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ORIGINAL CONTRIBUTION

Mechanical Properties of AA 7075/Al_2O_3/SiC Nano-metal Matrix Composites by Stir-Casting Method

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Abstract Demand rises in a worldwide series of the new materials at national and international level. The metal matrix nano-composites are extremely beneficial in several applications such as aerospace, automobile, armed forces, and other commercial applications due to lightweight and cost-effective. In the present study, three various hybrid compositions, namely nano-Al_2O_3 (20–30 nm), nano-SiC (50 nm), and Mg 1 wt% (fixed), were used as reinforcement materials. Magnesium is to enhance the wettability of Al_2O_3 and SiC particles in the Al matrix. The compositions are executed at 1.0, 2.0, 3.0, and also 4.0 weight % of nano-Al_2O_3 and nano-SiC. The cast samplings undertake the tests like heat treatment, microstructural examination, density, tensile, hardness, impact, SEM, EDAX, and XRD analysis. SEM images subject that the nanoparticles relatively disperse as well as attain fine grain microstructure in the matrix. The results reveal that the reinforcement of nanoparticles in Al 7075 matrix substantially increases the mechanical behaviour when compared to base metal.

Keywords AA 7075 · Nano-materials · SiC · Al_2O_3

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Introduction

Aluminium alloy nano-composite is useful in the aerospace, automobile, defence, and structural applications. The hybrid nano-composites have distinct properties. In the manufacturing process, different ceramic powders such as boron carbide, zirconia, aluminium oxide (Al_2O_3), and silicon carbide (SiC), are added to the lightweight aluminium alloy to enhance the mechanical properties. The hybrid composites have been established lately with increased mechanical properties. The present research reported the constant blending, along with the good wetting by using the parameters such as stirring time, rate, and temperature. Among several manufacturing procedures, the standard stir casting is an enticing technique for producing AMMCs which is relatively inexpensive. In various reinforcements, silicon carbide in addition to Al_2O_3 is chemically proper for lightweight aluminium as well as provides an ideal bonding with the matrix [1]. Faisal and Kumar et al. [2] made an experimental test on the mechanical and tribological behaviour of nano-scaled silicon carbide-reinforced aluminium composites. In different mechanical properties analysed, hardness had shown an improvement to around 66% with 2.5% enhancement of nano-SiC filler. For tribological properties i.e. wear and coefficient of friction, although showed betterment by 10% approximately, however, was not monotonic and deteriorated with enhancement past 1.5% of SiC nano-fillers by weight. It could be observed that the increment or decrement in various properties with nano-SiC improvement between 2% and 2.5% does not offer several benefits.

Pugalenthi et al. [3] produced metal matrix composites based on aluminium 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 sample consisting of maximum proportion of Al_2O_3 (89% of Al 7075+2% of SiC+9% of Al_2O_3) displayed the high tensile strength of 403.6 MPa and also the maximum hardness of 116 VHN as well as low % of elongation worth of 2.689%.

Ramakoteswara Rao et al. [4] create AMMCs, Al 7075 alloy chosen as the metal matrix and also reinforcement product as titanium carbide (TiC) (2–10%) having a dimension of 2 microns, were improved by electric stir-casting path. 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 to base metal. The wt% of ceramic particles was the most significant requirements influencing the hardness of composites developed by stir-casting treatment. 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 to the base alloy. From the research study, it is concluded that Al 7075/TiC reveals greater mechanical and tribological properties.

Bandhu and Thakur [5] investigated the Al 7075 alloy-based particulate-reinforced matrix composites have been effectively fabricated by stir-casting route. Different mechanical properties such as tensile strength, hardness, and impact toughness of the produced samples were determined. He reported that due to complicated designed products and very high particulate loading, the stir-casting route possesses an additional advantage rather than some other manufacturing techniques. The microhardness of particle-reinforced MMCs is superior than that of unreinforced Al 7075 alloy. The tensile examination explored that Al 7075/15wt% B_4C has superior UTM of 261 MPa while contrasted to other reinforced composites. Al 7075/15wt% B4C composite shows improved hardness values of 174 BHN when contrasted to the further ceramic composites.

Baradeswaran et al. [6] prepared the Al 7075 alloy hybrid MMCs using stir-casting route. The outcomes revealed enhancement in tensile strength, hardness, flexural strength and wear resistance while improving the wt% of aluminium oxide particles.

Kumar and Dhiman [7] investigated the details of wear rate of the Al 7075 hybrid Al MMCs strengthened by 7 wt% of silicon carbide (SiC) and 3 wt% of graphite as well as recognised that the wear rate elevates with increasing applied loads. Sherafat et al. [8] gave the physical and mechanical characteristics of the Al 7075 and identified that compression and tensile strength improved were as ductility reduced while decreasing base powder.

Ranganathan and Madhankumar [8] studied that Al 5052/SiC MMCs were successfully made. The hardness of the MMC is located to be maximum for 4% SiC. The tensile strength of the MMC is found to be maximum for 4% SiC. MMC with 4% SiC is identified to be the most effective product based on the characterisation of the mechanical properties.

Pradeep et al. [9] analysed mechanical behaviour of Al 7075/SiC metal matrix composites by varying weight fraction of composition such as Al 7075/8wt% SiC, Al 7075/6wt% SiC, Al 7075/4wt% SiC, Al 7075/2wt% SiC through stir-casting technique. The experimental test outcomes report that the incorporation of a silicon carbide (SiC) reinforcement content by matrix material improves yield strength, compressive strength, hardness, and UTS.

The primary objective of the research work is to evaluate the mechanical characteristics of Al 7075 alloy enhanced with three sorts of ceramic reinforcements, viz. SiC (50 nm), Al_2O_3 (20–30 nm), and 1 weight % of Mg (micro). The tensile, hardness, and impact strength outcomes are much better when compared to a non-reinforced matrix metal. The tensile toughness of the metal matrix nano-composite samplings is tested under the automated universal testing machine, and a hardness test is performed on a Vickers hardness machine. The microstructures of the composites are analysed by utilising the optical microscopic lens, scanning electron microscopy (SEM), EDAX, and XRD.

Experimental Work

Material Selection

Al 7075 is chosen as the base metal, and it is bought from Mr Aluminium Enterprise, Bangalore. The chemical composition of AA 7075 was assessed utilising the optical emission spectrometer (Shimadzu, Japan, Model: TDA-700) at Chennai, and its values are shown in Table 1. The nano-reinforcement material is selected as Al_2O_3 (20–30 nm), SiC (50 nm), and Mg (microns), and their properties are given in Table 2.

Fabrication Procedure

The stir-casting equipment used for this study which is located at Karunya University, Coimbatore, is utilised for this experimental work. The dimension of the mould used for casting is 100 × 100 × 10 mm. The raw products used

Table 1 The chemical composition of Al 7075 alloy

Al 7075	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	Reminder

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

Material	Density (g/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

Table 3 Specifications of stir-casting machine

Make Swamequip	
Capacity	2 kg
Operating temperature	100–1500 °C
Operating voltage	440 V, 3 phase

for carrying out this work are as follows. The specifications of the stir-casting machine are shown in Table 3

- Matrix material: AA 7075
- Reinforcement materials: nano-SiC (50 nm) and nano-Al_2O_3 (20–30 nm)
- Surfactant: Mg powder (microns)
- Crucible: graphite crucible
- Stirrer: stainless steel stirrer

Aluminium 7075 alloy melts in a graphite crucible in an electrical resistance heater. The preheated nano-Al_2O_3 and nano-SiC (900 °C) and 1 weight % of Mg added to the graphite crucible [10]. After that, the slurry is mechanically mixed utilising a three-bladed stainless steel stirrer continually for 5 min at 650 rpm (semi-solid mixing). In the meanwhile, the composite slurry is poured into the preheated metallic mould and allowed for solidification. Finally, the composite specimens removed after 3 min. The same procedure fabricated aluminium matrix composites with various weight portions (1, 2, 3, and 4 wt%) of nano-Al_2O_3 and nano-SiC. After that, casted specimens are cut as per ASTM standards [10, 11]. The process parameters followed during casting are shown in Table 4.

Table 4 Process parameters during stir casting

Stirring speed	650 rpm
Preheat temperature	900 °C
Stirring temperature	750 °C
Stirring time	5 min

Heat Treatment

T6 heat treatment is used for aluminium alloys to improve their mechanical properties. Muffle furnace equipment is used for carrying out this work. Here the heat treatment is done at 530 °C for 2 h, complied with by water quenching, along with ageing treatment did at 200 °C for 6 h. Before heat treatment, casted samplings initially cut according to ASTM specifications using wire-cut electric discharge equipment [12, 13].

Results and Discussion

Density Measurement

Density plays an essential feature in composite product study. As this material has a range in the automobile sector and also in the aerospace field, they need to be of lightweight. Integrating some strengthened products like nano-lightweight aluminium oxide along with nano-silicon carbide decreases the density of composites. The Archimedes principle that is splitting the mass of a specimen by the quantity displaced by that specimen in the water beaker is used to compute density [14]. The theoretical and experimental density is shown in Fig. 1.

$$\rho_c = \frac{1}{\left(\frac{W_{Al}}{\rho_{Al}}\right) + \left(\frac{W_{Al_2O_3}}{\rho_{Al_2O_3}}\right) + \left(\frac{W_{SiC}}{\rho_{SiC}}\right) + \left(\frac{W_{Mg}}{\rho_{Mg}}\right)}$$

Tensile Test

The tensile properties of the Al 7075 alloy and its composites is examined on a computerised universal testing machine of 50KN capacity. By utilising software programme throughout the examinations displayed stress and strain information and noted the same. And this record is

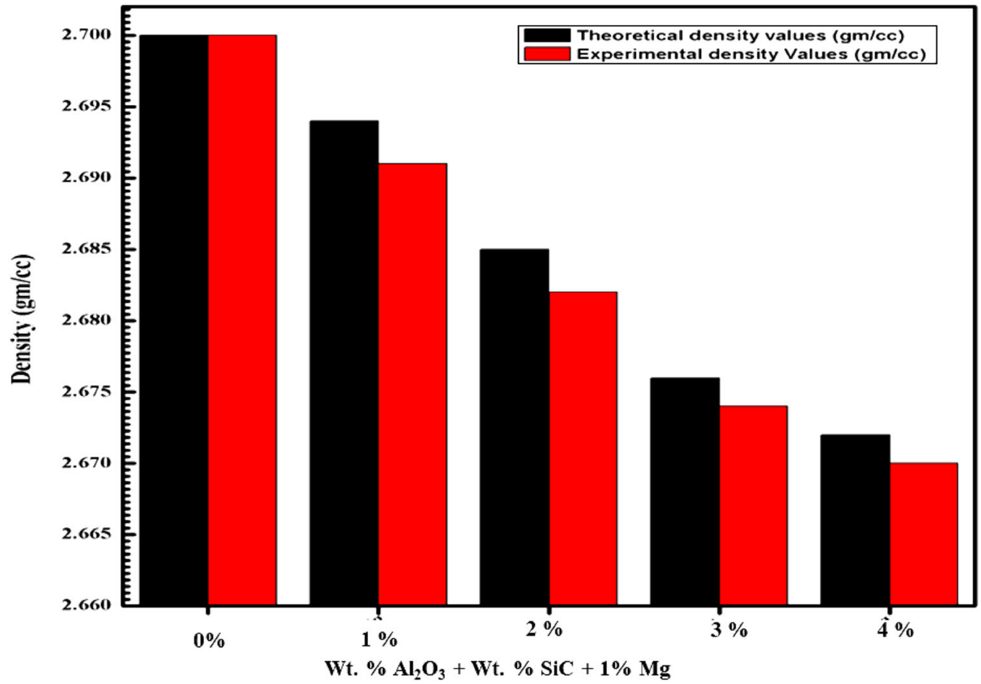

Fig. 1 Density measurement for different wt% of compositions

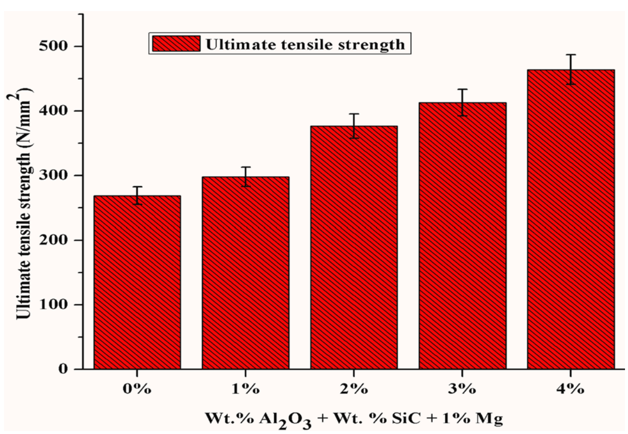

Fig. 2 Wt% of nano-reinforcement versus UTS

assisted for more evaluation. The specimens are prepared as per ASTM E8 standards for the testing of the product. The size of the samples was taken as 100 × 100 × 10 mm.

Figure 2 reveals the variant of tensile strength of the composites with the various weight portions of Al_2O_3 (20–30 nm) and SiC (50 nm) particulates. It was found that the tensile strength enhanced with a rise in the weight portion of Al_2O_3 and SiC. The aluminium oxide and silicon carbide fragments act as obstacles to the misplacements when taking up the loads used. The difficult reinforcement particles block the progressing misplacement front, therefore enhancing the matrix. Excellent bonding of smaller-sized dimension reinforcement fragments with the matrix is the factor for these actions. The observed enhancement in tensile strength of the composite is credited to the fact that the filler Al_2O_3 and SiC possess greater strength [15].

Percentage of Elongation

From the report of Fig. 3, it can be observed that with increasing of wt% of Al_2O_3 and SiC reinforcement, the percentage of elongation for AMMCs decreases. From the figure, it can be identified that when compared to unreinforced alloy the percentage elongation of the composites is minimum.

Compression Test

The examinations disclosed that the compressive strength progressively enhanced by the increase in wt% of the Al_2O_3 and SiC reinforcement contributed to the metal matrix. The optimum compressive strength was observed at 4% aluminium oxide and silicon carbide. The pattern of increase in compressive strength is outlined in Fig. 4. When the reinforcements are included, the particle reinforcements create cores which lead to the majority of grain development. Therefore, the motion is limited better, which causes better strength. Hence, the monitoring in the general boost of the compressive strength is explainable and appropriately justified [16].

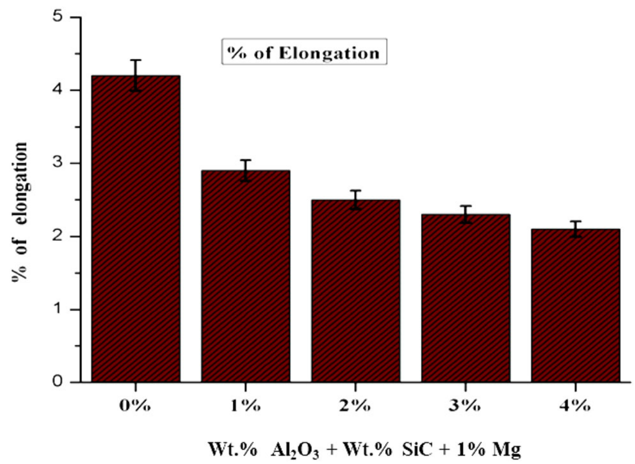

Fig. 3 Percentage elongation versus wt% of the nano-(Al_2O_3 + SiC) reinforcement

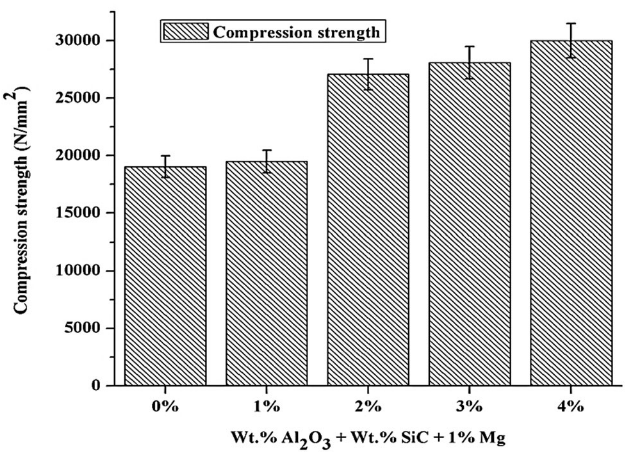

Fig. 4 Wt% of nano-reinforcement versus compression strength

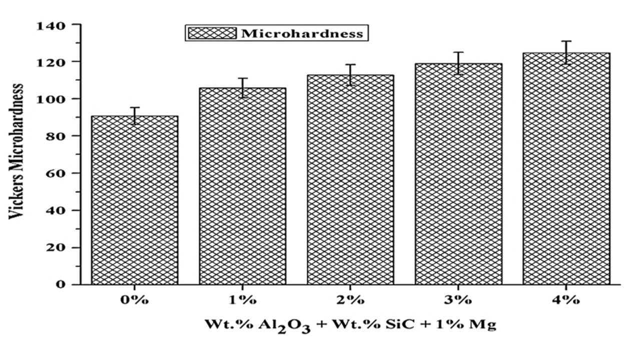

Fig. 5 Wt% of nano-reinforcement versus microhardness values

Microhardness

There is an analysis of the microhardness of the composite sampling by using Vickers microhardness equipment. A load of 50 grams for 10 s is applied on specimens. There is the performance of an examination at five distinct places where the average value was taken. Figure 5 discloses that by incorporating nano-Al_2O_3 and nano-SiC, the hardness values increases more when compared to the unreinforced alloy [17].

The microhardness exposes that its magnitudes enhance (linearly) considerably with gratitude in the content of SiC and Al_2O_3 particle reinforcement relative to Al 7075 alloy. It can be observed that the microhardness of composites was higher than that of its base alloy. This might be attributed to the existence of nano-aluminium oxide (Al2O3) and nano-silicon carbide (SiC) particles in the aluminium matrix.

Weight Loss (Tribological Properties)

Figure 6 shows the effect of wt% of (Al_2O_3 + SiC) particles on weight loss. It exposes that the weight loss of the composites decreases progressively 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 [18].

Microstructural Evaluation

Optical Microscope

The optical microscopic images reveal that there is a consistent distribution of nano-Al_2O_3 and nano-SiC particle reinforcements in the Al matrix. From the microphotographs, it appears to be a good bonding in between the matrix and the nano-reinforcements. The microscopic images of composites (1–4 wt%) with a magnification of 500 × are shown [19]. The optical microscopic image is displayed in Fig. 7a–e.

SEM Analysis

Microscopic evaluations of the metal matrix and nano-composite specimens were done by scanning electron microscopy. The mechanical properties of any kind of particle-enhanced metal matrix composites depend upon the particle dispersion, particle dimension, particle imperfections, surface area abnormalities, and particle matrix bonding. It is consequently essential to perform a

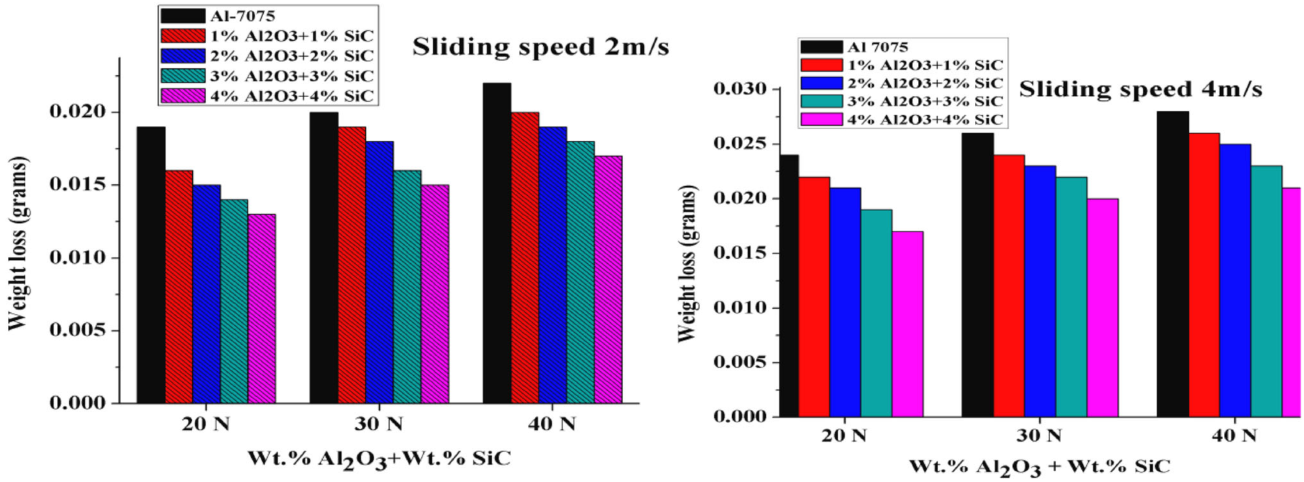

Fig. 6 Load versus weight loss at a sliding speed of 2 and 4 m/s

microevaluation on the new product in order to acquire far better understanding of its microstructural features. The refined samplings were cleansed with Keller's reagent. Scanning electron microscopic lens (SEM) analysis is utilised efficiently in microanalysis and cracks examination of composites. Scanning electron microscopy is carried out at high magnification, produces high-resolution images, and precisely determines microscopic objects [20]. The process proceeds up to 4 wt% of (Al_2O_3 + SiC), i.e. Figure 8a–e.

EDAX Analysis

The element composition of the Al//Al_2O_3/SiC alloy was analysed by EDAX spectral study. The EDAX spectrum shows the presence of aluminium (Al), silicon carbide (SiC) in a suitable weight ratio. The EDAX graphs for Al 7075, 1% (Al_2O_3 + SiC), and 4% (Al_2O_3 + SiC) are shown [21]. The EDAX analysis for two compositions is displayed in Fig. 9a–c.

XRD Analysis

The X-ray diffraction results for the fabricated composites are displayed in Fig. 10a–c. These outcomes show the existence of aluminium (in the biggest peaks), and the visibility of aluminium oxide and silicon carbide particles is shown by small optimal. The XRD pattern verified the visibility of aluminium, Al_2O_3, and SiC particles in the hybrid composite. The XRD method is one of the critical phase study executed in the MMNC to determine the reaction between the ceramic components and alloy. The XRD pattern confirmed the existence of Al 7075, aluminium oxide (Al_2O_3), and silicon carbide (SiC) particulate in the metal matrix composite [22].

Conclusions

In the present research, Al 7075/Al_2O_3/SiC nano-composites prepared by the stir-casting method and the influence of nano-Al_2O_3 and nano-SiC particle material on mechanical properties of the AMMCs were explored. The outcomes could be summarised as follows.

- The results revealed that incorporation of nano-SiC/Al_2O_3-reinforced products is superior to base Al 7075 alloy in contrast to tensile strength and hardness.
- Diffusion of nano-SiC/Al_2O_3 fragments in an aluminium matrix enhances the hardness of the matrix material.
- It shows that the percentage of elongation tends to decrease by enhancing reinforcement weight portion, which validates that silicon carbide and alumina enhancement improve brittleness.
- From this study, ultimate tensile and yield strength values increase with increasing weight percentages of nano-SiC in addition to nano-Al_2O_3 in the matrix.
- The hardness improves after increasing SiC and Al_2O_3 particles in metal matrix.
- SEM results exposed the presence of Al_2O_3, SiC, and also Mg particles in the alloy matrix distributed equally throughout the MMNC.
- Preheating temperature, stirring time, speed, and stirrer design are the essential parameters for the fabrication of suitable composite material.
- EDAX and XRD analysis clearly shows the presence of elemental composition and also the presence of Al, Al_2O_3, and SiC in the composite.

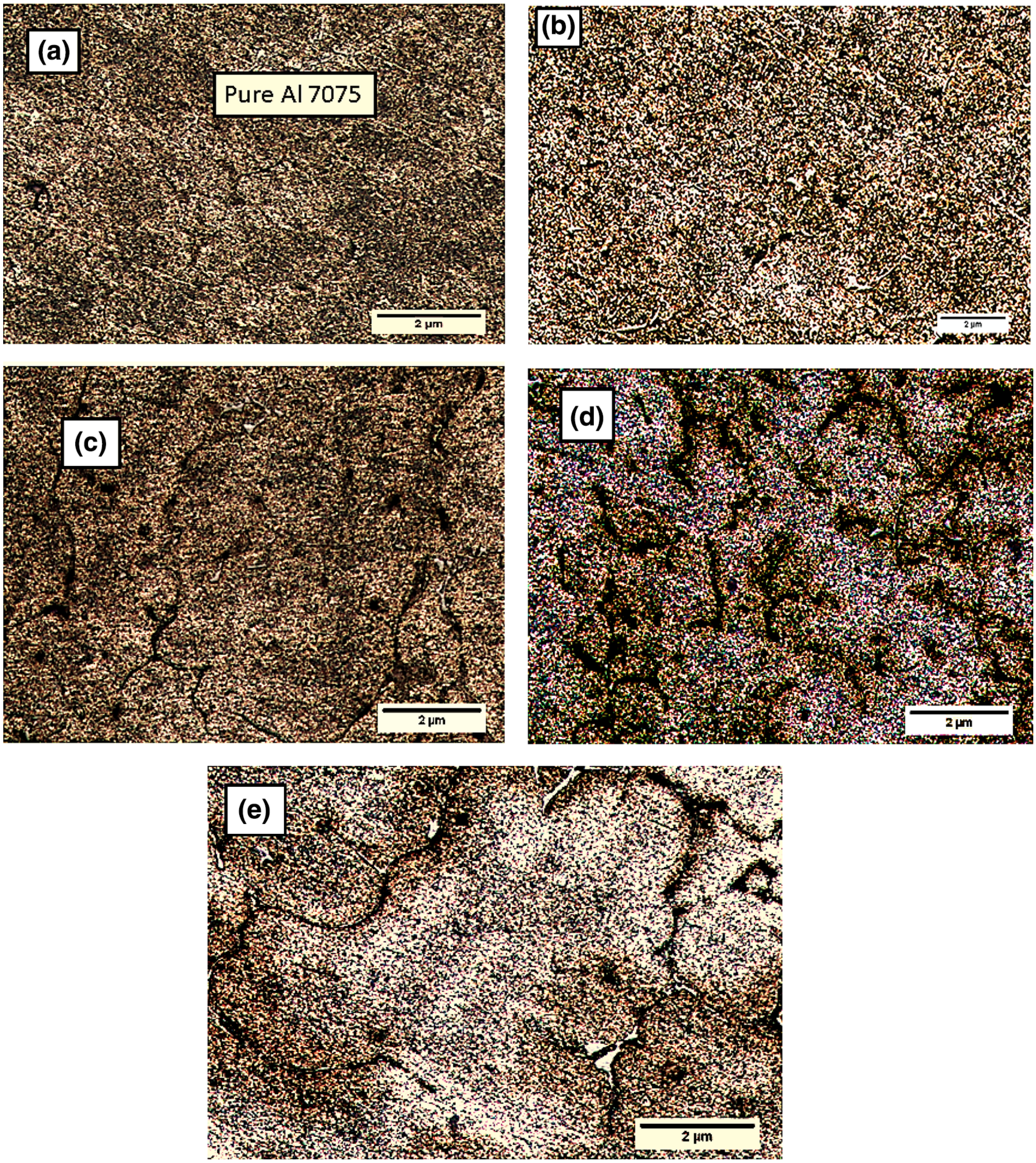

Fig. 7 Optical micrographs show the microstructure of the Al/Al_2O_3/SiC MMCs with **a** 0% (Al_2O_3 + SiC), **b** 1% (Al_2O_3 + SiC), **c** 2% (Al_2O_3 + SiC), **d** 3% (Al_2O_3 + SiC), and **e** 4% (Al_2O_3 + SiC)

The Scope of Future Work

1. The research work further is extended by varying geometrical angle of stirrer and stirring speed.
2. By using ultrasonic-assisted casting method, wettability and agglomeration tendency may be minimised to a large extent.
3. Varying reinforcement grain size can vary results.

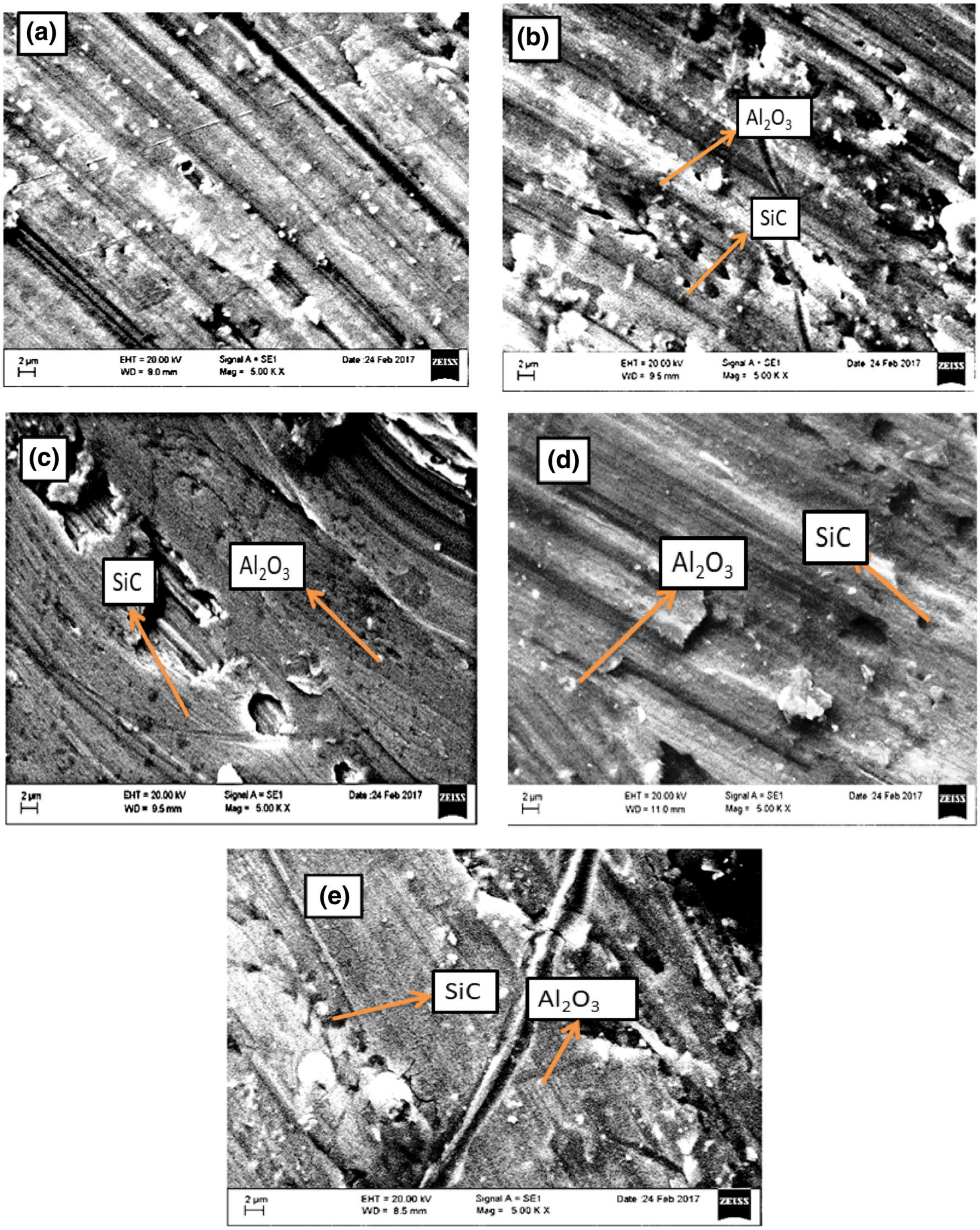

Fig. 8 SEM microstructure of the Al/Al_2O_3/SiC MMCs with **a** 0% (Al_2O_3 + SiC), **b** 1% (Al_2O_3 + SiC), **c** 2% (Al_2O_3 + SiC), **d** 3% (Al_2O_3 + SiC), and **e** 4% (Al_2O_3 + SiC)

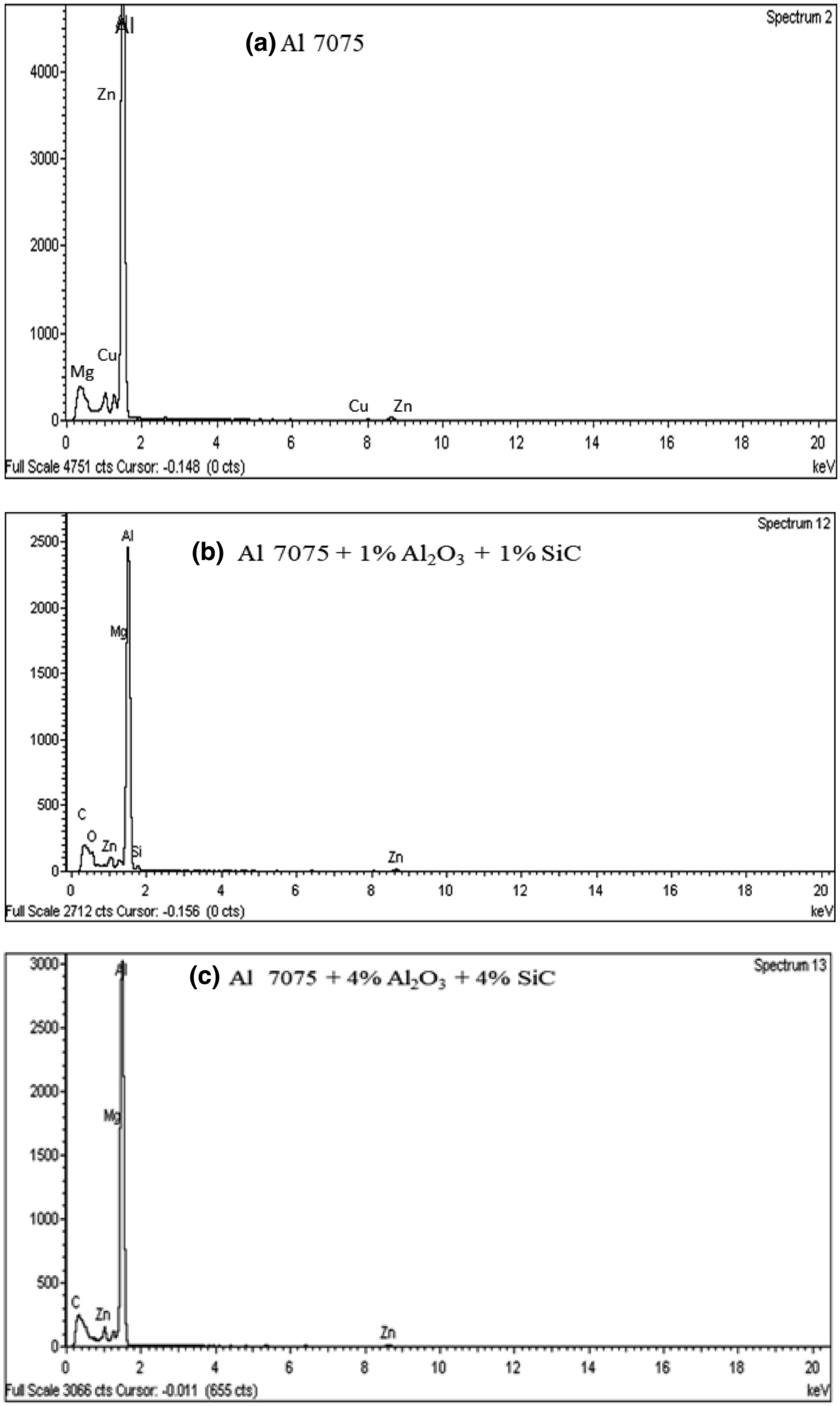

Fig. 9 **a** EDAX analysis for Al 7075. **b** EDAX analysis for 1% (Al_2O_3 + SiC). **c** EDAX analysis for 4% (Al_2O_3 + SiC)

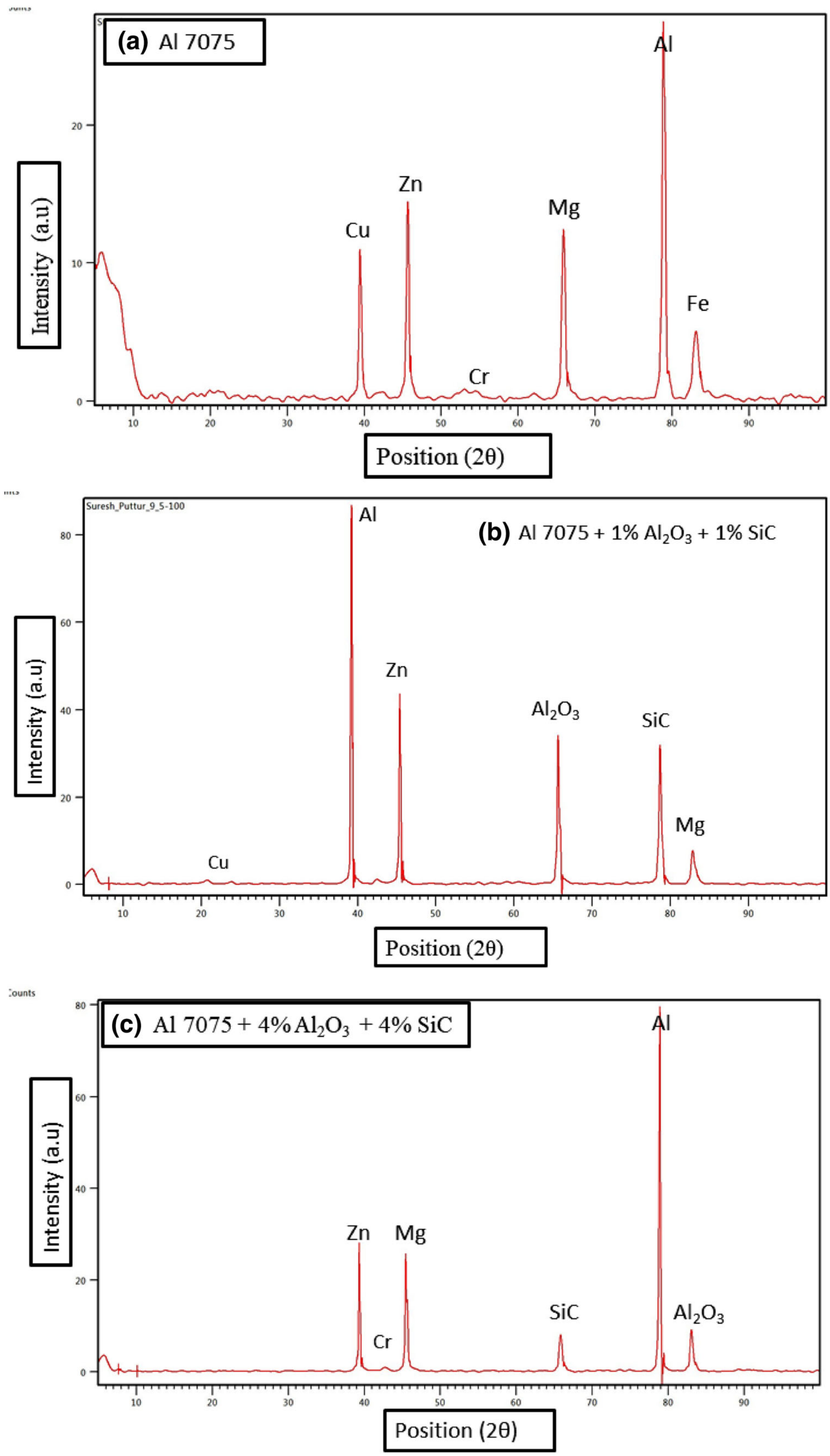

Fig. 10 **a** XRD analysis for Al 7075. **b** XRD analysis for 1% Al_2O_3 + 1%SiC. **c** XRD analysis for 4% Al_2O_3 + 4%SiC

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Compliance with Ethical Standards

Conflict of interest The author(s) declare(s) that there is no conflict of interest.

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