Effect of Variations in Microwave Processing Temperatures on Microstructural and Mechanical Properties of AA7075/SiC/Graphite Hybrid Composite Fabricated by Powder Metallurgy Techniques

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Abstract

Due to the demand in present industrial, aerospace, defense sectors for lightweight high-performance aluminum (Al) particle-reinforced metal matrix composites, the advancement of techniques to fabricate these composites with superior mechanical properties have gained technological interest in the modern world. In this direction, SiC and graphite reinforced AA7075 matrix composite material has been fabricated in this study, through hybrid microwave sintering techniques. The microwave sintering temperatures for the optimized volume fraction composition of AA7075/SiC/graphite hybrid composite has been varied from 400 to 550 °C with a step value of 50 °C. The obtained results showed a superior improvement in the mechanical properties for microwave sintered composites as compared to the conventionally sintered composites. Mechanical properties are found to show increasing trend with increasing microwave sintering temperatures up to 500 °C, after that, a downfall is observed in their mechanical properties, which can be attributed to the increased average grain size of the composite at 550 °C. Selection of SiC as primary reinforcement material helped in achieving high mechanical strengths, and through microwave sintering, an increment of 37.2% in tensile, 26.6% in compression, and 16.5% in hardness is achieved. From this investigation, it is also observed that the selection of materials that shows high response to microwaves helps in achieving the enhanced mechanical properties for the hybrid composites processed by microwave sintering techniques.

1. Introduction

Among the available composite materials, the particle-reinforced aluminum metal matrix composites are gaining huge attention and demand day by day in industrial, defense and aerospace sectors due to their superior features such as high strength-to-weight ratio, high stiffness, corrosion resistance, high wear resistance, and low-cost as compared to the traditional aluminum alloys [1–4]. Selection of reinforcement particles is mainly associated with many factors including the type of application intended, matrix-material used, volume fraction levels, reinforcement material, shape, size, orientation, and dispersion of reinforcement particles in matrix materials. Notably, these factors severely affect the mechanical properties of the composite materials [5–7]. The typical reinforcement materials include SiC, B₄C, graphite, TiC, WC, ZrC, ZrO₂, AlN, TiO₂, BN, Al₂O₃, graphene, CNT, etc. [8–12]. The robustness of composites is mainly associated with the interface bond strength between the matrix and the added reinforcement-particles. Accordingly, several investigations have been carried out across the globe towards understanding the behavior of interfaces between different matrix and reinforcement particles. There are different techniques to fabricate the particle-reinforced metal matrix composites. The conventional methods include liquid processes such as stir casting, compo casting, squeeze casting, pressure infiltration, and rapid solidification, etc. The solid-state processes mainly include powder metallurgy, and accumulative roll bonding [9, 12–15]. It is found that the composites fabricated via conventional techniques often contain many defects such as high porosities, weak interface bonds due to poor wetting behavior between liquid matrix and reinforcement particles, and large differences in density of the matrix and reinforcement particles, which ultimately result in non-uniform dispersion of

reinforcement particles in the matrix materials [16–18]. In powder metallurgy-based techniques, the properties of materials can be effectively tailored by varying the process parameters. Studies have revealed that the porosity levels and interface bond strength of the composite material can be improved by applying high compaction pressures. On the other hand, the moderate sintering temperatures help in lowering the flow stress levels in the matrix materials and reduce the voids between the reinforcement particles [19, 20].

In various powder metallurgical processes, the microwave and spark plasma sintering (SPS) techniques employ unique features such as low sintering temperatures, low sintering periods, and rapid heating rates, which ultimately improve the overall properties of the composite materials [21]. Free-energy of the system has to be reduced in order to start the sintering process, and thereby, the mass transportation kinetics can improve the sintering efficiency due to the improved diffusion process, which eventually leads to the effective transfer of atoms in the crystalline solids. Notably, the controlled diffusion conditions yield good sintered products, and the factors that affect the diffusion phenomenon are often found to be sintering temperatures and concentration of defects in the sample [22]. In SPS process, passing of a high-density DC pulsed current through the sample under the external applied pressure results in spark discharges among the powder particles due to joule heating effects and leads to the partial melting of outer edges of powder particles and cause particle-aggregation in the samples. SPS process restricts the grain growth phenomenon and enhances the densification process owing to its rapid heating rates, quick sintering times, and low sintering temperature conditions [23–27].

Microwave sintering is one of the most suitable sintering techniques for particle-reinforced metal matrix composites due to the rapid internal heat generation phenomenon in ceramic particles by absorbing the microwaves. Heat generation takes place inside the powder particles by the oscillation of dipoles at microwave frequencies (300 MHz to 300 GHz) [10, 28, 29]. Microwave heating phenomenon depends on the response of a material to alternating electric and magnetic fields of microwaves.

Permittivity/dielectric constant (ϵ') and dielectric loss (ϵ'') measures the response of a material to an electric field. Ability of material to store the electric energy in it is measured by Permittivity/dielectric constant (ϵ'), whereas the dielectric loss (ϵ'') represents the ability of material to convert the electric energy to heat. In a similar manner, response of a material to magnetic fields is determined by permeability (μ') and magnetic loss (μ''). The storage of electric energy takes place in a material via polarization of the bound charges, and the conversion of electric energy into heat takes place via relaxation of the polarized molecules along with conduction of free-electrons. Polarization-loss is the primary source for heat generation in dielectric insulators (alumina, quartz, zirconia, etc.) with no free charges, and the conduction-loss is the primary source for heat generation in highly conducting materials such as metals under microwave electric fields. There are different types of materials which respond only to electric or magnetic fields, and some materials can respond to both electric and magnetic fields of microwaves (Fe_3O_4 , $\text{BaFe}_{12}\text{O}_{19}$, CuFe_2O_4 , $\text{CuZnFe}_4\text{O}_4$, $\text{NiZnFe}_4\text{O}_4$). The scale of penetration depth of microwaves determines whether the material reflects, transmits or absorbs the microwaves. Materials with relatively low depth of penetrations in the order of μm with $\tan \delta_e \leq 0.01$ (loss tangent) are

microwave reflectors such as metals, and materials with penetration depth in the order of cm with $\tan \delta_e \geq 0.1$ are generally microwave absorbers, and the materials with large penetration depths of in the order of meters are microwave transmitters and these materials transmit the microwaves without leading to any absorption/attenuation of the microwave energy [30]. Employing the susceptor materials in microwave sintering setup enables the hybrid microwave heating. Some studies reported that a temperature difference of 400 °C was noted between the inner core and surface of PZT (lead zirconate titanate) ceramics during direct microwave heating, while uniform heat distribution was observed in the case of susceptor-based hybrid microwave heating conditions [31], which also helped in the reproducibility of the process. The commonly used susceptor materials include SiC, carbon, etc., due to their rapid heat generation phenomenon through the absorption of microwaves even at room temperatures.

In the present work, investigations have been carried out on SiC and graphite reinforced AA7075 matrix material. SiC and graphite materials are specifically selected in this work owing to their high response to microwaves and have penetration depths of 1.93 and 4 cm, respectively [32]. Their rapid heating rates along with susceptor-based hybrid microwave heating helps in the uniform heat distribution throughout the sample. It is demonstrated that the higher mechanical properties with strong interface bonds can be achieved by combining the present matrix and reinforcement particles combinations.

2. Materials And Methods

2.1. Raw Materials

In the present work, Aluminium 7 series alloy AA7075 (Zn as the major alloying element) was used as a matrix material with an average particle size (APS) of 10 µm, and the received powder composition levels are shown in Table 1. Silicon Carbide (SiC) and graphite powders were utilized as reinforcement particles with an average particle size (APS) of 1µm and 5µm, respectively and are shown in Fig. 1.

Table 1

Composition levels of received AA7075 Powders

Al	Zn	Mg	Si	Cr	Fe	Cu	C	Ag
86.04	5..99	2.55	0.8	0.05	0.32	0.64	2.04	1.45

2.2. Composite Powders Preparation

Composite powders were prepared in a way to distribute the reinforcement particles in the matrix material uniformly. To distribute the reinforcement particles in the matrix material uniformly, ball milling techniques with proper milling parameters were used; those are listed in Table 2 [28, 33–35].

Table 2
Ball milling parameters while composite powders preparation

<i>Ball Milling Parameters</i>	
Milling Speed	600 RPM
Milling time	4h
Ball to Powder ratio	15:1
Process Control Agent (PCA)	Acetone
Ball Material	Tungsten Carbide (WC)
Vial Material	Hardened Steel

2.3. Cold Compaction and Sintering

A manual hydraulic pellet press with 30 tons capacity was used to prepare the cold compacts from the composite powders. D2 die steel was used as die material, a total of four samples for each specific test were prepared, and two types of geometries were prepared for different tests i.e., tensile, compression and hardness.

Two different sintering mechanisms were implemented in the present work, conventional and microwave. Conventional sintering was performed at 620°C for 120 min in a protected environmental condition. Microwave sintering was performed at three sintering temperatures i.e., 400, 450, 500, 550°C at a heating rate of 10°C/min for 30 min, SiC susceptor was used for preheating the samples up to its critical temperatures (T_c) in order to couple the microwaves with Aluminium matrix material (microwave reflector) for internal heat generation [30, 32, 36], and alumina insulation was used to prevent heat losses. The cold compacts were placed at centre of cavity, and sintering was performed at the multimode cavity [10, 28, 29, 36]. Figure 2 represents the dimensions of composite samples for mechanical tests after sintering and machining operations.

2.4. Analysis of composites

Prepared composite samples were tested mechanically to find out the tensile, compression, and hardness tests. Compression and tensile tests were carried out on Instron UTM machine with a strain rate of 1mm/min, and compression test was performed according to ASTM E9 standards. The Micro Vickers hardness test was performed with a loading force of 200gms for 15s, and the obtained values were the average of 5 measurements. W-SEM & XRD analysis were carried out to perform microstructural and secondary phase characterizations. For better microstructure visualizations composite samples were polished using higher grit size (up to 2500) emery papers and then polished with diamond paste. The polished samples were etched with Keller's reagent (190 mL distilled water + 5 mL HNO₃ + 3 mL HCl + 2

mL HF). Porosity calculations were performed by using Archimedes principle. Figure 3 represents the schematic diagram showing the path of the present work in step wise manner.

3. Results And Discussions

3.1. Microstructural analysis

Figure 4 shows the SEM images of the microwave sintered AA7075 + 7%SiC + 5% graphite hybrid composite at different temperatures. From the images, the presence of micro voids is observed in all the samples. Microwave sintering essentially helps in improving the mechanical properties of the composite materials as compared to the conventionally sintered composites. The unique features of microwaves enable the sintering process to be very suitable for making the high-performance composites with low grain growth, quick sintering times, low temperature processing and eliminate the generation of secondary phases at interface regions. The further analysis of SEM images revealed that the increasing microwave sintering temperature leads to the grain growth in materials as represented in the form of statistical grain size distribution analysis given in Fig. 14. Some reports stated that during microwave processing, the increase in kinetic energy of free ions at grain boundaries leads to the reduction in activation energy for a forward shoot of free ions and reduces the chances of reverse shoot of free ions. Such process fundamentally enables an enhanced diffusion of inter particle free ions and facilitates for a rapid growth of grains in the materials [37]. On the other hand, the ball milling of composite powders helps in the reduction of activation energies by creating a greater number of free surfaces. The generation of micro cracks due to the repeated collisions during the ball milling process increases the internal energies of the powder particles. This makes the amount of energy needed for diffusion is low by reducing the energy needed for the creation of vacancies [38]. The observations such as the microstructures with clean surfaces, absence of secondary phases (as confirmed in XRD analysis), and superior mechanical properties indicated the existence of strong interface bonding between the matrix and reinforcement particles. The low sintering temperatures, short sintering period, and rapid heating rates in microwave processing helped for a rapid diffusion process, which eventually made the microwave sintered samples to be highly densified with low porosity levels.

3.2. Porosity and density levels

Pores are the air gaps exist between the powder particles during the compaction process in powder metallurgy techniques. These pores act as obstacles for heat propagation and diffusion phenomena, and also act as pre-existing crack sites where the crack initiates and propagates. The coalesce of neighboring micro cracks leads to the early failure of the material. Main aim of every researcher in this field is to minimize the defects in the material and to enhance the performance of the materials. In the powder metallurgical process, the porosity levels can be reduced by varying the process parameters. Some studies stated that the mechanical properties of the final materials are mainly influenced by the quality and features of the green compacts. The quality of the green compact mainly depends on the densification mechanism and powder deformation behavior during the compaction process [39, 40].

Notably, the high compaction pressures at low rates (quasi static compaction) reduces the porosity levels in the materials as compared to high compaction rates (dynamic compaction) [19]. In order to minimize the porosity levels, in this present work, a high compaction pressure of 600 MPa was applied at low compaction rates [41]. Figure 5 demonstrates the porosity levels of the fabricated composite sintered through different sintering mechanisms. Figure 5(a) represents the porosity levels in AA7075 + x%SiC (x = 0–10) composite sintered through conventional technique. It is observed from the obtained results that the increasing content of SiC raises the porosity levels in the material, whereas the respective relative-density levels are found to be decreasing as shown in Table 3. One of the reasons for the observed increase in porosity levels with reinforcement volume fraction levels is the difference in the thermal expansion coefficient of the matrix and reinforcement particles. Notably, such phenomenon will be more effective in the case of conventional sintering technique, which is due to its long exposure to high temperatures for a long period of time. The variations in deformation behaviors of matrix and reinforcements during compaction process also influence the porosity levels of composite materials. Figure 5(b) represents the porosity levels in the AA7075 + 7%SiC + x%graphite hybrid composite sintered through conventional technique. It is observed that the porosity levels are increasing with graphite reinforcement content levels and the respective relative-density levels are decreasing as shown in Table 4. Minimizing the differences in the thermal expansion coefficient of matrix and reinforcement particle influences the porosity levels in the composite, where the low temperature processing conditions with short sintering periods help in reducing the porosity levels in the composite. Figure 5(c) represents the porosity levels in the AA7075 + 7%SiC + 5%graphite hybrid composites sintered through microwave technique at different temperatures. It is observed that the porosity levels are reduced to 2.5% from 4.5% for microwave sintered composites at 400 °C. When the microwave sintering temperature is increased to 500 °C, the porosity levels is reduced to 1.8%, which is around 60% reduction in the porous levels, and the respective relative-density levels are increased as shown in Table 5; This represents the improved densification of the composite material due to the microwave sintering process as compared to the conventional sintering process. A slight increase in porous levels is observed in the composite microwave-sintered at 550 °C. This can be attributed to the observed increased average grain size of the composite material as shown in Fig. 14.

Table 3
Density levels of AA7075 + x%SiC composite sintered through
conventional technique

	Theoretical Density	Experimental Density	Relative Density
S0	2.810	2.776	98.8
S1	2.814	2.766	98.3
S2	2.818	2.756	97.8
S3	2.822	2.743	97.2
S4	2.826	2.736	96.8
S5	2.830	2.737	96.7
S6	2.834	2.735	96.5
S7	2.838	2.727	96.1
S8	2.842	2.723	95.8
S9	2.846	2.724	95.7
S10	2.850	2.722	95.5

Table 4
Density levels of AA7075 + 7%SiC + x%graphite composite sintered through
conventional technique

	Theoretical Density	Experimental Density	Relative Density
S7G0	2.837	2.727	96.1
S7G1	2.832	2.721	96.1
S7G2	2.826	2.708	95.8
S7G3	2.821	2.702	95.8
S7G4	2.815	2.694	95.7
S7G5	2.810	2.683	95.5
S7G6	2.804	2.675	95.4
S7G7	2.799	2.664	95.2

Table 5
Density levels of AA7075 + 7%SiC + 5%graphite composite sintered through microwave technique

	Theoretical Density	Experimental Density	Relative Density
S7G5M400	2.810	2.740	97.5
S7G5M450	2.810	2.748	97.8
S7G5M500	2.810	2.759	98.2
S7G5M550	2.810	2.756	98.1

3.3. XRD analysis

In composite materials, generation of secondary phases at interface region affects the mechanical properties in a severe way. Availability of excess free energies during sintering process cause initiation of chemical reaction between matrix and reinforcements, the rate of reactivity depends upon the time of exposure to high temperatures and particle sizes of matrix and reinforcement particles. As the particle size of particles decreases its surface to volume ratio increases that leads to high reactivity of nano particles and also the ability to form clusters in the matrix material increases [42]. Figure 6 represents the XRD analysis of S7G5 hybrid composite sintered through conventional sintering at 600°C (S7G5C600) and microwave sintered composite at 400, 450, 500, and 550°C. From the results obtained it is observed that, secondary phases SiO_2 and Al_4C_3 are observed in conventionally sintered composite, long time exposure to high temperatures and availability of high carbide phase in the composite material led to the formation of Al_4C_3 compound. While, no such secondary phases are observed in microwave sintered composites at different temperatures. Enhanced diffusion mechanism at low temperatures for short period in microwave sintering make composite materials free from intermetallic compounds. Some studies reported that the presence of some intermetallic compounds like fine Al_4C_3 act as grain pinning agents that hinders the growth of grains, grain boundary movements and even activates the precipitation strengthening mechanism [43–46].

3.4. Mechanical properties

Mechanical properties of a composite material mainly depend on the interface bond strengths between the matrix and reinforcement particles. Every research aims at enhancing the mechanical properties of the composites by understanding the particular matrix and reinforcements interface chemistry. In the present work, initially, the concentration of SiC was varied from 0 to 10% in AA7075 matrix material and sintered through conventional method. Figure 7 represents the mechanical properties of the AA7075 + x%SiC (x = 0–10) composite material. It is observed that the addition of SiC reinforcement particles enhanced the mechanical properties of the composite material, where a high mechanical strength of around 323 and 382 MPa was noted in tensile and compression strength, respectively for AA7075 + 7%SiC composite. Similarly, Fig. 8 represents the hardness values of AA7075 + x%SiC (x = 0–10)

composite materials. It is observed that the hardness values are increasing with reinforcement content levels and a hardness value of 96 Hv was observed for the S7 composite. To this optimized 7% SiC volume fraction levels, the graphite was added at various volume fraction levels from 0 to 7% and sintered through conventional method. Figure 9 represents the mechanical properties of the AA7075 + 7%SiC + x%graphite ($x = 0-7$) hybrid composite material. It is observed that the addition of graphite reinforcements further enhances the mechanical properties of the composite material up to 5% volume fraction levels, and hardness values are increasing with reinforcement content levels, where a hardness value of 109 Hv was observed for S7G5 hybrid composite as shown in Fig. 10. In previous investigation, the addition of graphite as primary reinforcement and SiC as secondary reinforcement showed an optimized volume fraction level of 8% graphite + 2%SiC in AA7075 matrix material with a mechanical strength of 357 and 385 MPa in tensile and compression, respectively, and a hardness value of 99 Hv [28]. In the present work, adding the SiC as primary and graphite as secondary reinforcements showed an optimized volume fraction levels of 7%SiC + 5%graphite in AA7075 matrix material with a mechanical strength of 365 and 451 MPa in tensile and compression, respectively, and a hardness value of 109 Hv. This showed that the addition of reinforcements with superior mechanical strength, high thermal conductivity, and low coefficient of thermal expansion as primary reinforcement enhances the overall properties of the hybrid composite material. From the XRD analysis, it is observed that the Al_4C_3 intermetallic compound is present in S7G5 hybrid composite sintered through conventional method. Some studies reported that the finer Al_4C_3 compound acts as grain pinning agent and hinders the grain movement and grain growth, and also activates the precipitation strengthening mechanism by which the mobility of dislocations obstructs and leads to low ductility levels in the composite material [43]. The differences in thermal expansion coefficients of matrix and reinforcement particles often cause uneven plastic deformations at the interface region and produces dislocation defects during the sintering process. These dislocation defects rapidly reduce while going away from the interface regions and the high-density dislocations at interface regions enable the enhanced dislocation density strengthening mechanisms, which in turn reduces the ductility of the composite material [47] as confirmed in this study from the obtained tensile stress-strain curves as shown in Fig. 13. To reduce these types of defects, researchers generally adopt the microwave processing techniques to fabricate the hybrid composites. As ceramic reinforcements are good absorbers of microwaves, the addition of hard ceramic particles with high penetration depths (d_p) of microwaves in the order of centimeters (cm) and low loss tangent values ($\tan \delta_e \geq 0.1$) such as SiC ($d_p = 1.93$ cm, $\tan \delta_e = 0.37$), graphite ($d_p = 1.34-2.09$ cm, $\tan \delta_e = 0.36-0.67$) helps in achieving the enhanced mechanical properties with low defects [30, 32]. Figure 11 represents the mechanical properties of the AA7075 + 7%SiC + 5%graphite hybrid composite sintered through microwave technique at different temperatures. It is observed that comparing the mechanical properties of the S7G5 hybrid composite sintered through conventional and microwave techniques, an increment in tensile strength from 365 to 392 MPa for 400 °C, 471 MPa for 450 °C, and 501 MPa for 500 °C microwave sintering temperatures was noted. The S7G5 hybrid composite microwave sintered at the temperature of 550 °C showed a tensile strength of 492 MPa. The observed decreased tensile strength from 501 MPa (at 500 °C) to 492 MPa (at 550°C) can be attributed to the increased average grain size of the hybrid composite material at 550 °C as shown in Fig. 14. Hardness values of microwave sintered samples

showed a superior enhancement with increasing sintering temperatures as shown in Fig. 12. In microwave sintering process, the particles are heated at the core and then it propagates to the surface layers and thereby it eliminates the temperature gradients between core and outer part of the particles. This essentially creates a uniform heat distribution throughout the material and forms the stronger interface regions [1, 24, 48–50]. The uniform distribution of reinforcement particles and strong interfaces between the matrix and reinforcement particles enable the Orowan strengthening mechanism. It should be noted that the microwave sintering process facilitates the controlled grain growth, grain boundary strengthening and dislocation strengthening mechanisms in the materials, which fundamentally play a major role in strengthening the hybrid composite material. In previous investigation, the addition of graphite as a primary reinforcement and SiC as a secondary reinforcement to AA7075 matrix material sintered through microwave technique showed a mechanical strength of 402 and 457 MPa in tensile and compression, respectively, and accommodated an optimum reinforcement levels of 10% (8%graphite + 2%SiC) in the matrix AA7075 material [28]. In the present work, the addition of SiC as a primary and graphite as a secondary reinforcement particle showed a superior enhancement in the mechanical properties. The S7G5M500 microwave sintered composite showed a mechanical strength of 501 and 571 MPa in tensile and compression, respectively, which represented an increment of 24.6% in tensile and 24.9% in compression strengths as compared to the previous work. The selection of SiC reinforcement with high penetration depth (d_p) and low loss tangent value as primary reinforcement could be the reason behind the achieved superior mechanical properties of S7G5 microwave sintered composite. As compared to the base alloy AA7075, the S7G5M500 microwave sintered composite showed a significant increment in the mechanical strength by 347% in tensile and 206% in compression.

4. Conclusion

This present work investigated the AA7075/SiC/graphite hybrid composite system. To the base AA7075 matrix material, the SiC and graphite was added as a primary and secondary reinforcement material, respectively. The investigation was carried out in order to find out the optimized volume fraction levels of SiC and graphite in AA7075 matrix material (which is 7%SiC + 5%graphite) through the conventional sintering technique. The composites with optimized volume fraction levels were also fabricated through microwave sintering technique at different temperatures and investigated their effects on the properties of the hybrid composite material. From the results obtained, the following conclusions can be drawn.

- From SEM images, clean microstructures were observed, and no intermetallic compounds were observed in microwave sintered composites. In conventionally sintered composite, the Al_4C_3 intermetallic compound was detected, which indicated that there could be rapid chemical reactions at interface regions.
- Composite sintered through microwave technique showed a superior enhancement in properties of the composite material in terms of porosity levels, secondary phase generation.
- As compared to our previous work, where graphite was added as a primary reinforcement material and SiC as a secondary, in this work, the SiC was added as a primary reinforcement and graphite as

a secondary particle, which showed a superior enhancement in the overall mechanical properties of the composite material.

- SiC particles were taken as a primary reinforcement material owing to their superior response to microwaves and their other properties such as high penetration depth in the order of cm, low loss tangent, and they generate rapid internal heat by absorbing microwaves as compared to graphite.
- Investigation on the effect of microwave sintering temperature on the optimized volume fractioned hybrid composite showed that the increasing microwave sintering temperature led to the grain growth in the composite material, where the composite microwave-sintered at 550 °C possessed an average grain size of around 19.66 μm . Further, a slight increment was observed in the porosity levels of the composite and a decrement was observed in their mechanical properties. These observations showed that the microwave sintering process can also lead to the poor performance of the composite material if the sintering temperature exceeds the critical temperature of the materials.
- From this investigation, it can be concluded that the selection of microwave-absorbing ceramic materials with high internal heat generation can help in enhancing the overall mechanical properties of the hybrid composite material, especially, the materials which are highly responsive to the microwaves should be selected as a primary reinforcement material in order to achieve the excellent mechanical properties in the hybrid composite systems.

Declarations

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Author's Contribution

Guttikonda Manohar: Conceptualization, Methodology, Data curation, Writing- Investigation, Original draft preparation. **K M Pandey & S R Maity**: Reviewing, Editing, Validation, Visualization, and Supervision

Data Availability

Authors confirm that the entire data obtained during the Experiment was included in this available manuscript.

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Authors declared that they have no conflict of interest.

Ethical Approval

Ethics Approval All experiments were conducted ethically and no issues regarding ethical issues arose during the experiments or the manuscript confection

Compliance with Ethical Standards

The Authors declare that they don't have known personal relationships or competing financial interest that could have appeared to influence the work reported in this manuscript.

Research Involving Human Participants and/or Animals - Not applicable

Informed Consent - Not applicable.

Consent to Participate

All the Authors are happily agree to contribute in this research work.

Consent for Publication

Consent was obtained from all authors to publish this manuscript. All the authors read and approved this manuscript to publish this article.

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Figures

Figure 1

SEM images of reinforcement particles (a) SiC particles (b) graphite particles

Figure 2

Composite Specimens with dimensions for mechanical tests

Figure 3

Schematic diagram showing the path of the present work

Figure 4

SEM images of AA7075+7% SiC+5%graphite (S7G5) composites microwave sintered at different temperatures (a) 400°C (b) 450°C (c) 500°C (d) 550°C

Figure 5

Porosity levels of (a) AA7075+x%SiC (x=0-10) conventionally sintered composite (b) AA7075+7%SiC+x%graphite (x=0-7) conventionally sintered composite (c) AA7075+7%SiC+5%graphite microwave sintered composite at different temperatures

Figure 6

XRD analysis of AA7075+7%SiC+5%graphite hybrid composite sintered through microwave technique at different temperatures

Figure 7

Mechanical properties of the AA7075+x% SiC (x = 0-10) composite sintered through conventional technique

Figure 8

Hardness values of the AA7075+x% SiC (x = 0-10) composite sintered through conventional technique

Figure 9

Mechanical properties of the AA7075+7%SiC+x%graphite (x = 0-7) hybrid composite sintered through conventional technique

Figure 10

hardness values of the AA7075+7%SiC+x%graphite ($x = 0-7$) hybrid composite sintered through conventional technique

Figure 11

mechanical strengths of AA7075+7%SiC+5%graphite hybrid composite sintered through microwave technique at different temperatures

Figure 12

hardness values of the AA7075+7%SiC+5%graphite hybrid composite sintered through microwave technique at different temperatures

Figure 13

Tensile stress-strain curves of the AA7075+7%SiC+5%graphite hybrid composite sintered through microwave technique at different temperatures

Figure 14

statistical grain size distribution analysis of S7G5 hybrid composite microwave sintered at different temperatures