International Journal of Applied Engineering and Technology ISSN: 2277-212X (Online)
An Open Access, Online International Journal Available at http://www.cibtech.org/jet.htm
2016 Vol. 6 (2) April-June, pp.16-23/Kumar and Sharma
Research Article

A COMPARATIVE STUDY ON THE MICROSTRUCTURES AND MECHANICAL PROPERTIES OF ALUMINIUM ALLOY Al 356 AND Al 356/Al_2O_3 METAL MATRIX COMPOSITE

***Abish Kumar and Amit Sharma**
Department of Mechanical Engineering, Arni University, Kathgarh, Indora
**Author for Correspondence*

ABSTRACT
Aluminium alloys are widely used for many commercial applications. One of aluminium alloys is Al 356 alloy found application in High strength airframe and space frame structural parts, machine parts, truck chassis parts, high velocity blowers and impellers. Al 356/Al_2O_3 composite is a metal matrix composite (MMC) that can be manufactured using stir casting method. With reinforcement of Al_2O_3 in matrix of alloy the properties of Al356 alloy can be greatly improved. A comparison of the mechanical properties and the microstructure of Al 356 alloy with Al356/Al_2O_3 metal matrix composite containing different % by weight of reinforcement was done in present work.

Keywords: *Al 356 Alloy, Stir Casting, Al356/Al_2O_3 Metal Matrix Composite (MMC), Aluminium Matrix Composite (AMC)*

INTRODUCTION
Composite materials have unique place in manufacturing industry because of their properties such as high strength and stiffness, wear resistance, thermal and mechanical fatigue and creep resistance. Till date a large number of composites have been invented & successfully found their use for different applications. Metal matrix composite (MMCs) is a advancement in production of composites (Usman *et al.,* 2014; Ambedkar *et al.,* 2016).
Here, in MMC matrix of metal or alloy & some reinforcement material is used to produce composite. Matrix is the base material in the composite. Among the various matrix materials available, aluminium and its alloys are widely used in the production of metal matrix composites. Different aluminium based composites with various reinforcement material have been reported by researchers. Reinforcement of aluminium alloy by hard and soft reinforcements such as SiC, MgO, graphite, Si-rice husk, Frreocrome slag and many more is continue in research industry and in production in many cases. Wide range of applications and requirement of metal matrix composites in industry for different applications put many researchers in finding a cost effective production methods for these composites (Clyne *et al.,* 1993; Mohanakumara *et al.,* 2014).
There are different methods for fabrication of composites, depending upon type of material involved and also on type of composite to be produced. Casting is commonly used method in production of MMC. Powder metallurgy is other widely used method for production of MMC. One of the obstacles in wide use of MMC in various applications is its plastic counterparts. But MMCs are preferred in many cases due to High strength; fracture toughness and stiffness are offered by metal matrices than those offered by their polymer counterparts (Kuzumaki *et al.,* 1998).
Commonly used matrix metals that offers good matrix for fabrication of MMCs are Titanium, Aluminium and magnesium. Modulus of reinforcements is a important parameter which decides the properties of MMC.
High modulus of reinforcement results in high strength. Operating temperature of composite is decided by frequency of its properties (Clyne *et al.,* 1993; Mohanakumara *et al.,* (2014), Alaneme and Bodunrin, 2013; Hindawi Publishing Corporation, 2014).
In this paper we have investigated comparison of properties of aluminium alloy Al 356 and its composite using alumina as reinforcement. Stir casting method was used in fabrication. Mechanical & micro structural study has been performed.

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MATERIALS & METHODS

Materials:

Al 356 aluminium alloy which acts as matrix was used in pure form. The detail of properties and composition of aluminium alloy (Al 356) are listed below in Table 1, 2, 3:

(i). *Chemical Composition:*

Table 1: Chemical Composition Al 356 Alloy

S. No.	Element	Wt%
1	Cu	0.20
2	Mg	0.25 to 0.45
3	Mn	0.10
4	Si	6.5 to 7.5
5	Fe	0.20
6	Zn	0.10
7	Ti	0.20
8	Al	Balance

(ii). *Mechanical Properties:*

Table 2: Mechanical Properties A356 Alloy

Property	Tensile Strength (MPa)	Hardness (BHN)	Toughness (Joule)	Fatigue Strength (1 × 10^7 MPa)	Endurance Limit	Modulus of Elasticity	Shear Strength
Value for Al 356	230	75	6	120	56	71	120

(iii). *Thermal Properties:*

Table 3: Thermal Properties A356 Alloy

Property	Latent Heat of Fusion	Specific Heat	Liquidus Temperature	Solidus Temperature
Value for Al 356	389kJ/kg	963 J/kg	615ºC	555ºC

(iv). *Applications of Al 356 Alloy:*

High strength airframe and space frame structural parts, machine parts, truck chassis parts, high velocity blowers and impellers.

Alumina: Chemically pure alumina (Al_2O_3) particles having a particle size of 50 μm were used.

Methods:

Stir Casting:

Stir casting method was used to prepare MMC. Amount of aluminium (Al 356) alloy and alumina (Al_2O_3) particles in desired quantity to produce composites having 5, 10, 15, and 20 volume percent alumina were evaluated using charge calculations. Reinforcement material (alumina) was first preheated at a temperature of 250^0C for 5 minutes to improve wettability with matrix forming alloy.

The Furnace temperature was set to about maximum 700-750ºC in order to minimize the chemical reaction between the substances. Melting of A356 ingots were performed at a temperature of 750ºc and the liquid alloy was then allowed to cool in the furnace to a semi solid state at a temperature of about 600^0C.

Reinforcement particles (pre-heated) were added to the molten alloy and stirring performed speed of 650 rpm for 10 minutes to reach mushy state. The composite slurry was then superheated to 720^0C and a second stirring performed to ensure uniform distribution of alumina particles using a mechanical stirrer was done. Four samples of composite with different percentage of alumina particles were cast into prepared sand moulds. Similar sample of Al 356 without reinforcement were also prepared for comparison.

Hardness Measurement (Alaneme *et al.,* 2013; Hindawi Publishing Corporation, 2014; Daniela *et al.*, 2011)

For hardness testing samples were prepared as per specification required for Brinell hardness Test (i.e. 10mm × 10mm × 25 mm). Samples were prepared first for testing by applying grinding and polishing.

As the hardness of sample will not be uniform throughout, due to factors such as cooling rate, gravity effect, and non uniform distribution of the particles in the ingot will give different values of hardness from top to bottom. To resolve this three tests for each sample at different points on sample were performed and the average of three was taken as hardness of the sample. The value of hardness on Brinell scale for samples with 0%, 5%, 10%, 15% and 20% of reinforcement is given in table 4.

Toughness Analysis (Alaneme *et al.*, 2013; Daniela *et al.*, 2011; Habeeb *et al.*, 2010; Froyen *et al.*, 2013; Li *et al.*, 2010):

Toughness of MMC was carried out on Charpy Impact Testing Machine. Four samples with different percentage of reinforcement were prepared. Samples with square cross-section of size (10 × 10 × 55) with single V-notches were prepared. Value of toughness of samples with 0%, 5%, 10%, 15% and 20% of reinforcement is given in table 5.

Tensile Testing:

Tension strength tests were performed on samples machined from the Al 356 alloy and the composites with dimensions of 6 mm diameter and 36mm gauge length. Tests were performed by universal testing machine (UTM) linked with computer to facilitate analysis with the help of software. Average of three values for each sample was taken as final value to guarantee reliability of the data generated. All specimens were test at room temperature.

Microstructure:

Metallurgical Microscope integrated with software operation was used for microstructure examination. As per requirement samples were cut in desired size and prepared for testing using Diamond polishing machine.

A series of emery papers of grit sizes ranging from 400µm – 1500µm were used to prepare sample surface for examination. Paste of Alumina powder was applied on sample to attain fine polishing, with valvet cloth replacing emery paper on polishing machine. Etching was done using Nital (solution of Methanol & Nitric acid) solution to explore surface of sample.

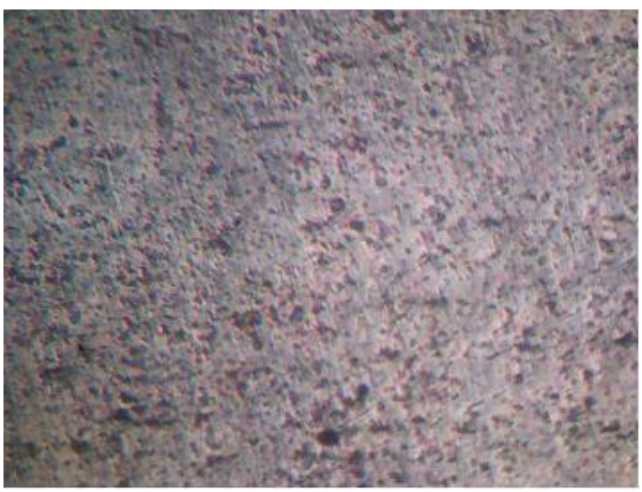

Figure 1: Micrograph of Al 356 **Alloy without Reinforcement**

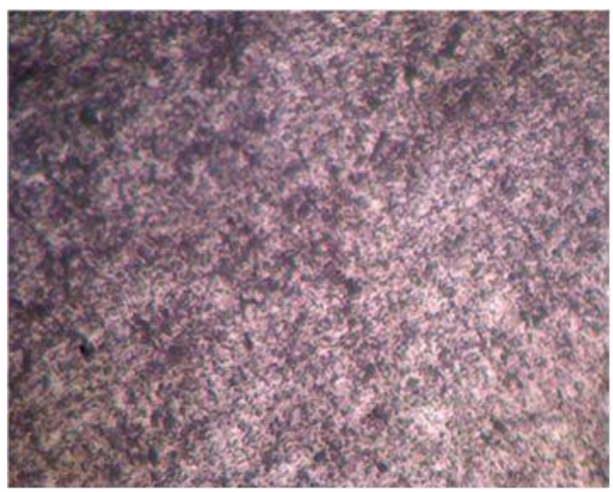

Figure 2: Micrograph of MMC (Al 356 Alloy with 5 % Reinforcement)

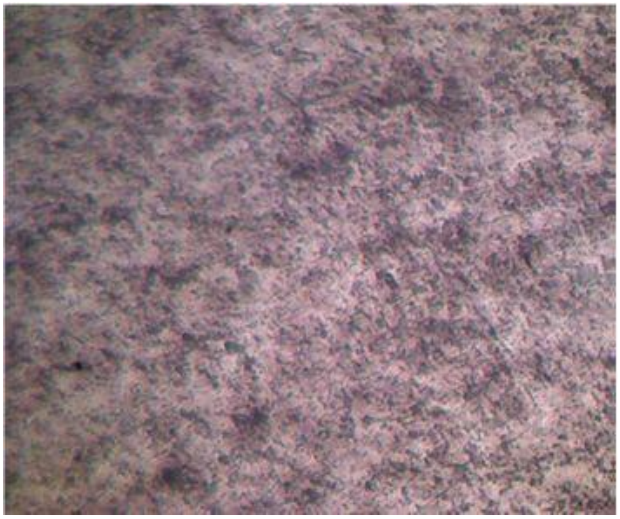

Figure 3: Micrograph of MMC (Al 356 Alloy with 10 % Reinforcement)

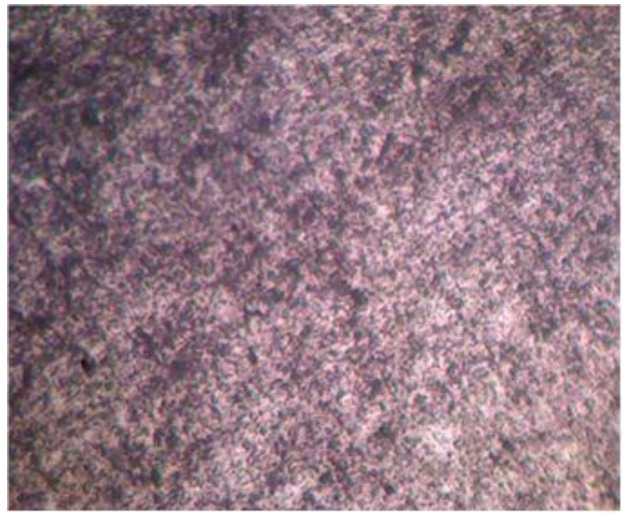

Figure 4: Micrograph of MMC (Al 356 Alloy with 15 % Reinforcement)

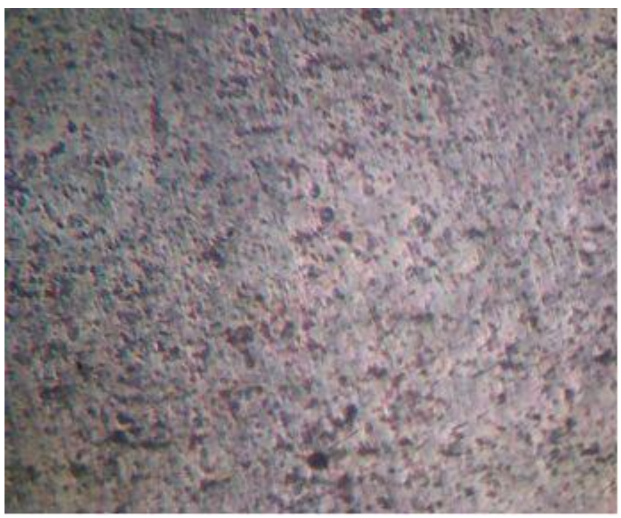

Figure 5: Micrograph of MMC (Al 356 Alloy with 20 % Reinforcement)

RESULTS AND DISCUSSION

Microstructure:

Figure 1, 2, 3, 4, 5 shows micrographs of samples of Al_2O_3 reinforced Al 356 composites with different combinations. Samples were observed under microscope at different magnifications (up to x1000) in order to select best one.

Observations show that the alumina particulates are visible and also ensure maximum dispersion of particulates in MMC. All samples show this parameter perfectly. All this shows good efficiency of the production technique.

Hardness Measurement:

With Load applied 100Kgf, Diameter of ball 2.5 mm, Testing time 30 seconds (Alaneme *et al.,* 2013; Hindawi Publishing Corporation, 2014).

We have obtained a increase in hardness with increasing percentage of reinforcement (Table 4) (Figure 6). This is due to increase in amount of particulates of alumina in metal matrix. As alumina is known for high hardness of particles, that let it to be used as abrasive. So, with increasing percentage of reinforcement hardness of MMC increases.

Table 4: Hardness Testing Results of Al 356 /Alumina MMC

S.No.	Alumina Particle wt%	Hardness (BHN)
1	0%,	75.33
2	5%,	82.6
3	10%,	92.13
4	15%	101.9
5	20%	112.22

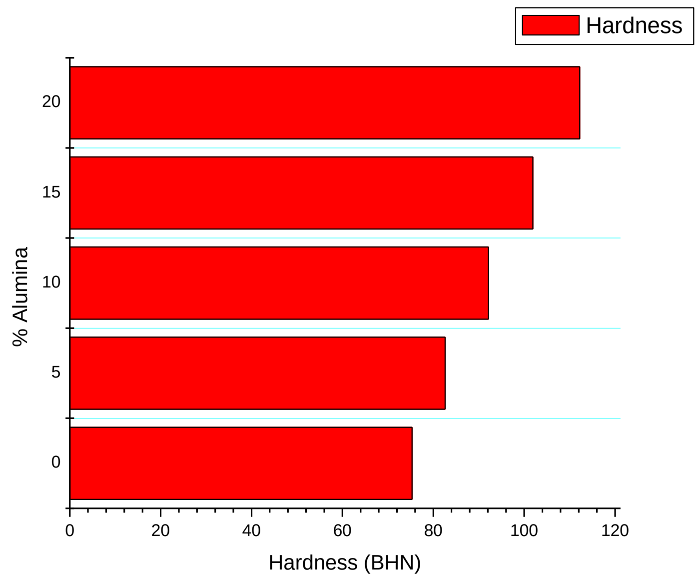

Figure 6: Hardness Vs Percentage Reinforcement

Toughness Measurement:
From impact test it is observed that there is increase in toughness with increasing percentage of reinforcement (Table 5). It is clear from figure 7 that large increase in value observed when going from 5 to 10 % reinforcement. Increase in toughness i.e. energy absorbed with increasing percentage of reinforcement is due to fact that alumina particles acts as brittle material so requires more energy for plastic deformation.

Table 5: Toughness Testing Results of Al 356 /Alumina MMC

S.No.	Alumina Particle wt%	Toughness (Joule)
1	0%,	6.16
2	5%,	7.33
3	10%,	10.16
4	15%	12.33
5	20%	13.22

Tensile Testing:
From figure 9 it is clear that tensile strength increases with increasing percentage of alumina reinforcement (Table 6). Similar behaviour i.e. Increase in tensile strength with increasing percentage of hard alumina particles reported by many researchers. This verifies accuracy of our results (Hindawi Publishing Corporation, 2014; Habeeb *et al.*, 2010; Froyen *et al.*, 2013; Li *et al.*, 2010).

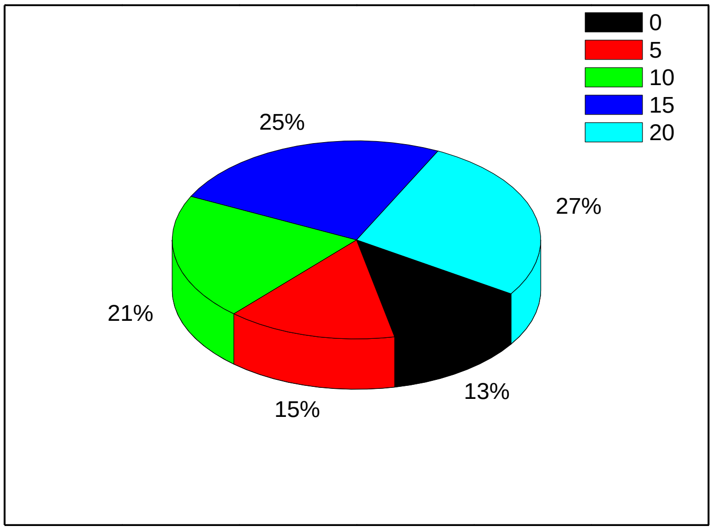

Figure 7: Toughness Vs Percentage Reinforcement

Table 6: Tensile Strength Testing Results of Al 356 **/Alumina MMC**

S. No.	Alumina Particle wt%	Tensile Strength (MPa)
1	0%,	232.23
2	5%,	264.96
3	10%,	281.45
4	15%	299.0
5	20%	316.11

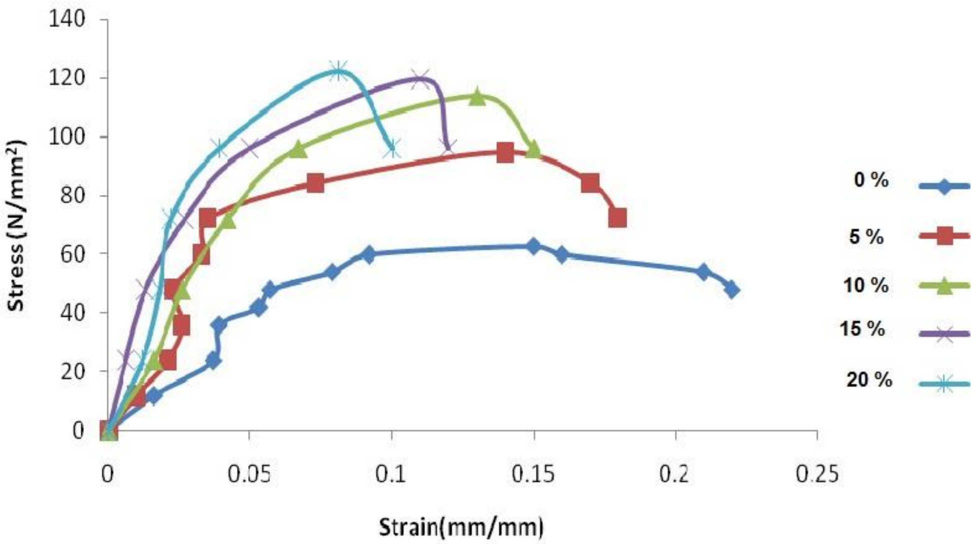

Figure 8: Stress – Strain Curves for all Samples for Al 356 / Al_2O_3 MMC

From figure 8, plot of stress Vs strain for all samples with and without reinforcement we observed that sample without reinforcement shows largest plastic strain and also shows least resistance to plastic deformation due to relatively lower flow stress in comparison with the MMC.

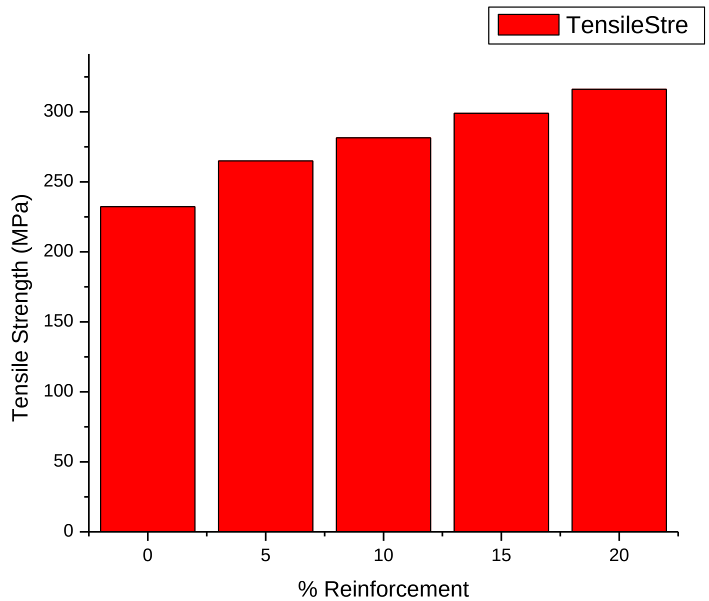

Figure 9: Tensile Strength Vs Percentage Reinforcement

Conclusion

Following conclusions have been drawn from all above analysis using different testing procedures for study of properties of metal matrix composite:

1. Addition of alumina particles in Al 356 alloy results in composite that have hardness greater than Al 356 alloy. Hardness of MMC increases with increase in percentage of alumina reinforcement. So, one can easily choose MMC with desired hardness by simply varying the reinforcement amount.
2. With increasing percentage of alumina amount of energy absorbed by MMC material increase. This increase has large value at 5-10 % alumina reinforcement.
3. Study of tensile strength behaviour confirms that alumina reinforcement increases strength of Al 356 alloy. This increase in strength continues with increase in percentage of alumina in MMC.
4. Microstructure study confirms formation of alumina particulate in Al 356 / Al_2O_3 MMC. This show feasibility of production technique.

ACKNOWLEDGEMENT

After all mighty God, I want to thanks Mr Amit Sharma (Assistant Professor) & Mr Anurag dhiman and all other staff members of department of mechanical engineering, Arni University for their help during my thesis work.

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