Tensile and wear behaviour of Al-4.5%Cu alloy reinforced fly ash/SiC by stir and squeeze casting with rolled composites

[1]G.N.Lokesh, [2]M.Ramachandra, [3]K.V.Mahendra

[1]Mechanical Engineering Department, Acharya Institute of Technology, Bangalore-560107, India
[2]Mechanical Engineering Department, BMS College of Engineering, Bangalore-560019, India
[3]Mechanical Engineering Department, Jyothy Institute of Technology, Bangalore-560062, India
Email: [1]lokeshgn32@gmail.com, [2]dr.mramachandra@gmail.com, [3]mahendrakv@gmail.com.

Abstract- Recycling of fly ash, the coal combustion waste product produced by thermal power plants, is an increasingly urgent problem associated with their storage and disposal, which may have negative effect on human and serious environmental issues. On the other hand, the high cost of aluminum Metal Matrix Composites (MMCs), reinforced with ceramic particles such as SiC and Al_2O_3 has limited their use in many engineering applications. In the present investigation, the Al-Cu matrix reinforced by fly ash and SiC particulate were fabricated using vortex stirring, followed by squeeze casting technique. The composites so produced were subjected to hot rolling for 30% reduction. The wear tests were carried out using a pin on disc technique. Microstructure of the composites was observed by scanning electron microscope (SEM). The results indicate that the hardness and tensile strength increases with increase in percentage of fly ash and SiC by stir, squeeze and rolled composites. But squeeze casting composites shows higher strength than stir casting. But rolled composites show higher mechanical properties than both stir and squeeze cast composites. The test results showed that rolled specimens fabricated by stir casting technique have greater wear resistance than those fabricated by squeeze casting technique. Microstructure shows better bonding between matrix particle interface and no fracture observed in rolled composites.

Index Terms— Fly ash, Stir casting, Squeeze casting, Wear.

I. INTRODUCTION

Metal Matrix Composites (MMCs) have fascinated significant attention because of their physical, mechanical, and tribological properties which can be tailored for a given application. Good cast ability, high corrosion resistance, and low density are some known properties of Al-Cu alloys. That is why they have found applications in the manufacturing of various automotive engine components such as piston, where dry sliding wear is a predominant process [1], [2]. Further development can be estimated from the reinforcement of these alloys with ceramic particulates [3], [4]. Incorporation of ceramic particles, into a metal matrix causes a significant increase in the hardness, tensile strength [5], [6], fatigue strength [7], flexural, stiffness and wear resistance [8] with low Coefficient of thermal expansion and higher thermal conductivity [9]. Composites produced using waste as reinforcements helps not only clearing environmental issues but also helps in increasing mechanical properties of the composites. One of the inexpensively available and also coming as waste form thermal power plant is fly ash. Al-alloy reinforced fly ash reveal superior damping characteristics [10] increases mechanical properties [11] and improved wear resistance [12]. The majority work reported in literature has been devoted to aluminium alloy with single reinforcement and not much work has been reported on the use of Al-alloy with two reinforcements casted by squeeze casting. Qiguo Zhang et al. [13] focuses on the fabrication of hybrid-particle-reinforced aluminum composites (Al/Sip + SiCp) via gelcasting and vacuum pressure infiltration and stated higher thermal conductivity and improved flexure strength. In the present study an attempt has been made to stir and squeeze cast Al-Cu alloy with two reinforcements, fly ash and SiC to form hybrid MMCs with different weight percentage. The hardness, tensile and wear behaviour of hybrid MMCs were investigated. The stir cast blanks were subjected to hot rolling process for different reductions. Microphotographs were taken by SEM after wear to know the distribution and fracture of reinforcements.

II. EXPERIMENTAL WORK

Fabrication of composite by vortex method and squeeze casting technique has been used to fabricate composite. The Al-Cu alloy is used as matrix and fly ash and SiC particulate is used as reinforcements. The chemical composition of the matrix alloy is shown in table 1. In vortex technique, the matrix alloy was cut to small pieces and then charged into crucible furnace of 3 kW power where it is heated to a superheat of 750^{o}C. Then the melt is stirred using mechanical stirrer. The fly ash particles were preheated to 210°C for two hours to remove moisture. The SiC particles were heated at 400°C temperature for 2 h before addition into the melt. The stirrer impeller was completely immersed in the molten metal with its axis coaxial with the crucible axis as shown in figure 1.

Table 1. Chemical composition of the base alloy (wt. %)

Cu	4.51
Mg	0.061
Si	0.52
Fe	0.59
Mn	0.13
Ni	0.06
Pb	0.03
Sn	0.02
Ti	0.012
Zn	0.12
Al	Balance

After the molten metal was fully melted, solid dry hexachloroethane degassing tablet was added to reduce the porosity. The stirrer was lowered into the melt slowly to stir the molten metal at the speed of 450 rpm. Various stirrer speeds, tilt angles and movement of stirrer from top to bottom in the crucible were used to obtain vortex strong enough to disperse the reinforcements into the melt. The preheated fly ash and SiC particles were added to the vortex between liquidus and solidus temperatures at the rate of 25g/min during the stirring time with Mg (0.6wt %) were also added to ensure good wettability of particles [14]. The time needed for the addition of fly ash and SiC particulate was varied between 10 and 20 minutes. When the addition of SiC particulate was completed, stirring of the mixture was continued for another 5 minutes and then the mixture was poured at 720^{o}C into the prepared steel die. The cast was withdrawn from the mold after complete solidification and then the required specimens were taken for investigation.

In squeeze cast technique, a special die set of 50 mm inside diameter, 100 mm outside diameter and 200 mm height provided with a punch of 50 mm diameter. The die set was manufactured from tool steel material. The die walls were coated by graphite to inhibit sticking of ingot to the walls [15]. The reinforcing particulate and small pieces of the matrix alloy were charged into the die. The die was heated using an electric furnace, until the matrix was melted and superheated. The temperature of molten metal was held at 720^{o}C for 30 minutes to achieve a uniform temperature distribution in the matrix. After through mixing of matrix and reinforcements, the melt was poured into preheated die cavity and solidification was carried out with a squeeze pressure of 110MPa for a period between 120 and 180 seconds [16]. Figure 2 and 3 shows pouring and squeezing the molten metal respectively. A gradually increasing pressure was applied to the aggregate through the punch. The maximum applied pressure of was maintained constant till complete solidification, then it is released. The casting inside the die was ejected using high-pressure press. The chemical composition of samples casted is shown in Table 2. The obtained cast was cut to the required shape and dimensions. The rolling samples were machined for a dimension of 180mm length, 12mm width and 12mm thickness. The samples were hot rolled with a temperature of 410°C and the thickness reduction of 0.25mm per each cycle into different final reductions to 30%, with intermediate heat treating process. The laboratory rolling mill with a loading capacity of 15tons is used for rolling the samples with no lubrications shown in figure 4.

Table 2. Measured composition of stir and squeeze cast samples (wt.%)

Sample		Composition
Sample 1	Base alloy	Al-4.5wt%.Cu alloy
Sample 2	Composite 1	2wt%Fly ash, 2wt%.SiC
Sample 3	Composite 2	2wt%Fly ash, 4wt%.SiC
Sample 4	Composite 3	2wt%Fly ash, 6wt%.SiC
Sample 5	Composite 4	4wt%Fly ash, 2wt%.SiC
Sample 6	Composite 5	4wt%Fly ash, 4wt%.SiC
Sample 7	Composite 6	4wt%Fly ash, 6wt%.SiC

The composites produced were subjected to T6 heat treatment [17]. The castings were heated to 450°C for 12 hours, quenched in 100^{0}C water and reheated to 170^{0}C for 16hours and cooled in the furnace temperature. Hardness measurements were performed using a Brinnel hardness tester with a load of 10kgf as per ASTM-E10-01. Hardness values were averaged over five measurements taken at different points on the cross-section. Tensile tests were carried out using samples prepared according to ASTM-E-8M-09 standard. These tests were conducted using a computerized universal testing machine (UTM) with 60KN capacity. Wear test was carried out using a computerized pin on a disc wear testing machine under ambient temperature conditions. Wear pins of 8mm diameter and 30mm heights were prepared and subsequently the weight loss of the materials was determined. Micro photographs were taken after wear test of each sample for SEM to examine the effect of the percentage of particle distribution.

Fig. 1. The molten metal was stirred to create a vortex

Fig. 2. The molten metal was pouring into the die

Fig. 3. The molten metal was squeezed using plunger

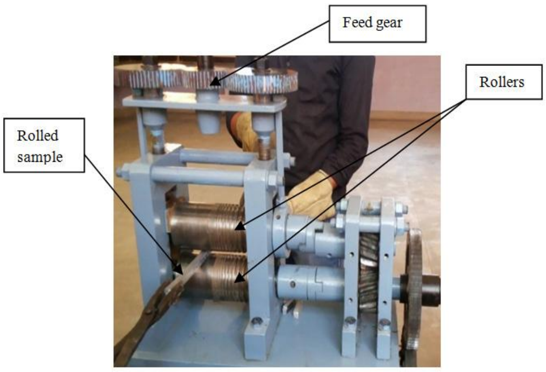

Fig.4. Rolling of composite in a rolling mill

III. RESULT AND DISCUSSIONS

A. Hardness

Fig. 5 shows that the hardness of squeeze cast matrix is higher than that of gravity matrix by about 12% approximately. The application of pressure during solidification in squeeze casting minimizes porosity and makes the metal denser, making the matrix to resist surfacial plastic deformation, rendering higher hardness to the matrix [18].

The dispersion of fly ash and SiC particles enhances the hardness, as particles are harder than Al alloy; the materials render their inherent property of hardness to the soft matrix. The peak hardness of 107BHN was found to be for an addition of 4 wt.% fly ash and 6 wt.% SiC particles in stir cast condition. The squeeze cast composites having 4 wt.% fly ash and 2 wt.% SiC was found to be 2% more harder than the corresponding stir casting. However, the peak hardness observed for addition of 4 wt.% fly ash and 6 wt.% SiC particles in both the cases and squeeze cast composite is 16% higher than stir cast composite. The hardness of Al-Cu/fly ash/SiC composites after hot rolling was found to increase gradually with an increase in the extent of reduction during rolling. This increase was observed from 99 to 129 BHN which is attributed primarily to the refined grain structure of matrix, presence of harder fly ash and SiC reinforcement and harder CuAl2 phase in the matrix, and also the higher constraint to the localized matrix deformation during indentation as a result of the presence of reinforcement. It is clear that the peak hardness of rolled sample 7 is 6.7% higher than that of squeeze cast composite for the same composition. The hardness in squeeze casting conditions may be due to combined effect of denser matrix and hard ceramic particles.

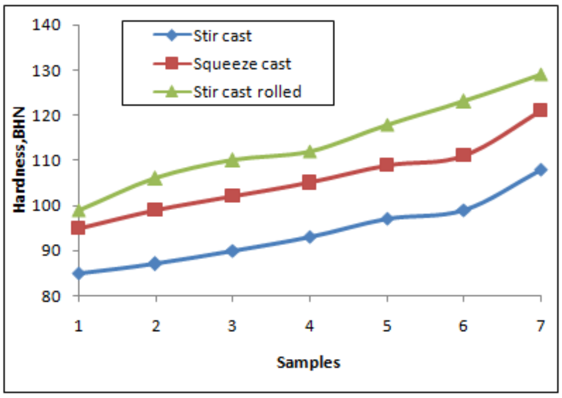

Fig. 5 Hardness of stir cast, squeeze cast and rolled composite.

B. Tensile Strength

The Ultimate Tensile Strength (UTS) results of stir cast, squeeze cast and rolled composites for varying percentage of particles is shown in Fig 6.

It is observed from the figure that the tensile strength of rolled composites is higher than stir cast and squeeze cast composites. The improvement in strength in rolling condition may be attributed to the absence of shrinkage porosity and fine grain structure. It can be observed from the figure that the addition of the fly ash and SiC particulates enhanced the tensile strength of the composites. It is true for both stir cast and squeeze cast conditions.

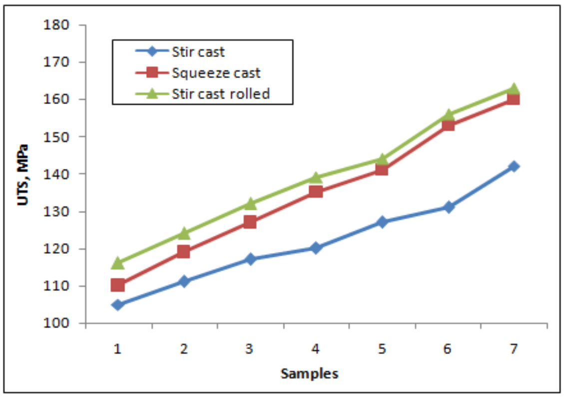

Fig. 6 Variation of ultimate tensile strength of stir cast, squeeze cast and rolled composite.

The composites attains peak strength on addition of 4 wt.% fly ash and 6 wt.% SiC particles in both the stir cast and squeeze cast conditions. However, the squeeze composites, having 4 wt.% fly ash and 6 wt.% SiC particles showed enhancement of 12.6% over the stir cast sample of same composition. But rolled composites of same composition shows increase in the strength compared to squeeze cast composites. It may also be upshot of smaller inter-particle spacing and closer packing of reinforcement in the matrix. Also, rolled composites further enhance the strength due to the absence of micro porosity, grain reinforcement and better interfacial bond between matrix and reinforcement [19].

C. Wear Test

The stir, squeeze and rolled composites were machined to a diameter of 8mm with height of 30 mm for perfect match in the wear testing specimen holder (separate arrangement) for the wear study. The tests were carried out using a computerized pin on a disc wear testing machine under ambient temperature conditions on specimens for normal load of 10N and for a constant track velocity of 80 m/sec. A hardened steel disc (60 HRc) was used as the counter body. The duration of the test was fixed to 60 minutes. For each experiment, a new pin and a new disc were used. Before the tests were conducted, both the pin and disc were degreased, cleaned and dried with acetone. The wear tracks on the specimen were observed under a SEM to examine the effect of the percentage of particulate on the wear behaviour of the composites. The test report of dry sliding wear of both stir cast and squeeze cast composites of different weight percentage particles is indicated in Fig 7.

It is observed that the both stir and squeeze cast composites shows peak strength for 60 minute duration, hence the wear studies of this composite is presented here. The squeeze cast composite showed decreases of 3.7 times lesser wear weight loss compared to stir cast composite over wear duration of 60 minutes. It may be attributed to hardness of the material a dominating factor affecting the wear resistance. The decrease in wear weight loss may also be attributed to higher load bearing capacity of hard reinforcing material. It can be noted that the composites show lower weight loss indicating the beneficial effect of addition of fly ash and SiC particles. It is evident that rolled composites show lesser wear weight loss when compare to stir and squeeze cast composites for the same duration in all the composites. This is due to the increase of hardness of the respective composites with the extent of rolling and also the abrasive nature of fly ash and SiC particles. The finer dispersion of the fragmented particles strengthens the composite. Since the average particle size of fly ash lies in the range 28-35μm, the extent of particles pulled out from the surface was smaller. With increase in reduction, the amount of particle present strengthens the matrix and hence more wear resistance is observed in rolled composites.

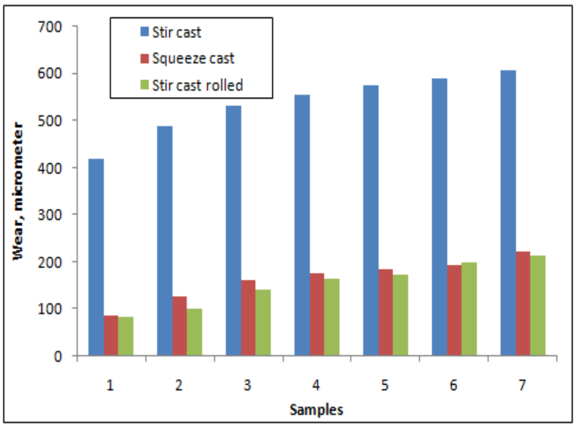

Fig. 7 Wear behavior of stir, squeeze and rolled composite for 10N load and 60minutes duration.

D. Microstructure

It can be seen in Figures (8, 9 and 10) that, the presence of grooves of varying sizes was observed frequently on the worn surface. The worn debris particles are likely to act as third body abrasive particles. The fly ash and SiC particles trapped between the specimen and counter face cause microploughing on the contact surface of the composite both in stir and squeeze casting.

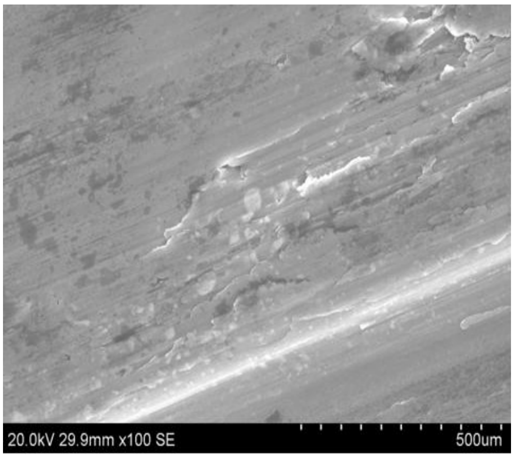

Fig. 8. Wear track of Al-Cu/4%fly ash/6%SiC composite in stir cast condition

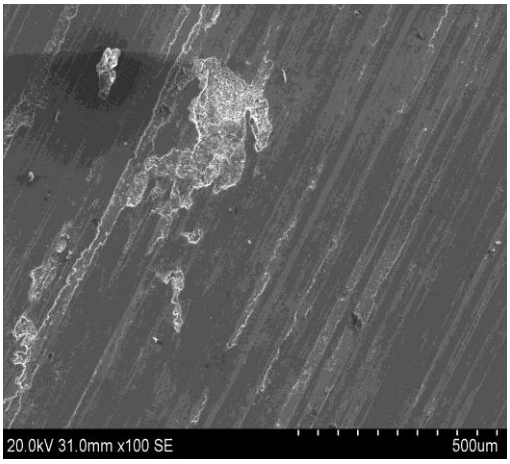

Fig. 9. Wear track of Al-Cu/4%fly ash/6%SiC composite in squeeze cast condition

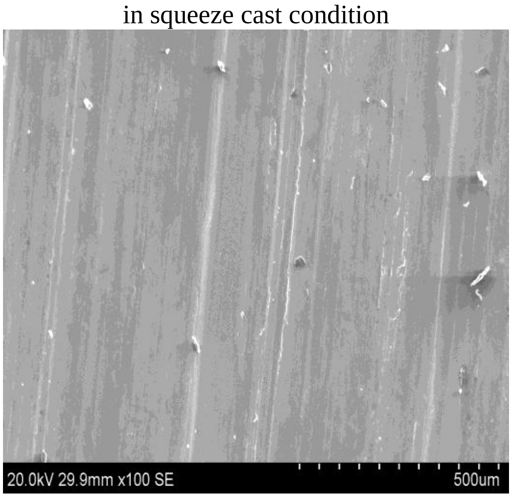

Fig. 10. Wear track of Al-Cu/4%fly ash/6%SiC composite in stir cast rolled condition

The wearing surface is characterized by a significant transfer of material between the sliding surfaces. Fly ash and SiC could be dispersed inside the matrix alloy with better bonding due to which the wear resistance occurred. More debris can be seen in the tracks of gravity and squeeze cast composite Fig. 8 and 9 while in Fig. 10 shows uniform wear track with reasonably lower debris. The lower wear weight loss of rolled sample may be due to the fact that the material is denser, better interfacial bond between the particle and the matrix than in the stir cast samples, reducing the possibility of particle pull out which may result in higher wear. Also it is observed that the rolled composite reinforced up to 4wt. %fly ash and 6wt. % SiC for a load of 10N, there is no fracture initiation at matrix particle interface.

IV. CONCLUSIONS

Effect of rolling and squeeze cast with addition of reinforcements on mechanical properties of fly ash and SiC particulates in Al-Cu matrix have been investigated in this paper. The test results showed that the fly ash up to 4% and SiC up to 6% by weight can be successfully added to Al-Cu alloy by both stir and squeeze casting route to produce composites. The hardness and ultimate tensile strength increases with an increase of fly ash and SiC particulates. The squeeze cast composites exhibit 16% higher hardness, 12% higher tensile strength for 4% flyash and 6%SiC composite when compared to corresponding stir cast composites. But the rolling composites exhibit better mechanical properties when compared to squeeze cast composites. The rolled composites manifest higher wear resistance as compared to both vortex and squeeze cast composites. Microphotographs of rolled composites shows better bonding between matrix, fly ash and SiC with no fracture observed at matrix particle interface after 30% reduction. Overall, Al-Cu alloy can be considered as a suitable matrix for the development of fly ash and SiC reinforced aluminium based composites by secondary process such as rolling.

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REFERENCES

[1] K.V. Mahendra, K. Radhakrishna, Fabrication of Al–4.5% Cu alloy with fly ash metal matrix composites and its characterization, Materials Science-Poland, Vol. 25, No. 1pp.57-68, 2007.

[2] M. Taya and R. J. Arsenanlt, Metal Matrix Composites: Thermo Mechanical Behavior, p. 157, Pergamon press, New York, 1989.

[3] I.A. Ibrahim, F.A. Mohamed and E.J. Lavernia, Particulate reinforced metal matrix composites a review, Journal of Materials Science 26, pp.1137 -1156, 1991.

[4] P. K. Rohatgi, R. Q. Guo, H. Iksan, E. J. Borchelt, and R. Asthana, “Pressure Infiltration Technique for Synthesis of Aluminum-Fly Ash Particulate Composite,” Materials Science and Engineering, A244, pp. 22-30, 1998.

[5] Olivier Beffort, Siyuan Long, Cyril Cayron, Jakob Kuebler, Philippe-Andre Buffat, Alloying effects on microstructure and mechanical properties of high volume fraction SiC-particle reinforced Al-MMCs made by squeeze casting infiltration, Composites Science and Technology 67, pp. 737–745, 2007.

[6] Adem Onat, Mechanical and dry sliding wear properties of silicon carbide particulate reinforced aluminium–copper alloy matrix composites produced by direct squeeze casting method, Journal of Alloys and Compounds, 489, pp. 119–124, 2010.

[7] N.E. Bekheeta, R.M. Gadelrabb, M.F. Salahc, A.N. Abd El-Azim, The effects of aging on the hardness and fatigue behavior of 2024 Al alloy/SiC composites, Materials and Design, 23, pp. 153-159, 2002.

[8] S. Long, O. Beffort , C. Cayron and C. Bonjour, Microstructure and mechanical properties of a high volume fraction SiC particle reinforced AlCu4MgAg squeeze casting, Materials Science and Engineering, A269, pp.175–185, 1999.

[9] Jung-Moo Lee, Sang-Kwan Lee, Sung-Jin Hong, Yong-Nam Kwon, Microstructures and thermal properties of A356/SiCp composites fabricated by liquid pressing method, Materials & Design, Volume 37, pp. 313-316, 2012.

[10] Sudarshan, M.K. Surappa, Synthesis of fly ash particle reinforced A356 Al composites and their characterization, Materials Science and Engineering, A 480, pp. 117–124, 2008.

[11] G.N.Lokesh, M.Ramachandra, K.V.Mahendra, T.Sreenith, Characterization of Al-Cu alloy reinforced fly ash metal matrix composites by squeeze casting method, International Journal of Engineering, Science and Technology,Vol. 5, No. 4, pp. 71-79, 2013.

[12] Suresh N, Venkateswaran S, Seetharamu S, Influence of Cenospheres of fly ash on the mechanical properties and wear of permanent moulded eutectic Al–Si alloys, Materials Science-Poland, Vol.28, No.1, pp.55-65, 2010.

[13] Qiguo Zhang, Mingyuan Gu, Effect of silicon carbide particles on properties of Al/Sip + SiCp, Materials Science and Engineering A 419, pp. 86–90, 2006.

[14] Cevdet Kaynak, Suha Boylu, Effects of SiC particulates on the fatigue behaviour of an Al-alloy matrix composite, Materials and Design 27, pp.776–782, 2006.

[15] E. Y. EL-Kady, F. Mahmoud, G. Nassef, Wear behavior of squeeze cast Al-SiC_p composites at room and elevated temperature, Alexandria Engineering Journal, Vol. 42, No.4, pp. 357-369, 2003.

[16] Olivier Beffort, Siyuan Long, Cyril Cayron, Jakob Kuebler, Philippe-Andre Buffat, Alloying effects on microstructure and mechanical properties of high volume fraction SiC-particle reinforced Al-MMCs made by squeeze casting infiltration, Composites Science and Technology 67, pp. 737–745, 2007.

[17] T.P.D. Rajan, R.M. Pillai, B.C. Pai, K.G. Satyanarayana, P.K. Rohatgi, Fabrication and characterization of Al–7Si–0.35Mg/fly ash metal matrix composites processed by different stir casting routes, Composites Science and Technology 67, pp. 3369–3377, 2007.

[18] K.R. Suresh, H.B. Niranjan, P. Martin Jebaraj, M.P. Chowdiah, Tensile and wear properties of aluminum composites, Wear 255, pp. 638–642, 2003.

[19] G. N. Lokesh, M. Ramachandra, K. V. Mahendra, Effect of Hot Rolling on Al-4.5%Cu Alloy Reinforced Fly Ash Metal Matrix Composite, International Journal of Composite Materials, vol 4(1), pp. 21-29. 2014.

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