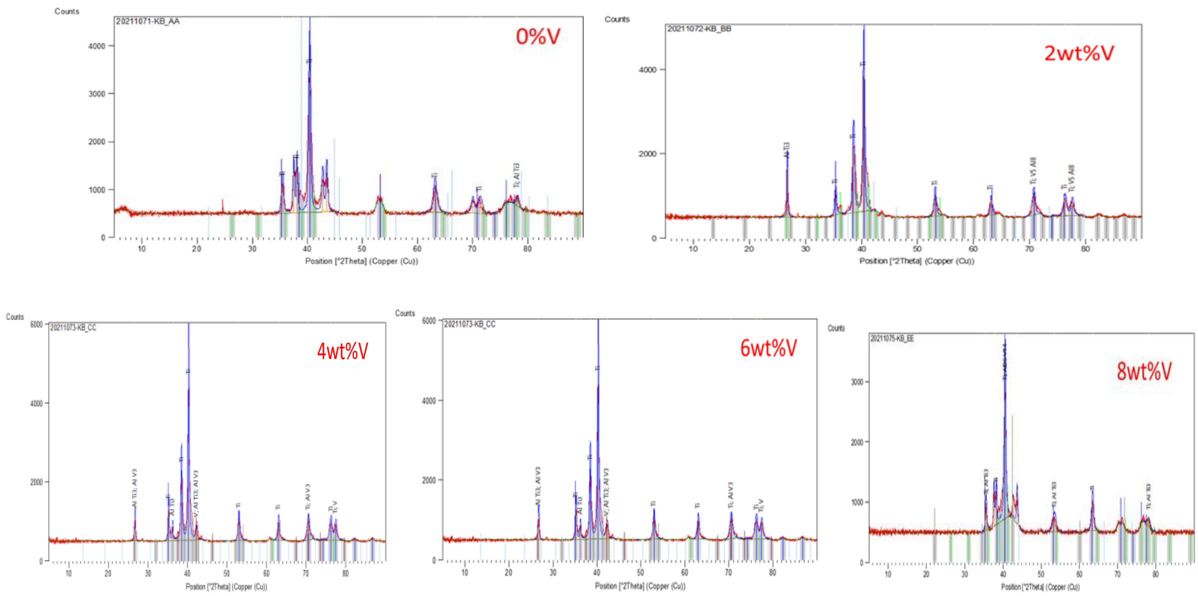

Figure 1: X-ray diffraction spectra of Ti4.5Al +X%V alloys

3.2. Microstructures of the Alloy

The Scanning Electron Microscope micrographs are shown in Figure 2a. The morphological structure of the Ti4.5Al master alloy is altered by the presence of vanadium. All of the samples under study had distinct grains and boundaries, however the Ti4.5Al sample had the largest grains and boundaries. The addition of vanadium caused this grain to shrink. Vanadium assisted to change the initial boundaries of the master alloy and functioned as a grain modifier of the alloy, which is why the alloy with vanadium had finer grain and boundaries. Grain reduction has been documented previously in the works of [8,24]. Of all the samples being examined, the Ti4.5Al +4wt%V has the fineest grain size. In addition to strengthening and hardening the alloy, this smaller grain may obstruct transit of disruption around boundaries. Energy Dispersive Spectroscopy examination of the alloys showed that titanium aluminium (TAl) and titanium (Ti) are the primary constituents found in each sample. However, Ti4.5A+2%V alloy, Ti4.5Al+4%V alloy, Ti4.5Al+6wt%V alloy, and Ti4.5Al+8wt%V alloy were found to contain vanadium components. This study did not observe any evidence of oxygen (O), which debonds alloy during sintering as has earlier reported by Anioke et. al. [8].This suggests that neither oxidation nor debonding take place during sintering, this indicated that the alloy was properly sintered and bonded by the spark plasma sintering process.

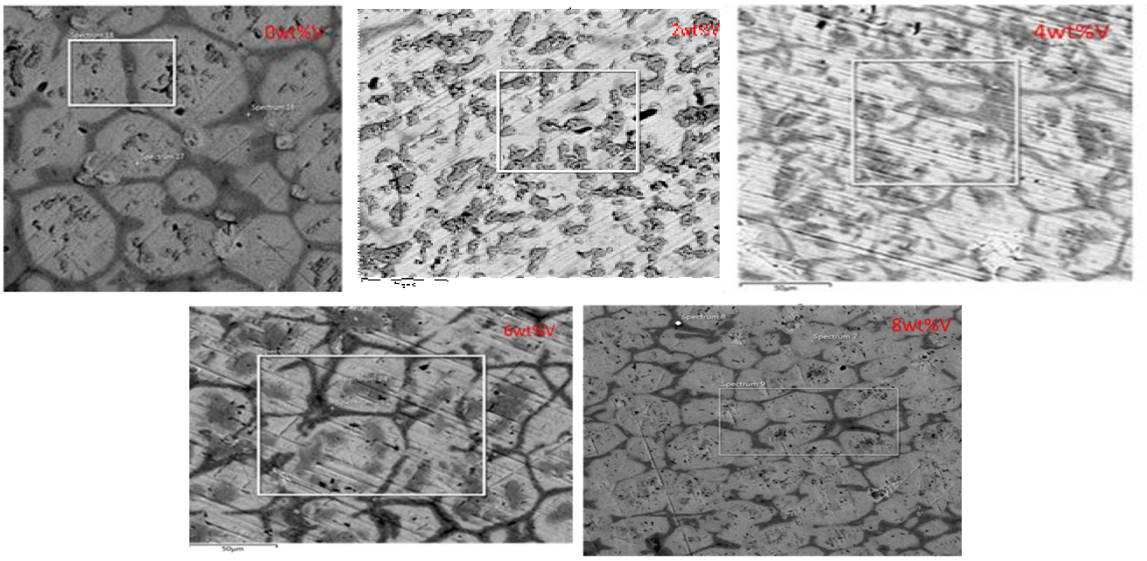

Figure 2a: Microstructural morphologies of Ti4.5Al +X%V alloys

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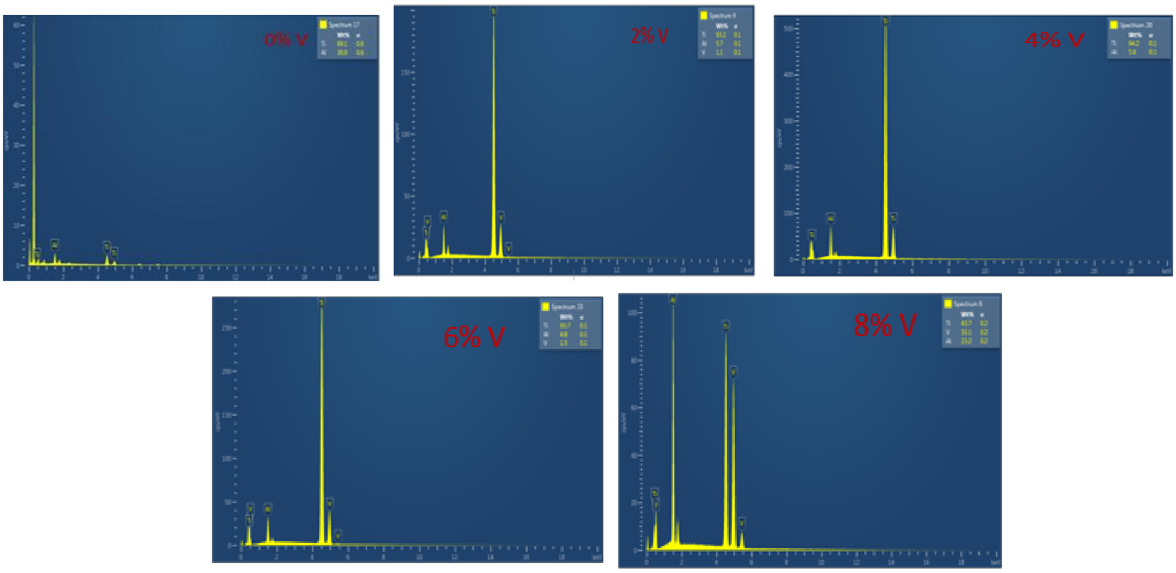

Figure 2b: Energy Dispersive Spectroscopy spectra of the samples

3.3 Alloy Wear Characteristics

The friction coefficient and wear rate data are displayed in Figures 4 and 5 respectively with respect to applied load and the weight percentage of vanadium. There was indication of increment in the wear rate and coefficient of friction as the applied load increased from 10N to 20N, which is in compliance with report of Anioke et. al. [8]. As the contact area of the sample and wear disc increased, the interface temperature rises, which increases the wear rate and coefficient of friction. The results align with the research conducted by Ceschini et al. [5] and Anioke et al. [8]. As the applied stress increases, the alloy's ease of use oxidizes in the air, increasing wear loss. For 0 and 4% Vanadium addition, the alloy wear rate increased from 1.033 to 1.268 and 1.739 to 4.52 (x 10^{-5} mm^3/N/M) at a load of 10 and 20 N, respectively. This increased the alloy's wear resistance by 22.70% and 159.92% at applied loads of 10 and 20 N, respectively, while the coefficient of friction decreased by 16.19% at applied loads of 10 N and increased by 153.4% at applied loads of 20 N at 4% V. The hard V_3Al (BCC) phase in the alloy is responsible for the decrease in the wear rate of the Ti4.5Al+4%V. Moreso. α_2-Ti_3Al phase in the alloys, which developed a weak protective layer that cleavage as the sliding period increased, caused a rapid increase in the friction coefficient as the sliding period increased, this is in accordance with reports of El Tayab and Wang [4] and Anioke et al. [8]. Slip movement is restricted along the planes by V_3Al phase, was supported the findings of Anioke et al. [8]. The low strength caused by plastic deformation decreased plastic shearing resistance, and thin film oxides formed by an increase in flash temperatures due to high friction during the wear process were the reasons given for the low wear rate of Ti4.5Al as stated by Teddy et al. [15], and Shima et al. [17]. Similar findings have previously been published by Anioke et al. [8] and Jianjun et al. [12], who found that the wear rate of titanium alloy decreases when resistant to plastic deforestation decreases.

3.3.1 Friction and Wear Mechanism

Figure 3 helps to visualize how alloys wear against sliding, wear morphologies of the surface are also provided. There were noticeable ploughing in the sliding direction, and the Ti4.5Al+6wt%V alloy's worn scar image made it evident that there was a lot of wear debris sticking to the worn surfaces. This demonstrates that friction surfaces' plastic deformation caused abrasive wear. This aligns with the findings of Anioke et al. [8] and Xu et al. [25], which showed that Ti-alloy may cause large sliding movement, the alloy's sliding interface and other surfaces experience strain rise and plastic shear stresses which agrees with El-Tayeb et al. [4]. But as the image illustrates, adding Vanadiun to Ti4.5Al alloy reduces the amount of wear debris that sticks to the worn surfaces. This is because of the hardening effect, which is consistent with the findings of El Tayeb et al. [4] and Anioke et al. [8]. Extrusion, fragmentation, and adhesion were attributed to these titanium alloys' variable elastic-plastic deformation. A rough surface and an increase in wear and wear debris are the results of the increased load. These findings are in line with those of Anioke et al. [8] and Revankar et al. [24], who found that plastic flow over

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sliding surfaces raises the true area of contact, leading to increased space connections and friction force. The titanium alloys' surface quality is improved by the addition of vanadium. At the friction surface's extremities, fine ploughing was found.

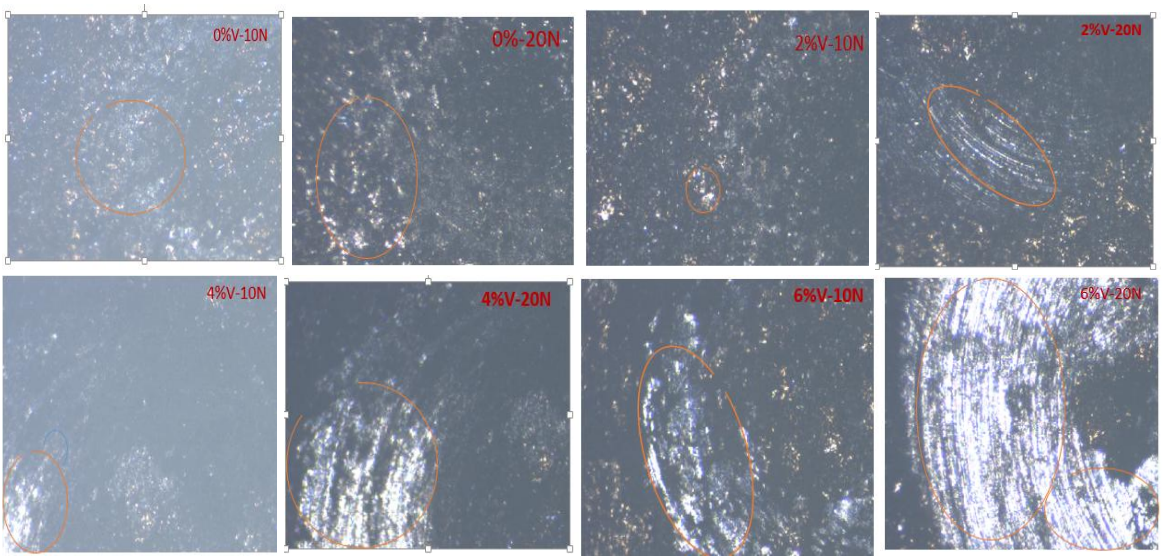

Figure 3: Morphologies of worn scar of the samples

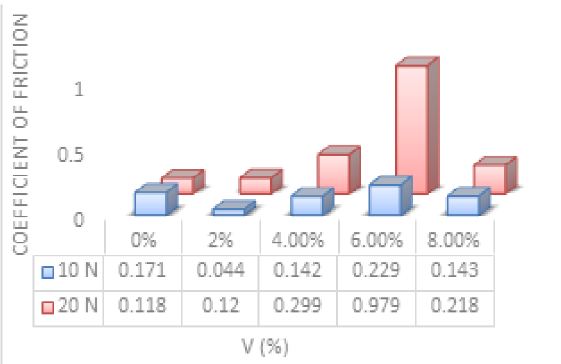

Figure 4: Effect of Vanadium percentage on Friction coefficient

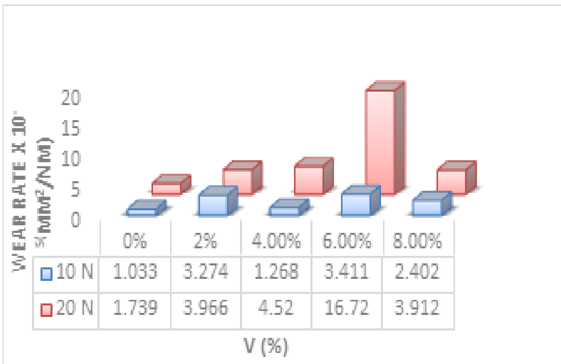

Figure 5: Effect of Vanadium percentage on Wear rate

IV.CONCLUSIONS

The results and discussion above allow for the deduction of the following conclusions.

1. At normal loads of 10N and 20N, the Ti4.5Al alloy's wear resistance was enhanced by the addition of vanadium.
2. The morphology of the Ti4.5Al alloy is affected by the addition of vanadium.
3. A rough surface and an increase in wear and wear debris are the results of the increased load.
4. At an applied load of 10 and 20N, the alloy's wear resistance decreased by 22.75 and 154.17%, respectively, as the alloy's wear rate increased from 1.033 to 1.268 and 1.739 to 4.52 (x 10-5 mm3/N/M) for 0 and 4wt% V addition.
5. The addition of vanadium to Ti4.5Al alloy has been demonstrated to increase the alloy's susceptibility to wear.

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