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CHARACTERISATION OF MECHANICAL PROPERTIES OF ALUMINIUM COMPOSITES FABRICATED BY STIR-CASTING AND POWDER METALLURGY

Juan Carlos Del Real Romero, Jesus Jimenez
Escuela Técnica Superior de Ingeniería, Spain

Ragul Manoharan, Revanth Shankar, Richard Joseph, Hariharasakthisudan
Loyola-ICAM College of engineering and Technology, India

ABSTRACT

Light and strong metal matrix composites (MMC) are highly anticipated for aerospace and automotive industries. The MMC's application fields can be significantly expanded if they possess enhanced strength at elevated temperatures also. This paper aims to study about the mechanical characteristics of Metal Matrix Composite (MMC) of Aluminium fabricated by Stir Casting and by Powder Metallurgy. The MMC of Aluminium consists of Magnesium, Zinc, Graphite and Graphene. Microscopic and Spectrometer studies were done on all the specimens. The Static tests like Tensile, Compression, Bending and Hardness were done in order to characterise the properties of the MMC. Using Pin on Disc wear machine, the wear properties of the Specimens which are made out of Cast and Powder Metallurgy were found by changing the Load, Velocity and Distance. The Wear surfaces of the Cast and Powder metallurgy specimens were also studied with the microscope. A Pre-Cracked Fracture Mechanics and virtual wear mechanics study of the Specimens is developed in ANSYS 18 using the material data obtained from CES-EDUPACK for the composite in order to obtain results about the crack propagation and wear in the MMC.

Key words: Stir Casting, Powder Metallurgy, Sintering, Fracture Growth.

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1. INTRODUCTION

There is an appreciable need for advanced materials with improved mechanical properties accompanied by cost reduction and feasibility of fabrication in the engineering world. Being a lightweight, cheap, corrosion-resistant metal it is widely used as a metal matrix composites (MMC's) for improving mechanical properties [23, 24]. Aluminium is usually reinforced with materials like Silicon Carbide, Titanium-di-Oxide, Boron Nitride, Molybdenum Sulphide, etc. This has led us to innovate a Metal Matrix Composite using Aluminium alloyed with Magnesium and Zinc and further reinforced with graphite and Graphene. We have fabricated the Metal Matrix Composite through two different manufacturing techniques, Stir Casting [18, 19, 21] and Powder metallurgy [15, 26] for understanding the mechanical properties in a better manner. The metal powders of Magnesium (0.5%) and Zinc (0.5%) were alloyed with Aluminium in order to improve the strength of the parent metal which find it's application in a lot of aerospace application. Moreover it is found from the state of art that the alloying metals with low melting point compared to that of the parent metal decreases the porosity during fabrication. Further the alloy is reinforced with materials like Graphene (2%,4%,6%)and Graphite(2%,4%,6%). The principle aim of adding Graphite into Aluminium is to increase the strength further and Graphite is added to make the component self- lubricating when this Metal Matrix Composite is used for bearing application. All the materials which are used are inexpensive and are available in abundance, though graphene whose production was once considered as expensive is now produced at very low cost. The elemental motivation behind the research is to find out which form of manufacturing either Stir Casting or Powder metallurgy proves better for the engineering applications especially for resisting the wear [16,25,27] . The wear debris were collected and metallurgical studies were made over it. The manufactured materials were made to undergo proper etching processes to have a good microscopic study results [30]. The fracture mechanics [1-9] model which is developed using ANSYS is also very much useful in studying about the propagation of Mode1,Mode2 and Mode3 fractures along with energy needed for it's propagation in the composite. A virtual custom made wear mechanics program is developed in ANSYS in order to compute the wear rate of different composites. The technical data needed for modelling the crack in ANSYS is obtained by CES-Edupack.

2. MATERIALS AND METHODS

2.1. Raw materials

The raw materials used for both types of manufacturing i.e Stir Casting and Powder Metallurgy is the same, with the only difference in the form that the matrix metal is used for instance aluminum billets are used in case of Casting and Powder alumnium of 99% purity is used for powder formation. The zinc and Magnesium powders of 99.9% of mesh size 200 is added as an alloying metal to the aluminum. Further, graphite of particle size 4 µm and graphene of 60 nm were added as a reinforcements.

2.2. Fabrication of Stir Casting Specimens

Aluminium 6063 in the form of billet is melted in the crucible of the Stir Casting equipment to a temperature of 700°c and then the dried alloying metals like Magnesium(0.5%) and Zinc(0.5%) is added, the percentage of Magnesium and Zinc are kept constant for all the batches. The Graphite (2%, 4%, 6%) and Graphene (2%, 4%, 6%) reinforcement is added respectively to each batch, henceforth three batch of composites with three different percentage of reinforcement were obtained. The total output weight of the stir casting is 1100g and the percentages were calculated from that reference weight. The stirrer is made to rotate at a rpm of 300 in order to obtain a uniform dispersion of the reinforcements and 'coverall' is added to remove impurities present in the casting. The final MMC obtained from casting is about 300mm in length and 30mm in diameter.

2.3. Fabrication of Powder metallurgy Specimens

The Pure Aluminium powder is mixed with other metal powders like Magnesium(0.5%), Zinc(0.5%) and are mixed well and it is followed by the mixing of grapheme (2%,4%,6%) and graphite(2%,4%,6%) reinforcements. The total weight of the powder that the die can take is found to be 17.08g and the percentage of reinforcments is calculated in accordance with the weight that the die can hold. The mixture is compressed under a constant load of 1.1KN for around 5 minutes. As the output of the compression, solid MMC is obtained. Similar to the Casting the percentage of Magnesium and Zinc is kept constant and only the percentage of graphite and graphene is changed to get a three different MMC composites. The formed MMC is sintered in a furnance with Argon supply for around 550°C(achieved in 15 minutes and maintained for 30 minutes in the same temperature) and allowed to cool inside the furnance till it reached the room temperature with continued Argon supply.

2.4. Mechanical Testing:

The specimens which are manufactured by both powder metallurgy and stir casting is made to undergo static mechanical testings like tensile and compression (all the test specimens are made in accordance with the ASTM standards i.e is dog bone for tensile and cylindrical for compression).The results obtained from the CES-Edupack and Physical testing were almost in accordance with each other. Vickers Hardness tests were taken for all the specimens whose results are presented below in table 1 and table 2.

2.5. Mircroscopic study

The specimens manufactured by stir casting and powder metallurgy has been polished using proper equipments and etched with an appropriate etchant and studied under opticat microscope using 500x magnification. The methods of preparation for the microscopic study for both Stir Casting and Powder metallurgy remains the same with an only difference where being the powder metallurgy specimens are directly abraded using the abrasive of grit size P600.The procedure for the microscopic study is made as follows:

- Initially the specimens are cut with a thickness of 5mm and diameter 30mm.
- The specimen is abraded with a Silicon Carbide sand paper of grade P240 (P600 incase of sintered) for around two minutes by hand in order to a plane surface.
- Then the specimens are given a co-planar finish by abrading in a polishing machine.
- The specimens are polished using a silk cloth which is intermittently applied by Alumina Solution(Particle thickness 3 micorns)
- Then finally the specimens are etched using Keller's Reagent having a composition of
- 95ml water, 2.5ml of HNO_3, 1.5ml Hcl, 1ml HF for around 10 seconds.
- After the etching process is done the specimen is washed with ethanol and dried using the drier.

The images obtained from the Optical Microscope for both Stir Casting and Powder Metallurgy specimen is given below.

2.6. Fracture Mechanics

Using the results obtained from CES-Edupack, the library of new composite materials are created. The geometry is drawn for a dimensions with length 20mm, width 10 mm and thickness 7mm, this dimensions are chosen to have a optimum fracture study. Semi-Elliptical crack is developed on this geometry in the middle and meshed using appropriate meshing tools of ANSYS. The Static loads and Boundary conditions are applied on the geometry and using the fracture tool, the different modes of Fracture namely K1, K2, K3 are studied along with the free energy (J-integral). Since the values obtained from the CES-Edupack for different composites show very minimal deviation form each other, henceforth fracture mechanics for Pure aluminium cast and one composite is computed.

2.7. Wear Mechanics

The virtual wear mechanics of the custom made specimens haven been developed in ANSYS by using ANSYS APDL codes. The results of wear obtained for the custom made material has been presented below.

CONCLUSION

- Pouring temperature plays a major role in the strength of the cast.
- Blow holes tends to reduce the strength of the cast.
- The percentage of Magnesium and Zinc plays a major role in determining the strength of the cast.
- More the percentage of Magnesium, more care should be taken during casting and sintering because Magnesium tends to catch fire, vaporises other reinforcements as well.
- Sintering temperature and the method of cooling plays a major role in determining the strength of powder formed specimens.
- The wear properties of cast is found to better than that of Sintered. • More machining of the cast specimen leads to wastage of reinforcements.
- The graphite tends to reduce the strength of the specimens.
- More percentage of graphite, better the lubrication but it tends to spread and cause more wear.
- The compression force that is applied to form specimens using Aluminium powder show applied gradually and maintained constant for atleast three minutes in order to obtain a good specimen.

Figures and Tables

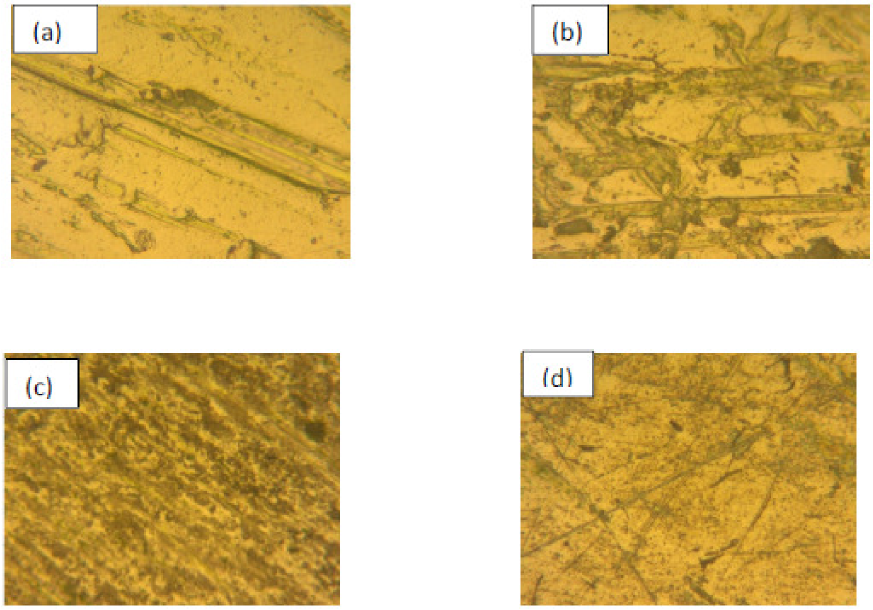


Figure 1 Optical Microscopic Images of MMC by Stir Casting (a)Pure Al;(b)MMC1[0.5%Zn,0.5%Mg,2%graphite,2%graphene]; MC2[0.5%Zn,0.5%Mg,4%graphite,4%graphene];MMC3[0.5%Zn,0.5%Mg,6%graphite,6%graphene];

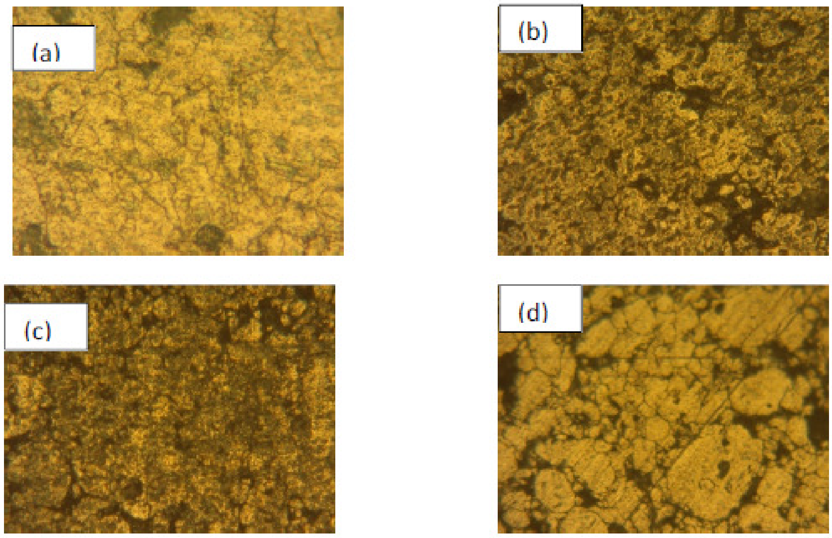


Figure 2 Optical Microscopic Images of MMC by Powder Metallrgy(a)Pure Al;(b)MMC1[0.5%Zn,0.5%Mg,2%graphite,2%graphene] MMC2 [0.5%Zn,0.5%Mg,4%graphite,4%graphene]; MMC3[0.5%Zn,0.5%Mg,6%graphite,6%graphene];

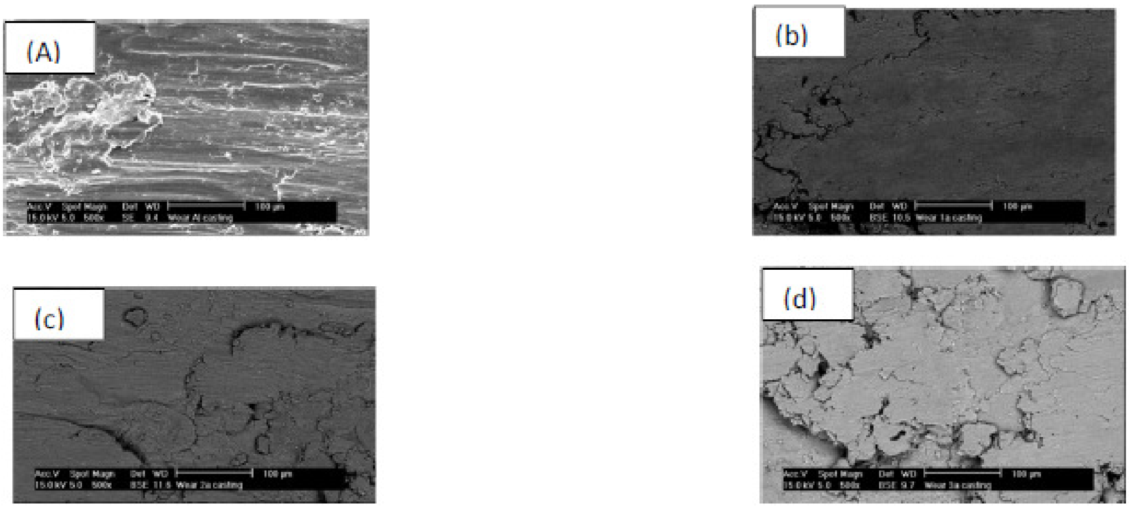


Figure 3.SEM images for tracing the elements present in Stir Casting Specimens;Zoom level=100µm;Dark Grey=Al_2O_3;Light Grey=Al; Black between grains=Al/C/Mg/O;Bright and White Points=ZnO/Fe_2O_3(on the Surface);Bright and White Points=MgO(embedded);

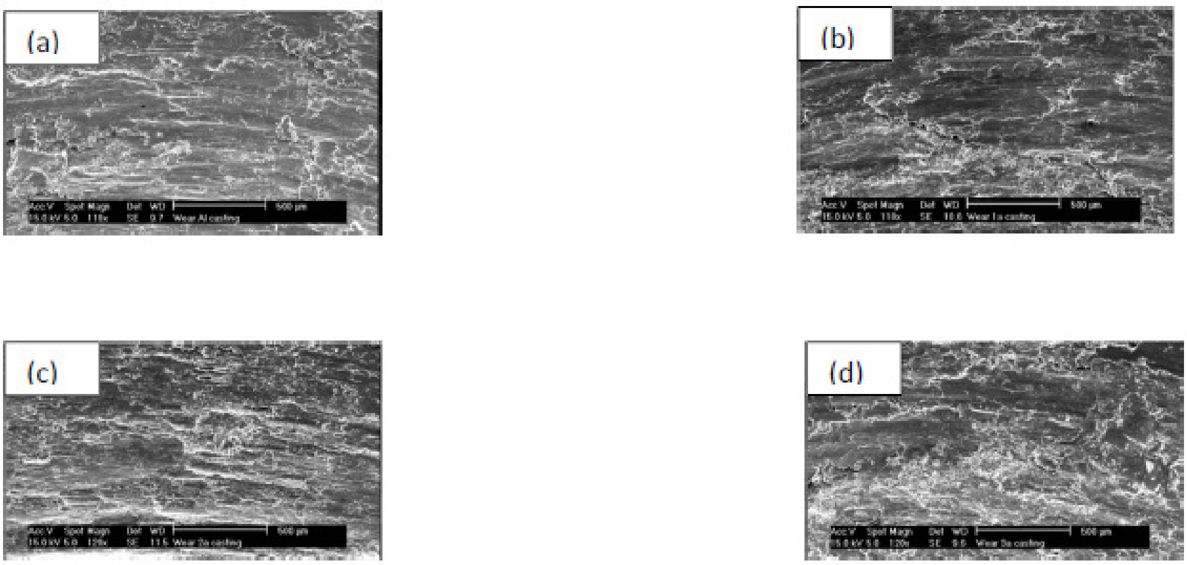
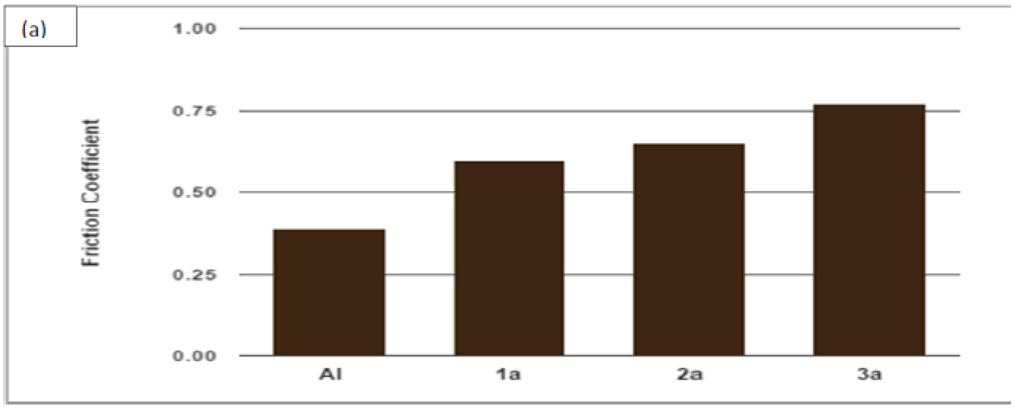


Figure 4. Tribology Results obtained from SEM for Sir Casting;Zoom level=500µm(a)Adhesive;(b)Adhesive;(c)Adhesive;(d)Adhesive;

Figure 5 SEM images for tracing the elements present in Powder Metallurgy Specimens;Zoom level=100μm; Dark Grey=Al_2O_3;Light Grey=Al; Black between grains=Al/C/Mg/O;Bright and White Points=ZnO/Fe_2O_3(on the Surface);Bright and White Points=MgO(embedded);

Figure 6 Tribology results obtained from SEM for Powder Metallurgy Specimens;Zoom level=500μm;(a)Adhesive;(b)Abrasive/Adhesive; (c)Abrasive/Adhesive;(d)Abrasive/Adhesive;



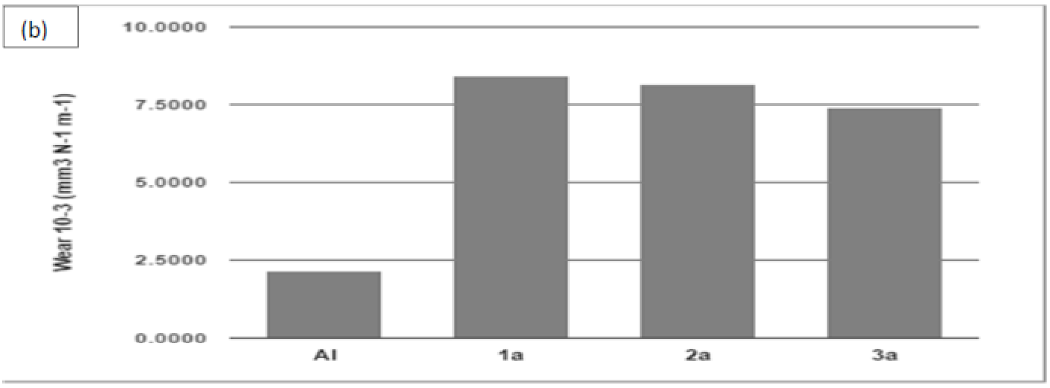
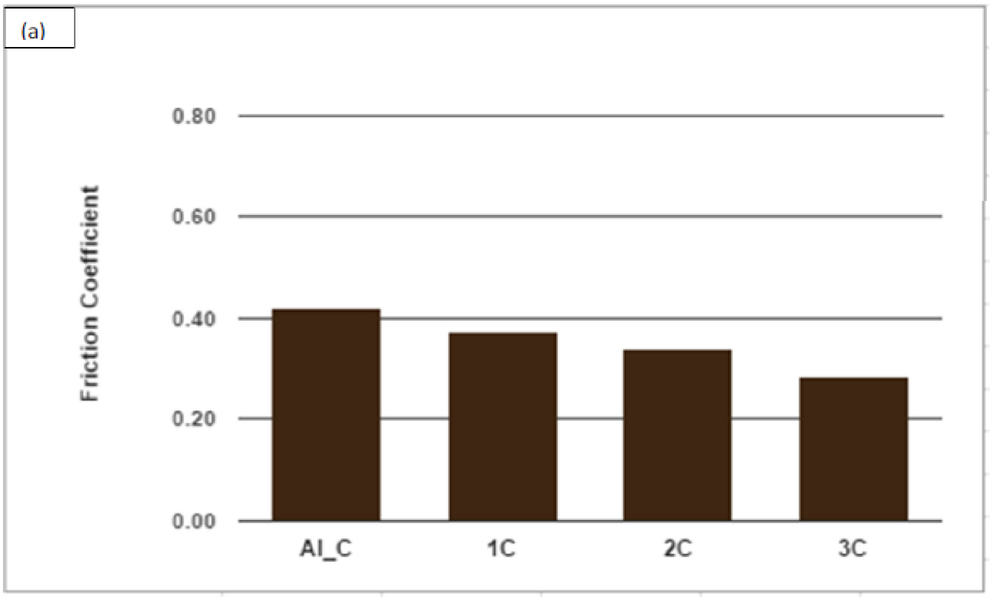


Fig.9. Pin on Disc;Load=5N;Sliding Distance=400m;Speed=180rpm;Track Radius=4mm; (a)Variation of Frictional Coefficient of the different composites manufactured by Powder Metallurgy; (b)Variation of Wear of the different composites manufactured by Powder Metallurgy;



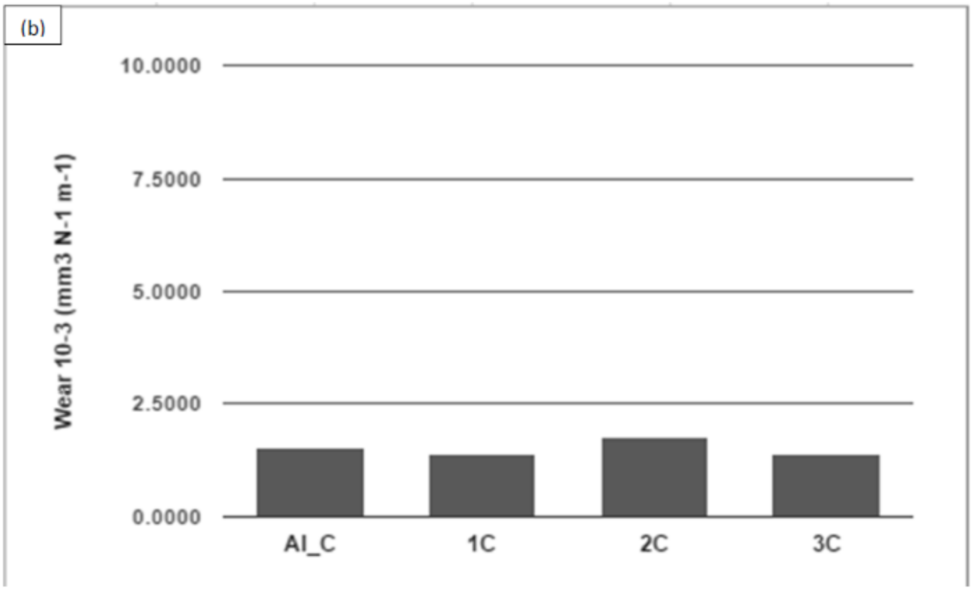
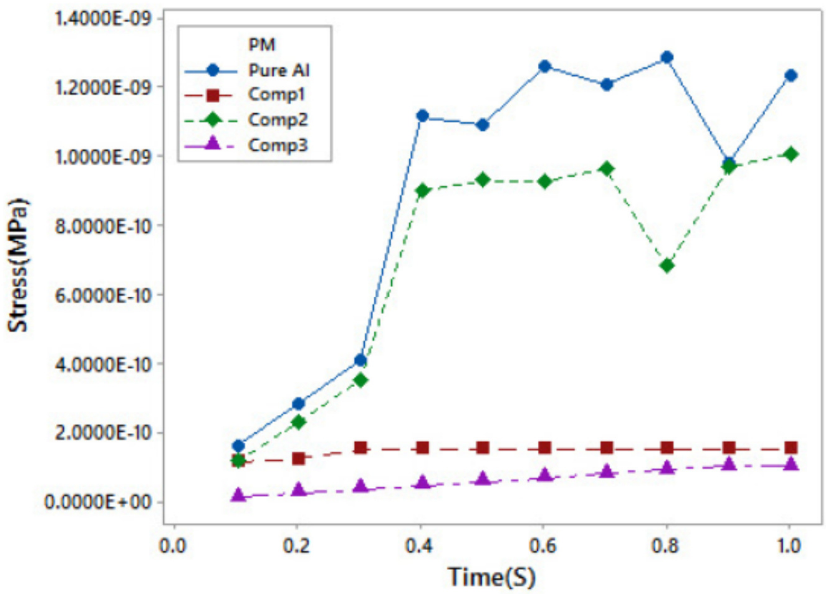


Fig.10. Pin on Disc;Load=5N;Sliding Distance=400m;Speed=180rpm;Track Radius=4mm; (a) Variation of Frictional Coefficient of the different composites manufactured by Stir-Casting; (b)Variation of wear of the different composites manufactured by Stir-Casting;



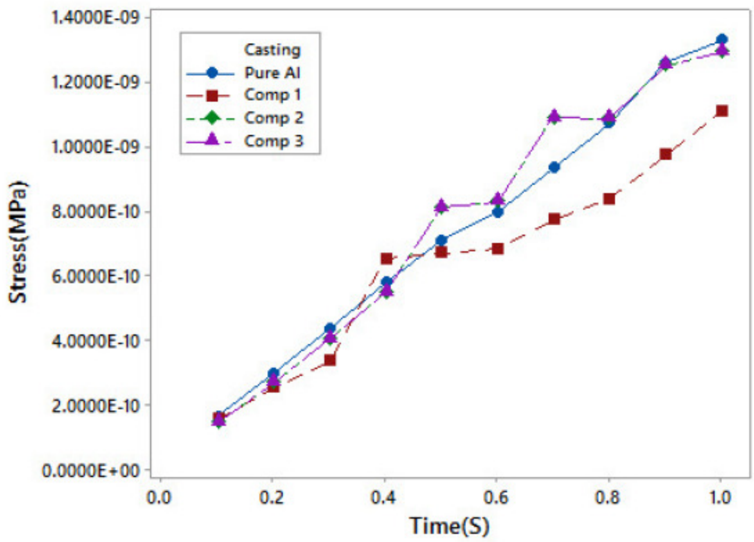


Fig.11. Transient Stress Analysis made in ANSYS18; (a) Variation of stress with respect to time for Powder Metallurgy Specimens;(b)Variation of stress with respect to time for the Stir-Casting Specimens.

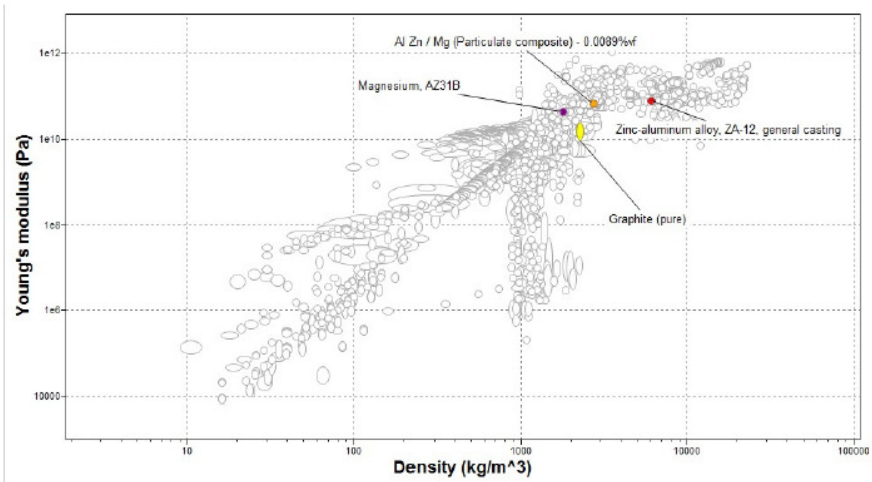


Figure 12 The Young’s modulus and Density variation after adding each reinfocements.

Table 1 Microhardness test result for casting

Hardness Vickers Test @ 0.5 Kgf Load, Dwell Time 10 Sec			
	Location 1	**Location 2**	**Location 3**
1	76.0	74.9	74.7
2	48.3	45.9	47.3
3	50.1	52.5	48.1
4	37.8	39.4	35.5

Table 2 Microhardness test result for Powder metallurgy

Hardness Vickers Test @ 15 Kg Load, Dwell Time 10 Sec			
	Location 1	**Location 2**	**Location 3**
1	58.05	58.08	58.07
2	131.94	131.68	132.01
3	118.23	118.25	118.20
4	100.98	100.95	100.93

Table 3 Fracture results.

	K1	**K2**	**K3**	**J-Int**	**Von-Mises**
Pure Al	-6839.9	1.3196	5.7168	931.7	58758
Al Composites	-6839.9	1.3198	5.7169	932.46	58758

Table 4 CES-Edupack properties for composites

PROPERTIES	**COMPOSITE 1**	**COMPOSITE 2**	**COMPOSITE 3**	**UNITS**
A.Physical Properties				
Density	2.67e3-2.73e3	2.67e3-2.73e3	2.67e3-2.73e3	Kg/m^3
B.Mechanical Properties				
Young's modulus	6.89e10-7.19e10	6.87e10-7.19e10	6.87e10-7.19e10	Pa
Yield Strength	1.56e7-5.74e7	1.56e7-5.73e7	1.56e7-5.73e7	Pa
Tensile Strength	4.16e7-1.53e7	4.16e7-1.53e8	4.16e7-1.53e8	Pa
Compressive Strength	1.56e7-5.74e7	1.56e7-5.73e7	1.56e7-5.73e7	Pa
Flexural modulus	6.89e10-7.19e10	6.87e10-7.19e10	6.87e10-7.19e10	Pa
Flexural strength	1.56e7-5.74e7	1.56e7-5.73e7	1.56e7-5.73e7	Pa
Shear modulus	2.49e10-2.7e10	2.49e10-2.7e10	2.49e10-2.7e10	Pa
Bulk modulus	6.3e10-8.3e10	6.29e10-8.29e10	6.29e10-8.29e10	Pa
Poisson's ratio	0.32-0.36	0.32-0.36	0.32-0.36	

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REFERENCES

[1] H.Li, N.Chandra, Analysis of crack growth and crack tip plasticity in ductile materials using cohesive zone models in the International journal of Plasticity, 19(2003)849-882.

[2] M.M.Abou-hamda, M.M.Megahad, M.M.I.Hammouda, Fatigue crack growth in double cantilever beam specimen with an adhesive layer in the Engineering Fracture Mechanics, S0013-7944(98)00018-6.

[3] Matthieu Maziere, Bernard Fedelich, Simulation of fatigue crack growth by crack tip plastic blunting using cohesive zone elements in the Procedia Engineering, 2(2010)2055-2064.

[4] E.T.Ooi, Z.J.Yang, Modelling multiple cohesive crack propagation using a finite element-scaled boundary finite element coupled method in the Engineering Analysis with Boundary Elements, 33(2009)915-929.

[5] Joris J.C.Remmers, Rene de Borst, Alan Needleman, The simulation of dynamic crack propagation using the cohesive segments method in the Journals of the Mechanics and Physics of Solids, 56(2008)70-92.

[6] M.S.Ala, M.A.Wahab, Modelling the fatigue crack growth and propagation life of a joint of two elastic materials using interface elements in the International Journal of Pressure Vessels and Piping, 82(2005)105-113.

[7] S.K.Maiti, S.Namdeo, A.H.I.Mourad, A scheme for finite element analysis of mode I and mixed mode stable crack growth and a case study with AISI 4340 steel in the Nuclear Engineering and Design, 238(2008)787-800.

[8] S.Rajakumar, T.Christopher, Fracture strength of centre surface cracked tensile specimens made of 2219-T87 Al alloy welding in the Transactions of Nonferrous Metals Society of China, 21(2011)2568-2575.

[9] J.Zhang, X.D.He, B.Suo, S.Y.Du, Elastic-plastic finite elements analysis of the effect of compressive loading on crack tip parameters and its impact on fatigue crack propagation rate in the Engineering Fracture Mechanics, 75(2008)5217-5228.

[10] Z.-H.Jin, C.T.Sun, A comparison of cohesive zone modelling and classical fracture mechanics based on near tip stress field in the International Journal of Solids and Structures, 43(2006) 1047-1060.

[11] E.H.Irhirane, M.Abousaleh, J.Echabbi, M.Hattabi, Modelling and simulation of the failure and stiffness degradation of a graphite epoxy in a three point bending test in the Journal of Engineering Materials and Technology, july 2010, vol.132/031013-1.

[12] W.A.Yao, X.F.Hu, A novel singular finite element on mixed-mode dud dale model based crack in the Journal of Engineering Materials and Technology, april 2012, Volume 134/021003-1.

[13] Hansang Kwon, Jayanta Mondal, Khaled AloGab, Väino Sammelselg, Miyazaki Takamichi, Akira Kawaski, Marc Leparoux on Graphene oxidereinforced aluminum alloy matrix composite materials fabricated by powder metallurgy in the Journal of Alloys and Compounds, december 2016, S0925-8388(16)34098-1.

[14] Jaroslaw Wozniak, Marek Kostecki, Tomasz Cygan, Magda Buczek, Andrzej Olszyna on Self-lubricating aluminium matrix composites reinforced with 2D crystals in the Composites Part B, november 2016, S1359- 8368(16)31443-3.

[15] K.L. Firestein, S. Corthay, A.E. Steinman, A.T. Matveev, A.M. Kovalskii, I.V. Sukhorukova, D. Golberg, D.V. Shtansky on High-strength aluminum-based composites reinforced with BN, AlB2 and AlN particles fabricated via reactive spark plasma sintering of Al-BN powder mixtures in the Materials Science & Engineering A, 681 (2017) 1–9.

[16] C. Antony vasantha kumar, j. Selwin rajadurai on Influence of rutile (TiO2) content on wear and microhardness characteristics of aluminium-based hybrid composites synthesized by powder metallurgy in the Trans. Nonferrous Met. Soc. China, 26(2016) 63−73.

[17] R.Ganesh, Ram Subbiah & K. Chandrasekaran on Dry Sliding Wear Behavior of Powder Metallurgy Aluminium Matrix Composite in the Materials Today: Proceedings 2, (2015) 1441 – 1449.

[18] V.Balaji, N.Sateesh, M.Manzoor Hussain on Manufacture of Aluminium Metal Matrix Composite (Al7075-SiC) by Stir Casting Technique in the Materials Today: Proceedings 2, (2015) 3403 – 3408.

[19] Sijo M T , K R Jayadevan on Analysis of stir cast aluminium silicon carbide metal matrix composite: A comprehensive review in the Procedia Technology, 24 (2016) 379 – 385.

[20] Sajjad Amirkhanlou∗ , Mohammad Reza Rezaei, Behzad Niroumand, Mohammad Reza Toroghinejad on Refinement of microstructure and improvement of mechanical properties of Al/Al2O3 cast composite by accumulative roll bonding process in the Materials Science and Engineering A, 528 (2011) 2548–2553.

[21] S.A. Sajjadi , H.R. Ezatpour , M. Torabi Parizi on Comparison of microstructure and mechanical properties of A356 aluminum alloy/Al2O3 composites fabricated by stir and compo-casting processes in the Materials and Design, 34 (2012) 106–111.

[22] Sudarshan, M.K. Surappa on Synthesis of fly ash particle reinforced A356 Al composites and their characterization in the Materials Science and Engineering, A 480 (2008) 117–124.

[23] M. Gupta, M.O. Lai, C.Y. Soo on Effect of type of processing on the microstructural features and mechanical properties of Al-Cu/Sic metal matrix composites in the MaterialsScienceand Engineering, A210(1996) 114-122.

[24] Mortaza Azarbarmas∗ , Masoud Emamy, Jafar Rassizadehghani, Mohammad Alipour, Mostafa karamouz on The influence of beryllium addition on the microstructure and mechanical properties of Al–15%Mg2Si insitu metal matrix composite in the Materials Science and Engineering A, 528 (2011) 8205–8211.

[25] G. Abouelmagd on Hot deformation and wear resistance of P/M aluminium metal matrix composites in the Journal of Materials Processing Technology, 155–156 (2004) 1395–1401.

[26] Powder Metallurgy and Ceramic Forming.

[27] A. Baradeswaran, A. Elaya Perumal on Study on mechanical and wear properties of Al 7075/Al2O3/graphite hybrid composites in the Composites: Part B, 56 (2014) 464–471.

[28] M.D. Bermúdez , G. Mart´ınez-Nicolás , F.J. Carrión , I. Mart´ınezMateo , J.A. Rodr´ıguez , E.J. Herrera on Dry and lubricated wear resistance of mechanically-alloyed aluminium-base sintered composites in the Wear, 248 (2001) 178–186.

[29] P.N. Bindumadhavan , T.K. Chia , M. Chandrasekaran , Heng Keng Wah , Loh Nee Lam , O. Prabhakar on Effect of particle-porosity clusters on tribological behavior of cast aluminum alloy A356-SiCp metal matrix composites in the Materials Science and Engineering, A315 (2001) 217– 226.

[30] Metallographic Principles and Practice by George F.Vander Voort.

[31] Jeykrishnan, S. Jayanthi Nathan and M.R. Karthik, Fabrication and Characterization of Aluminum Titanium Di-Boride Metal Matrix Composites Using Stir Casting Technique. International Journal of Mechanical Engineering and Technology, 8(4), 2017, pp. 13–18.

[32] F. Anand Raju and Dr. M.L.S. Deva Kumar, Production and Mechanical Characterization of Al-7075-T6 and Fly Ash Composite by Stir Casting Hot Die Process. International Journal of Mechanical Engineering and Technology, 7(6), 2016, pp. 225–235.

[33] Navnath Sambhaji Kalyankar, Rahul D. Shelke and Deepak D. Barkul. Study of Properties of AL LM-25/SIC Metal Matrix Composite Fabricated by using Stir Casting Method. International Journal of Mechanical Engineering and Technology, 7(5), 2016, pp. 133–141.