

# Effect of Fly Ash and Silica Particles on Mechanical and Thermal Properties of A-356 alloy

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**Abstract**— This study investigates the effect of fly ash and silica particles on the mechanical and thermal properties of A-356 alloy. A-356, an aluminum alloy, is popular and has gained significant attention due to its lightweight and excellent mechanical properties. A-356 was reinforced with fly ash and silica at different weight percentages, and the composite was fabricated using a sand casting technique at around 660°C. Hardness and thermal resistance tests were conducted, revealing a significant enhancement in hardness and thermal resistance with the addition of fly ash and silica particles. The microstructural analysis through S.E.M. and XRD showed a uniform distribution of fly ash and silica particles throughout the matrix.

**Keywords**— aluminum alloy, scanning electron microscope, sand casting, Vickers hardness.

- Automotive industries, due to their lightweight, reduce fuel efficiency.
- Electronics appliances due to their thermal conductivity.
- Marine structures where corrosion resistance and light weight are essential.

These extensive uses can lead to considerable savings in materials and, in several instances, reduce environmental pollution. On the other hand, it has been observed that upon specific loads, the material fails, so it was the need of the day to design and manufacture new materials to meet the desired physical and mechanical properties.

New progress in the field of material engineering is to manufacture materials having low cost, high performance, lightweight, and improved mechanical properties. Aluminum Matrix composites have gained attention as they play a crucial role in industries where the combination of light weight, strength, and thermal resistance is required. The manufacturing of these composites requires a suitable manufacturing process, and that is casting. Sand casting is economical, has a long history, and is still responsible for tonnage of production. During casting, the matrix is first melted at around 660°C, and then it can be poured into a mold of the required shape [1, 2]. Metal matrix composite exhibits enhanced mechanical properties; research shows that aluminum-based composites have improved mechanical strength over unreinforced alloys [3, 4]. Babu Rao et al. 2010, observed that by the addition of fly ash particles, there is an observable increment in the mechanical properties of A-356; he further stated that the use of fly ash in the alloy can reduce the cost of aluminum products [5]. Rohatgi et al. 2006, studied that the addition of fly ash particles into aluminum decreases material content, cost, and weight. He added fly ash in aluminum by stir casting and observed that the density and hardness of the casting increased with an increase in fly ash content [6]. Li Yue Ying et al. 2007, studied the mechanical properties of fly ash-reinforced aluminum composites; they observed that the hardness of aluminum composite was higher than that of aluminum itself. By adding fly ash content, hardness

## I. INTRODUCTION

Composite materials are the combination of two or more distinct materials bonded together so that all the constituents embedded in them have different and unique properties and are not soluble in each other. Composite materials always have a soft phase embedded in the hard phase or vice versa; most commonly, the hard phase behaves as a reinforcement and the soft phase as a matrix. Composites are classified into various categories based on the reinforcement embedded in them; the most common of them are Metal Matrix composites, in which the reinforcement is always metal; Ceramic Matrix composites, in which reinforcement is always ceramic; and fiber-reinforced composites, in which reinforcement is in the form of fibers.

The potential for the increasing demand for metal matrix composite is huge in applications in the aeronautical, automobile, and marine industries. Some typical applications are listed below.

- Aircraft components such as structural parts, engine parts, and landing gears

also increased [7]. Mahindra and Radhakrishna, 2007, observed a uniform distribution of fly ash content and aluminum composite; they concluded that hardness increased with an increase in fly ash particles [8]. M.C Donald, along with his co-workers, conducted a study, and they observed that to obtain the homogenous distribution of fly ash particles in aluminum, the melt should be stirred properly [9]. Anilkumar et. Al, 2021, studied the hardness and tensile strength of aluminum alloy reinforced with fly ash; he concluded that hardness and tensile strength increased with rising the fly ash content and decreased with reducing the fly ash content [10].

This paper comprises the details of every step carried out in three phases. The First phase deals with the properties and introduction of materials used in this study. The Second phase deals with the manufacturing of the test specimen. The third phase deals with the experimental investigation.

## II. MATERIALS AND METHODS

The following materials are used in this research

### A. A-356 alloy

A-356 is a special type of aluminum alloy and is composed of aluminum and other elements such as silicon, magnesium, iron, copper, and zinc; it was verified by elemental analysis technique and compared with existing standards [11]. It is extensively used in industries due to its lightweight, strength, durability, and corrosion resistance. Its properties and composition are shown in Table 1, given below. Figure 1 shows a typical A-356 alloy.



Figure 1. A-356 alloy

Table 1. Composition and properties of A-356 alloy

Constituents	Percentage	Properties	Value
Aluminum	92.05%	Density	2.67 g/cc
Silicon	7%	Hardness	70MPa
Magnesium	0.35%	U.T.S.	234MPa
Iron	0.20%	YTS	165MPa
Copper	0.20%	Machinability	50%
Manganese	0.10%	Share strength	143MPa
Zinc	0.10%	Melting temperature	700°C

### B. Fly Ash

It is a byproduct of coal combustion in power plants collected at the exhaust with the help of filters. It is used as a reinforcement in this research due to its favorable mechanical properties. The chemistry and sample of Fly ash are given in Figure 2 and Table 2, respectively.



Figure 2. Fly Ash

Table2. Chemical Composition of Fly Ash

Element	Weight percentage
C	16.65
O	48.75
Mg	1.07
Al	9.11
Si	13.48
P	0.65
S	0.37
K	0.98
Ti	0.50
Ca	4.62
Fe	3.80

### C. Silica

Silica, also known as Silicon dioxide, is a naturally occurring compound that is plentiful in the earth's crust. It has numerous industrial uses that make it a popular choice in the manufacturing of a wide range of applications. It is used as another reinforcement material; a sample of silica is shown in Figure 3 below.



Figure 3. Silica

### III. EXPERIMENTAL PROCEDURE

#### A. Casting Process

In this research, a type of liquid phase fabrication, Sand Casting, is used as it is cheap and inexpensive compared to other manufacturing processes. It is a foundry process used to produce tools by pouring molten metal into a sand mold and is ideal for small batches produced in contrast to permanent casting. Several steps are involved in the casting process, shown in Figure 4 below. Mold fabrication and melting process are given in Figures 5 and 6 below.

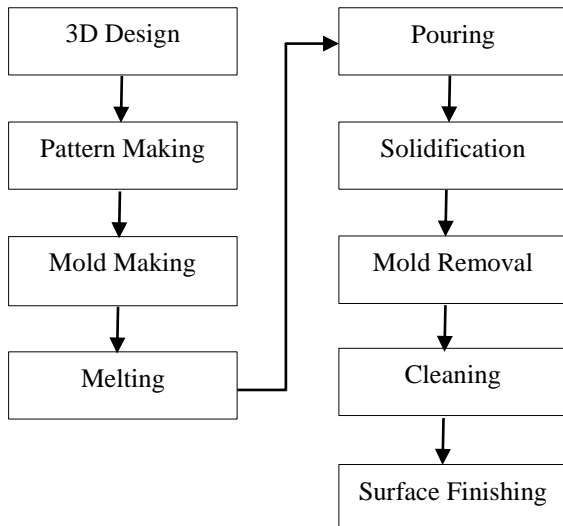


Figure 4. Sand Casting Activities



Figure 6. The melting process

#### B. Composing Alloy

Following the initiation of the melting process, the aluminum melt proceeded at a gradual pace. During this time, three different samples, which vary in weight percentage, were separated. The overall base metal, aluminum, weighed 10.01 kilograms and the constituent fly ash and silica were 0.66 kilograms each. Each sample weighs 1.10 kilograms. The details of each sample are given in Table 3 below. Figure 7 below shows the pouring Process.

Table 3. Composition and weight percentage of each sample

S.No	A356 Alloy (wt. %)	Fly Ash (wt. %)	Silica (wt. %)
1	100% (1100 gm.)	0%	0%
2	90% (990 gm.)	10% (110 gm.)	0%
3	90% (990 gm.)	0%	10% (110 gm.)



Figure 5. Mold of fabricating



Figure 7. The Pouring process

#### C. Microscopy

1: S.E.M.: The Scanning Electron Microscope is a powerful tool used to observe samples at the Nanoscale. Similar to a light microscope, it uses light but instead uses a concentrated electron beam to generate a detailed image of the sample surface. S.E.M.

images show that the microstructure of A-356 is not significantly affected by the addition of fly ash and silica. There is a small change in porosity. However, the overall microstructure remains the same, as shown in Figure 8. S.E.M. micrographs of each sample are shown in Figure 8 below.

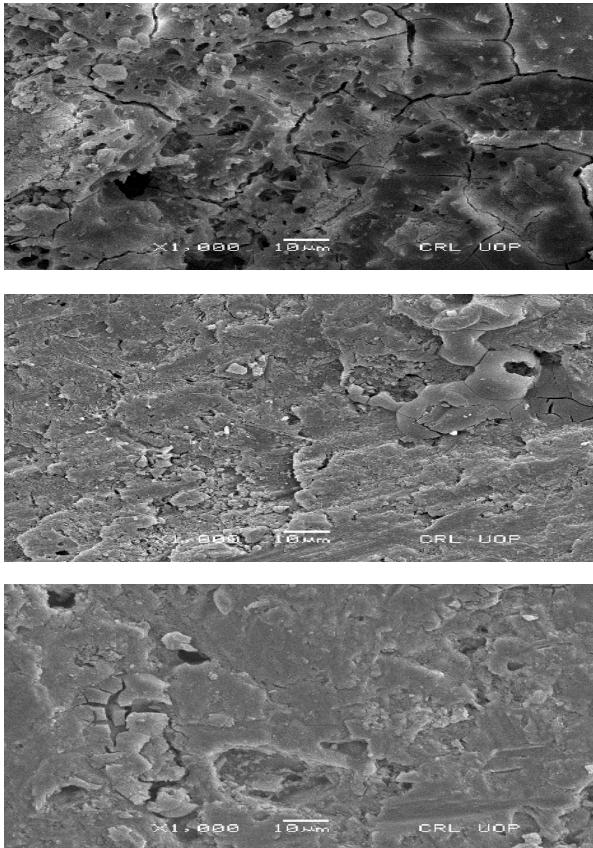


Figure 8: S.E.M. Micrographs showing the porosity of each sample

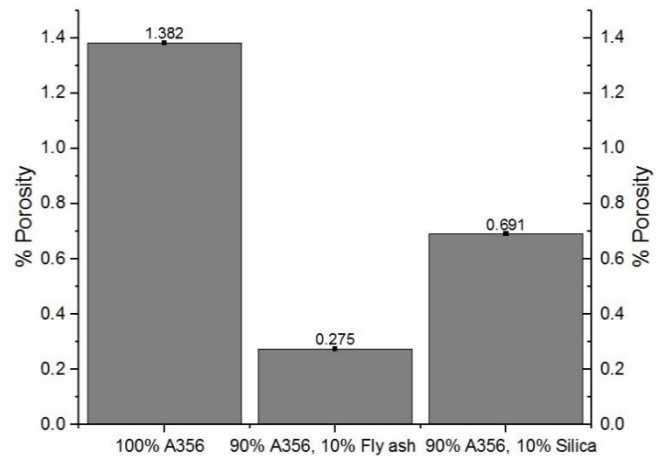


Figure 9: Comparison of percent porosity of base sample with the sample having 10% Fly ash and 10% Silica.

#### D. Hardness Test

In materials science, hardness testing plays a vital role in assessing the durability of materials and determining their strength and sustainability for specific applications. There are various methods for determining the hardness of materials. By conducting these test methods, researchers can ensure that the materials are suitable for the intended use. There are various types of hardness tests shown below.

- Vickers hardness test
- Brinell hardness test
- Rockwell hardness test
- Knop hardness test

The Vickers hardness test is employed in current research to study and evaluate the strength of A-356. The load applied was 20 kgf and each sample was subjected to around 10 to 15 seconds. Figure 10 below shows Vickers's hardness test apparatus.



Figure 10: Performing Vickers Hardness Test

#### 2: ImageJ Porosity Calculation

It is an open-source image processing and analysis software widely used worldwide. It utilizes a wide range of tools for Image processing. Most usually, it includes functions like filtering, enhancing images, reducing noise, and geometric transformation. It also manipulates features like particle size, intensity, shape, and texture. Figure 9 below shows a comparison of the percent porosity of each sample.

In this research, the light load Vickers hardness test (HV-20) was used to analyze the hardness of the samples.

$$HV = \frac{2F \sin 136^\circ}{d^2}$$

$$HV = 1.854 F/d^2$$

H.V. = Vickers Hardness

F = load (KGF) = 20kgf

d = mean of the two diagonals d1 and d2

Dwell time = 10-15 seconds

After calculating the mean diagonal of each sample and putting values in the formula provided, the hardness of each sample has been determined, as shown in Table 4 given below in the result section.

### E. Thermal Resistance

Thermal conductivity was determined indirectly by determining the thermal conductivity using ASTM E-1225. The specimen was placed between two standard materials with known thermal conductivity and high accuracy. To minimize heat losses, longitudinal guard waves were installed with an identical temperature gradient, as shown in Figure 11 below.

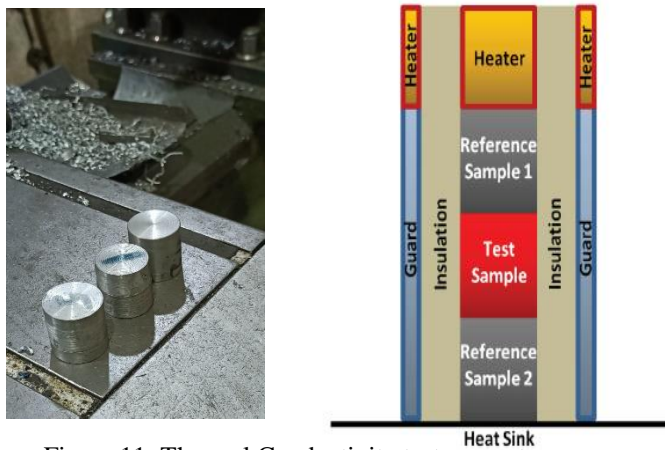


Figure 11: Thermal Conductivity test apparatus

This technique measures the thermal conductivity of materials by establishing a controlled temperature gradient across the specimen and measuring the resultant heat flow. It operates on the principle of thermal conductivity. The relation is given below.

$$K = \frac{Q.L}{A.\Delta T}$$

After finding thermal conductivity, we can easily find thermal resistance with the help of the following relation.

$$R = \frac{L}{kA}$$

### IV. RESULTS

Tables 4 and 5 presented below illustrate that the incorporation of fly ash and silica particles significantly affects the properties of Hardness and Thermal resistance. Specifically, the introduction of 10% fly ash particles results in a 10.03% increase in hardness compared to the original value. The actual hardness value of A-356 measured was 79 kgf/mm<sup>2</sup>, but with the addition of 10% fly ash particles, it rises to 87.8 kgf/mm<sup>2</sup>, indicating a clear correlation between the addition of fly ash particles and the hardness of A-356 alloy. Furthermore, silica particles exhibit lower thermal conductivity, causing an increase in thermal resistance. Thus, the inclusion of 10% silica particles enhances thermal resistance by 15.08% compared to the original value. The results of Vickers's Hardness test and Thermal resistance test are given in Tables 4 and 5 below.

Table 4: Results of Vickers Hardness Test

Sr	Description			Hardness Value
	A356	Fly Ash	Silica	
1	100%	0%	0%	79 kgf/mm <sup>2</sup>
3	90%	10%	0%	87.8 kgf/mm <sup>2</sup>
5	90%	0%	10%	80.3 kgf/mm <sup>2</sup>

Table 5: Results of Thermal Resistance

Sr	Description			Thermal Conductivity	Thermal resistance
	A356	Fly Ash	Silica		
1	100%	0%	0%	191.1 W/m.K	2.61 × 10 <sup>-5</sup> K/W
3	90%	10%	0%	178.6 W/m.K	2.85 × 10 <sup>-5</sup> K/W
5	90%	0%	10%	162.1 W/m.K	3.04 × 10 <sup>-5</sup> K/W

### DISCUSSIONS

While the microstructure of A-356 alloy remains stable with the addition of fly ash and silica particles, the mechanical property hardness and thermal resistance are positively influenced. Fly ash contributes to increased hardness, making the alloy more robust, while silica enhances thermal resistance, making it more suitable for applications requiring lower thermal conductivity. Therefore, the use of fly ash and silica can improve the overall performance of A-356 alloy in specific industrial applications without compromising its microstructural integrity.

### CONCLUSIONS

The percent fly ash and silica particles exhibit a direct correlation with hardness and thermal resistance; as the amount of these particles increased, so did the hardness and thermal resistance increase. The actual value of the hardness of A-356

recorded was 79 kgf/mm<sup>2</sup>, and the thermal resistance recorded was  $2.61 \times 10^{-5}$  K/W. With the addition of fly ash and silica particles, hardness increased by 10.03 percent when 10% fly ash was added, and thermal resistance was increased by 15.08% when 10 % silica particles were added.

On the other hand, Scanning Electron Microscope images show that the addition of fly ash and silica particles enhances the porosity of A-356. The porosity of pure A-356 was recorded as 1.382%; with the addition of 10% fly ash and 10% silica, it was reduced to 0.275% and 0.691%, respectively.

#### REFERENCES

- [1] K. Vijaya Bhaskar, S. Sundarrajan, M. Gopi Krishna, K. Ravindra Materials today: proceedings, 2017
- [2] [https://www.matweb.com/search/datasheet\\_print.aspx?matguid=d524d6bf305c4ce99414cabd1c7ed070](https://www.matweb.com/search/datasheet_print.aspx?matguid=d524d6bf305c4ce99414cabd1c7ed070)
- [3] Adarsh Patil, N.R. Banapurmath, Anand M. Hunashyal, Vinod Kumar V. Meti I.O.P. conference series. Materials Science and Engineering, 2020
- [4] Babu Rao, J., Venkata Rao, D. and Bhargava, N.R.M.R. "Development of ALFA Lightweight Composites," International Journal of Engineering Science and Technology, Vol. 2, No. 11, pp. 50-59, 2010.
- [5] Babu Rao, J., Venkata Rao, D. and Bhargava, N.R.M.R. "Development of ALFA Lightweight Composites," International Journal of Engineering Science and Technology, Vol. 2, No. 11, pp. 50-59, 2010.
- [6] Rohatgi, P.K., Weiss, D. and Nikhil Gupta "Application of fly ash in the synthesis of low-cost metal matrix composites for automotive and other engineering applications," J.O.M., vol. 58, No. 11, pp. 71-76, 2006.
- [7] LI Yue-ying, Cao Zhan Yi and Liu Yong Bing "Mechanical behavior of ZL109/Al<sub>2</sub>O<sub>3</sub>•SiO<sub>2</sub> particle reinforced composites", Transactions of Nonferrous Metals Society of China, vol. 17, pp. 290-294, 2007.
- [8] K.V. Mahindra, K. Radhakrishna, Materials Science-Poland, Vol. 25, No. 1, 2007
- [9] Badia. F.A, McDonald, Graphite Al - A New Method of Production and Some Foundry Characteristics. Trans Am Foundry Men's Soc Volume 7(1971): pp 630
- [10] H.C. Anilkumar, H.S. Hebbar, K.S. Ravishankar, 2011, Mechanical Properties of Fly Ash Reinforced Aluminium Alloy (A16061) Composites International Journal of Mechanical and Materials Engineering (U.M.M.E.), Vol.6, 41-45
- [11] [https://www.matweb.com/search/datasheet\\_print.aspx?matguid=d524d6bf305c4ce99414cabd1c7ed070](https://www.matweb.com/search/datasheet_print.aspx?matguid=d524d6bf305c4ce99414cabd1c7ed070)



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