EFFECT OF LOAD AND SLIDING DISTANCE ON TRIBOLOGICAL PROPERTIES OF AISI 1040 STEEL BY MAGNETRON SPUTTERED Ti-6Al-4V COATING

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ABSTRACT: In the present study, Ti-6Al-4V-2B₄C coatings are deposited using a DC magnetron sputtering system on AISI 1040 steel substrates. The composition and elemental confirmation of the coating was explored by SEM, XRD and EDS. Wear and friction tests were trained to study the influence of sliding distance and load on tribological behaviour of Ti-6Al-4V-2B₄C coated AISI 1040 steel for machine elements. Wear tests were performed on coated AISI 1040 steel substrates counter to E-52100 steel balls by using a ball-on-disc wear testing apparatus under 2N and 3N normal loads at room temperature. The different sliding distances (63, 78, 94 and 110 m) has taken for wear test under room temperature and low coefficient of friction obtained for higher sliding distance and load. Ti-6Al-4V-2B₄C coated AISI 1040 steel reduces the frictional coefficient from 0.65 to 0.23 and improves the wear resistance. Specific wear rate of the coating reaches the maximum value with higher sliding distance. On the outset, it is clearly showing that the formation of oxide layers of Ti-6Al-4V-2B₄C coatings mainly affects its tribological characteristics.

KEY WORDS: Magnetron sputtering, sliding distances, wear, friction, Ti-6Al-4V-2B₄C.

1. INTRODUCTION

Aeronautical and medical fields are focusing on Ti-6Al-4V alloy (titanium grade-5) in line for its solitary strength-to-weight proportion [1]. Industrial machinery and components are habitually failed during working due to surface damage [2]. It is also has been rectified through surface modifications techniques especially by wear-resistant coatings. High-quality films with a good vary of industrially necessary have been developed through magnetron sputtering deposition technique [3, 4]. One of the familiar materials in the engineering field is carbon steel AISI 1040 and properties enhancement is achieved by various hard coatings [5]. Nitrides and carbides with higher hardness take on a vital role in the surface designing field.
Carbide coatings deliver higher hardness than nitride coatings which exhibit low wear nature on steel [6]. Applications of boron carbide coating are boundless; such as fusion reactors and coatings on nozzles etc. Higher hardness has been achieved through B₄C coatings on steel and it is often used as fusion reactors [7, 8]. In this study, wear characteristics of Ti-6Al-4V-2B₄C coated AISI 1040 steel is studied by a ball-on-disc wear test machine. The sliding distance and load were selected with a suitable range of working environments for genuine machine components.

2. MATERIALS AND METHODS

![Figure 1: SEM of (a) Pure AISI 1040 steel (b) Ti-6Al-4V-2B₄C Green compact](image)

Fig. 1(a) shows the surface morphology of the pure AISI 1040 steel. The target is the prepared forms of pure Ti, Al, V and B₄C powders. Pre-compacted Ti, Al, V and B₄C raw powders exhibit an irregular shape is shown in Figure 1 (b). AISI 1040 steel is coated through the magnetron sputtering process with prepared Ti-6Al-4V-2B₄C target. Substrates of 3 mm thicknesses with 60 mm diameter AISI 1040 steel plates are taken for coating. Before sputtering the chamber was vacuumed to 1x10⁻⁵ bar for a free flow of atoms in the chamber. The temperature of 100 ± 20 °C was kept up during the coating with 0.5h and 1h coating time duration has been fixed for all coatings. Gas pressure range of (Ar) 0.001 to 0.1 bar has been maintained as during sputtering coating. Wear test carried out by ball-on-disc wear tester on AISI 1040 coated steel with loads (2 and 3N) and different sliding distances (63, 78, 94 and 110 m). AISI 52100 steel balls with 10 mm diameter and hardness of 450 VHN were used as the counter body. The loss of mass was weighed with high accuracy of ±0.001 mg by way of a
sensitive electronic balance and weight loss has been converted into volume loss. Further corresponding wear parameters such as SWR and CoF were calculated according to the reference [9].

![XRD pattern of coating](image)

**Figure 2:** XRD pattern of coating

XRD peaks of B₄C reinforced Ti-6Al-4V is shown in Figure 2. Elemental presence is confirmed by elements peaks; Ti peaks represented by high-intensity peaks using 2θ angle of 35.2°, 40.1°, 62.8°, 70.5°, 76.2° and 77.2° are connected with (1 0 0), (1 0 1), (1 1 0), (1 0 3), (1 1 2) and (2 0 1) crystal planes are authenticate by JCPDS 89-2762. Also, another element of Aluminium was acknowledged by different peaks with 20 values of 38.4°, 44.8° and 78.3° through (1 1 1), (2 0 0) and (3 1 1) planes authenticate by JCPDS file no 89-4037. Vanadium peak is identified at (1 1 0) plane with a 2θ angle of 41.2° and authenticate by JCPDS file no 65-6689. The 20 values of 53.4°, 58.8° and 65.1° through (2 0 0), (2 1 4) and (0 2 7) planes have confirmed the presence of Boron carbide and authenticate by JCPDS file No 75-0424. Based on the presence of different peaks present in the coating it is confirmed that no oxide peak is identified in the coating.
3. RESULTS

3.1. Friction coefficients

![Graph: Coefficient of friction within sliding distance under 2N and 3N load]

**Figure 3:** Coefficient of friction within sliding distance under 2N and 3N load

Fig. 3 deals with the frictional parameter of coatings against various sliding distances. In the earlier stage higher coefficient of friction has been noticed for all sliding distances then decreased gradually and reaches almost steady state value. The testing sliding distances of 63–110 m has noticed with some coefficient of friction fluctuations also noticed probably at higher loads and sliding distances. The various range of coefficient of friction is recorded in Fig.4 with different load and sliding velocity. The results were obtained with the loads of (2N, 3N) at normal working atmosphere and (0.52, 0.65, 0.79 and 0.92 m/s) sliding velocities. The formation of protective layer maybe happened and protects the sliding surfaces from frictional behaviour; hence decreased level of coefficient of friction is noticed for all working samples and sliding distances. Once the sliding velocity rises from (0.52 m/s to 0.92 m/s) subsequently coefficient of friction decreases by the effect of protective layer. For all sliding distances lower value of coefficient of friction is obtained and maximum value is obtained as 0.65 for of 3 N against 110 m sliding distance of and minimum of 0.31 for 2 N against 63 m sliding distance is obtained. Initially, the coefficient of friction value is higher and it decreases bit by
bit due to the formation of oxide between the ball and coated surface. The developed oxide layer acted as a protective layer between the ball and coated surface for all loads with various sliding velocity. The above results were compared with other findings achieved under matching test circumstances [10]; frictional coefficients of this Ti-6Al-4V-2B₄C coating is lower.

![Figure 4: Coefficient of friction for different sliding velocities and normal loads](image-url)

3.2. Analysis of wear rates of counter body coating

Failure of coating is expressed for all testing cycles that express the increased life of all coatings which confirms through opposition of ruptured nature. Fig.5 shows wear scar images of AISI 52100 steel counter body. Based on the SEM results it is identified that broadened wear marks and wear track width for higher loads under similar sliding distance circumstance. Moreover, sliding distances varies from 63–110 m and wear track width incremental is noticed accordingly under similar loads. Also, during wear test Ti-6Al-6V-2B₄C coatings are not ruptured and fully stable; hence not identified any ejected particles form coatings. The wear scar areas are mainly influenced by counter body and sliding distance. The 110 m sliding distances produces the higher wear areas with a sliding velocity of 0.92 m/s and 3 N load.
Figure 5: Worn surfaces of counter surface with various sliding distances: (a) 2N load, (b) 3N load

Figure 6: Specific wear rates at different sliding distances and loads

Figs. 6 illustrate the specific wear rates of E-52100 steel ball and Ti-6Al-6V-2B₄C coatings. It is observed that for all sliding distances with applied load the specific wear rate is increased gradually. The maximum specific wear rate of $4.4726 \times 10^{-5} \text{ mm}^3/\text{Nm}$ and normal
wear volume of 0.00881 $mm^3$ was observed during sliding. According to the derived results, a higher wear rate is observed with 110 $m$ sliding distance and obtained higher and lower specific wear rates of $4.4726 \times 10^{-5} \; mm^3/Nm$ and $1.0132 \times 10^{-5} \; mm^3/Nm$ individually. The weight loss during sliding is denoted in Figs. 7 that shows the overall weight loss with sliding distance and load. The higher weight loss of 0.008 g is noted for 3N load and weight losses of all others are lower. Weight loss of the coating is also influenced by surface hardness of the counter body as well as the hardness of the coated surface. The weight loss and specific wear rates of this Ti-6Al-6V-2B$_4$C coating are produced significant results with similar load and sliding distance.

![Figure 7: Wear loss at different sliding distances and loads](image)

4. DISCUSSION

4.1. Frictional behavior

The present discussion focused on the effect of B$_4$C reinforcement on frictional behavior coatings. In sliding contacts, CoF varies with sliding distance and loads; the reinforcement plays a major role in reducing the CoF. At the initial stage, the contact between the surfaces of a specimen in the ball and disc led to low frictional force, so that CoF decreases due to the ploughing effect. The reinforcement from the coating is protruding out at
the normal load to reduce the CoF. Under heavy load, there might be higher wear and CoF which leads to poor tribological behaviour. The addition of hard reinforcement material (B₄C) results in the dropping of CoF. It shows that CoF decreases gradually due to the development of an oxide layer in between the disc and ball during sliding. During sliding, heat is generated by friction between contact surfaces in addition to the adhesion of flat and spherical surfaces of sliding. Due to the relative motion of the counter surface, the continuous generation of frictional heat and low heat dissipation rate occur due to time lacking. Again, as a result of the superior flow ability of the coating surface and more sliding action; frictional heating is reduced and subsequently, the coefficient of friction is also reduced.

4.2. Wear behavior

![SEM image of the wear track](image1)

![EDS of worn surface](image2)

**Figure 8:** (a-b) SEM image of the wear track (c) EDS of worn surface
Based on load and sliding distance increment; the formation of the transfer layer increases gradually. The transfer layers were found in between the sliding surfaces for sliding distance higher than 63 m. Besides, when the sliding distance increases more than 63 m wear rate also increases accordingly. The formation of the transfer layer controls the wear behaviour of sliding surfaces due to its lubricating nature. Figure 8 (a) illustrates the worn surface analysis of Ti-6Al-4V-2B₄C coated AISI 1040 steel by SEM which includes transferred oxide layers and Figure 8 (b) confirms the presence of oxide layer by Energy Dispersive Spectrum (EDS) analysis. In addition, Based on obtained results, the presence of icosahedron-based borides in the B₄C increases the nanohardness of the coating as well as low wear rate. The presence of hard B₄C ceramic particles controls the wear rate of the contact surfaces during sliding even for higher loads and sliding distances. Additionally transferred layer and hardness of the counter body (E-52100 steel ball) are the key factors connected to the wear of the coating.

5. CONCLUSIONS

Wear behaviour of Ti-6Al-6V-2B₄C coating was investigated and results are drawn.
- The Ti-6Al-6V-2B₄C coatings are not ruptured up to 110 m sliding distance under the normal atmospheric test conditions.
- The lubricating film is created between coating and E-52100 ball during sliding by developed oxide layer which supports to improve the wear resistance also gradually decrease the CoF for higher loads and sliding distances.
- The Ti-6Al-6V-2B₄C coatings delivers better wear performance even for higher loads and sliding distances; thus E-52100 steel ball shows higher wear rates.
- The higher and lower value of coefficient of friction of Ti-6Al-6V-2B₄C coatings is 0.49 (under 3 N and 110 m) and 0.23 (under 2 N and 63 m) respectively.
- As an outset, Ti-6Al-6V-2B₄C coated AISI 1040 steel is a good replacement for engineering applications such as bearings, tappets, gudgeon pins, etc.
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