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ORIGINAL ARTICLE

Fabrication and Investigation of Mechanical Behaviors of TiB_2 Reinforced AMCs

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Abstract The automotive and aerospace industries are replacing monolithic conventional materials with composite materials for making variety of components. The aluminum metal matrix composites (AMCs) are a lightweight high perforce materials. The aluminum matrix composites (AMCs) have high strength to weight ratio as well as high corrosion resistance properties. Many automobile and aerospace components are made of AMCs. The stir casting fabrication technique is mostly used by researchers for the fabrication of aluminum matrix composites. In this research, Al 6063 matrix composites were fabricated by reinforcing varying percentages of TiB_2 through the stir casting process. The wt% of TiB_2 varied from 1 to 3% in Al 6063. The mechanical behavior of developed composites was analyzed. The result showed that tensile strength, hardness, and impact strength of composites were enhanced by 55.51%, 63.98%, and 28.13% respectively in comparison with the matrix material.

Keywords Stir casting · Composite · Reinforcement · Hardness · Tensile strength · Impact strength

1 Introduction

Now a day, metal matrix composite material is becoming one of the possible solutions for replacing conventional materials to enhance the performance of materials. Many components of automobile and aerospace vehicles are made of composite materials to improve the service life of components [1–4]. In the category of metal matrix composite, aluminum matrix composites (AMCs) are lightweight, corrosion-resistant, and high-strength-to-weight materials. Because of these properties of AMCs, it is widely used in automobile and aerospace applications [5–7]. The properties of AMCs depend on the properties of matrix materials, reinforcement materials, and fabrication processes. In AMCs, mainly power or flakes of silicon carbide, silicon oxide, alumina, boron carbide, titanium carbide, titanium oxide, titanium boride, zirconium oxide, tungsten carbide, graphite, and molybdenum disulfide carbon nanotubes are used as reinforcement materials [8–14]. The size of reinforcement powder may be from micro to nano-scale. The reinforcement properties and wettability to the matrix material affects the properties of fabricated composites. The coating of reinforcements improves the wettability and interfacial bonding of reinforcement with matrix material [15–20]. Do-Suck Han et al. [21] used MgO coated Al_2O_3 particulates for making aluminum matrix composites and reported that the MgO coating on Al_2O_3 particulates improved wettability of Al_2O_3 in composite. The wetting agents such as Mg and Ti are also used as wetting agents in AMCs to improve wettability [22, 23]. The selection of processing routs of composite play vital in determining composite properties. The AMCs

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can be fabricated by various processing techniques such as Power metallurgy, Spray deposition In situ casting, Infiltration, Squeeze casting, Ultrasonic cavitation techniques, etc. [22–26]. Hu et al. [27] fabricate composite through flux-assisted melt and semisolid stir casting techniques. It was found that the properties of flux-assisted liquid melt fabricated composite were superior to the composite developed by semisolid stir casting. The stir casting technique is a low-cost and easier fabrication process and is mostly used by researchers for the development of aluminum matrix composites. Vanarotti et al. [28] found that the hardness of Al/SiC composite developed through stir casting increased with the weight percentage of SiC in the matrix material. Christy et al. [29] found that the hardness and tensile strength of the Al/TiB_2 composite improved due to the addition of TiB_2 in Al. However, the ductility of composites decreased. Ravichandran et al. [30] developed TiO_2-reinforced aluminum matrix composite through the powder metallurgy route. It was reported that tensile strength and hardness of composites improved. Lu et al. [31] fabricated AMCs reinforced with TiB_2 and B_2O_3. They reported that the tensile strength of the TiB_2 reinforced composite was superior to that of the B_2O_3 reinforced composite. Sharma et al. [32] deliberated the impact of the weight percentage of Gr on the mechanical properties of Al/Gr composites. The studies revealed that when the weight percentage Gr in the matrix increased higher than 4%, the hardness and tensile strength of the composite decreased. The composite of 4% graphite reinforcement showed higher mechanical properties than 16% Gr reinforced composite. Al-Salihi et al. [33] fabricated Al 7075/ Al_2O_3 composite with varying percentage of reinforcement. It was found that the strength and hardness of composite enhanced by 34.3% and 26.3% higher than the Al 7075. Kanth et al. [34] fabricated a hybrid composite by reinforcing fly ash and silicon carbide in aluminum. They found that the tensile strength and hardness of fabricated hybrid composite were higher than that of single reinforcement fly ash and SiC composites. Kumar et al. [35] reported that the mechanical properties of Al/ZrO_2 nano-particle reinforced composite increased as the weight of ZrO_2 percentage increased in the Al. Hanizam et al. [36] fabricated CNT reinforced composite and reported that hardness and tensile strength of 0.5 wt. % CNT reinforced composite enhanced 76.3% and 108.4% respectively that of the matrix material. Sharma and Kumar [37] developed Al-6061/Al_2O_3/SiC/CeO_2 hybrid composites. It was found that a hardness of 2.5 wt% (CeO_2 /Al_2O_3 /SiC) reinforced hybrid composite was 17.02% elevated than Al-6061material.The important previous researches' findings is summarized in Table 1.

Table 1 Summary of previous researches

S. no.	Reinforcements/composites/fabrication techniques	Important findings	References
1	Aluminum matrix composites (AMCs)	Mechanical, tribological, corrosion resistance and physical properties of AMCs is higher in comparison with Al and its alloys. It is widely used in automobile and aerospace industries for many applications	[1–7]
2	Reinforcement materials	SiC, SiO_2, Al_2O_3, BN, TiC, TiO_2, TiB_2, ZrO_2, WC, Gr, MoS_2, CNT are the important reinforcement materials used in AMCs. The reinforcement properties and wettability to the matrix material affects the properties of fabricated composites	[8–14]
1	Reinforcement coating	Coating of reinforcement particulates improves its wettability to the matrix material. The wetting agents Mg and Ti are also improves wettability of AMCs	[15–23]
2	AMCs fabrication Techniques	The casting technique is easier and cost effective AMCs fabrication process. The properties of flux-assisted liquid melt fabricated composite showed superior to the composite developed by semisolid stir casting	[24–30]
3	Al/SiC, Al/Al_2O_3, Al/TiB_2, Al/TiO_2, Al/Gr, Al/CNT, Al/ZrO_2 composites	SiC, Al_2O_3, ZrO_2 and TiO_2 increase the hardness of composite. TiB_2 and Gr improve tensile strength and hardness of composite. However, the ductility of composites decreased	[28–30, 32, 33, 35, 36]
4	Al/B_2O_3	The tensile strength of the TiB_2 reinforced composite was superior to that of the B_2O_3 reinforced composite	[31]
6	Hybrid Composite Al/SiC/Fly	Tensile strength and hardness hybrid composite was found higher than that of single reinforcement fly ash and SiC composites	[34]
7	Hybrid composites Al-6061/Al_2O_3/SiC/CeO_2	Hardness of 2.5 wt.% (CeO_2/Al_2O_3 /SiC) reinforced hybrid composite 17.02% higher than Al-6061material	[37]

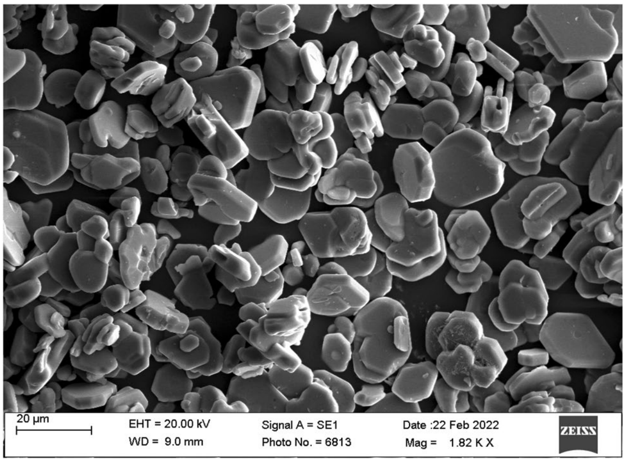

Fig. 1 SEM image of TiB_2 particulate

The literature review reveals that selection of reinforcement in the matrix material is one of the important factors in AMCs to obtain desired properties of material. The TiB_2 reinforcement material is strong and stiff, environmentally friendly aluminum, and does not form any surface compounds on AMCs. In addition, TiB_2 are electrically and thermally conductive [38, 39]. These characteristics of TiB_2 make a better choice as reinforcement in comparison with other reinforcements for making AMCs. In this research, aluminum matrix composites were fabricated by reinforcing varying weight percentage TiB_2 particulates in Al 6063 matrix material through the stir casting process. The effects of TiB_2 on tensile strength and hardness of composites were investigated and reported.

2 Materials and Methods

Al-6063 was used as a matrix material for the development of composites. The main alloying elements and their weight percentage were Al-95.43%, Mn-0.56%, Fe-1.35%, Mg-0.78%, Si-1.85%, and Zn-0.03%. The TiB_2 powder was used as reinforcement. The particle size of TiB_2 was 325 mesh and has 99.9% purity. The scanning electron microscopy (SEM) image of TiB_2 powder is depicted in Fig. 1.

The stir casting process was selected for the fabrication of composites. The main controlling process parameters in this fabrication process were processing temperature, stirring temperature, speed and time, and the temperature of the mold [9, 40, 41]. The composites with a varying weight percentage of TiB_2 were processed by the stir casting process. Firstly, the matrix material (Al-6063) was heated at 850^{O}c using a stir casting setup shown in Fig. 2.

Further, TiB_2 powder was preheated at 350 °C using a muffle furnace to remove moisture [40]. The molten matrix material was cooled to 700 °C and stirred at 350 rpm using mechanical stirring as shown in Fig. 2 and vertex of molten metal was created. The preheated TiB_2 was poured in the vertex of molten metal and stirred for seven minutes continuously. Mg powder of 1% by weight was added and mixed into the molten material to improve the wettability of TiB_2 and fluidity of melt [9, 42]. The wt. % of TiB_2 in matrix material increased from 1 to 3%. The molten mixture was poured into preheated 250 °C cast iron mold [40]. The composition of fabricated composites listed in Table 2.

The tensile testing was performed following the ASTM standard E8/E8M-09. The size of the sample to test tensile strength is shown in Fig. 3. Tensile testing was performed at a constant speed of 5 mm/min at room temperature using a universal test machine (Neelam Engineering Company, Agra, India.). The Charpy test was carried out using a digital impact test (AIT-300D, Fasne Test Equipment Pvt. Ltd, Maharashtra, India). Three samples were tested for each composite. Vickers strength test was performed

Fig. 2 Stir casting setup

Table 2 Composition of Composites

S. no.	Composites
1	Al-6063 + 1% TiB_2
3	Al-6063 + 2% TiB_2
5	Al-6063 + 3%TiB_2

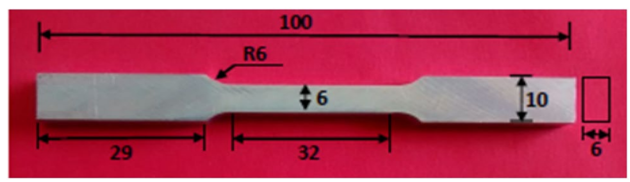

Fig. 3 Specification of tensile testing samples (mm)

with a weight of 5 kg and for the 30 s dwell time. Three readings at different locations in each sample were taken.

3 Results and Discussion

The successful fabrication of TiB_2 reinforced aluminum matrix composites was fabricated. Microstructure analysis is a valuable tool to gain information on how the material was made and the quality of the resulting material. The microstructure of a material can strongly influence physical properties such as strength, toughness, ductility, hardness, corrosion resistance, and wear resistance. The optical microscopy was carried out to observe the microstructure and distribution of TiB_2 particulates in fabricated composites. For the micrographic examination, samples were prepared by cutting the composites followed by grinding and polishing with different grades of emery paper using a double disk metallographic polishing machine. The prepared samples were etched with Keller's reagent for 60 s. The etched samples were washed with distilled water. After that, it was dried and washed with acetone to remove water particles from the samples. The optical micrographics of samples were carried out using Radical Metallurgical Microscope (Model No.RMM-88), Radical Scientific Equipments Pvt. Ltd, Ambala, India at 50× magnification. The image of optical micrographs of 1, 2, and 3% TiB_2 reinforced composites is depicted in Fig. 4. Figure 4 shows the presence and distribution of TiB_2 particulates in fabricated composites. Furthermore, Fig. 4c shows a larger amount of TiB_2 particulates in comparison with Fig. 4a, b. The reason is that, this composite contains a higher weight percentage of TiB_2 in the composite in comparison with others. However, Fig. 4a shows the least amount of TiB_2 particulates. The variations in the number of visible particulates of TiB_2 in composites are due to the varying weight percentage of TiB_2 in composites.

The tensile tests were performed on the samples using computerized UTM at a strain rate of 5 mm/min. The test result of tensile strength and percentage elongation of each category of composite is tabulated in Table 3 and depicted in Figs. 5 and 6. Figure 5 reveals that the tensile strength of fabricated composites improve due to doping of TiB_2 in the matrix material. Furthermore, the tensile strength of composites increases with the percentage weight of TiB_2 increase in the matrix. The maximum tensile strength of 3%

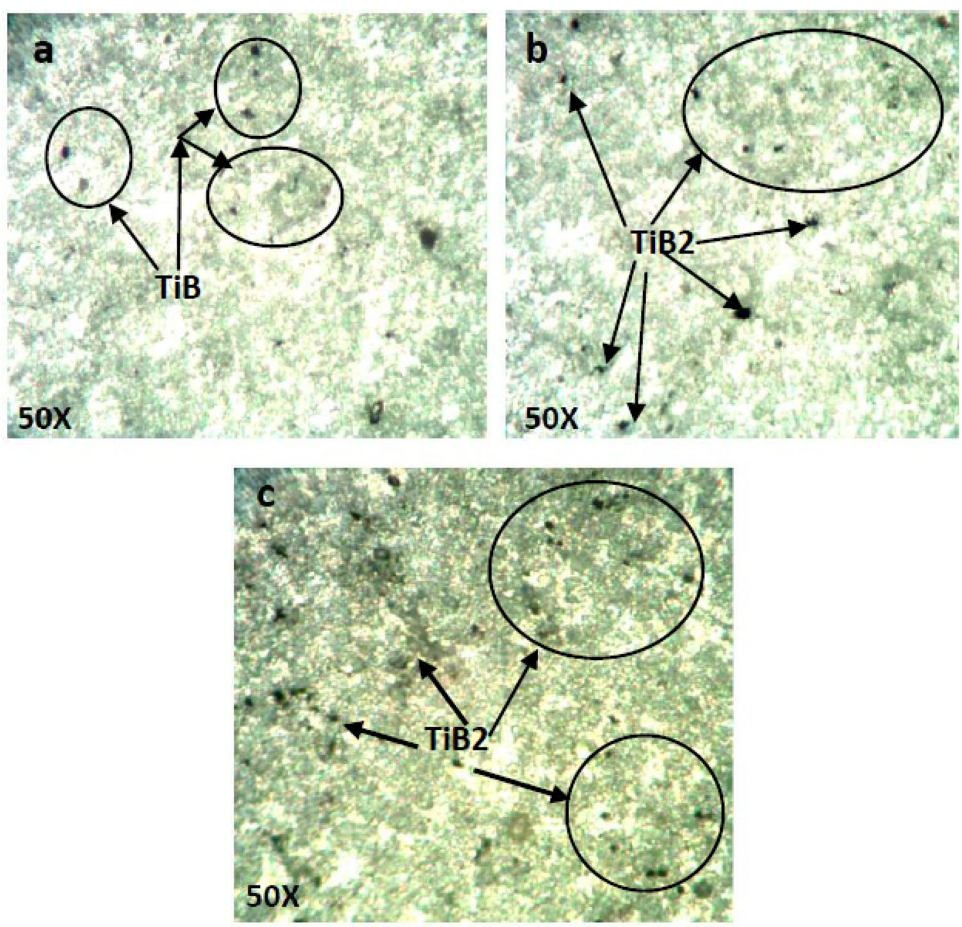

Fig. 4 **a** 1% **b** 2% **c** 3% reinforced composites

Table 3 Tensile strength and % elongation of composites

S. no.	Material	Sample	Tensile strength (N/mm^2)	Mean tensile strength (N/mm^2)	% Elongation	Mean % elongation
1	Al-6063 (matrix)	1	32.54	36.41	09.12	10.24
		2	39.78		11.54	
		3	36.92		10.06	
2	Al + 1%TiB_2 composite	1	42.52	42.02	12.31	11.69
		2	41.33		11.54	
		3	42.21		11.21	
4	Al + 2%TiB_2 composite	1	43.60	45.73	09.20	09.41
		2	49.45		09.71	
		3	44.13		09.32	
6	Al + 3%TiB_2 composite	1	58.36	56.20	07.52	08.36
		2	53.85		08.89	
		3	56.41		08.68	

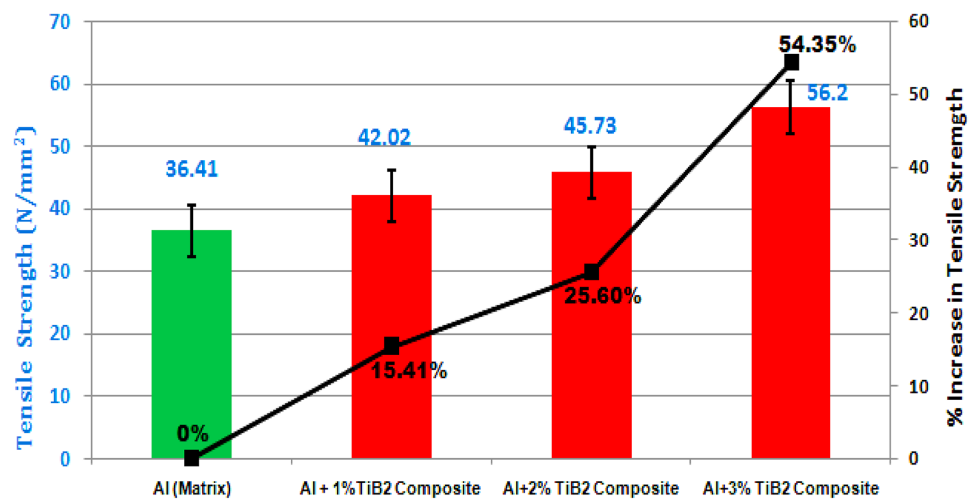

Fig. 5 Tensile strength of composites

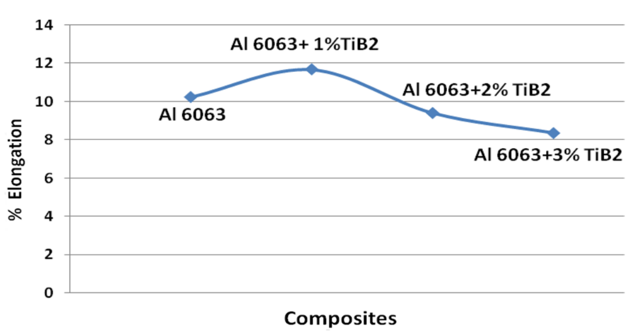

Fig. 6 % Elongation of composites

TiB_2 reinforced composite has been found to be 56.20 N/mm^2 which is 56.35% higher than that of the matrix material. The tensile strength of 1% and 2% TiB_2 reinforced composites have been found to be 42.02 and 45.73 N/mm^2 which are 15.41% and 25.60% superior to the matrix material. Figure 6 shows that the percentage elongation of composites of 1% TiB_2 reinforced composite is higher than that of 2% and 3% TiB_2 reinforced composites. Furthermore, the percentage of elongation of 2% and 3% TiB_2 reinforced composites is lower than the matrix and 1% TiB_2 reinforced composite. The decrease in percentage elongation may be due to brittleness in properties developed because of the higher weight percentage of TiB_2 in composites [9, 12, 38, 42, 43]. The scanning electron microscopy of tested samples was carried out and depicted in Fig. 7. Figure 7a–c shows more ductile and dimple fracture as compared to Fig. 7d. Vickers hardness of composites was measured at three places of each composite and reported in Table 4 and Fig. 8. Figure 8 reveals that doping of TiB_2 in matrix material improves the hardness of composites. The hardness of composites increases with weight percentage doping of TiB_2 in composites. The improvement of hardness in the composite may be due to the reinforcement of hard particulates of

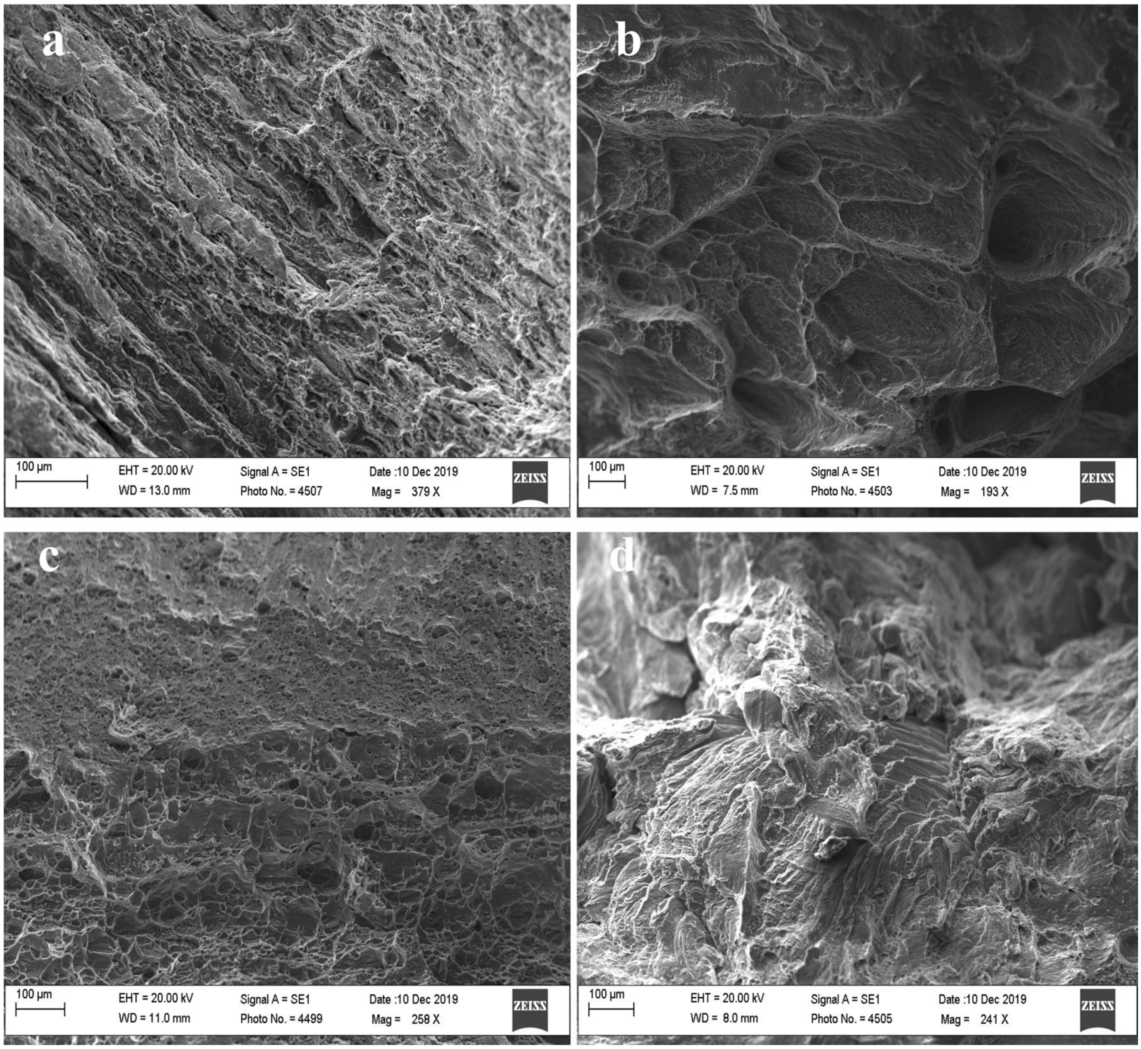

Fig. 7 SEM images of tested samples **a** Al 6063 **b** 1% TiB_2 reinforced composite **c** 2% TiB_2 reinforced composite **d** 3% TiB_2 reinforced composite

Table 4 Testing data of hardness

S. no.	Material	Sample	Hardness (HV)	Mean hardness (HV)
1	Al-6063 (matrix)	1	29.38	29.21
		2	29.72	
		3	28.52	
2	Al + 1%TiB_2 composite	1	35.41	36.66
		2	36.62	
		3	37.95	
4	Al + 2%TiB_2 composite	1	42.39	42.86
		2	42.52	
		3	43.67	
6	Al + 3%TiB_2 composite	1	48.34	47.90
		2	47.12	
		3	48.25	

TiB_2 in matrix material [9, 29, 38, 39]. The hardness of 1%, 2%, and 3% TiB_2 reinforced composites has been found to be 13.65%, 20.26%, and 53.23% elevated than the matrix material. The shorter standard error bars of Figs. 5 and 8 shows that reported data are closely distributed around the average value. Furthermore, the standard error bars of 2% and 3% TiB_2 reinforced composites do not overlap with the standard error bar of matrix material (Al) which indicates that the data reported are statistically significant.

4 Conclusion

1. The successful fabrication of TiB_2 reinforced aluminum matrix composites was fabricated.
2. The doping of TiB_2 in matrix material improved tensile strength and hardness.

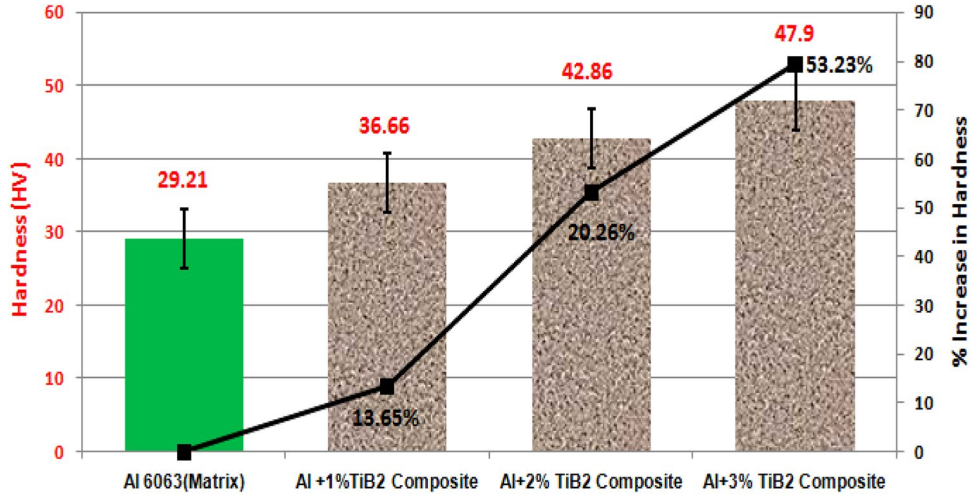

Fig. 8 Hardness of composites

3. The tensile strength and hardness of composites increased with the increase in the weight percentage of TiB_2 in matrix materials.
4. The maximum tensile strength of 3% TiB_2 reinforced composite was found to be 56.20 N/mm^2 which was 56.35% higher than that of the matrix material.
5. The hardness of 3% TiB_2 reinforced composite was found to be 53.23% elevated than the matrix material.
6. Percentage elongation of composites decreased with the increase in weight percentage of TiB_2 in composites.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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