Journal of Mines, Metals and Fuels, *71(12B): 299-305; 2023. DOI: 10.18311/jmmf/2023/45736*

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.com/index.php/jmmf*

Development and Evaluation of Mechanical Properties of AL6061 Based Hybrid Nano Composites Reinforced with Al_2O_3 and ZrO_2

P. S. Shreyas[1], B. P. Mahesh[2], S. Rajanna[3] and B. S. Ragavendra[4]

[1]*School of Mechanical Engineering, REVA University, Bangalore - 560064, Karnataka, India; shreyas.ps@reva.edu.in*
[2]*Department of Mechanical Engineering, JSSATE, Bangalore - 560060, Karnataka, India*
[3]*Department of Mechanical Engineering, Government Engineering College, Mosale Hosahalli, Hassan -573212, Karnataka, India*
[4]*Department of Mechanical, Government Polytechnic, Chintamani - 563125, Karnataka, India*

Abstract

MMC usage is rising in popularity right now. Studying the advantages of the Aluminum 6061 alloys reinforced with Al_2O_3 and ZrO_2 is the main goal of this work, which is finished using a stir-casting setup. With the use of a computerized universal testing machine, the MMCs' compressive and tensile tests were conducted. The experimental findings revealed that adding Al_2O_3 as a uniform 2.5% as well as increasing ZrO_2 by 1, 2, 3, and 4% increased the compressive and tensile strength.

Keywords: *Aluminium6061, Al_2O_3, ZrO_2, Mechanical Properties*

1.0 Introduction

A composite is a material system made up of two or more materials that have considerably different physical and chemical properties than their component parts. A composite material is made up of two phases: matrix (continuous phase) and reinforcement (dispersing phase), which are physically and chemically distinct and are joined to make composite materials[1]. Composite materials occur in nature in various forms and were invented by the Egyptians more than three thousand years ago when straw was integrated into mud bricks. Material advancement leads to the production of newer materials with various outstanding features. The materials employed in various applications are becoming increasingly diverse. Having said that, researchers also make an extra effort to produce more effective materials. Composite materials are created to improve mechanical qualities over traditional materials. The introduction of reinforcing agent results in an improvement in composite properties. Since the previous few decades, researchers have been worried about the employment of metallic materials as matrices and sophisticated ceramic particles as reinforcement in a variety of applications. Composite materials are classed based on their matrix material, such as Metal Matrix Composites (MMCs), Polymer Matrix Composites (PMCs), and Ceramic Matrix Composites (CMCs), as well as their reinforcing agents, such as particles, fiber, and laminate reinforced composites. MMCs have grown in popularity in recent years due to their superior strength, stiffness, wear resistance, and creep resistance as compared to wrought alloys. Aerospace, space, maritime, and vehicle (ground & transportation) industries necessitate sophisticated engineered materials

**Author for correspondence*

with improved properties, high performance, increased efficiency, and, most importantly, lower manufacturing costs[2-4].

Aluminum (Al) is the most abundant metal on the planet. Aluminum Metal Matrix Composites (AMMCs) have become increasingly popular in a variety of fields, including marine, aerospace, transportation, and defence, due to their exceptional properties such as low density of 2.7 g/cm^3 [5-11]. Which is nearly one-third the density of steel and thus lightweight, exceptionally enhanced strength, better stiffness, improved resistance to wear, and low coefficient of thermal expansion. Aluminum-based composites are regarded as the most important engineering material for research, with several publications over the last two decades[12-16].

2. Methodology and Materials

2.1 Material

The hybrid aluminum MMCs were fabricated using Al6061 as the matrix material. The primary alloying components of Al6061 alloy, which is a member of the 7xxx series, are Zn, Mg, and Cu. Due to its exceptional strength and corrosion resistance, Al6061 is primarily used in aircraft spars, stringers, and highly stressed structural applications[17-20].

2.1.1 Aluminum (Al6061)

The metal matrix Al6061 is typically used in the creation of composite materials. There are various valuable aluminum alloys available, but 6061 is distinguished by its flexibility, castability, and resistance to corrosion. This substance has frequently been used as a raw material for MMCs reinforced with different types of particulates. Tables 1 and 2 list the compound composition and alloy characteristics[21-23] the ingots of the material as shown in Figure 1.

2.1.2 Aluminum Oxide (Al_2O_3)

Al_2O_3, most commonly referred to as alumina, has well-known features because of a strong inner atomic link between ions. It can go through multiple crystalline stages before relapsing into the hexagonal alpha phase at extremely high temperatures. It is the preferred material for a variety of applications due to its increased hardness, superior dielectric characteristics, and better thermal properties[24–26]. It is between 50 and 70 nanometers in size.

2.1.3 Zirconium Dioxide (ZrO_2)

The material of zirconium oxide, also known as ZrO_2, is white and crystalline. The crystal's monoclinic crystalline structure has the most logical appeal as a form. Cubic zirconia, a dopant stabilizer, is manufactured in a range

Table 1. Al606 Composition

Components	Copper	Manganese	Magnetism	Chromium	Titanium	Iron	Silicon	Zinc	Aluminium
% of Composition	0.36	1.0	0.10	0.20	0.10	0.5	0.2	0.10	97.44

Table 2. Compositions of ZrO_2, Al_2O_3, and Al6061

Material	Density gm/cm^3	Temperature in °c	Young's Modulus (E) in GPA	Poisons Ratio (μ)	Hardness Number (BHN)	Ultimate Tensile Strength in MPa
Al 6061	2.69	580	70-80	0.33	30-33	110-182
Al_2O_3	3.78	1700	300	0.21	450-500	650-660
ZrO_2	5.89	2715	92-95	0.34	130-145	300-330

(a) Al6061 (b) ZrO_2 (c) Al_2O_3

Figure 1. **(a)** Al6061's primary components; **(b)** Zirconium dioxide (40-50nm); **(c)** Al_2O_3 (50-70nm).

Table 3. Composition used to prepare specimens

Specimen Name	Composition in percentage		
	Al	**Al_2O_3**	**ZrO_2**
A	100	0	0
B	95	5	0
C	93	5	2
D	91	5	4
E	89	5	6
F	87	5	8

of ensigns to be employed as a gemstone-like diamond stimulant[27–30].

2.2 MMC Preparation

Using a liquid metallurgy vortex (Stir casting technique), the preparation of AI6061/Al_2O_3 composites and AI6061/Al_2O_3/ZrO_2 hybrid composites was completed. One of the most well-known methods in liquid metallurgy is stir casting, which involves using a mechanical stirrer to generate a vortex. A crucible was used to hold a certain amount of Al6061 alloy ingots before they were placed inside an electric furnace to melt. Although aluminium alloy melts between 660°C and 700°C, the molten matrix slurry and vortex are created by superheating the alloy to 800°C in the melting furnace[31].

Figure 2. Electric heaters.

3.0 Experimental Details

In accordance with the standards set by the ASTM, the Al6061 reinforced with Al_2O_3 and ZrO_2 test specimens are put through the mechanical properties test.

3.1 Hardness Test

Brinell testing for hardness is performed according to with ASTM E10 standards, utilizing a 5mm indent and a

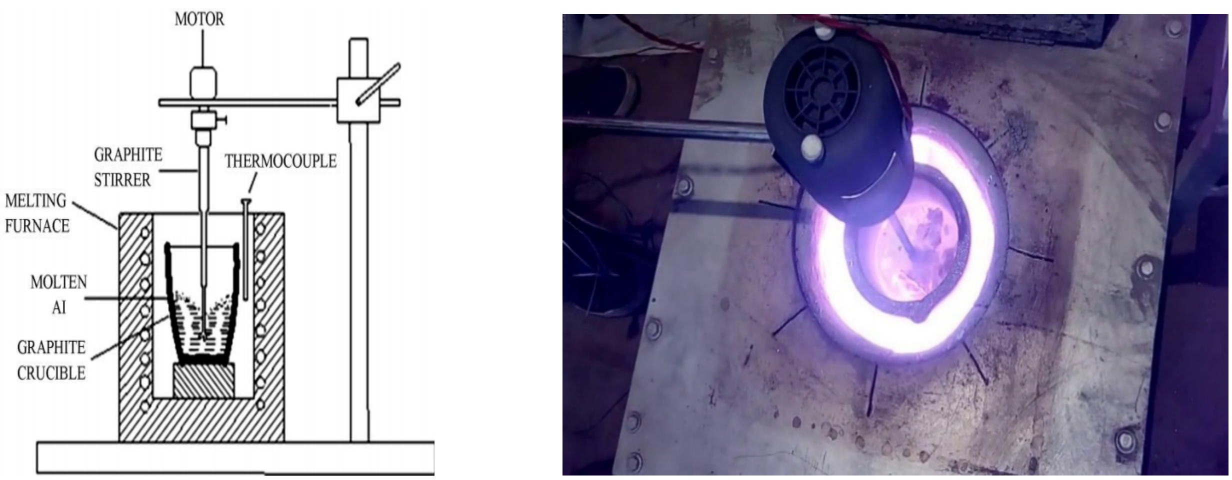

Figure 3. **(a)** Casting stir **(b)** Combining the base metal and reinforcing.

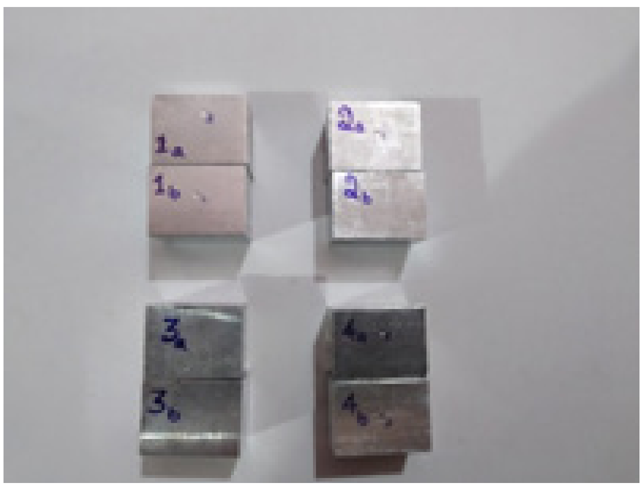

Figure 4. Hardness Test Specimens

1kg force on the sample. The sample for the hardness test is illustrated in Figure 4.

3.2 Tensile Test

Results from this test involve the composite's UTS, the young's modulus, positions ratio, and other characteristics using UTM. The specimens' gauge length is 50 mm, and their diameter is 10 mm, and all test samples are made in accordance with ASTM A370 criteria.

4. Results and Discussions

4.1 Hardness Test

At room temperature, the Brinell hardness test is performed using the Brinell hardness test apparatus. Table 4 and Figure 5 demonstrate how the BHN of various composites varies. The hardness increases as the fraction of aluminium oxide with constant ZrO_2 increases.

Table 4. BHN Results

Specimen	Value of BHN
A	48
B	56
C	62
D	70
E	78
F	84

4.2 Tensile Test

Tensile tests are accepted as the best method for estimating the mechanical properties of synthesized composites. The results of the tensile test carried out on the various samples described in Table 3 can be seen clearly in Table 5, including the Ultimate Tensile Strength in MPa, Yield Strength in MPa, and Percentage of Elongation. The results of the strengthening with Aluminum oxide (Al_2O_3) and zirconium dioxide (ZrO_2) on the universal testing apparatus for Aluminum 6061 composites are shown in Figure 6 a result of the synthetic composite's classification. The results of ZrO_2 and Aluminum oxide (Al_2O_3) particle reinforcement on the UTS of Al6061 composites can be

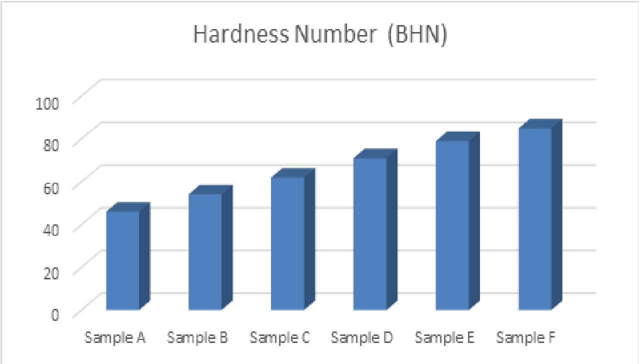

Figure 5. Comparison of hardness in a graphical manner.

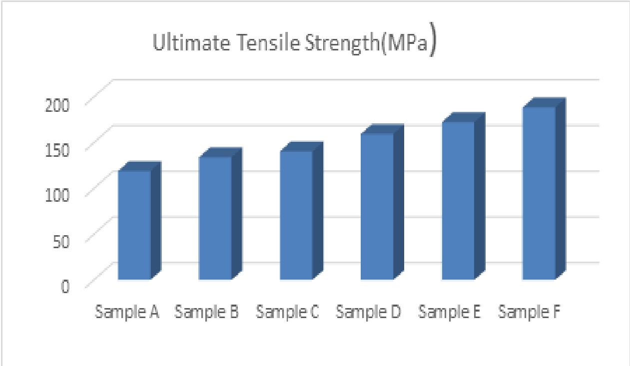

Figure 6. Ultimate Tensile Strength (MPa) for several samples presented qualitatively.

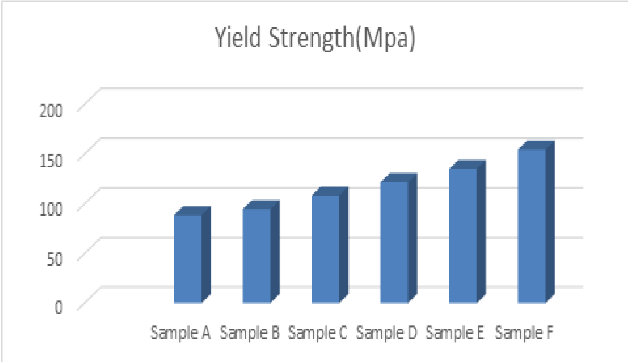

Figure 7. Yield Strength (MPa) in a graphical format for several samples.

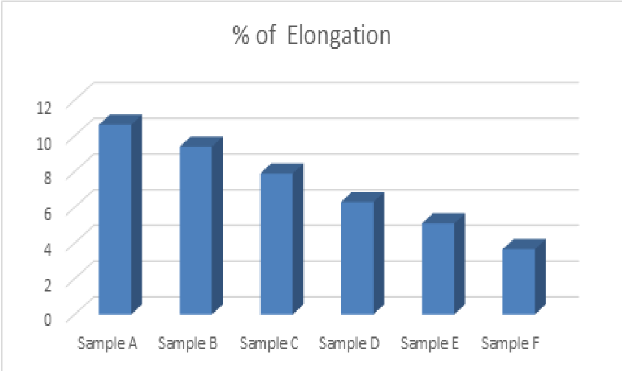

Figure 8. Graphical depiction of elongation percentage for various samples.

Table 5. Tensile Test Properties

Sl. No	Sample	UTS	Yield Strength	Percentage of Elongation
1	A	119.18	88.61	10.63
2	B	134.23	94.68	9.4
3	C	140.65	108.32	7.9
4	D	159.62	121.63	6.3
5	E	172.51	135.11	5.1
6	F	188.62	154.61	3.66

seen in Figure 6. The Ultimate Tensile Strength of the composite climbed as a result of ZrO_2 persistence and rising percentages by weight of Al_2O_3 particles. UTS of aluminium casting.

Figure 7 and Figure 8 displays the number of samples that showed yield strength in MPa and percentage of elongation respectively, after a tensile test was conducted. The Al6065 alloy's insistently reinforced Al_2O_3 and Zro_2 nanoparticles receive the imposed load. It is also obvious that the matrix-reinforcement line and the extended departure idiocy are related. The additional rationale is still applicable to the stimulating element for grain refinement. Strength increases gradually as Al_2O_3 and ZrO_2 particle reinforcement levels are increased as weight percentages in cast samples. With the presence of both reinforcements, such as Al_2O_3 and ZrO_2 particles, which have solid hold, great allocation, and close filler, and clear and regular commandeering of reinforcement inside these-cast materials, this improvement in commonality can be understood by different methods that consider the transfer of weight and disruption in strength. Table 5 the Values of Ultimate Tensile Strength (UTS) and Yield strength is in MPa.

5.0 Conclusion

With the help of the stir cast method, Al_2O_3 and ZrO_2 reinforced with Al6061 MMC had been successfully arranged. After the testing, the hardness gradually increased with an increase in reinforcing proportion. By increasing the proportion of reinforcement, the tensile characteristics of the composite samples will be improved even more. Publicized metallurgical micrographs show that the reinforced atom is evenly distributed throughout the aluminium matrix. As a result, it reduces casting flaws like blow holes and porosity and produces superior results than a simple composite material. Although the percentage of elongation decreases as reinforcement weight increases, the presence of hard particles causes brittleness, which reduces the composite's ductility. The tougher ceramic Al_2O_3 and ZrO_2 particles may also qualify for this.

6.0 References

1. Ravindran S, Mani N, Balaji S. Mechanical behaviour of aluminium hybrid metal matrix composites – A review. Mater Today Proc. 2019; 16(2):1020-33. Doi: https://doi.org/10.1016/j.matpr.2019.05.191.
2. Ravesh SK, Garg TK. Effect of hybrid reinforcement on mechanical behavior of aluminium matrix composite. Int J Eng Res Appl. 2012; 2(6):727-31.
3. Mahendra Boopathi M, Arulshri KP, Iyandurai N. Evaluation of mechanical properties of aluminium alloy 2024 reinforced with silicon carbide and fly ash hybrid metal matrix composites. Am J Appl Sci. 2013; 10(3):219-29. Doi: https://doi.org/10.3844/ajassp.2013.219.229.
4. Prasad BK, Dan TK, Rohatgi PK. Characterization and microstructural modifications of a pressure die cast eutectic aluminium–silicon alloy-graphite composite. Mater Trans. 1993; 34(5):474-80. Doi: https://doi.org/10.2320/matertrans1989.34.474.
5. Venkateshwarlu G, Prasad AMK, Ramesh Kumar K. Nanotechnology: A new prospective in organic coating - Review. Int J Curr Eng Technol. 2011; 5(6):201-6.
6. Patel M. Experimental studies of mechanical properties and tribological behaviour of aluminium composite reinforced with coconut shell ash particulates. Int J Curr Eng Technol. 2011; 32(4):1066-71.
7. Sofiah AGN, Samykano M, Kadirgama K, Mohan RV, Lah NAC. Metallic nanowires: Mechanical properties – Theory and experiment. Mater Today. 2008; 39(6):127-32. Doi: https://doi.org/10.1016/j.apmt.2018.03.004.
8. Devaraju, Kumar, Kotiveerachari. New trends, strategies and opportunities in thermoelectric materials: A perspective. Mater Today. 2013; 45:576-85.
9. Ravindran P, Manisekar K, Vinoth Kumar S, Rathika P. Graphene fiber: A new trend in carbon fibers. Mater Today. 2013; 51:448-56.
10. Nagaral M, Auradi V, Kori SA. Mechanical behavior of Al7025-B4C particulate reinforced composites. Appl Mech Mater. 2014; 592(5):170-4. Doi: https://doi.org/10.4028/www.scientific.net/AMM.592-594.170.
11. Maheswaran P, Renald CJT. Tribological investigation and development of brass composite bearing material. Int J Curr Eng Technol. 2017; 5(2):2347-235.
12. Pugalenthi P, Jayaraman M, Natarajan A. Evaluation of mechanical properties of aluminium alloy 7075 reinforced with SiC and Al_2O_3 hybrid metal matrix composites. Appl Mech Mater. 2015; 766-7:246-51. Doi: https://doi.org/10.4028/www.scientific.net/AMM.766-767.246.
13. Manikandan C. A comparative study on the microstructures and mechanical properties of Al 6061 alloy and the MMC Al 6061/TiB2/12p. Int Res J Eng Technol. 2017; 4(4):231-9.
14. Saheb DA. Aluminum silicon carbide and aluminum graphite particulate composites. ARPN J Eng Appl Sci. 2011; 6:41-6.
15. Bansal S, Saini JS. Mechanical and wear properties of SiC/graphite reinforced Al359 alloy-based metal matrix composite. Def Sci J. 2015; 65:330-8. Doi: https://doi.org/10.14429/dsj.65.8045.
16. Basaravaraju S, Arasukumar K, Bendigeri C, Umesh CK. Mechanical properties of matrix reinforced composite material. Int J Innov Sci Eng Technol. 2012; 1:107-12.
17. Kumar HCA, Hebbar HS, Shankar KSR. Effect of fly ash hybrid reinforcement on mechanical property and den-

sity of aluminium 356 alloy. Int J Mech Miner Eng. 2011; 6:41-5.
18. Anilkumar HC, Hebbar HS, Ravishankar KS. Mechanical properties of fly ash reinforced aluminium alloy (Al6061) composites. Int J Mech Mater Eng. 2011; 6:41-5.
19. Kok M. Microstructure and mechanical properties of extruded Al/Al_2O_3 composites fabricated by stir-casting process. J Mater Sci. 2005; 161(3):381-7. Doi: https://doi.org/10.1016/j.msea.2005.03.063.
20. Veeresh Kumar GB, Rao CSP, Selvaraj N, Bhagyashekar MS. Studies on Al6061-SiC and Al7075-Al_2O_3 metal matrix composites. J Min Mater Charact Eng. 2010; 9(1):43-55.
21. Ramesh D, Swamy RP, Chandrashekar TK. Role of heat treatment on Al6061-Frit particulate composites. J Min Mater Charact Eng. 2012; 11(4):353-63. Doi: https://doi.org/10.4236/jmmce.2012.114028.
22. Vignesh S, Sanjeev C. Influence of temperature on fatigue life for friction stir welding of aluminum alloy materials. Int Conf Therm Mater Mech Eng. 2012; 1:15-6.
23. Swamy ARK, Ramesha A, Veeresh Kumar GB, Prakash JN. Effect of particulate reinforcements on the mechanical properties of Al6061-WC and Al6061-Gr MMCs. J Min Mater Charact Eng. 2011; 10(12):1141-52. Doi: https://doi.org/10.4236/jmmce.2011.1012089.
24. Ravi B. A study on microstructural behaviour and mechanical properties of composites fabricated by friction stir processing. Int J Eng Sci Invention. 2012; 6(10):216-22.
25. Prasad HP, Sharma P, Chauhan G, Sharma N. Processing of 5083 aluminum alloy reinforced with alumina through microwave sintering. Int J Curr Eng Technol. 2015; 2(1):315-9.
26. Veeresh Kumar GB, Rao CSP, Selvaraj N. Forgeability and machinability of stir cast aluminum alloy metal matrix composites. J Min Mater Charact Eng. 2011; 10(1):59-91. Doi: https://doi.org/10.4236/jmmce.2011.101005.
27. Pradhan SN, Nagaral M, Auradi V. Mechanical properties of the as-cast silicon carbide particulate reinforced aluminium alloy metal matrix composites. Int J Curr Eng Technol. 2012; 1(3):201-20.
28. Shreyas PS, Mahesh BP, Rajanna S, Rajesh N. Evaluating the tribological properties of aluminium based hybrid composites reinforced with Al_2O_3 and ZrO_2 nano particles. Mater Today Proc. 2021; 45(1):429-33. Doi: https://doi.org/10.1016/j.matpr.2020.12.1012.
29. Venkatesha BK, Saravanan R, Anand Babu K. Effect of moisture absorption on woven bamboo/glass fiber reinforced epoxy hybrid composites. Mater Today Proc. 2021; 45(part1):216-21. Doi: https://doi.org/10.1016/j.matpr.2020.10.421.
30. Venkatesha BK, Saravanan R. Effect of cenosphere addition on mechanical properties of bamboo and E-glass fiber reinforced epoxy hybrid composites. Int J Veh Struct Syst. 2020; 12(4):447-51. Doi: https://doi.org/10.4273/ijvss.12.4.18.
31. Venkatesha BK, Pramod Kumar SK, Saravanan R, Ishak A. Tension fatigue behaviour of woven bamboo and glass fiber reinforced epoxy hybrid composites. IOP Conf Ser Mater Sci Eng. 2020; 1003:0120187. Doi: https://doi.org/10.1088/1757-899x/1003/1/012087.