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Comparison between the Effect of Adding MSGNP and B4C-WC Nanoparticles on the Metallurgical and Mechanical Characterization of Al-7075 Composites Produced by Stir Casting

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HIGHLIGHTS

- The metallurgical and mechanical properties of an Aluminum-based matrix composite (AMC) are investigated.
- The AMC has an Al-7075 matrix reinforced with 35 nm MSGNPs fabricated by stir casting.
- OM, SEM, EDS, and XRD were used to analyze the microstructure.
- Mechanical testing showed Rockwell hardness, tensile strength, and analysis for the Al 7075/MSGNP composite.
- The alloy Al-7075 with 8wt% MSGNP had the best manufacturing and evaluation results.

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ABSTRACT

Metal Matrix Composite (MCC) reveals considerably better properties, such as low density, high tensile strength, hardness, and good resistance to wear compared with every alloy or other metal. The current study concentrated upon the assessment of the properties of aluminum matrix composites (AMCs) synthesis with the Al-7075 as a matrix and the MSGNPs that sieved to (35 nm) at different weight fractions percentages as reinforcements using stir-casting method and compared with Al7075/B4C-WC nanocomposites. These experiments aim to select the appropriate type and percentage of reinforcement particles for producing Al-7075 composites with the best mechanical properties. The mechanical properties, as well as the metallurgical features for analyzing the microstructure and the distribution of (MSGNP, SiC-WC) into the composite alloy specimens, have been studied utilizing the mechanical tests and the Optical Microscopy (OM), Scanning Electron Microscope (SEM), Energy Dispersive Spectroscopy (EDS), and X-Ray Diffraction (XRD) SEM pictures. By reviewing the mechanical test results, they manifested that the value of the composite's ultimate strength was enhanced with the additive concentration of nanoglass. The maximum tensile strength was obtained for the sample comprising 4% MSGNP—the composite with 6 wt.% B4C and WC have the highest hardness value, which means the increase of the added composite material beyond 10% will decrease the hardness. The X-ray diffraction (XRD) examination results illustrate the various phases of the two-theta value-generated diffraction patterns for the Al-7075/MSGNP and Al-7075/B4C-WC workpieces materials. These examinations show that the matrix of Al and the clear glass are the two major composite constituents and contain B4C, WC, and aluminum matrix, which are consistent with what was shown by the optical microstructure of the composite. The Al-7075 microstructure analysis also demonstrated a virtuous metallic bonding between the particles of Al and the uniformly dispersed and transparent glass particles at the optimal addition of 8wt%. Such enhancement was ascribed to the reinforcement's sufficiency and the uniform dispersion of MSGNP. Therefore, the addition of 8 wt.% was chosen in the present work.

1. Introduction

Many approaches, such as various casting methods, mechanical milling, and powder metallurgy, have been employed in the formulation of aluminum matrix composites (AMCs) over the preceding years. Amongst the total such approaches, the technique of melting and casting is mostly preferred for manufacturing because it is relatively cheap and eases production [1]. In addition to its less expense, the stir casting technique offers a large material span and processing conditions. Due to the stirring action, it can fabricate composites with a strengthening volume fraction of (30%) with enhanced bonding between the reinforcements and

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the matrix metal. Concerning such benefits, the stir casting technique was selected, particularly for the present investigation of the production of composites [2].

The present study contributes to the efforts that aim to develop AMCs with elevated performance indices at a reduced cost. The AMC is a category of metal matrix composites (MMCs) currently utilized in aerospace and automobile manufacturing. Al is favored as a constructional material in these uses owing to its lightweight. The aluminum alloy (Al-7075) has many encouraging characteristics, like high strength, toughness, stiffness, and wear resistance among the aluminum alloy series. The particulates of ceramic are added to the Al base matrix as a strengthening to fabricate the AMCs, providing improved strength [3-4].

Al is an ecologically friendly material due to its adeptness to be re-cycled and its various applications that prove the high aluminum production requirement. The solid wastes, such as the cullet (smashed glasses) and metals, are not bio-degradable and water soluble. Re-cycling such wastes to make new produces could decrease the contest it poses to the natural surroundings. Therefore, the only selection left is re-cycling them to discard them from the surroundings [5-6].

Glass has a prevailing amount of silicon (Si); thus, it's the most broadly utilized substance as a reinforcing [7]. On the scale of Mohs, the oxide glass possesses hardness in the range (5 - 7), with silica glass possessing the uppermost hardness. Also, boron carbide (B4C) and Tungsten carbide (WC) have a high hardness. So, it can be employed as a strengthening that raises the hardness of AMCs. Researchers are strongly testing and exploring approaches to reinforce aluminum and its alloys using ceramic particles [8].

Using the particulates of silicon carbide (SiC) in the matrix Al-7075 alloy elucidated that the all-mechanical characteristics revealed enhanced values, except for the elongation to failure [9]. For the produced nanocomposites employing the approach of stir-casting by the nanoparticles of silicon carbide (mechanically crushed) into an aluminum matrix alloy, the research results evinced a (45%) improvement in the maximum tensile strength, a (41%) in the yield strength and a (125%) in the hardness, as well as the compressive strength improvement from (31.1 MPa) to (60.3 MPa) at a (5%) silicon carbide (SiC) addition [10]. Also, the utilized silicon carbide (SiC) to reinforce the Al-6061 alloy manifested the yield and ultimate tensile strength enhancement with (0-4 wt.%) addition. At the same time, the elongation was observed to decrease progressively as the content increased from (0%) to (4%). Additionally, it was noticed that silicon carbide (SiC) is a good strengthener in the alloy of Al [11]. Furthermore, the other employed additives in the previous studies are titanium carbide (TiC) [12], tungsten carbide WC [13], alumina (Al_2O_3) [14], Si_3N_4 [15], and AlN [16], as well as the results revealed that the addition of these reinforcements enhanced the performance of aluminum and its alloys. Moreover, the waste utilization in reinforcing the alloys of Al has been verified positive [17].

The above literature review explains that Al alloys and MSGNP are normally employed in engineering. Few attempts have been conducted for stir casting Al7075/MSGNP composites and exploring the MSGNP's weight percentage's influence on The current study concentrated upon the assessment of the properties of aluminum matrix composites (AMCs) synthesis with the Al-7075 as a matrix and the MSGNPs that sieved to (35 nm) at different weight fractions percentages as reinforcements using stir-casting method and compared with Al7075/B4C-WC. It is envisaged that the fine nanoparticulate strengthening additives will achieve better performance than the coarse ones. The specimens' mechanical properties, as well as the metallurgical features, have been studied utilizing the mechanical tests and the SEM pictures, respectively, therefore increasing the understanding of the influence of waste materials on the properties of Al-7075 alloy and noting the properties of AA7075/MSGNPs composite.

2. Materials and Methodology

The analyzed materials in the current investigation include:

1. The matrix material:
   - The aluminum alloy (Al-7075)
2. The reinforcement materials:

Microscopic slide glass nanoparticles (MSGNP), a mix of 50% of boron carbide (B_4C) and 50% of tungsten carbide (WC)

2.1 The Matrix Material

Al-7075 alloy was utilized as a matrix material since it's a precipitation-hardened Al alloy having Zn, Mg, Cu, and Cr as the chief alloying components. It has good mechanical properties and a good strength value comparable to many steels. It also has good fatigue strength and high corrosion resistance, among the other similar alloys. Table 1 lists the chemical analysis of the used aluminum alloy Al-7075. Table 2 shows the physical and mechanical properties of the utilized aluminum alloy Al-7075 ingot imported from Hanwei Company, Chain. The purchased ingot plate has dimensions (500 mm x 200 mm) and a thickness of (2mm). The plate was cut into small strips to be put in a suitable melting pot.

Table 1: Chemical analysis of the used aluminum alloy Al-7075

Element	Mg	Fe	Ti	Si	Mn	Zn	Cu	Ti	Cr	Al
Wt.% composition	2.5	0.5	0.02	0.4	0.3	5.6	1.5	0.2	0.15	Balance

Table 2: Physical and mechanical properties of the utilized aluminum alloy Al-7075

Item	Unit	Values	Item	Unit	Values
Density	g/cc	2.81	Poisson of Ratio	-	0.33
Hardness (HB 500)	-	30	Machinability	%	70
compressive strength	MPa	330	Melting temperature	°C	677-700
Ultimate tensile strength	MPa	200	Shear modulus	GPa	269
Elongation	%	11	Shear strength	MPa	331
Modulus of Elasticity	GPa	71.7			

2.2 The Reinforcement Materials

This work utilized the glass powder as the main strengthening in the nanoparticle form determined from the microscope slides. The obtained particles were rinsed completely below the running water to remove all contaminants. Then, the particles were dehydrated in the open air for 24 hours. After that, such particles were ground and pulverized into smaller particles utilizing a ball milling machine to become powdery. The produced powder particles were separated by using a laboratory sieve shaker. The sieved fine glass powder having a size of (35 nm) was first gathered and then dried in an oven at a temperature of (120°C) for 24 hours) to remove the volatile content. After that, the boron carbide and tungsten carbide powders were obtained from the market. The particle sizes of the used boron carbide and tungsten carbide nanoparticles are 33.50 nm and 36.42 nm, respectively. The SEM picture of the nano-reinforcement MSGNPs, WC, and B_4C particles utilization is revealed in Figure 1a, b and c respectively, and Table 3 depicts the particle chemical analysis, while the particle size physical, mechanical, and thermal properties of the MSGNPs, WC, and B_4C are listed in Table 4.

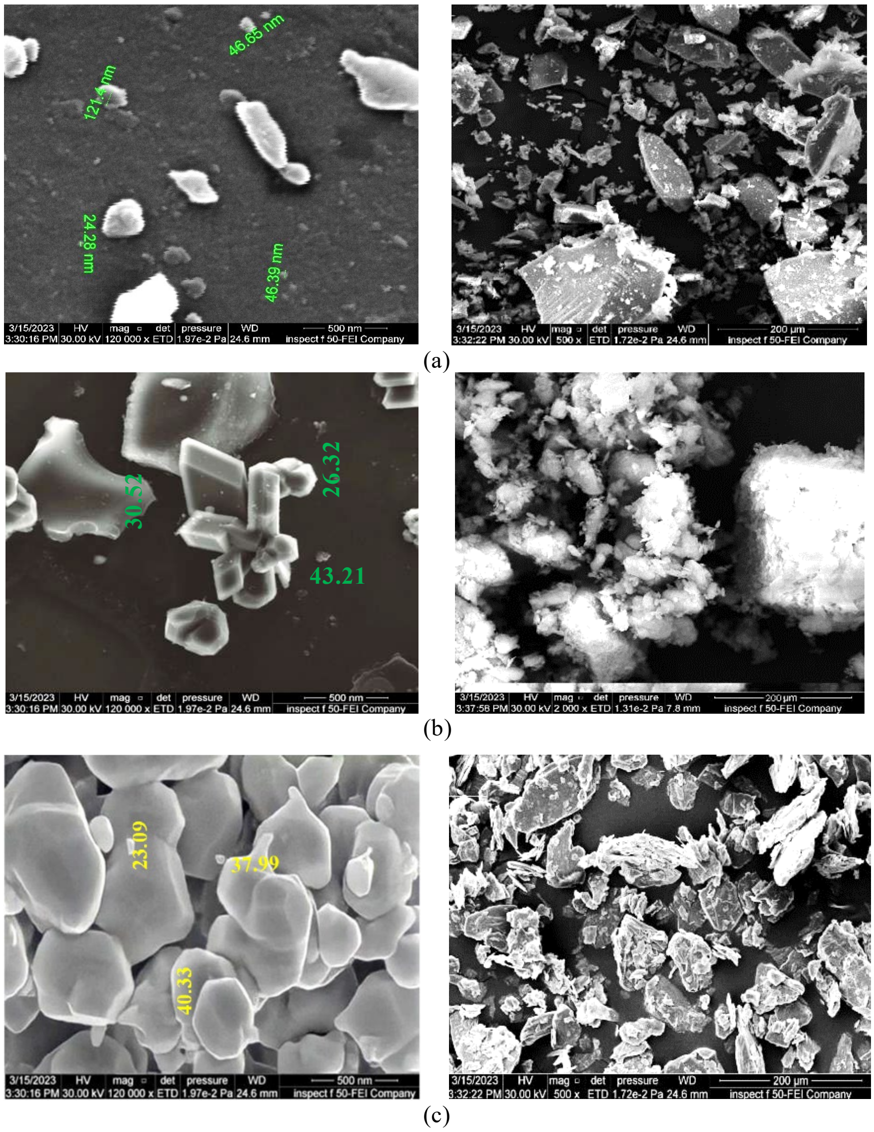


Figure 1: The SEM picture of (a) microscopic slide glass nanoparticles (MSGNP), (b) boron carbide (B_4C), and (c) tungsten carbide (WC)

Table 3: The chemical analysis of the clear glass powder (MSGNP)

Microscopic Slide Glass Nanoparticles									
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
Boron Carbide Nanoparticles									
Element	**B**	**C**	**B+C**	**B_2O_3**	**Si**	**Fe**		**N**	**W**
%	72.2	1.2	0.03	14.3	6.4	1.2		4.3	0.03
Tungsten Carbide									
Element	**W**		**Fe**		**Na_2O**			**C**	
%	98.89		0.11		14.3			4	

Table 4: The physical and mechanical properties of the additive nano powder [7, 12-13]

Physical/Mechanical	Unit	MSCNPs	B4C	WC
Density	g/cc	2.48	2.52	15.63
Hardness	Mohs	6	2.8	7.5
Color	-	Grayish White	Black	Black
Particle size	nm	35	33.50	36.42
Reflective index at 546.07	Nm	1.517	2.346	2.420
Poisson of Ratio	-	0.2	0.18	0.24
Annealing temperature	°C	545	-	-
Softening temperature	°C	720	-	-
Melting point	°C	-	2350	2870
Flexural Strength	MPa	520	550	350
Fracture toughness	MPa	0.9	4.6	3.8
Thermal properties				
Thermal conductivity	W/m.K	1.3	29	85
Coefficient of thermal expansion	10-6 mm	9	4.5	5.4
Specific heat	J/Kg.k	840	750	280

3. The Fabrication Method

3.1 The Reinforcement Materials

The suggested MMC was synthesized by using four various concentrations of compositions as shown in Tables 5 and 6, where the magnesium quantity is kept fixed at (2%), as the proportion of reinforcement materials was changed from (0%) to (10%). Additionally, a (1 wt.%) flux was added to remove the slug.

Table 5: Concentration of Al7075/MSGNP

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

Table 6: Concentration of Al7075/B4C-WC

Sample	Al7075 (%)	Magnesium (%)	B4C (%)	WC (%)	Cumulative of B_4C+WC
1	100	0	0	0	0
2	98	2	1	1	2
3	96	2	2	2	4
4	92	2	4	4	8
5	90	2	5	5	10

3.2 Stir-Casting Main Parameters

3.2.1 Preheating the reinforced particles

Preheating the reinforced particles is important to reduce their moisture content; otherwise, gases and moisture can result in the agglomeration of particles. Before blending the additive particles with the melt of Al, the temperature of additive particles was augmented to (400°C) for (1 hour) in a muffle furnace to improve wettability and remove the gases. The particle's humidity reduction will increase the surface energy and improve its interaction with the Al, as it creates further active particles in the matrix of Al and a smaller amount of porosity in the Al casting [18]. Care was taken to put every gram of powder in foil before being held into the furnace

3.2.2 Stirring speed

The stir-casting technique is highly dependent upon the stirring speed factor. The reinforcing particle dispersion into the melted metal can be achieved via a vortex generated due to the stirring speed's effect, and it's also obvious that the stirring raises the wettability. Also, the stirring rate directly influences the flow pattern of melted metal flow [19]. The elevated-speed rotating mechanical stirrers or the ultrasonic stirrers can achieve active mechanical stirring for enhancing the wetting between the reinforcing particles and the melted metal, regarded as a critical parameter for the uniform distribution of reinforcement particle dispersion in the melted metal [20]. Thus, in the current investigation, the used mean stirring speed was chosen to be (450 rpm) and lasted for around (2 min).

3.2.3 The added magnesium element to the molten matrix

The wettability of the Al melt with reinforcement particles can be enhanced via the alloying elements addition, such as Mg and Cr. Beyond removing slag from the melt, strips of Mg were supplemented to the melt to increase the liquid Al wettability because it reduced the surface tension. Mg doesn't merely raise the strength of alloy but also results in the formation of Mg oxide if it reacts with the O_2, which decreases the blowholes number that seems into the Al casting [21].

3.2.4 The preheating temperature of the mold

A steel mold was used to prepare the test specimens' casting. It was preheated to a temperature of (500°C). Preheating such mold is necessary as it helps remove the caged gas from the slurry, which would otherwise result in porosity [22].

3.2.5 The reinforcement particles' size

It has a significant determinant in the quality of the casting. The effect of utilizing various sizes of the silicon carbide (SiC) grit on the mechanical properties of AMC (Al+4%Cu+5%Sic) via the procedure of stir casting with varying temperatures of pouring (700, 725 and 750°C) was investigated [23]. It was obtained that the mechanical properties (impact hardness, impact strength, and tensile strength were enhanced by increasing the size of the grit of the SiC reinforcement particles. Thus, the effect of employing different proportions of MSGNPs, B_4C, WC, and MSGNPs upon the mechanical properties (tensile strength and hardness) of the producing composites was studied in the current work.

3.2.6 The pouring temperature

The distance between the crucible and the mold, rate of pouring, and temperature play a significant part in enhancing the Al-based MMCs' mechanical properties. To prevent gas entrapment, the pouring rate and the temperature must be homogenous [22]. Numerous investigators have investigated the effect of the temperature of pouring upon the AMCs' mechanical properties employing the procedure of stir casting. Also, the effect of utilizing (3) temperatures of pouring (800˚C, 820˚C and 840˚C) of Al/TiB_2 and (730˚C, 750°C and 770˚C) of Al/SiCp MMCs produced employing the procedure of stir casting was studied [24]. Additionally, it was obtained that a higher fracture toughness and tensile strength took place at the MMCs of Al/TiB_2 compared to the Al base alloy and the Al/SiCp MMCs. Furthermore, the ultimate hardness was attained at the pouring temperatures (750˚C and 820˚C) in the Al/SiCp and the MMCs of Al/TiB_2, respectively.

Furthermore, the effect of using (3) pouring temperatures while producing Aluminum SiC MMCs with additional benefits of Cu and Mg via the procedure of stir casting was investigated [25]. It was inferred that the pouring temperature has an important influence on the microstructure and the mechanical behavior, making it an important parameter to synthesize the Al/SiC/Mg/Cu composites. Therefore, in the present investigation, the temperature of the pouring of the melted composite was in the (700-720°C) range.

3.3 Fabrication of Aluminum Matrix Composites (AMCs) Via Stir-Casting

The stir casting technique is a simple and less expensive method of creating aluminum matrix composites (AMCs). Such a process involves mechanically blending the strengthening particles into a bath of melted metal, and then the resulting mixture is transported to a shaped mold exactly before it solidifies. The significant topic in such a procedure is getting a virtuous wetting between the strengthening particle and the melted metal. The composite sample was produced by utilizing the method of stir casting depicted in Figure 2a [26], ensuring a further homogenous distribution of the strengthening particles. The matrix (Al-7075) was firstly superheated at a temperature of (700°C) in the electric melting furnace shown in Figure 2b. After the alloy was totally melted, a powder of flux was supplemented as molten, helping eliminate the slag from the melt. If the slag is removed, the strips of Mg were supplemented to the molten, since the magnesium evaporates at (450°C). The warmed particles of glass in the muffle furnace displayed in Figure 2c of 2%, 4%, 8%, and 10% (via weight) were gradually placed into the slurry at a temperature of (720°C) as well as stirred with a stirrer made of stainless steel for avoiding the powder agglomeration and ensuring its homogenous dispersion. Such casting procedure was isolated by using the Argon gas pumped throughout a lateral tube. Figure 3 shows the produced composite samples.

The slurry temperature was increased to a liquid phase, and the spontaneous stirring was sustained for rotating for a time of (2 min) with a mean speed (450 rpm) of stirring. The melted composite was then straight poured into a mold made of steel and heated to a temperature of 500°C to produce samples for testing, as shown in Figure 2d. The same steps were applied with casting the Al-7075 alloy as the base material with a different weight percentage (0%, 2%, 4%, 8%, and 10%) of B_4C and WC-reinforced nanoparticles.

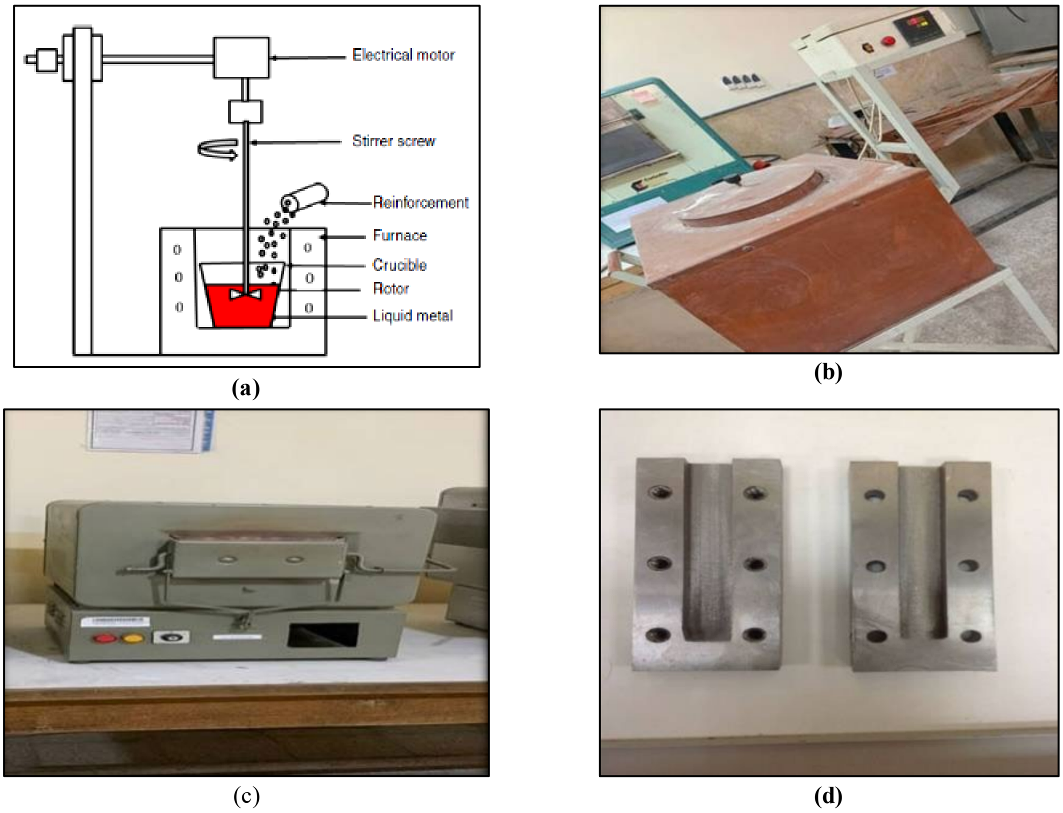


Figure 2: (a) stir casting setup [26], (b) the electric melting furnace, (c) muffle furnace, and (d) steel mold

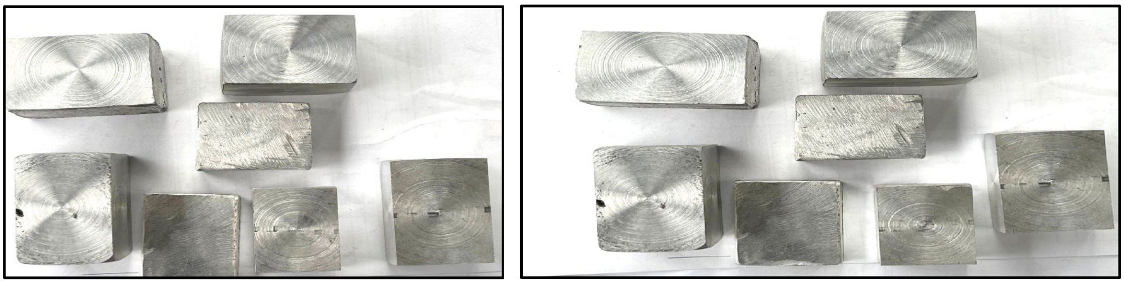


Figure 3: The produced composite samples

4. The Experimental Examination Details

Microstructure and mechanical properties of the fabricated matrix (Al-7075) reinforced with 0%, 2%, 4%, 8%, and 10% powders additives are considered in testing the specimens. For every test, (5) specimens from every mixture were evaluated, and the average result was computed for analysis. The particle dispersion in the manufactured composites was evaluated utilizing microstructural analysis. It was envisioned for understanding a reasonable dispersion of the particles of strengthening in the matrix (Al-7075). Additionally, the composites' microstructural features were tested using an optical microscope. Employing a JSM-7800 F excessive resolution analytical field emission scanning electron microscope equipped with an Energy-Dispersive X-ray (EDX) spectroscopy, the surface's morphology, and the elemental composition were also measured. The investigation of the microscopic composition of the samples was acquired at various stages of the metal's manufacturing. These stages can be summarized in the following steps:

The specimens were then mounted after being cut into small pieces, using a mixture of self-curing dental base acrylic resin in a powder form and a specific liquid, which must be combined very rapidly before being placed on the sample, allowed to dry and harden.

Using a disk-rotary grinding machine and water, an abrasive paper (SiC) was used to ground to several grades of smoothness, starting at 220, 320, 500, 800, 1000, 1200, and 3000. The used grinding machine type (DAP-5) works at (220 V) and (3 A).

The ground samples were polished until they resembled mirrors on polishing cloth using alumina (Al_2O_3) slurry. The polishing machine type (Metaserv) is powered by voltage (230 V-240 V) and current (2.85 A). The etching processes were implemented by employing Keller's reagent (95 ml distilled water, 2.5 ml HNO_3, 1.5 ml HCl, and 1.0 ml HF) and a DC power supply to show the microscopic structure of the produced composite material. When performing an SEM examination, the samples were first immersed in the solution, cleaned with tap water, dried with an air dryer, and then adjusted with the current values of (50 A) at the voltage (90 V) for a period of (45–55) seconds. In addition to the previous steps, it was coated with gold water to increase their electrical conductivity, allowing higher-quality SEM images to be produced.

The present phases in the fabricated workpiece composites were examined using the XRD analysis. All samples were scanned in a step of (2°) from (10°) to (90°) at a (2°/min) speed, whereas this analysis was run at (30 mA) and (40 kV). The XRD of the workpiece substances was examined using the backloading planning technique [27]. They were tested utilizing a PANalytical Empyrean diffractometer fitted with a PIXcel detector, CuKa 1 radiation, stationary slits, and a Fe filter (1.540598 Å) and using Crystal software. The tensile test was conducted according to standard (ASTM-E8) at room temperature, employing a WDW-200E universal tensile testing machine with an exerted (20 kN) load and a (0.5 s-1) rate of strain. Figure 4 reveals the used standard tensile test specimen.

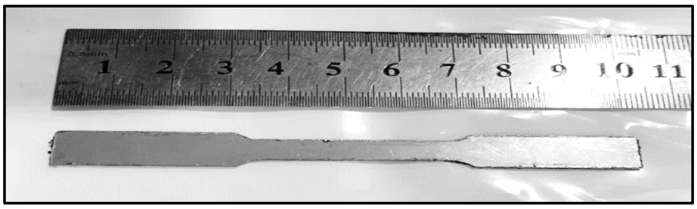


Figure 4: The tensile test specimen

Specimens of the test of hardness were arranged via polishing with different sizes of the abrasive grinding paper grit, pursued via the polishing process by a polishing machine for achieving mirror-like smooth surfaces. The Rockwell hardness number device was utilized for conducting the hardness test according to the standard ASTM E-18. The smooth surface samples were indented by a load of (10 kg) for a dwell time of (10 sec). The hardness value was obtained by calculating the mean of (4) measurements registered for every location upon the surface of the specimen. The Rockwell hardness no. was computed using the subsequent equation [28]:

$$RHN = E - h\,0.002 \quad mm \tag{1}$$

where: E: Constant that depends upon the indenter geometry (130 for a steel ball indenter and 100 for a diamond identer).
h: The lasting increment in the penetration depth owing to the chief load.

5. Results and Discussion

The chemical content of the fabricated workpiece materials Al-7075/MSGNP and Al-7075/B4C-WC are given in Tables 7 and 8, respectively. Table 7 displays the analysis of the Al-7075/MSGNP workpiece, which comprises silica, Al, Mg, and Fe. The first is increased by adding the glass nanoparticles to improve the tensile strength, hardness, corrosion, and rupture resistances at high-temperature conditions [29-30]. In addition, the produced workpiece presents other elements, such as nickel, manganese, zinc, copper, and caladium. The study results of the chemical composition for all Al-7075/B_4C-WC compositions were similar. There is a significant chemical reaction between MSGNP and aluminum particles. Table 8 demonstrates the presence of a carbide's composition of B_4C and WC. Large peaks of oxygen may also be seen alongside the carbon, reflecting the amount of oxidation that occurs throughout the stir-casting process and being the primary factor in the change of mechanical characteristics. The alloying constituents of the base matrix (Al-7075) are characterized via the Zn, Mg, Cu, Si, and Cr peaks.

Table 7: Chemical composition of the Al-7075/MSGNP

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	89.20

Table 8: Chemical composition of the Al-7075/B_4C-WC

Element	Wt.% composition	Element	Wt.% composition
Al	61.35	Si	1.43
O	17.87	B	1.22
C	8.52	Mg	1.09
Cu	6.95	Cr	0.58
Mn	4.78	W	0.42

5.1 The Microstructure Examination

A microstructural description of the composites was implemented to determine the way the MSGNPs were dispersed into the composites produced composites. Figure 5a depicts the Al-7075 microstructure with (0 wt.%) nano clear powder of glass, which revealed a virtuous metallurgical bonding between the aluminum particles. Figure 5b shows the Al-7075 microstructure having various percentages of the clear nano additives of glass, such as 2%, 4%, and 8%, respectively. It was observed that the MSGNP was found in the matrix inside the grains and at the grain borders.

If the concentration of MSGNP was augmented to about (8%) as shown in Figure 5d, a similarly dispersed MSGNP was found, and the porosity decreased compared to Figure 5c when the MSGNP concentration was 4%. Such enhancement was ascribed to the reinforcement's sufficiency and the uniform dispersion of MSGNP. Therefore, the addition of 8 wt.% was chosen in the present work.

Nevertheless, if the content of strengthening (MSGNP) is augmented to about (10 wt.%) as shown in Figure 5e, the microparticles of glass start to agglomerate, creating dark black zones into the matrix of Al-7075. Generally, the fair MSGNP dispersion into the composites is ascribed to the truth that the AMCs quality is governed via the glass particles wetting in the Al.

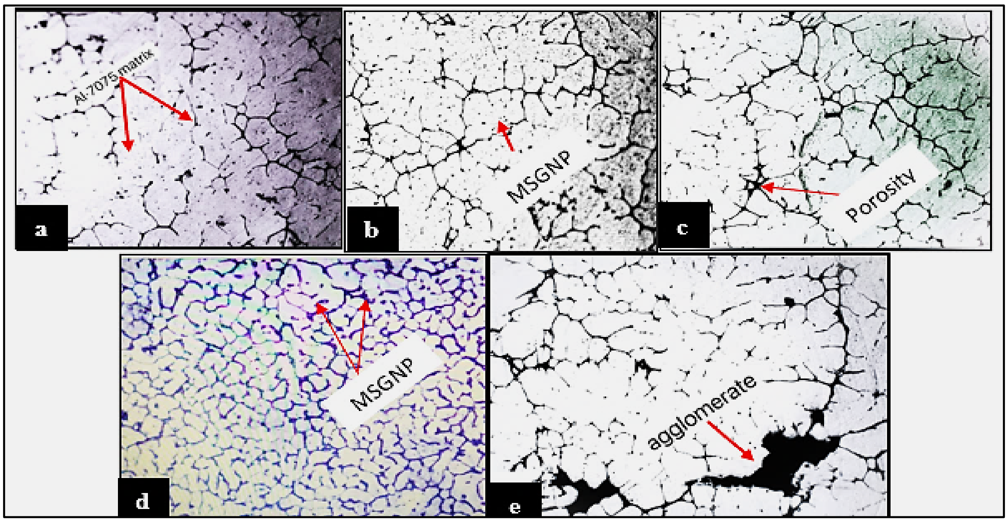


Figure 5: Images of the Al-7075 MMCs microstructure at 40x magnification; (a) 0 wt.% MSGNP, (b) 2 wt.% MSGNP, (c) 4 wt.% MSGNP, (d) 8 wt.% MSGNP, and (e) 10 wt.% MSGNP

Boron carbide (B4C) and tungsten carbide (WC) are distributed at certain locations in the matrix, such as grain borders and on the grains. The Al-7075 microstructure images with (0 wt.%, 2 wt.%, 4 wt.%, 8 wt.%, and 10 wt.%) B4C-WC, respectively are evinced in Figure 6 a to e. The dark black regions are present due to the accumulation of B_4C-WC during the stir-casting process. Figure 6 e manifests the dislocation of the particles from their place during the grinding process and leaving them with a trace of porosity, which created the most isotropic conduct of the composites that have a further tendency to reduce the mechanical properties. This is due to the ceramic particles wetting into the aluminum, and the difference in density and melting point between additive particles and aluminum matrix controls highly affects the quality of MMCs. Hence, increasing the weight percentage of the ceramic reinforcement particles increased the trapped air, resulting in higher porosity.

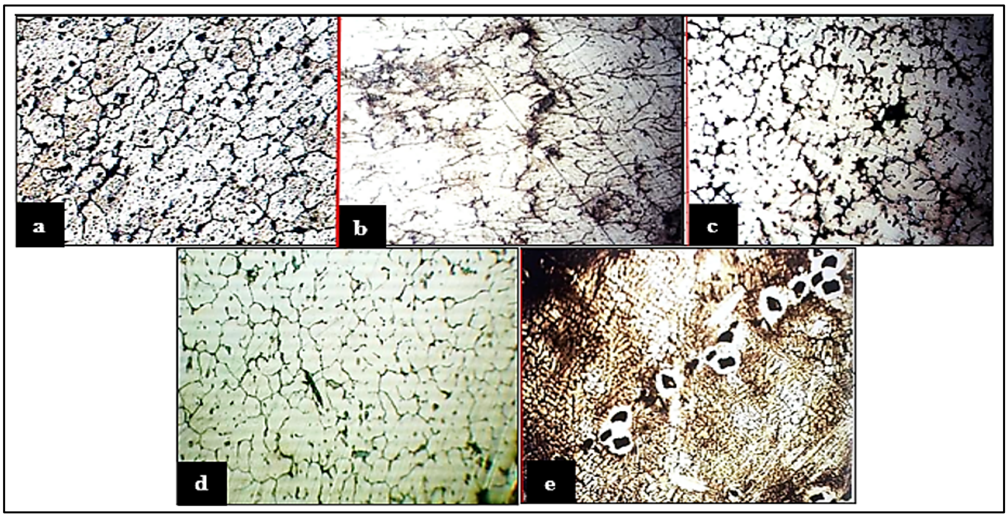


Figure 6: Images of the Al-7075 MMCs microstructure at 40x magnification; (a) 0 wt % B_4C-WC, (b) 2 wt.% B_4C-WC, (c) 4 wt.% B_4C-WC, (e) 8 wt.% B_4C-WC, and (d) 10 wt.% B_4C-WC

5.2 The Analysis of SEM and EDX

The images of SEM and the EDX patterns of Al-7075/MSGNP are portrayed in Figure 7 a-c. The EDX analysis was conducted to examine the adsorption of glass into the aluminum matrix and any other elements that might be present between the matrixes. Figure 7c of the analysis of EDX demonstrates the presence of silicon composition increases in composite material compared with Al-7075 base alloy. Al-7075 base alloying components are characterized by O, Na, and C peaks. The EDX analysis outcomes for the whole compositions of Al-7075/MSGNP were alike, as shown in Figure 7c for serving as an example for the SiO2 oxidation as well as its existence; therefore, the (8 wt.%) workpiece composition was chosen in the present work. Table 9 views the chemical composition of Al-7075/MSGNP that has been listed per EDX.

Figure 8 a-c displays the SEM image and the EDX analysis of Al-7075 8% wt% B4C-WC composite. The analysis was performed to examine the adsorption of B4C and WC into the matrix of Al and the other components that might exist in the matrixes, as elucidated in Figure 8a. From the analysis SEM, the presence of a carbonaceous composition in the composites confirms the presence of B4C and WC in Figure 8b. Large peaks of oxygen may also be seen alongside the carbon, reflecting the amount of oxidation that occurs throughout the stir-casting process and being the primary factor in the change of the mechanical characteristics. Al-7075 base alloying components are characterized via the Zn, Mg, Cu, Cr, and Si peaks. The EDX analysis shown in Figure 8c outcomes for the whole compositions of Al-7075-B4C-WC were alike; therefore, the (8 wt.%) weight was chosen for the fabrication of the workpiece material as previously concluded from Figure 3 for serving as an example for the B4C-WC oxidation as well as its existence. Table 10 illustrates the compositions that were listed per EDX results.

Table 9: Chemical composition of the Al-7075/MSGNP via the 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

Table 10: Chemical composition of the Al-7075-8 wt.% B4C-WC via EDX

Element	Wt.% composition	Element	Wt.% composition
Al	61.35	Si	1.43
O	17.87	B	1.22
C	8.52	Mg	1.09
Cu	6.95	Cr	0.58
Mn	4.78	W	0.42

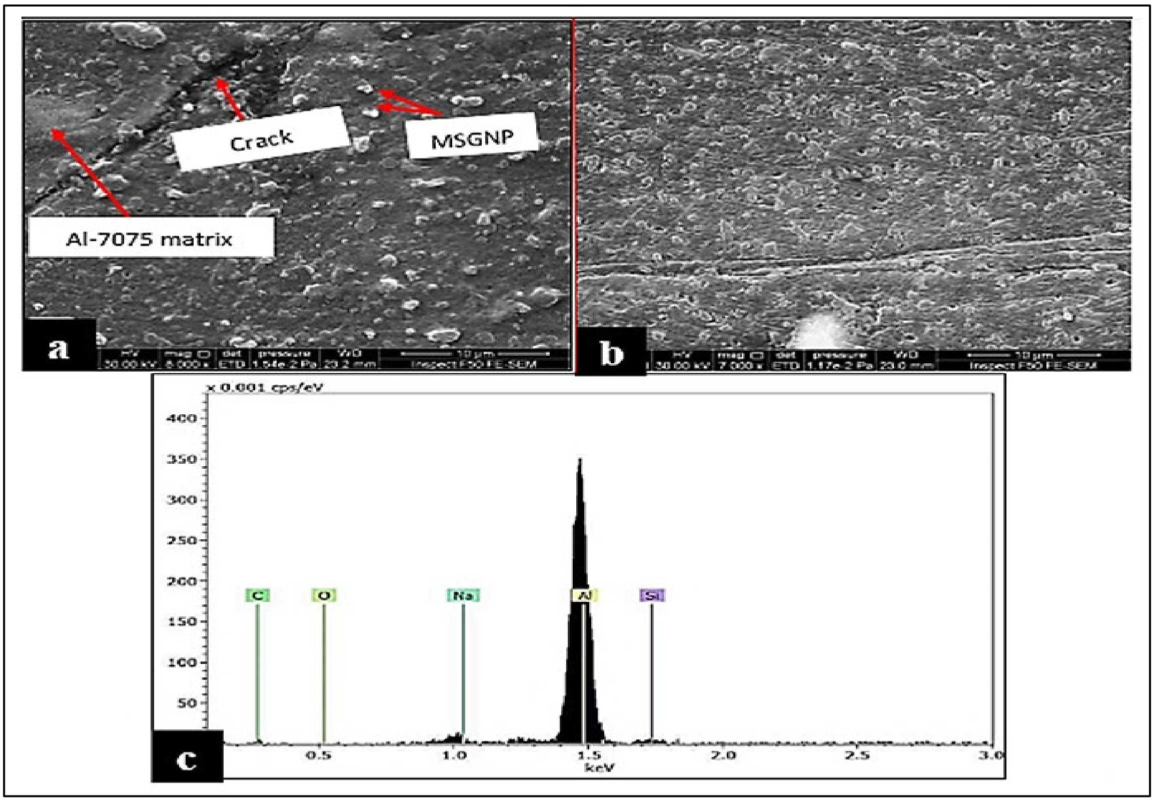


Figure 7: (a) SEM micrographs of the MMCs, (b) MMCs EDX analysis, and (c) The Al-7075-8 wt.% MSGNP spectrum

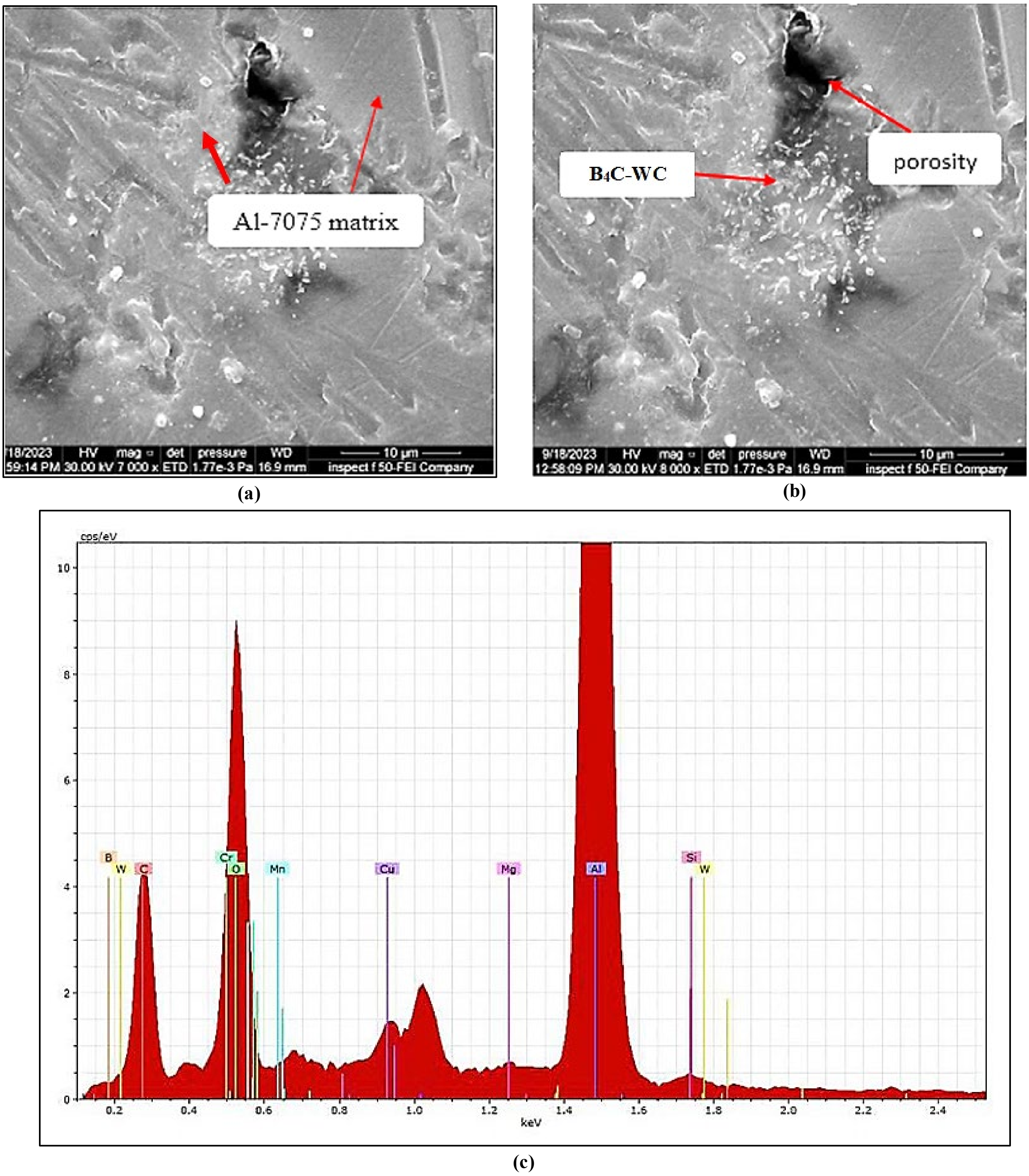


Figure 8: (a) SEM micrographs of the MMCs, (b) MMCs EDX analysis, and (c) The Al 7075-8 wt.% B_4C- WC EDX spectrumChemical composition of the Al-7075-8 wt.% B_4C-WC via EDX

5.3 The XRD Analysis

Figures (9 and 10) show the X-Ray Diffraction (XRD) examination results. These figures illustrate the various phases of the 2 theta value-generated diffraction patterns for the Al-7075/MSGNP and Al-7075/B4C-WC workpieces materials, respectively. The phases in the composites phases were varied due to the two different theta values. These phases were recognized via the analysis of XRD, characterized by their strong peak intensities, which surely included the SiO_2, as shown in Figure 9. The Figure also shows that the matrix of Al and the clear glass are the two major composite constituents. Figure 10 shows that they contain B, WC, and aluminum matrix, which is consistent with what was shown by the optical microstructure of the composite.

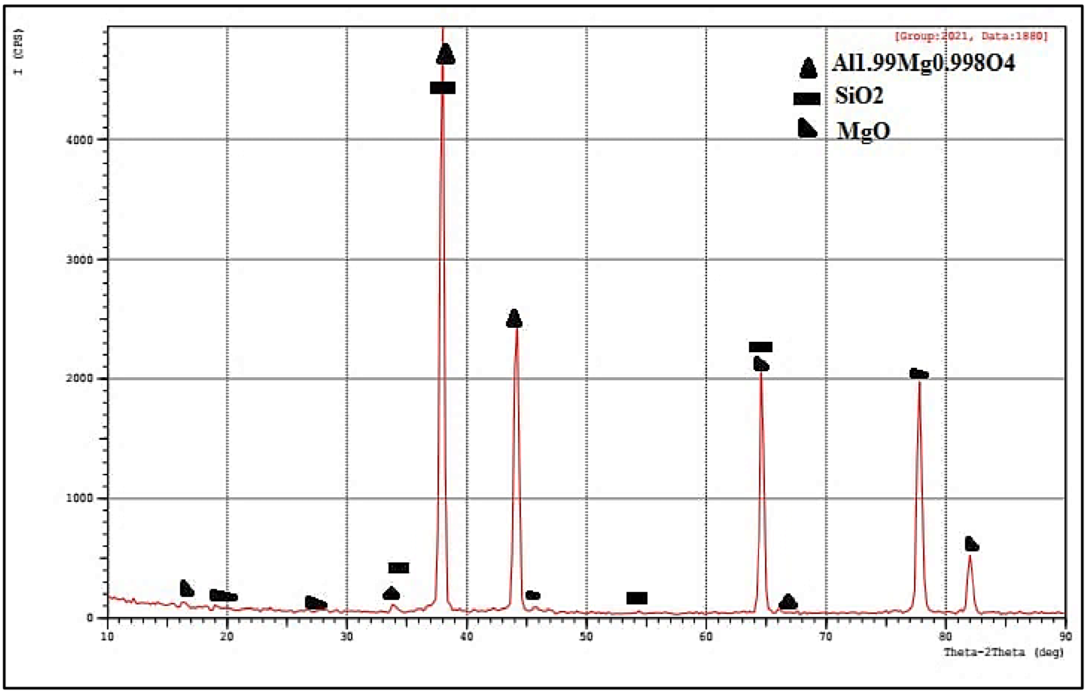


Figure 9: The XRD pattern of composite samples analysis of Al-7075/MSGNP workpiece material

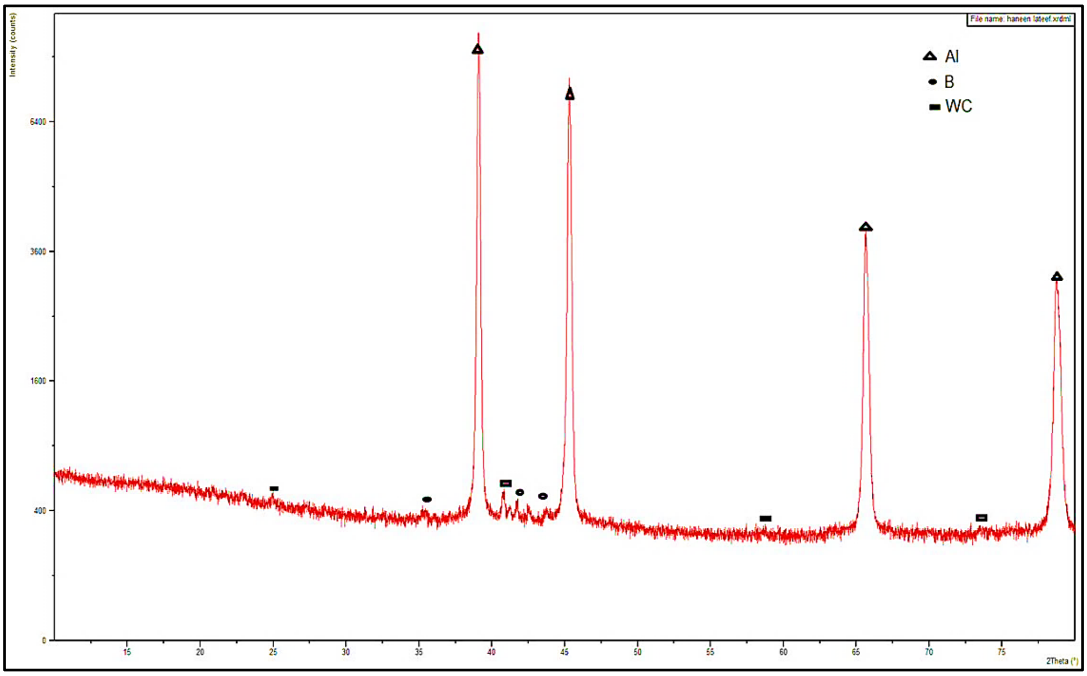
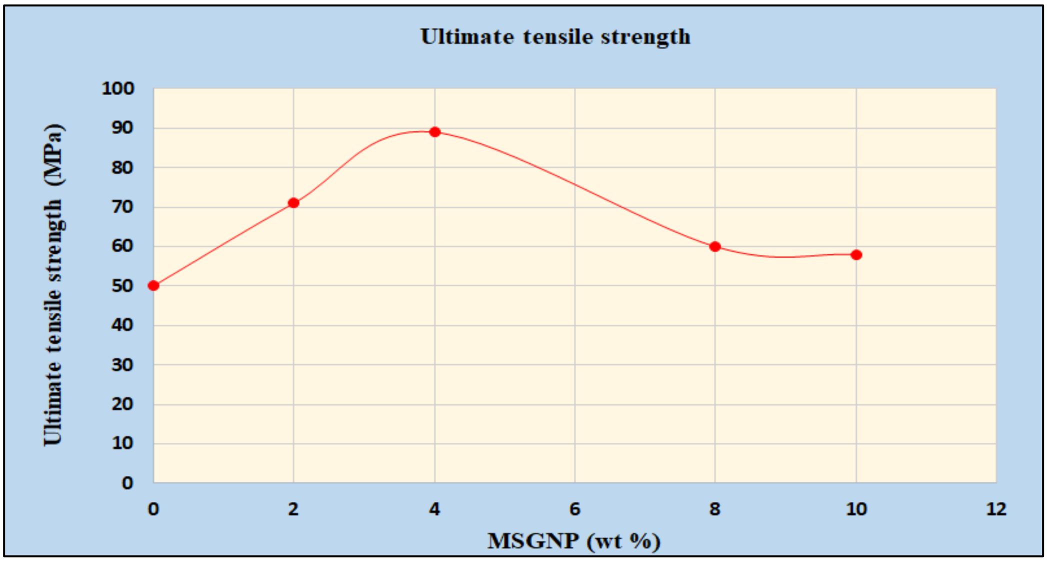


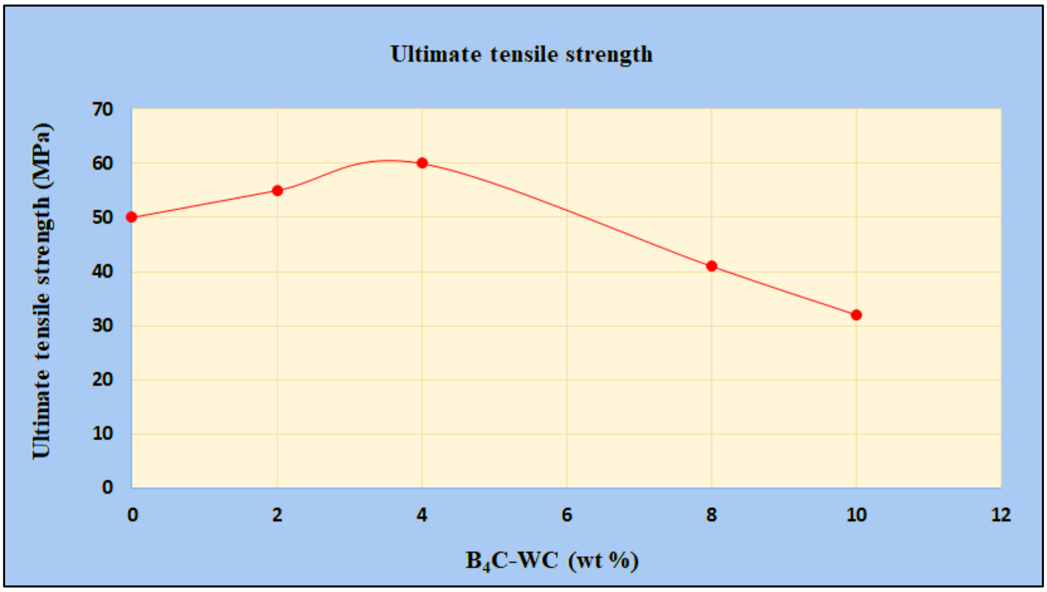
Figure 10: The XRD pattern of composite samples analysis of Al-7075/B_4C-WC workpiece material

5.4 The Mechanical Properties

The ultimate tensile strength of the workpiece samples Al-7075/MSGNP is shown in Figure 11a. The mean tensile strength values for the (0%, 2%, 4%, 8%, and 10% wt.%) of MSGNP were measured to be (50, 71.2, 89.16, 60 and 58.3 MPa), correspondingly. It shows that the value of the composite's ultimate strength was enhanced with the additive concentration of nanoglass. The maximum tensile strength was obtained for the sample (3) comprising 4% MSGNP. Some other studies have observed similar patterns, and this is due to the elevated glass particles' wettability with the matrix of Al. Also, the wettability effect is reduced by increasing the concentration of the added nano particles, which leads to a decrease in the bonding strength between the Al alloys and the particle reinforcement owing to the agglomeration of particles. If the AMCs are stressed, the matrix dislocation mobility is constrained by the particles, restricting the plastic flow. This might clarify why the tensile properties of AMCs have enhanced and the other mechanical attributes, like the compressive strength and stiffness [31-33]. The increased nano glass content to 10% wt. Reduced the ultimate strength compared to the value achieved when adding 4%. The cause for such reduction can be ascribed to the multiplication of dislocation, which results in the accumulation of dislocation, hampering the further deformation, and the outcome will lead to failure. Figure 11b shows the effect of B4C and WC nano additives carbides upon the ultimate tensile strength of the matrix of Al. The mean ultimate strength values for the (0%, 2%, 4%, 8%, and 10 wt.%) of reinforced B4C-WC samples were measured to be (50, 55.3, 60.6, 41.4, and 32.3 MPa), respectively.



(a)



(b)

Figure 11: The ultimate tensile strengths for the produced workpieces of; (a) Al-7075/MSGNP; (b) Al7075/B4C-WC

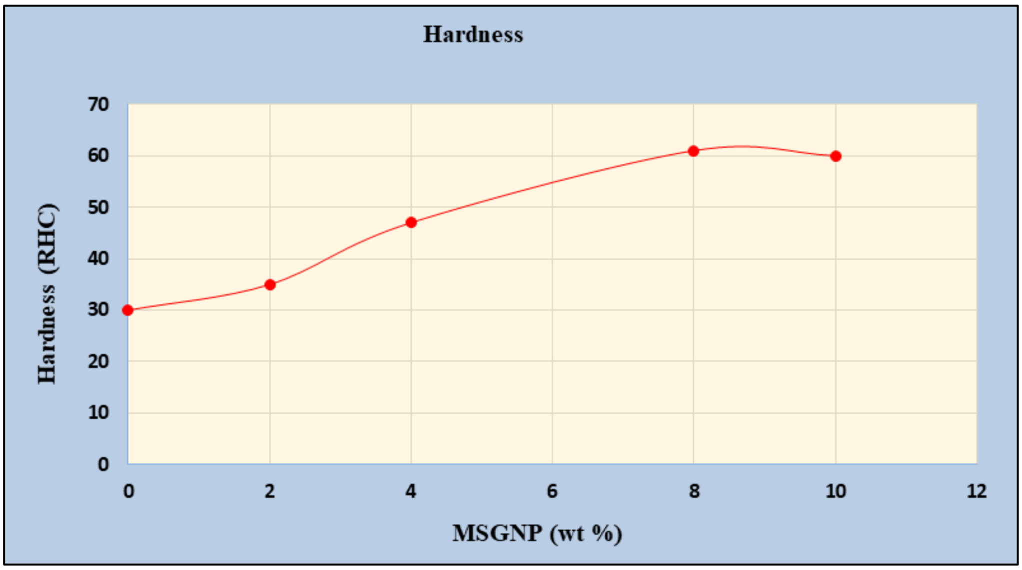
Ultimate tensile strength was augmented by increasing the percentage value of reinforcement metal. This increment is due to the role of particles, which tend to restrain the movement of the matrix in their vicinity and tend to impede the dislocation motion.

5.4.1 The microhardness analysis

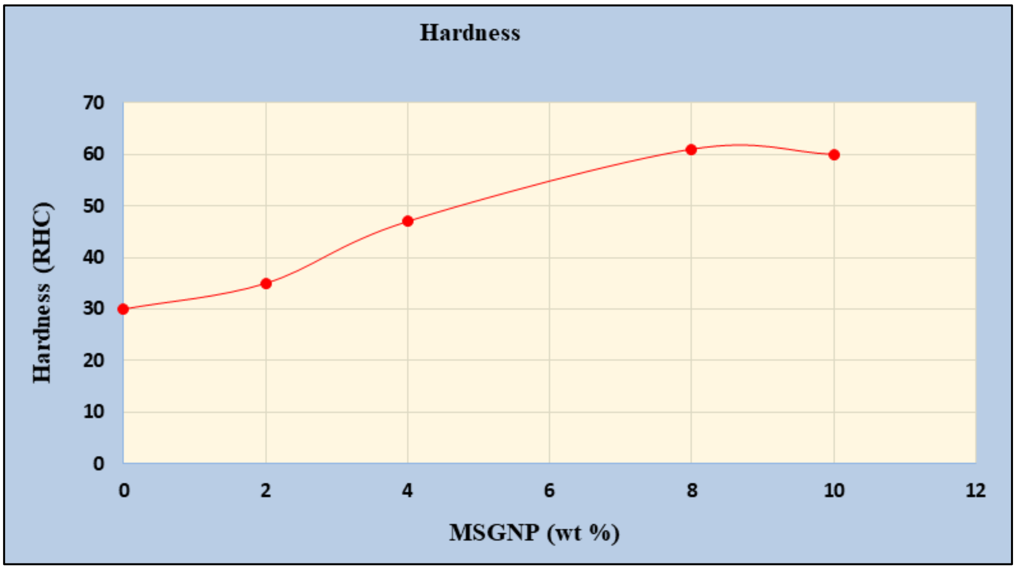
Figure 12a demonstrates the influence of adding MSGNP strengthening to the Al alloy on the values of the microhardness of workpiece composites. The average values of the obtained microhardness of used samples for the (0%, 2%, 4%, 8%, and 10 wt.%) of MSGNP were (30, 35, 47,61, and 60 HRC). The reason for the decrease in the ultimate tensile strength value while the hardness increases in the produced Al-7075/MSGNP composites alloy with added nanoparticle content of 8 and 10% can be explained by the fact that the agglomeration of reinforcing particles in 8 wt.% and 10 wt.% samples cause poor wettability between the particles and the matrix, and the obtained bonding was weak, which led to a decrease in the strength, although the increase in the nano-additive increases the generation of brittle carbides, which leads to an increase in hardness.

The composite having 8 wt.% MSGNP revealed the uppermost value of hardness, and this means that the composite material hardness was increased by increasing the strengthened particles (MSGNP) weight percentage. This is owing to the existence of very hard ceramic particles (MSGNP) in the matrix of Al alloy, which represents a vigorous restriction to the localized deformation of the matrix through the indentation [34], as well as a uniform dispersion of the particles of MSGNP.

Figure 12b manifests that with the addition of B4C and WC reinforcement carbides to the aluminum alloy, the obtained hardness measurement results were (30, 42.7, 47.3, 50, 41.1, and 28 HRC) for the composites produced by adding (2%, 4%, 8%, and 10 wt.%) of B4C and WC, respectively. The composite with 6 wt.% B4C and WC have the highest hardness value, which means the increase of the B4C and WC composite material beyond 10% will decrease the hardness due to the poor wettability between the aluminum matrix and the reinforcement.



(a)



(b)

Figure 12: The microhardness of the fabricated workpiece of; (a) Al-7075/MSGNP; (b) Al-7075/B_4C-WC

6. Conclusion

In the present experimental work, the Al-7075/MSGNP and Al-7075/B_4C-WC nanocomposites have been synthesized via stir casting, increasing the strengthening particles' volume percentage. The experiment's objective is to select the appropriate type and percentage of the strengthening particles for producing Al-7075 composite materials with the best mechanical properties. The following are the drawn conclusions depending on the results of the current work:

1) Al-7075/MSGNP and Al-7075/B_4C-WC evinced a reliable distribution of the reinforcement particles at (8 wt.%). Nevertheless, if the reinforcement content is augmented to about (10 wt%), the nanoparticles start to agglomerate, creating dark black zones in the matrix of Al-7075 alloy.
2) The peak of ultimate tensile strength was at the (4 wt.%) integration rate for all reinforcement particles; after that, this strength declined.

3) The Rockwell hardness slowly augmented if the MSGNP particle addition was elevated from (0 wt.%) to (10 wt.%). While using (10 wt.%) B_4C-WC resulted in lower hardness than (0 wt.%) B_4C-WC.
4) Increasing the reinforcement content to no more than (10 wt.%) increases the trapped air, results in higher porosity, and decreases the strength and the hardness of the composite due to the poor wettability between aluminum and reinforcement as well as the captured bubbles and gas through the procedure of manufacture.
5) Generally, the MSGNP nanoparticles have fair distribution in composites. In addition, the ultimate tensile strength and hardness obtained with Al-7075/MSGNP were higher than Al7075/B_4C-WC.

Author contributions

Conceptualization, H. Lateef and S. Ali; writing—original draft preparation, H. Lateef and S. Ali; writing—review and editing, H. Lateef and S. Ali; supervision, S. Ali. All authors have read and agreed to the published version of the manuscript.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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