JJMIE

Volume 17, Number 3, September. 2023
ISSN 1995-6665
Pages 319– 326
https://doi.org/10.59038/jjmie/170301
Editor-in-Chief: Prof. Ali M. Jawarneh

Jordan Journal of Mechanical and Industrial Engineering

Fabrication of Al-6061/SiC Nano Composite Material Through Ultrasonic Cavitation Technique and Its Analysis

Abdul Kalam Azad[1*], Mohamed Fayas Saffiudeen[2], Abdullah Syed[2], Fasil T. Mohammed[2]

[1]Department of Chemical Engineering and Technology, Jubail Industrial College, Jubail Industrial City 31961, Kingdom of Saudi Arabia.

[2]Department of Mechanical Skills, Jubail Technical Institute, Jubail Industrial City 31961, Kingdom of Saudi Arabia.

Received 28 Mar 2022 Accepted 4 jul 2023

Abstract

A material with high strength and low weight plays a vital role in aerospace and automotive industries. Aluminium metal matrix composite is one such material which is mainly produced using stir casting technique. However, the improper control of process parameters such as stirring time, feeding techniques, temperature control of this technique can lead to Porosity and Agglomeration in the composite. The above problems are well addressed by carrying out the innovative ultrasonic cavitation technique with the usage of stepped ultrasonic horn, cooling system and furnace processor. Introduction of ultrasonic wave in the liquid stage molten metal helps better mixing of Nano Silicon carbide (SiC) powder in the composite material of liquid state. In addition to the above, the ultrasonic wave induces the formation of newer grains thereby reduces the grain size of metal matrix. Moreover, it will significantly improve the strength, hardness and wear resistance. The molten aluminium 6061is reinforced with 0.3 to 1.5 volume % of Nano SiC particles and its uniform dispersion is confirmed with the steady increment in Brinell hardness value from 58 to 101 after each loading of SiC. The mechanical properties such as tensile strength, ductility and hardness are investigated and the distribution of particles were estimated by scanning electron microscope.

Keywords: Metal matrix nanocomposites; Aluminium 6061;Horn; Ultrasonic cavitation; Microstructure.

1. Introduction

Nanocomposites (NC) are multicomponent materials having nanoscale (10^{-9}m) particle insertion in one of the phases. They are likely to have surprising characteristics as a result of the fusion of each component. Ceramic matrix nanocomposite (CMNC)[1], polymer matrix nanocomposite (PMNC)[2,3]and metal matrix nanocomposites (MMNCs)[4] are the three main types of nanocomposites depending on their matrix. MMNCs have been explored during the last three decades, and their potential benefits over traditional monolithic alloys are becoming more recognized. Due to the high strength, low density, stiffness and high temperature resistance, aluminium based metal matrix composites have been used in aerospace, automobiles, military, gas turbine engine, space and structural applications [5].So far, the highest commercial quantities have been recognized for aluminum matrix composites which account for 69 % of the annual MMNCs mass production. Better yield strength and ultimate tensile strength have been demonstrated with the use of ceramic micro particles in the composite, although ductility is decreased as the weight % of reinforcements in the matrix increases which bounds its usage. Numerous studies have shown that adding nanoscale ceramic reinforcement can increase characteristics while maintaining ductility. Since the high temperature, strength and modulus retention of most ceramics are far larger than those of the metal matrix, the high temperature performance is also dramatically enhanced with the incorporation of nano-ceramic particles[6].

Both solid and liquid state processing techniques were utilized to create these composites, while the latter having the benefit that the fluidity of the metal allows for the use of a broad variety of reinforcements and the capacity to generate near net shaped casting. Some standard techniques for liquid state fabrication of MMNCs reinforced with powders, fibers and whiskers are stir casting, squeeze casting, spray deposition and In-situ. However, it is difficult to disperse nanoparticles uniformly in the metal composite and it could be possible by utilizing the technique of combined solidification process with ultrasonic cavitation developed by Lan et al. [7]. Porosity, agglomeration and uneven distribution of nano particles are the foremost issues in aluminium based MMNC which could be overcome by the newly developed cavitation as it increases the effectiveness of ultrasonic degassing by between 30 and 60%. Under optimal circumstances, ultrasonic degassing can more than reduce the hydrogen concentration of ingots and castings while also enhancing their density and plasticity. Deformed

* Corresponding author e-mail: azad_a@rcjy.edu.sa.

semi-finished products can be more reliably used when as-cast metal has retained strength. It is significant to note that oxide flotation occurs concurrently with the bubble-assisted hydrogen removal. In this case, cavitation develops and forms on the non-wettable surface of these oxide particles. The fluidity (length of spiral) of A1/Si-Mg alloy is 500 mm without treatment, 550 mm after argon blasting, and 670 mm after ultrasonic treatment, making this effect quite obvious. A thorough assessment of recent experimental, theoretical, and numerical work on characterizing the mechanical properties of nano composites was provided by Hurang Hu et al. [8]. According to micromechanics theories, for typical composite materials, the constituent quality, constituent volume %, inclusion form, orientation and state of dispersion all affect the composites overall mechanical properties. The link between the filler and the matrix as well as the elements mentioned above play a role in how much the mechanical properties of nanocomposites increase [9].

Numerous research work has been carried out to reinforce the aluminium with a variety of nano materials as it plays a vital role in enhancing the properties of MMNC. The iron aluminate ($FeAl_2O_4$) formed as a result of reactive sintering between iron and alumina particles improves the wear, density, hardness, deformation, and corrosion resistance of the iron-based aluminum MMNC constructed by Gupta et al.[10]Jamwal et al. introduced titanium carbide (TiC) along with aluminium oxide (Al_2O_3) in aluminium (Al-1100) matrix to fabricate the Al/Al_2O_3-TiC nano composites using stir casting process and reported that the tensile strength is improved from 120.4 up to 149.3 MPa due to strong interfacial bonding of matrix material with Al_2O_3 and TiC. Moreover, the wear rate is decreased with an increase in the reinforcement content over the range of 0-20 wt.% [11].Vinod et al. examined the physical and mechanical properties of agro waste (rice husk ash/fly ash) incorporated onto the aluminium A356 matrix by double stir casting process.It has been discovered that the addition of both organic and inorganic particles enhances the mechanical properties of composites [12].Donthamsetty et al. investigated and compared the hardness and tensile strength of A356 reinforced with various nanomaterials at the same weight proportion to pure alloy. The reinforcements are evidently evenly distributed throughout the matrix of aluminum. Thus the addition of nanoparticles enhances the tensile characteristics and hardness while reducing the ductility. Although there is a reduction in ductility in each case, it is still within the acceptable range, or 4-6% of A356 alloy [13].

Al-SiC metal matrix composites' yield strength, ultimate strength, and ductility were examined by A. C. Reddy et al.The Al 6061 matrix alloy is shown to contribute more ultimate tensile strength (UTS) than the Al 6063 and Al 7072 matrix alloys. Compared to Al 6063 matrix alloy, Al 7072 matrix alloy has a lower UTS. The difference in matrix alloy has a significant impact on the ductility of composites [14]. Al-SiC composites have substantially lower ductility than unreinforced aluminum alloy. The matrix alloys of Al 6061, Al 6063, and Al 7072 have the lowest ductility. In their analysis of the ultrasonic melt degassing, G.I. Eskin et al. identified a significant link between hydrogen removal and cavitation production [15]. It is observed that the thermal properties like thermal conductivity, coefficient of thermal expansion, thermal diffusivity have been enhanced than the base matrix as reported by Jiang et al. [16]. According to investigations by Bandil et al., the SiC integrated Al matrix reduces the density of the manufactured composite. SiC particles provide a lubricating coating on the counter surface, which lowers the wear rate of composites as well as the coefficient of friction. Preheat temperature, size and wt % of SiC particles plays the significant role in reducing the corrosion rate [17]. The highest corrosion protection efficiency is observed at 20 wt.% SiC, where uniform dispersion of SiC particles results in a maximum corrosion protection efficiency of 56.58% [18]. Gangwar et al. utilized the hybrid fuzzy Preference Selection Method (f-PSI) to select the alternative material for ship, based on the physical, mechanical and corrosion characteristics of a novel hybrid aluminium composites. Besides, varying proportions of zirconium oxide, SiC was incorporated into the al matrix by means of stir casting method to achieve the sufficient properties for ship body applications [19].

In the present study, silicon carbide (SiC) particles with a mean size of 40–65 nm were used to strengthen the Al 6061–T6 base matrix due to its better thermal conductivity, stiffness, high wear resistance and excellent dielectric properties. Utilizing ultrasonic cavitation, Al 6061-T6 MMNCs were made, and the dispersion of SiC particles throughout the range of 0.3% to 1.5% of reinforcement was studied along with its mechanical characteristics, such as ultimate tensile strength and hardness.

2. Materials and Methods

2.1. Design of Ultrasonic Horn

The ultrasonic horn, which transmits ultrasonic waves from the booster to the molten metal is a crucial component of an ultrasonic cavitation machine. As proposed by Gurrappa et al. [20]. For the fabrication of components appropriate for usage in chemical environments, the titanium alloy Ti 6Al-4V was selected to ensure an efficient ultrasonic wave transmission. Additionally, it can develop protective oxide scales on its surface in various types of chemical, acidic, marine, and industrial environments at both low and elevated temperatures. Physical properties and chemical composition of Ti 6Al-4V data sheet were obtained from MAHER company, U.K. as displayed in Table 1 and 2. Stepped horns were chosen for this work over other types of horns because they are easy to construct, manufacture and produce the most vibration amplification [21]. Thehorn's diameter and length were used, as indicated in Figure 1.

Table 1. Physical properties of Ti6Al-4V

Material	Melting point (°C)	Modulus of elasticity (GPa)	Shear modulus (GPa)	Poissons ratio	Density (g/cm^3)	Thermal conductivity (W/m^{-k})	Specific heat (J/g.°C)
Titanium alloy Ti 6Al-4V	1604-1660	114	44	0.33	4.43	6.7	0.5263

Table 2. Chemical Composition of Ti6Al-4V

C	**N_2**	**O_2**	**Al**	**V**	**H_2**	**Fe**	**Ti**
0.08%	0.05%	0.2%	5.50%	3.5-4.5%	0.01%	0.30%	Balance

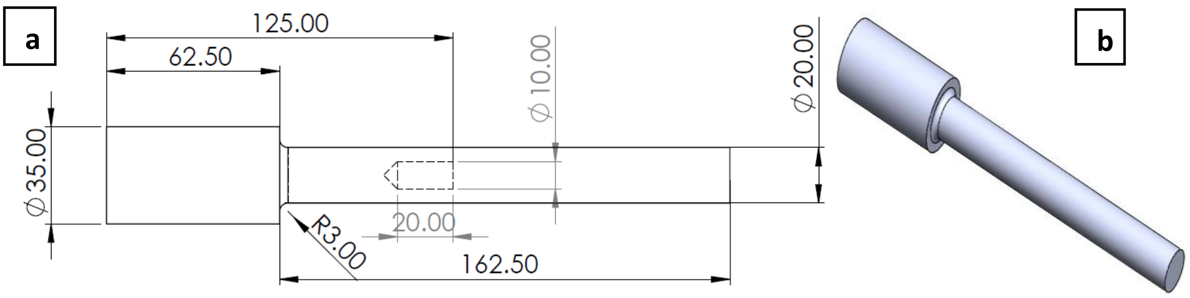

Figure 1. Amplitude of vibration and stress development in horn, all dimensions are in mm (a) 2D (b) 3D view

2.2. Design of Horn Based on Calculation

Sound velocity $(c) = \frac{\sqrt{E}}{\rho}$ (1)

$$= \frac{\sqrt{114E9}}{4430} = 5072.83 \text{ m/s}$$

Wave length $(\lambda \max) = \frac{\text{sound velocity (c)}}{\text{frequency (f)}}$ (2)

$$= \frac{5072.82}{20000} = 250\text{mm}$$

Length of the horn $= \frac{\lambda}{2}$ (3)

Input amplitude (a_{in}) = 20µm

Output amplitude $(a_o) = a_{in} \left[\frac{d_1}{d_2}\right]^2$ (4)

$$= 10 \times 10^{-6}(0.035/0.020)^2 = 31\mu m$$

Where d_1 and d_2 are step diameter of Horn

Max stress on node= $\pi E\, a_o / L$ (5)

$$= 3.14 \times 114 \times 10^3 \times 31 \times 10^{-6} / 0.125$$

$$= 88.82 \text{ Mpa}$$

2.3. Design of Cooling System

Given parameter max. operating temperature 1000°C
Thermal conductivity of Titanium = 21 W/mK
Temperature at node1= 750°c
Area at node 1 = $9.62 \times 10^{-4} m^2$
Area at node 2 = $9.62 \times 10^{-4} m^2$

Figure 2shows the cooling system for Horn which is provided to avoid failure of transducer from high temperature.

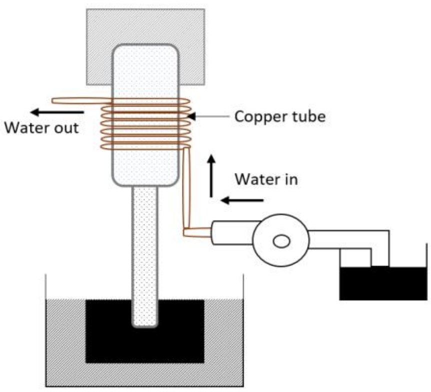

Figure 2. Cooling System of Horn

2.3.1. Fourier law of heat conduction

$Q = \frac{-KAdt}{dx}$ (6)

Where, Q is heat transfer rate
A is heat transfer area
dx is length heat transfer
dt is temperature difference

$$Q = \frac{K \times \Delta T}{dx/A} = \frac{K \times \Delta T}{\frac{L_1}{A_1} + \frac{L_2}{A_2}} = \frac{2.19 \times (750 - T_2) \times \Delta T}{\frac{0.0425}{3.14 \times 10^{-4}} + \frac{0.0625}{9.62 \times 10^{-4}}} = 4500 \text{ watts}$$

Temperature at node (T_2) = 415 °C
$Q = m\, C_p\, \Delta t$
Mass flow rate of water (m) =$Q/ C_p\, \Delta t$
m = 4500/4816×(415-25)
Mass flow rate of water (m) = 0.16 Kg/min

2.4. Design of Furnace

A resistance furnace comprises primarily of a crucible, resistance coil, and shell, as well as a cooling system, in which heat is freed and transmitted directly to solid charge mass for the goal of effecting a physical or chemical change. In order to achieve effective manufacturing of composite, the resistance furnace has been considered as following.

Minimum amount of material required = 1.5 kg

$$\textbf{Volume of material} = \frac{\textbf{mass}}{\textbf{density}} = \frac{1.5}{2.7 \times 10^{-3}} = 555.5\textbf{cm}$$

Total volume of material= vol. of material + vol. of slag +allowance = 555.5+145 = 700 cm^3

Volume of metal charge = $(\pi d^2 / 4)$ H (7)

$700 = (3.14 \times d^2 /4) \times 1.6d$
Height to diameter ratio (H/D) = 1.6 - 2.0
Diameter of the crucible = 82.5 mm
Height of the crucible = 132.5 mm

2.5. Selection of Material

Aluminium alloys are metal alloys in which aluminum (Al) is the core ingredient. Copper, magnesium, manganese, silicon, and zinc are instances of alloying elements. Casting alloys and wrought alloys are the two major kinds, which are further subdivided into heat-treatable and non-heat-treatable subclasses[22].Wrought items, such as rolled plate, foils, and extrusions, account for around 85% of aluminum production. Each wrought alloy is assigned a four-digit number by the IADS (International Alloy Designation System). The principal alloying ingredient is indicated by the first digit. Modifications in impurity limits or alloying elements are indicated by the second digit. Unalloyed aluminum with natural impurity limitations has a second number of zero; numbers 1 to 9 imply particular control of one or more particular impurities or alloying components. The final two numbers serve only to differentiate between the various aluminum alloys in the group. Aluminium alloy 6061 is a medium-strength alloy that is widely used in manufacturing. It is one of the most frequently used aluminum alloys for everyday use as shown in table 3, that offers excellent properties and applications [23, 24, 25, 26, 27, 28].

Table 3. Features and applications of Aluminium as a core matrix in MMNCs.

Nano materials	Features of MMNC	Applications
Graphite	Call resistance, reduced friction, wear and weight, self-lubricating, lighter, less expensive, and conserves Lead, tin, zinc, copper.	Bearings, cylinders
Glass/carbon bubbles	Light material	Automobile and aerospace
Zircon/silicon alloy	Tough, abrasion resistant materials.	Impeller, shrouds for machine, cutting tools
SiC particles	Better specific stiffness, strength, wear resistance and compact in weight	Brake rotor, piston, caliper and liner Propeller shaft
SiC whiskers	Low coefficient of thermal expansion, Reduced reciprocating mass, better specific strength and stiffness	Connecting rod, Turbocharger
Graphite/Al_2O_3/SiC	Enhanced effectiveness, reduced wear, anti-seizing, cold start, lightweight, and fuel-efficient.	Piston rings, cylinder liners, connecting rods, and automobile pistons
Al_2O_3	Improved strength and stiffness	Connecting Rod
Short Al_2O_3 fibers	Wear resistance, high operating temperature, reduced reciprocating mass, high creep and fatigue resistance	Piston crown, Piston ring
Long Al_2O_3 fibers	Improved strength, stiffness and reduced reciprocating mass	Connecting rod
Aluminium oxide fibers, carbon fibers	Improved strength, compact in weight and wear resistance	Engine block
Fibre flax	Reduced weight and wear	Piston
Titanium carbide	Reduced weight and lowest wear rate	Piston, connecting rod
Basalt short fibre	Decreased corrosion rate	Automobile engine parts

2.6. Ultrasonic Machine and Non-Ferrous Melting Furnace

Ultrasonic cavitation machine, 2000W power from Johnson Plastosonic, India is a special purpose machine which is mainly used for ultrasonic welding and ultrasonic cavitation. It consists of a booster and mechanical horn with low-frequency electrical signals are supplied to a transducer in an ultrasonic machine, which transforms the electrical energy into high-frequency (~20 KHz) mechanical vibration. The frequency is amplified by the booster and the sound wave produced by the horn is roughly 5000 m/s. Vibrations have a normal amplitude of 30 to 35 μm The power output of this method ranges from 500 to 3000 watts.. Static load is applied to the tool to provide pressure.

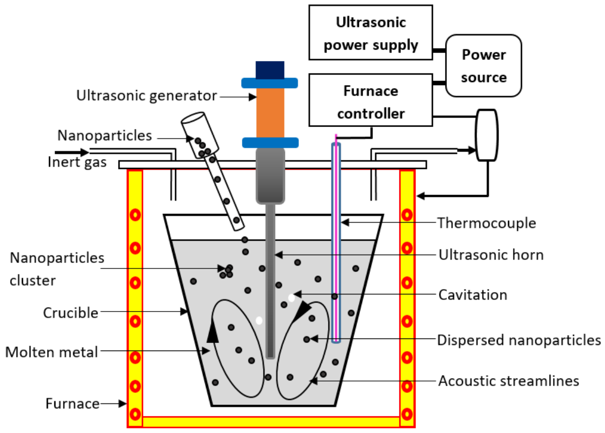

Figure 3. Ultrasonic Cavitation process

2.6.1. Non Ferrous Melting Furnace

Aluminum is melted in a stationary furnace with a square-shaped shell (operating temperature: 1000 ^{o}C, power rating: 5 kw, A1 grade kandhal heating coil). Metals are lost while indirect form of melting due to oxidation/carbon formation by the fuel or combustion features. The furnace's interior is lined with refractory and insulation bricks to maintain the liquid metal at 1200°C. This brick furnace liner is mechanically built with additional locks to ensure the liner's tightness and keep the crucible with a diameter of 100 mm and a height of 300 mm.

3. Experimental Setup and Procedure

3.1. Setup

Fabrication method is the most crucial element while constructing the aluminium MMNC. Stir casting was therefore chosen since it is the most straightforward and economical method for liquid state processing[29].Processing and controlling components make up the experimental setup of ultrasonic cavitation process as shown in figure 3. In a tiny stainless steel (SS310) crucible, Al6061 was melted using an electric resistance heating device. Argon gas was used to safeguard the melt at a flow rate of 6 L/min. A temperature controller was used to keep track of the processing temperature and the input amplitude is regulated in the generator.

3.2. Experimental Procedure

The aluminum 6061-T6 material was melted in the furnace at 800^{o}C for around 10 minutes before being choked. The nano SiC (40-65nm) particle has been progressively introduced to the molten metal together with argon gas. To pre-mix the particle, mechanical stirring at 500 RPM for 10 minutes is performed, followed by dipping the ultrasonic probe into the molten metal at a height of 25mm. Set any one input amplitude position and start the ultrasonic liquid processing and the Al-SiC molten metal is poured into the die cavity as followed by the earlier research work [30].

3.3. Micro structure analysis

For surface morphology, MMNCslabs were cut to produce the samples for microscopic analysis. To prevent overheating of the samples, coolant was utilized during the cutting process. The samples were ground and polished using customary methods, and then they were etched using Keller's reagent followed by water washing. A scanning electron microscopy (SEM) was performed on the produced samples.

3.4. Mechanical properties

Tensile test samples were prepared (gauge length of 32mm and thickness of 6mm) as per the ASTM E8 standard from the MMNCs to determine its tensile properties with the usage of INSTRON machine. Brinell hardness test was employed to determine the hardness of MMNCs as per ASTM E10 standard. As depicted in the figure 4, a specified load (F) is applied to a carbide ball with a fixed diameter (D), which is then held for 10 to 15 seconds before being released and the hardness is also assessed at several points on the MMNCs sample. The resulting impression is visually measured with a handheld microscope to determine the size of the indent over at least two diameters, typically at right angles to one another, and the average value is taken (D_i). The following equation (8) is used to determine the Brinell hardness number.

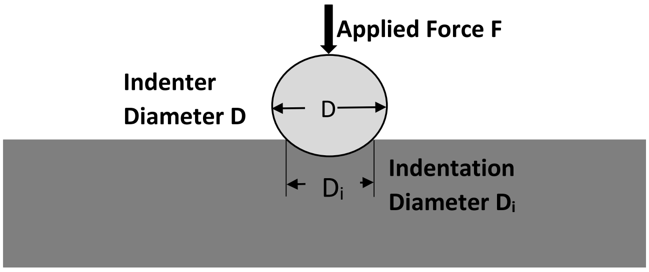

Figure 4. Force and Ball indentation

$$BHN = \frac{F}{\frac{\pi}{2}D.(D-\sqrt{D^2-D_i{}^2})} \quad (8)$$

F – Load (Kg)
D – Diameter of the ball (mm)
D_i– Diameter of the indention (mm)

4. Results and Discussion

In this work, Theory of micro mechanics, mechanical properties and distribution of Nano composites and design parameters of sonotrode are identified. The net power coming from the source is constant and the intensity decreases in proportion to distance from the sonotrode squared. The following parameters of % volume and coefficient distribution of solid particle, surface intensity and amplitude of vibration are behind in strengthening this MMNC. Accordingly, ultrasonic cavitation technique is an innovative method for producing composite materials that decreases porosity and agglomeration in the composite material by adjusting process parameters such as stirring duration, feeding procedures, and process temperature.

4.1. Microstructure

Aluminium 6061 reinforced with 0.3, 0.5, 0.8, 1.0, 1.25, and 1.5 volume % Nano SiC with ultrasonic processing at 2.0 kW power were examined with scanning Electron Microscope (SEM) and typical microstructure are shown in Figure5(a-f) respectively. Aspect ratio could be increased due to the incorporation of nano size SiC particles. Owing to the high surface tension of the melt and the inadequate wetting between the particles and the melt, clusters of SiC were clearly visible even though SiC has a slightly greater density than Al matrix [31]. SiC nanoparticles over the range of 50-130nm in diameter and agglomerates of ~500nm in diameter were distinguished. Moreover, slight pits that could be seen on the surface morphology, were triggered by the cavitation of ultrasonic waves, which is consistent with the research published in 2018 by Jiang and Yu et al. [32]. However, the nano particles were efficiently distributed and disseminated in the matrix with the existence of dendrites. Increasing the volume % of SiC particles leads to a steady decline in the average particle size ranging from 500 to 150 nm. It could occur because of the higher particle loadings which can lead to increased shear forces during mixing and processing, resulting in particle fragmentation. The distribution of SiC in the molten aluminum matrix depends upon the stepped horn, stir casting configuration, position of impeller, speed and characteristics of the incorporated nano particles. Consequently, the dispersion of solid particle is impeding the dislocation movement within the grain boundary.

4.2. Mechanical properties

Table 4displays the mechanical characteristics of composites such as tensile strength, hardness, and ductility. Brinell hardness value of the MMNCswasescalated to 43% and % elongation declined to 1.1% when compared to the base Al 6061 matrix which is due to the gradual incorporation of filler content from 0.3-1.5%.Similar tendency has been revealed with the earlier research done by Gopalakannan and Senthilvelan et al. [6].The composites tensile strength characteristics are found to be greater than those of the basic matrix with 1.25 volume % having greater tensile strength, which is thereafter lowered owing to agglomeration of the filler content and increased dislocation density. The mismatch in thermal expansion coefficients between the matrix and evenly distributed nano-SiC inclusions might result in a high dislocation density, with the nano-SiC inclusions serving as dislocation mobility impediments. Due to the high dislocation density of matrix metal, the characteristics of MMNCs are expected to be substantially increased even with a low volume percent. The dislocation density relationship to the weight percentage and degree of thermal mismatch could be observed evidently. Therefore, for tiny particles and for higher weight fractions, this effect would be significant. According to Murthy et al., data from the processing maps demonstrates that the uneven area increases as the volume % of SiC increases which further agreed with this work[33].Furthermore, earlier review studies reveals that the Al-SiC composite have better mechanical characteristics of enhanced Diffusion joint strength, higher tensile strength, specific stiffness, resistance to wear and compacted weight[34, 35]. Therefore, the existence of SiC on the Aluminium matrix has a greater impact on augmenting the mechanical properties. Thus the fabrication technique of stir casting and ultrasonic cavitation process played a vital role in determining the properties on the developed aluminium MMNC.

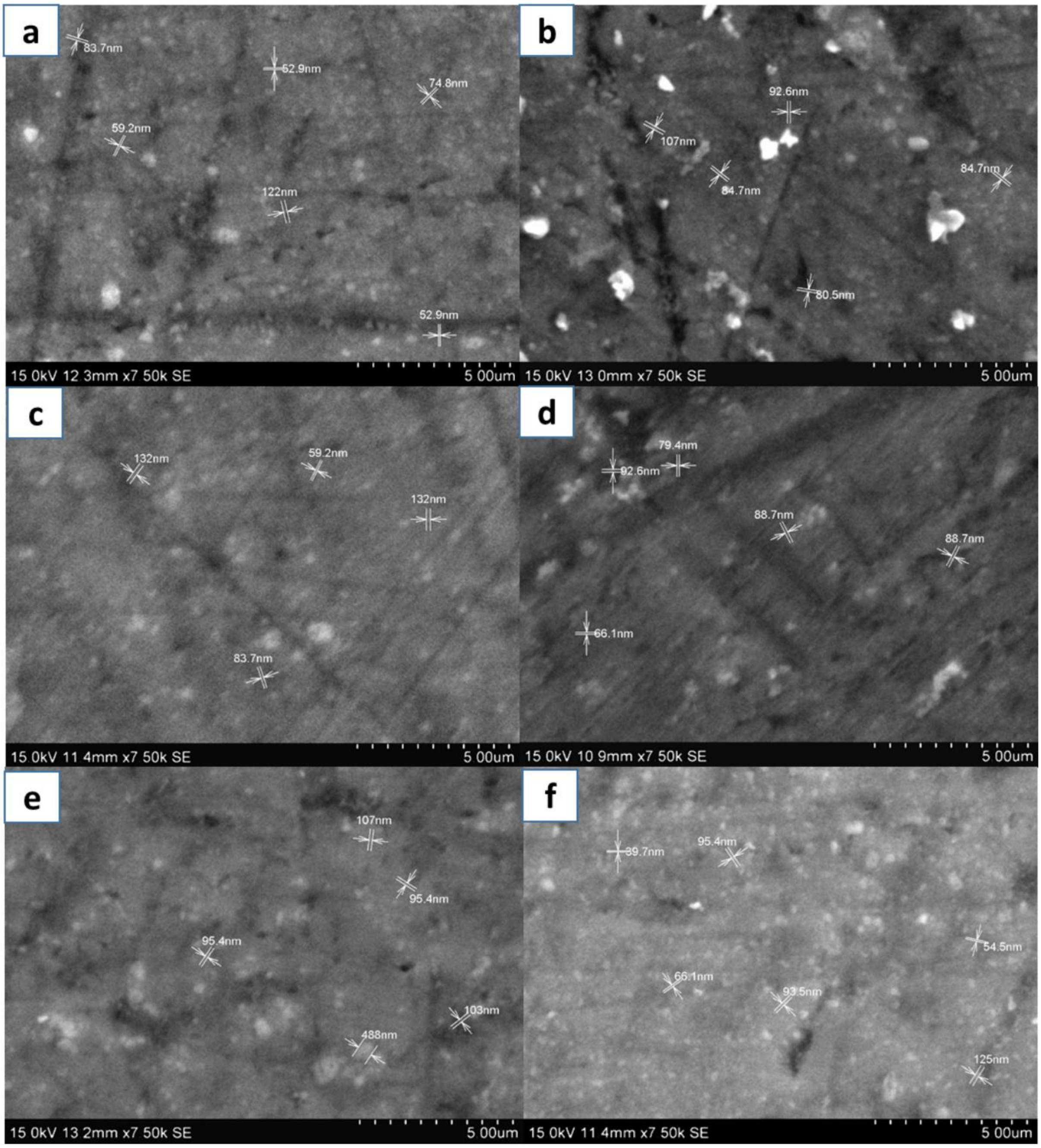

Figure 5. SEM images of Aluminium 6061 reinforced with nano SiC (a) 0.3% (b) 0.5% (c) 0.8% (d) 1.0% (e) 1.25% (f) 1.5%

Table 4. Properties of fabricated Al-SiC nano composite

S.No.	Sample	Ultimate Stress (MPa)	%ΔL	Hardness (BHN)	Particles sizedistribution (nm)
1	Al6061	125.0	6.1	58	-
2	Al6061+0.3V% SiC	142.8	3.5	69	500.5
3	Al6061+0.5V% SiC	164.3	3.1	78	420.8
4	Al6061+0.8V% SiC	189.4	2.8	87	340.6
5	Al6061+1.0V% SiC	221.6	2.4	91	280.2
6	Al6061+1.25V%SiC	260.5	1.8	98	225.7
7	Al6061+1.5V% SiC	180.6	1.1	101	150.2

5. Conclusion

The significant conclusions of the Fabrication and testing of Al6061/SiC a metal matrix composites are as follows.

- The use of ultrasonic cavitation liquid processing methods in the manufacture of Al6061/SiC Nano composites with filler content up to 1.5 vol.% was effective.
- The homogeneous dispersion and reduction of SiC particles in the matrix system was demonstrated by microstructural examinations.
- Brinell hardness of the composite is increased by up to 43% when the filler content is increased.
- The composites tensile strength characteristics are found to be greater than those of the basic matrix, with 1.25 vol.% having greater tensile strength, which is thereafter lowered owing to agglomeration of the filler particle.

Considering its advantages of high stiffness and strength over homogenous materials, the fabricated MMNC could thereby replace conventional engineering materials. Due to its outstanding desirable features, it is recommended to design for a range of industrial applications, including brake rotor and piston for the automotive industry, single aisle and broad body wings, nacelle, brackets, engine blades for the aircraft industry, and liner propeller shaft for the maritime industry.

Funding

This research received no external funding.

Conflicts of interest

The authors declare that they have no conflict of interest.

6. References

[1] P.Palmero, "Structural Ceramic Nanocomposites: A Review of Properties and Powders Synthesis Methods". *Nanomaterials*, Vol. *5*,No.2, 2015,656-696.

[2] A. K. Azad, L. Unnikrishnan, S. Mohanty, S.K. Nayak, "Nanomaterial Enhanced Polyelectrolyte Membranes for Hydrogen-Oxygen Fuel Cells". Polymer Korea, Vol. 45, No.1, 2021, 101-112.

[3] A. K. Azad, A. Gupta, L. Unnikrishnan, S. Mohanty, S. K. Nayak, "Sulfonated Poly (Ether Ether Ketone) and its Blended Nanocomposite for Proton Conducting Membranes". Journal of Polymer Materials, Vol. 38, No.1-2, 2021, 121-136.

[4] P.Madhukar, N.Selvaraj, C. S. P. Rao,S. K. Mishra, "Fabrication of Light Weight Metal Matrix Nanocomposites Using Ultrasonic Cavitation Process: A State of Review", Materials Science Forum, Vol. 969, 2019, 882–888.

[5] R.K.Bhushan, S. Kumar, "Influence of SiC Particles Distribution and Their Weight Percentage on 7075 Al Alloy". Journal of Materials Engineering and Performance, Vol. 20, 2011, 317–323.

[6] S. Gopalakannan, T. Senthilvelan, "Synthesis and Characterisation of Al 7075 reinforced with SiC and B_4C nanoparticles fabricated by ultrasonic cavitation method". Journal of Scientific & Industrial Research, Vol. 74, 2015, 281-285.

[7] J. Lan, Y. Yang, X. Li, "Microstructure and microhardness of SiC nanoparticles reinforced magnesium composites fabricated by ultrasonic method", Materials Science and Engineering: A, Vol. 386, 2004, 284-290.

[8] H. Hurang, L. Onyebueke, A. Abatan, "Characterizing and Modeling Mechanical Properties of Nanocomposites- Review and Evaluation". Journal of Minerals & Materials Characterization & Engineering, Vol. 9, No. 4, 2010, 275-319.

[9] T. Hielscher, "Ultrasonic production of nano-size dispersions and emulsions". arXiv preprint arXiv:0708.1831 (2007).

[10] P. Gupta, D. Kumar, M. A. Quraishi, O. Parkash,"Effect of sintering parameters on the corrosion characteristics of iron-alumina metal matrix nanocomposites". Journal of Materials and Environmental Science, Vol. 6, No. 1, 2015, 155-167.

[11] A. Jamwal, U. K. Vates, P. Gupta, A. Aggarwal, B.P. Sharma, (2019). "Fabrication and Characterization of Al2O3–TiC-Reinforced Aluminum Matrix Composites". Advances in Industrial and Production Engineering, 2019,349-356.

[12] B. Vinod, S. Ramanathan, V. Ananthi, "Fabrication and Characterization of Organic and In-Organic Reinforced A356 Aluminium Matrix Hybrid Composite by Improved Double-Stir Casting". Silicon, Vol. 11, 2019, 817–829.

[13] S. Donthamsetty, N. R. Damera, P. K. Jain, "Ultrasonic Cavitation Assisted Fabrication and Characterization of A356 Metal Matrix Nano composite Reiforced with SiC, B4C, CNTs". AIJSTPME, Vol. 2, No. 2, 2009, 27-34.

[14] A. C. Reddy, E. Zitoun, "Matrix Al-alloys for silicon carbide particle reinforced metal matrix composites",Indian Journal of Science and Technology". Vol. 3, No. 12, 2010, 1184-1187.

[15] G. I. Eskin, "Cavitation mechanism of ultrasonic melt Degassing". Ultrasonics sonochemistry, Vol. 2, No. 2, 1995, S137-S141.

[16] M. Yang, J. Novak, R. Fink, J. Brookover, N. Jiang, "Properties of a Newly Developed Carbon-Aluminum Nanocomposite". Applied Nanotech, Inc., 3006 Longhorn Blvd., Suite 107 Austin, TX 78758, USA.

[17] S. P. Dwivedi, R. Sahu, "Effects of SiC Particles Parameters on the Corrosion Protection of Aluminum-based Metal Matrix Composites using Response Surface Methodology". Jordan Journal of Mechanical and Industrial Engineering, Vol. 12, No. 4, 2018, 313-321.

[18] K. Bandil, H. Vashisth, S. Kumar, "Microstructural, mechanical and corrosion behaviour of Al–Si alloy reinforced with SiC metal matrix composite". Journal of Composite Materials, Vol. 53, No. 28-30, 2019, 4215-4223.

[19] S. Gangwar, P. Arya,V. K. Pathak, "Optimal Material Selection for Ship Body Based on Fabricated Zirconium Dioxide/ Silicon Carbide Filled Aluminium Hybrid Metal Alloy Composites Using Novel Fuzzy Based Preference Selection Index". Silicon, Vol. 13, 2021, 2545–2562.

[20] I. Gurrappa, "Characterization of titanium alloy Ti-6Al-4V for chemical, marine and industrial applications". Materials Characterization, Vol. 51, No. 2–3,2003, 131-139.

[21] K. H. Mughal, M. A. M. Qureshi, A. A. Qaiser, "Numerical Evaluation of State of the Art Horn Designs for Rotary Ultrasonic Vibration Assisted Machining of Nomex Honeycomb Composite". 2021.

[22] Y. Yong, L. Jie, L. Xiaochun, "Study on bulk aluminum matrix nano-composite fabricated by ultrasonic dispersion of nano-sized SiC particles in molten aluminum alloy". Materials science & Engineering, Vol. 380, No. 1-2, 2004, 378-383.

[23] I.J. Polmear, 1981; Light Alloys- Metallurgy of the light metals. Metallurgy and materials science series, Edward Arnold (publishers) Ltd, London, UK.

[24] M. Haghshenas, "Metal–Matrix Composites". Reference Module in Materials Science and Materials Engineering, 2016, 1-28.

[25] S. K. Aithal, N. R. Babu, H. N. Manjunath, K. S. Chethan, "Characterization of Al-SiCP Functionally Graded Metal Matrix Composites Developed through Centrifuge Casting Technique". Jordan Journal of Mechanical and Industrial Engineering, Vol. 15, No. 5, 2021, 483-490.

[26] V. R. Rao, N.Ramanaiah, M.M.M.Sarcar, "Optimization of Volumetric Wear Rate of AA7075-TiC Metal Matrix Composite by Using Taguchi Technique". Jordan Journal of Mechanical and Industrial Engineering, Vol. 10, No. 3, 2016, 189-198.

[27] M. Ali, S. Falih, "Synthesis and Characterization of Aluminum Composites Materials Reinforced with TiC Nano- Particles". Jordan Journal of Mechanical and Industrial Engineering, Vol. 8, No. 5, 2014, 257-264.

[28] E. Vannan, P. Vizhian, "Corrosion Characteristics of Basalt Short Fiber Reinforced with Al-7075 Metal Matrix Composites". Jordan Journal of Mechanical and Industrial Engineering, Vol. 9, No. 2, 2015, 121-128.

[29] M. Patel, B. Pardhi, D. P. Sahu, S. K. Sahu, "Different Techniques Used for Fabrication of Aluminium Metal Matrix Composites". International Journal of Engineering and Techniques, Vol. 7, No. 1, 2021, 1-8.

[30] X. Li, Y. Yang, D. Weiss, "Theoretical and experimental study on ultrasonic dispersion of a nano particles for strengthening cast aluminum alloy A356". Metallurgical Science and Technology, Vol. 26-2, 2008, 12-20.

[31] K. M. Shorowordi, T. Laoui, A. S. M. A. Haseeb, J. P. Celis, L. Froyen, "Microstructure and Interface Characteristics of B4C, SiC and Al2O3 Reinforced Al Matrix Composites: A Comparative Study". Journal of Material Processing Technology, Vol. 142, No. 3, 2003, 738-743.

[32] D. Jiang, J. Yu, "Fabrication of Al2O3/SiC/Al Hybrid Nanocomposites Through Solidification Process for Improved Mechanical Properties". Metals Vol. 8, No. 8, 2018, 572.

[33] S.V.S. N. Murty, B. N. Rao, B.P. Kashyap, "On the hot working characteristics of 6061Al– SiC and 6061–Al2O3 particulate reinforced metal matrix composites". Composites Science and Technology, Vol. 63, No. 1, 2003, 119-135.

[34] P. Garg, A. Jamwal, D. Kumar, K. K. Sadasivuni, C. M. Hussain, P. Gupta, "Advance research progresses in aluminium matrix composites: manufacturing & applications". Journal of Materials Research and Technology, Vol. 8, No. 5, 2019, 4924-4939.

[35] T. Prater, "Friction Stir Welding of Metal Matrix Composites for use in aerospace structures". Acta Astronautica, Vol. 93, 2014, 366-373.