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Research Article

Effect of Tungsten Carbide Addition on the Microstructure and Mechanical Behavior of Titanium Matrix Developed by Powder Metallurgy Route

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The ambition of this research work is to evaluate the hardness and wear behavior of titanium alloy reinforced with tungsten carbide particle (WC) composite prepared by powder metallurgy route. Titanium alloy with 5 and 10 wt% tungsten carbide reinforced particle (WC) composites was manufactured through powder metallurgy technique. The hardness and wear properties of the composite are measured in hardness and wear tests. The microstructures of the composite are evaluated by utilized optical microscopy. The fabricated titanium composites exhibit improved hardness and wear resistance. The hardness and wear specimens were prepared and tested by used Vickers hardness tester and a pin-on-disk wear test apparatus machine at room temperature. The hardness, wear rate, and CoF of TMCs are 476.79 VHN, 13.158 mg/m ($\times 10^{-3}$), and 0.955420243, respectively. The results elucidated the microstructure, hardness, wear rate, coefficient of friction, and SEM images of wear for the effects of added reinforcement tungsten carbide.

1. Introduction

The intensifying importance for diminution in weight of the materials accumulates energy, and to lessen fumes in automobiles and aircraft motor vehicles has been appropriate to the enrichment of innovative, frivolous automobile materials among the extensively modern decennium. Metal matrix composites (MMCs) play a vital role in lightweight materials to facilitate endeavor to combine the high solidness, stiffness, and sturdiness given by a metal matrix [1–3]. Titanium alloy is extensively utilized in the chemical industries, aerospace, marine [4], and biomedical devices and parts [5]. Augmentation of the mechanical possessions of titanium alloy is of most important interest for several applications [6] and different surface amendment methods which are planned to meet the diverse requirements [7].

Titanium matrix composites (TMCs) have great physical, chemical, and mechanical characteristics among which accumulate their benefits owing to low density, high toughness, and corrosive resistance, high specific strength, thermal stability, erosion, corrosion, and creep resistance [8]. Titanium alloys are creatures utilized additionally frequently in the design of new landing gear and flight control support arrangement. These alloys, which are flatter and more gladly obtainable, demonstrate superior strength-to-weight ratios than steel alloys. Titanium alloy parts necessitate less finishing, are further simply preserved, are less prone to crumble in overhaul, and necessitate less renovated dispensation than most high-strength alloy steel parts.

TMCs usually added ceramics reinforcements are TiB2, WC, TiN, SiC, TiC, ZrC, graphite, TiB, AIN, CNT, etc. This reinforcement enhanced physical, chemical, and mechanical characteristics [9]. Kim et al. [10] premeditated friction and wear behavior of TMCs with TiB + TiC composites. The additional granular particles are the finest way to advance the friction distinctiveness and the wear loss appreciably diminished. Kun et al. [11] observed Ti-TiC composites showed hardness, strength, and wear resistance were improved with the reinforcements.

Based on the literature, amid these reinforcements, tungsten carbide (WC) has been recognized as a superior reinforcement for TMCs because of its chemical compatibility with Ti, high hardness, high strength, and high wear resistance. WC utilized replaceable chip for cutting tools, drill for printed circuit board, end mill, drill, mold, roll, and nozzle. Tungsten carbide (WC) possessing its high strength, good chemical stability, better resistance, high hardness, high rigidity, and low density at towering temperature is good promising ceramic material [12]. Rajaganapathy et al. [13] found the presence of WC particles to have significantly improved mechanical and tribological characteristics, respectively. Lekatou et al. [14] reported the use of WC particles and alloys in sliding wear effectiveness which was outstandingly superior by commencing the carbide phase. Huang et al., [15] fabricated AMCs/WC composite and found the identical distribution of WC particles, superb WC/Al interfacial bonding. It was determined that augmented WC particles supported the grain refinement and enhanced the hardness and strength, but reduced the ductility.

The generally following fabrication methods are usually used in TMCs such as stir casting, squeeze casting, and powder metallurgy [16]. Powder metallurgy technique is the easiest and appropriate technique to make and fabricate MMCs amid numerous enhancements such as the identical sharing of reinforcements in matrix necessity of low temperature while contrasted to other melting methods and cost-effective ones [17, 18]. An et al. [19] fabricated Ti64/TiBw composites by P/M process and exhibited the best wear resistance. Anandajothi et al. [20] produced Ti6Al4V/TiB2/TiC hybrid composites through P/M roué. The reinforcement particles added in Ti6Al4V alloy and effect of particles are superior enhanced density and hardness properties through the PM route.

Kgoete et al. [21] extensively enriched the corrosion resistance and hardness of Ti6Al4V alloy reinforced with TiN particles and benefit of Ti6Al4V/TiN composites as in aerospace applications. Li et al. [22] prepared TiCp/Ti6Al4V composite and identified enhanced microhardness and tensile strength compared matrix material Ti6Al4V and elongation of TiCp/Ti6Al4V composite decreased. Soorya Prakash et al. [23] studied Ti-6Al-4V/B4C composites through powder metallurgy route and results showed augmented hardness and corrosion resistance and diminished density, and the addition of reinforcement b4c enhanced the wear resistance. Taotao et al. [24] observed adding Ti2AlC/TiAl particles in Ti6Al4V alloy and enhanced the generally mechanical properties of the composite sheets. Jiao et al. [25] reinforced Ti-6Al-4V alloy with Ti5Si3þ-TiBw hybrid composites in an effort to augment the mechanical properties like higher tensile strength and the superior wear resistance of the matrix alloy. Rahmani et al. [26] reported Ti-6Al-4V/TiO2/Ag hybrid composites explained augmented ultimate strength, structural integrity, and mechanical properties.

Based on the studies, the matrix material Ti-6Al-4V reinforced with WC particles has not been carried out. Hence, the primary objective of the research is to prepare the Ti-6Al-4V matrix to reinforce with tungsten carbide composites by powder metallurgy route. After that, the composites involve hardness, wear, microstructure, and SEM testing and improve mechanical properties.

2. Materials and Methods

2.1. Assortment of Matrix and Reinforcement Material. In the current research, Ti-6Al-4V alloys (Grade 5) were preferred as a main matrix with a density of 4.43 g/cc. Grade 5 alloys have amazing and superb amalgamation of high strength, density, good corrosion resistance, toughness, heat treatability, and good ductility. Grade 5 titanium has good welding and fabrication characteristics [27]. The compositions of titanium Ti-6Al-4V alloy (grade 5) are as shown in Table 1.

Tungsten carbide (WC) is a gorgeous reinforcement for matrix alloys owing to its intense hardness, high modulus of elasticity, high melting point, and good wettability [28]. It is precisely exigent to manufacture WC particles reinforced composite with a consistent circulation of WC particles by powder and liquid metallurgy process because of the bulky concentration gradient [29]. Consequently, WC was preferred as reinforcement particles in the current work. The chemical compositions of the WC particle are shown in Table 2. In addition to reinforcement are 5 and 10 wt% WC particles with an average particle size of 45 μm which were taken for the research.

2.2. Preparation of Composite. The powder metallurgy method was deliberated upon for embryonic TMCs reinforced with WC made during the chemical vapor authentication process. Predominantly, the powders were weighted up in conformity with diverse compositions as Ti-6Al-4V alloys with 5% and 10% WC. The weighed proportion was then intermingled to make use of a planetary ball mill for a sum of 7 hours through an interlude of 45 minutes for each and every 1 hour for the progress of the dispersal of WC into the matrix. These descriptions carry an obvious vision for the

Table 1: Chemical composition of titanium Ti-6Al-4V alloys.

Alloying elements	Chemical composition (wt. %)
C	0.08
N	0.05
O	0.2
H	0.013
V	4.5
Al	6.55
Fe	0.25
Ti	88.16

Table 2: Chemical composition of WC.

Alloying elements	C	Ni	Cr	Fe	W
Chemical composition (wt. %)	5.2	9.5	4.8	0.2	Balance

dispersal of WC in TMCs. The composite combination was then dense at 750 MPa using a hydraulic press to attain cylindrical specimens with 100×30 mm in diameter and height, respectively. Subsequent to compacting, composite specimen as per standard measurements was sintered in the incidence of air at 950°C for 1 hour [30].

2.3. Microstructure. The composite work piece stayed scholarly for dispensing with junk present on a superficial level. Molecule conveyance remains evaluated at the help of an optical magnifying lens. The projecting procedure remained investigated under the optical magnifying instrument to decide the support example of hurtle cast chuck structure. A segment stayed engraved from the castings. They lingered granule utilizing 100 coarseness SiC sheets followed by 230 to 1000 evaluations of emery sheet previous to ocular reconnaissance; the examples were precisely cleaned and carved by Keller's reagent to acquire a superior difference.

2.4. Hardness. Microhardness testing is a procedure that was used to assess the material microhardness with the guide of an infinitesimal range. The estimation of microhardness was estimated by utilizing MVH-II advanced miniaturized scale hardness apparatus. Here, a diamond boulder indenter is stacked on the matter to be tried from a couple of grams to 1 kilogram. The measurement lengthwise of the notion is determined from the size of a magnifying lens and the applied burden is used to gauge the estimation of microhardness. Ordinarily, a square-formed indenter or rhombohedral molded indenter is utilized in the microhardness test. They chose a load that is applied to the matter utilizing dead loads accessible in the analyzer.

2.5. Wear. Dry sliding wear tests for an alternate example were performed by utilizing a pin-on-circle machine provided by DUCOM. The specimen was murmured alongside the neutralized face of a rotating disc circle with a wear pathway width of 60 mm. The specimen was stacked adjacent to the circular disc during a deadweight stacking framework. The wear test for various examples was conveyed beneath the typical loads up to 40N and a sliding speed of 4 m/s. Wear tests were directed for an all-out sliding separation of 3000 m underneath equal environmental factors as bantered beneath. The wear test boundaries subtleties appear in Table 3.

2.6. Scanning Electron Microscopy (SEM). SEM microscopy is utilized productively in microexamination and behavior of strong inorganic materials. Filtering electron microscopy is accomplished at high misrepresentations, causes high-goal symbolism, and precisely quantifies extremely small facial appearance and items. SEM gives finished high-goal symbolism of the tester by rastering an engaged electron pillar over the surface and recognizes determined signals. A vitality dispersive X-beam analyzer is additionally utilized to invest with basic location and quantitative compositional data.

3. Results and Discussion

3.1. Microstructure. Figures 1 and 2 show the optical microphotographs of Ti-6Al-4V/WC MMCs. Consistent delivery of the reinforcements in the matrix and the homogeneity of the composites can be witnessed. Further less porosity is related with superior hardness in metal matrix composites. The presence of WC particles has an appetite to the conception of cracks. As a result of the bonding, the deflect becomes pliant and superior in consignment, shatter of the composites is measured by dimples and void, and clusters are obtainable, scrawny rupture of composites in the structure of cracks and shatter is owing to the very brawny interfacial bonding among the tungsten carbide particle, and titanium matrix is excellent.

3.2. Microhardness. Figure 3 shows the microhardness of Ti-6Al-4V alloys reinforced with 5% and 10% WC particles. The powder metallurgy method prepared the specimen and took 5 trials. The maximum microhardness values are 432.87 VHN for 5% WC and 476.79 VHN for 10% WC. The hardness value 30 (HB500) which compared aluminium alloys with WC particles was very less [31].

The enhancement in microhardness of composite is owing to the subsequent reasons: (i) the consistent delivery of WC particles in the composites; (ii) towering hardness of WC particles; and (iii) the selection of titanium matrix and fabrication methods. The results show to develop the better microhardness of the composite by using a powder metallurgy route to prepare the composites.

3.3. Wear Rate Analysis. The wear test samples of Ti-6Al-4V alloys and with WC are as shown in Figure 4. The wear rates of Ti-6Al-4V alloys decrease with comparative augment in the WC particles, as shown in Figure 5. The maximum wear rate values are 4.3 for 5% WC and 13.158 for 10% WC. It is accurate that the titanium alloy materials show a cryptogram

Table 3: Wear test parameters.

Load (N)	40
Sliding velocity (m/s)	4
Sliding distance (m)	3000
Dimension (diameter × length mm)	30 × 100

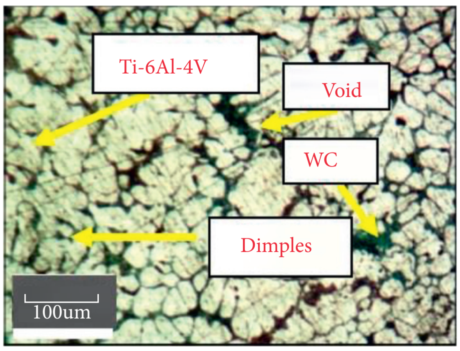

Figure 1: Optical microstructure of Ti-6Al-4V with 5 wt% of WC.

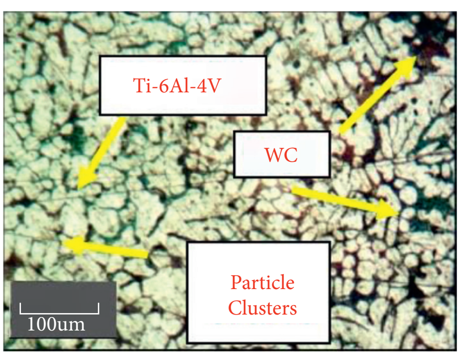

Figure 2: Optical microstructure of Ti-6Al-4V with 10 wt% of WC.

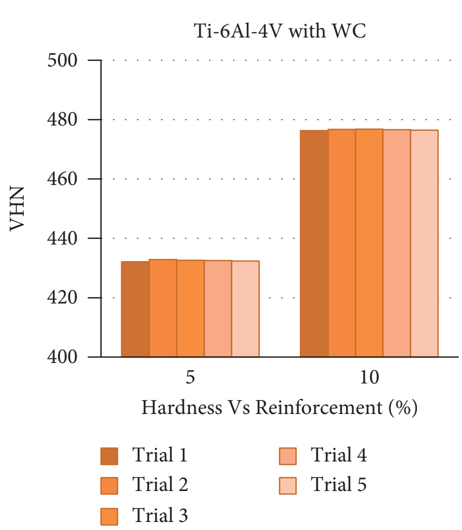

Figure 3: Microhardness of TMCs.

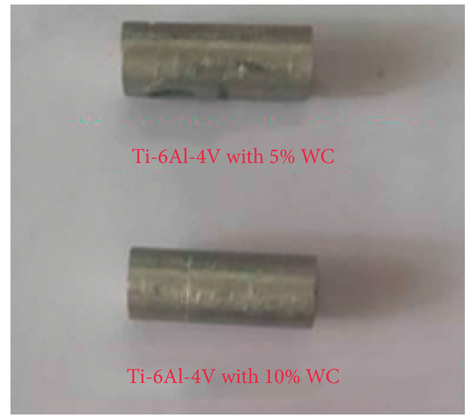

Figure 4: Wear test samples.

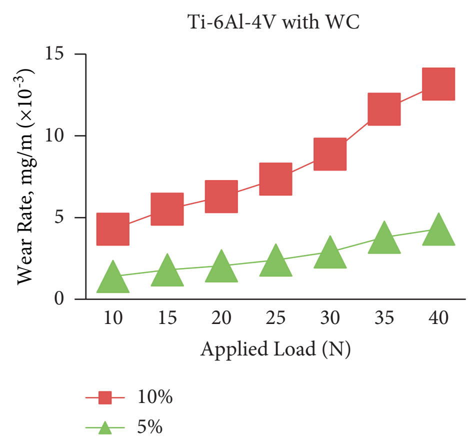

Figure 5: Effect of WC particles on wear rate.

of enhanced wear rate that the collision of applied load 40N on wear rate is extremely towering and is simply obvious from the fissure among the wear rate curves conspired for different wt% of reinforcements. The WC is important for wear rate of developed composites and the same relic could be viewed by the majority of the researcher's universally [32]. These augments in wear rate with augmented WC particles and load for all the trial specimens measured can be attributed to the superior quantity of plastic deformation and delamination wear crash with particles and loads. The wear rate is owing to the reality that in particles and load augments, the metal contact makes certainly augmented abrasion at the interface. Predictably, friction augments the temperature and thus directs the incidence of plastic deformation. While compared to Ti-6Al-4V alloys, the urbanized MMCs oppose the particles and load considerably ever since the entrenched WC particle diminishes the plastic deformation by deterring disarticulation [33–35].

3.4. Coefficient of Friction (COF). The effect of WC particles and applied load displayed diminish in CoF for augment in sliding speed at a constant sliding distance of 3000 m. The CoF of Ti alloy decreases with comparative augment in the

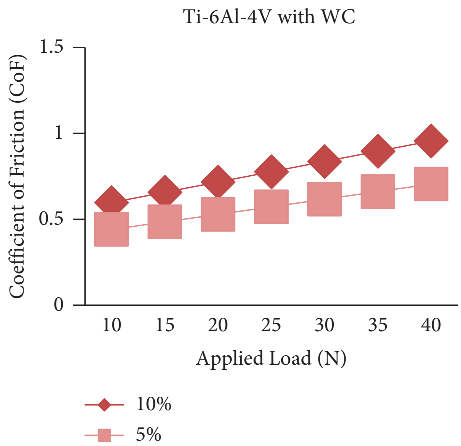

Figure 6: Effect of WC particles on CoF.

WC particles. It could be obviously visualized that a low CoF value was attained at sliding speeds for composites. The maximum CoF values are 0.7045872 for 5% WC and 0.955420243 for 10% WC. It is precise that the titanium alloy materials confirm signs of improved CoF when compared to Figure 6 which presents the impact of WC particles and applied load up to 40N on CoF is augmented and is minimally apparent from the crevice among the CoF curves connived for different wt% of reinforcements. As of the time when reinforcement particles obtrude from the matrix, CoF value augments gradually [36]. The present research wraps up for CoF augmentation at any time the applied load augments for all of the titanium composite specimens with the intention of also at constant sliding speed.

3.5. Worn Surface Analysis. The powder metallurgy route prepared Ti-6Al-4V alloys with 5 wt% and 10 wt% of WC added work piece reveals the superior mechanical and Tribological behaviour, with the goal of substantiating the worn surfaces during analysis with scanning electron microscopy (SEM). The worn surface of powder metallurgy route Ti-6Al-4V alloys with WC composites at 40N load and the corollary reveals the arrangement of plastic deformation, fine grooves, debris, delamination, and pit holes easily predictable from Figures 7 and 8. Wear debris was in addition observed on the worn surface, which was the distinctive attribute of adhesive wear. Adhesive wear supported material relocates and directs to an augment in coarseness and the formation of flanges on the inventive surface. This can be depicted as plastic deformation of fragments surrounded by the surface coating, partially owing to brawny adhesive forces between particles, other than in addition owing to accretion of vigour in the plastic region among the asperities through comparative motion. The quantity of grooves augmented as the wear resistance diminishes. This consequence can be ascribed to the allocation of the abrasion force and surface tiredness originates by surface fatigue and adhesive wear. The grooves and pit holes on the worn surface of WC particles were much less than folks on the worn surface of the Ti-6Al-4V substrate. Several pit holes proved plastic deformation and displacement of material from

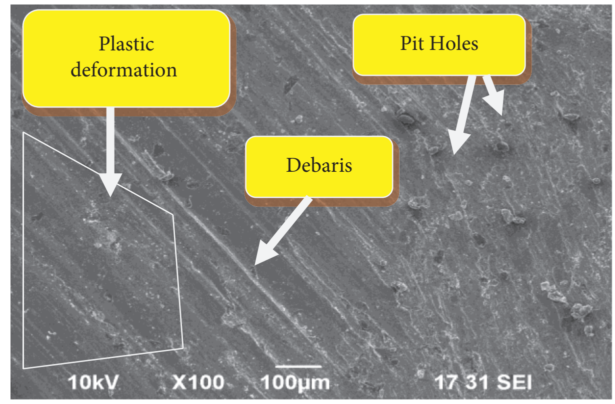

Figure 7: Worn surface analysis of powder metallurgy wear specimen (5 wt%).

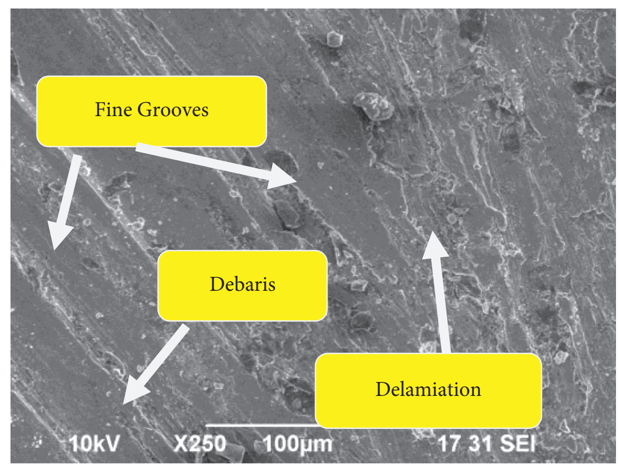

Figure 8: Worn surface analysis of powder metallurgy wear specimen (10 wt%).

collision locations to the void rims. An obvious incise vision in fig notifies that the swiftness of delamination is small when contrasted to Ti alloy. Based on all of these formulations, it is unrestrained that wear rate is less for the newer composite because it is higher hardness than the base alloy by the way of WC particles.

4. Conclusions

(1) In summary, the research concludes the innovative amalgamation Ti-6Al-4V/WC composites fabricated by extremely well-known and simplest process of powder metallurgy route.

(2) The mechanical properties of hardness and wear behavior properties were appraised.

(3) The microstructure of the composite specimen proved uniform distribution of the WC particle in the Ti-6Al-4V alloys, interfacial bonding between the tungsten carbide particle and titanium matrix, and the homogeneity of the composites.

(4) This new composite urbanized hardness augmented drastically with augments in hard particle

reinforcement WC and microhardness values are 432.87 VHN for 5% WC and 476.79 VHN for 10% WC.

(5) The pin-on-disc wear test machine has divulged that the wear resistance increases in the midst of augment in WC up to 5 and 10 wt% and the wear rate values are 4.3 for 5% WC and 13.158 for 10% WC.

(6) CoF augments with WC particles content and applied load. The CoF values are 0.7045872 for 5% WC and 0.955420243 for 10% WC.

(7) As the weight percent of WC particles increases, SEM micrographs of worn surfaces show a decrease in microcracks and delamination.

Data Availability

The data used to support the findings of this study are included in the article. Further data or information required are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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