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ORIGINAL RESEARCH

Mechanical and wear behavior of Al 7075/Al_2O_3/SiC/mg metal matrix nanocomposite by liquid state process

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Abstract

Hybrid composites with aluminum matrix and non-metallic reinforcements are identifying extensive applications in automobile, aircraft, and military industries due to their high strength-to-volume ratio, corrosion resistance, excellent machinability, wear resistance, high thermal conductivity, etc. Nanocomposite materials are usually selected for structural applications since they possess desirable association of mechanical properties. The hybrid metal matrix nanocomposite development has come to be the most crucial area of material science engineering. In the present study, the Al 7075 is reinforced with 1.0, 2.0, 3.0, and 4.0 wt.% of (Al_2O_3 + SiC) and 1 wt.% of magnesium (Mg) to manufacture the hybrid composite. Magnesium (Mg) is mainly used to increase the wettability of the nanocomposites. The present research is focused on determining the mechanical and wear properties of Al 7075 in the existence of Al_2O_3 (20–30 nm), SiC (50 nm), and magnesium (micro). The compositions are increased from 1 to 4 wt.%, and stir casting method are used for the fabrication of aluminum metal matrix nanocomposites. The mechanical characteristics of metal matrix composites such as tensile strength, compression strength, and hardness test are studied by carrying out experiments on the computerized universal testing machine and Vickers hardness equipment. The microhardness, compression strength, and tensile strength of aluminum 7075 alloy increases by incorporating $Al_2O_3$and SiC reinforcements. Wear analysis was done to examine the effect of SiC and Al_2O_3 ceramic particles using a pin on disc apparatus. Worn out areas of the specimens were analyzed by SEM, energy dispersive analysis X-ray (EDAX), and XRD analysis.

Keywords Al 7075 · Nano-Al_2O_3 · Nano-SiC · SEM · Wear behavior

1 Introduction

Conventional monolithic materials have constraints in attaining an excellent assortment of hardness, strength, rigidity, durability, and density. To get over these imperfections as well as to fulfill the ever before raising the need for modern technology, composites are one of the most attractive materials. Nanometal matrix composites (NMMCs) have substantially increased properties consisting of high strength, modulus of elasticity, and damping ability when compared with the softer alloys (Al 7075). However, the inadequate ductility and also minimized crack strength restricts the applications of traditional metal matrix composites (MMCs). To enhance the flexibility and even crack hardness of the standard composites, the new course of materials called NMMCs is established by strengthening particles in the nanometer range [1]. Among the variation of fabricating methods offered for intermittent metal matrix composites, stir casting is the commonly used technique because it is a cost-effective method.

In this work, aluminum alloy 7075 is used as a matrix phase. It is strong, with strength comparable with many steels, and has good fatigue strength and good machinability. Its relatively high cost limits its use to applications where cheaper alloys are not suitable. Aluminum 7075 has a density of 2.8 g/cm^3. The addition of high strength, high modulus refractory particles to a ductile metal matrix produce a material whose mechanical properties are intermediate between the matrix alloy and the ceramic reinforcement.

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Nadeem and Kumar [2] researched on the mechanical and tribological behavior of nanoscaled silicon carbide reinforced aluminum composites. In different mechanical properties analyzed, hardness had shown an improvement to around 66% with 2.5% enhancement of nano-SiC filler. Tribological properties, i.e., wear and the coefficient of friction, although revealed improvement by 10% roughly, however, was not monotonic in nature and deteriorated with enhancement past 1.5% of SiC nanofillers by weight. It could be observed that the increment or decrement in various properties with nano-SiC improvement in between 2 and 2.5% does not offer several benefits.

Baradeswaran and ElayaPerumal [3] prepared the Al 7075 hybrid metal matrix composite using stir casting method. The results revealed improvement in tensile strength, hardness, flexural strength, and wear resistance while improving the wt.% of aluminum oxide particles. Pugalenthi et al. [4] produced metal matrix composites based on aluminum including Al_2O_3 and SiC with different weight percentages by using stir casting process. Hardness test and tensile test have been executed making use of the specimens. With the enhancement of SiC and Al_2O_3, the hardness and tensile strength rise while the ductility reduces. The specimen consisting of a maximum proportion of Al_2O_3 (89% of Al7075 + 2% of SiC + 9% of Al_2O_3) displayed the great tensile strength of 403.6 MPa, maximum hardness of 116 VHN, and low elongation value of 2.689%.

Ramakoteswara Rao et al. [5] fabricated AMMCs, Al 7075 alloy chosen as the metal matrix and also reinforcement product as titanium carbide (TiC) (2–10%) having a dimension of 2 μm were improved by mechanical stir casting route. Pin-on-disc apparatus was used for wear mechanism. The rate of wear, friction coefficient, and weight loss were acquired from reinforced and non-reinforced composites. The outcomes indicate good wear resistance compared with base metal. The wt.% of ceramic particles was the most significant requirement influencing the hardness of composites developed by the stir casting method. Therefore, Al 7075 having 8% of TiC fragments revealed the best hardness. By increasing the wt.% of TiC, the wear resistance increases. The improvement of 10% titanium carbide does not progress the wear resistance significantly. The wear price of the composites reduced with raising the weight percentage of titanium carbide (TiC) particulates compared with the base alloy. From the research study, it concluded that Al 7075 reveals greater mechanical and tribological properties.

Senthilvelan et al. [6] were done on the fabrication as well as characterization of SiC, Al_2O_3, and B_4C reinforced Al-Zn-Mg-Cu alloy (AA 7075) metal matrix composites. Al_2O_3 and B_4C are the common enhancing products used in lightweight aluminum matrix composites. Rajmohan et al. [7] revealed the evaluation of mechanical and wear properties of hybrid aluminum matrix composites. A few research studies were carried out on SiC composites as a result of the higher expense of SiC powders. Umanath et al. [8] exposed the analysis of dry sliding wear actions of Al6061/SiC/Al_2O_3 hybrid metal matrix composites. However, SiC is an appealing reinforcement material as a result of its outstanding chemical and thermal stability and excellent bonding properties with aluminum concerning Al_2O_3 and B_4C.Karthikeyan and Nallusamy [9] carried out the investigation on mechanical properties and wear behavior of Al-Si-SiC graphite composite utilizing SEM. Hybrid composites are those composites which have a combination of two or even more reinforcements. Yuan et al. [10] researched the mechanical residential or commercial properties and tribological actions of lightweight aluminum matrix compound enhanced with in situ AlB_2 bits. The measures of hybrid composites are an evaluated amount of the specific elements where there is more constructive stability between the significant advantages and drawbacks.

Ravi Kumar and Dileep [11] analyzed that fabricated composites consisting of 4% Ni and 2, 4, 6, and 8% of SiC as reinforcements in the base matrix of pure Al is efficiently accomplished with loads of 160 kN as well as sintering temperature level was maximized to 530 ± 5 °C. The hardness of the composites enhanced with raising percentage of SiC; optimal rise was acquired for 8% SiC composite, with a rise of 87%. The wear resistance of the compounds enhanced dramatically with the increase of SiC portion. Maximum wear resistance was acquired for 8% SiC composite, with a rise of 90%. The enhancement of SiC to the matrix was hence efficient in increasing the mechanical as well as tribological properties of pure Al.

The main objective of the study presented in the work is to explore the opportunity of incorporating the nano-Al_2O_3 and nano-SiC powder with Al 7075 alloy to develop a lightweight hybrid metal matrix nanocomposite materials. Specific interest is provided to define the mechanical properties and wear behavior of the metal matrix composites.

2 Selection of materials

Al 7075 having a density 2.8 g/cc, ultimate tensile strength 572 Mpa (T6 condition), and Young's modulus 72 GPa was used as a matrix material. 7075 is an aluminum alloy, consisting of zinc as its primary alloying component. It possesses essential applications in automobile, aerospace, military, and marine sectors. The combination of $Al_2O_3$and SiC particles made use of the secondary reinforcement material. Four different weight percent of nano-$Al_2O_3$and nano-SiC (1.0%, 2.0%, 3.0%, and 4.0%) and the fixed weight percent of micro Mg (1.0%) were chosen in the experiments [12]. The metal matrix and also nanoreinforcement material properties are shown in Tables 1 and 2.

Table 1 Chemical composition of Al 7075

Al7075	Zn	Mg	Cu	Fe	Cr	Mn	Si	Ti	Others	Al
% composition	5.9	2.1	1.4	0.2	0.19	0.05	0.052	0.047	0.025	Remainder

The stir casting method was carried out for the fabrication of the nanocomposites. The cast specimens were distinguished mechanically by performing tension test (ASTM E8), compression test (ASTM E 9), and hardness test (ASTM E92-17). Tensile and compression examinations were carried out on universal testing equipment, and hardness examinations were executed on the Vickers hardness machine. SEM was accomplished to review the reinforcement of ceramic particle diffusion in the composites. Energy dispersive spectroscopy (EDS) record was made use of to identify the numerous elements existing in the different sections of the sample [13].

3 Experimental procedure

The experimental arrangement for fabricating the hybrid composites is shown in Fig. 1. The setup comprises of melting furnace, preheated furnace, and three-bladed stainless steel stirrer coated with alumina. The graphite crucible selected for melting the lightweight aluminum. Aluminum alloy 7075 was dissolved in the electric furnace at 650 °C and the preheated nano-Al_2O_3 and nano-SiC (900 °C) and 1 wt.% of magnesium slowly incorporated into liquefied metal [14]. The metal mixing went through for stirring at about 10 min. Soon after, the liquefied fluid slurry poured into the preheated metal died. Aluminum matrix composites with various wt.% of nano-Al_2O_3 and nano-SiC were made, including 0, 1, 2, 3, and 4. The mechanical characteristics such as the tensile test, compressive test, and microhardness specimens were prepared as per ASTM standards. The microstructure of the composites is executed through SEM, energy dispersive analysis X-ray (EDAX), and XRD evaluation.

4 Results and discussions

4.1 Tensile test (ASTM E8)

According to ASTM E8 standard, the ultimate tensile strength was examined on the rectangular rod of casted composites. The fine grit grinding mesh paper was used to brighten the test samples to reduce the machining scrapes and the impacts of surface area flaws on the specimen. The computerized universal testing machine (UTM) loaded with 50 kN load applied to perform the tensile test. Figure 2 depicts the effect of nanosized Al_2O_3 + SiC on the tension behavior of Al 7075/Al_2O_3/SiC metal matrix nanocomposites (MMNCs). It is apparent that by enhancing the nanoparticles proportions up to 4 wt.%, the ultimate tensile strength (UTS) increases. The ceramic nanoparticles interrelate with dislocations that lead to raising the tensile strength [15].

The average value of UTS of base Al 7075 alloy and Al 7075/4.0 wt.% of (Al_2O_3 + SiC) MMNC are 269 MPa and 462 MPa, respectively. The increase in the ultimate tensile strength of MMNC is almost 72% when compared with the base alloy.

4.2 Compression test (ASTM E9)

The compression test was carried out on five specimens by a computerized universal testing machine (UTM) at ambient temperature. The significant compression strength of casted samples was determined according to ASTM E9 standards. Because it is an automated machine, the compressive strength was captured precisely.

The significance of nanoreinforcement on the compression test of the Al7075/SiC/Al_2O_3 composites is shown in Fig. 3. As the wt.% of nano-(Al_2O_3 + SiC) in the metal matrix is improved up to 4%, the compression strength increases [16]. The reason is a uniform distribution of nanoceramic particles in Al melt. The rise in compression strength value is 30 when compared with base Al 7075.

4.3 Microhardness (ASTM E92-17)

The microhardness testing was measured as per ASTM E92-17standards using Vickers hardness testing equipment with a 10-mm ball indenter and 50-kg load for dwell time 10 s. At room temperature, the evaluation was conducted, and the hardness measurement was taken at four distinct locations

Table 2 Physical properties of nano-Al_2O_3 and nano-SiC

Material	Density (gm/c^3)	Melting point temp(°C)	Young's modulus (GPa)	Thermal conductivity (W/m K)	Thermal expansion (10^{-6}/K)
Al_2O_3	3.95	2075	413	38.4	10.8
SiC	4.2	1682	137	20.5	11

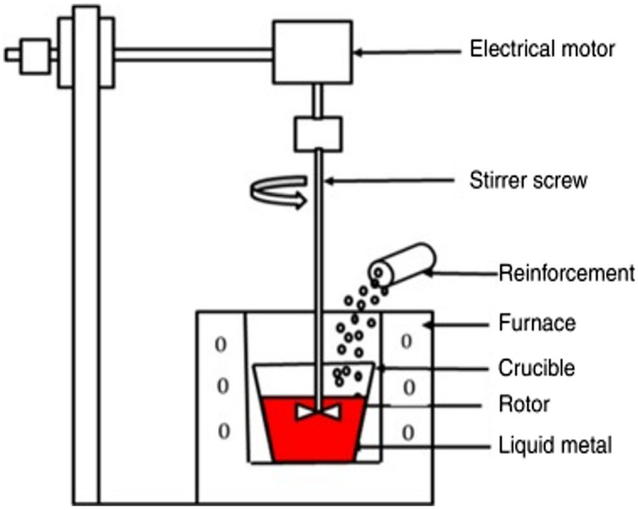


Fig. 1 Stir casting setup

on every specimen to acquire mean average hardness value [17, 18].

The impact of nano-Al_2O_3 and nano-SiC on the hardness character of Al7075/Al_2O_3/SiC composites is shown in Fig. 4. Addition of ceramic particle weight percentage slowly and gradually improves the hardness of the nanocomposite. For contrast, base AA7075 alloy has a hardness value of 90 BHN and 1.wt.% of (Al_2O_3 + SiC) nanoparticle-reinforced MMNC has a hardness value of 110 BHN.

The existence of nano-Al_2O_3 and SiC, their great bonding with aluminum, and the uniform blending of Al_2O_3 and SiC in the Al matrix by adding 1 wt.% of Mg increased, the hardness of the nanocomposites. The included nanoparticles avoid the motion of dislocations which consequently increases the hardness.

5 Wear behavior

5.1 Specific wear rate

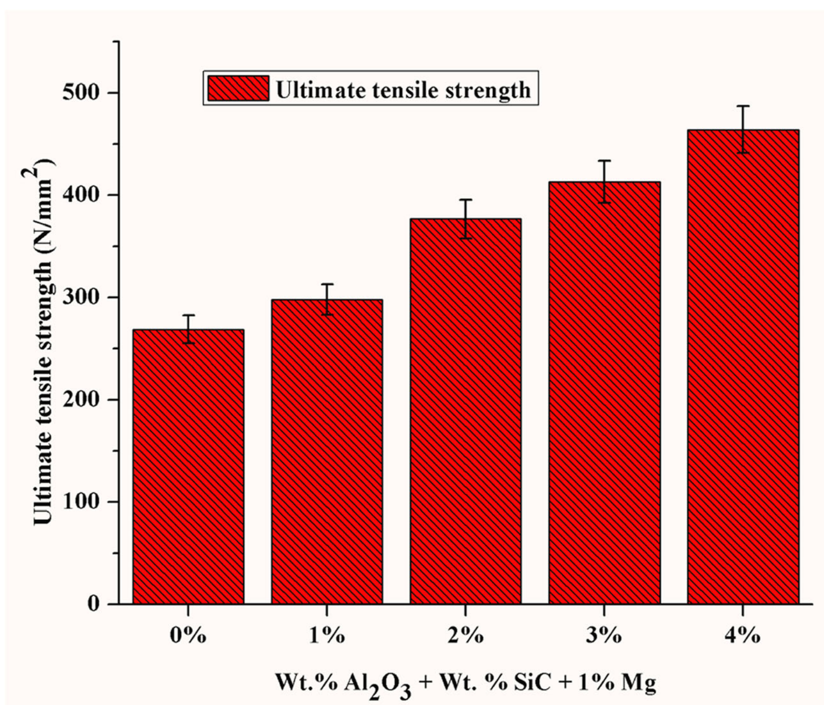
The volume of wear generated depends on the load applied, sliding velocity, sliding distance, and environment. The samples were made with the size of 6 mm diameter and 30 mm length as per ASTM G99-95 specifications. Wear tests on reinforced specimens and unreinforced Al 7075 alloy are performed under a dry sliding condition under three different applied loads of 20, 30, and 40 N under two different sliding velocities of 2 and 4 m/s for all samples [6].

The specific wear rate of Al 7075 and reinforced composites is shown in Fig. 5. By adding the wt.% of nano-(Al_2O_3 + SiC) particles in the melts, the wear rate is reduced and at 4 wt.% the specific wear rate is minimum as compared with the remaining compositions. The reason is due to the incorporation of hard nanoreinforcement particles causing improvement in the hardness and decrease in the physical area of contact and as a result of that the specific wear rate decreases.

5.2 Coefficient of friction

Figure 6 reveals the difference in the coefficient of friction with a weight percentage of reinforcement. It is identified

Fig. 2 wt.% of nanoreinforcement vs. UTS



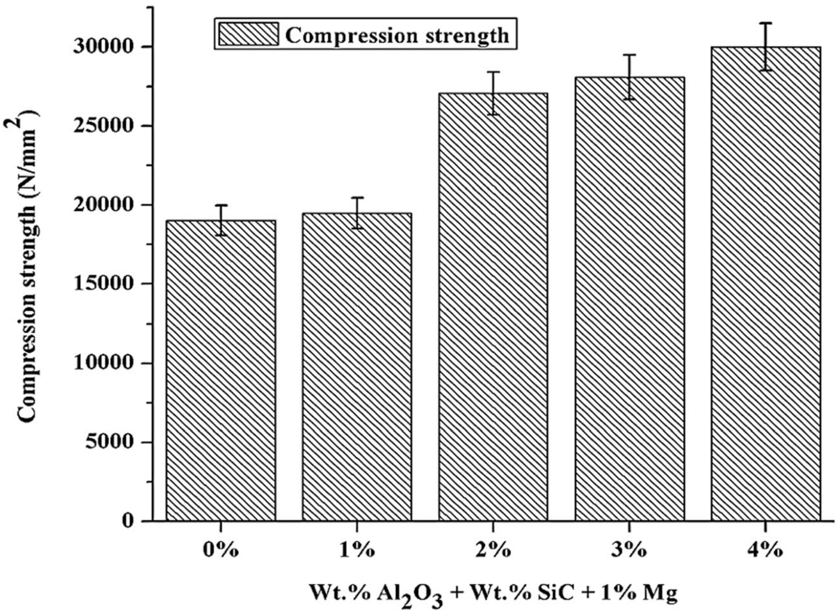


Fig. 3 wt.% of nanoreinforcement vs. compression strength

that the coefficient of friction decreases with increasing wt.% of Al_2O_3 + SiC via 1, 2 ,3 , and 4% for both 2 and 4 m/s sliding velocity. The effect of Al 7075/Al_2O_3/SiC hybrid composite reduces the coefficient of friction [19]

5.3 Weight loss

Figure 7 indicates the influence of the weight percentage of Al_2O_3 + SiC particles on weight loss. It reveals that the weight loss of the composites decreases gradually with increasing applied loads of 20, 30, and 40 N, respectively. The decrease in weight loss of composites is due to the reinforcement of nanoparticles; a hard reinforcement in a soft pattern improves the hardness, and thus the weight loss of the matrix alloy is reduced [20].

6 Microstructural evaluation

The composite specimens of dimensions with a 2-mm diameter and 10-mm thickness were cut for microstructural studies of unreinforced and reinforced samples. The samples were polished with SiC grit papers manually using standard metallographic process. After cleaning, the specimens were etched with Keller's reagent earlier to their microstructural examination by SEM (Scanning Electron Microscopy) [1].

Figure 8a–e displays the scanning electron micrographs of worn surface composites. It shows the reasonably homogeneous distribution of alumina and silicon carbide particles in the composites. The process parameters, such as stirring speed and time, cause good bonding between metal and matrix. Minimum scratches and grooves are observed. Sozhamannan's [21]

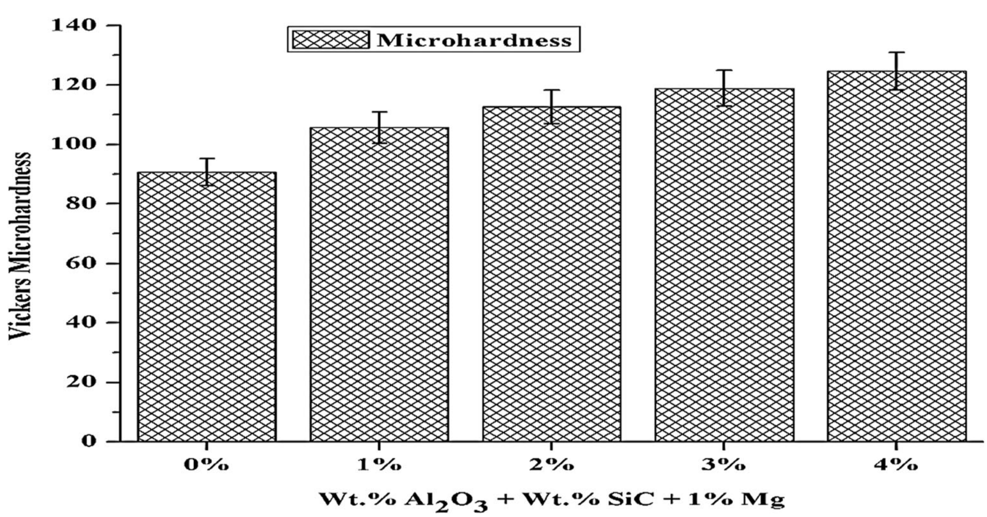


Fig. 4 wt.% of nano-reinforcement vs. Microhardness values

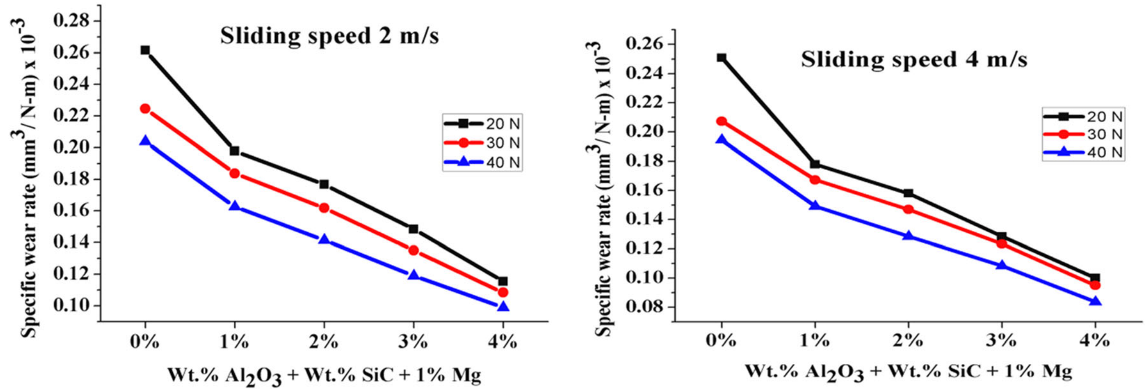


Fig. 5 wt.% of reinforcement vs. specific wear rate at sliding speed 2 and 4 m/s

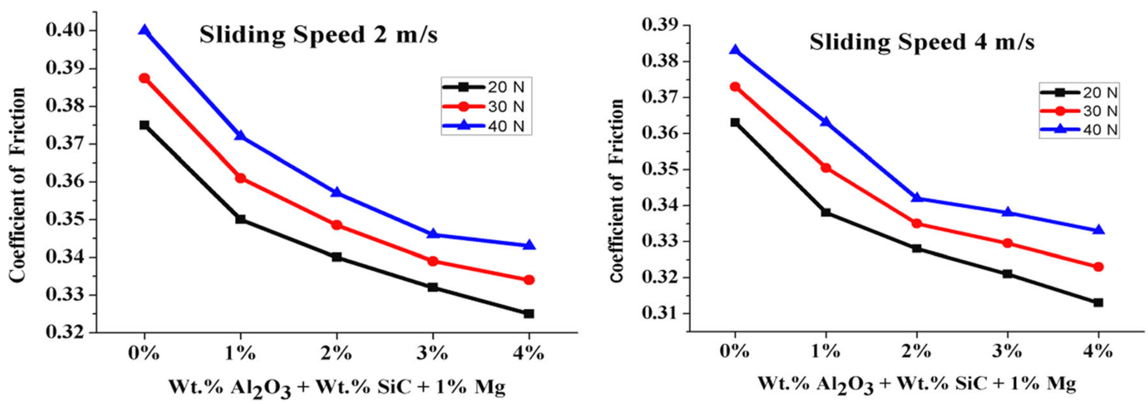


Fig. 6 wt.% of reinforcement vs. coefficient of friction at sliding speed 2 and 4 m/s

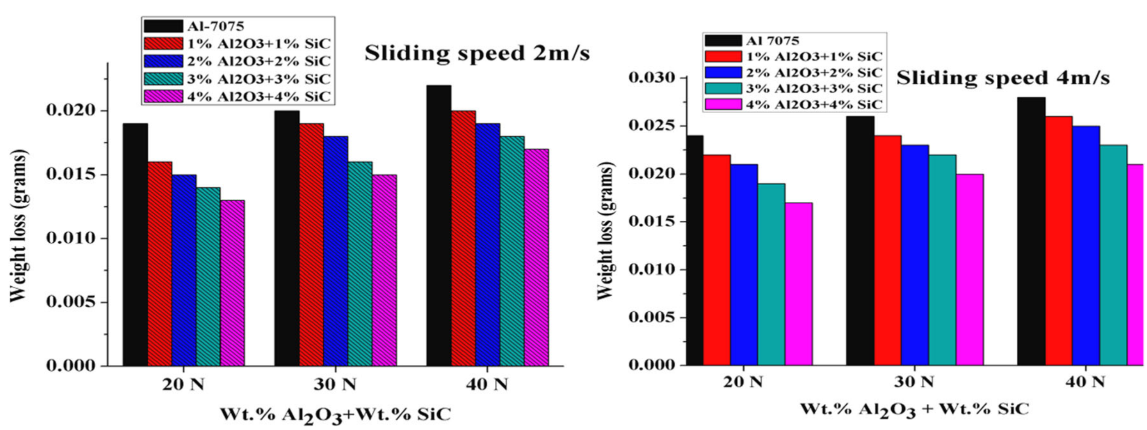


Fig. 7 Load vs. weight loss at a sliding speed of 2 and 4 m/s

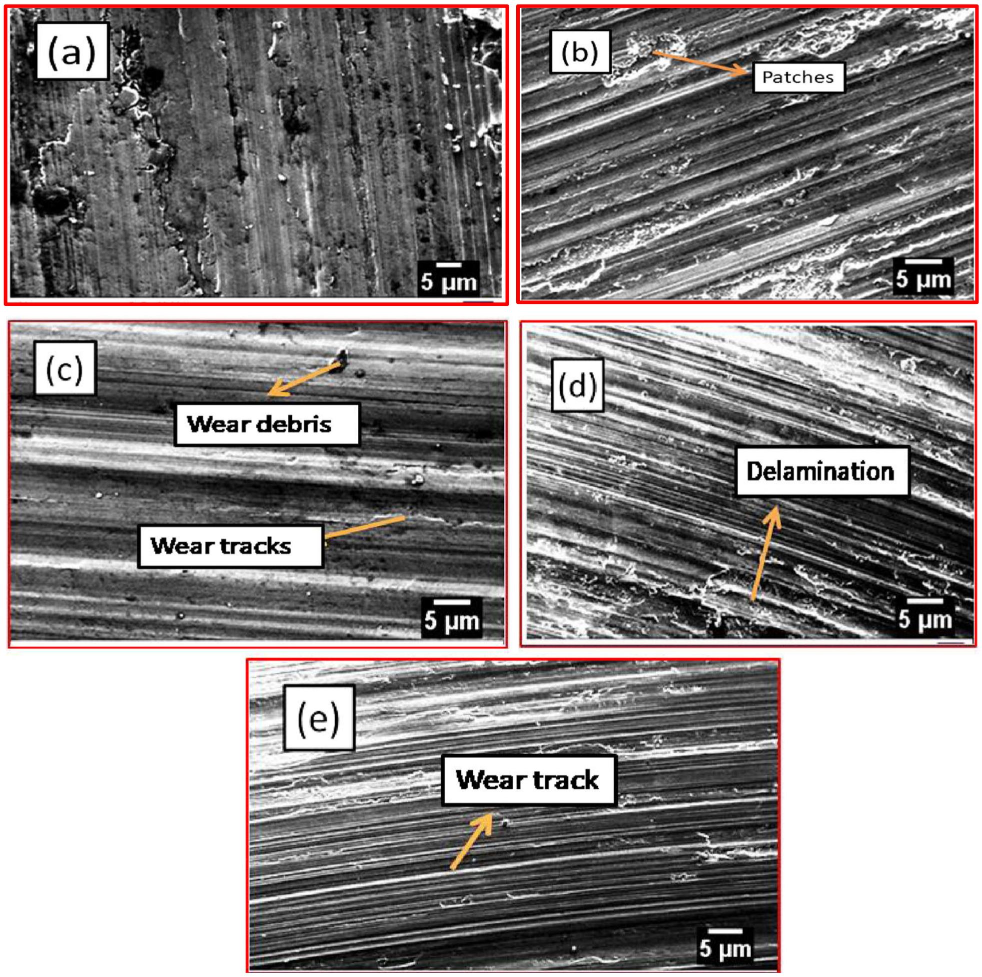


Fig. 8 SEM analysis of **a** pure Al 7075, **b** 1%(Al_2O_3 + SiC), **c** 2%(Al_2O_3 + SiC), **d** 3%(Al_2O_3 + SiC), and **e** 4%(Al_2O_3 + SiC)

investigational effort concentrated the effect of stirring time and processing temperature on Al-11Si-Mg alloy reinforced by silicon carbide particles (SiCp). The samples were ready at 700 °C, 750 °C, 800 °C, 850 °C, and 900 °C. In the samples prepared at 850 °C and 900 °C, particle clustering and pores were observed. High strengths are developed up to 800 °C and after that start decreasing. Bhushan et al. [22] determined that with the rise in stirring speed from 180, 250, 400, and 1400 rpm the mechanical properties such as impact strength and hardness are improved for Al alloy MMCs, and he suggested that it could be due to extra power applied by the stirrer at higher rpm. Based on literature review, stirring speed and pouring temperature play a key role in the homogeneous distribution of matrix and reinforcements.

Generally, the wettability between liquefied matrix materials and ceramic particles has actually been poor. In order to increase wettability, mechanical energy might be employed to get rid of surface tension. An equiaxed type was attained from dendrite structure because of mixing of the melt prior to and after presenting particles. It increases the wettability and integration of nanosized particles inside the melt. It concludes that nanoparticles are distributed homogeneously in the matrix. Superior interfacial bonding is achieved among the reinforcements and matrix due to the incorporation of 1 wt.% of magnesium in smaller amounts at the time of stirring which increases the wettability. Additionally, the microstructural analysis (SEM) exposed the uniformity of the nanocomposites.

6.1 SEM morphology

A scanning electron microscope was employed to analyze the surface of the as-cast specimens. It can be observed from the SEM image in Fig. 9. Figure 9a–e shows that reinforcement particle such as Al_2O_3 and SiC are distributed evenly throughout the specimen. Clustering of the reinforcement particles was not seen in the composites. Hence, the stir casting method helps in attaining the uniform distribution of reinforcement particles in the Al alloy matrix.

6.1.1 XRD analysis

XRD patterns of the 7075 Al alloy reinforced with 1.0, 2.0, 3.0, and 4.0 wt.% Al_2O_3/SiC are shown in Fig. 10. In XRD, the physical content of the constituents present in the

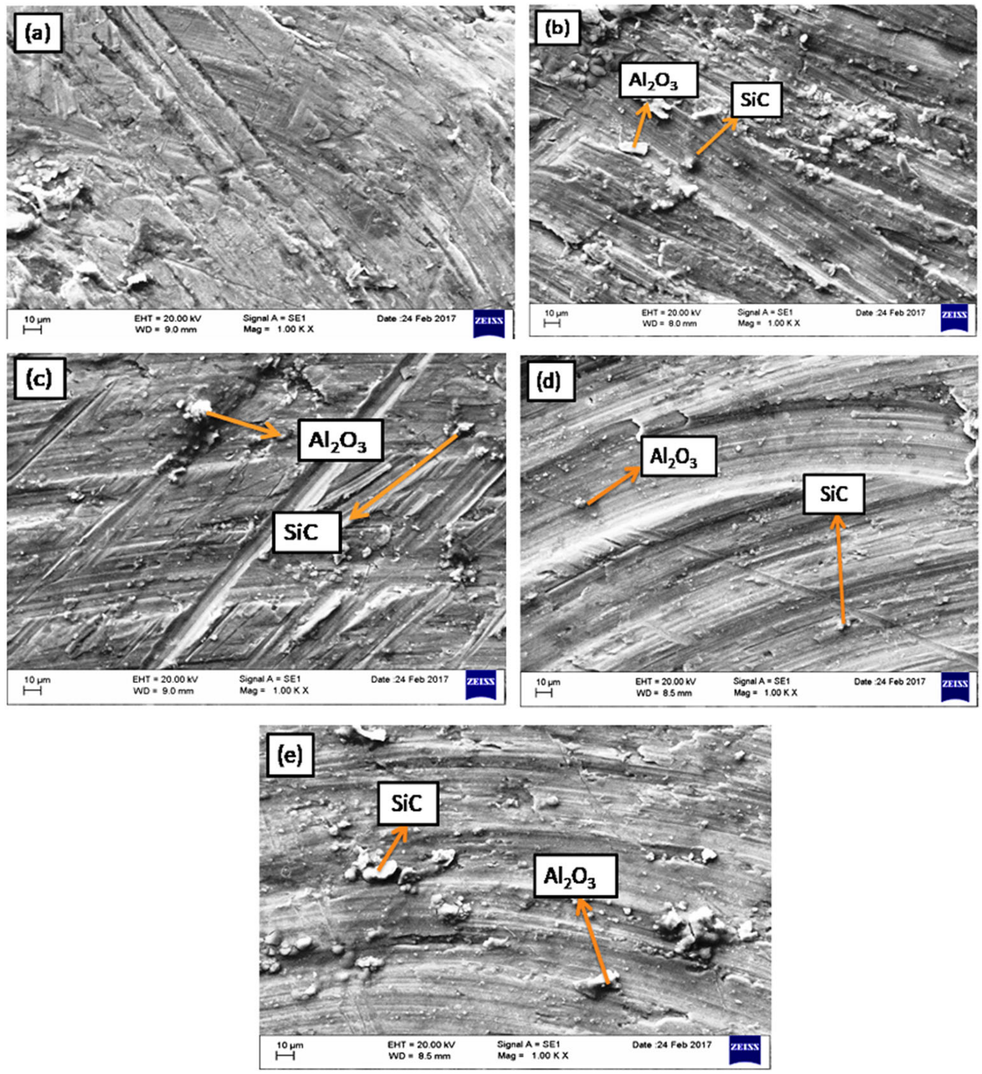


Fig. 9 SEM morphology analysis of **a** pure Al 7075, **b** 1%(Al_2O_3 + SiC), **c** 2%(Al_2O_3 + SiC), **d** 3%(Al_2O_3 + SiC), and **e** 4%(Al_2O_3 + SiC)

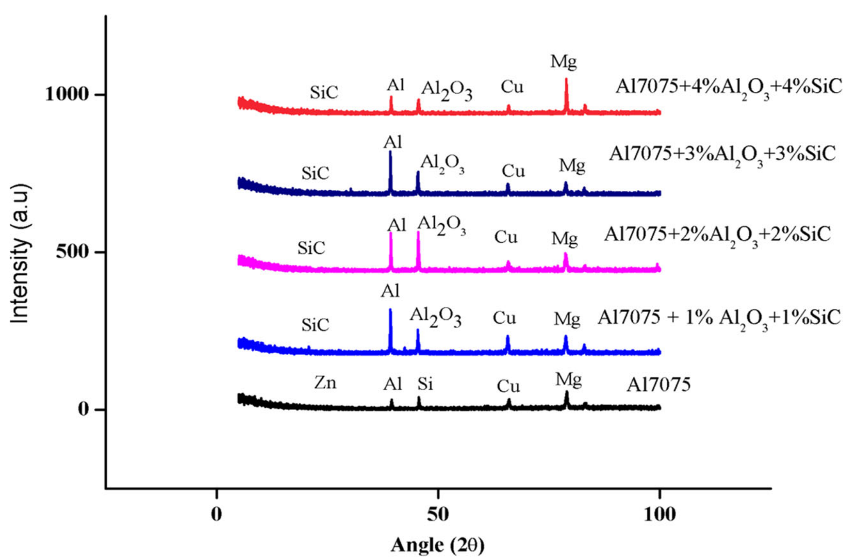


Fig. 10 XRD analysis of **a** Al 7075, **b** 1% (Al_2O_3 + SiC), **c** 3% (Al_2O_3 + SiC), and **d** 4% (Al_2O_3 + SiC)

samples are indicated in the form of graphs. With the help of Powder X software, the XRD graphs are compared with various JCPDS cards. Figure 10 proves the presence of reinforcements in matrix alloy. The XRD pattern confirmed the presence of Al matrix; Al_2O_3 and SiC particulate in the composite. It reveals the composite having cubic structure. The four strong peaks in all patterns are identified whose 2θ values are around 38.95°, 45.306°, 60.02°,and 78.306° respectively.

7 Conclusions

In the present work, research on the mechanical and wear properties of Al 7075/Al_2O_3/SiC was done. The Al 7075 alloy reinforced with 1.0, 2.0, 3.0, and 4.0 wt.% of nano-(Al_2O_3 + SiC) composites has efficiently manufactured by stir casting process. Alloying of Al matrix with 1 wt.% Mg and its segregation at the interfaces has been found to be effective in restricting the formation of the Al_4C_3 at the interfaces during casting. Oxidation of reinforcement particles has prevented/restricted the chemical reaction at interfaces. The compressive strength, ultimate tensile strength (UTS), and hardness values increase by increasing the weight percentage of nano-$Al_2O_3$and nano-SiC reinforcement. SEM examination of Al alloy and its nanocomposites produced under optimum conditions mentioned above show that distribution of reinforcement particles is homogeneous; reactions on the SiCp/matrix interface are not observed. The mechanical behavior of the composites increases with increasing wt.% of nano-(Al_2O_3 + SiC) when compared with the unreinforced alloy. XRD analysis clearly shows the presence of elemental composition and also the presence of Al, Al_2O_3, and SiC in the composite. Al 7075/Al_2O_3/SiC indicates good wear resistance compared with the Al 7075 alloy. However, increasing the weight percentage of nanoreinforcements improves the wear resistance. By increasing applied loads from 20 to 40 N, the weight loss of the composite increases. Hybrid metal matrix nanocomposites exhibit a significant decrease in friction coefficient and wear rates with an increase in the wt.% of reinforcement particles.

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Compliance with ethical standard

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

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