ISSN No:-2456-2165

Effect of Pouring Temperatures on Microstructure and Mechanical Properties of Al-16Si Hyper Eutectic Alloys Reinforced with 4 Wt% Al2O3 Using Stir Casting Process

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Abstract:- Aluminium-silicon (Al-Si) alloys have become the preferred choice for modern automobile engines, replacing conventional cast iron materials. This transition has resulted in significant improvements in both fuel efficiency and reduced vehicle emissions. The superior performance of Al-Si alloys can be attributed to their unique microstructure, characterized by primary silicon crystals with diverse shapes such as polygons, plates, and feathery structures, along with the presence of an eutectic phase (α -Al + eutectic silicon). The distribution of these microstructures can vary depending on factors like pouring temperature and the addition of other compounds like alumina, which further enhance the mechanical and tribological properties. For instance, alloys with 16% silicon and 4% alumina (Al-16Si- 4% Al2O3) exhibit improved hardness and wear resistance compared to their conventional counterparts. X-ray diffraction (XRD) analysis has revealed the presence of SiO2, Al2O3, and Al-rich intermetallic compounds while scanning electron microscopy (SEM) images demonstrate the modification of primary silicon structures (feathery, star, and plate-like shapes) and eutectic silicon structures (coarse acicular and flake-like shapes) due to the addition of alumina content. Notably, the brittle phase formation Al2O3, SiO2, , and Al-rich intermetallic compounds contribute to enhanced mechanical and tribological properties. Experimental studies conducted in this field have demonstrated that increasing the alumina content leads to higher hardness values, and wear tests conducted under varying loads and speeds have shown improved wear resistance with increasing alumina content.

***Keywords:-** Al-Rich Intermetallic Compound; Tribological Properties Al-Si- Al2O3 alloy Al-16Si- 4%Al2O3.*

I. INTRODUCTION

Hypereutectic Al-Si alloys have gained significant popularity in, automotive aerospace, automotive and general engineering industries due to their outstanding properties. In various engineering applications, the utilization of lightweight Al-Si alloys as a replacement for traditional cast iron in automobile engines has emerged as a promising strategy, leading to fuel economy savings and reduced vehicle emissions.[1] Al, being the lightest element on Earth, finds extensive use in the automotive sector owing to its lightweight nature, which enhances fuel efficiency. Mechanical behavior and wear properties are two critical factors considered in the selection of materials. To optimize the performance of aluminium alloys, recent advancements have focused on incorporating grain refinement techniques such as Al2O3, which effectively improve the microstructure and mechanical properties through various processing methods. The automobile industry has witnessed a significant rise in the use of metal matrix composites (MMCs), particularly those with an aluminium matrix. MMCs based on Al-Si alloys have demonstrated remarkable improvements in properties. The wide adoption of Al-Si alloys can be attributed to their lightweight nature, excellent cast ability good specific strength, improved wear resistance, and cost-effectiveness. The distribution and morphology of Si particles within hypereutectic Al-Si alloys play a crucial role in determining the wear and mechanical properties. Various morphologies, including acicular, feathery, and spherical shapes, have been observed in the Si phase. Notably, alloys with uniformly distributed eutectic Si particles in a spherical form have exhibited superior performance. Incorporating grain refiners like TiB2 and Al2O3 into the aluminium matrix has proven effective in enhancing hardness, strength, and wear resistance. These grain refiners play a vital role in impeding grain growth. This paper aims to investigate the impact of incorporating 4% Al2O3 into an Al matrix composite and its subsequent effects on material properties.

II. MATERIALS AND METHODS

For the fabrication of Al-16Si 3Al2O3 composite samples, the materials employed include alumina ingot with a purity of 99.95%, master alloy(Al-50%Si), and Gamma-Al2O3. The stir casting process was employed to produce the Al-16Si 4% Al2O3 composite. Subsequently, the composite samples underwent wear testing to evaluate their tribological, mechanical, and physical properties.

A. Preparation of the Sample Al-Si-4% Al2O3:-

To prepare the Al-16Si 4Al2O3 composite, a conventional stir casting method was employed. The process involved melting we use aluminium ingot and master alloy in a crucible with melting furnace. The melting temperatures used for each component were as follows: 720°C for commercially pure aluminium ingot, 770°C for Al-50wt%Si master alloy, and 820°C for Al2O3 particles. Different weight percentages of Al2O3 particles were added to achieve the desired composition of Al-16Si 4Al2O3. The stirring action was applied during the casting process to ensure the homogeneity of the mixture. By following this method, the Al-16Si 4Al2O3 composite was successfully prepared.

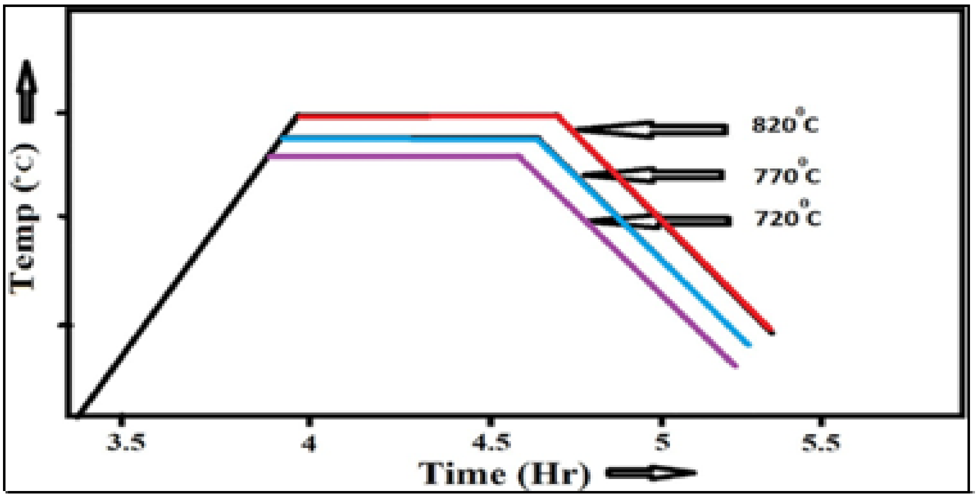

Fig 1. Graph Plot Between Time and Temperature of Al-16Si-4% Al2O3 Sample by alloy Steel Method [14]

Fig 2. Sample of AMC Having 4%Al_2O_3 Casted at 820^0C

Fig. 3 (A) Casting of AMC by Alloy Steel Mould, (B) Al-16Si-4%Al_2O_3 Sample Cast at 820^{0}C by Stir Casting Method.

B. Characterization:-

The XRD analysis was conducted on samples of dimensions 10mm x 10mm x 2mm to examine the different phases present. The analysis of the matching peaks with data files from the JCPDS (Joint Committee on Powder Diffraction Standards) database utilized a Cu-Kα target.

C. Hardness and Density:-

To calculate the hardness value of the specimens, we use a micro-Vickers hardness tester. The tester featured a diamond pyramid with a square base as the indenter. An applied load of 1kgf was exerted on the samples for a duration of 15 seconds. Prior to the hardness measurement, the samples were carefully prepared by polishing to ensure that the horizontal faces were parallel. The VHN of the samples was obtained by measuring the two diagonals of the indentation at five different locations on each sample. For the density tests the machine name (Mettler-Toledo) density was employed. The density of each sample was measured individually using this machine

D. Wear Study:-

Calculate the tribological behaviour of the sample, the sample of dimensions 10mm in diameter and 30mm in height was subjected to testing using a wear testing machine (pin-on-disc), as depicted in Figure 1. The applied load to the sample was varied within the range of 40 to 60N, and the rotation speed of the disc was set at 300, 400, and 500rpm. The wear track radius was 40mm, and the tests were conducted at room temperature without the use of any lubrication materials. Each test lasted for a duration of 5 minutes.

The wear-testing machine was equipped with a microprocessor control system that provided real-time data on height loss (measured in microns) and the coefficient of friction. The mass loss due to wear for each sample was calculated using the formula:

$V = KFS$

Where: V represents the wear volume in cubic millimeters (mm3), K denotes the wear rate in cubic millimetres per Newton-meter (mm3/Nm), F signifies the applied normal load in Newtons (N), and S represents the sliding distance in meters (m)

Fig.4 Setup of Pin on-Disc wear test [16]

III. RESULTS AND DISCUSSIONS

A. XRD Analysis:-

Based on the XRD analysis results, the major peaks observed indicate the presence of silicon and aluminium in the tested samples. However, small peaks suggest the existence of SiO2 (silicon dioxide) and Al2O3 (aluminium oxide). Notably, with an increase in the percentage of Al2O3, the intensity of peaks corresponding to the formation Al-rich intermetallic compound (Al3.21Si0.47) significantly increased, as illustrated in Fig. 3.1(a-c). Fig.4 Setup of Pin on-Disc wear test [16]

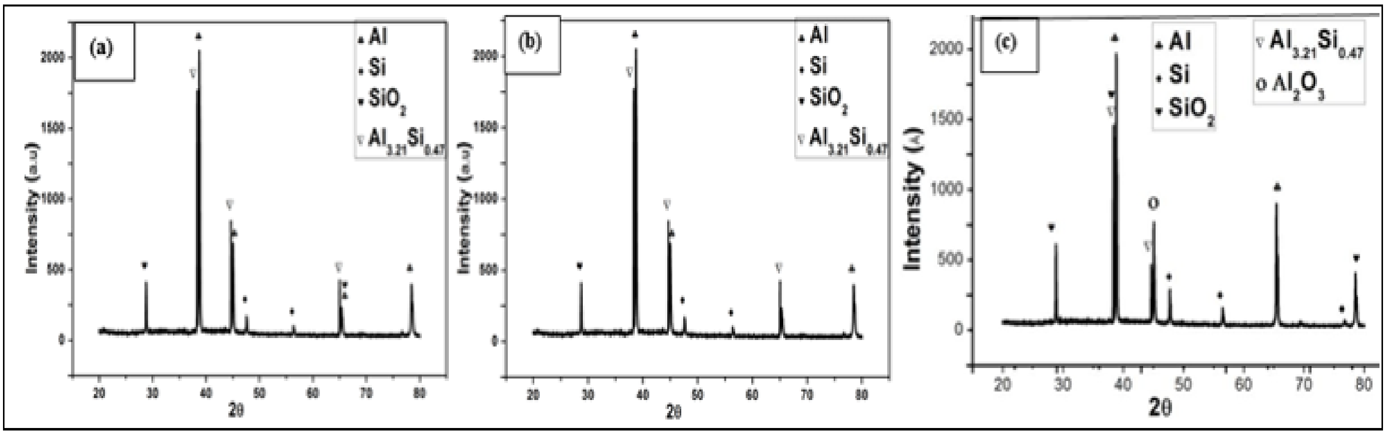

Fig 5. XRD Plot of (A) Al-16Si-2%Al_2O_3 (B) Al-16Si-3%Al_2O_3 (C) Al-16Si-4%Al_2O_3

B. Density and Hardness:-

Table 1. Different Sample of the Density and Hardness.

Sample	Temperature	Hardness(VHN)	Density(g/cc)
Al-16Si-3% Al_2O_3	720˚C	**70**	2.5295
Al-16Si-3%Al_2O_3	770˚C	**75**	2.5418
Al-16Si-3%Al_2O_3	820˚C	**69**	2.6129

According to Table 1, it is evident that both hardness and density increase when increases the aluminium addition. The density of Al2O3 is approximately 3.95g/cc. The increase in hardness can be attributed to the formation of a harder intermetallic phase like Al-rich. However, this increase in hardness comes at the expense of a small increase in density.

Interestingly, the hardness value exhibits an increase with increasing temperature within the range of 720˚C to 770˚C. This could be due to uniform distribution of alumina then improved wettability. However, the hardness value starts to decrease when the pouring temperature is further increased from 770˚C to 820˚C. This decrease can be attributed to the dominant factor of grain growth at higher temperatures, which negatively affects the hardness of the material.

C. Wear Study:-

The formation of a stable grain intermetallic compound is more pronounced in the case of the sample prepared at 770°C compared to 720°C and 820°C. This finding suggests that at 770°C the wear rate of the Al-16Si-4%Al2O3 sample is lower as depicted in Figure 5. The enhanced wettability and more distribution of alumina at higher temperatures contribute to this effect. Additionally, the Al-rich intermetallic compound formation acts as a resistance mechanism against wear, further reducing the wear of the material

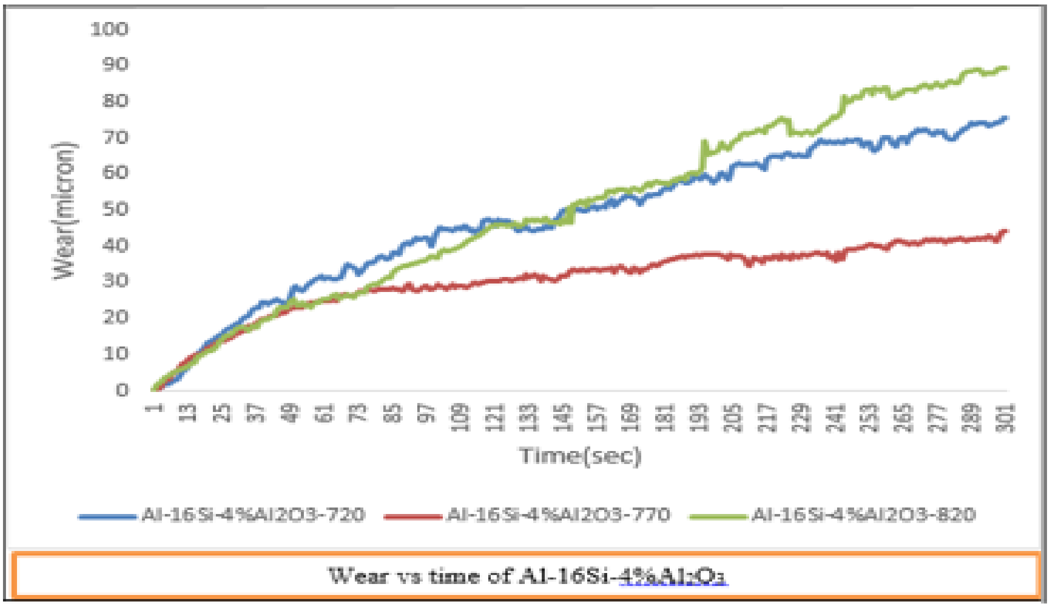

Fig.6 Different Temperature at Constant Rpm and Load Mass Loss of the Sample

Table 2. Different Temperature at Constant Load and Rpm Mass Loss of the Sample

Name of the sample	Temperatures	Mass Loss of the sample
Al-16Si-4% Al_2O_3	720 ˚C	0.0045
Al-16Si-4%Al_2O_3	770 ˚C	0.0041
Al-16Si-4%Al_2O_3	820 ˚C	0.0072

D. Microstructure Study:-

The optical micrographs presented in Figure 7, observed at 10X magnification , illustrate the uniform distribution of phases throughout the sample when poured when temperature is high that is 770°C compared to 720°C. However, when temperature above 770°C, specifically at that time 820°C, grain coarsening and accumulation occur, leading to a decrease in mechanical properties.

Analysing the microstructures shown in Figure 7, it can be observed that as the when alumina content3% to 4%, increases there is an increase in the nucleation of pro-eutectic and primary silicon. At 3% alumina content, the silicon particles tend to form agglomerates instead of being soluble in aluminium. Primary and pro-eutectic silicon structures typically have a needle-like morphology and are brittle in nature. However, in the composite containing 4% alumina, more rounded-like structures are observed instead of needle-like ones, which ultimately enhances the wear behaviour and mechanical properties of the material.

In Figure 8, Scanning Electron Microscopic images taken at a magnification of 5000X demonstrate the finer details of the sample

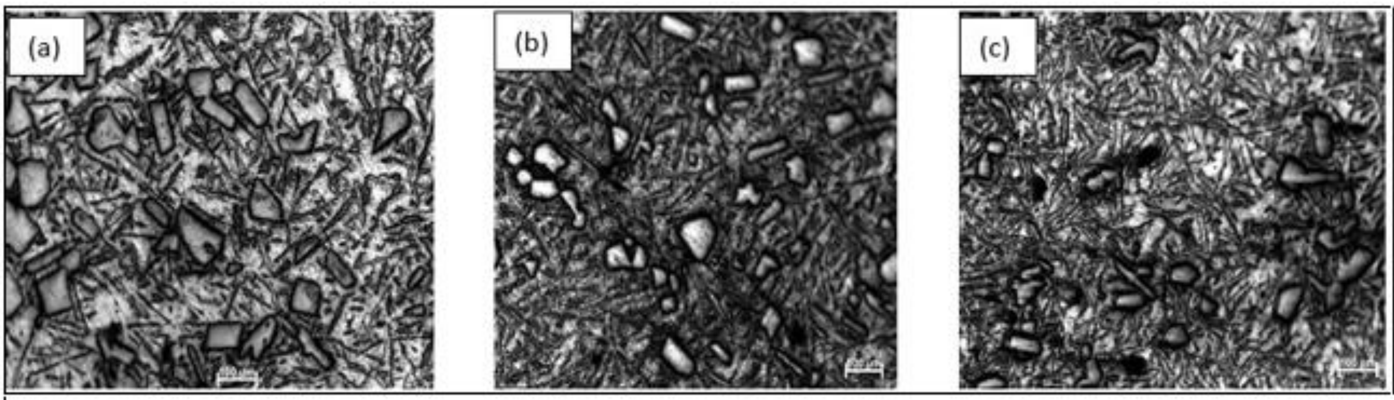

Fig..7 (a) Al-16Si-4%Al_2O_3 720℃ 10X , Fig.(b) Al-16Si-4%Al_2O_3 770℃ 10X , Fig.(c) Al-16Si-4%Al_2O_3 820℃ 10X

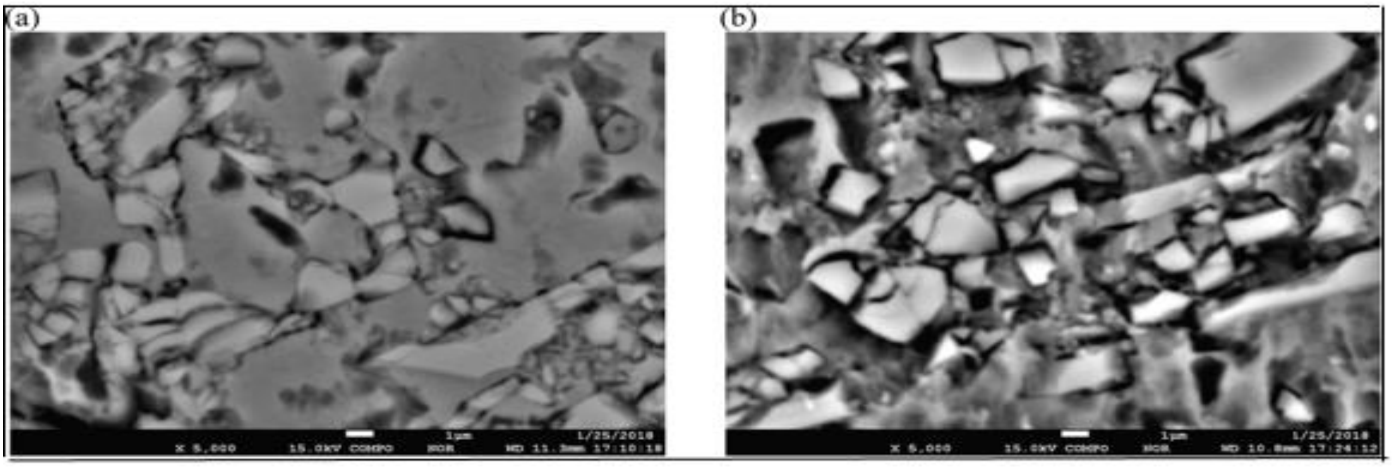

Fig. 8 SEM Micrograph Al-16Si-4% Al2O3 in Different Pouring Temperatures (A) 770ºc (B) 820 ºc

IV. CONCLUSION

The X-ray diffraction (XRD) analysis reveals prominent peaks corresponding to the presence of aluminum and silicon in the Al-16Si-4Al2O3 composite. Additional minor peaks Al2O3 and SiO2 signify the existence. Interestingly, as the increases alumina content when intensity of peaks associated with the compound rich Al intermetallic (Al3.21Si0.47) exhibits a significant rise, as depicted in Figure 3.1(a-c).

The enhanced hardness observed in the composite can be formation of a harder phase, namely the Al-rich intermetallic compound. This transformation comes at the expense of minimal changes in density, implying a delicate trade-off between improved mechanical properties and marginal alterations in mass.

Tribological investigations reveal that the wear rate of the alloys escalates with higher loads and rotation speeds, except for the Al-16Si-4Al2O3 sample poured at 770°C, which exhibits reduced wear. This intriguing behavior could be attributed uniform distribution of limina the improved the wettability at the higher pouring temperature, as well as the formation intermetallic with rich Al intermetallic compound, which enhances the material's resistance to wear.

Microstructural examinations, as depicted in Figure 7, unravel the effects of alumina content on the nucleation of primary silicon and With an increase in alumina content from 3% to 4%, there is a discernible augmentation in the amount of these silicon phases. At 3% alumina, the solubility of silicon in the aluminum matrix diminishes, leading to the formation of agglomerates rather than homogenous dissolution.

In the realm of aerospace applications, the Al-Si alloys find themselves adorned with various roles. They grace the skies as fuselage and aero-structures, empower engines with blades and combustion chambers, shield against corrosion through anticorrosion coatings, display intelligence through smart paints, and fortify space structures against impacts.

Within this scientific tapestry, the interplay of crystal structures, phase compositions, mechanical properties, and tribological characteristics captivates our senses. It is through these discoveries and advancements that the Al-Si alloys continue to unveil their scientific allure and unlock new frontiers of possibility

ACKNOWLEDGMENT

This research is part of academic research under the Department of MME GCE, Keonjhar India.

REFERENCES

[1]. Zhou J, Duszczyk J and Korevaar B M 1991 *Jou. of mate. Sci.* **26**(11) 3041-50.
[2]. Gupta M and Lavernia E J 1995 *Jour. of mat. Proc. Tech.***54**(1-4) 261-70
[3]. Zhou W and Xu Z M 1997 *Jour. of Mat. Proc. Tech.* **63**(1-3), 358-63
[4]. Tee K, Lu L and Lai M O 1999 *Jou. of Mat. Pro. Tech.* **89** 513-19
[5]. Tjong S C, Wu S Q and Zhu H G 1999 C*omp. Sci. and Tech.* **59**(9) 1341-47.
[6]. Ipina J P, Yawny A and Oliver C G 2003 *Jou. of comp. mat.* **37**(22) 2001-10
[7]. Ge L L, Liu R P, Li G, Ma M Z and Wang W K 2004 *Mat. Sci. and Eng. A* **385**(1- 2) 128-32

[8]. El-Labban H F, Abdelaziz M and Mahmoud E R 2016 *Jou. of Kin. Saud Uni.- Eng. Sci.* **28**(2) 230-39.
[9]. Wasly H S 2016 *International Res. of Eng. and Tech.* **03** (11) 1350-55
[10]. Ping Shen, Hidetoshi Fujii, Taihei Matsumoto, Kiyoshi Nogi, J. Am.Ceram. Soc. 87 (7)(2005) 12651273.
[11]. J. Majhi, S.K. Sahoo, S.C. Patnaik, B. Sarangi, A. Behera, Int. J. Sci. Res. Dev. 6 (7) (2018) ISSN : 23210613.
[12]. G. Abouelmagd, J. Mate. Proc. Tech. 155-156 (2004) 1395–1401.
[13]. A. Mandal, R. Maiti, M. Chakraborty, B.S. Murty, Mater. Sci. Eng., A 386 (2004) 296–300
[14]. Majhi, J., Mandal.A, Sahoo S K, ,Patnike S C , Sarangi.B, Jena k p" *Materials Today: Proceedings* 33 (2020):55395543.
[15]. Peng Zhang, Weiyi Zhang, Yunhui Du, Yujie Wang " High performance Al-1.5wt% -Si-Al2O3 composite by vortex-free high speed stir casting" Journal of Manufacturing Processes 56 (2020) 1126-1135
[16]. Sahu, S. K., Patra, R. K., & Majhi, J. (2022). Effect of addition of 3% Al2O3 on mechanical and microstructural properties in Al-16Si hypereutectic alloys with pouring temperature. *Mat. Today: Proc.*.62(2022)5850-5855
[17]. Parida, J., S. C. Pattnaik, S. C. Mishra, and A. Behera. "Effect of heat treatment on wear behaviour of al-7 wt% Si-X wt% mg alloys." Mat. To.: Proc. 33 (2020)