

Comparative Microstructural Analysis of Al7068 with Al7075 and review of the micro & nanoparticles reinforced with aluminum metal matrix composite materials

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Abstract

The present review focuses on the microstructural comparison of Al7068 and Al7075 alloys reinforced with micro- and nano-sized particles in aluminum matrix composite materials. Different reinforcement materials such as silicon carbide (SiC), aluminum oxide (Al₂O₃), magnesium oxide (MgO), titanium carbide (TiC), boron nitride (BN), silicon nitride (Si₃N₄), titanium diboride (TiB₂), and silicon dioxide (SiO₂) have been used by researchers to evaluate the influence on the microstructural and mechanical behavior of aluminum alloys. This review as well as explores the effect of micro and nano particles on grain refinement, phase distribution, interfacial bonding of Al7068 and Al7075 aluminum alloys. Different casting methods such as stir casting, powder metallurgy, squeeze casting, and ultrasonic-assisted casting, are also discussed. The mixing of micro- and nanoparticles improves the tensile strength, hardness and wear resistance of the composites. Furthermore, the study compares the microstructural characterization of Al7068 and Al7075 base alloys. This review provides a comprehensive to understand the recent investigations in micro- and nano-reinforced aluminum matrix composites.

Keywords: Al7068, Al7075, Microparticles, Stir casting, Optical Microscopic, AMMC.

1. Introduction

Aluminum Metal Matrix Composites is one of the important engineering materials because of its high strength/weight ratio as well as improved wear resistance, good thermal stability, and superior mechanical properties. These materials are widely used in aerospace, automobile, marine and defense applications. From all aluminum alloys, Al7068 and Al7075 are considered is one of the most suitable matrix materials due to its excellent tensile strength and machinability.[1] The mixing of micro- and nano-sized reinforcement particles into aluminum alloys has been improved the mechanical and microstructural properties of metal matrix composites. The mechanical properties of metal matrix composite are strongly influenced by the different types of reinforcement, manufacturing method, and processing parameters. The clear understanding of synthesis routes, reinforcement selection, and resulting mechanical behavior is essential for industry to optimizing for the industrial use. While important progress has been done in manufacturing techniques and applications, challenges related to large-scale production and commercialization still remain. Resolving these issues is critical role to expanding the practical adoption of AMCs across diverse industrial sectors. [2]

The microstructural analysis of aluminum matrix composites is use to determining the mechanical behavior. Microstructural Parameters such as grain size, particle distribution, porosity, interfacial bonding, and phase formation directly affect the strength and durability of the composite material. Therefore, the comparative microstructural study of Al7068 and Al7075 reinforced composites is essential for understanding its suitability for advanced engineering applications.[3]

This review presents the microstructural comparison of Al7068 and Al7075 alloys reinforced with micro- and nano-sized particles. The study also discusses the influence of different reinforcements and fabrication techniques on the mechanical and microstructural properties of aluminum metal matrix composites. Al7068 mainly contains of aluminum (Al) as the base element, with key alloying elements such as magnesium (Mg), zinc (Zn), and copper (Cu), along with minor additions of zirconium (Zr) and chromium (Cr). This alloy's compositions make it material too stronger to achieve greater tensile strengths exceeding many steels, making it one of the strongest commercially available aluminum alloys.[4]

2. Literature Review

A. Shanmugam et. al (2023) have done work on machining of Aluminum 7075 metal matrix composites by abrasive water jet machining (AWJM). By using Taguchi and DEAR methods, the effects of pressure, standoff distance, and traverse speed on material removal rate, surface roughness, and taper angle were analyzed. The optimal machining condition was identified as 180 MPa pressure, 3 mm standoff distance, and 40 mm/min traverse speed, which resulted in noticeable improvements in surface quality. Traverse speed was found to be the most influential parameter. SEM analysis of the machined surface revealed typical features such as ploughing marks, ductile fracture, and minor cracking, confirming the influence of machining conditions on surface integrity [5]. K. R. V. Gudipalli et. al (2024) shows the tribological improvement of Al7075-SiC composites through the mixing of graphite as a solid lubricant. While Al7075-SiC composites are widely used in engineering applications, due to its friction and wear characteristics limitations. For this purpose, Al7075-SiC/Graphite hybrid composites containing 3–9 wt% graphite have been fabricated via stir casting and tested under dry sliding conditions. Using Taguchi optimization, ANOVA, and regression analyses, the influence of sliding distance, load, and graphite content on wear and friction was systematically examined. The results indicate that 9 wt% graphite reinforcement noticeably decreases both wear rate and coefficient of friction, made the self-lubricating composites. From the among the parameters, sliding distance dominantly affected wear behavior, whereas graphite composition (77% contribution) applied the extreme influence on frictional response, with load is a secondary role. Overall, the work demonstrates that graphite addition effectively transforms Al7075-SiC composites into advanced self-lubricating materials, thereby broadening its applicability in demanding tribological environments [4].

M. Alipour et. al (2023) investigated the microstructural changes and mechanical performance of Al–10Zn–3.5Mg–2.5Cu/graphene nanoplate (GNP) composites prepared by via ball milling and stir casting. Reinforcement of GNPs, due to its large specific surface area, significantly improved the strength characteristics of the composites. Microstructural observations indicated that GNP addition improved the grain refinement, although at higher content GNPs (1 wt%) no further reduction in grain size was observed. Tensile testing demonstrated that GNP reinforcement has been enhanced ultimate tensile strength (UTS), with the addition of 0.7 wt% GNP composite and achieving UTS 582 MPa. Furthermore, T6 heat treatment (solutionizing at 460 °C for 8 h, water quenching, and aging at 120 °C for 24 h) resulted the superior strength compared to other processing conditions. However, excess amount of GNP addition led to agglomeration at grain boundaries, which acted as preferential sites for crack initiation and propagation. Overall, the conclude that a controlled addition of GNPs—particularly at 0.7 wt%—optimally enhances the strength of Al–Zn–Mg–Cu alloys, while excessive reinforcement can decreases fracture resistance due to agglomerate formation [1].

A. A. Akinwande et. al (2023) investigated the lightweight high-entropy alloys (LHEAs) used as reinforcements for Al-7068 aerospace alloy composites. LHEA composition (Al–Li–Mg–Be–Ti–Cu) have been added at 4, 10, and 16 wt% using stir casting, with the aim of improving both strength and ductility. X-ray diffraction analysis report confirmed the formation of BCC and FCC phases originating from the LHEA, along with secondary CuAl_2 and MgBe_{13} intermetallic phases. The microstructural distribution of LHEA particulates varied with different amount content at : sparse at 4%, uniform at 10%, and partially clustered at 16% [6]. P. Samal et. al (2023) compared the mechanical properties and microstructure of copper-based hybrid composites alloys reinforced with SiC–graphite and WC–graphite microparticles, produced by using the stir casting method. The results show that both microparticles are uniformly distributed throughout the copper matrix and are clearly identified through microstructural and phase analyses. With the mixing of hard ceramic microparticles significantly improves the tensile strength and hardness in both composites. Among them, WC–graphite reinforced composites exhibited superior mechanical properties compared to SiC–graphite reinforced ones. Fracture analysis indicates that both composites firstly fail through ductile fracture test, confirming its ability to retain toughness while gaining strength[7]. J. Sharma et. al (2024) explores the impact of zirconium dioxide (ZrO_2) reinforcement on the mechanical performance of Al7075 alloy, with focus to make compositions for aerospace-grade applications. Al7075– ZrO_2 composites has been synthesized via stir casting, mixed with both micron-sized (1–3 wt%) and nano-sized (0.17–0.51 wt%) ZrO_2 particles. Mechanical testing evaluated peak stress, load capacity, and yield strength [8]. B. Pu et. al (2020) discusses the effect of silicon carbide nanoparticles (SiC_{np}) on the precipitation behavior of Al7075 alloy. The $\text{SiC}_{\text{np}}/7075\text{Al}$ composite has been synthesized using powder metallurgy techniques, such as shift-speed ball milling, hot pressing, and hot extrusion, followed by T6 heat treatment. [9]

Even at a low reinforcement level of 1 vol%, SiCnp have been found to significantly alter precipitation kinetics, provided finer, uniformly dispersed η' precipitates while simultaneously increasing dislocation density. With increasing addition of SiC nanoparticles to the Al7075 alloy, both the yield strength (YS) and ultimate tensile strength (UTS) of the SiCnp/ Al7075 composites showed an excellent improvement. The maximum values, YS of 559 MPa and a UTS of 609 MPa, have been achieved at 1.0 vol% SiCnp reinforcement, representing improvement of 72 MPa and 53 MPa, respectively, compared to the unreinforced matrix [9]

2.1. Outcomes of Literature Review

The recent studies indicated that these microparticles have potential to improve grain refinement, interfacial bonding, thermal stability, and overall mechanical performance of aluminum matrix composites. Further investigation is also required to understand the effect of different micro and nanoparticles percentages, casting techniques, and processing parameters on the microstructural and mechanical behavior of these composites.

In addition, comparative studies between micro- and nano-reinforcements are still limited, creating opportunities for future research in the development of lightweight and high-performance engineering materials for aerospace, automobile, and structural applications. Tables 1 present the summary of previous research work related to aluminum matrix composites reinforced with different micro- and nano-sized particles.

Table 1. Summary of literature review.

S.No	Author's Name /Aluminum Alloy	Fabrication methods	Investigation Approach	Reinforcement	Key Findings	Ref. No.
1	A. Shanmugam <i>et al.</i> (2023)/ Al7075	Al7075	Abrasive water jet machining	Taguchi and DEAR methods	optimal machining condition was identified as 180 MPa pressure, 3 mm standoff distance, and 40 mm/min traverse speed, which resulted in noticeable improvements in surface quality	[5]
2	K. R. V. Gudipalli <i>et al.</i> (2024) / Al7075	Stirring Process	ANOVA	SiC, Graphite	With the mixing of graphite content reduces both the coefficient of friction and wear rate	[4]
3	S. Ahmad <i>et al.</i> (2024) / Al-7075	stir casting	Pin-on-disc setup	TiO ₂	Higher TiO ₂ compositions (6–8%) displayed stable tribological performance, while 10%. Higher compositions (8–10%) showed increasing wear rates at higher sliding speeds	[10]
4	J. Sharma <i>et al.</i> (2024) / Al7075	Stir Casting	Tensile Testing, Optical Microscopic	zirconium dioxide (ZrO ₂)	micron-sized (1–3 wt%) and nano-sized (0.17–0.51 wt%) ZrO ₂ particles. Mechanical testing evaluated peak stress, load capacity, and yield strength	[8]
5	B. S. Lovevanshi <i>et al.</i> (2024) / Al 7075	Ultrasonic transducer, two-stage stir casting	SEM, Optical microscopy	Synthetic	Strength and hardness both increased, and the highest values were found to be 569.172 MPa and 178.86 HV.	[11]
6	M. Alipour <i>et al.</i> (2023) / Al–10Zn–3.5Mg–2.5Cu	ball milling and stir casting	Microstructural changes and mechanical performance	graphene nanoplate (GNP)	GNP addition improved the strength and grain refinement. GNP addition improved the grain refinement	[1]
7	P. Samal <i>et al.</i> (2023) / Cu matrix (C87600) -	Stir casting	Microstructural and Fracture analysis , FESEM, XRD	SiC–graphite and WC–graphite	WC–graphite reinforced composites exhibited superior mechanical properties compared to SiC–graphite reinforced ones. Fracture analysis indicates that both composites firstly fail through ductile fracture test, confirming its ability to retain toughness while gaining strength	[7]
8	A. A. Akinwande <i>et al.</i> (2023) / Al6061-T6 alloy	Stir Casting	Using response surface methodology	palm kernel shell ash (PKA), rice husk ash (RHA), and waste steel particles (STP)	2–4% RHA and PKA enhanced tensile and flexural strengths, while 4–6% led to a decline in strength. Meanwhile, 2–6% of the particles enhanced the tensile and compressive strengths and moduli	[12]

Table 1. Summary of literature review.

S.No	Author's Name /Aluminum Alloy	Fabrication methods	Investigation Approach	Reinforcement	Key Findings	Ref. No.
9	A. Abebe Emiru <i>et al.</i> (2023) / Al6061		Physical, mechanical, tribological behaviour and morphological behaviour	MoS ₂ , SiC and B ₄ C	Highest density was observed at Al6061/12% SiC/4% MoS ₂ Maximum hardness 114.03 HV showed at 12% B ₄ C/ 4% MoS ₂	[13]
10	S. Kolappan <i>et al.</i> (2022) Al7068	Stirring Process	UTM	SiC, fly ash, Coconut shell	Tensile strength is increased and hardness showed 173 BHN at 8 wt% SiC and 4 wt% CSFA	[14]
11	B. Pu <i>et al.</i> (2020) / Al7075	shift-speed ball milling, hot pressing, and hot extrusion	SEM, EDX, XRD	SiC	Yield strength of 559 MPa and a Ultimate tensile strength of 609 MPa, have been attained at 1.0 vol% SiC	[15]
12	A. Mahadikar <i>et al.</i> (2020) /Al7068		Tribological behavior and impact strength	Magnesium (Mg) and Zinc (Zn)	Mg from 2.2% to 3% and Zn from 7.3% to 8.3%. Wear rate test results showed that the alloy with 3% Mg and 7.6% Zn gained the lowest wear rate under loads of 2 kg and 3 kg, indicating better wear resistance. .2% Mg and 7.6% Zn demonstrated the highest impact strength	[16]
13	M. Ravikumar <i>et al.</i> (2018) /Al7075	Stir casting	Taguchi method	SiC, Al ₂ O ₃	Hardness of Al7075 at SiC 9% and Wear Rate at SiC 3% , Al ₂ O ₃ maintain at 2%	[17]
14	M. Madhusudhan <i>et al.</i> (2017) Al7068	Stirring Process	Vickers test & UTM	ZrO ₂	Tensile strength of Al7068 is increased by 13 % and 40% hardness improved.	[18]
15	W. Ruirui <i>et al.</i> (2017) Al7075	Ball milling, and semi-solid stirring	SEM, EDX	Al ₂ O ₃	Tensile strength and hardness increase by 1.5% of Al ₂ O ₃	[19]
16	Asiva Noor Rachmayani <i>et al.</i> (2015)/ Al7068		XRD	LHEA: Al ₃₀ Li ₂₀ Mg ₁₀ Be ₂₀ Ti ₁₀ Cu ₁₀	Composites containing 4, 10, and 16 wt% LHEA have been synthesized and characterized. Formation of BCC and FCC phases found in the LHEA, along with CuAl ₂ and MgBe ₁₃	[20]

3. Microstructural Comparison of Al7068 with Al7075

From the optical microscopic images of Al7068 alloy at 50 X and 1000 X magnifications as shown in fig 1 (a) & fig1(b), the microstructure shows a dense dendritic structure with interconnected grain boundaries. The lower magnification image at 50 X shows the distribution of dendrites formed during the solidification of metal as well as indicating rapid cooling and uniform grain formation. The higher magnification image 1000 X clearly shows the grain boundaries and segregated dark regions, which may correspond to intermetallic compounds formed due to alloying elements such as zinc, magnesium, and copper.

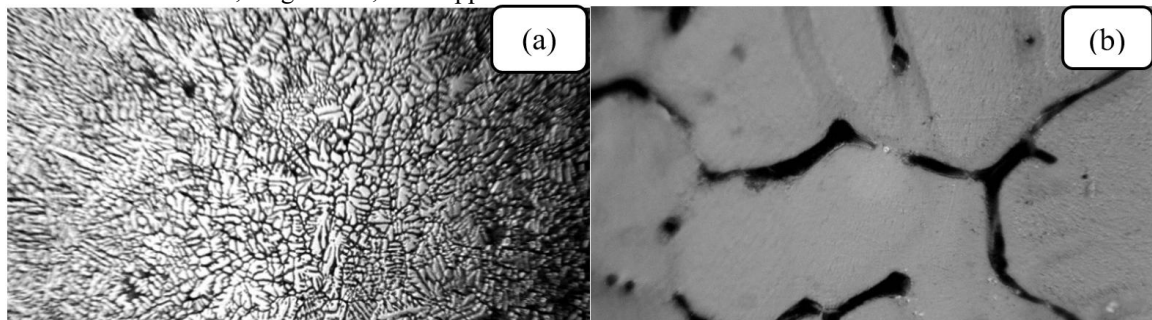


Fig. 1. (a) Optical Microscopic Image of Al7068 at 50 X Fig. 1.(b) Optical Microscopic Image of Al7068 at 1000 X

The optical microscopic images of Al7075 alloy at 200 X and 100 X magnifications as shown in fig 2(a) & fig 2 (b) exhibit a homogeneous microstructure with fine equiaxed grains. The structure appears more uniform and less dendritic than Al7068. The grains are evenly distributed, indicating good solidification behavior and proper heat treatment response.

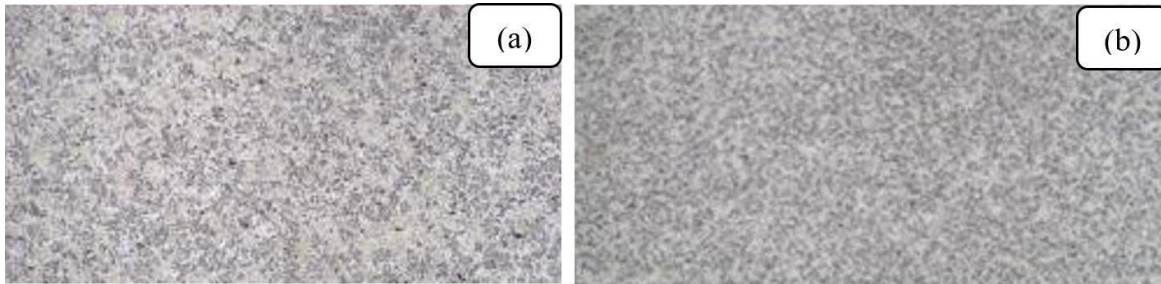


Fig. 2. (a) Optical Microscopic Image of Al7075 at 200 X[8] Fig. 2. (b) Optical Microscopic Image of Al7075 at 100 X[8]

Table 1 Comparison of Al7068 V/S Al7075

Parameter	Al7068	Al7075
Grain Structure	Dendritic and compact	Fine equiaxed grains
Grain Size	Relatively finer and denser	Slightly larger and uniform
Segregation	More visible interdendritic regions	Less segregation
Precipitate Formation	Higher precipitate concentration	Moderate precipitate distribution
Porosity	Very low	Low
Mechanical Strength	Higher	High
Hardness	Higher due to refined grains	Moderate to high
Wear Resistance	Better	Good
Toughness	Moderate	Better toughness
Overall Microstructure	Dense and highly strengthened	Uniform and balanced structure

4. Conclusion & Future work

- The most existing studies have done on the individual reinforcement of aluminum alloys using either Silicon Carbide (SiC) or Silicon Nitride (Si_3N_4). So, several researchers have investigated the effects of Silicon Carbide (SiC) and Silicon Nitride (Si_3N_4) individually on mechanical behavior. The stir casting method is an best choice for casting metal matrix composites such as the micro SiC/ Si_3N_4 particles reinforced Al7068 aluminum alloys.
- The microstructural analysis of Al7068 and Al7075 alloys showed noteworthy differences in grain morphology and phase distribution. Al7068 showed the finer and denser dendritic structure with noticeable precipitate formation, which contributes to its mechanical property's excellent hardness, tensile strength, and wear resistance. The presence of closely packed grains and reduced porosity indicated the improved structural properties as well as improved load-bearing capability.
- On the other side, Al7075 showed the more homogeneous and equiaxed grain structure with comparatively lower segregation. This uniform microstructure provides the balanced combination of strength, toughness, fatigue resistance, and machinability.

- The comparative analysis confirms that Al7068 is more suitable for high-strength and wear-resistant applications as well as for toughness are required. The study highlights the importance of microstructural characteristics to determining the mechanical behavior as well as for the engineering applications of aluminum alloys.
- Al7068 reinforced with micro or nanoparticles such as SiC, Si₃N₄ and graphene can be explored to further improve the mechanical properties.

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