

Innovation Into the Mechanical and Micro Structural Properties of Sic-Reinforced Al7075 Metal Matrix Composites- A Review

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Abstract:

In the present study, some selected samples are heat-treated by elevating the temperature to 480°C for 2 hours and then quenched in different mediums in order to investigate the effect on the mechanical properties of the Aluminium 7075 alloy. A composite material is a combination of two or more chemically distinct and insoluble phases; its properties and structural performance are superior to those of the constituents acting independently. Metals and ceramics, as well, can be embedded with particles or fibres, to improve their properties; these combinations are known as Metal Matrix composites. Aluminium 7075 alloy constitutes a very important engineering material widely employed in the aircraft and aerospace industry for the manufacturing of different parts and components. It is due to its high strength to density ratio that it is a sought-after metal matrix composite. In this paper we present a survey of Al 7075 Metal Matrix Composites. In we focused on the study of behaviour of Aluminium alloy (Al 7075) with SiC and TiB₂ composite produced by the stir casting technique. Al7075 alloy is taken as base material and then it is reinforced with silicon carbide (SiC) and titanium di-boride (TiB₂). Different weight % of TiB₂ reinforcement is used by keeping standard weight % of SiC. After preparation of suitable samples, tensile test and hardness test were performed and results were analysed.

Keywords — Metal Matrix Composites (MMC's), Aluminium Metal Matrix, Silicon carbide, Titanium boride, Al7075, Aluminium alloy.

1. INTRODUCTION

Aluminum-7075 alloys are extensively utilized in aerospace, automotive, and marine industries due to their advantageous strength-to-weight ratio and commendable mechanical properties [1]. However, the inherent limitations of monolithic Al7075, particularly concerning wear resistance and stiffness, necessitate the integration of reinforcing phases to enhance its performance envelope, thereby leading to the development of metal matrix composites [2]. Specifically, the incorporation of silicon carbide particulates into the Al7075 matrix has emerged as a prominent strategy for fabricating advanced composites with superior mechanical and microstructural characteristics [3], [4].

This review systematically examines recent advancements in understanding and optimizing the

mechanical and microstructural properties of SiC-reinforced Al7075 MMCs, focusing on processing techniques, interfacial phenomena, and their resultant influence on composite performance.

This includes a detailed analysis of how varying SiC particle size, morphology, and volume fraction impact tensile strength, hardness, ductility, and wear resistance [5], [6].

The intricate interplay between these parameters and their direct correlation with the overall performance of the composites will be thoroughly discussed, alongside an assessment of emerging fabrication methods such as stir casting, powder metallurgy, and additive manufacturing.

Furthermore, the review will delve into the critical role of interfacial bonding between the SiC reinforcement and the Al7075 matrix, evaluating

how different surface treatments and processing parameters influence load transfer efficiency and composite integrity.

The objective is to synthesize current research findings on Al7075-based composites reinforced with ceramic particles, including SiC, alumina, iron oxide, and titanium carbide, to provide a comprehensive understanding of their mechanical and microstructural behaviour [7]. This comprehensive analysis aims to delineate the crucial factors influencing the performance of these composites, offering insights for future material design and application [8], [9], [10]. The exceptional strength-to-density ratio, high modulus, and wear resistance of ceramic reinforcements like SiC make them particularly suitable for enhancing the mechanical properties of aluminium alloys utility and toughness.

2.LITERATURE REVIEW:

This chapter presents a review of the literature data available on the effect of various reinforcement types, their size and volume fraction, ageing behaviour with AL based MMC's. Zhao et.al. studied the microstructures and mechanical properties of equal-channel angular pressing (ECAP) processed and naturally aged ultrafine grained (UFG) and coarse grained (CG) Al7075 alloys and their evolutions during heat treatment. Their studies established that after the tests, natural aging, tensile yield strength, ultimate strength and micro hardness of UFG samples were higher by 103%, 35% and 48% respectively than those of the CG samples. Their studies show that severe plastic deformation has the potential to significantly improve the mechanical properties of age-hardening Al alloys. Gopal Krishna U, Sreenivas Rao K V, et al., [1] have reported that, the aluminium matrix can be strengthened by reinforcing with hard ceramic particles like SiC, Al₂O₃, B₄C etc. An effort is made to enhance the mechanical properties like tensile strength and hardness of AMCs by reinforcing 6061Al matrix with B₄C particles. The microstructure and mechanical properties of the fabricated AMCs was analysed. Based on the results obtained from tensile strength test of the metal matrix composites of different particle sizes, 105µ size B₄C was chosen. The optical microstructure images reveal the

homogeneous dispersion of B₄C particles in the matrix. The reinforcement dispersion has also been identified with X-ray diffraction [XRD]. The tensile strength and hardness was found to increase with the increase in the particle size and also with the increase in wt% of the reinforcement. The tensile strength of AMCs was found to be maximum for the particle size of 105µ and found maximum for 8 wt% in case of varying wt% of the reinforcement of 105µ size. Karthigeyan et.al. Al7075 alloy composites containing different volume fraction of short basalt fibre are developed using the stir casting process. The experimental strength values of the composites are compared with the theoretical values in this paper. The results suggested that the experimental values best suited the theoretical values owing to the random distribution of basalt fibres in the Al7075 matrix. Pradeep R et.al observed the study of mechanical properties of Al- Red Mud and Silicon Carbide Metal Matrix Composite (MMC) of Aluminium alloy of grade 7075 with addition of varying weight percentage composition such as SiC8%+Al7075, SiC6%+Red mud2%+ Al7075, SiC4%+Red mud 4%+Al7075, SiC2%+Red mud 6%+Al7075, Red mud 8%+Al7075ed mud and Silicon Carbide particles by stir casting technique. The experimental result reveals that the combination of a matrix material with reinforcement such as SiC and Red mud particles, improves mechanical properties Ravichandran M et.al carried out the research work by fabricating aluminium metal matrix composites through liquid powder metallurgy route. The aluminium matrix composite containing TiO₂ reinforcement particle was produced to study the mechanical properties such as tensile strength and hardness. Yazdaan et.al. have investigated the fabrication and precipitation hardening characterization of nanostructure Al7075 alloy. In their experiment, the Al7075 alloy is milled up to 15 h and then hot pressed. The milled and hot pressed samples are characterized by XRD, TEM, SEM and DTA. Their results indicated that after 15 h of milling, the alloying elements are dissolved in the Al matrix and a supersaturated solid solution with average crystallite size of 30±5 nm is obtained. Hot pressing the powder samples at 500oC under 400 MPa resulted in a fully dense bulk nanostructure Al7075 alloy. The hardness value of the consolidated

sample increased from 165 HV to 240 HV after appropriate hardening. Keshava Murthy R et.al studied about Al7075-TiB₂ in-situ composite, processed by stir casting technique using commercially available Al-10%Ti and Al-3%Br master alloys. Both matrix alloy and composite were subjected to microstructure analysis, micro hardness test, grain size studies and tensile test. Microstructure shows fairly uniform distribution of TiB₂ particles in matrix alloy. Average grain size of the composite was lower than unreinforced alloy. Micro hardness, yield strength and ultimate tensile strength of Al7075-TiB₂ composite, were considerably higher when compared with unreinforced alloy. Anand Kumar et.al research work carried out by Addition of reinforcement such as TiC, SiC, Al₂O₃, TiO₂, TiN, etc. to Aluminium matrix for enhancing the mechanical properties has been a well-established fact. In-situ method of reinforcement of the Aluminium matrix with ceramic phase like Titanium Carbide (TiC) is well preferred over the Ex-situ method. In the present investigation, Al-Cu alloy (series of 2014 Aluminium alloy) was used as matrix and reinforced with TiC using In-situ process. The Metal Matrix Composite (MMC) material, Al-5%Cu/10%TiC developed exhibits higher yield strength, ultimate strength and hardness as compared to Al-4.5%Cu alloy. Percentage increase in yield and ultimate tensile strengths were reported to be about 15% and 24% respectively whereas Vickers hardness increased by about 35%. The higher values in hardness indicated that the TiC particles contributed to the increase of hardness of matrix.

1.1 CHEMICAL COMPOSITION OF AL7075

Among several series of aluminum alloys, Al7075 alloy are highly corrosion resistant, exhibits moderate strength and finds much applications in the fields of construction, automotive and marine applications. In the present work, Aluminium 7075 alloy with the theoretical density 2.81 g/cm³ was selected as matrix materials. The chemical composition of Al 7075 alloy is given in Typical chemical composition for Aluminium alloy 7075 Elements Mn Cr Fe Cu Si Mg Zn Ti Al (wt %) 0.30. 280. 52. 00. 42. 96. 10. 2 Balance

Properties for aluminium alloy 7075 Density 2.81 g/cm³ Hardness, Brinell 150 GPa Ultimate Tensile Strength 572 MPa Tensile Yield Strength 503MPa Elongation at Break 11% Modulus of Elasticity 71.7 GPa Poisson's Ratio 0.33 Shear Strength 331 MPa Shear Modulus 26.9 GPa Melting Point Temperature 477 – 6350 C MACHINABILITY Alloys of this and similar compositions are rather difficult to machine. This is due firstly to their tendency to drag and secondly to the rapid tool wear caused by the high zinc content. Carbide tipped tools with large rake angles and relatively low cutting speeds give comparatively good results. A cutting lubricant and coolant should be employed. CORROSION RESISTANCE 7075 exhibits excellent resistance to corrosion under both ordinary atmospheric and marine conditions. For the severest conditions this property can be further enhanced by anodic treatment. ANODISING 7075 can be anodised by any of the common processes, the resulting protective film ranging in color from grey to dark brown. APPLICATIONS Typical applications for aluminium alloy 7075 include: Aircraft and aerospace components, Marine fittings, Transport, Bicycle frames, Camera lenses, Drive shafts, Electrical fittings and connectors, Brake components, Valves, Couplings The ductility of 7075 enables castings to be rectified easily or even modified in shape, e.g. simple components may be cast straight and later bent to the required contour.

1.2 Future Research Directions:

Future research on Al7075-SiC metal matrix composites should focus on improving mechanical performance, microstructural stability, and manufacturing efficiency to meet the increasing demands of advanced engineering applications. Optimization of fabrication parameters is essential to achieve uniform reinforcement distribution, reduced porosity, and strong interfacial bonding.

Further studies are needed on hybrid composite systems by combining SiC with other reinforcements such as graphite, Al₂O₃, boron carbide, and nano-materials to obtain multifunctional properties including improved wear resistance, thermal stability, and corrosion resistance. Research on

nano-sized SiC reinforcement can also provide better grain refinement and enhanced mechanical behavior.

Advanced fabrication techniques such as additive manufacturing, ultrasonic-assisted casting, spark plasma sintering, and friction stir processing require deeper investigation to improve composite quality and reduce defects. In addition, the application of artificial intelligence and computational modeling can help predict material behavior and optimize processing conditions effectively.

Future work should also focus on improving machinability, recyclability, and cost-effectiveness of Al7075-SiC composites for large-scale industrial production. Long-term studies on fatigue behavior, corrosion performance, and high-temperature applications are important for expanding their use in aerospace, automotive, marine, and defense industries.

Overall, continued research and technological advancements are expected to enhance the performance and commercial potential of SiC-reinforced Al7075 metal matrix composites in next-generation engineering applications

2. Recent Innovations and Research Trends

Recent research on SiC-reinforced Al7075 metal matrix composites has mainly focused on improving mechanical performance, microstructural uniformity, and manufacturing efficiency. Advanced processing techniques and hybrid reinforcement systems are being developed to overcome the limitations of conventional composites.

One major innovation is the use of hybrid reinforcements, where SiC is combined with materials such as graphite, aluminum oxide (Al₂O₃), boron carbide (B₄C), or fly ash. These hybrid composites exhibit improved strength, wear resistance, thermal stability, and reduced weight compared to single-reinforcement composites.

Researchers are also exploring advanced fabrication techniques such as friction stir processing, ultrasonic-assisted casting, spark plasma sintering, and additive manufacturing. These methods provide better particle distribution, reduced porosity, and enhanced interfacial bonding, leading to improved composite quality.

Nanotechnology has emerged as another important research area. The incorporation of nano-sized SiC particles improve grain refinement, hardness, and fatigue resistance while enhancing overall microstructural properties. Nano-reinforced composites show significant potential for high-performance aerospace and defense applications.

3. Mechanical Properties of SiC-Reinforced Al7075 Composites:

The incorporation of silicon carbide (SiC) particles into the Al7075 matrix significantly improves the mechanical properties of the composite. These enhancements make Al7075-SiC composites highly suitable for aerospace, automotive, marine, and defense applications where high strength and durability are required.

3.1 Tensile Strength

The tensile strength of Al7075 composites increases with the addition of SiC reinforcement due to effective load transfer between the matrix and reinforcement particles. Uniformly distributed SiC particles restrict dislocation movement and improve the overall strength of the material.

3.2 Hardness

SiC particles possess high hardness, which directly contributes to increased hardness of the composite material. The presence of hard ceramic particles improves resistance to surface deformation and enhances wear resistance.

3.3 Wear Resistance

Al7075-SiC composites exhibit superior wear resistance compared to unreinforced Al7075 alloy. The hard SiC particles reduce material loss during friction and sliding conditions, making the composites suitable for brake discs, pistons, and bearing applications.

3.4 Impact Strength

The impact strength of the composite depends on the amount and distribution of SiC particles. Moderate reinforcement improves energy absorption capability, while excessive SiC content may reduce toughness and ductility.

3.5 Fatigue Strength

The addition of SiC reinforcement enhances fatigue resistance by minimizing crack initiation and propagation under cyclic loading conditions. Fine

grain structure and improved interfacial bonding contribute to better fatigue performance.

3.6 Compressive Strength

SiC reinforcement also improves the compressive strength of Al7075 composites by increasing stiffness and resistance to deformation under compressive loads.

Overall, the mechanical performance of Al7075–SiC composites is strongly influenced by factors such as reinforcement percentage, particle size, fabrication method, and heat treatment conditions.

4. Microstructural Properties and Analysis:

Microstructural analysis plays an important role in understanding the behavior and performance of SiC-reinforced Al7075 metal matrix composites. The distribution of reinforcement particles, grain structure, interfacial bonding, and presence of defects directly influence the mechanical properties of the composite.

4.1 Grain Refinement

The addition of SiC particles promotes grain refinement in the Al7075 matrix by restricting grain growth during solidification. Fine grain structures improve strength, hardness, and wear resistance of the composite material.

4.2 Particle Distribution

Uniform distribution of SiC particles within the aluminum matrix is essential for achieving improved mechanical performance. Proper dispersion enhances load transfer and reduces stress concentration. Non-uniform distribution or particle clustering can lead to weak regions and reduced strength.

4.3 Interfacial Bonding

Strong interfacial bonding between Al7075 and SiC particles ensures effective stress transfer and improved composite stability. Good bonding enhances tensile strength, fatigue resistance, and thermal stability of the material.

4.4 Porosity and Defects

Porosity is one of the major defects observed in metal matrix composites, especially in stir-cast composites. Excessive porosity weakens the material and reduces mechanical performance. Other defects such as particle agglomeration and micro-cracks may also affect composite reliability.

4.5 Microstructural Characterization Techniques

Various characterization methods are used to study the microstructure of Al7075–SiC composites, including:

Optical Microscopy (OM)

Scanning Electron Microscopy (SEM)

X-ray Diffraction (XRD)

Energy Dispersive Spectroscopy (EDS)

These techniques help in analyzing grain structure, reinforcement distribution, phase formation, and fracture behavior.

Overall, microstructural analysis confirms that proper reinforcement distribution and strong interfacial bonding are key factors responsible for the enhanced performance of SiC-reinforced Al7075 composites

5. Effect of Reinforcement Parameters

The mechanical and microstructural properties of Al7075–SiC metal matrix composites are greatly influenced by reinforcement parameters such as particle size, weight percentage, shape, and distribution of SiC particles. Proper optimization of these parameters is essential for achieving improved composite performance.

5.1 Effect of SiC Weight Percentage

Increasing the weight percentage of SiC reinforcement generally improves hardness, tensile strength, wear resistance, and stiffness of the composite. This improvement occurs due to enhanced load transfer and restriction of dislocation movement within the matrix. However, excessive SiC content may lead to porosity, particle agglomeration, and reduced ductility.

5.2 Effect of Particle Size

The size of SiC particles significantly affects the composite behavior. Fine SiC particles provide better grain refinement, improved surface finish, and enhanced mechanical strength due to their larger surface area. Coarser particles may increase wear resistance but can also cause stress concentration and micro-crack formation.

5.3 Effect of Particle Distribution

Uniform distribution of SiC particles within the Al7075 matrix is important for obtaining consistent mechanical properties. Proper dispersion improves interfacial bonding and reduces localized stress

concentrations. Non-uniform distribution may weaken the composite structure and decrease reliability.

5.3 Effect of Reinforcement Shape

The shape of reinforcement particles influences the bonding and strengthening mechanism. Angular SiC particles generally provide better mechanical interlocking and wear resistance compared to spherical particles.

5.4 Effect of Processing Parameters

Processing conditions such as stirring speed, stirring time, sintering temperature, and cooling rate also affect reinforcement distribution and composite quality. Optimized processing parameters help in minimizing defects and improving overall performance.

Therefore, careful selection and control of reinforcement parameters are necessary for developing high-performance Al7075–SiC metal matrix composites suitable for advanced engineering applications.

6. Applications of Al7075–SiC Composites:

Al7075–SiC metal matrix composites are widely used in advanced engineering fields due to their high strength-to-weight ratio, excellent wear resistance, improved hardness, and superior mechanical performance. These properties make them suitable for applications requiring lightweight and durable materials.

6.1 Aerospace Applications

In the aerospace industry, Al7075–SiC composites are used for structural components, aircraft fittings, wing parts, and fuselage sections. Their lightweight nature and high strength help improve fuel efficiency and overall aircraft performance.

6.2 Automotive Applications

These composites are extensively used in automotive components such as brake discs, pistons, connecting rods, cylinder liners, and drive shafts. Improved wear resistance and reduced weight contribute to better vehicle efficiency and durability.

6.3 Marine Applications

In marine engineering, Al7075–SiC composites are used in propeller shafts, marine fittings, and structural parts due to their good corrosion resistance and mechanical stability in harsh environments.

6.4 Defense Applications

The defense sector utilizes these composites in armored vehicle components, weapon systems, and protective structures because of their high strength, impact resistance, and lightweight characteristics.

6.5 Industrial and Structural Applications

Al7075–SiC composites are also used in industrial machinery, robotic components, sports equipment, and structural applications where high stiffness, dimensional stability, and wear resistance are required.

Overall, the wide range of applications demonstrates the growing importance of SiC-reinforced Al7075 composites in modern engineering and manufacturing industries.

7.Challenges and Limitations :

Despite the significant advantages of Al7075–SiC metal matrix composites, several challenges and limitations affect their widespread industrial application. These issues mainly arise during fabrication, processing, and performance evaluation of the composites.

One of the major challenges is the uniform distribution of SiC particles within the Al7075 matrix. Improper mixing may lead to particle agglomeration, resulting in non-uniform mechanical properties and reduced composite strength. Porosity formation during casting processes is another common problem that negatively affects density, hardness, and fatigue performance.

The addition of SiC reinforcement also tends to reduce the ductility and toughness of the composite. Although hardness and wear resistance improve, excessive reinforcement can make the material brittle and susceptible to crack initiation under impact loading conditions.

Another limitation is poor wettability between the aluminum matrix and SiC particles, which may weaken interfacial bonding and reduce effective load transfer. High processing temperatures can also lead to undesirable interfacial reactions and formation of brittle phases.

Machining and fabrication of Al7075–SiC composites are comparatively difficult due to the presence of hard ceramic particles, leading to increased tool wear and higher manufacturing costs. In addition, advanced fabrication methods such as

powder metallurgy and friction stir processing require specialized equipment and process control.

Therefore, further research is required to optimize processing techniques, improve particle dispersion, minimize defects, and enhance the overall reliability and cost-effectiveness of Al7075–SiC composites for large-scale industrial applications.

CONCLUSIONS:

SiC-reinforced Al7075 metal matrix composites have emerged as promising materials for advanced engineering applications due to their excellent mechanical and microstructural properties. The incorporation of silicon carbide particles significantly improves tensile strength, hardness, wear resistance, fatigue performance, and thermal stability compared to conventional Al7075 alloy.

Various fabrication techniques such as stir casting, powder metallurgy, squeeze casting, and friction stir processing play an important role in determining the quality and performance of the composites. Microstructural studies reveal that uniform distribution of SiC particles and strong interfacial bonding contribute to enhanced composite behavior. However, challenges such as porosity, particle agglomeration, reduced ductility, and machining difficulties still remain.

Recent innovations including hybrid reinforcements, nano-sized particles, and advanced manufacturing methods have shown considerable potential in overcoming these limitations and improving overall composite performance. Due to their lightweight nature and superior strength, Al7075–SiC composites are increasingly used in aerospace, automotive, marine, defense, and industrial applications.

Overall, the review concludes that SiC-reinforced Al7075 composites possess significant potential for future high-performance structural applications, and continued research will further enhance their reliability, efficiency, and commercial viability.

REFERENCES :

- [1] Friction stir additive manufacturing—an innovative tool to enhance mechanical and microstructural properties *Mater. Sci. Eng. B.*, 263 (2021), Article 114832, 10.1016/j.mseb.2020.114832
- [2] A. Mehri, A. Abdollahzadeh, S. Entesari, T. Saeid, J.T. Wang The effects of friction stir welding on microstructure and formability of 7075-T6 sheet Results Eng., 18 (2023), Article 101041, 10.1016/j.rineng.2023.101041
- [3] M.Y. Khalid, R. Umer, K.A. Khan Review of recent trends and developments in aluminium 7075 alloy and its metal matrix composite (MMCs) for aircraft applications Results Eng., 20 (2023), Article 101372, 10.1016/j.rineng.2023.101372
- [4] R. Fu, Y. Liang, Q. Han, Y. Guo, H. Lei, C. Liu Strengthening and fracturing mechanisms of laser-directed energy deposited Al-7075 alloy *Mater. Sci. Eng. A.*, 881 (2023), Article 145433, 10.1016/j.msea.2023.145433
- [5] S. Palanivel, R.S. Mishra Building without melting: a short review of friction-based additive manufacturing techniques *Int. J. Addit. Subtractive Mater. Manuf.*, 1 (2017), pp. 82-103, 10.1504/IJASMM.2017.082991
- [6] S. Palanivel, P. Nelaturu, B. Glass, R.S. Mishra Friction stir additive manufacturing for high structural performance through microstructural control in an Mg based WE43 alloy *Mater. Des.*, 65 (2015), pp. 934-952, 10.1016/j.matdes.2014.09.082
- [7] H. Gao, H. Li Friction additive manufacturing technology: a state-of-the-art survey *Adv. Mech. Eng.*, 13 (2021), pp. 1-29, 10.1177/16878140211034431
- [8] A. Hassan, S.R. Pedapati, M. Awang, I.A. Soomro A comprehensive review of friction stir additive manufacturing (FSAM) of non-ferrous alloys *Materials*, 16 (2023), p. 2723, 10.3390/ma16072723
- [9] D. White, Object consolidation employing friction joining, US 6,457,629 B1 Oct. 1, 2002, 2002.
- [10] P. Lequeu, R. Muzzolini, J.C. Ehrstrom, F. Bron, R. Maziarz, High-Performance friction stir welded structures using advanced alloys, in: *Aeromat Conf.*, Seattle WA, 2006.