Submitted: September 21, 2024 Revised: October 8, 2024 Accepted: October 24, 2024

Study on n-TiB_2 particulates reinforced Al7075 nano composite for soil nail applications: mechanical, wear, and fracture characterizations

M. Gangadharappa [1] ✉, H.R. Geetha [2], N.K. Manjunath [3], G.L. Umesh [4],

M.M. Shivakumar [3]

[1] Visvesvaraya Technological University, Belagavi, Karnataka, India

[2] KR Pet Krishna Government Engineering College, KR Pet, Karnataka, India

[3] BMS College of Engineering, Bengaluru, Karnataka, India

[4] Bangalore Institute of Technology, Bengaluru, Karnataka, India

✉ gangahitu2011@gmail.com

ABSTRACT

Stir casting was used to produce Al7075/n-TiB_2 composites with three distinct n-TiB_2 weight percentages: 1, 1.5, 2 and 2.5 %. The mechanical and tribological characteristics of Al7075/n-TiB_2 composites have been investigated in dry sliding situations. Evenly distributed dispersion of n-TiB_2 particulates and the strong interfacial interaction among the matrix as well as reinforcement are confirmed by the microstructural characterization. Composites with 1, 1.5, 2 and 2.5 % reinforced n-TiB_2 show the better mechanical properties when compared to base alloy. Fracture research revealed that n-TiB_2 reinforced aluminum matrix composites and non-reinforced aluminum alloy exhibited ductile expression in the form of dimples. Dry sliding wear assessments have been performed using pin-on-disc instruments. We measured the wear loss of the nano composites and found that the cumulative wear loss variation with n-TiB_2 is linear for each composite. According to the SEM examination of worn-out surfaces, oxidative wear is responsible for specimens that fall within the prescribed stress and sliding distance. The experiment demonstrates that wear loss decreases linearly with an increase in the weight percentage of titanium diboride nanoparticles. The obtained results show that the fabricated nano composites exhibit improved hardness of 14 %, tensile strength of 9 % and wear resistance of 20 % when compared to the base alloy.

KEYWORDS

Al7075 • n-TiB2 • microstructure • mechanical properties • wear behavior • fracture surface

Acknowledgements. *The authors are thankful to BMS College of Engineering, Karnataka, India and Vivekananda Research Laboratory, Karnataka, India for the continuous support in carrying out this research work.*

Citation: Gangadharappa M, Geetha HR, Manjunath NK, Umesh GL, Shivakumar MM. Study on n-TiB_2 particulates reinforced Al7075 nano composite for soil nail applications: mechanical, wear, and fracture characterizations. *Materials Physics and Mechanics*. 2024;52(6): 101–113.
http://dx.doi.org/10.18149/MPM.5262024_9

Introduction

Aluminum alloys are becoming more and more popular for structural applications, especially in the automotive and aerospace industries, due to their high specific power, low density, high conductivity, and high strength to weight ratio, all of which have a positive economic impact [1]. Metal matrix composites with an aluminum basis are

Publisher: Peter the Great St. Petersburg Polytechnic University

commonly utilized due to their high modulus, strength-to-weight ratio, stiffness, corrosion resistance, and wear resistance. These composites have superior mechanical characteristics than conventional metals and alloys [2]. Frequently utilized ceramics for reinforcement include of SiC, TiC, Al_2O_3, and B_4C. These can be utilized as long fibers, tiny whiskers, irregular or irregular, or as particles [3]. Liquid composites are used to create aluminum metal matrix composites (AMMCs). Due to its unique features, TiB_2 stands out when compared to ordinary ceramic reinforcements due to its higher thermodynamic stability, higher hardness, and low density. Due to its many advantages over the ex-situ process, researchers have been concentrating on the development of aluminum-TiB_2 in situ composites with metal matrix in recent years. Better in-situ production of Al alloys is made possible by the exothermic reaction and increased wettability of TiB_2 with aluminum, which results in a better interface bonding and less variation in the thermophysical features of the two during heating. Ceramics with poor wettability have higher porosity, bad mechanical characteristics, and uneven dispersion [4]. Researcher [5] studied Cu-Sn alloy with 7.5 wt. % of Si_3N_4 particles reinforced composites fabricated by using conventional stir casting method. It is stated that Cu-Sn alloy with 7.5 wt. % of silicon nitride particles reinforced composites showed lesser densities as compared to the base Cu-Sn alloy. The wear resistance of Cu-Sn alloy increased with the incorporation of Si_3N_4 particles. Several investigations into the mechanical properties and strengthening techniques of TiB_2/A356 composites have been conducted; the results indicate significant improvements in tensile strength [6]. Al7475 alloy was used to make composites with 2, 4, 6, 8 and 10 wt. % of B_4C particles. By incorporating particles into the matrix, the density of Al alloy composites was lowered. Al7475 alloy with B_4C composites exhibited superior tensile properties at room and elevated temperatures as compared to the base alloy [7]. Researcher [8] studied effect of nanosized Al_2O_3 and Al_2O_3-SiC on mechanical, wears and fracture surface of Al7075 composites for soil anchoring applications. It was concluded that, in contrast to Al7075 alloy, hybrid MMCs enhanced tensile strength and superior hardness. The obtained results indicate that highest hardness of 78 VHN and tensile strength of 126 MPa were achieved for developed hybrid composites. According to Zulkamal et al. [9], the semi-solid A356 alloy's wear resistance was enhanced, and its microstructure was rectified with the inclusion of TiB_2 particles. Low cycle fatigue studies on in-situ TiB_2/A356 composites were carried out by Deepak et al. [10], who discovered that TiB_2 particles significantly affected the composites' hardness, tensile strength, structure, and fatigue life. The microstructure, type of reinforcement, percentage of interfacial bonding, average load, sliding distance, and sliding-speed are the main factors influencing the mechanical and tribological characteristics of composites. Among all these characteristics, particle size has a favorable impact on the composites' performance. According to literature survey, a large number of researchers have studied various grades of aluminum, but comparatively few have studied the impact of n-TiB_2 wt. % on Al7075 alloy. The novelty of the research is to investigate the mechanical and wear properties of newly developed n-TiB_2 reinforced Al7075 composites and analyze the surface morphology. Overall, the results showed that Al composites reinforced with nanosized TiB_2 particles could be good materials where wear-resistant and high-strength components are crucial, especially in the civil-structures, aerospace, and automotive engineering industries.

Materials and Methods

Stir casting produced a homogeneous distribution, which improved the characteristics of aluminum composites. Therefore, the stir casting method was used for the current study's hybrid MMC manufacturing. Bright extruded rods of Al7075 and n-TiB_2 particles were employed to make these composites. Table 1 displays the weight percentage of Al7075's chemical makeup.

Table 1. Chemical composition of Al7075 alloy (wt. %)

Content	Al	Cu	Mg	Si	Fe	Mn	Ni	Pb	Sn	Ti	Zn	Cr
wt.%	Rem	1.480	2.306	0.059	0.256	0.052	0.052	0.023	0.012	0.052	5.424	0.280

The Al7075 (base alloy) was first melted by using graphite crucible at 750 °C [11,12]. Subsequently, the molten melt was mixed with 30–50 nm sized n-TiB_2 (1, 1.5, 2, and 2.5 %) particulates that had been preheated to 450 °C. During the stirring operation, the pre-heated reinforcement particles were mixed with the base alloy. Inert gases were extracted from the molten aluminum metal matrix using a degassing tablet. Melting the slurry required 60 sec of stirring at 150 rpm, and then it was put into a pre-heated mold. The as-cast samples were taken out of the mold once they had set. As-cast and nano-composites were both machined to prepare the test samples using CNC machining. The relevant ASTM standards were followed in the preparation of test specimens for wear and mechanical testing. Hybrid MMC samples were polished using diamond paste and different-sized grit sheets to produce a clean surface finish in preparation for microstructural analysis. After using Keller's reagent to etch these specimens, they were left to dry in the open. The produced hybrid MMCs were examined for microstructure using Nikon E-200 optical microscope. The developed hybrid MMCs were exposed to microhardness testing using a Vickers Micro Hardness testing apparatus in compliance with E92-ASTM guidelines. Specimens with diameters and thicknesses of 20 mm each were used to evaluate the hardness. For thirty seconds, a constant 5 kg load was applied by using diamond shape indenter. Tensile testing was carried out utilizing a 450 KN weight on a Universal Testing Machine (UTM) in compliance with ASTM E8 requirements (gauge length is 50 mm and gauge dia is 10 mm). Tensile strength values varied by less than 10 %, according to the results, which were based on average values of three test samples with similar compositions. The pin-on-disc test apparatus was used in accordance with ASTM G99 guidelines to measure wear loss (30 mm length and 6 mm dia). The mean values, with variances of less than 10 %, were considered after three wear test specimens with comparable compositions were analyzed.

The prepared composites' densities were determined by applying the Archimedes principles, and theoretical densities were calculated by applying the rule of mixture in accordance with the percentage of reinforcement weight, as indicated in this equation [13]:

$$\rho_c = \rho_m V_m + \rho_r V_r, \quad (1)$$

where ρ_c is the composite density, ρ_m is the matrix density, ρ_r is the reinforcement density, V_m is volume fraction of mass, V_r is the volume fraction of reinforcement.

One of the crucial physical characteristics that will significantly affect the composite's mechanical and tribological qualities is porosity. The primary factors influencing the porosity for the composites are mechanical alloying, sintering temperature, and compaction pressure. The porosity percentages of the resulting composites were computed using [14]:

$$Porosity = \frac{Theoretical\ density - Experimental\ density}{Theoretical\ density} \cdot 100. \quad (2)$$

Figure 1 shows the framework of the present research investigation.

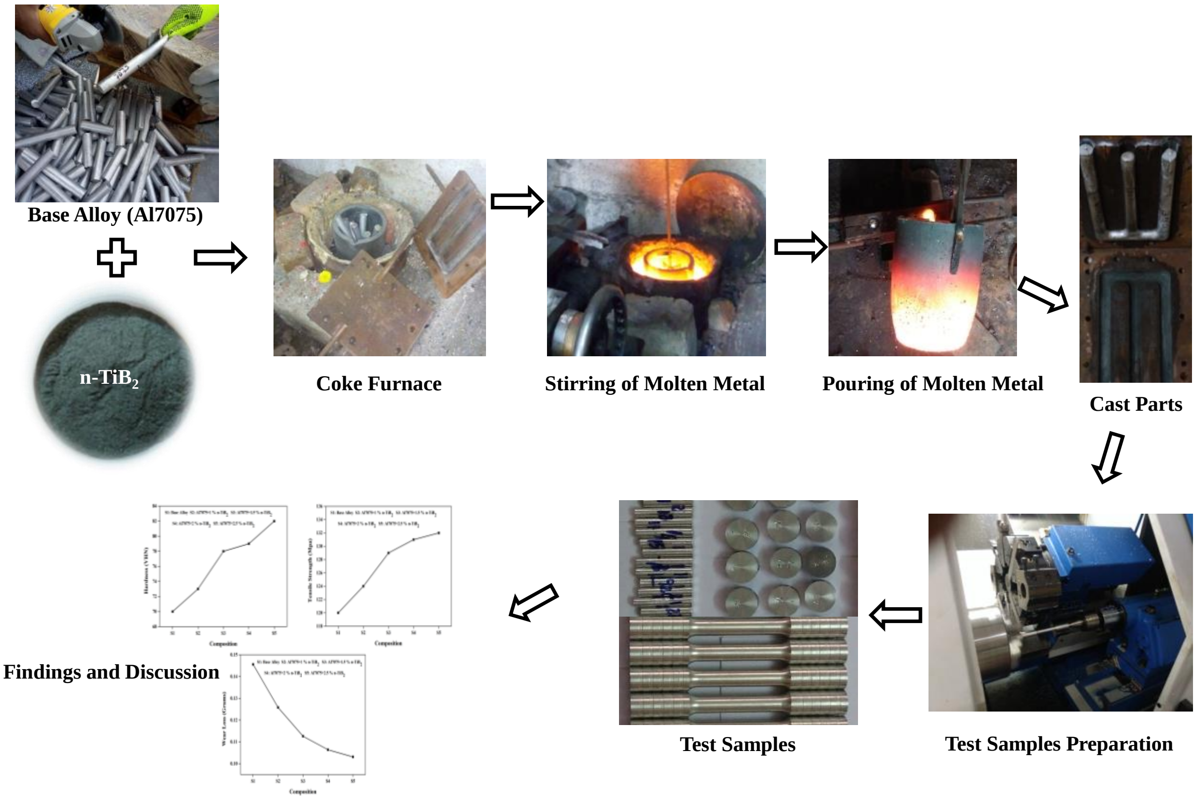


Fig. 1. Framework of the present research investigation

Findings and Discussion

Micro-structural Investigation

A matrix material's reinforcing particle distribution is examined via microstructural analysis. The mechanical and wear characteristics of Al7075/n-TiB_2 nanocomposite are analyzed by microstructural characteristics. The optical microstructure pictures of base alloy and developed nanocomposites are displayed in Fig. 2.

The micro structural pictures of all the samples show an equal distribution of small-pored n-TiB_2 particles. Since liquid metallurgy method was used to produce the specimens, porosity cannot be totally removed. It is also evident from microstructural pictures that cluster formation increases as % of n-TiB_2 increases from 1 to 2.5. The existence of more n-TiB_2 clusters is one of the primary reasons for the improved mechanical and wear features. The uniform dispersion of n-TiB_2 nanoparticles in the base matrix strengthens the interfacial-bond between the reinforcement element and the base matrix, which explains the improved mechanical and wear properties of the 2.5 wt. % n-TiB_2 composite. The number of n-TiB_2 particles increases with the nucleation sites because it provides additional barriers to the fractures in the grains that cause the change of the grain structure [15,16].

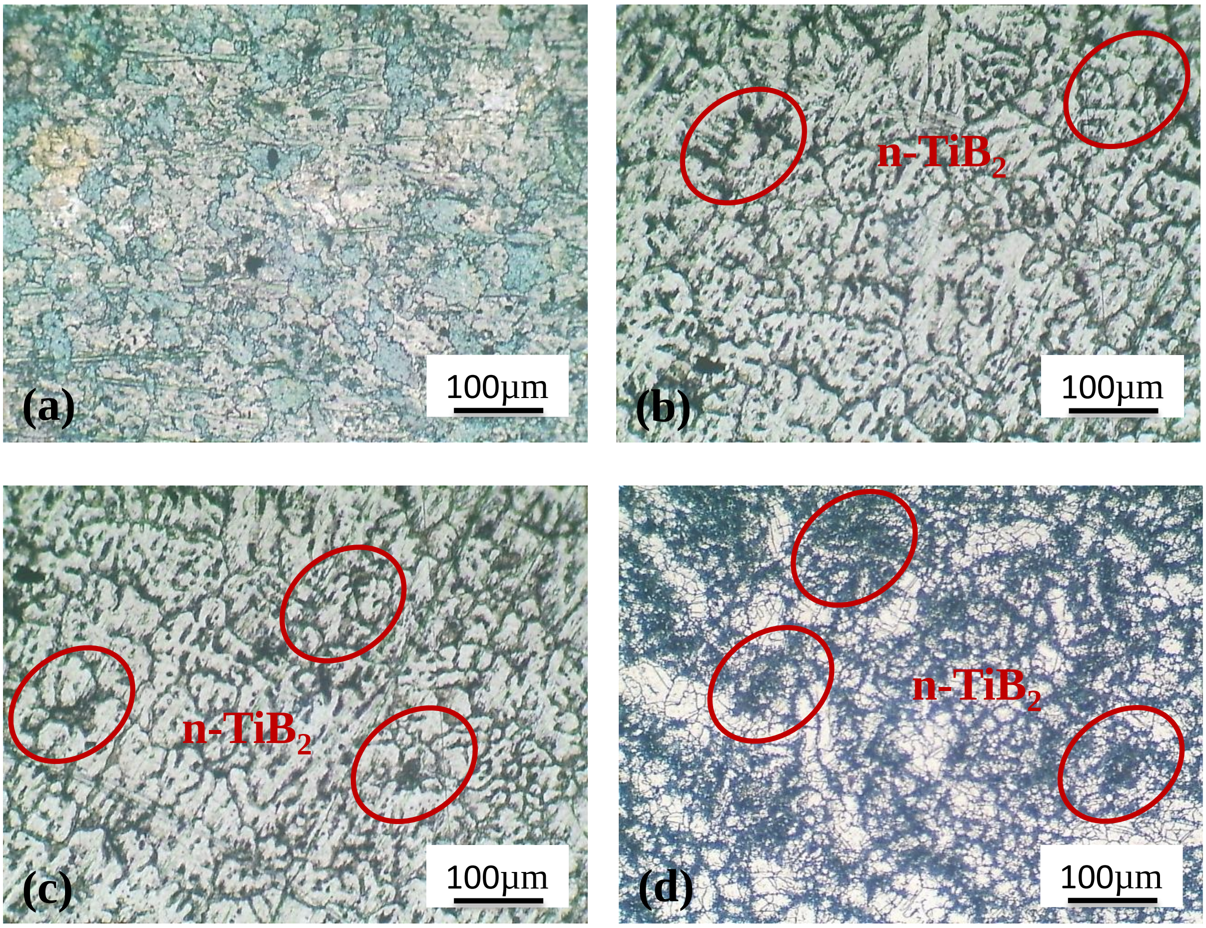


Fig. 2. Microstructure of (a) Base alloy, (b) 1.5 % n-TiB_2 composites, (c) 2 % n-TiB_2 composites and (d) 2.5 % n-TiB_2 composites

Energy dispersive X-ray spectroscopy study

Energy dispersive X-ray spectroscopy (EDS) analysis was performed on the fabricated nano MMCs samples in order to assess the chemical compositions of the Al7075/n-TiB_2 composite. The results are shown in Fig. 3. The analysis unequivocally demonstrates that

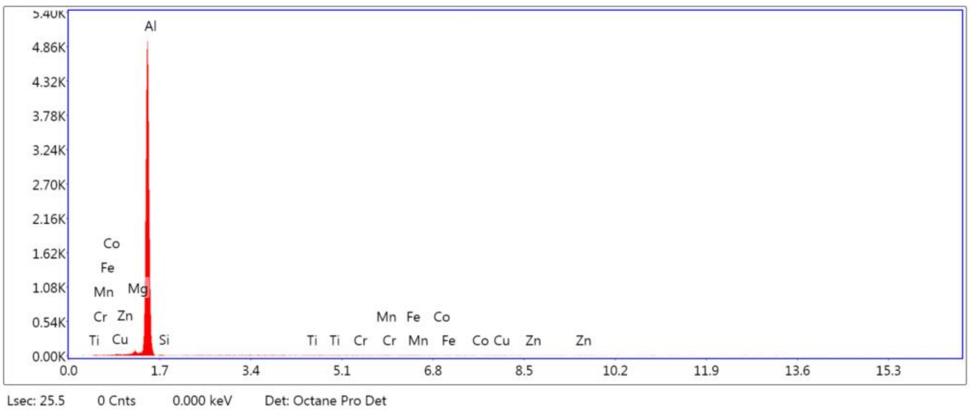


Fig. 3. EDS analysis of Al7075+2.5 % n-TiB_2

Al, Mn, Cu, Co, Ti, and other elements occur over a range of peaks. The result displays the EDS study's "Ti" peak. It provides proof that developed nano MMCs contain TiB_2 particles [17].

Density and porosity

The Archimedes method for determining density uses the fact that the apparent weight of an object submersed in liquid is lighter that the object's weight in air by the weight of the volume of liquid that the object displaces. Figure 4 illustrates the variation in the porosity and the density of Al7075/n-TiB_2 composites.

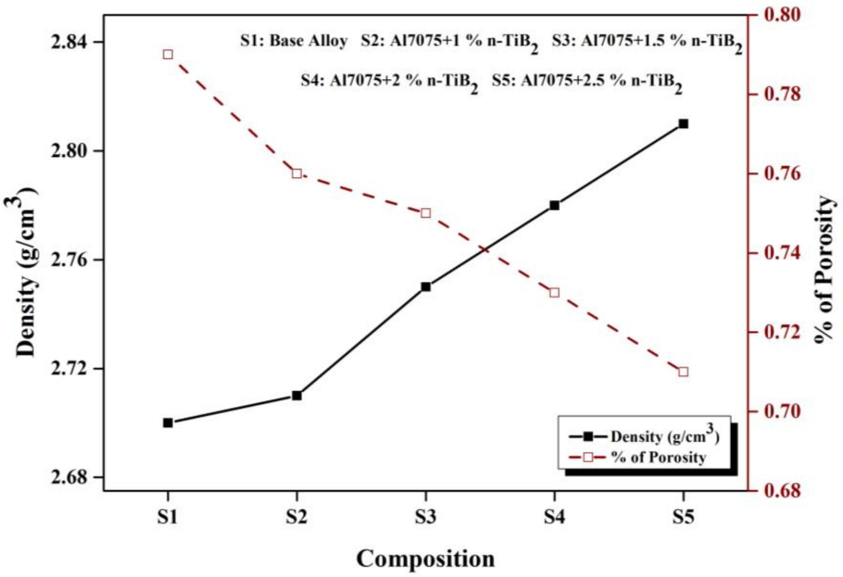


Fig. 4. Effect of n-TiB_2 on Density and porosity

Theoretical and experimental density values for Al7075/n-TiB_2 composites show a nearly similar trend and are nearly in agreement with one another. Density levels rise with the reinforcement addition. This increment of density values may be the cause of the high n-TiB_2 (hard) particle density [18]. The lower porosity of all the composites shows that reinforcement and matrix material have a strong interfacial bond. High compacting pressure and the temperature of sintering are the two primary factors that can impact the porosity within a composite [19,20].

Hardness

Figure 5 displays the hardness of the Al7075/n-TiB_2 composites. It is found that the 2.5 wt. % n-TiB_2 composite has far higher hardness values than the other composites. The produced composites' increased hardness could be credited to many factors [21]. First off, the n-TiB_2 particulates have a higher hardness than matrix alloy, and this hardness is enhanced by the reinforcements' homogeneous distribution throughout the matrix. Second, adding robust hard particles refines the grains of the aluminum alloy, which raises the dislocation density at the matrix-reinforcement interfaces and raises the produced composites' hardness values. Ultimately, the mass of the produced composites increases with increasing in reinforcement content, and this densification improves the composites' hardness [22]. When the n-TiB$_2$ wt. % rose from 0 to 2.5, the hardness values improved from 70 to 84 VHN.

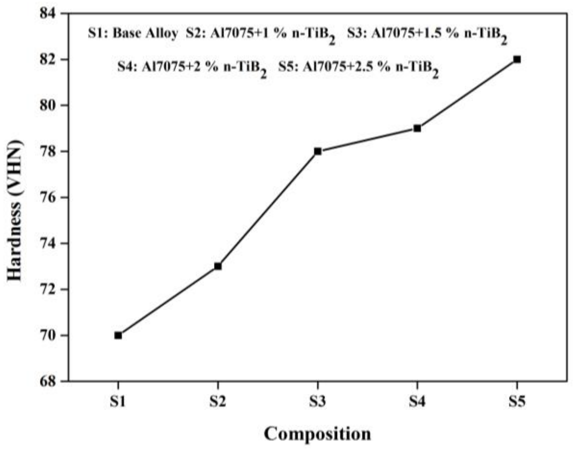


Fig. 5. Effect of n-TiB$_2$ on hardness

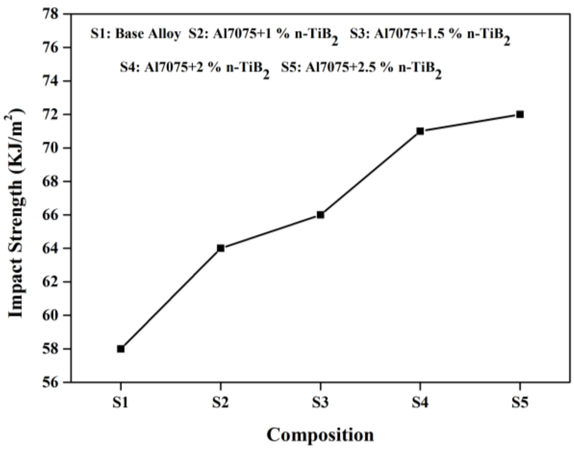


Fig. 6. Effect of n-TiB$_2$ on toughness

Toughness

The sample's energy absorption during an abrupt load was determined by an impact test procedure that adhered to the ASTM D256 standard. In this test, the amount of energy in a material upon break can be determined using the strength value. The impact strength of the composites is determined using the Charpy impact test. The strength variation of toughness for Al7075/n-TiB$_2$ composites with varying reinforcements is displayed in Figure 6. The n-TiB$_2$ composite with 2.5 wt. % showed higher impact strength than the others. The uniform dispersion of n-TiB$_2$ particulates in the matrix and strong interfacial bonding are the reasons for the high ductility. The main cause of the lower impact strength reported by most composites is the existence of pores and microcracks.

Tensile strength

Figure 7 shows that as the weight percentage of n-TiB$_2$ content increased, the hybrid composites' tensile strength increased as well. The reported outcomes are consistent with what has been seen in the majority of hard particle reinforced micro MMCs [23]. Other studies [24,25] detailed the strengthening mechanisms and connected them to the enhanced load-sustaining capability of the resulting composite, which was attained by increasing the wt. % of hard nano particulates and enhancing the resistance to the dislocation or movement of the particles.

Strength increased as a result of the generated nano MMCs' resistivity to dislocations, and the tension strength was increased even more by including additional n-TiB$_2$ particles into the MMCs. The hard particle's characteristics made the material stronger. The ultimate strength was increased by hard nanoparticles rather than dislocations. Several additional researchers reported similar findings [26]. A higher concentration of n-TiB$_2$ resulted in an improvement in the ultimate tensile strength, which is commonly ascribed to a decreased degree of porosity along with a more even distribution of reinforcement of hard particles. This fact is supported by the results obtained from most hard particles reinforced nano composites. The micro MMCs solidified more quickly as a result of the matrix's level of reinforcement. This is usually caused by the complexity that results from the inclusion of strong nanoparticles, which obstructs dislocation motions across the base matrix [27].

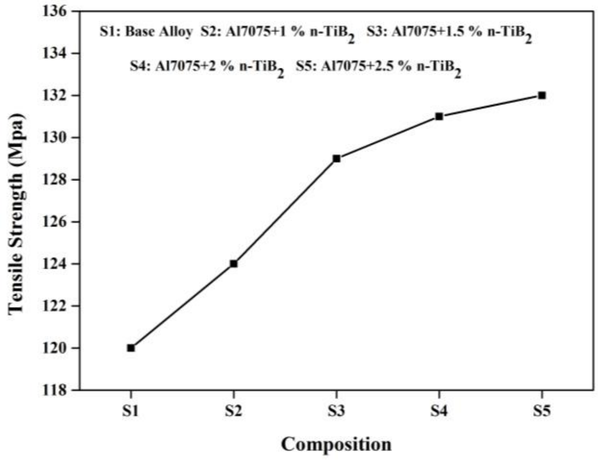


Fig. 7. Effect of n-TiB_2 on tensile strength

Figure 8 shows the stress-strain curves for the alloy and nanocomposites. These curves' primary characteristics are that as particle content rises, tensile strength increases as fracture strain decreases. When compared to the nanocomposites, the base alloy is shown to have the largest plastic strain and to show the least resistance of plastic deformation due to its relatively lower flow stress. It is noted that, in comparison to the base alloy, all of the nanocomposites exhibit greater strength. This is because the nanoparticles have been strengthened and the grains have been refined. The mismatch strengthening and elevated load bearing brought on by the nano-sized particles are typically responsible for the increase in strength in nano-MMCs. It is deduced that this might be because of variations in the CTE between the reinforcements and the matrix. The dislocation's mobility within the matrix is impeded by the hard nanoparticles, which is why the durability of the nano-MMCs is found to be greater compared to base matrix. During tensile tests, the hard ceramic nanoparticles' ability to trap dislocations resulted in an increase in the nanocomposites' tensile strength [28,29].

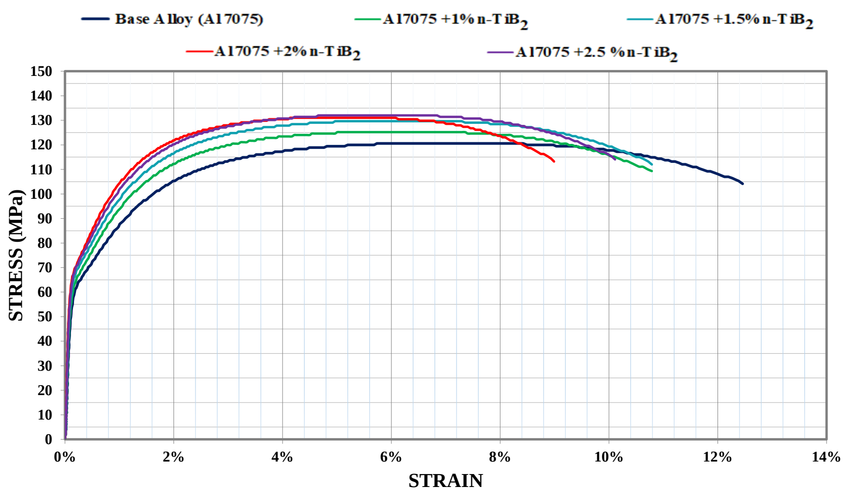
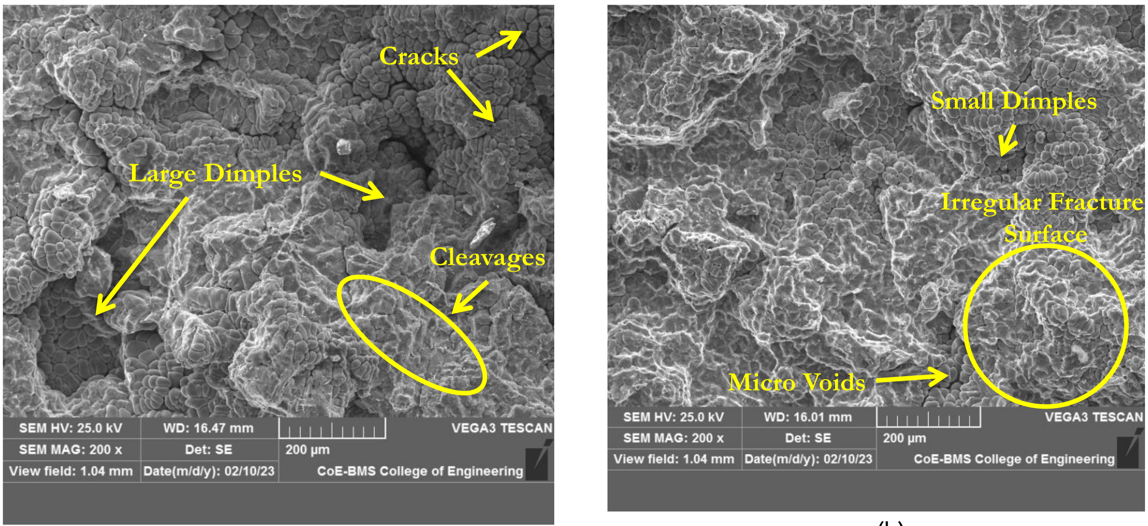


Fig. 8. Effect of n-TiB_2 nanoparticles concentration on stress-strain curves

When tension load was applied, higher weight percentage of reinforcements caused significant debonding at the matrix-reinforcement material contact point, which reduced ductility. Tensile fractured surface of the as-cast and 2.5 % n-TiB_2 reinforced MMC specimen are depicted in Fig. 9. The development of small pores on shattered material surfaces was the reason for the extreme ductility observed in MMC manufacture. In comparison to nanocomposites, as-cast elements with fractured surfaces showed more dimple shapes, suggesting superior ductile strength. The addition of n-TiB_2 particles caused the failure type to change from ductile to brittle, according to fractography investigations. This displacement is indicated by the dimples on the surface fractured specimen and the deformed area. More hard reinforcements resulted in more microcracks, indicating that the material was less ductile. The architecture of fractured surfaces frequently exhibited a higher density of voids and cracks. Because of their presence in the soft matrix, the robust particles created a triaxial stress state that ultimately led to void formation. This implies that there is a strong relation between the reinforcement being used and the matrix material, and that the size and shape of the reinforcements have an impact on bonding. Linear relationship observed between the dimple diameters and the composite's strength. Tensile sample fracture surfaces revealed details about the composition of nanoparticles at the interface. Hard nanoparticle pullout and fracture were two of the fracture processes that decreased ductility. The outward propagation of cracks from their centers was enhanced by voids at the particle and matrix interfaces [30,31].



(a) (b)

Fig. 9. Fracture surface of (a) base alloy and (b) 2.5 % n-TiB_2 composites

Wear loss

In the present investigation, all the wear test samples were tested with a constant load of 10 N, sliding speed of 500 rpm and sliding distance of 1000 m have been considered. Figure 10 shows the wear rates for both the Al matrix alloy and the Al/n-TiB_2 MMCs. The amount of n-TiB_2 that exists in reinforced composites has been found to increase the transition load. It was also observed that the composite had a lower wear rate than the base metal. The wear resistance that the composite samples given by releasing n-TiB_2 into the surface that contacts them during sliding is most likely the cause of this.

Alpas and Zhang [32] examined the sliding wear characteristics of Al-Si alloys reinforced with TiB_2 particles. It was concluded that TiB_2 reinforcement greatly improves wear resistance based on their studies.

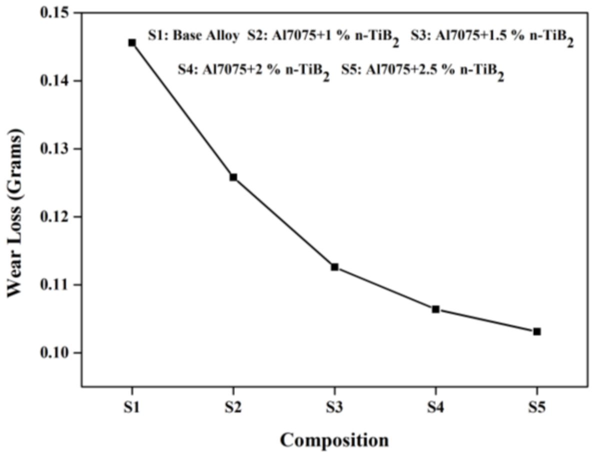
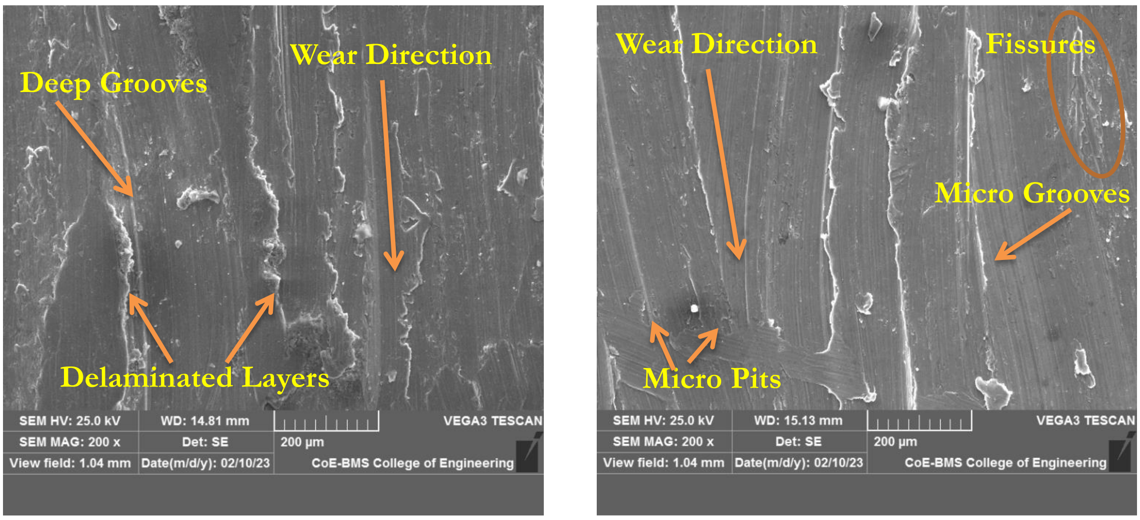


Fig. 10. Effect of n-TiB_2 on wear loss



(a) (b)

Fig. 11. SEM micrographs of worn surfaces of (a) base alloy and (b) 2.5 % n-TiB_2 composites

A thin film forms between the surfaces that meet when sliding wear causes n-TiB_2 particles to shear and stick to the metal surface with the principal axis parallel to the sliding direction. Moreover, the n-TiB_2 hard film can bear stress within low load circumstances without breaking or turning plastic due to its incredibly limited ductility. Research has repeatedly demonstrated that wear rate as well as surface damage may be decreased if material used at the counter contact is prevented from plastically deforming. The n-TiB_2 strong film in composites efficiently reduces the wear rates while sustaining high loads [33]. Therefore, the pace at which the sheared reinforcing layers stick to the sliding surfaces determines how well the n-TiB_2 particulates in the composite materials can slow down wear. The test samples' sliding wear tracks were inspected using scanning electron microscopy (SEM). SEM analyses of the wornout surfaces provided evidence about how hard particles affected the produced composites' wear characteristics.

Wornout surface of the as-cast and 2.5 % n-TiB$_2$ reinforced MMC sample are depicted in Fig. 11, where they display worn surfaces as depicted in SEM images.

These pictures show different-sized grooves on the wornout surfaces, most likely caused by worn debris particles acting as secondary abrasive bodies. Hard particulates within the alloy prevented plastic deformation, resulting in the forming of these grooves and small patches on the worn surfaces [34]. The n-TiB$_2$ particles significantly increased wear resistance by facilitating the development of a protecting effect on the surface under the applied load. The beneficial effects of n-TiB$_2$ particulates on the wear characteristics of MMCs have been shown by this investigation. The n-TiB$_2$ particles that were put into the counterface and test samples caused micro-ploughing on the MMCs' contact surfaces. SEM pictures of the fabricated nano composites in Fig. 11(b) reveal substantially less debris and more consistent sliding wear tracks. When compared to as-cast alloys, nano composites exhibit greater wear resistance due to their increased density and superior interfacial adhesion between the particles and base matrix. There was less wear loss because the steel discs could not penetrate the composite materials due to the presence of ceramic particles [35].

Conclusions

This work investigated the effects of n-TiB$_2$ weight percentage on both the tribological and mechanical characteristics of Al7075/TiB$_2$ composite. The following are the principal findings.

One of the most effective methods for fabricating Al7075/n-TiB$_2$ composites is stir casting. When producing nano composites with strong matrix-reinforcement bonding, a uniform dispersal of the reinforcement was attained. The developed composites' density values increased linearly as the wt. % of n-TiB$_2$ particles increased. Addition of n-TiB$_2$ particulates improved hardness of developed nano composites. Results show that composites reinforced by 2.5 wt. % of n-TiB$_2$ was found to be the hardest with hardness of 82 VHN. Tensile strength increased when the weight of n-TIB$_2$ particles increased with 132 MPA, the maximum tensile robustness was observed for 2.5 % of the nano composites reinforced with n-TIB$_2$. The obtained results show that the fabricated nanocomposites exhibit improved hardness of 14 %, tensile strength of 9 % and wear resistance of 20 % when compared to the base alloy. Fracture research exposed that n-TiB$_2$ reinforced aluminum matrix composites and unreinforced aluminum alloy exhibited ductile expression in the form of dimples. The equiaxed dimples and low depth were found in the particle-reinforced aluminum matrix composite. Compared to the Al/n-TiB$_2$ reinforced composites, the unreinforced aluminum alloy had a greater wear rate. In the developed nano composites, the wear rate decreased as n-TiB$_2$ concentration increased.

References

1. Agarwal S, Angra S, Singh S. A review on the mechanical behaviour of aluminium matrix composites under high strain rate loading. *Materials Physics and Mechanics.* 2023;51(6): 1–13.
2. Medvedev AE, Atroshchenko VV, Selivanov AS, Bogdanov AR, Gorbatkov MV, Logachev YV, Lobachev VS. Influence of various friction stir processing (FSP) schemes on the microstructure and properties of AD31 aluminium alloy busbar. *Materials Physics and Mechanics.* 2024;52(1): 95–107.
3. Gowrishankar TP, Sangmesh B. Role of heat treatment on mechanical and wear characteristics of Al-TiC composites. *Materials Physics and Mechanics.* 2024;52(1): 108–117.
4. Mohd Joharudin NF, Abdul Latif N, Mustapa MS, Badarulzaman NA. Effects of Untreated and Treated Rice Husk Ash (RHA) on Physical Properties of Recycled Aluminium Chip AA7075. *International Journal of Integrated Engineering.* 2020;12(1): 132–137.
5. Adaveesh B, Prabhushankar GV, Nagaral M. Tribological and tensile behaviour of Si_3N_4 reinforced Cu-Sn matrix composites. *Materials Physics and Mechanics.* 2023; 51(4): 11–22.
6. Ravikumar N, Reddappa HN, SureshR. Study on mechanical and tribological characterization of Al_2O_3/SiCp reinforced aluminum metal matrix composite. *Silicon.* 2018;10: 2535–2545.
7. Chandrasekhar GL, Vijayakumar Y, Nagaral M, Rajesh A, Manjunath K, Kaviti RVP, Auradi V. Synthesis and tensile behavior of Al7475-nano B_4C particles reinforced composites at elevated temperatures. *Materials Physics and Mechanics.* 2024;52(3): 44–57.
8. Ravikumar M, Naik R, Vinod BR, Chethana KY, Rammohan YS. Study on nanosized Al2O3 and Al2O3-SiC on mechanical, wear and fracture surface of Al7075 composites for soil anchoring applications. *Materials Physics and Mechanics.* 2023;51(6): 24–41.
9. Zulkamal NAM, Nasir LMM, Anasyida AS. Microstructure and wear properties of T6 heat treated semisolid A356-TiB_2 composite, *J. Phys. Conf. Ser.* 2018;1082: 012065.
10. Deepak Kumar S, Jha SK, Karthik D, Mandal A. Fatigue analysis of A356-TiB_2 (5 wt. %) in-situ nano composites, *Materials Today Proceedings.* 2019;18(3): 774–779.
11. Samal P, Surekha B, Vundavilli PR. Experimental investigations on microstructure, mechanical behavior and tribological analysis of AA5154/SiC composites by stir casting. *Silicon.* 2021;17(7): 3317–3328.
12. Ononiwu NH, Ozoegwu CG, Ifeanyi JG, Nwachukwu VN, Akinlabi ET. The influence of sustainable reinforcing particulates on the density, hardness and corrosion resistance of AA 6063. *Frattura ed Integrità Strutturale.* 2022;16(61): 510–518.
13. Kumar N, Gautam G, Gautam RK, Mohan A, Mohan S. Synthesis and characterization of TiB_2 reinforced aluminium matrix composites: a review. *J Inst Eng (India) Ser D.* 2016;97: 233–253.
14. Surya MS, Prasanthi G. Effect of silicon carbide weight % and number of layers on microstructural and mechanical properties of Al7075/SiC functionally graded material. *Silicon.* 2022;14(4): 1339–1348.
15. Dwivedi SP, Sahu R. Effects of SiC Particles Parameters on the Corrosion Protection of Aluminum-based Metal Matrix Composites using Response Surface Methodology. *Jordan Journal of Mechanical and Industrial Engineering.* 2018;12(4): 313–321.
16. Ali M, Falih S. Synthesis and Characterization of Aluminum Composites Materials Reinforced with TiC Nano-Particles. *Jordan Journal of Mechanical and Industrial Engineering.* 2014;8(5): 257–264.
17. Sreenivasa Iyengar SR, Sethuramu D, Ravikumar M. Study on micro-structure, hardness and optimization of wear characteristics of Al6061/TiB2/CeO2 hot-rolled MMCs using Taguchi method. *Frattura ed Integrità Strutturale.* 2023;65: 178–193.
18. Dey D, Bhowmik A, Biswas A. Effect of SiC content on mechanical and tribological properties of Al2024-SiC composites. *Silicon.* 2022;14(1): 1–11.
19. Daniel AA, Murugesan S, Manojkumar, Sukkasamy S. Dry sliding wear behaviour of aluminium 5059/SiC/MoS_2 hybrid metal matrix composites. *Materials Research.* 2017;20(6): 1697–1706.
20. Ononiwu NH, Ozoegwu CG, Jacobs I, Nwachukwu VN, Akinlabi ET. The influence of sustainable reinforcing particulates on the density, hardness and corrosion resistance of AA 6063. *Frattura ed Integrità Strutturale.* 2022;61(61): 510–518.
21. Kumar V, Angra S, Singh S. Influence of rare earth elements on aluminium metal matrix composites: A review. *Materials Physics and Mechanics.* 2023;51(2): 1–20.
22. Agarwal S, Angra S, Singh S. A review on the mechanical behaviour of aluminium matrix composites under high strain rate loading. *Materials Physics and Mechanics.* 2023;51(6): 1–13.

23. Chawla N, Shen YL. Mechanical behavior of particle reinforced metal matrix composites. *Advanced Engineering Materials.* 2001;3(6): 357–370.
24. Bhowmik A, Dey D, Biswas A. Characteristics study of physical, mechanical and tribological behaviour of SiC/TiB$_2$ dispersed aluminium matrix composite. *Silicon.* 2022;14(3): 1133–1146.
25. Faisal N, Kumar K. Mechanical and tribological behaviour of nano scaled silicon carbide reinforced aluminium composites. *Journal of Experimental Nanoscience.* 2018;13(1): S1–S13.
26. Akbari MK, Baharvandi HR, Shirvanimoghaddam K. Tensile and fracture behavior of nano/micro TiB$_2$ particle reinforced casting A356 aluminum alloy composites. *Materials & Design.* 2015;66: 150–161.
27. Wang H, Li Y, Xu G, Li J, Zhang T, Lu B, Yu W, Wang Y, Du Y. Effect of nano-TiC/TiB2 particles on the recrystallization and precipitation behavior of AA2055-TiC+TiB2 alloys. *Materials Science and Engineering: A.* 2023;871: 144927–144927.
28. Wang H, Zheng H, Hu M, Ma Z, Liu H. Synergistic effect of Al2O3-decorated reduced graphene oxide on microstructure and mechanical properties of 6061 aluminium alloy. *Scientific Reports.* 2024; 14: 16213.
29. Ravikumar M, Reddappa HN, Suresh R, Babu ER, Nagaraja CR. Study on micro - nano sized Al_2O_3 particles on mechanical, wear and fracture behavior of Al7075 metal matrix composites. *Frattura ed Integrità Strutturale.* 2021;58: 166–178.
30. Rajasekaran NR, Sampath V. Effect of In-Situ TiB$_2$ particle addition on the mechanical properties of AA 2219 Al alloy composite. *Journal of Minerals & Materials Characterization & Engineering.* 2011;10(6): 527–534.
31. Sridhar Raja KS, Hemanandh J, Mohan Krishna J, Muni Sai Preetham R. Effect of TiB2 on mechanical properties and microstructural of aluminium composite. In: Arockiarajan A, Duraiselvam M, Raju R. (eds.) *Advances in Industrial Automation and Smart Manufacturing. Lecture Notes in Mechanical Engineering.* Singapore: Springer; 2021. P.697–703.
32. Zhang J, Alpas AT. Wear regimes and transitions in Al_2O_3 particulate reinforced aluminium alloys. *Materials Science and Engineering: A.* 1993;161(2): 273–284.
33. Sreenivasan A, Paul Vizhian S, Shivakumar ND, Muniraju M, Raguraman M. A study of microstructure and wear behaviour of TiB$_2$/Al metal matrix composites. *Latin American Journal of Solids and Structures.* 2011;8(1): 1–8.
34. Ganesh K, Hemachandra Reddy K, Sudhakar Babu S, Ravikumar M. Study on microstructure, tensile, wear, and fracture behavior of A357 by modifying strontium (Sr) and calcium (Ca) content. *Materials Physics and Mechanics.* 2023;51(2): 128–139.
35. Ravikumar M, Hanumanthe G, Umesh GL, Raghavendra S, Darshan SM, Shivakumar MM, Santhosh S. An Experimental Investigation on Effect of B4C/CeO2 Reinforcements on Mechanical, Fracture Surface and Wear Characteristics in Al7075 Hybrid Metal Matrix Composites. *International Journal of Integrated Engineering.* 2024;16(5): 100–113.

About Authors

M. Gangadharappa
PhD, (Visvesvaraya Technological University, Belagavi, Karnataka, India)

H.R. Geetha
Master Technology, Assistant Professor (K R Pet Krishna Government Engineering College, K R Pet, Karnataka, India)

N.K. Manjunath
Master Engineering, Assistant Professor (BMS College of Engineering, Bangaluru, Karnataka, India)

G.L. Umesh
PhD, Assistant Professor (Bangalore Institute of Technology, Bangalore, Karnataka, India)

M.M. Shivakumar
Master Technology, Assistant Professor (BMS College of Engineering, Bangaluru, Karnataka, India)