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Investigation of Adding Microscopic Slide Glass Nano Particles on the Metallurgical Characterization and Mechanical Properties of Cast Aluminum 7075 Composites

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ABSTRACT

Metal matrix composite (MCC) exhibits significantly better properties, like hardness, low density, high tensile strength, and good wear resistance compared to any alloy or other metals**.** In the present study, the effect of using different proportions (2, 4, 8 and 10 wt.%) of microscopic slide glass nanoparticles (MSGNPs) on the properties of Al-7075 alloy was investigated. The results of the experimental study of the metallurgical characterization and mechanical properties of aluminum MMC that formed by stir casting method were obtained. Stir casting is a process of introducing a reinforcing material into a molten metal by stirring action. Also, the results of the aluminum MMC were compared with those for the base alloy material. Optical microscopy, scanning electron microscope (SEM), energy dispersive spectroscopy (EDS), and X-ray diffraction study (XRD) were carried out to analyze the microstructure and the dispersion of the (MSGNPs) into the composite alloy specimens. Regarding the mechanical properties, the Rockwell hardness gradually increased when the addition of MSGNPs was raised from 0 to 10 wt.%. Additionally, there was a rise in the ultimate tensile strength, peaking at the incorporation rate of 4 wt.% MSGNPs and thereafter, this strength declined. Therefore, the addition of microscopic slide glass nanoparticles to the Al-7075 is virtuous to enhance the properties of this alloy for the engineering application.

Keywords: microscopic slide glass nanoparticles, aluminum 7075, metal matrix composite.

INTRODUCTION

The current investigation is participation to the efforts aiming to develop the Aluminum-based Matrix Composites (AMCs) with elevated indices of performance at a decreased cost. AMCs are a class of Metal Matrix Composites (MMCs) presently used in the industries of automobile and aerospace. Aluminum is preferred as a structural material in such applications due to its light weight. And, among the series of aluminum alloys, aluminum 7075 alloy possesses numerous promising properties, such as high stiffness, high toughness, high strength, and virtuous resistance to wear. Ceramic particulates are supplemented to the aluminum base matrix as reinforcement for fabricating AMCs, which gave an enhanced strength [1, 2].

Aluminum is an ecological agreeable material because of its proficiency to be recycled as well as its different uses proving the elevated aluminum's manufacture need. The solid wastes, like the cullet (broken glasses) and the metals aren't water soluble and biodegradable. The recycling of these solid wastes for making fresh products could reduce the challenge it poses upon the natural environment. Thus, the merely choice left is to recycle them for getting rid of them from the environment [3, 4].

Glass has a predominant content of Si, so it is one of the most widely used materials as a reinforcing. [5]. On the Mohs scale, the oxide glass has a hardness ranging from 5 to 7 with silica glass having the highest hardness [6]. Therefore, it can be used as a reinforcement that increases the hardness of aluminum matrix composites.

Investigators are vigorously experimenting and discovering methods for strengthening the aluminum and its alloys utilizing the particles of ceramic.

Numerous methods, like different casting techniques, powder metallurgy, and mechanical milling have been utilized in the AMCs formulation through the previous few decades. Amongst the whole such methods, the method of melting and casting is the highly favorable for the manufacturing since it's comparatively inexpensive and facilitates the manufacture [7]. Besides its low price, the method of stir casting provides a big span of material as well as treating circumstances, and also it can synthesize composites with up to a (30%) reinforcement volume fraction with enhanced bonding between the matrix of metal and the reinforcements owing to the action of stirring. Regarding the all such advantages, the method of stir casting was chosen, especially for such investigation for the composites manufacture [8].

Utilization of SiC particulates utilization in the AA7075 matrix manifested that the whole mechanical properties evinced improved values, with the exception of elongation to the failure [9]. For the manufactured nano-composites employing a stir-casting procedure via SiC carbide nanoparticles (mechanically pulverized) into a metal matrix of Al alloy, the outcomes of research elucidated enhancements of 45% in ultimate tensile strength, 41% in yield strength, and 125% in hardness, and also the compressive strength enhancement from (311 MPa) to (603 MPa) at a (5%) SiC inclusion [10]. The used SiC for reinforcing the AA6061 illustrated the yield as well as maximum tensile strength improvement with (0-4 wt.%) inclusion, whereas the elongation was noted for reducing increasingly as the content augmented from (0) to (4%). And, it was seen that the SiC is a virtuous strengthener in the aluminum alloy [11]. Also, other used additives in the preceding investigations are TiC [12], WC [13], Al_2O_3 [14], Si_3N_4 [15], and AlN [16], and the outcomes demonstrated that the supplement of such reinforcements improved the Al and its alloys performance. As well, the use of waste in reinforcing and strengthening the aluminum alloys has proved successful [17]. The use of wastes like rice husk ash [18], and fly ash [19], and glass, was searched. −90 μm was employed for enhancing the Al scrap properties as well as the outcome portrayed that the maximum compressive strength and the maximum tensile strength were improved by raising the additive fraction. Also, it was noticed that the impact strength and elongation were decreased; nevertheless, the investigational analysis upon the tribological characteristics wasn't assessed [20, 21].

The literature clarifies that the aluminum alloys and the microscopic slide glass nanoparticles are commonly utilized in engineering. However, no attempt has been made to stir casting AA7075/MSGNP composites and explore the effect of the weight percentage of MSGNPs on the physical and mechanical properties of the composites. The present study focuses on the evaluation of the properties of AMCs fabrication with the AA7075 as the matrix and the microscopic slide glass nanoparticles (MSGNPs) sieved to 35 nm at various percentages of weight fractions as the reinforcements employing the technique of stir-casting. It's visualized that the additive's fine particulate reinforcement will perform better performance than the coarse ones. The mechanical properties and the metallurgical features of the specimens have been investigated utilizing mechanical tests and SEM micrographs, respectively, thus raising the knowledge upon the waste materials' effect upon the AA7075 properties as well as observing the AA7075/MSGNPs composite properties.

MATERIALS

The materials analyzed in the work are listed below:

- Matrix material –Aluminum (AA7075) alloy,
- Reinforcement material – microscopic slide glass nanoparticles (MSGNPs).

Matrix material

AA7075 alloy was used as the matrix material because it is a precipitation hardened aluminum alloy containing zinc, magnesium, copper, and chromium as the main alloying elements, according to the chemical composition given in in the Table 1 together with that for the standard alloy for comparison purpose. It is strong and has good mechanical properties, including strength comparable to numerous steels, fatigue strength, and corrosion resistance. The physical and mechanical properties of AA7075 are shown in the Table 2. The whole data of chemical analysis were obtained via the optical emission spectroscopy

Table 1. Chemical compositions of the used AA7075 aluminum alloy (wt.%) and standard alloy

Element	Mg	Fe	Ti	Si	Mn	Zn	Cu	Cr	Al
Wt.%	2.5	0.5	0.02	0.4	0.3	5.6	1.5	0.15	Balance
Standard alloy	2.1-2.9	0-05	0-0.2	0-0.4	0-0.3	5.1-6.1	1.2-2	0.18-0.28	Balance

Table 2. Physical and mechanical properties of the used AA7075

Property	Unit	Values
Density	gm/cm^3	2.81
Hardness (HB 500)	HB	60
compressive strength	MPa	330
Ultimate tensile strength	MPa	200
Elongation	%	11
Modulus of elasticity	GPa	71.7
Poisson s of Ratio	--	0.33
Machinability	%	70
Melting temperature	°C	477-700
Shear modulus	GPa	26.9
Shear strength	MPa	331

(OES) test and the properties of base material were taken as per ASM material data sheet.

Reinforcement metal

In this research, glass powder was used as the major reinforcement in form of particles obtained from a microscope slide. The particles were washed thoroughly under the running water to remove all impurities, after which they were dried in the open air for one day. Then, these particles were crushed and ground from microscopic-slide glass into smaller particles by a milling process using a ball mill to obtain a powdery form. This process was pursued by sieving process employing a laboratory sieve shaker whose upper aperture was 2.38 mm. The fine glass powder sieved to 35 nm was collected and then oven dried at 120°C for 24 h to remove the volatile content. Figure 1 reveals the SEM image of MSGNPs, and the chemical composition of MSGNPs is depicted in Table 3. The particle size, physical, mechanical, and thermal properties of MSGNPs are given in Table 4.

METHOD

Processing of MMCs by stir casting

Stir casting is the simplest and least expensive way of making AMCs. This method includes mechanically mixing the reinforcing particles into a molten metal bath, and the resulting mixture is then transferred to a formed mold just before it completely solidifies. The important issue in this process is to get a good wetting between the molten metal and the particle reinforcement. The composite specimen was made using stir casting technique, whose experimental setup is shown in Figure 2 [22], to ensure a more uniform

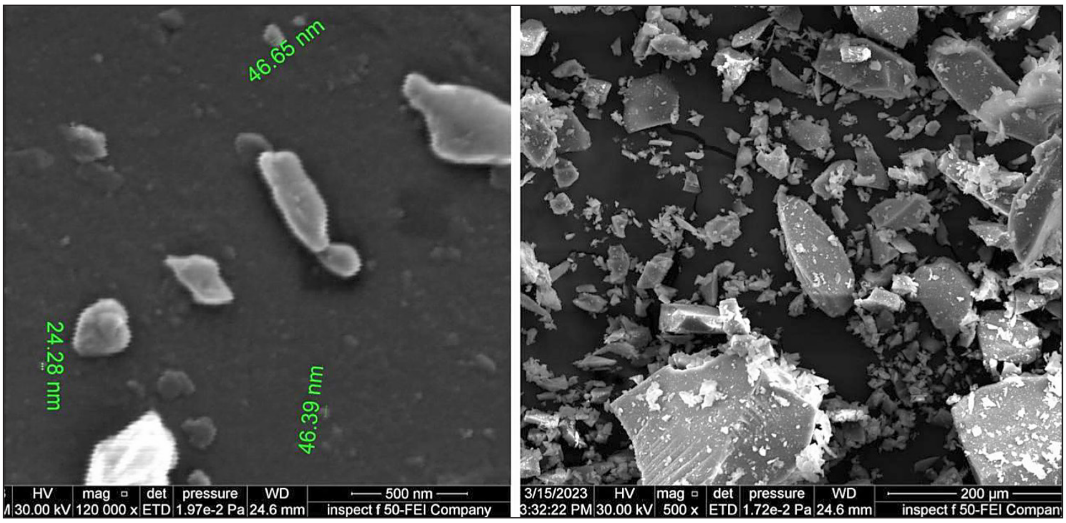


Figure 1. The SEM image of MSGNPs

Table 3. Chemical composition of microscopic-slide glass nanoparticles MSGNP

Element	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	CaO	K_2O	MgO	SO_3	TiO_2
%	72.2	1.2	0.03	14.3	6.4	1.2	4.3	0.03	0.01

Table 4. Physical and mechanical properties of MSGNPs

Property	Unit	Values
Particle size	nm	35
Density	g/cc	2.48
Hardness	Mohs	6
Light transmission, total solar	%	91.5
Reflective index at 546.07	Nm	1.517
Coefficient of expansion	°C	90.6 × 10-7
Poisson s of Ratio	--	0.2
Strain point	°C	494
Annealing temperature	°C	545
Softening temperature	°C	720

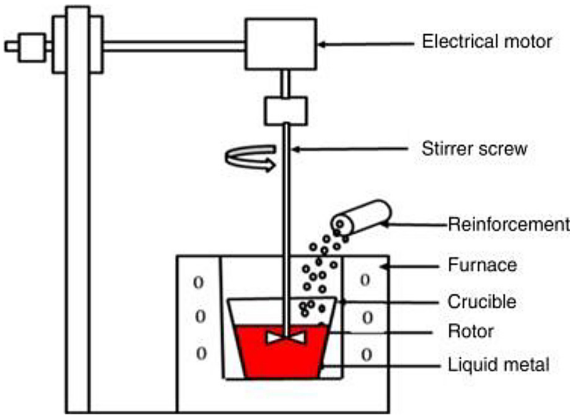


Figure 2. Stir casting setup [22]

dispersion of the reinforcing particles. The matrix alloy (AA7075) was initially superheated at 700°C. After Al was completely melted, flux powder was added as a melt aiding to remove the slag from the molten. When the slag was removed, magnesium strips were added to the molten, because Mg evaporates at a temperature of 450°C. The warmed glass particles of 2%, 4%, 8% and 10% (by weight) were slowly put into the slurry at 720°C and stirred with a stainless steel stirrer to avoid the agglomeration of powder and to ensure its uniform distribution. This process was done with the help of Argon gas that was pumped through a side tube. The slurry temperature was augmented to a totally liquid-state, and the automatic stirring was continued to around 2 min with a (450 rpm) average stirring speed. Then, the molten composite was directly decanted into a steel mold (heated to 500°C) to prepare specimens for the testing purpose.

Composite preparation

The proposed metal matrix composite was fabricated at four different compositions, as listed in Table 5, where the amount of added magnesium was kept constant at 2%, and the added glass proportion was varied from 0 to 10%. Thus, the potential compositions of the novel composite are listed in this table. In addition to that, 1wt.% of flux was used to remove the slug.

Important parameters in stir casting

Reinforcement particles preheating

Preheating the particulates is important to prevent the moisture from entering the particulate; otherwise, the moisture and gases can cause particulate agglomeration. Before mixing with the aluminum melt, the temperature was increased to 400°C for one hour in a muffle furnace to improve the wettability and remove any type of other gases. Thus, reducing the humidity of the particles increases the surface energy and enhances its interaction with the aluminum, as it produces more effective particles in the aluminum matrix and less porosity in the casting [23]. Care was taken to put each gram of powder in foil before being introduced into the oven.

Table 5: Concentrations of the composite material [%]

Sample	Al7075	Magnesium	Glass
1	100	0	0
2	96	2	2
3	94	2	4
4	90	2	8
5	88	2	10

Stirring speed

The stir casting method relies heavily on the stirring speed parameter. The distribution of reinforcing particles in molten metal is caused by a vortex that is created as a result of the influence by the speed of stirring. Therefore, it is evident that the stirring increases the wettability. The rate of stirring has a direct impact on the flow pattern of molten metal [24]. High-speed rotary mechanical stirrers or ultrasonic stirrers can be used to achieve effective mechanical stirring to improve the wetting between the melted metal and the reinforcing particles, which is considered to be a crucial factor in the homogeneous distribution of reinforcement particles in the molten metal [25]. Therefore, in the present work, the average used stirring speed was selected to be 450 rpm and continued for about 2 min.

Wetting element (magnesium) added to molten

The wettability of aluminum melt with reinforcement particles can be improved by adding alloying elements, like calcium and magnesium**.** After the slag was removed from the molten, magnesium strips were added to the molten to increase the wettability of liquid aluminum since it lowers the surface tension. Magnesium does not only increase the alloy's strength but also causes magnesium oxide to form when it reacts with oxygen, which reduces the amount of blowholes that appear in the casting [26].

Mold preheating temperature

A steel mold used for preparing the test specimens was heated to 500°C. Preheating this mold is vital because it aids in the removal of trapped gas from the slurry, which would otherwise cause porosity [27].

Size of reinforcement

The size of reinforcement, the distance between the mold and the crucible, the pouring rate, and the pouring temperature are all significant determinants in the quality of casting. To prevent the gas entrapment, the pouring rate and temperature should be uniform [28]. The influence of using different grit sizes of SiC upon the mechanical properties of AMC (Al+4%Cu+5%Sic) by stir casting process with changing the pouring temperatures (700, 725, and 750°C) was studied [29]. It was found that the mechanical properties (impact strength, tensile strength, and hardness were improved via raising the grit size of the reinforcement particles of SiC. Therefore, the effect of using various percentages of MSGNPs on the mechanical properties (hardness and tensile strength) of the Al7075/MSGNP composites has been investigated in the present study.

Temperature for pouring

Pouring temperature plays an important role for improving the mechanical properties of Aluminum-based metal matrix composites. Several researchers have studied the influence of the pouring temperature on the mechanical properties of AMCs using stir casting process. Investigated. The influence using three pouring temperatures (800°C, 820°C and 840°C) of Al/TiB_2 as well as (730°C, 750°C and 770°C) of Al/SiCp metal matrix composites manufactured employing stir casting technique was investigated [30]. It was found that a higher tensile and fracture strength were occurred at the MMCs of Al/TiB_2 in comparison with the Al/SiCp MMCs and the aluminum base alloy. The maximum hardness was reached at the pouring temperatures of 820°C and 750°C in the MMCs of Al/TiB_2 and Al/SiCp, correspondingly. The influence of utilizing three pouring temperatures whilst fabricating Aluminum SiC metal matrix composites, with further advantages of Mg and Cu by stir casting method was studied [31]. It was concluded that the pouring temperature possesses a significant effect upon the microstructure and mechanical conduct, creating it as a vigorous factor for synthesizing the Al/SiC/Mg/Cu composites. Thus, in the present work, the pouring temperature of the molten composite was within the range of (700–720°C).

Experimental details

The microstructure and mechanical properties were considered for AA7075 reinforced with 0%, 2%, 4%, 8%, and 10% microscopic-slide glass nanoparticles subjected based on the tests of specimens. For each test, five samples from each mix were assessed, and the mean outcome was calculated for the analysis.

Microstructural examination

The distribution of glass particles into the produced composites was assessed using microstructural examination. It was intended to obtain a fair MSGNPs distribution into the AA-7075 matrix. The microstructural characteristics of the created composites were examined employing an optical microscope. Using a JSM-7800F extreme resolution analytical field emission (SEM) fitted with EDX spectroscopy, the surface morphology as well as the elemental composition was measured by (EDX) spectroscopy. The samples underwent a variety of grinding, polishing, and gold coating procedures before being prepared for the microscopic analysis, as manifested in the Figure 3. In order to etch the samples, Keller's reagent (1.0 ml HF, 1.5 ml HCl, 2.5 ml HNO_3, and 95 ml water) was used.

XRD characterization

The phases present in the composites formed were identified using the analysis of X-Ray Diffraction (XRD). Samples were scanned in the range from 10° to 90° at a speed of 2°/min while the XRD was running at (40 kV) and (30 mA). The XRD examination of the materials was performed utilizing a back loading preparation technique [32]. The materials were examined using a PANalytical Empyrean diffractometer equipped with a PIXcel detector, fixed slits, and Cu-Ka1 radiation with a Fe filter (= 1.540598 A). The used software is called Crystal. Impact match was used to identify the stage.

Tensile strength test

Tensile testing was performed in accordance with standard (ASTM-E8) at the room temperature using a machine of type WDW-200E with an applied load capacity of (20 kN) and a strain rate of 0.5 mm/min. The standard specimen used in the tensile test is evinced in Figure 4.

Hardness test

The specimens of hardness test were prepared by grinding with various grit sizes of grinding paper, followed by polishing with a polishing machine to achieve mirror-like smooth surfaces. A Rockwell hardness apparatus was used to conduct the hardness test in accordance with ASTM E-18 standard, and the smooth-surfaced samples that have already been prepared were indented for 10 seconds with a (100 kg) load. The value of hardness was determined by measuring the average of four readings that were recorded for each position on the specimen surface. Rockwell hardness number was calculated according to the following formula [33].

$$RHN = E - 0.002\,h \qquad (1)$$

where: E – a constant relying upon the indenter form (100 for the diamond indenter and 130 for the steel ball indenter),

Figure 3. Microstructural examination: (a) grinding machine, (b) polishing machine, and (c) gold coating machine

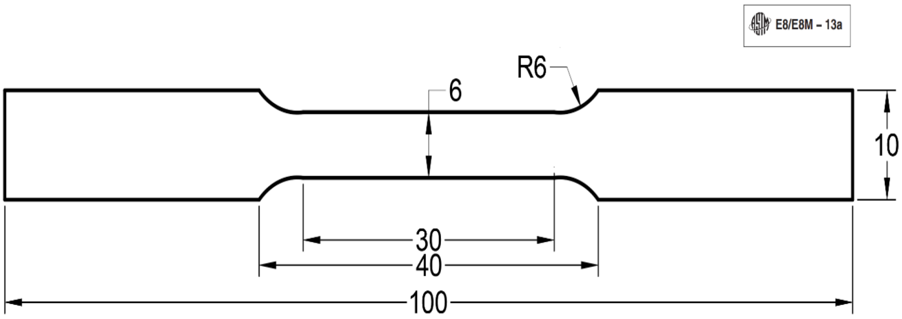


Figure 4. Tensile test specimen according to ASTM E8M-13a

h – the permanent increment in the penetration depth owing to the main load, in mm.

RESULTS AND DISCUSSION

Metallurgical characterization

Chemical composition of Al7075/MSGNP

The chemical composition for the fabricated composite material is elucidated in the Table 6; therefore the 8% was chosen, the metal matrix composite contains aluminum, magnesium, iron and silicon, and the last element, which increased by the added glass, works to improve the tensile strength, hardness, and resistance to pitting, making the composite material more resistant to corrosion and rupture at the elevated temperature. The sample was tested in the Central Organization for Standardization and Quality Control, Baghdad, Iraq.

Microstructure

Microstructural characterization of the composites was used to determine how the glass particles were distributed inside the resulting composites. Figure 5a illustrates the microstructure of AA7075 alloy at 0 wt% microscopic-slide glass nanoparticles, and the microstructure of AA7075 portrayed a virtuous metallurgical bonding among the Al particles. Figures from 5b to 5e depict the microstructure of AA7075 alloy with different percentages of glass (2%, 4%, 8%, and 10%), and it has been observed that the MSGNPs are found in the matrix at sites, such as those on the grain boundaries and within the grains. When the MSGNPs concentration was increased to around 8% in figure 5d, the equally scattered microscopic-slide glass nanoparticles (MSGNPs) were found, and the open porosity decreased in figure 5d compared to figure 5c when the MSGNPs concentration was 4%. Such enhancement was ascribed to the sufficiency of reinforcement as well as the uniform distribution of MSGNPs with an addition of 8 wt.%. However, when the reinforcement (MSGNPs) content has been increased to around 10 wt.%, Figure 5e, the nano glass particles begin to agglomerate, creating dark black regions in the AA7075 matrix. In general, the MSGNPs have a fair distribution in composites, which is attributable to the fact that the quality of AMCs is controlled by the wetting of glass particles in aluminum. There is a significant chemical reaction between the nano glass powder and the aluminum particles.

Analysis of SEM and EDX spectroscopy

Figure 6 manifests the SEM image and EDX patterns of 7075 alloy, and the EDX analysis was carried out to examine the glass adsorption in the aluminum matrix as well as any other elements that might be present in the matrices. Figure 6a views the SEM image of AA7075-8%wt.%SiO_2 composite. Figure 6b displays the EDX analysis demonstrating the increase of Si element in the composites than that in the base material, confirming the presence of Si. The alloying elements of the AA7075 base matrix are represented by the peaks for Na, C, O, Si and Al. The results of the EDX study for all AA7075-SiO_2 compositions were similar; therefore, the 8% MSGNPs result shown in Figure 5d was chosen to serve as an example of the oxidation and the presence of SiO_2. In Table 7, the chemical composition of AA7075 is listed in accordance with the EDX.

XRD Analysis

Figure 7 evinces the XRD result, displaying the various 2theta value-generated diffraction patterns of the phases. The phases in the composites changed as a result of different two theta values. The phases being identified by the analysis of XRD, which were described via their robust peak

Table 6: The chemical composition of the fabricated AA7075/MSGNPs

Element	Wt.% composition	Element	Wt.% composition
Mg	1.11	Ni	0.01
Fe	0.20	Ti	0.02
Si	1.83	Ca	0.007
Cu	1.37	Ga	0.01
Mn	0.14	Zr	0.01
Zn	5.84	Al	89.2

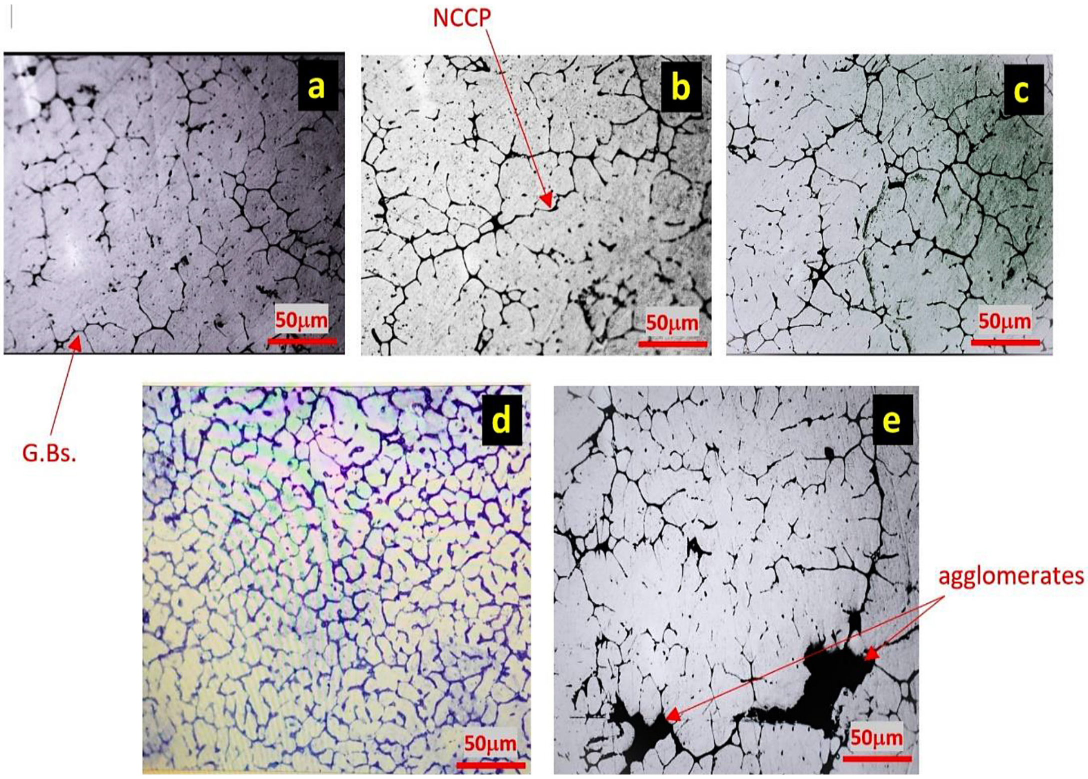
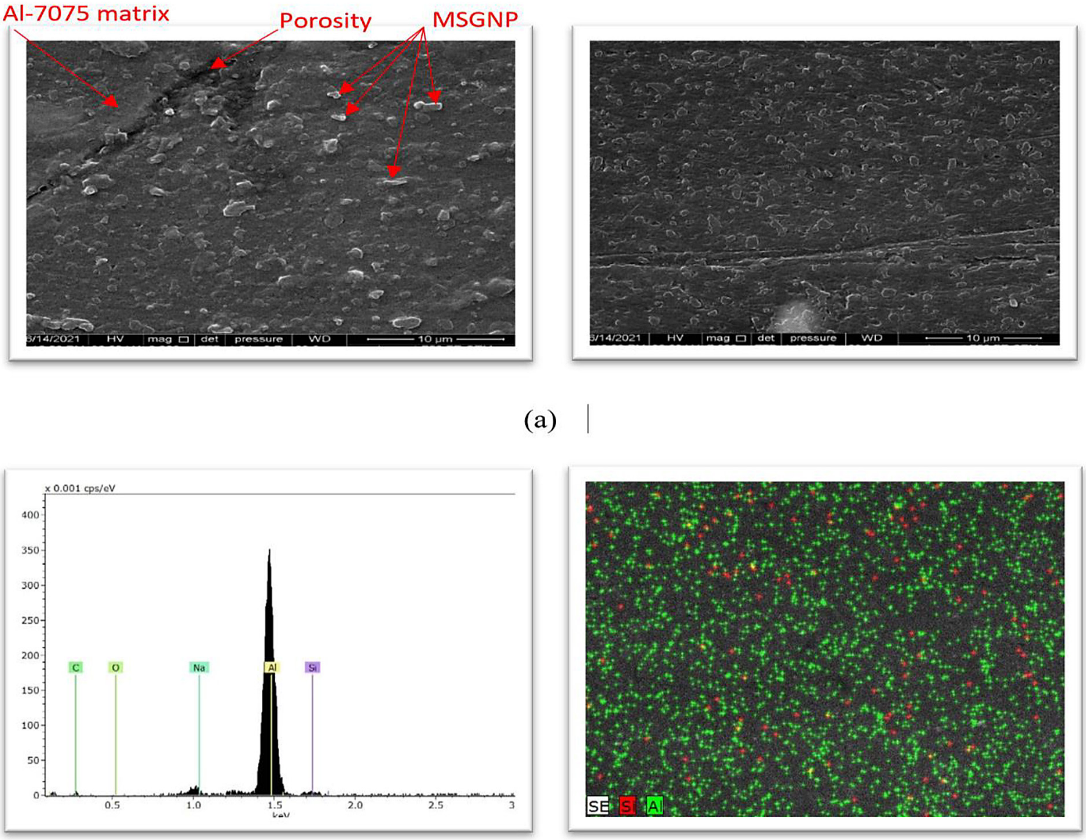


Figure 5. The microstructure image of Al 7075 MMCs (0%, 2%, 4%, 8%, and 10%): (a) 0 wt.%, (b) 2 wt.%, (c) 4 wt.%, and (d) 8 wt.%, and (e) 10 wt.% MSGNPs at 200X



(a)

(b)

Figure 6. AA7075-8wt.% glass spectrum for: (a) The SEM micrographs of MMCs, and (b) The EDX spectra result of MMCs

Table 7: Chemical composition of AA7075 by EDX

Element	Wt.% composition	Element	Wt.% composition
Mg	1.12	Ni	0.01
Fe	0.22	Ti	0.02
Si	1.83	Na	2.1
Cu	1.37	C	0.02
Mn	0.14	O	0.01
Zn	5.84	Al	Balance

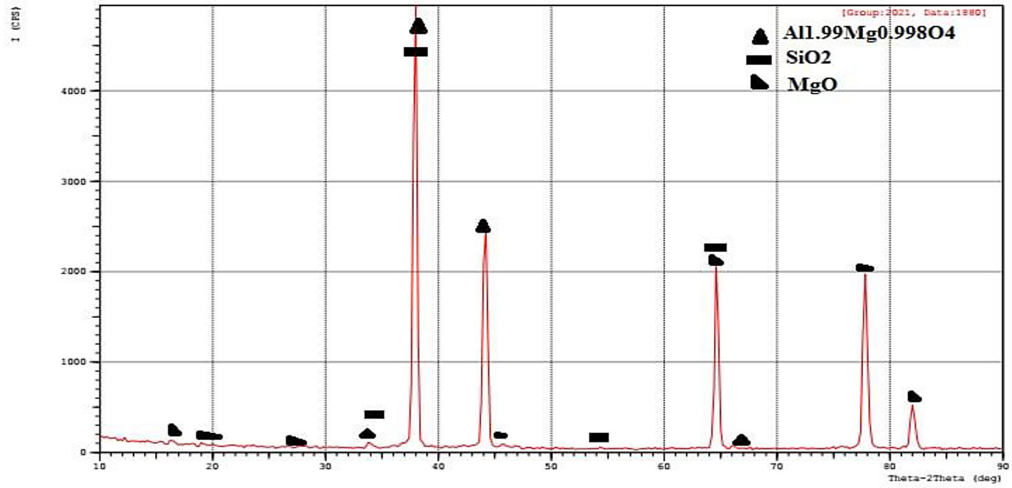


Figure 7. The XRD analysis of MMCs

intensities, certainly contained SiO_2. Also, this figure exhibits that the MSGNP and aluminum are the two main components of the composite, which is consistent with the optical microstructure of the composite.

Mechanical properties

Tensile strength

Figure 8 elucidates the ultimate tensile strength of the AA7075 specimens reinforced with MSGNPs. The average values of tensile strength for 0%, 2%, 4%, 8%, and 10% specimens were measured to be 50, 71.2, 89.16, 60, and 58.3 MPa, respectively. The tensile strength value of the created composite also improved, as shown in this figure 7. The greatest ultimate tensile strength was found for the sample 3, which includes 4% MSGNPs. As demonstrated in figure 7, the ultimate tensile strength improves as the proportion of MSGNPs increases. This is owing to the high wettability of glass particles with the aluminum melts. The bonding strength between the aluminum alloy and the reinforcing particles is reduced due to the particles agglomeration. When AMCs are stressed, the particles act as agents that impede the mobility of dislocation inside the matrix, restricting the plastic flow. This might explain why AMCs' tensile properties have improved, as well as other mechanical qualities, such as stiffness and compressive strength [34]. With an increase in glass of 10%, there was a small reduction into the ultimate tensile strength compared to the value achieved when adding 4%. However, 10% still results in an improvement in yield, ultimate tensile strength, and the final tensile strength was comparatively compared to the control. And, the reason for this decrease is attributed to the effect of dislocation multiplication, which leads to the accumulation of dislocation impeding further deformation, and the result of this is up to failure.

Hardness analysis

Figure 9 portrays that after adding the MSGNP reinforcement to an aluminum alloy, the average values of hardness for 0%, 2%, 4%, 8%, and 10% specimens were measured to be 30, 35, 47, 61, and 60 RHC, respectively. The composite

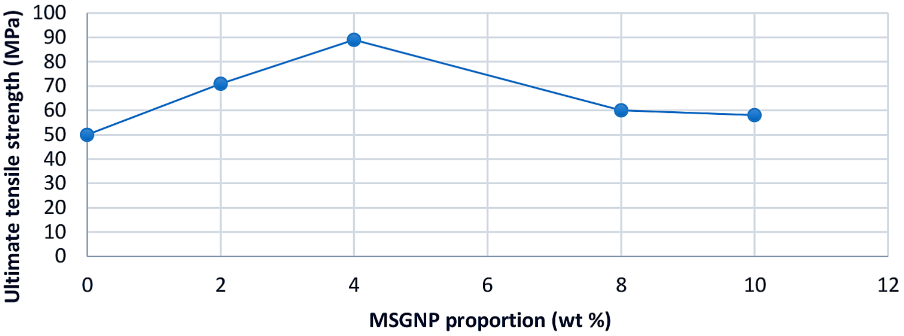


Figure 8. Ultimate tensile strength of aluminium MMC

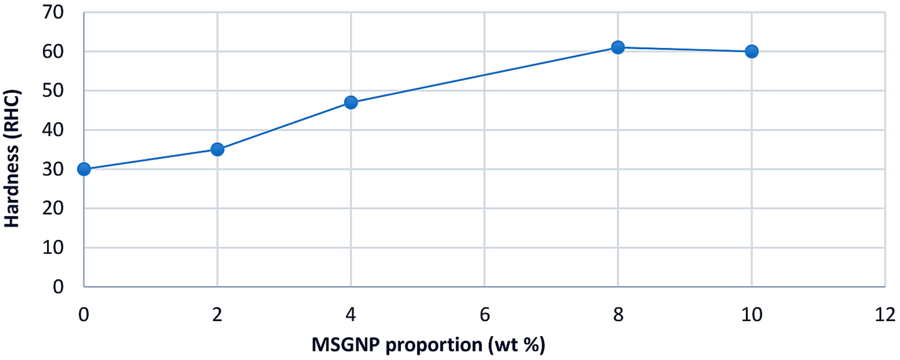


Figure 9. Microhardness of aluminium MMC

with 8% MSGNP has the highest hardness value in the present study. This means the hardness of the composite material increases with the increase in the weight percentage of the reinforced particles (MSGNP). This is due to the presence of extremely hard ceramics (MSGNP) particles in the aluminum alloy matrix, a stronger limit on the localized matrix deformation during indentation [35], and a homogenous distribution of MSGN particles. Although the hardness is directly proportional to the weight percentage, a decrease in the hardness was observed at 10% wt compared value obtained at 8%wt of MSGNP, the reason is due to nano glass particles begin to agglomerate in the Al-7075 matrix. Thus, causing a decrease in the hardness.

CONCLUSIONS

In this experiment, Al7075/MSGNP composites were fabricated by stir casting with increasing volume percentage of reinforcement particles. Mechanical behaviour and microstructure of the prepared AMMCs were analysed and obtained the appropriate level of MSGNP reinforcement required to produce Al-7075 composites. The outcomes were concise below.

1. The Al7075/MSGNP composites were manufactured using the stir casting technique, which demonstrated a consistent dispersion of nano glass particles at 8%. the porosity increased with a proportional rise in the MSGNP. Increased porosity can be linked to entrapped gas and bubbles during the production process.
2. The microstructural analysis of Al-7075 revealed a good metallurgical bonding between the Al particles and the microscopic slide glass nano particles uniformly dispersed at the optimum addition of 8 wt.%.
3. As MSGNPs was raised, the composite's hardness increased from 30 HRC to 60 HRC, while the tensile strength having maximum value of 89 MPa at 4% of MSGNPs, where the base metal was 50 MPa.
4. XRD manifested that the two main components of the composite were aluminium and glass.

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