An Experimental and Investigation on the Micro-structure Hardness and Tensile Properties of Al-GrFe$_3$O$_4$ Hybrid Metal Matrix Composites

Suresh Vellingiri
Professor
Department of Mechaical Engineering,
Holy Mary Institute of Techology and Science,
Hyderabad,
India

In the current scenario, aluminium metal matrix composites (AMMCs) are most important as an auspicious high class of materials. Metal matrix composites are emerging as very much endowed materials exclusively in the fields of automotive, aerospace, electrical and electronics for their numerous applications and technical challenging properties. In the present work, a courageous is perfect to prepare and compare the hardness and tensile properties of LM25-graphite (Gr) and LM25-graphite (Gr)-Ferrous oxide (Fe$_3$O$_4$) hybrid composites. The composites were primed to make use of stir casting process in which quantity of reinforcement is speckled from 4 wt% of Gr and 3 wt% of Fe$_3$O$_4$. The prepared composites are characterized by micro-structural studies and tensile properties were estimated as per the standards. The microphotographs of the composites revealed the reasonably homogeneous supply of the particles in composites with a group at a small number of places. The dispersed graphite and Fe$_3$O$_4$ in LM25 alloy contributed to enhancing the tensile strength of the composites. The SEM of the illustration specifies the homogeneous supply of the reinforcement particles in the matrix without any annulled.

Keywords: *aluminium alloy LM25; tensile strength; Fe$_3$O$_4$; Gr; SEM; stir casting; microstructure.*

1. INTRODUCTION

Composite materials have played a vital role in the field of engineering. In addition, advanced technology in the industries has required to attain the demands from rapidly developing industries such as aircraft, marine, and automobile [1-3].

In recent years Metal Matrix Composites (MMCs) have attracted much attention due to their excellent mechanical properties such as high specific strength and wear resistance. Some of the typical applications are bearings, automobile pistons, cylinder liners, piston rings, connecting rods, sliding electrical contacts, turbocharger impellers, space structures. MMCs components need to be formed into the desired shapes and finished to the required dimensions and tolerances. Metal Matrix Composites are given their required shape by bonding, brazing, powder metallurgy techniques, casting, and metal spraying and by forming operations such as bending, swaging, drawing and extrusion [4,5].

Aluminium in its alloy form is currently used for the manufacturing of various engine parts. The limitation of aluminium is that it is prone to scratches and indentations very easily. So, a need arises to fabricate an aluminium-based composite which will be wear resistant in nature by the addition of suitable reinforcements in defined proportion. Aluminium matrix composites have excellent ability to bear tensile as well as compressive forces Shabani and Mazahery [6-8]. Research has been going on by attempting different reinforcement materials into the aluminium matrix to improve and enhance the properties of the composite. For the fabrication of the composites, casting, powder metallurgy, friction stir processing, ball milling and hot rolling and vacuum hot pressing are some of the techniques which are used by researchers. However, casting process is largely used because of its low cost and high production rate Faraji et al. [9], Baghani et al. [10], Shabani et al. [11], but formation of clusters and agglomeration of reinforced particles in the base metal is one of the main problems of casting process Mazahery and Shabani [12].

Cast LM 25(A356) alloy, which is extensively used in automotive, aerospace, and other weight-sensitive industries, is one of the most well-developed aluminium alloys, due to its outstanding properties, such as good specific strength and excellent castability and corrosion resistance [13]. LM25 propositions a moral machinability [14].

Reinforcement surges the strength, stiffness and the temperature resistance capacity and depresses the density of MMC. In edicts to realise these possessions, the assortment depends on the type of reinforcement, its process of production and chemical compatibility with the matrix and the succeeding facet must be measured while choosing the reinforcement material. Reinforcements are pigeonholed by their chemical composition, shape, dimensions and properties as in gradient material

Received: July 2018, Accepted: January 2019
Correspondence to: Dr Suresh Vellingiri
Department of Mechanical Engineering, Holy Mary Institute of Technology and Science, Hyderabad, India.
E-mail:winsureshv2011@gmail.com
doi: 10.5937/fmet1903511S

and their volume fraction and spatial distribution in the matrix. The effect of different types of reinforcements such as silicon carbide (SiC) whiskers, alumina (Al_2O_3) fibre and SiC particle on the properties of metal matrix composites (MMCs), fabricated by powder metallurgy has been investigated[15]. While SiC and Al_2O_3 reinforced AMMCs remained the most premeditated, partial research have been steered on dry sliding tribology of Al-Gr- Fe_3O_4 composite.Graphite is considered as the most important constituent for solid lubrication of the ceramic reinforcement composites [16,17]. Further investigation influence of Gr for wear behaviour of Al 7075/ Al_2O_3/5 wt.% Gr hybrid composite (2, 4, 6 and 8 wt.% of Al_2O_3) found that the ceramic phase weight percentage increased and finally suggested the wear behaviour of hybrid composites contains graphite that shows superior resistance to wear [17].

Iron oxide also plays an important role in the aerospace industry, as it has been incorporated in composite propellant to improve its burning rate. Because the combustion mechanism of propellants is highly dependent on the decomposition of ammonium perchlorate (NH_4ClO_4 or AP), nowadays there are many studies concerning the catalytic effect of nano-Fe_2O_3 on thermal decomposition of ammonium perchlorate. Iron oxide is a mineral compound which occurs abundantly in nature. It presents more than one crystal structure and also different structural and magnetic properties [18,19]. The main forms of these minerals are hematite, magnetite and maghemite [20,18]. Crystal structure of the three oxides can be defined in terms of close-packed planes of oxygen anions with iron cations in octahedral or tetrahedral interstitial sites [18,20-22]. Since, magnetite (Fe_3O_4) is a standout amongst the crystallographic phases of iron oxide, particularly in its nanosized forms. This displays four different crystalline polymorphs with remarkable properties. The primary structures, hematite (α- Fe_2O_3) and maghemite (γ- Fe_2O_3), happen in nature and alternative oxides in the structures beta (β- Fe_2O_3) and epsilon (ε- Fe_2O_3) are nanometric structures which are commonly produced in research laboratory [19].

Among the variety of manufacturing processes available for discontinuous metal matrix composites, stir casting is generally accepted as a particularly promising route, currently practised commercially. Its advantages lie in its simplicity, flexibility and applicability to large quantity production with cost advantage [23-27]. The focus of this research work is to investigate the mechanical properties and microstructure of fabricated composites.

2. EXPERIMENTAL DETAILS

2.1 Material selection

LM25 aluminium alloy having a density of 2.68 gm/cm^3 and protuberant properties like weight, toughness, heat conduction etc., be chosen as the base matrix due to its usage in automotive pistons. In order to enhance the wear resistance, the reinforcement of Fe_3O_4 particles with 200 mesh sizes was selected. It has the density property of 5.24 gm/cm^3, higher hardness relative to SiC and Al_2O_3, excellent chemical and thermal stability which makes it as a suitable reinforcement to improve the wear performance of the alloy. The graphite is also selected as the reinforcement material and it has the density of 2.26 g/cm^3 and the hardness of the composites decreases as the % of graphite (Gr) increases [28,29]. The spectroscopy analysis was carried out for LM25 aluminium alloy and its chemical composition was given in Table 1.

Table 1 Chemical composition of LM25 aluminium alloy

MATERIALS	%
Copper	0.2 max
Magnesium	0.20-0.60
Silicon	6.5-7.5
Iron	0.5 max
Manganese	0.3 max
Nickel	0.1 max
Zine	0.1 max
Lead	0.1 max
Tin	0.05 max
Titanium	0.2 max
Aluminium	Remainder

2.2 Preparation of composite

Stir casting method was applied for the manufacturing and fabrication of the composite due to its expenditure effectiveness. The primary matrix material was encumbered into a graphite crucible and liquefied in an electric resistance furnace. The dissolving of the alloy occurred in an inert gas atmosphere, which avoids chemical reaction and produces a sound casting. Upon melting the preheated reinforcements were added at regular intervals and stimulated constantly at 350 rpm for 6 minutes to ensure consistent distribution of the reinforcement particles. The molten metal was then poured at a temperature of 760°C into preheated (300°C) steel moulds with dimensions of 100 × 14 mm and allowed to solidify as shown in Figure 1.

Figure 1 Casted Specimen

3. TESTING OF COMPOSITES

3.1 Micro structural investigation

The composite specimen remained erudite for eliminating rubbish present on the surface. Particle distribution remains estimated at the support of optical microscope as shown in Figure 2. The casting process remained inspected under the optical microscope to determine the reinforcement pattern of cast structure. A section remained cut from the castings. They remained grained using 100 grit silicon carbide paper tracked by 220, 400, 600 and 1,000 grades of emery paper before optical surveillance the samples were mechanically polished and etched by Keller's reagent to obtain a better disparity. The specimens remained pictured on diverse magnifications (100x, 200x, 400x) to display the occurrence of reinforcements and its distribution of the metal matrix diverse elements/ compounds which were present in the graphite and boron carbide are difficult to distinguish by optical micrographs.

Figure 2. Optical microscope

3.2 Microhardness

Microhardness testing is a technique which was utilized to estimate the material microhardness with an aid of microscopic scale. For this work, measurement of microhardness was measured by using MVH-II digital microhardness equipment as shown in Figure 3. Here, a diamond indenter is loaded on the material to be tested from a few grams to 1 kilogram. The length of impression is calculated from the scale of a microscope and the applied load is utilized to measure the value of microhardness. Typically, square-shaped indenter or rhombohedral shaped indenter is used in the microhardness test. The selected load is applied to the material using dead weights available in the tester.

Figure 3 Vickers hardness tester

3.3 Tensile strength

The micro tensile test was conceded out in harmony with ASTM B-557M standards by means of different specimens as a dimension of 100 mm length and a gauge length of 30 mm as shown in Figure 4 for each MMC's family. The cast specimens are prepared by the machining as per the standard. The micro-tension was conceded out for the elongation, load capacity, tensile properties, with respect to the speed, for the sample, tensile readings recorded. The digital tensometer among two perfunctory seize is used to hold the tensile specimen as shown in Figure 5.

Figure 4 Dimension of tensile test specimen

Figure 5 Micro Tensile Test - Digital tensometer

3.4 SEM analysis

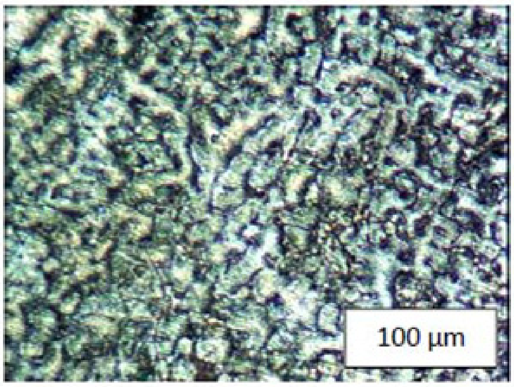
Scanning electron microscopy (SEM), also known as SEM analysis or SEM microscopy, is used very efficiently in microanalysis and failure psychotherapy of solid inorganic materials. Scanning electron microscopy is achieved at high exaggerations, engenders high-resolution imagery and accurately measures very tiny facial appearance and objects. SEM provides completed high-resolution imagery of the taster by rastering a focused electron beam across the surface and distinguishes derived or backscattered electron signal. An energy dispersive X-ray analyser is also used to endow with elemental detection and quantitative compositional information.

4. RESULTS AND DISCUSSIONS

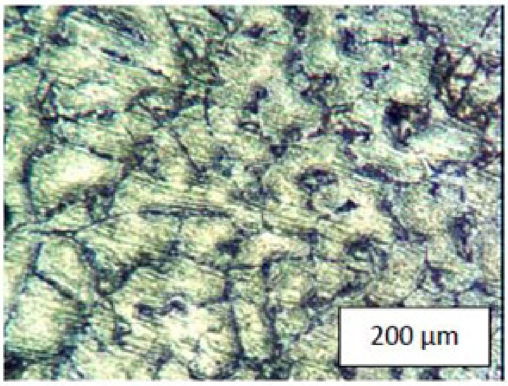
4.1 Microstructure

4.1.1 Microstructure of LM 25 with 4% of Gr

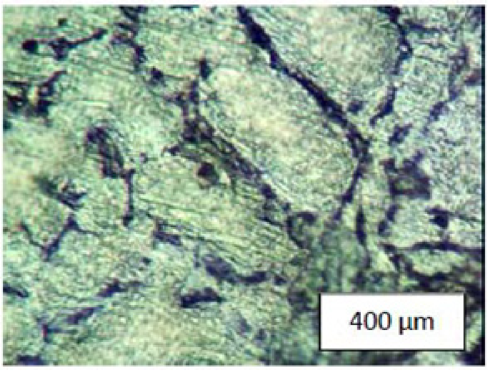
The optical microstructures of aluminium alloy LM 25 with a reinforcement of 4%graphite are shown in Figure 6 at different magnifications 100x, 200x and 400x. Microstructural investigation reveals that the particle distribution in the matrix was uniform. It was clear that the 4% graphite react with the aluminium and arising Al_4C_3 carbide induces corrosion and its larger volume in relation to the substrates can cause squeezing out from the matrix to the reinforcement. This leads to breaking and degradation of reinforcement, and finally leads to deterioration of the strength properties.



(a)



(b)

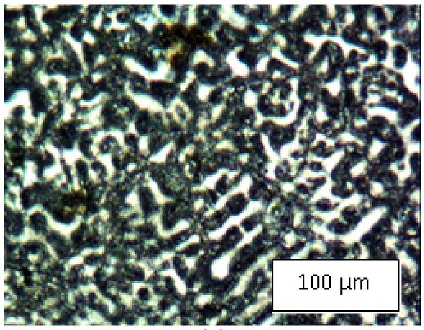


(c)

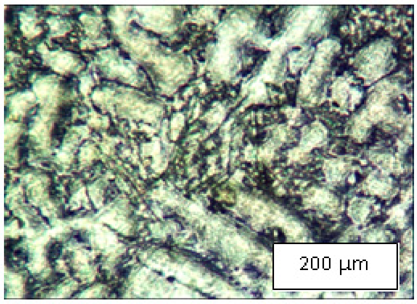
Figure 6 Optical microstructure of the aluminium alloy LM25 with 4 % Gr, (a) 100x (b) 200xand (c) 400x

4.1.2 Microstructure of LM 25 with 4 % of Gr and 3 % of Fe3O4

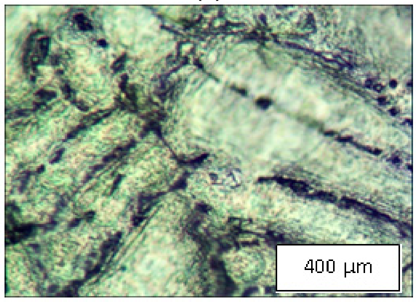
The optical microstructures of aluminium alloy LM25 and reinforcement 4% graphite and 3% iron oxide are shown in Figure 7 at different magnifications 100x, 200x and 400x. Micro structural investigations reveals that the particle distribution in the matrix was uniform. It was clear that when the percentage of iron oxide is increased, corrosion of the matrix occurs. It may be due to the formation of iron oxide by the reaction between carbon and iron, and it results from reduction in strength and hardness.



(a)



(b)



(c)

Figure 7. Optical microstructure of the aluminium alloy LM25 with 4 % Gr and 3 % of Fe_3O_4, (a) 100x (b) 200xand (c) 400x

4.2 Hardness test

Before conducting this test, the specimen was prepared with the dimension of 10 mm X 12 mm. The surface to be tested should appear with a metallographic finish, so for that, the surface finish was done by the various grit size (100, 220, 400, 600 and 1000) emery papers.

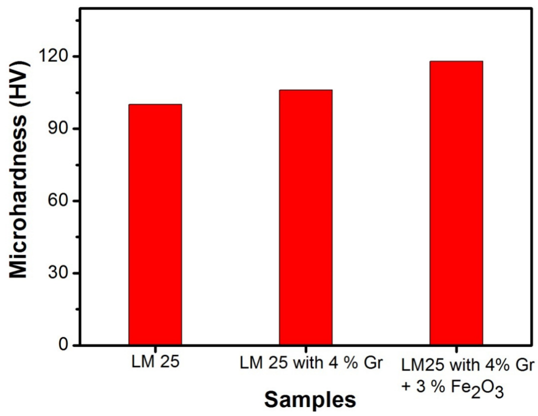


Figure 8. Microhardness result: A 200 grams load was utilized to produce an impression over the surface of the material for the dwell time of 20 seconds. From this hardness test, the value of microhardness for the sample such as LM25 alloy without reinforcement and the wt. % variation of different reinforcements such as Gr and Fe_3O_4 in Al alloy MMCs were determined and it displayed shown in Figure 8.

4.3 Tensile test

From Figure 9, it demonstrated that the tensile strength of the composites augmented with augmenting in Fe_3O_4 reinforcement, and the tensile strength is additional in hybrid composites than single reinforcement. Figure 9 shows the variation in micro tensile strength with the MMC's. Whereas raising the reinforcement of graphite (4%) and iron oxide (3%) load rate augment regularly.

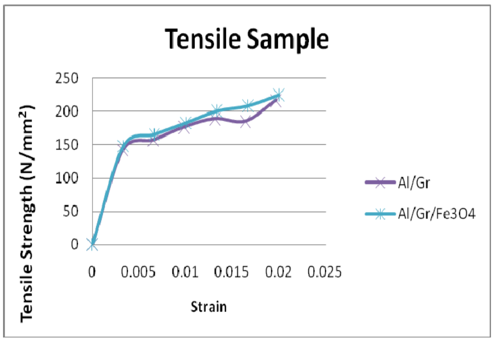
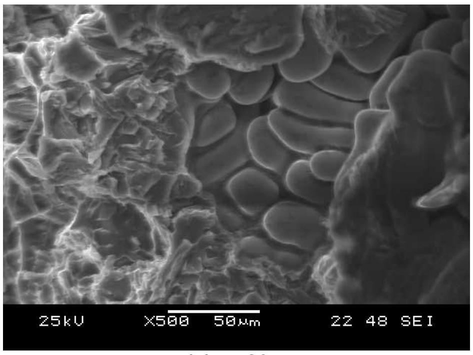


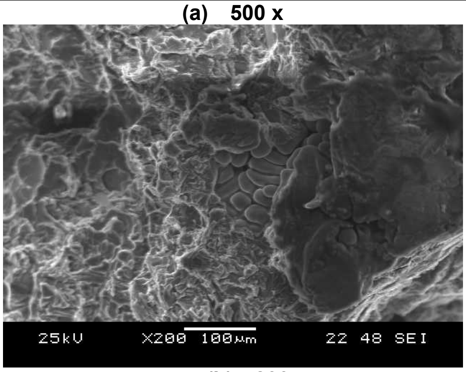
Figure 9. Tensile strength results

4.4 SEM analysis

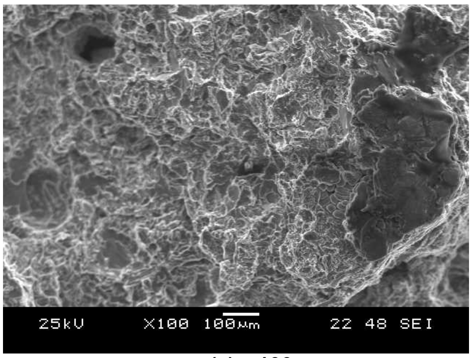
The fracture accessible in Figure 10 demonstrated a graphite flake protruding from the matrix. It seems that the graphite flake with characteristic laminar structure is detained in the matrix. The graphite surface appears to be clean devoid of any reaction products stuck particles of the matrix material. The SEM images of the aluminium composite are shown in Figure 10. It plainly divulges that the splinter is squashy. The crumb is visibly as lustrous as it is unvaryingly disseminated. From this result, it can be concluded that the fracture instigates at the tarnished part which is examined in the optical micrograph. When the prerogative of graphite as swelling the ductility behaviour of the material is reduced slightly, it results from augment in hardness extensively.



(a) 500 x



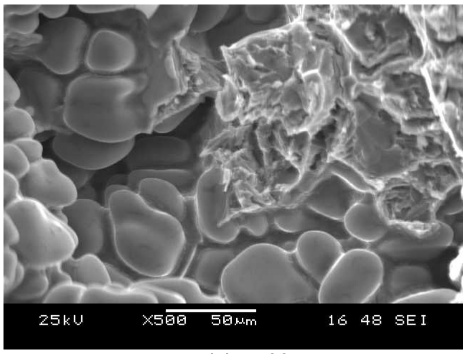
(b) 200 x



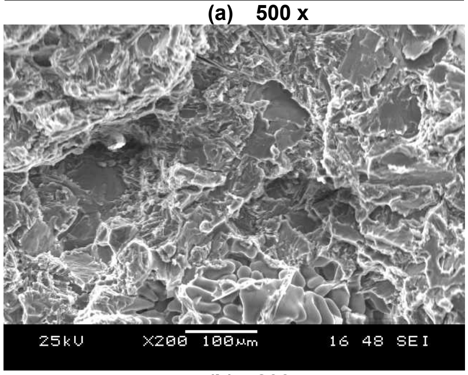
(a) 100 x

Figure 10. SEM micrograph of the tensile test mixture Al/4 % Gr, (a) 500x (b) 200x and (c) 100x

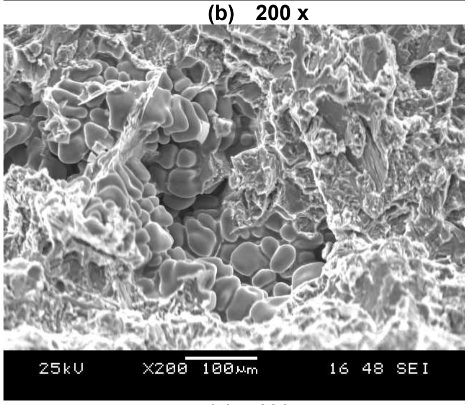
The SEM images of the aluminium composite are shown in Figure 11. It obviously divulges that the rupture is pliable. The granule is evidently perceptible as glowing as it is homogeneously scattered. From this consequence, it can be completed that the splinter initiates at the rusty part which is conversed in the optical micrograph. When the percentage of iron oxide was raising the ductility behaviour of the material is decreased slightly, it results in an increase in hardness considerably.



(a) 500 x



(b) 200 x



(c) 100 x

Figure 11. SEM micrograph of the tensile test mixture Al/4 % Gr/3%Fe_3O_4, (a) 500x (b) 200x and (c) 100x

5. CONCLUSIONS

- It has been observed that the tensile properties of the composites such as tensile strength, of the composites, are also deeply prejudiced by the adding together of reinforcement.
- The tensile strength of Gr and Gr/Fe_3O_4 reinforced hybrid particulate aluminium composites was deliberated and the maximum tensile strength observed is 228N/mm^2 at 4% of Gr and 3% of Fe_3O_4. The tensile behaviour of SiC/Gr reinforced hybrid composites demonstrated improved results when contrasted with single reinforcement.
- The Hardness value is 118 VHN compared to adding 4% of Gr better results produced Fe_3O_4.
- From the studies of microstructure, it divulges that the uniform distribution of reinforcing particulates take place in the matrix.

REFERENCES

[1] Beaumont, P.W.R. et al. (Editors): Structural integrity and durability of advanced composites: Innovative modelling methods and intelligent design, Woodhead Publishing, Cambridge, 2015.

[2] Jawaid, M., Thariq, M. (Editors): Handbook Sustainable Composites for Aerospace Applications, Woodhead Publishing, Cambridge, 2018.

[3] Zweben, C., Beaumont P.W.R. (Editors): Comprehensive Composite Materials II, Elsevier, Amsterdam, 2018.

[4] Chandler H.E.: *Machining of Metal Matrix Composites and Honeycomb Structures. Metals Handbook, Vol. 16 Machining*. Ninth Edition. Materials Park OH: ASM International; 1989.

[5] Waleed, W.A., Chathriyan, A., Sam Singh Vimal, R.: Experimental Investigation on the Influence of Process Parameters in Thermal Drilling of Metal Matrix Composites, FME Transactions, Vol.46, pp.171-176, 2018.

[6] Shabani, M.O., Mazahery, A.: Suppression of segregation, settling and agglomeration in mechanically processed composites fabricated by a semisolid agitation processes, Trans. Indian Inst. Metals. Vol.66, pp.6570,2013.

[7] M. Farkašova, E. Tillova, M. Chalupova,: Modification of Al-Si-Cu cast alloy, FME Transactions, Vol. 41, pp.210-215, 2013.

[8] Surendran, R., Manibharathi, N., Kumaravel, A.: Wear Properties Enhancement of Aluminium Alloy with Addition of Nano Alumina, FME Transactions, Vol. 45,pp. 83-88, 2017.

[9] Faraji, A. et al.: Numerical and experimental investigations of weld pool geometry in GTA welding of pure aluminum, J. Cent. South Univ. Vol.21, pp.2026, 2014.

[10] Baghani, A. Bahmani, A., Davami, P., Varahram, N., Shabani, M.O.: Numerical investigation of the effect of sprue base design on the flow pattern of aluminum gravity casting, Defect Diffus. Forum. Vol.344, pp.4353, 2013.

[11] Shabani, M. et al.: Silicon morphology modelling during solidification process of A356 Al alloy, Int. J. Cast. Metals Res. Vol.25, pp.5358, 2012.

[12] Mazahery, A., Shabani, M.O.: Experimental investigation on the aging response, hardness and total impact energy absorption of sr-modified heat-treatable cast automotive aluminum alloys, Trans. Indian Inst. Metals. Vol.67, pp.7537-59, 2014.

[13] Baradarani,B. et al.: The effect of Zr on the properties of an A356 Aluminium cast alloy, *The third joint conference of 13th conference of the Iranian Metallurgical Engineering Congress and 21th Conference of the Iranian Foundry Society,* 2009.

[14] Mazahery, A. and Shabani, M.O.: Influence of the hard coated B_4C particulates on wear resistance of Al-Cu alloys, Composites: Part B, Vol. 43, No. 3, pp.1302–1308, 2012.

[15] Ahamed, A.R., Asokan, P. and Aravindan, S.: EDM of hybrid Al-SiCp-B4Cp and Al-SiCp- Glass-pMMCs, International Journal of Advanced Manufacturing Technology, Vol. 44, Nos. 5–6, pp. 520–528, 2009.

[16] Baradeswaran, A. Elaya Perumal, A.: Wear and mechanical characteristics of Al 7075/graphite composites, Compos. Part B Eng. 56, pp.472– 476, 2014.

[17] Baradeswaran, A. ElayaPerumal, A.: Study on mechanical and wear properties of Al 7075/Al2O3/graphite hybrid composites, Compos. Part B Eng. 56, pp.464–471, 2014.

[18] Cornell R.M, Schwertmann U: *The iron oxides: structure, properties, reactions, occurrences and uses*, Weinheim: Wiley-VCH, 2000.

[19] Machala L. et al.: Polymorphous transformations of nanometric iron (III) oxide: a review. Chem Mater, Vol.23(14), pp.3255-3272, 2011.

[20] Babay S, Mhiri T, Toumi M.: Synthesis, structural and spectroscopic characterizations of maghemite γ-Fe2O3 prepared by one-step coprecipitation route. J MolStruct Vol. 1085, pp.286-293, 2015.

[21] Zboril R, Mashlan M, Petridis D.: Iron (III) oxides from thermal processes-synthesis, structural and magnetic properties, mossbauer spectroscopy characterization, and applications. Chem Mater Vol.14, No.3, pp.969-982, 2002.

[22] Teja S.A, Koh P.Y.: Synthesis, properties, and applications of magnetic iron oxide nanoparticles. Prog Cryst Growth CharactMater, Vol. 55, No.1-2, pp.22-45,2009.

[23] Ulhas K., Annigeri G.B., Veeresh K.: Method of stir casting of Aluminum metal matrix Composites: A review. Materials Today: Proceedings, Vol. 4, Issue 2, Part A, pp.1140-1146, 2017.

[24] Hashim, J., Loony, L., and Hashmi, M.S.J.: Metal Matrix Composites Production by Stir Casting Method, Journal of Materials Processing Technology, Vol.92-93, pp.1-7, 1999.

[25] Pai, B.C., Pllia, R.M., and Satyanaryanak, G.: Stir Cast Aluminum Alloy Matrix, Key Engineering Materials, Vol. 79-80, pp. 117-128, 1993.

[26] Rupa, D.G., Meenia, H.: SiC Particulate Distribution Dispersed Composites of An AL-Zn-Mg-Cu Alloy Property Comparison with Parent Alloy, Jounral of Materials Characterizations, Vol. 54, pp. 438-445, 2005.

[27] Balasivanandha, S.: Influence of Stirring Speed and Stirring Time on Distribution of Particles in Cast Metal Matrix Composite", Jounral of Material Processing Technology, Vol. 171, pp. 268-273, 2006.

[28] Ravindran, P., Manisekar, K., Narayanasamy, P., Selvakumar, N., Narayanasamy, R.: Application of factorial techniques to study the wear of Al hybrid composites with graphite addition', Materials and Design, Vol. 39, pp.42–54,2012.

[29] Madeva Nagaral, Pavan, R., Shilpa, P. S., Auradi, V.:Tensile Behavior of B4C Particulate Reinforced Al2024 Alloy Metal Matrix Composites, FME Transactions, Vol.45, pp.93-96, 2017.

ЕКСПЕРИМЕНТ И ИСТРАЖИВАЊЕ ТВРДОЋЕ И ЗАТЕЗНЕ ЧВРСТОЋЕ У МИКРОСТРУКТУРИ ХИБРИДНИХ КОМПОЗИТА СА МЕТАЛНОМ МАТРИЦОМ ОД Al – Gr – Fe_3O_4

С. Велингири

Данас су композити алуминијума са металном матрицом најзначајанији материјали високе класе. Користе се као веома софистицирани материјали у аутомобилској, авио, електро и електронској индустрији јер имају широку примену и техничка својства пуна изазова. У овом раду припремили смо и упоредили тврдоћу и затезну чврстоћу хибридних композита LM25 (Gr) и LM25 (Gr)/(Fe_3O_4). При изливању прво је сипан композит да би се искористиле предности процеса изливања мешањем, при чему се масени проценат ојачања кретао од 4% Gr до 3% Fe_3O_4. Извршена је карактеризација микроструктуре композита а својства затезне чврстоће су одређена према стандардима. Микрофотографије су показале да постоји релативно хомогено присуство честица у композитима. Расејани графит и Fe_3O_4 код легуре LM25 су допринели побољшању затезне чврстоће. Скенирајућа електронска микроскопија је показала хомогени распоред честица из ојачања у матрици.