Evaluation of Mechanical and Thermal Properties of Aluminium-7475 Reinforced with Graphite and Fly ash.

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Abstract. The aluminium is used for variety of reasons and they are known for their improved strength, stiffness, wear resistance which are useful in the marine, space, transport, automobile related industries. When aluminium reinforced with ceramic materials like fly ash, silicon carbide, tungsten carbide, boron carbide, fired bricks then a composite of better plastic forming capability, excellent heat and wear resistance will be formed. The objective of the experiment is to assess the thermal and mechanical properties of the Aluminium Metal Matrix Composites (AMMCs) when reinforced with ceramics. Aluminium (Al-7475) based metal matrix composites reinforced with varying weight percentage of Graphite(Gr) (3%, 6%, 9% and 12%) and fly ash being constant (10wt%) by the stir casting process. The composites tensile strength and hardness improved with the amount of graphite content improved in weight percentage up to 9% then decreased. While the composite's Thermal Conductivity(TC) and Coefficient of Thermal Expansion(CTE) varying temperature range from 50°C to 300°C reduces with increase in weight percentage of the graphite content.

1. Introduction

Combination of good corrosion resistance with strength, metal matrix material is suitable for a variety of engineering applications. They are light weight used in a small number of aircrafts, helicopters, and spacecraft. Fly ash as a potential discontinuous and finely divided particles mixed in metal matrix composites due to their less cost and low-density reinforcement which are available in large quantities as a waste by the thermal power plant. Aluminium based metal matrix composites are used in making of connecting rod, contractors, piston, where sliding play a vital role. These are used as they have excessive wear of the mating components. In the recent past various techniques for the manufacture of aluminium metal matrix composites with different reinforcements have been produced. In the industries various manufacturing processes such as solid, semi-solid and liquid state processes have been adopted. J.Hashim et al.[1] presented liquid stage handling has attracted more attention, among which the stir casting strategy is basic, cost-effective, and broadly utilized in different businesses. Further, Mohammed Imran et al. [2] prepared samples by stir casting method Al-7075 bagasse ash graphite composites were formed. The results of the investigations are tensile and the

hardness gradually increased by changing the weight percentage of reinforcements. Increasing the bagasse ash weight percentage contributes to the creation of slag during the casting process to prevent this by adding graphite. That gave the advantage in reducing slag formation and reduced loss of material. J.K. Chen et al. [3] explained the thermal conductivity with increase of aluminium graphite composites and can be handled thoroughly by changing the wt% of graphite; the method of powder metallurgy gives excellent interface bonding and can avoid dangerous surface interaction and reactions between aluminium and particle graphite. Moreover, K Sunil Kumar Reddy et al. [4] assessed the thermal and mechanical properties of aluminium (Al-7475) matrix composite has been strengthened by weight percentage of reinforcements. Graphite varying in 3 intervals 3%, 6% and 9wt% and Sic is constant 10wt%.S. Jacob et al. [5] evaluated the mechanical and thermal properties of Al-7075/Al₂O₃(5%, 10% and 15%) matrix composites. Tensile strength and hardness of AMMCs is increased up to 10wt% of reinforcement and further decreases by increasing the reinforcement percentage. The thermal conductivity of AMMCs increased up to 10wt% of Al₂O₃ further decreases by increasing the reinforcement percentage. The distribution of temperature and thermal flux in the Al-7075/ Al₂O₃ metal matrix is superior at 10wt%of

the reinforcement. Anil Kumar et al. [6] fabricated aluminum (Al 6061) / fly ash matrix composites through the process of closed stir casting and stated that the strength, hardness, and ductility of the MMC decreased by increasing particle size. Ala Mohammed Razzaq et al. [7] used fly ash reinforcement has a spherical shape with wide spread of particle with space. The value of impact strength is more with the pure Al6063 and during the fracture of energy decreases steeply with increasing percentage of Fly-Ash particles. Shanmugha sundaram et al. [8] introduced the use of pure aluminium with fly ash to manufacture composites was explored using a stir casting process. They concluded that the density of the aluminium metal matrix composites diminished as the % of fly ash reinforcement is rised. These composites' mechanical properties like as micro hardness improves with an increment in fly ash content. Vipin K. Sharma et al. [9] used fly-Ash MMCs were prepared by using stir casting method with different wt% of fly ash (2%, 4% and 6%). Fly ash was distributed throughout the MMCs equally. The increase in the content of fly ash increases the wear resistance. The coefficient of friction is the lowest with medium fly ash content (4wt%). The maximum coefficient of friction is obtained with high fly ash content (6wt%). Coefficient of friction rises due to increasing the weight percentage of the fly ash.S.A. Mohan Krishna et al.[10] found that the Coefficient of Thermal Expansion (CTE) of aluminium 6061-SiC-Gr hybrid metal matrix composites was diminished among the addition of silicon carbide, graphite in equal ratio and CTE values are expanded along augmentation of

temperature up to 300°C. The explanation for CTE reduction is due to the lower Coefficient of Thermal Expansion values for silicon carbide and graphite relative to the aluminium base material. Thermal conductivity of AMMCs was diminished among the addition of silicon carbide, graphite in equal ratio. D. Sujan et al. [11] found the thermal expansion coefficient values were abbreviated as the proportion of the reinforcement percentage increased. K S K Reddy et al. [12] investigated the thermal and mechanical properties of Al7020 composite with Sic and Gr as reinforcements concluded the improvement of strength and hardness by varying weight % of reinforcements in 3 intervals 3%, 6% and 9wt% and Sic is constant 10wt% .Sharma et al. [13] examined the fabrication of composite material through the liquid state stir casting route. In this analysis base metal is aluminium Al-6082 T6 reinforced with silicon nitride by the different percentage of weight ranges from 0 wt% to 12 wt% in a stage of 3 wt%. The weight percentage of the reinforcement (silicon nitride) rises which results in reduced ductility. However ultimate strength and hardness increases. S. Kosaraju et al[14] presented mechanical properties at sub zero temperature, tensile strength got increased.

In this study, the hardness, tensile strength, coefficient of thermal expansion and thermal conductivity of an Al-7475 metal matrix reinforced with Fly-Ash and Gr have been analysed in terms of their % and effect, and the closed Stir-Casting method is considered to cast these hybrid MMCs based on their advantages including effortlessness , low cost and simple transportability[15].

2. Materials And Methods

2.1 Aluminium 7475

In the current work Aluminium-7475 is utilized as the main(matrix) material. It is available in flat **Table1.** Chemical Composition of Al-7475(wt%)

Element	Al7475
Zn	5.26
Cu	1.48
Mg	2.11
Mn	0.01
Fe	0.06
Si	0.03
Cr	0.19
Ti	0.03
Al	Balance

2.2 Graphite.

sheets with the thickness of 2.5mm. It is commonly used for various engineering applications such as shell castings, aircrafts planes and other aerospace assemblies that require high strength to weight ratio. Chemical composition of Al-7475 is listed in Table.1

Graphite is utilized as auxiliary reinforcement material since of its extraordinary machining
Fig. 1. Graphite in the form of powder

2.3 Fly-ash

Fly-ash is the least expensive and lowest density reinforcement-material accessible as a solid waste by product after coal combustion in thermal power

Fig. 2. Fly-Ash Powder

3. Sample Preparation

In Stir casting method to manufacture the Al-Metal Matrix Composite (MMC), Al-7475 blocks are placed into crucible available in furnace for the purpose of liquefying. The heat is supplied initially up to 783°C for 25 min to the furnace. The five-blade mechanical stirrer was placed in the crucible

Fig.3. Stir-Casting Setup

Table2. Samples prepared

Sample	Composition (wt%)
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capabilities, extreme liquefying point, high-temperature stability, and less thermal expansion coefficient [16]. In the present work, the 50 μm graphite is fluctuated by four different weight percentages (3%, 6%, 9% and 12%).

plants. The combination of aluminium matrix metal and fly ash reinforcement to comeback the cost basis for across the board uses, such as aerospace and other applications [17,18]. In the present project ten weight% fly ash having 50 μm used in all the combinations of composition.

to stir the liquid at 420 rpm up to 5 min time to generate vortex in the place of melt. Then adding the reinforcements (Fly ash and Gr) in the crucible. Before adding the reinforcements into the crucible, the reinforcements are preheated (200°C to 450°C) to improve the wettability of the reinforcements. Reinforcements of the required quantity according to the crucible size are taken and wrapped in an aluminium foil and are measured using the digital weight measurer. Initially 10% of fly ash is introduced which is equal to 50g with 4 different proportions of graphite 3%,6%,9% and 12% are equal to 15g, 30g, 45g, 60g respectively. Because of wettability of the reinforcements, it leads to uneven dispersion to cause the losses of mechanical and thermal properties. The complete mixture is mixed at 620 rpm up to 10 min, then the properly mixed mixture is poured into the available mould (100*100*10 mm) to maintain the required temperature (680°C) and it can be solidifies then take the specimen from the mould. Same process is used for other samples. The stir-casting set up with the stirring rod attachment and Al-MMCs are demonstrates in Fig. 3 and 4. Samples prepared are presented in Table2.

No.	Flyash (wt %)	Graphite (wt %)	Al7475
1	10	3	Balance

2	10	6	Balance
3	10	9	Balance

4. Experimentation

4.1 Tensile Testing

Tensile testing, also known as tension test is a performance-testing method used to determine the amount of tensile stress that can be withstood by a sample of material. A UTM (or) Universal Testing Machine is used to perform this test. A specimen of MMC was subjected to static loads of compression and tension to accurately determine its mechanical properties. The specimen used for testing was prepared according to the ASTM 08 standards with dimensions are 25 mm Gauge length, 6 mm neck and a grip length of 12 mm as shown in Fig.5.

Fig. 5. Tensile test sample dimensions

4.2 Hardness Test

A Test for hardness is performed on the specimens to determine their level of resistance to indentation, respectively. In this case, Rockwell's Hardness test was adopted to determine the characteristics of the MMC. As the base metal being used here is Aluminium, Rockwell's B scale is used to test the specimen. The tool used in the B scale is a spherical steel indenter of 1/16-inch (1.588 mm), the load applied being 100 kgf. About 5 readings are taken for each specimen under a static load of 5kg under

the indenter for 10 seconds. The average of all 5 readings is considered as MHV(Micro Hardness Value).

Fig.6. Hardness Test Specimens

4.3 Coefficient of Thermal Expansion

Coefficient of Thermal Expansion (CTE) is one of the thermal properties of a material, and the CTE test is used to determine the extent of this property

4	10	12	Balance
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Fig. 4. Al-Metal matrix composite samples

exhibited by a material. A metal is said to expand on heating and contract on cooling. A Thermo-Mechanical Analyser (TMA) uses this principle in a test where a cuboidal specimen of the composite of dimension 5mm x 5mm x 3mm is subjected to temperatures ranging from 50°C to 300°C individually. A Thermo Mechanical Analyzer is used to quantify (or) measure the CTE.

4.4 Thermal- Conductivity Test

The test of thermal conductivity is used to find the thermal conductivity and diffusivity of a material. The Laser Flash Method is adopted to carry out these tests on a specimen of 10mm x10mm x 3mm at a temperature range from 50°C to 300°C by using Laser Flash Analyser 457 shown in Fig.7.

Fig.7. Laser Flash Analyser

5. Results And Their Discussion

5.1 Mechanical - Properties

5.1.1 Hardness-Property

The impact of change of fly ash with graphite reinforcements on Aluminium-7475/Graphite/fly ash composite material hardness is indicating in the Fig.8. The maximum hardness value of the Hybrid MMCs was achieved is 64.6 HRB at 9 weight% of Gr. content and 10 weight% of fly-ash. The hardness-property of the composite increases while increment the weight percentage of the graphite until 9% due to clustering behavior of Gr during stir casting process led to porosity and that could be

filled with fly ash content and then decreased with 12%Gr.

Fig. 9. Tensile Strength of Al7475/Fly-Ash/Gr

Fig. 10. CTE vs Temperature for the Al7475/Fly-Ash/Gr

Fig. 8. Hardness-property of Al7475/Fly-Ash/Gr

5.1.2 Tensile-Strength

The impact of change of fly ash and graphite reinforcements on Al-7475/Gr/fly ash composite material. Tensile strength is indicating in the Fig.9. The maximum tensile strength of the Hybrid MMCs was achieved is 255.6 Mpa at 9wt% of graphite content and 10 wt% of fly ash. The tensile-strength of the Al-MMC increases while increment the weight percentage of the graphite upto 9wt% content with 10 weight% of fly-ash and then slightly decreased with 12wt%Gr.

5.2 THERMAL PROPERTIES

5.2.1 Coefficient of Thermal Expansion (CTE)

The thermal-expansion coefficient property of Al 7475 reinforced with fly ash and graphite with the changing temperature from 50°C to 300°C is indicating in the Fig.9. From the figure the weight percentage of the graphite increases which results in CTE values of the composite material is diminished. The maximum CTE value of the Hybrid MMCs was achieved is $14.2 \times 10^{-6}/^{\circ}\text{C}$ at 300°C.

5.2.2 Thermal-Conductivity (TC)

Laser flash strategy is intensely utilized for measuring thermal-conductivity and thermal diffusivity[19].The thermal conductivity can be determined by consider the values of density, thermal-diffusivity and specific heat products, of Al7475/fly ash/Gr composite. Table 3 displays the density values of Al-MMC with graphite percentage vary (0%, 3%, 6%, 9% and 12%) and 10 weight % of fly-ash. Fig.11 gives the information of specific heat capacity of Al7475/fly ash/ Gr composites with changes of temp. From below shown fig., it was understood that sp. heat was expanded as temperature increases but with increment of temp., the sp. heat capacity of Al7475/fly ash/ Gr composites diminished as the increment of weight percentage of reinforcement.

Table 3. Experimental values of ρ for Al-MMC

S.No	Al-MMCs	ρ value (g/cc) Experimental
1	Al 7475	2.256
2	Al7475 + 10% fly ash + 3% Graphite	2.361
3	Al7475 + 10% fly ash + 6% Graphite	2.534
4	Al7475 + 10% fly ash + 9% Graphite	2.760
5	Al7475 + 10% fly ash + 12% Graphite	2.884

Thermal diffusivity of Al7475/fly ash/Gr hybrid metal matrix composites along the different temperatures between 50°C to 300°C is shown in Fig.12. From the below shown figure, it was recorded that thermal diffusivity diminished as the wt% of

Fig. 12. Alteration of Thermal-diffusivity vs Temp

Fig. 13. Thermal-Conductivity vs Temp. of Al-7475/Fly-Ash/Gr

6. Conclusion

Fig. 11. Alteration of Sp. heat vs Temp. of Al/Gr/Fly-Ash composites

graphite content increased. The maximum TD value of the Hybrid MMCs was achieved is $5.24 \times 10^{-3} \text{ m}^2/\text{s}$ at 50°C.

The thermal conductivity values for this composite material along the different temperature from 50°C to 300°C is shown in Fig.13. From the below shown figure, it was recorded that thermal conductivity diminished as the wt% of graphite content increased. The maximum TC value of the Hybrid MMCs was achieved is 135 W/m.k at 250°C. It is also noted that the thermal-conductivity values of Al-metal matrix composites increased compared to unreinforced aluminium 7475 alloy. In the literature, it was stated that thermal conductivity of hybrid-MMCs expanded as weight percentage of silicon carbide raises along the changing temperature. S.A. Mohana Krishna et al.[20] the thermal conductivity is improved by the addition of graphite into the aluminium and sic mixture. Sateesh N et al.[21] the environmental impacts studied on fiber composites. Pandey, U. et al[22] fabrication techniques for metal matrix composites studies including stir casting.

The study done so far was to evaluate the impact of Gr (3%, 6%, 9% 12% weight) and 10 wt.% of FlyAsh in the Aluminium 7475 material. The motive behind carrying out this experiment was to fabricate multiple sample of variable compositions of multiple materials (Al/Fly-Ash/Gr hybrid MMCs) and test their Mechanical Properties (Tensile Strength, Hardness) and Thermal Properties (Thermal-Conductivity, Coefficient of Thermal Expansion) within a temp. ranging from 50°C to 300°C.

The following points have been concluded based on the experiments conducted:

1) It is observed that the Hardness property of the Al/Fly-Ash/Graphite hybrids is more than that of Aluminium 7475 alloy. The Hardness values achieved are higher as the properties are enhanced by varying the composition of Graphite (3%, 6%, 9%, and 12% respectively) and 10% of Fly-Ash.

2) The maximum Hardness value achieved is 64.6 HRB at 9 wt.% of Graphite with 10 wt.% of Fly-Ash. The vindication behind such a drastic increase is the significant increase in ceramic phase because of the addition of Fly-Ash particulates then decreased at 12wt% of Graphite.

3) A significant improvement in the Tensile-Strength of the hybrid MMCs is observed by comparing with that of the base metal.

4) Higher Tensile Strength is achieved as the composition of the Gr. reinforcement is increased with 10 weight% of Fly-Ash. The maximum tensile strength value achieved is 255.6 MPa at 9 weight% of Gr. and 10 weight% of Fly-Ash. The vindication behind such a drastic increase in the Tensile Strength values is because of the addition of Fly-Ash.

5) A reduction of the CTE (Coefficient of Thermal Expansion) values is perceived as the graphite composition is increased with 10% of Fly-Ash. The vindication for the reduced in the Co. Thermal Expansion values could be accredited to the much lower CTE value of Gr. when compared to that of the AMMC and Fly-Ash.

6) As the temperature is increased, the CTE of the AMMC is also observed to be increased. The maximum CTE value achieved at 10 wt.% of Fly-Ash and 3wt% of Graphite at 300°C and Low-value of the CTE which is $(5.24 \times 10^{-6}/^{\circ}\text{C})$ is evinced for 3 wt.% of Gr. with 10 weight% of Fly-Ash at 50°C

7) A reduction in the thermal conductivity (TC), thermal-diffusivity and sp. heat values of Aluminium7475/Fly-Ash/Gr Al-MMCs were noticed as the composition of graphite is increased with 10 wt.% of Fly-Ash.

8) The thermal conductivity of the AMMCs is escalated as the temperature increases. The maximum thermal conductivity value is 135 w/m-k was achieved at 300°C with Al7475 with reinforcements 12wt%Gr and 10wt%flyash due to more Graphite, it increases thermal energy.

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