Experimental Study on Mechanical Properties of Aluminium Metal Matrix Composites (AA 6061 Reinforced With MOS_2)

[1]E. Subba Rao, [2]M. Janardan, [3]N.Ramanaiah

[1]Dept. of ME, Loyala Institute of Technology and Management, Sattenapalli, Guntur, AP, India

[2]Abdulkalam Institute of Technological Sciences, Khammam, Kothagudem, Telangana India

[3]Dept. of ME, AU College of Engineering (A), Andhra University, Visakhapatnam, AP, India

Abstract

The present study is aimed to evaluating the mechanical properties of aluminum metal matrix composite (AMMC). An effort is made to enhance the mechanical properties of AMMCs by reinforcing AA6061 matrix with Molybdenum Disulfide (MoS_2) particles. AMMCs were made, AA6061 as matrix material and MoS_2 as reinforcement material, through stir casting method. AMMCs with varying percentage by different wt. 1% to 5% MoS_2 were fabricated. A systematic study of the matrix metal and AMMCs were done to evaluate the mechanical properties in as cast and cold rolling condition. It was observed that in comparison to the matrix metal, the precipitation kinetic was accelerated by adding the MoS_2 particles. It was noticed that, mechanical properties are increase with the increase in wt. % of the reinforcement up to 4% MoS_2 further addition there is a diminution in both the conditions (as cast and cold rolling condition). It was also thought-out that 4% MOS_2 composite shows better mechanical (hardness, yield strength and tensile strength) properties and low % of elongation than all other compositions in both the conditions. Optical microscopy and SEM were carried out to authenticate the mechanical properties of the matrix metal and AMMCs.

Keywords

AA6061, MOS_2 (as Casted and Cold Rolling), Mechanical Properties and SEM

I. Introduction

Composites are engineered or naturally occurring materials made from two or more constituent materials with significantly different physical or chemical properties that remain separate and distinct within the finished structure. The bulk material forms the continuous phase that is the matrix (e.g. metals, polymers) and the other acts as the discontinuous phase that is the reinforcement (e.g. ,ceramics, fibers, whiskers, particulates).While the reinforcing materi.al as usually carries the major amount of load &the matrix enables the load transfer by holding them together [1]. Composite materials are gaining wide spread acceptance due to their characteristics of behavior with their high strength to weight ratio [2]. The interest in Material Matrix Composites (MMCs) is due to the relation of structure to properties such as specific stiffness or specific strength. Material matrix composites are being increasingly used in aerospace and automobile industries owing to their enhanced properties such as elastic modulus, hardness, tensile strength at room and elevated temperatures, wear resistance combined with significant weight savings over and reinforced alloys [3-4]. The material matrix composite can be reinforced with particles and fibers. However, the biggest interest in composite materials is observed for those reinforced with hard ceramic particles due to the possibility of controlling their mechanical properties.

Heat treatable wrought Alumina-Magnesium-Silicon alloys (AA6xxx) are of medium strength and extensively employed in aircraft, automobiles and marine applications. AA6061 aluminum alloy is often used for its light weight, good mechanical properties obtained through Mg2Si precipitate at the micrometer scale [5]. Grain refinement is one of the techniques used to improve the mechanical properties of polycrystalline metals. Grain boundaries (GBs) have serious effects on the mechanical properties of metallic materials as barriers of dislocation transmission or as sources or sinks of dislocations. In the case of coarse-grained metals, dislocation structures are formed in the grains, and a large number of interactions between the lattice dislocations take place. The mechanical properties of coarse-grained metals are governed mainly by these interactions. Therefore, the interaction between lattice dislocations and grain boundaries is a very important phenomenon that has to be studied to elucidate the unusual mechanical properties [6].

Mechanical properties were affected by selection of the volume fractions, size, and distribution of the reinforcing particles in the matrix [7]. They are used more often, compared with the composite materials of other metals, due to the broad range of their properties and also due to the possibility of replacing the costly and heavy elements made from the traditionally used materials [8]. Metal matrix composites reinforced with particles tend to offer enhancement of properties processed by conventional routes [9].

AMMC are the competent material in the industrial world. Due to its excellent mechanical properties it is widely used in aerospace, automobiles, marine etc. [10]. The aluminum matrix is getting strengthened when it is reinforced with the hard ceramic particles like B_4C, SiC MoS_2 and Al_2O_3 etc. Aluminum alloys are still the subjects of intense studies, as their low density gives additional advantages in several applications. These alloys have started to replace cost iron and bronze to manufacture wear resistance parts. The alloys primarily utilized today in construction of aircraft structures, such as wings and fuselages, more commonly in homebuilt aircraft than commercial or military aircrafts.

Aluminum hybrid metal matrix composites shows better improvement in hardness with the increasing in percentage of reinforcement where as decrease in density [11]. Mechanical properties (hardness, tensile strength and yield strength) of hybrid composites were increased with increasing Wt. % addition of reinforcements [12]. Aluminum alloy AA6061 is available in a wide range of structural shapes, as well as sheet and plate products. This alloy has good wieldable characteristics [13]. Aluminum is also ubiquitous element and one of the trace elements with moderate toxic effect on living organisms[14]. Hence the desire in the engineering community to develop a new material with greater mechanical properties, without much compromising on the strength to weight ratio led to the development of the metal matrix composites [15-16].

Grain refiners (Sc, Tibor and Zr) containing AA4043 and AA5356 fillers added to AA6061 alloy was attributed to lower silicon/

magnesium segregation at grain boundaries [17]. The inter metallic particles are distributed uniformly in the composites and thus produced are fully dense with improved strength, which increases with the reinforcement content [18].
A limited research work has been reported on AMMCs reinforced with MoS_2 due to higher raw material cost and poor wetting. MOS2 is a robust material having excellent chemical and thermal stability, high hardness (HV=30 Gpa) and low density (2.52g/cm^3) and it is used for manufacturing bulletproof vests, armor tank etc. Hence, MOS_2 reinforced aluminum matrix composite has gained more attraction with low costing route [19].

II. Materials and Methods

A. Materials

AA6061 is used as matrix metal and Molybdenum Di Sulfide (MoS_2) powder of size 3-5 mesh as reinforcement material. The chemical composition of AA6061 and MoS2 powder is shown in table.1 and table.2 respectively.

Table 1: Composition of AA6061 Matrix Metal

Ele	Cu	Mg	Si	Fe	Mn	Zn	Ti	Cr	Al
%	0.19	0.82	0.67	0.19	0.06	0.03	0.07	0.08	Rem

Table 2: Composition of MoS_2

Elements	MO	S
%	59.94	40.06

III. Experimental Work

The simplest and the most cost effective method of liquid state fabrication is stir casting [20]. In this work stir casting technique is employed to fabricate, which is a liquid state metal in which a dispersed phase (reinforcement particulates) is mixed with a molten metal by means of stirring. The matrix AA6061 was melted at 700^{0}C in an electric furnace. At this high temperature magnesium ribbons were added into the molten alloy to increase the wet ability. An appropriate amount (1% of the wet. of base metal) of MoS_2 powder was preheated (350^{0}C) and then added slowly to the molten aluminum alloy. Simultaneously, the molten metal was stirred thoroughly at a constant speed of 300rpm with a stirrer for a period of 15 min. For a evenly dispersing MoS_2 particles in the molten aluminum alloy the high temperature AMMC was poured into the preheated (400^{0}C) cost iron mould. The same procedure was followed to get the AMMC's of different wt. %,1%, 2%, 3%, 4% and 5% (having dimensions 300mmx300mmx6mm) the experimental setup is shown in fig. 1.

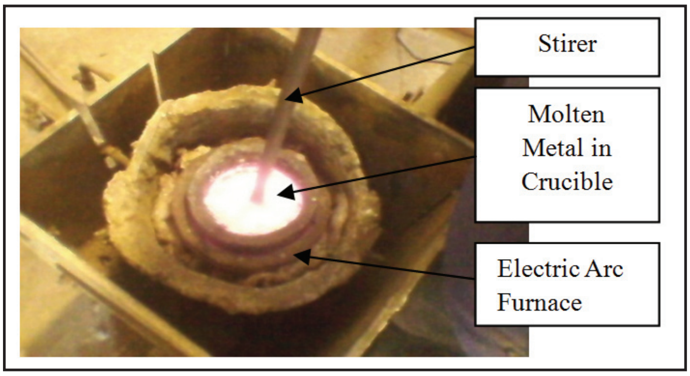

Fig. 1: Molten Metal in the Furnace

B. Treatment of AMMC

Fabricated composite was divided into equal parts of size 150x150x 6mm by mechanical cutting and are used for studying the mechanical properties in both the conditions (as cast and cold rolling).

C. As Cast

The fabricated specimens (150x150x6) were proposed to test for mechanical properties without any treatment.

D. Cold Rolling (CR)

The composite plate thickness was reduced by 10% through rolling process using a rolling mill.

E. Testing of AMMC

The fabricated specimens were proposed to test for mechanical properties like hardness, tensile strength, yield strength and % of elongation.

F. Hardness test

Hardness measurements were carried out on the matrix metal and composite samples by using standard Vickers hardness test machine. Vickers hardness measurements were carried out in order to investigate the influence of particulate weight fraction on the matrix hardness.

G. Tensile Testing

The specimens were machined to get dog boned structure as per ASTM E-8 standards. Test was carried out on a computerized UTM (TUE-C-600 Model Machine). The tensile test specimens are as per ASTME-8 as shown in fig. 2

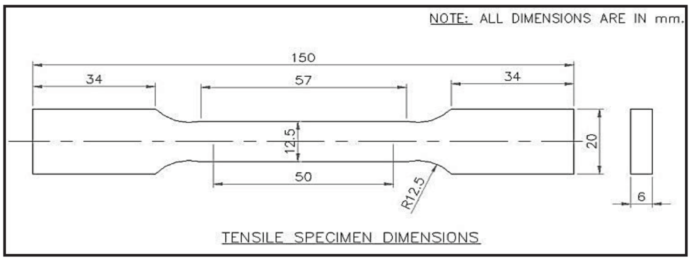

Fig. 2: Tensile Test Specimen as per ASTM –E8

H. Microstructure of AMMC

Microscopic analyses of the matrix metal and composite samples were performed by optical microscopy and Scanning electron microscopy. An Image analyzer was used to examine the distribution of the reinforcement particles within the aluminum matrix. The mechanical properties of any particle reinforced metal matrix composites depend on the particle distribution, particle size, particle flaws, surface irregularities and particle matrix bonding. It is therefore, necessary to conduct a microscopic analysis on the new material in order to gain better understanding of its micro structural characteristics. The polished specimens were cleaned with acetone and etched with (Methanol (25ml) + Hydrochloric acid (25ml) + Nitric Acid (25ml) + Hydrofluoric acid 1 drop) solution.

IV. Results & Discussions

A. Hardness

The tests revealed that, the hardness of the composite specimen is increased gradually with increase in the wt. % of MoS_2 powder

 ISSN : 2249-5762 (Online) | ISSN : 2249-5770 (Print)

incorporated in the metal matrix. The same thing was observed in hybrid composites (10 and 11). Table 3 shows hardness (VHN) of the composite at various percentage of reinforcement (MoS_2) in both the conditions (as cast and cold rolling). Fig: 3 show the hardness all composites (1%, 2%, 3%, 4% & 5% of MOS_2) in both the conditions. Cold rolling condition composite shows better hardness values than as cast condition and out of all conditions and compositions, 4% of MoS_2 composite shows better hardness.

Table 3: Hardness (VHN) of the composite at various percentage of reinforcement (MoS_2) in both the conditions (as cast and cold rolling)

Condition / % of reinforcement MoS_2	As cast	Cold Rolling
1%	65	72.0
2%	89	92.0
3%	101	102.0
4%	109	110.0
5%	91	95.00

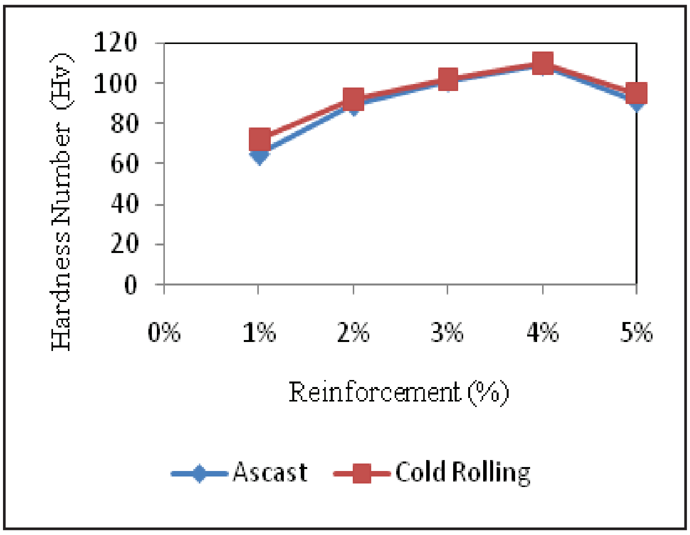

Fig. 3: Hardness (VHN) of the Composite at Various Percentage of Reinforcement (MoS_2) in both the Conditions (as Cast and Cold Rolling)

Mechanical Properties (Tensile Strength, Yield Strength & % of Elongation)

The tests revealed that, the tensile strength of the composite specimen is increased gradually with increase in the wt. % of MoS_2 powder incorporated in the metal matrix. The same thing was observed in hybrid composites (11). Fig. 4 shows the tensile strength of all composites (1%, 2%, 3%, 4% & 5% of MOS2) in as cast, and cold rolling condition. Out of all, the cold rolling condition composite shows better tensile strength values than all cast condition. 4% of MOS_2 composite made with cold rolling shows better mechanical properties than all other compositions. Similar trend was observed for yield strength (Fig: 5).

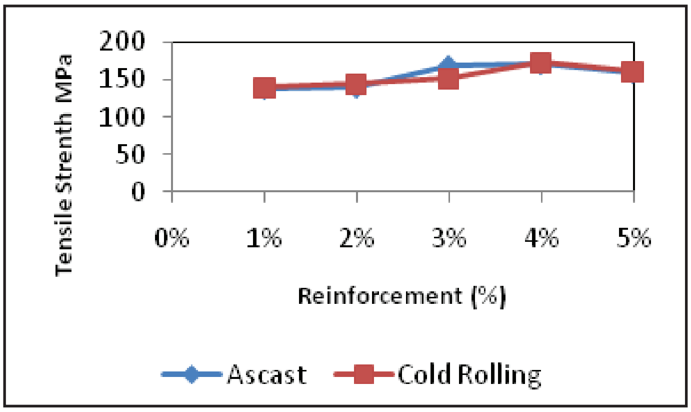

Fig. 4: Tensile Strength of Composites (1%, 2%, 3%, 4% & 5% of MoS2) in as cast and cold rolling

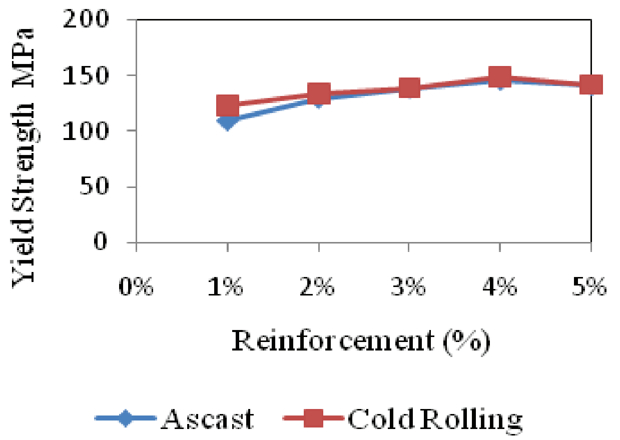

Fig. 5: Yield strength of composites (1%, 2%, 3%, 4% & 5% of MoS2) in as cast and cold rolling

Whereas the percentage of elongation of the composites are decreased gradually with increase in the wt. % of MoS2 powder incorporated in the metal matrix. Fig. 6 show the percentage of elongation of all composites (1%, 2%, 3%, 4% & 5% of MoS2) in both the conditions. Composites made with cold rolling shows the lower percentage of elongation values than as cast condition. Out of all 4% of MOS_2 Composite shows lowest % elongation than all other composites.

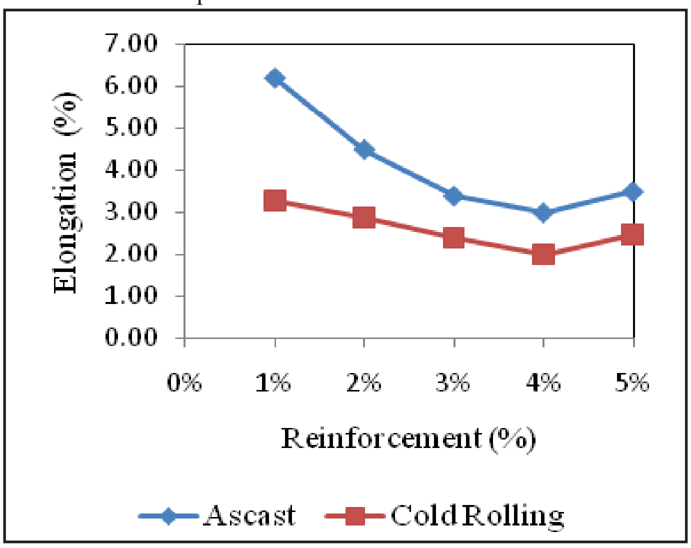

Fig: 6. The percentage of elongation of Composites (1%, 2%, 3%, 4% & 5% of MoS2) in as cast and cold rolling as casted and cold rolling

V. Micro Structure

The morphology, density, type of reinforcing particles and its distribution have a major influence on the properties of particulate composites [1]. The specimens were prepared for microstructure analysis by thoroughly polishing and etching. Then the specimens were observed under an optical microscope and SEM for studying the microstructure.

Micrograph of the matrix metal (AA6061) in T6 temper is shown in the fig. 7(a). It shows number of Mg_2Si articles present in artificially aged (T6) alloy and shows columnar without reinforcement and significant grain refinement was noticed when reinforced material (MoS_2) were added to the matrix metal (Fig. 7(b-d) in as cast condition.

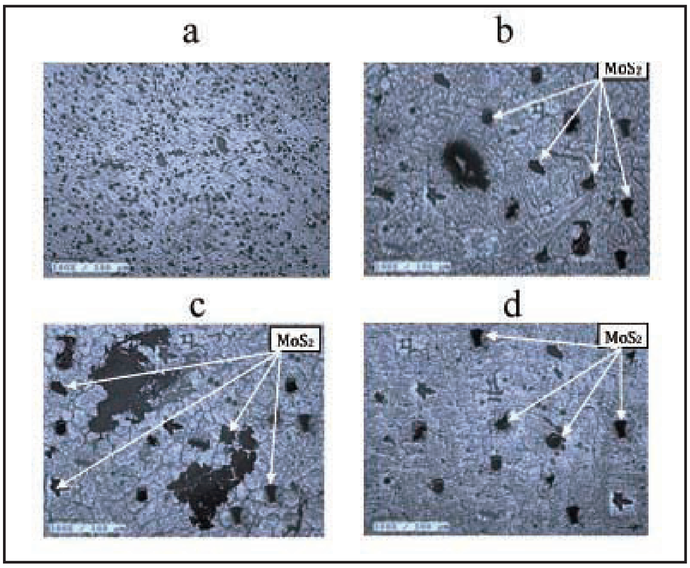

Fig. 7: Micrographs of (a) Matrix metal-T6 (b) 3% MoS_2 cast composite, (c) 4% MoS_2 cast composite and d. 5% MoS_2 cast composite

Micrograph of the cold rolling composite is shown in the Fig. 8a-c. It shows number of Mg_2Si and MoS_2 particles present and significant grain refinement was noticed when reinforced material (MoS_2) were added to the matrix metal.

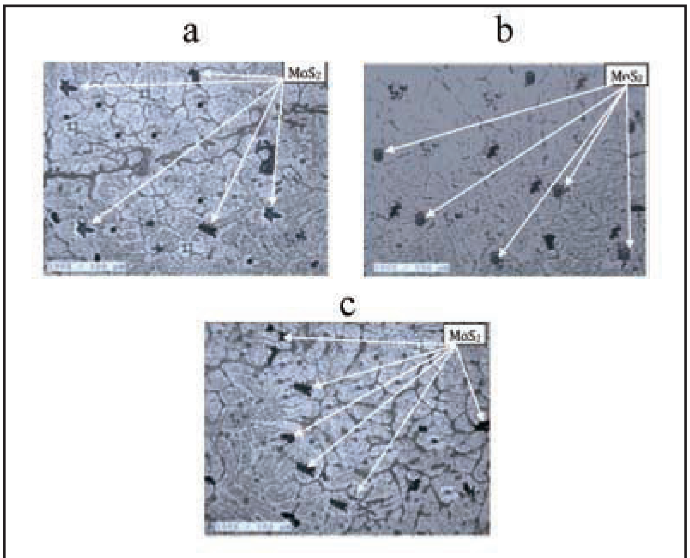

Fig. 8: Micrographs of (a) 3% MoS_2 cold rolling composite, (b) 4% MoS_2 cold rolling composite and (c) 5% MoS_2 cold rolling composite

In fig. 9(b) and (c), small MoS_2 particles are clearly visible, while almost no fine MoS_2 particles are visible in the cast composite (the particles appear white in the SE images due to charging of the nonconductive MoS_2). Comparing the grain structure of the composite there is some grain refinement over the matrix material (Fig. 9(a). While complete quantitative data were difficult to obtain from the matrix material, columnar grains are clearly visible.

Conversely, the microstructure of the composite has much smaller grains. Fig. 9(c). shows a fine with many smaller grains predominantly near MoS_2 particles. . With the observed dispersion of fine MoS_2 particles throughout the matrix in the cold rolling, it is possible that the high number of potential heterogeneous nucleation sites could give rise to a further refined grain structure. However, in the as cast composite (Fig. 9(b), there are large grains are observed.

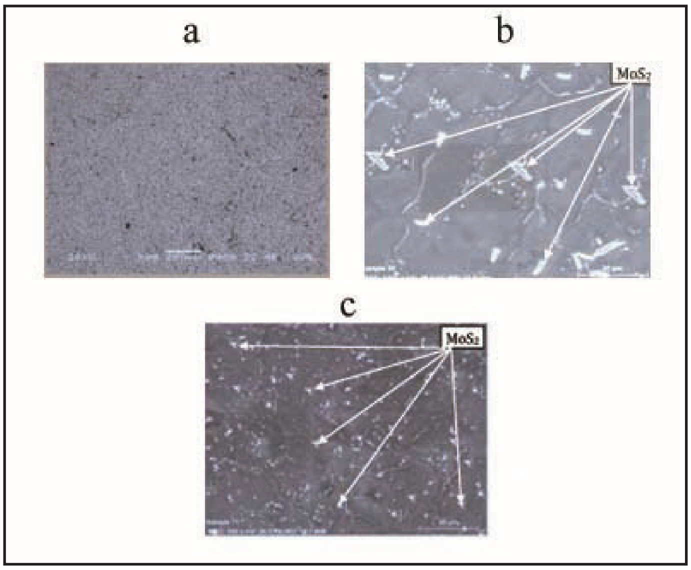

Fig. 9: SEM Micrographs of (a) Matrix Metal (b) As cast (AA6061+MOS_2) composite and (c) Cold rolling (AA6061+MOS_2) composite

VI. Conclusion

The AA6061-MOS_2 composites of combinations 1%, 2%, 3%, 4% & 5% were produced through stir casting method. The mechanical properties of the composite of as cast and cold rolling were evaluated and compared matrix material and observed the distribution of reinforcements (precipitates) are homogenously distributed. The following conclusions are made from the study.

1. AA6061-MOS_2 composites AMMCs (AA6061/MOS_2) were successfully fabricated by stir casting method.
2. The mechanical properties of 4% MOS_2 cold rolling AMMC showed better value than all other composites.
3. Out of all the conditions, cold rolling of 4% of MOS_2 shows better yield and tensile strength but lower % of elongation.
4. Optical micrographs and SEM micrographs revealed that the MOS_2 particles were well distributed in the Aluminum matrix with cold rolling followed by heat treatment condition.

References

[1] Prashant Sharma,"Determination of Mechanical Properties of Aluminum Based Composites", International Journal on Emerging Technologies 3(1): pp. 157-159, 2012.

[2] Pai, B.C., T.P.D. Rajan, R.M. Pillai,"Aluminum matrix composite castings for automotive applications", Ind. Foundry J., 50: pp. 30-39, 2004.

[3] A. Chennakesava Reddy, Essa Zitoun Indian Journal of

ISSN : 2249-5762 (Online) | ISSN : 2249-5770 (Print)

Science and Technology, Vol. 3 No. 12 (Dec 2010)
[4] B. Neitzel, M. Barth, M. Matic,"Weight Reduction of Discs Brake Systems with the Utilization of New Aluminum Material", SAE Technical Paper Series, 940335, Warrendale, PA, USA.
[5] Shen Y, Garnier J, Allais L, Crepin J, Ancelet O, Hiver JM. Proc Eng 2011;10:3429
[6] T. Shimokawa, T. Kinari and S. Shintaku: Phys. Rev. B 75 (2007) 144108(1-11).
[7] A. Wodarczyk-Fligier, L.A. Dobrzaski, M. Adamiak Influence of heat treatment on properties and corrosion resistance of Al-composite, Journal of Achievements in Materials and Manufacturing Engineering 21/1, pp. 55-58, 2007.
[8] L.A. Dobrzaski, A. Wodarczyk, M. Adamiak,"Composite material based on EN AW-Al Cu4Mg1(A) aluminum alloy reinforced with the Ti(C,N) ceramic particles, Materials Science Forum 530-531 (2006) 243-248].
[9] Mohanty RM, Balasubramanian K, Seshadri SK. Boron carbide-reinforced aluminum 1100 matrix composites: Fabrication and properties. Material Science Eng. A 2008; 498, pp. 42–52.
[10] Ch. Shoba, N. Ramanaiah, D. Nageswara Rao, Aging behavior of aluminum hybrid metal matrix composites, Materials Science an Indian journal, Vol.10. Issue11, 2014, pp. 484-489
[11] Bhargavi Rebba and N. Ramanaiah, Investigations on Mechanical Behaviour of Hybrid composites (AA2024 with B4C and MOS2)
[12] B4C and MoS2 Reinforced AA2024 Hybrid Composites, Journal of Manufacturing Science and Production, Oct, 2015, DE GRUYTER
[13] Feng YC, Geng L, Zheng PQ, Zheng ZZ, Wang GS,"Fabrication and characteristic of Al-based hybrid composite reinforced with tungsten oxide particle and aluminum borate whisker by squeeze casting. Materials& Design 2008; 29 : 2023–6.
[14] Ibrahim, I.A., F.A. Mohamed, E.J. Lavernia, 1991. Metal matrix composites-a review. J. Mater. Sci., 26: 1137-1157.
[15] Buraimoh, A.A., S.A. Ojo, J.O. Hambolu, S.S. Adebisi,"Aluminium chloride exposure had no effects on the epidemics of wistar rats", Am. Med.J., 3: pp. 210-219, 2012.
[16] Sinclair, I., P.J. Gregson,"Structural performance of discontinuous metal matrix composites. Mater. Sci. Technol., 3: pp. 709-726, 1997.
[17] K. Prasad Rao , N. Ramanaiah , N. Viswanathan, Partially melted zone cracking in AA6061 welds, Materials and Design, Vol: 29, 2008, pp. 179–186
[18] C.J. Hsu, P.W. Kao , N.J. Ho,"Inter metallic - reinforced aluminum matrix composite produced in situ by friction stir processing", Materials Letters 61, 2007, pp. 1315-1318.
[19] Sannino, A.P., H.J. Rack,"Dry sliding wear of discontinuously reinforced aluminum composites: Review and discussion", Wear, 189: pp. 1-19, 1995.
[20] Kerti I, Toptan F.,"Micro structural variations in cast MOS2-reinforced aluminum matrix composites (AMCs). Mater. Lett.2008; 62:1215–8. 4.
[21] Hashim J., Looney L., Hashmi M.S.J.,"Metal Matrix Composites: Production by the Stir Casting Method", Journal of Material Processing and Technology, 92, pp.17, 1999.

E SUBBA RAO, Associate Professor, Department of Mechanical Engineering, Loyala Institute of Technology and Management, Sattenapalli, Guntur, Andhra Pradesh, India.

M. JANARDAN, Professor & Principal, Abdulkalam Institute of Technological Sciences, Khammam, Kothagudem, Telangana, India.

DR. N. RAMANAIAH, Professor, Department of mechanical engineering, AU College of Engineering (A), Andhra University Visakhapatnam, Andhra Pradesh, India