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Research Article

Microstructure and Mechanical Behaviour of Ti-6Al-4V Matrix Reinforced with WCp Developed by Squeeze Casting

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The aim of this study is to evaluate the wear and micro hardness of a Ti-6Al-4V matrix reinforced with 10% and 15% tungsten carbide particle (WCp) composite manufactured using the squeeze casting process. Optical microscopy is used to determine the microstructures of the composite. A pin-on-disc wear test equipment and Vickers hardness at atmospheric temperature were used to examine the wear behaviour wear rate, CoF, and micro hardness qualities of primed samples. Loads of 10 N to 80 N, velocities of 4 m/s, and distances of 1000 m to 2000 m are considered for analyzing the wear behaviour of Ti-6Al-4V composites. The wear rate values are 25.683 for 10% WCp, 30.957 for 15% WCp, and 37.683 and 30.957 for 20% WCp. A scanning electron microscope (SEM) is utilized to examine the worn surface of the composites. For 10% WCp, the CoF values are 0.82 and 0.87, and for 15% WC, 0.88 and 0.956. The micro hardness values are 692 VHN for 10% WCp and 835 VHN for 15% WCp. The wear rate, microstructure, SEM images, coefficient of friction, and hardness of TMCs for totaling reinforcing tungsten carbide particle (WCp) possessions were discovered to be improved.

1. Introduction

Importance in the development of innovative materials with elegant properties is growing on a regular basis, and composite materials, which are primarily developed of composite materials, are marketed as a simple and improved method of obtaining materials with exceptional properties [1–3]. Metal matrix composites (MMCs) are a form of manufacturing and technology material that incorporates a strong reinforcement addicted to a metal matrix to increase qualities with particular stiffness, specific strength, wear resistance, good corrosion resistance, hardness, and high elastic modulus [4, 5]. Titanium and titanium alloys have a number of unique characteristics, such as high specific strength and lightweight, which support the use of titanium and titanium alloys as a matrix material in future structures [6–8]. TMCs have a wide range of applications in the automotive, aerospace, and marine industries [6, 9].

In recent years, a growing number of studies have been carried out to improve metal matrix composites by utilizing reinforcement [4–6, 10]. As a result, if researchers can discover a suitable reinforcement to improve the mechanical characteristics of Ti–6Al–4V matrix composites, the Ti–6Al–4V will be able to overcome some shortcomings, such as reduced hardness and Young's modulus [11, 12], and find new uses. Because of its high hardness, high thermal stability, high modulus, approximate thermal expansion coefficient, and Poisson's ratio to Ti–6Al–4V matrix, tungsten carbide (WCp) is a preferred choice for reinforcement [13–15]. As a result, WCp is likely to be a good reinforcing material for Ti–6Al–4V matrix composites, which should have outstanding mechanical characteristics.

Particle-reinforced TMCs exhibited considerable routine increase in terms of strength, creep resistance, wear resistance, low density, high toughness, corrosive resistance, thermal stability, and erosion [10, 16]. Particularly, squeeze casting possessed the strong interfacial rapport strength to accomplish the superior intensification effect, further than the conventional augmentation method.

Titanium dioxide, silicon carbide, titanium carbide, boron carbide, aluminium oxide, titanium nitrate, zirconium carbide, graphite, tungsten carbide, titanium diboride, aluminium nitride, and carbon nanotube are often used in TMCs. The physical, chemical, and mechanical properties of this reinforcement were excellent [11–16].

Chen et al. [17] applied WC/W2C eutectic reinforcement in TMCs owed to the subordinate interfacial reactivity amid W2C and Ti. Such W solid solution interface is additional effectual to relocate anxiety from the matrix to the WC/W2C than to facilitate of the TiC layer.

Sivakumar et al. [18] fabricated Ti–6Al–4V (Ti64)/SiCp with improved hardness and compressive strength. The ideal density was attained at a compaction pressure of 6.035 MPa, and microstructure annotations indicated that TMCs exhibited improved wettability and bonding structure.

Li et al. [19] produced novel combination composites TMC/CNT that show potential in industry due to their higher-quality features such as high elastic modulus and low density. Fabrication procedures have an impact on the characteristics of TMCs, which has a considerable impact on their machinability, according to the findings.

Ren et al. [20] used powder metallurgy to fabricate titanium matrix composites with 20% Wp. Due to the charisma of many strengthening mechanisms, such as tungsten segment strengthening and firm elucidation strengthening, 20WP/Ti reveals outstanding perfunctory properties. The addition of Wp reinforcing phases masks the composite's adiabatic shear sensitivity. Kellen and Amit [21] created titanium-boron carbide-boron nitride composites, with overall results of crack-free titanium-matrix composites with superior hardness of 700 HV and 99.1 percent density, as well as a staggering 33% reduction in corrosion bunch growth in the air when compared to commercially pure titanium.

Yang et al. [22] investigated Ti/$CaTiO_3$ particles, finding that the $CaTiO_3$ particles effectively increased Ti strength

Table 1: The compositions of titanium Ti-6Al-4V alloy (grade 5).

Alloying elements	Chemical composition (wt%)
Al	7.83
Fe	0.36
C	0.06
N	0.04
O	0.3
H	0.0236
V	6.35
Ti	85.04

Table 2: The chemical composition of WC.

WC elements	Fe	Cr	Ni	C	W
WC chemical composition (wt%)	0.6	5.7	8.8	4.4	Remaining

Figure 1: Squeeze casted specimen: (a) Ti-6Al-4V with 10 wt% WC composites; (b) Ti-6Al-4V with 15 wt% WC composites.

Figure 2: Pin-on-disc wear test machine.

Table 3: Wear test parameters.

Load (N)	10 to 80
Sliding velocity (m/s)	4
Sliding distance (m)	1000 to 2000
Dimension (dia × length mm)	30 × 100

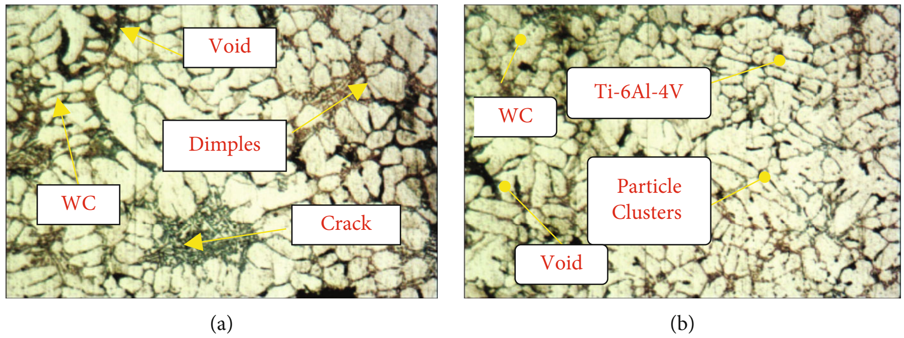

Figure 3: Squeeze casting microstructure of (a) Ti-6Al-4V with 5 wt% of WC and (b) Ti-6Al-4V with 10 wt% of WC.

without sacrificing elongation to malfunction. It is situated with the goal of increasing yield strength from 450 MPa for pure Ti to more than 850 MPa for TMCs with only a 2.5 wt% addition of $CaTiO_3$, while maintaining a 30 percent elongation to failure.

Sun et al. [23] looked into how Ti/TiB composites were made using vacuum induction melting and multidirectional forging techniques. A spheroidized-phase, uniformly distributed TiB and dual-scale silicides were visible in the micrograph of the consequential composite. Its agility was greatly improved, with an elongation of up to 120 percent. The easy instigation of fractures at grain boundaries and the deterioration were the main reasons for the decrease in strength. Cast WCp/Ti was fabricated by laser injection process, according to Liu et al. [24]. WCp has the advantage of delivering fewer carbon atoms. The coating reveals superior ductility and conceals the retort invention TiC. Under an external load, the retort layers are effective at load transfer.

Stir casting, powder metallurgy, and squeeze casting are some of the most commonly used invention techniques in TMCs [25–27]. Squeeze casting advantage is cast machine parts manufactured in a solitary stride route with stumpy squeeze pressure. As a result, squeeze casting is a good method for making machine components when combined with cheap initial materials [28–31].

Dmitruk et al. [32] developed Ti-Al-C/Al-Si MMCs using the squeeze casting method, which allows for the efficient production of pore-free MAX phase-based MMCs with significantly higher wear resistance and hardness than commonly available Al-Si alloys.

The primary goal of this study is to look into the capabilities of various aspects, such as

(i) introducing new materials: squeeze casting was used to create tungsten carbide particles (WCp) reinforced with titanium alloy Ti-6Al-4V alloys

(ii) hardness and wear resistance are improved by Ti-6Al-4V alloys/WCp composites

(iii) the bonding of the composites is examined using an optical microscope (OM) and a scanning electron microscope (SEM)

2. Materials and Methods

2.1. Matrix and Reinforcement. The primary matrix in this investigation was Ti-6Al-4V alloys (grade 5), and the density is 4.53 g/cc. Ti-6Al-4V alloys combine strength, density, great corrosion resistance, good ductility, heat treatability, and toughness in an astonishing way. Grade 5 titanium alloys have excellent welding and fabrication properties, as indicated in Table 1 [16, 33–36].

Tungsten carbide (WC) is an attractive reinforcement for matrix alloys [16, 37, 38] because of its extreme hardness, high modulus of elasticity, high melting temperature, and excellent wettability. Because of the significant density gradient, it is very important to make WC particles reinforced composites with a harmonised distribution of WCp using squeezing techniques [39, 40]. As a result, WCp was chosen as a reinforcement particle in the current study. In Table 2, the WCp substance concertos are presented. 5 and 10 wt% WCp with a typical particle size of 40 m were tested in addition to reinforcement.

2.2. Preparation of Composite: Squeeze Casting Techniques. In general, squeeze casting is defined as a secondary process in composites stir casting techniques [41]. Due to rousing, the metal congealed under force to reduce porosity in squeeze casting. The force unit's main components were a punch and a special cylindrical steel die. There was a 0.05 to 0.1 mm agreement between the punch and the die to keep the force contained by the die and avoid melt seepage during pressing. The TMCs created by stir casting were melted again and accurately cast into a 300°C preheated die mould. After that, the punch was instantly subordinated to the fluid metal's surface. After maintaining a 150 MPa applied force for 4 minutes, the congeal casting was used to prepare the specimen 100 × 30 mm as shown in Figure 1.

2.3. Microstructure Tests, Wear Test, and Hardness Test. The overall work piece remained academic in nature, removing any garbage that was there on a surface level. Molecule transport is still monitored using a visual magnifying lens. The projection approach was examined using an optical magnifying tool to identify the support example of a cast structure. A section of the castings remained uncut. They were grained to produce 100 coarseness silicon carbide

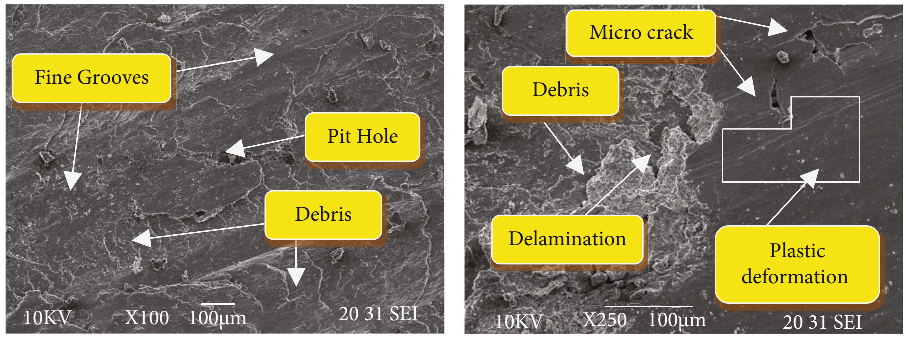

Figure 4: Worn surface analysis of squeeze casting wear specimen.

Table 4: Wear rate values of Ti-6Al-4V matrix with 10% WCp (sliding distance 1000 m).

Applied load	Ti-6Al-4V matrix with 10% of WCp	Ti-6Al-4V matrix with 15% of WCp
10	11.848	16.848
20	13.156	18.156
30	15.9735	20.9735
40	17.099	22.099
50	19.407	24.407
60	21.042	26.042
70	23.331	28.331
80	25.683	30.957

Table 5: Wear rate values of Ti-6Al-4V matrix with 15% WCp (sliding distance 1000 m).

Applied load	Ti-6Al-4V matrix with 10% of WCp	Ti-6Al-4V matrix with 15% of WCp
10	22.848	28.848
20	24.156	31.156
30	26.9735	33.9735
40	27.099	36.099
50	29.407	39.407
60	32.042	42.042
70	34.331	45.331
80	37.683	47.957

paper before optical reconnaissance, followed by 200 to 1000 emery paper assessments. To obtain a superior difference, Keller's reagent was employed to clean and carve the samples. The samples were visualised at various magnifications to demonstrate the occurrence of fortifications and the conveyance of the metal lattice diverse components/mixes that were accessible in graphite and boron carbide, which are difficult to distinguish by optical micrographs.

Microanalyses of strong inorganic materials are both aided by SEM microscopy. Filtering electron microscopy allows for high misrepresentations, high-goal symbolism, and exact quantification of extremely minute face features and objects. SEM gives finished high-goal symbolism of the tester by rastering an engaged electron pillar across the surface and recognising determined or backscattered electron signals. A vitality dispersive X-beam analyzer is also used to invest with basic location and quantitative compositional data.

An additional sample was tested for dry sliding wear using a pin-on-disc equipment provided by DUCOM, as illustrated in Figure 2. The specimen was positioned next to the neutralising face of a revolving disc circular with a 60 mm wide wear route. Using a deadweight stacking structure, the specimen was put next to the circular disc. Wear tests were performed on several specimens with typical loads of up to 80 N and a sliding speed of 4 m/s. Under the same environmental circumstances as those mentioned below, wear experiments were done for a total sliding separation

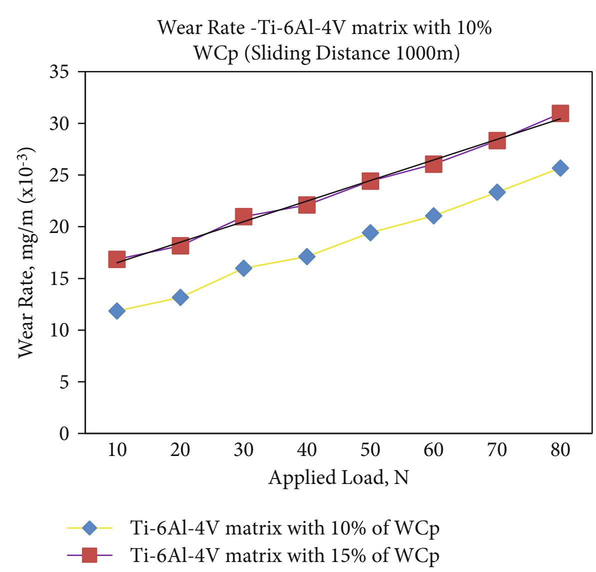

Figure 5: Wear rate of Ti-6Al-4V matrix with 10% WCp (sliding distance 1000 m).

of 1000 to 2000 m. Table 3 shows the complexities of the wear test limits.

Micro hardness testing is a technique for determining the micro hardness of a material using an infinitesimal scale as a reference. The MVH-II advanced miniaturised scale hardness instrument was used to calculate micro hardness

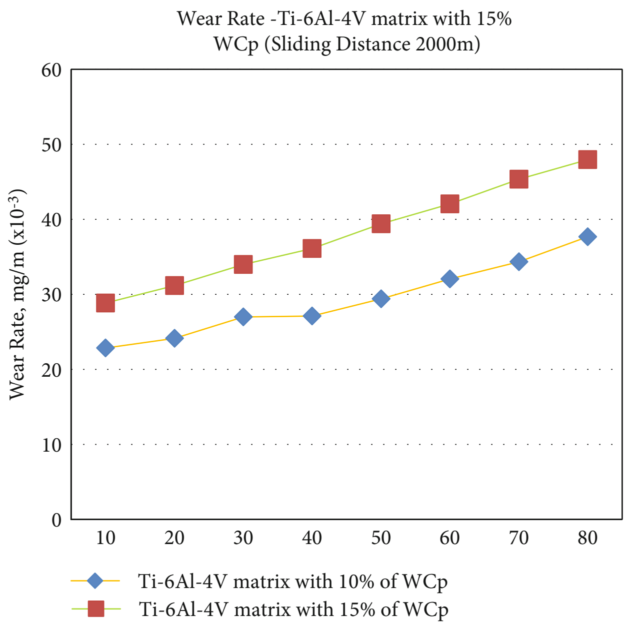

Figure 6: Wear rate of Ti-6Al-4V matrix with 10% WCp (sliding distance 1000 m).

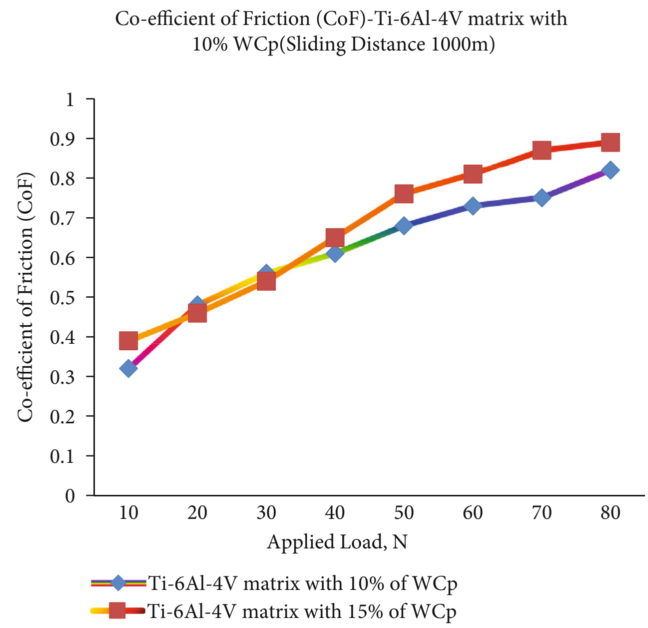

Figure 7: μ–Ti-6Al-4V matrix with 10%WCp (sliding distance 1000 m).

Table 6: μ values of Ti-6Al-4V matrix with 10% WCp (sliding distance 1000 m).

Applied load	Ti-6Al-4V matrix with 10% of WCp	Ti-6Al-4V matrix with 15% of WCp
10	0.32	0.39
20	0.48	0.46
30	0.56	0.54
40	0.61	0.65
50	0.68	0.76
60	0.73	0.81
70	0.75	0.87
80	0.82	0.89

Table 7: μ values of Ti-6Al-4V matrix with 15% WCp (sliding distance 2000 m).

Applied load	Ti-6Al-4V matrix with 10% of WCp	Ti-6Al-4V matrix with 15% of WCp
10	0.468	0.52
20	0.568	0.578
30	0.596	0.635
40	0.628	0.72
50	0.695	0.785
60	0.778	0.8469
70	0.84	0.924
80	0.88	0.9556

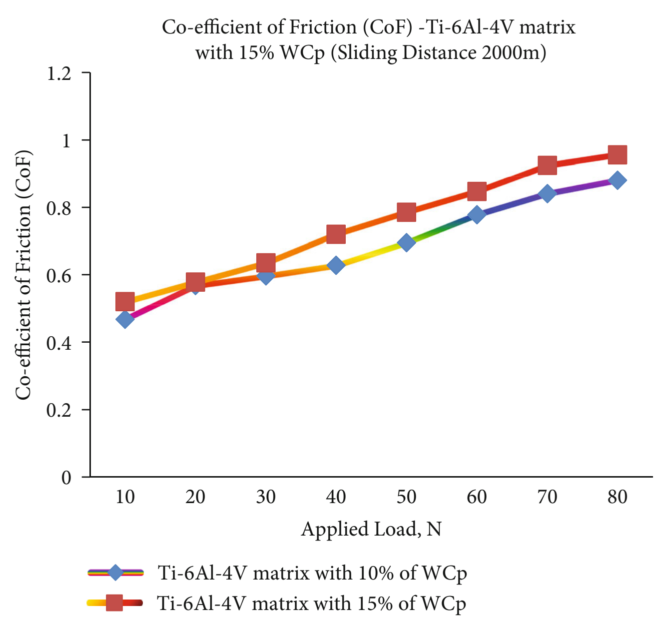

Figure 8: μ–Ti-6Al-4V matrix with 15%WCp (sliding distance 2000 m).

for this study. A diamond stone indenter is placed on the material to be tested, which can range in weight from a few grammes to one kilogramme. The length of the impression is defined by the size of a magnifying lens, and the applied force is used to estimate the assessment of micro hardness. A square-formed indenter is utilized in most micro hardness testing. They picked a load that is applied to the material using the analyzer's dead loads [16].

3. Result and Discussion

3.1. Optical Microscope and SEM Analysis. Figures 3(a) and 3(b) show TMCs formed by squeeze casting and their

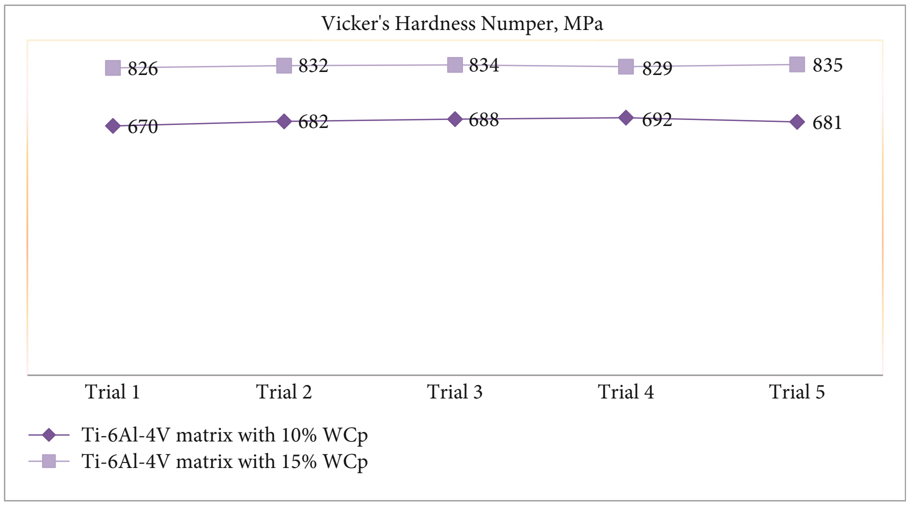

FIGURE 9: Micro hardness of the Ti-6Al-4V alloy matrix reinforced with WCp.

microstructure (b). When compared to stir casting, the superior uniform distribution of WCp in the titanium alloy matrix material was clearly perceived. The presence of WCp has a proclivity for the formation of cracks, and the resulting bonding leads to resilient warp with increased consignment. The exceptionally strong interfacial connection between the tungsten carbide particle and the titanium matrix causes rapid fracture of composites in the form of fractures and shatter, which is assessed by dimples, voids, clusters, and cracks [41–46].

Figure 4 demonstrates the worn surface of squeeze casting Ti-6Al-4V with 10% WCp and 15% WCp composites at up to 80 N load. As a result of the heavy force at the make contact with surface, the result displays the arrangement of plastic deformation, fine grooves, debris, delamination, micro fractures, and pit holes, as well as the path to further amount of material subtraction from the samples. Furthermore, it was well known that void, delamination, and particle supplement deficiencies were not found on worn surfaces. As a result of luminosity plastic deformation at the contact surface due to squeezing, our findings point to a moderate delamination with fewer damages and tiny grooves [42–45].

3.2. Wear Rate Analysis and Coefficient of Friction (CoF). Wear regularly arises while multipart facades living being contacted mutually owing to relative motion; accordingly, material defeat arises. Therefore, the amount of wear is supposed to be moderated in practical applications automotive, aircraft, spacecraft, medical equipment, and defense, particularly for decisive works. The figure shows the wear rate of different WCp reinforcements and sliding distance various from 1000 m to 2000 m. The wear rate values are listed in Tables 4 and 5.

Figures 5 and 6 show how the wear rates of Ti-6Al-4V alloys reduce as the WCp augments virtually. The wear rate values are 25.683 for 10% WCp, 30.957 for 15% WCp, and 37.683 and 30.957 for 20% WCp. The Ti-6Al-4V/WCp composite materials accurately confirm a cryptogram of superior wear rate, in which the influence of applied load ranges from 10 N to 80 N on wear rate and is only evident beginning the fracture amid the wear rate curve connives for varied wt percent of reinforcements. The WCp is important for the wear rate of urbanised TMCs, and the majority of researches have noticed the same residue [16, 42].

CoF is computed as

$$\mu = \frac{FF}{P}, \quad (1)$$

where μ is the coefficient of friction, FF is the frictional force, and P is the applied load.

When the sliding speed and distance were increased from 1000 to 2000 m, the WCp and applied load revealed a reduction in μ. With a virtual increase in the WCp, μ of Ti alloys decreases. It is easy to imagine that low CoF values for TMCs were reached at sliding speeds. The μ values for 10% WCp are 0.82, 0.87, and 0.88 and 0.956 for 15% WCp, respectively, as shown in Tables 6 and 7. When compared to Figures 7 and 8, it is clear that the TMCs substantiate a pattern of increased μ. Nearby, the collision of WCp and applied stress up to 80 N on μ has widened, as seen by the crack between the μ camber conspiring for 10% and 15% of reinforcements. The μ values grow continuously as WCp overhangs from the matrix [43]. The current research enfolds up for μ growth for all TMC samples as the applied load rises, with the goal of additionally expanding at sliding speed.

3.3. Micro Hardness. Figure 9 illustrates the micro hardness of Ti-6Al-4V alloys reinforced with 10% and 15% WCp. The micro hardness of the composite samples primarily depends on the circulation of WCp. Enhanced micro hardness can be attained in nearly every one of the TMC samples by inserting the tungsten particles and glowing spreading in the matrix. The micro hardness values are listed in Table 8.

Table 8: Micro hardness values of the Ti-6Al-4V alloy matrix reinforced with WCp.

Trials	Ti-6Al-4V matrix with 10% WCp	Ti-6Al-4V matrix with 15% WCp
1	670	826
2	682	832
3	688	834
4	692	829
5	681	835

The micro hardness values are 692 VHN for 10% WCp and 835 VHN for 15% WCp. The consequences illustrated to advance the superior micro hardness of the composite by using a squeeze casting route to prepare the composites. The Ti-6Al-4V alloy matrix material reinforced with TiC, TiB, B4C, BN, and (Ti,Mo)C/C particles achieved hardness of 766 HV, 19.6 GPa, 971 HV, 1168 HV, and 15 GPa, respectively, and compared with the current investigation, using WCp particles improved superior hardness of the composites [44–49].

4. Conclusion

The subsequent interpretation was haggard commencing this present investigative work:

(i) Squeeze castings were produced efficiently using two distinct TMCs, including Ti-6Al-4V alloys strengthened with 10% and 15% WCp

(ii) When compared to stir casting, the superior uniform distribution of WCp in the Ti-6Al-4V alloy matrix material was perceptibly assumed

(iii) The significance indicated the preparation of plastic deformation, superior grooves, debris, delaminating, micro fractures, and pit holes due to deep force at the contact surface, verifying the approach to supplemental quantity of material deletion from the samples

(iv) The wear rate values are 25.683 for 10% WCp, 30.957 for 15% WCp, and 37.683 and 30.957 for 20% WCp. It is established that Ti-6Al-4V/WCp composites authenticate a higher wear rate cypher, that the conflict of applied load up to 80 N on wear rate is extremely large, and that the rupture between the wear rate connives for different wt percent of reinforcements which purely manifest beginning the rupture between the wear rate connives for different wt percent of reinforcements. For 10% WCp, the CoF values are 0.82 and 0.87, and for 15% WCp, 0.88 and 0.956

(v) The micro hardness values are 692 VHN for 10% WCp and 835 VHN for 15%WCp. The fine showed to precede the higher micro hardness of the TMCs by using a squeeze casting route to practice the composites

Data Availability

The data used to support the findings of this study are included in the article. Should further data or information be required, these are available from the corresponding author and upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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