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PREPARATION AND CHARACTERIZATION OF ALUMINUM METAL MATRIX COMPOSITE REINFORCED WITH SiC /Al_2O_3 AND METAL PARTICLES USING STIR CASTING PROCESS

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ABSTRACT*:* Hybrid Aluminum metal matrix composite (AMMCs) is an area of research now a days because of its use in automotive, aerospace and high-performance applications. These AMMCs have properties i.e. good strength, light weight, increased wear resistance, hardness and better mechanical properties. In this study a hybrid composite of matrix aluminum 2218 alloy and particle reinforcement of SiC, Al_2O_3 and metal (grey cast iron) was prepared by using stir casting process. Annealing was done in order to homogenize the composite matrix and remove stresses arise from casting in a metal mold. Mechanical testing and optical microscopy were carried out. Energy dispersive x-ray spectroscopy (EDX) was made to provide the elemental analysis or composition of composite at the selected regions. Mechanical testing results have revealed that the tensile strength, hardness and toughness energy of the composite was increased than the monolithic material and changing the percentage of reinforcement have significant effect on it. Micro structural analysis showed that the particulate reinforcements were distributed uniformly throughout the composite.

Keywords*:* Aluminium metal matrix composites (AMMC's), Stir casting, Grey cast iron, Mechanical properties.

INTRODUCTION

Engineering design of material has been moved towards composite materials to reduced weight, cost and achieve better properties and quality in materials (Rana *et al*., 2012; Hassan *et al*., 2012; Chawla and Shen, 2001). MMCs have advanced performance as compared to parent material. Among all composites, aluminum metal matrix composites AMMCs are getting more importance because of their lightness, high strength, moderate casting temperature and other properties (Suresh *et al*., 2011).

Many kinds of Ceramic materials, e.g. SiC, TiC, Al_2O_3, MgO, TiO_2, BN and graphite are mostly used as reinforcement in aluminum-based composites. These materials have properties such as high corrosion resistance, high compressive strength, high hardness and wear resistance (Groover, 2010; Bharat *et al*., 2012; Ala-Kleme *et al* 2006, Miracle, 2005).

Research on AMMCs reinforced with SiC and Al_2O_3 has already been done successfully on various aluminum alloys. Addition of these particles increases the hardness and strength of composite (Jokhio *et al*., 2011; Hong *et al*., 2003; Boopathi *et al* 2013). Beside addition of these particles incorporation of metal particles may also be advantageous to play inimitable role in achieving the good mechanical properties of metal matrix composite (Jokhio *et al*., 2011). Also, metal particles have less wetting issues as compared to ceramic particles (Adeosun *et al*., 2014).

The purpose of this research is to develop a hybrid composite by the reinforcement of three different particles namely silicon carbide (SiC), alumina (Al_2O_3) and metal (grey cast iron particles) by changing the volume percentages of these reinforcements using stir casting process. In this study mechanical properties and microstructure of 2218 aluminum alloy reinforced with SiC/Al_2O_3 and metal (grey cast iron) particles through stir casting process, is investigated at different percentages of reinforcement by volume by keeping the total reinforcement 7%.

MATERIALS AND METHODS

Aluminum alloy Al-2218 was used as a matrix material. Its composition is shown in Table.1. The reinforcement of SiC, Al_2O_3 and grey cast iron was taken at a size of 53µm. Alloy steel die of size 35mmx120mmx225mm was utilized and specimen shapes were made in die by milling, as shown in Fig.1.

It contains two tensile specimen impressions, one impression for impact test from which two impact specimen was made and a round specimen for hardness testing. An allowance of 2-4mm was also provided in die for shrinkage and machining. In addition to allowances tapper was also given for easy ejection of specimen.

Table 1. Chemical Composition of 2218 Aluminium alloy

Element	%wt.
Cu	4
Ni	2
Mg	1.5
Al	Balance

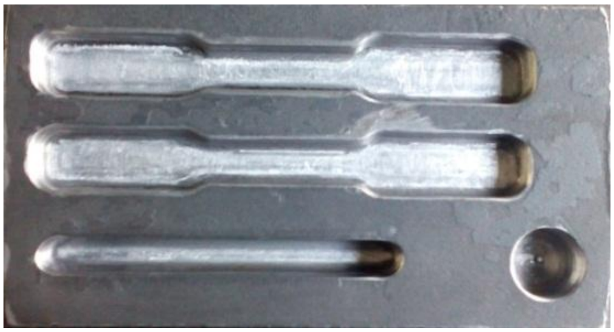

Figure 1. Mold Die for Casting Composite

The required quantity of aluminum alloy was placed in a graphite crucible with small amount of cover flux. Crucible was placed in a gas fired furnace for melting as shown in Fig. 2.

Purpose of cover flux is to cover the surface of molten alloy to avoid absorption of hydrogen gas. The temperature of furnace was raised slowly to 740 to 760^{O}C to melt alloy completely. Temperature was measured by a K-type thermocouple and a temperature recorder. Reinforcement was preheated in the same gas fired furnace at the alloy temperature and die at temperature 400℃ approx. in order to aid flow of metal into die.

Figure 2 Gas fired furnace utilized for melting

Optical pyrometer was used to measure die temperature. After melting the alloy completely, crucible was taken out from furnace and cool to such a temperature that it goes into to semi solid state. At this stage the viscous liquid was stirred at 400-500rpm and reinforcement was added during stirring. Stirring was done for 3 minutes in order to mix reinforcement completely. The mixture thus prepared was reheated to 760℃; degasser was added, stirred for 2 minutes and poured into all cavities of metallic mold.

After all the heats are taken the samples were annealed at 415^{O}C for 2 hours to homogenize and remove internal stresses from composite material. 7 Samples were prepared with different percentage of grey cast iron, Alumina and Silicon Carbide as mentioned in Table 2. Preparation of tensile and impact test specimens of finish sizes was done according to ASTM standard E-8 and E-23 (ASTM, 2015).

Tensile testing of aluminum reinforced composite material was carried out on MTS–810 machine. Micro computer-controlled pendulum machine of Jinan Shidai Shijin Instrument was used for impact testing with model no JBW – 300 and energy ranging from 0 – 300J.Brinell hardness of composite material was measured with portable hardness tester of Time instrument model HLN-11A, having accuracy of ±6HLD. For hardness surface of the samples was prepared first by using different emery papers from low grit to high grit to make surface smooth and free of dents.

Table 2 Samples No with added reinforcement percentage and heat treatment condition.

Sample No.	Grey cast iron %wt.	Al_2O_3 + SiC %wt.	Condition
1	0	0	As Cast
2	0	0	Annealed
3	7	0	Annealed
4	5	1+1=2	Annealed
5	3	2+2=4	Annealed
6	1	3+3=6	Annealed
7	0	3+3=7	Annealed

Test references standards used for sample preparation was ASTM - E3 (ASTM, 2011), for etching was ASTM- E407 (ASTM, 2007). After that all the samples were etched with Keller’s reagent to reveal the microstructure features. Optical microscopy was done to reveal microstructures of etched samples at 200X magnification. Energy dispersive X ray spectroscopy (EDX) was made by Scanning electron microscope (SEM) named Tescan Vega 3 equipped with Oxford EDS X Man analyzer. EDX analysis was carried to provide the elemental analysis or composition of composite at the selected points or regions.

RESULTS AND DISCUSSION

Hardness Testing: Variation in hardness was found for different volume %age of reinforcement in Fig 3. Sample1 has more hardness as compared to the annealed sample 2 due to its brittle structure. By adding reinforcement, hardness of material increases from sample 3 to a maximum at sample 7. It is evident from the graph that reinforced 2218 aluminum alloy has more hardness as compared to un-reinforced alloy.

Addition of harder particles increases the hardness of composite material. It has been reported that particulate reinforcements such as SiC and Al_2O_3 (Hutchings, 1986; Hosking and Portillo, 1982) are desired to deliver higher hardness. The increase in particle volume fraction also increases the hardness of composite as observed by (Howell and Ball, 1995). The reason of increase in hardness is due to increased strain energy at the periphery of the particles dispersed in the matrix Al_2O_3 (Kim *et al.,* 2003). The reinforcement size, composite structure and good interface bonding (Deuis *et al*., 1996).

Tensile Testing: The hardness of each sample shows the properties of the composite material.

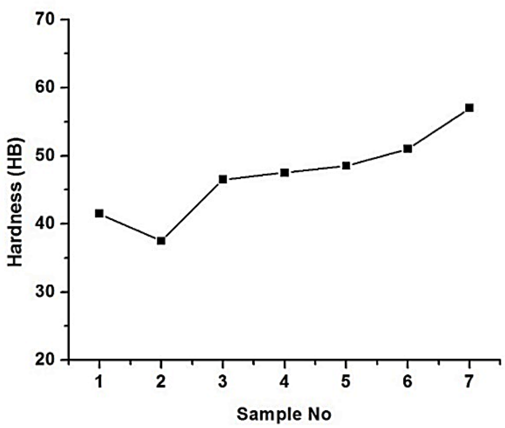

Figure 3 Plot of hardness for different samples

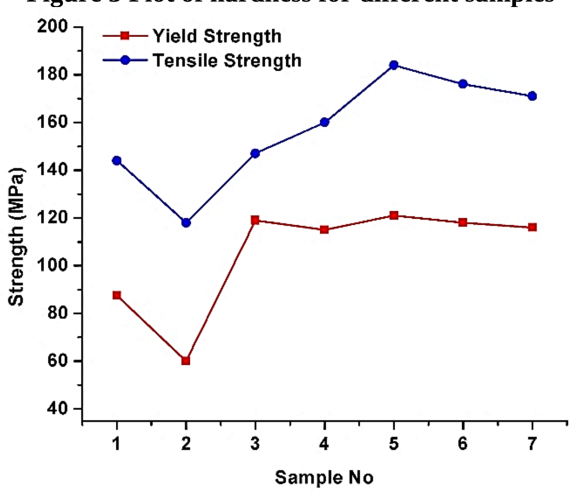

Figure 4 Plot of Yield Strength, Ultimate Tensile Strength for different samples

The load-displacement data obtained for each specimen was converted to plots of stress-strain and were examined to evaluate mechanical properties. Fig. 4 shows the yield and tensile strength of various samples. Lowest strength is of sample 2 which is aluminum alloy in annealed condition. The maximum tensile strength 184 MPa was shown by composite sample 5 which contain 4 wt% Al_2O_3 +SiC and 3wt% Grey cast iron. Addition of reinforcements initiate new grain formations which restrict dislocation mobility and ultimately results in greater strength.

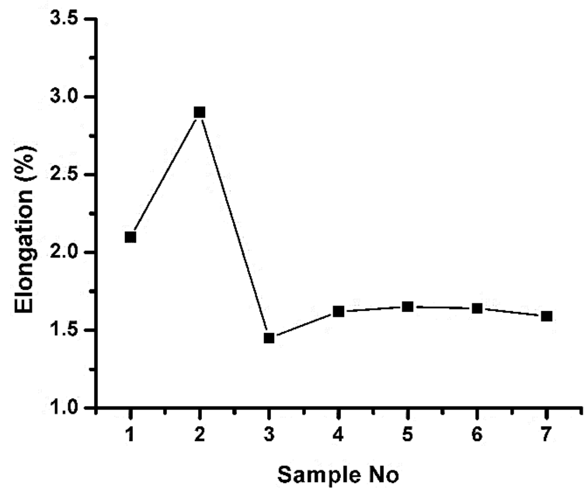

Figure 5 Percentage elongations for various samples

Moreover, preheating of reinforcement can also hep to improved interface strength and better dispersion of the particles in the matrix (Thakur and Dhindaw, 2001). It was repoted that the reinforcements such as SiC and Al_2O_3 (Gomes *et al*., 2005; Meena *et al.*, 2013).

Fig. 5 shows that addition of reinforcement decreases the percentage elongation of composite. Un-reinforced aluminum has high percentage elongation especially in annealed condition.

Impact Testing: Annealed sample 2 has minimum impact strength while highest value was given by sample 5 which contains 3% Grey Cast Iron + 2% Al2O3 + 2% SiC as seen in Fig. 6. Sample 5 absorbs more energy than other samples which results in high impact strength.

Microstructure: The microstructure was characterized by optical microscopy and Scanning electron microscope. The micrographs of all samples are shown in Fig 7. In Fig 7 (a) & (b) microstructure shows the dendritic structure of 2218 Al alloy in as cast and annealed samples without any reinforcement. But remaining samples Fig 7 (c-g) containing different percentage of reinforcements clearly shows uniform distribution of reinforcement (black spots) in the matrix of aluminum alloy.

Energy Dispersive X-Ray Analysis: Energy dispersive x-ray spectroscopy (EDX) was done to provide the elemental analysis or composition of composite at the selected points or area of selected samples.

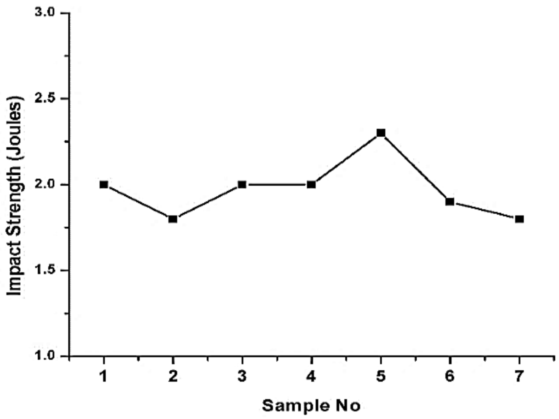

Figure 6. Impact strength of all samples

Sample 1 was selected that was cast aluminum 2218 alloy without reinforcement and other sample (5) which was reinforced with 3% GCI, 2% Al2O3 and 2% SiC particles. Microstructure of sample 1 is shown in Fig. 8 where black areas are grain separated by white grain boundaries.

Microstructure of Sample 5 which has highest yield and tensile strength among all other samples of composite is shown in Fig. 9. EDX analysis of grain boundaries and within grains is shown as spectrum 1 and 3 respectively. Spectrum 3 graph showed presence of iron at grain boundaries which was not observed within the grain in spectrum 1. Presence of iron at grain boundaries is in greater amount, it weakens the grain boundaries. This was the reason that sample 3 which contains only grey cast iron particles shows brittle behavior and therefore break at a lower strength level.

Distribution of reinforcement are also main factor of variation in the properties of samples having different percentage of particles. Particle reinforced metal matrix composites shows both ductile and brittle mode of failure (Qian *et al*., 2002). Size and shape of Particle are important because angular particle can act as stress riser and rounded particles are preferred for better impact properties. Interface decohesion, particle fracture and matrix yielding are major failure mechanisms of metal matrix composites reinforced with metal particles (Sijo and Jayadevan, 2016; Sijo and Jayadevan, 2018).

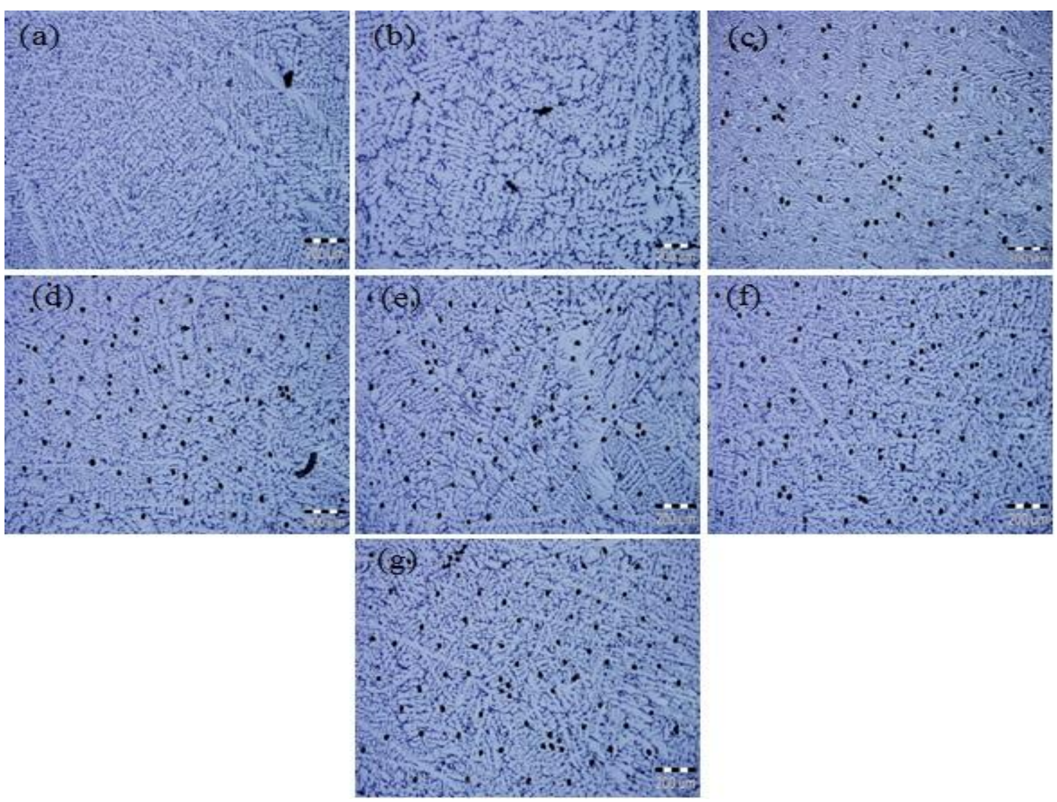

Figure 7 Microstructure of (a) As cast (b) Annealed 2218 alloy (c) Composite material reinforced with 7% grey cast iron particles (d) Composite reinforced with 5% grey cast iron, 1%SiC and 1%Al_2O_3 particles (e) Composite reinforced with 3% grey cast iron, 2%SiC and 2%Al_2O_3 particles (f) Composite reinforced with 1% grey cast iron, 3%SiC and 3%Al_2O_3 particles (g) Composite reinforced with 3.5%SiC and 3.5%Al_2O_3 particles

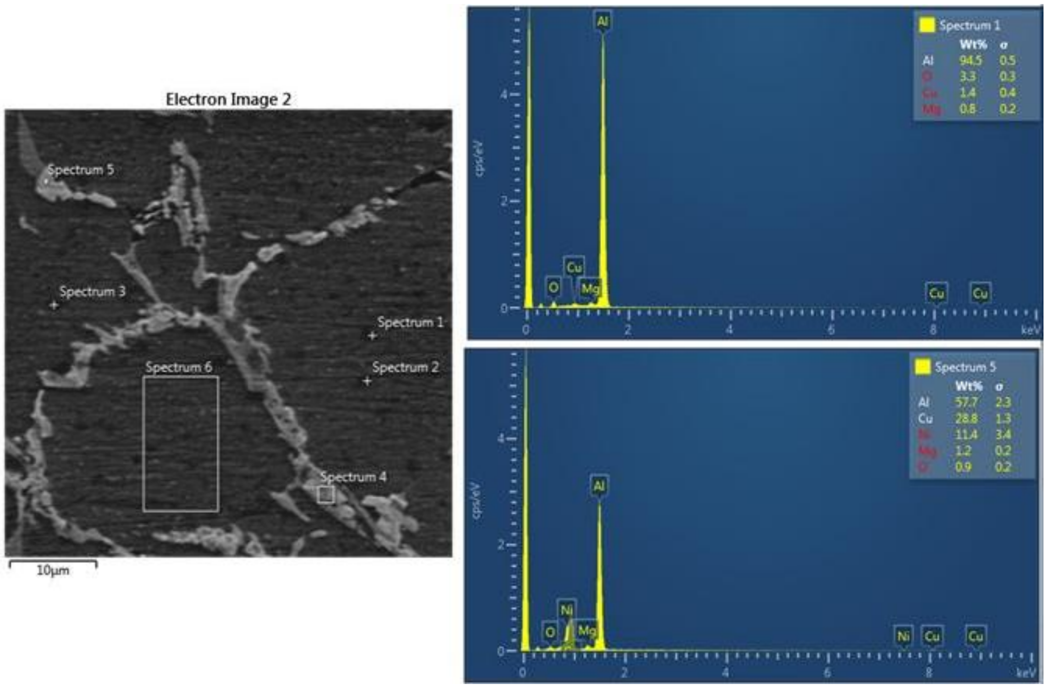

Figure 8 Microstructure of as cast sample (without any reinforcement) and EDX analysis of spectrum 1 and spectrum 5.

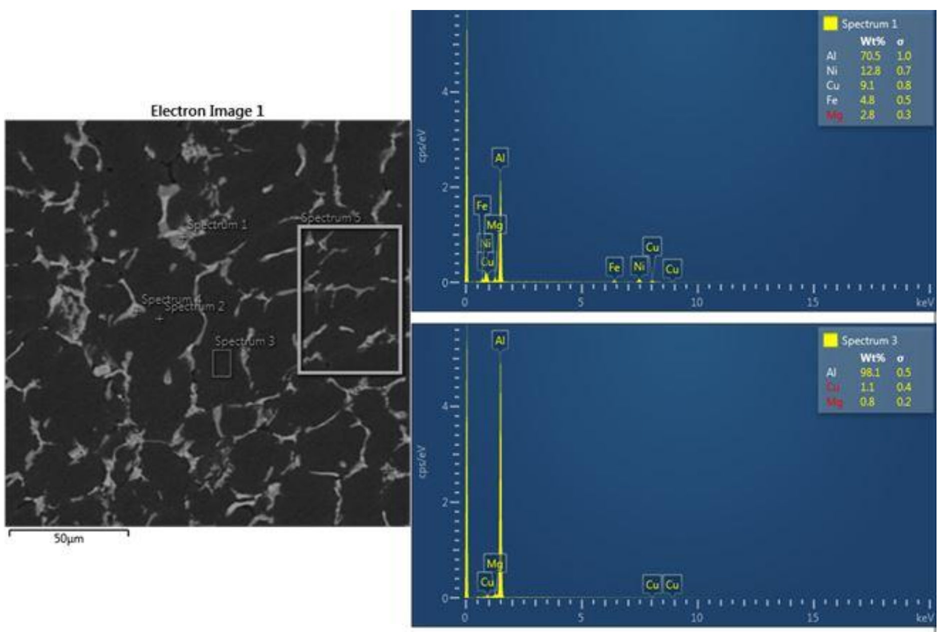

Figure 9. Microstructure and EDX analysis of composite sample 5 containing 3wt.% grey cast iron, 2wt.%SiC and 2wt.%Al_2O_3 particles in 2218 Al alloy.

Conclusions: Aluminum alloys can be strengthened with the addition of reinforcement in form of particles to make composite that possess greater extent of hardness and strength.

1. Hybrid composite shows versatile combination of properties.
2. Addition of grey cast iron up to 3% along with 2% silicon carbide and 2% aluminum oxide showed highest yield strength of 121MPa and tensile strength up to 184MPa but maximum hardness was shown by the composite containing 3.5% silicon carbide and 3.5% aluminum oxide. This is because of that the

ceramic particles posses' higher hardness as compared to grey cast iron metal particles.

3. Addition of grey cast iron particles up to greater volume% i.e. 7% shifts the behavior of composite to brittle nature.
4. Percentage elongation decreases by the addition of reinforcement. Minimum elongation was showed by sample 3 that has brittle behavior and maximum elongation was shown by sample 2 of aluminum 2218 alloy without reinforcement in annealed condition. This is because annealing of Al-2218 alloy softens the matrix structure.
5. Highest impact strength was shown by sample 5 that has higher yield and tensile strength. So, it is concluded that addition of grey cast iron particles at 3% by volume to composite is in favor of increasing the mechanical properties.
6. Extreme hardness can only be obtained by addition of hard ceramic particles. Sample 7 of composite material has high hardness up to 57 HB among all others.
7. Applications of metal matrix composite requiring high hardness for abrasive and wear resistance can be met by use of hard particles. But where hardness is not a major requirement use of grey cast iron particles along with ceramic particles gives better and novel combination of properties.

REFERENCES

Adeosun, S.O., E.I. Akpan, S.A. Balogun and A.S. Abdulmunim (2014). Tin (II) Chloride a Suitable Wetting Agent for AA1200-SiC Composites. International Journal of Chemical, Nuclear, Metallurgical and Materials Engineering, 8(4), 307-301.

Ala-Kleme, S., P. Kivikytö-Reponen, J. Liimatainen, J. Hellman and S.P. Hannula (2006). Abrasive wear properties of metal matrix composites produced by hot isostatic pressing. Proc. Estonian Acad. Sci. Eng, 12(4), 445-454.

ASTM E8/E8M. (2015). Standard Test Methods for Tension Testing of Metallic Materials. ASTM International, West Conshohocken PA, 2015.

ASTM E3, (2011). Standard Guide for Preparation of Metallographic Specimens. ASTM International, USA, ASTM E3, 2011.

ASTM E407, (2007). Standard Practice for Microetching Metals and Alloys," ASTM International, West Conshohocken, PA, USA, ASTM E407, 2007(2015).

Boopathi, M. M., K.P. Arulshri and N. Iyandurai (2013). Evaluation of mechanical properties of aluminium alloy 2024 reinforced with silicon carbide and fly ash hybrid metal matrix composites. American journal of applied sciences, 10(3), 219.

Bharath, V., M. Nagaral and V. Auradi (2012). Preparation of 6061Al-Al2O3 metal matrix composite by stir casting and evaluation of mechanical properties. International Journal of Metallurgical & Materials Science and Engineering, 2(3), 22-31.

Chawla, N. and Y.L. Shen (2001). Mechanical behavior of particle reinforced metal matrix composites. Advanced engineering materials, 3(6), 357-370.

Chen, R., A. Iwabuchi, T. Shimizu, H.S. Shin and H. Mifune (1997). The sliding wear resistance behavior of NiAl and SiC particles reinforced aluminium alloy matrix composites. Wear, 213(1-2), 175-184.

Deshmanya, I.B. and G.K. Purohit (2012). Prediction of hardness of forged Al7075/Al2O3 composites using factorial design of experiments. International Journal of Engineering Research and Applications, 2(1), 84-90.

Deshmanya, I.B. and G. Purohit (2012). Development of mathematical model to predict micro-hardness of Al 7075/Al2O3 composites produced by stir-casting. Journal of Engineering Science and Technology Review, 5(1), 44-50.

Deuis, R.L., C. Subramanian and J.M. Yellup (1996). Abrasive wear of aluminium composites—a review. Wear, 201(1-2), 132-144.

Gomes, J.R., A. Ramalho, M.C. Gaspar and S.F. Carvalho (2005). Reciprocating wear tests of Al–Si/SiCp composites: A study of the effect of stroke length. Wear, 259(1-6), 545-552.

Groover, M.P. (2010). Fundamentals Of Modern Manufacturing: Materials, Processes, and Systems.4th ed. (John Wiley & Sons. Inc).

Hassan, M.K., Y. Mohammed and E.H. Abu (2012). Improvement of Al-6061 alloys mechanical properties by controlling processing parameters. International Journal of Mechanical & Mechatronics Engineering, 12(02), 14-18.

Hong, S. J., H.M. Kim, D. Huh, C. Suryanarayana and B.S. Chun (2003). Effect of clustering on the mechanical properties of SiC particulate-reinforced aluminum alloy 2024 metal matrix composites. Materials Science and Engineering: A, 347(1-2), 198-204.

Hutchings, I. M. (1987). Wear by particulates. Chemical Engineering Science, 42(4), 869-878.

Hosking, E. M. and F.F. Portillo (1982). R. Wunderlin and R. Mehrabian. J. Mater. Sci, 17, 477-498.

Howell, G. J. and A. Ball (1995). Dry sliding wear of particulate-reinforced aluminium alloys against automobile friction materials. Wear, 181, 379-390.

Jokhio, M.H., M.I. Panhwar and M.A. Unar (2011). Manufacturing of Aluminum Composite Material Using Stir Casting Process. Mehran university research journal of engineering & technology, 30(1).

Kumar, V., P. Kumar, and K. Puneet (2013). Development of AA2218-Al_2O_3 MMCs and characterization for mechanical properties. International Journal of Innovative Research in Science, Engineering and Technology, 2(5),1510-1517.

Kim, S.W., U.J. Lee, S.W. Han, D.K. Kim and K. Ogi (2003). Heat treatment and wear characteristics of Al/SiCp composites fabricated by duplex process. Composites Part B: engineering, 34(8), 737-745.

Meena, K.L., A. Manna, S.S. Banwait and D. Jaswanti (2013). An analysis of mechanical properties of the developed Al/SiC-MMC’s. American Journal of Mechanical Engineering, 1(1), 14-19.

Miracle, D.B. (2005). Metal matrix composites–from science to technological significance. Composites science and technology, 65(15-16), 2526-2540.

Qian, L., T. Kobayashi, H. Toda, T. Goda and Z.G. Wang (2002). Fracture toughness of a 6061Al matrix composite reinforced with fine SiC particles. Materials Transactions, 43(11), 2838-2842.

Rana, R.S., R. Purohit and S. Das (2012). Reviews on the influences of alloying elements on the microstructure and mechanical properties of aluminum alloys and aluminum alloy composites. International Journal of Scientific and Research Publications, 2(6), 1-7.

Sijo, M.T. and K.R. Jayadevan (2016). Analysis of stir cast aluminium silicon carbide metal matrix composite: A comprehensive review. Procedia technology, 24, 379-385.

Sijo, M.T. and K.R. Jayadevan (2018). Characterization of Stir Cast Aluminium Silicon Carbide Metal Matrix Composite. Materia*ls Today: Proceedings*, *5*(11), 23844-23852.

Suresh, S.M., D. Mishra, A. Srinivasan, R.M. Arunachalam and R. Sasikumar (2011). Production and characterization of micro and nano Al2O3 particle- reinforced LM25 aluminium alloy composites. Journal of Engineering and Applied Sciences, 6(6), 94-97.

Smagorinski, M.E., P.G. Tsantrizos, S. Grenier, A. Cavasin, T. Brzezinski and G. Kim (1998). The properties and microstructure of Al-based composites reinforced with ceramic particles. Materials Science and Engineering: A, 244(1), 86-90.

Thakur, S.K. and B.K. Dhindaw (2001). The influence of interfacial characteristics between SiCp and Mg/Al metal matrix on wear, coefficient of friction and microhardness. Wear, 247(2), 191-201.