T ANIL KUMAR
HEMAVATHY S
BALASUBRAMANYA H S
SHANKARA
and
DIVAKARA SHETTY A S

Effect of ultrasonic vibrations and silicon carbide additions on microstructure, mechanical and tribological behavior of Al7075 alloy

Aluminium alloy Al7075 is a novel alloy used in various applications where strength is critical factor compared to its corrosion resistant behaviour. It has been reported in many literatures that fine-grained equiaxed microstructure results in improved quality of the metal in turn reduction in cracking. Many investigators have also found that when mechanical vibrations induced during solidification of metals and alloys, modify its microstructures. During solidification process, when high intensity ultrasonic waves are made to propagate through the molten metals, results in formation of fine-grained equiaxed structure by the suppression of columnar grains. In the present investigation the effect of silicon carbide (SiC) particulate addition and effect of ultrasonic vibration on mechanical properties and tribological behaviour of aluminium metal matrix (Al-MMC) composites has been investigated. A specially fabricated die assisted with ultrasonic vibration module was employed for investigation. The specimens were fabricated as per ASTM standards. Laboratory experiments were conducted on prepared specimens for different frequencies and a constant amplitude. The mechanical properties such as ultimate tensile strength and yield strengths are determined for both alloy and for the alloy with reinforcement. The findings are analysed. Microstructure examination reveals the presence of a aluminium dendrites surrounded by fine secondary phase particles. Hardness measurements have also been carried out. Dry sliding wear studies on composites were carried out using pin-on-disc testing machine for varying speeds and loads. The experiments were conducted for three different loads 1kg, 2kg and 3kg and disc speed of 400, 600 and 800 rpm for a test duration of 5 minutes. Weight loss method has been considered for the analysis. The weight loss of the composites was found to increase with the increase in normal load. With increased speed increase in the weight loss has been observed. Reduction in weight loss were noticed after SiC reinforcement additions and specimens with castings taken at higher ultrasonic frequency. The result indicates that SiC and ultrasonic frequency has an influence on the wear properties of the composite.

Keywords: Ultrasonic processing, supply frequency, ASTM standard.

1.0 Introduction

Aluminium (Al7075) is one of the most commonly used aluminium alloy for aerospace applications as it exhibits some of the outstanding properties such as high strength to low weight ratio and better stress corrosion resistance. Al7075 alloy primarily consists of 5.1-6.1% of zinc, 2.1-2.9% of magnesium and 1.2-2.0% of copper. These alloys are heat treatable as well. The property of the pure metal can be increased by heat treatment or by the reinforcement. Nano-sized silicon carbide and boron carbide were reinforced to Al7075 alloy to increase the strength of the base metal. The ultimate tensile strength of as cast Al7075 alloy was improved by 62% of the base metal by the addition of 0.5% by weight of boron carbide, whereas for the addition of 0.5% by weight of silicon carbide, the strength was increased by 31%. The micro hardness of Al7075 alloy was improved by 55% by the addition of boron carbide and 35% by the addition of silicon carbide [1].

The effect of vibration on grain morphology was first reported by Sokoloff [1]. Several other researchers were also conducted similar investigations on improving the microstructure. The major effect on inducing the ultrasonic vibrations is to promote nucleation, thereby reducing the size of grains. This in turn results in sound casting with improved features and enhanced mechanical properties.

Addition of single and hybrid particles like aluminium oxide and aluminium oxide with silicon carbide for Al 7075 alloy had increased the hardness by 63.7% and 81.1% using stir casting. The ultimate tensile strength was increased by

Blind peer reviews carried out

Messrs. T Anil Kumar, Hemavathy S and Balasubramanya H S, Department of Mechanical Engineering, Ramaiah Institute of Technology, Bangalore, Karnataka 560054, Shankara, Department of Civil Engineering, Amrita School of Engineering, Bengaluru, Amrita Vishwa Vidyapeetham, India and Divakara Shetty A S, Professor, Engineering Department, University of Technology and Applied Sciences IBRI, Sultanate of Oman. E-mail: baluhs.md@gmail.com

about 60.1% and 73.8%. The reinforcement of 2% of alumina and 2% of alumina with 2% and 4% of silicon carbide were tested [2]. The aluminium Al7075 alloy was reinforced with 3%, 6% and 9% of silicon carbide to enhance the performance of base metal. Among them, 6% silicon carbide sample showed the higher ultimate tensile strength of 180.93MPa and the least tensile strength was observed in 3% silicon carbide of 98.19 MPa. Initially, the ultimate tensile strength increases with the increase in the percentage of silicon carbide after 6% of silicon carbide, decreasing trend has been observed. The Rockwell hardness was found to be maximum for 9% of silicon carbide reinforcement. As the percentage of reinforcement increases, the hardness of the material also increased [3].

2.0 Material and methods

The base material and the reinforcement material were selected from the literature review. The base metal Al7075 alloys were tested for initial chemical composition before the experiments. For reinforcement, 200 mesh silicon carbide was used by 4% by weight of base metal. The chemical composition shown in Table 1.

TABLE 1: CHEMICAL COMPOSITION OF AL7075ALLOY [4]

Element	Specification for Al7075 alloy	Observed values
Al	Rem	REM
Zn	5.1-6.1	5.25
Mg	2.1-2.9	2.24
Cu	1.2-2.0	1.42
Si	0.40 max	0.07
Fe	0.50 max	0.21
Mn	0.30 max	0.02
Ti	0.20 max	0.03
Cr	0.18-0.28	0.22

Fig.1: Ultrasonic module with die during casting

In the present work, the casting were taken using the specially fabricated die assisted with cold water circulation arrangement around it. It is coupled with ultrasonic vibration module in order to induce vibration during the solidification. The main advantage of introducing vibration is that, it promotes the grain refinement by obtaining fine equiaxed grains supressing the formation of straight and long dendrites during the solidification process [5]. The obtained grain structure results in improved strength of the casting. Induction coil furnace was employed for casting. The molten alloy temperature was maintained at a temperature of 760°C for 1 hour. A known quantityof hexachloroethene was added into molten metal as degassing agent. After removal of slag preheated silicon carbide of 4% by weight was introduced into the melt. Molten metal was poured in the precoated-preheated cast iron molds. The vibration module was turned on. The amplitude was kept constant of 30V and frequencies were varied in the range 0kHz, 1kHz, 20kHz and 40kHz with the assistance of signal generator. The castings with varying grain size were obtained for each frequencies are being subjected to testing.

3.0 Experimental details

A. TENSILE TEST

Tensile test is the most commonly used test in order to find the ultimate tensile strength, yield strength, ductility and percentage of elongation of the material. The tensile tests were conducted on standard tensometer as per ASTM E08-8 standard. Prior to loading, the specimens are polished with silicon carbide abrasive papers in grit size ranges from 220 to 800 in order to remove the surface defects [6]. The test is conducted using computer operated horizontal bench-type tensometer in Ramaiah Institute of Technology, Bangalore. The tests were conducted for as-cast and composite specimen at frequencies 0kHz, 1kHz, 20 kHz and 40kHz. Figs.2(a) and 2(b) shows the tensile test specimen before and after test.

Fig.2(a): Tensile test specimen (before test) (b): After tensile test

B. HARDNESS TEST

Hardness measurements were carried out on as cast Al7075 alloy and Al7075+SiC particulate composite specimen obtained at varied frequency levels. Brinell hardness tester was employed for conducting experiments. Load applied was

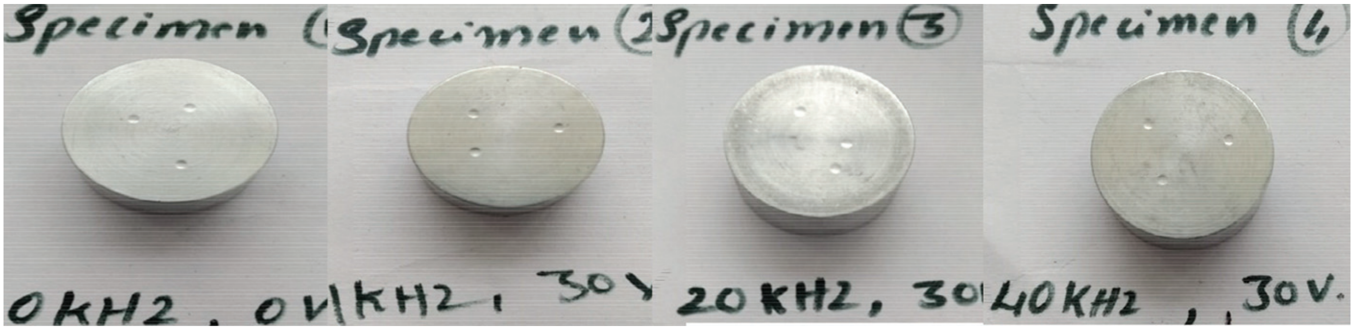


Fig.3: Hardness test specimen

60 kg and an indenter of 10 mm diameter steel ball was used. Cylindrical specimen of 20 mm c/s of diameter and length 30mm were prepared and polished on different grits of emery paper [7]. The polished specimen were tested. On average three hardness measurements across the c/s of the specimen has been considered for the analysis. Fig.3 shows the images of hardness specimens.

C. WEAR TEST

The wear test has been carried out using pin-on-disc tribometer shown in Fig. 4 for 3 different loads 1kg, 2kg and 3kg. The duration of the test is 5 minutes with disc speeds 400rpm, 600rpm and 800rpm.

Fig.4: Pin on disk tribometer

Experimental details

The procedural steps are described below

- Specimen dimension of 10mm × 30mm length were machined from the as-cast alloy and the alloy with reinforcement additions.
- Initial weight of the specimen was noted down. The specimen was fixed to the specimen holder.
- The motor was switched on.
- Surface of the specimen was made to contact the disc.
- At the end of the test, the specimen was removed from the specimen holder, surface was cleaned with acetone, dried and weighed in an electronic balance.
- Weight loss method has been considered for the analysis.

4.0 Result and discussion

A. MICROSTRUCTURE

Fig 5(a), (b) and (c) shows the microphotograph of the as-cast AA7075 and AA 7075 alloy with SiC additions at supply frequency of induced vibration 0kHz, 1kHz and20kHz.The obtained microstructure reveals the formation of evenly distributed fine aluminum dendrites with secondary phase particles.

B. TENSILE TEST

The results of the tensile tests carried out as the as-cast alloy and the alloy reinforced with SiC is illustrated in the Fig 6 shown below. It can be seen from the figure that the as-cast alloy exhibits the least tensilt strength of 127.6 MPa; whereas the reinforced alloy added specimen exhibits increasing trend

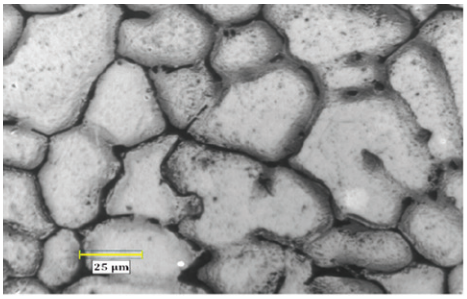
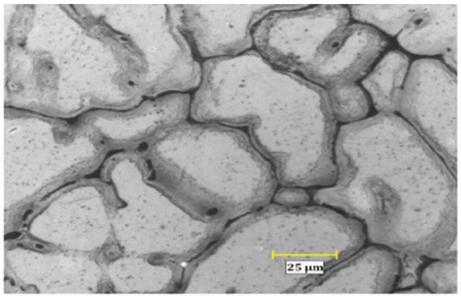
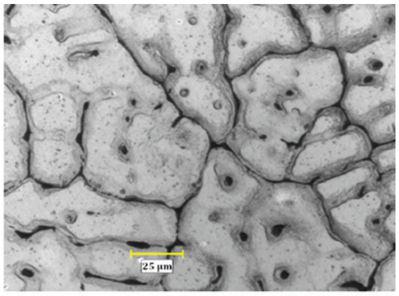


Fig.5(a): Microstructure of as cast- 0 KHz with 4% silicone carbide



(b): Microstructure of as cast- 1 KHz with 4% silicone carbide



(c): Microstructure of as cast- 20KHz with 4% silicone carbide in the tensilt strength values. Increased trend has been observed for increasing the frequency values. Maximum value of 202.4 MPa is noticed for the specimen reinforcement of 4% SiC addition at frequency of 40Hz.

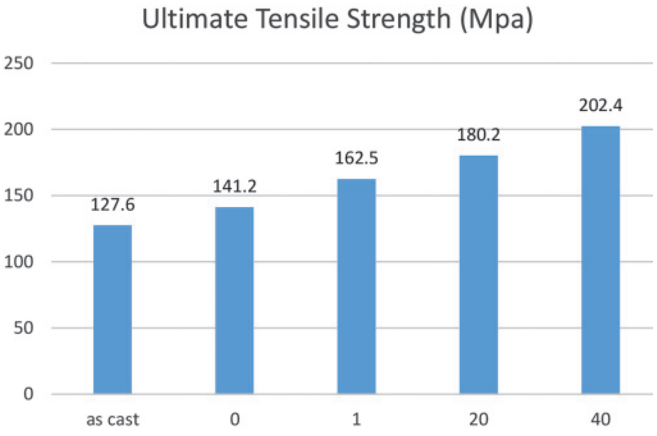


Fig.6: Ultimate tensile strength distribution

Hardness test

The results of the hardness tests carried out as the as-cast alloy and the alloy reinforced with SiC is illustrated in the Fig.7 shown below. It can be seen from the figure that the as-cast alloy exhibits the least hardness value of 87.12 BHN; whereas the specimen with reinforced alloy exhibits increasing trend in the hardness values.

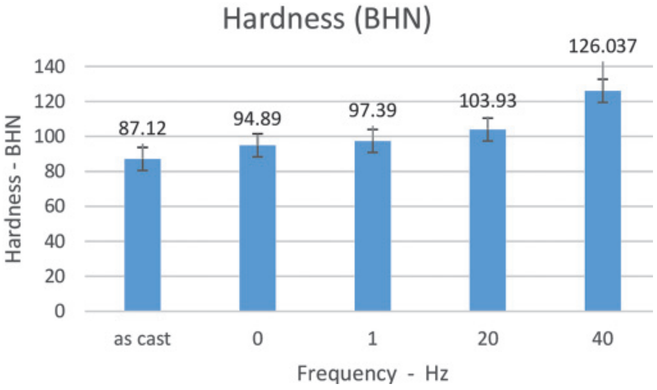


Fig.7: Hardness vs frequency

By the addition of 4% by Wt. of silicon carbide into aluminium alloy, the hardness value is being increased by 8.9% due reinforcement. By inducing vibration during the solidification for the grain refinement, upon increasing the frequency of the vibration hardness of the specimen also increases. Maximum value of the hardness is noticed for the specimen reinforcement of 4% SiC addition at 40 kHz.

Wear test

The experiments were conducted with changing load, velocity and duration. In first and second set of experiments velocity and load was varied keeping constant test duration of 5 minutes. ASTM G99 standard is followed in the present investigation. In this study tests were conducted in three stages highlighted in Table 2.

Figure below shows the variation of weight loss for different combinations. Fig.8(a) shows the variation of weight loss for different specimen varients at a speed of 400 rpm.

It can be seen from the figure that with increase in frequency values during solidification process the wear rate reduces gradually. The similar decreasing trend in wear rate is observed for all the conditions investigated as illustrated in Figs 8(b) and 8(c). SiC reinforced composite exhibit higher wear resistance under different sliding velocities. This is due to the fine equiaxed grains formed during solidification and distribution of secondary phase particles around fine aluminum grains. This behaviour can also be attributed to the presence of SiC particles on the counter surface, which act as a transfer layer and effective barriers to prevent large-scale displacement of specimen. Least weight loss was drawn for 4% SiC addition at a speed of 400 rpm. It has also been observed that weight loss in the as-cast specimen is more compared to other treated specimen this may be due to presence of soft, course Alpha-Al grain structure.

Wear tests were carried out at a load of 2 kg. It can be seen from the Fig.9(a), (b) and (c) that the weight loss in the as-cast specimen is more compared to the specimen with reinforcement. This might be due to presence of soft, course Alpha-Al grain structure. Upon increasing the load the weight loss also increases in comparison with previous set of experiments has been observed. Due to the presence of very finely distributed secondary phase particles around aluminium grains. Lesser weight loss was observed at a supply frequency of 40 kHz. Upon increasing the speed weght loss also increases which can be seen in Fig.9(d). But decreasing trend is observed for the composite specimens. Least weight loss was observed for the test samples prepared at frequency of 40 kHz.

Wear tests were carried out at a load of 3kg. It can be seen from the Figs.10(a), (b) and (c) that the weight loss in the as cast specimen is more compared to the specimen with

TABLE 2: WEAR TEST PARAMETERS

Conditions	Stage I	Stage II	Stage II
Load applied, kg	1	2	3
Test duration, min	5	5	5
Sliding speed, m/s	400, 600, 800	400, 600, 800	400, 600, 800
Frequency range, kHz	0, 1, 2, 3, 4	0, 1, 2, 3, 4	0, 1, 2, 3, 4

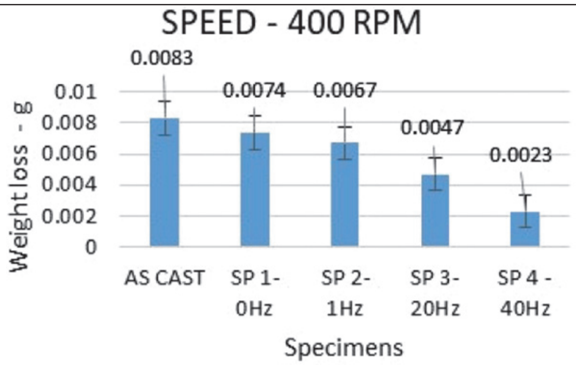


Fig.8(a): Load 1Kg and speed 400 RPM

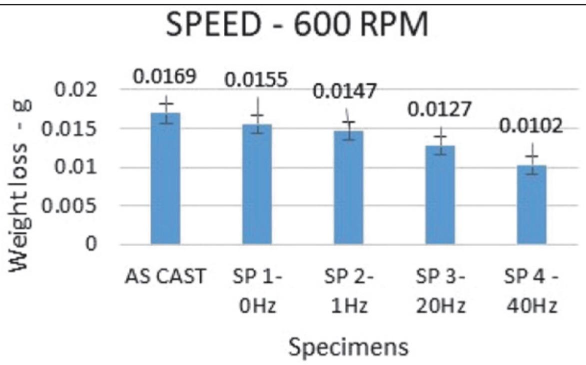


Fig.8(b): Load 1kg for 5 minutes of duration

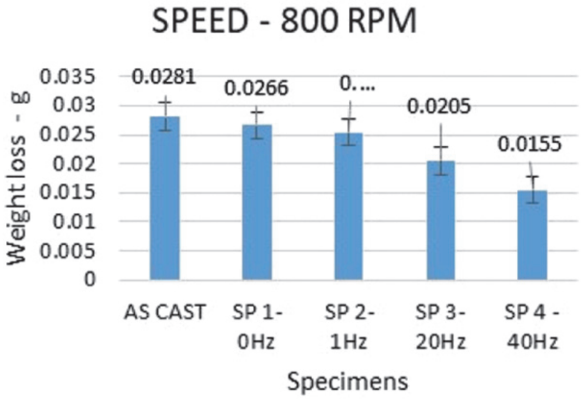


Fig.8(c): Load 1Kg and speed 800 RPM

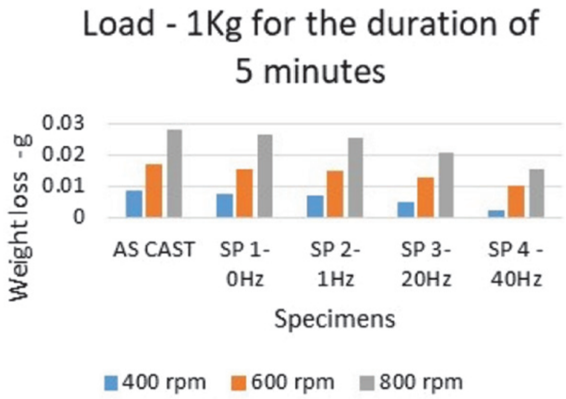


Fig.8(d): Load 1kg for 5 minutes of duration

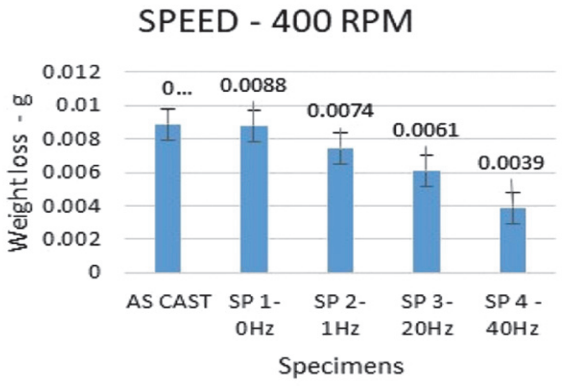


Fig.9 (a): Load 2Kg and speed 400 RPM

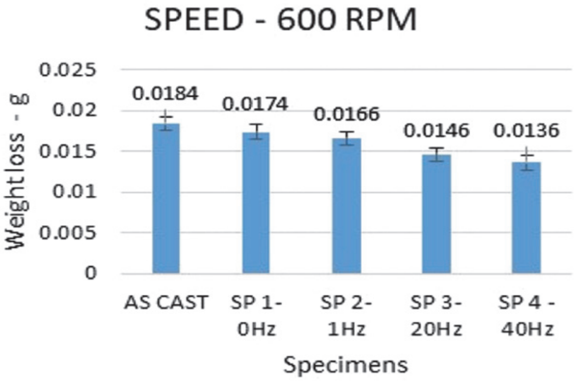


Fig.9 (b): Load 2Kg and speed 600 RPM

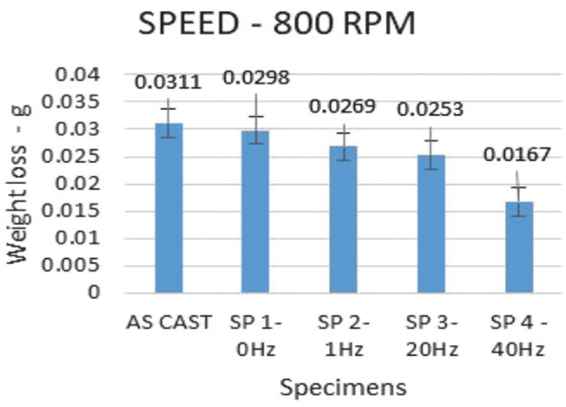


Fig.9 (c): Load 2Kg and speed - 800 RPM

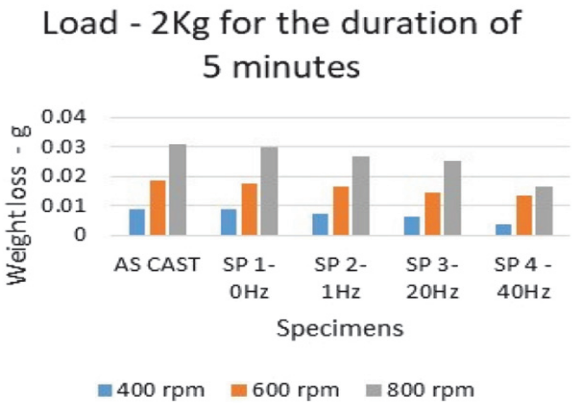


Fig.9 (d): Load 2 kg for 5 minutes of duration

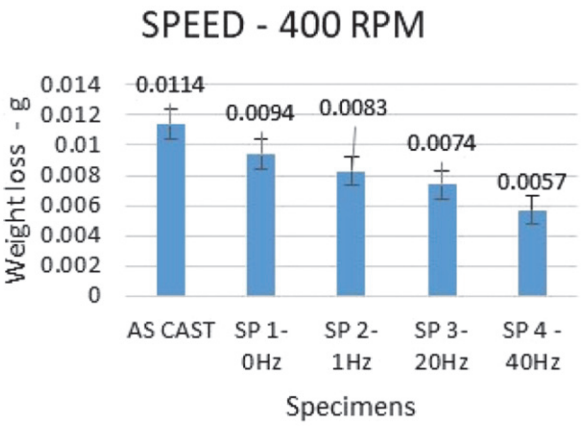


Fig.10(a): Load 3Kg and speed 400 RPM

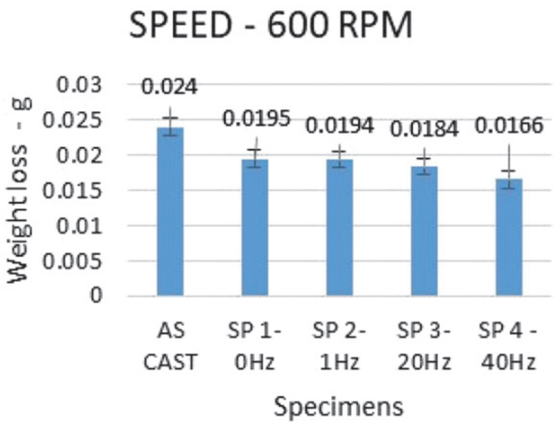


Fig.10(b): Load 3Kg and speed 600 RPM

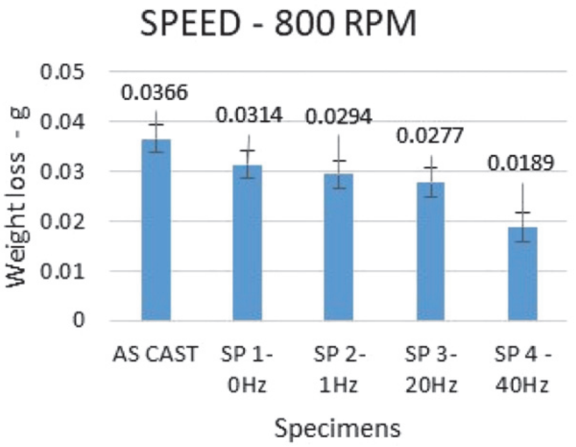


Fig.10(c): Load 3Kg and speed 800 RPM

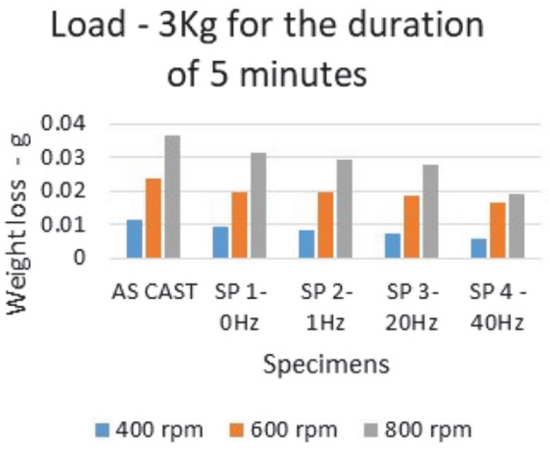


Fig.10(d): Load 3Kg for 5 minutes of duration

reinforcement.This might be due to presence of soft, course Alpha-Al grain structure. Upon increasing the load the weight loss also increases in comparison with previous set of experiments has been observed. Due to the presence of very finely distributed secondary phase particles around aluminium grains. Lesser weight loss was seen at a supply frequency of 40 kHz. As the speed increases the weight loss also increases as observed in Fig.10(d). Least weight loss was reported for the test samples prepared at frequency of 40 kHz.

6.0 Conclusions

- The alloy and composite was successfully fabricated using liquid metallurgy technique. Differrent castings were prepared by varying the frequency levels.
- Maximum hardness value was found to be 126.037 BHN for the composite containing 4 % SiC addition at a supply frequency of 40 kHz in comparision with as cast specimen which exhibit lower hardness value of 87.12 BHN.
- UTS values was found to be more for specimen with SiC additions fabricated at 40 kHz frequency and there is an improvement of 58.57% in UTS has been observed in comparison with as-cast specimen.
- Micro structure studies reveal the distribution of the particles and dendritic structure. Fine secondary particles distributed around a-Al grains
- From the wear studies it is observed that, the load, sliding speed and ultrasonic frequency are the contributing factors affecting the wear.
- It was found that wear resistance of the composite increases with increased addition of reinforcements and selected higher frequency during the fabrication.

References

[1] Gopalakrishnan S., Senthilvelan T, (2015): Synthesis and characterization of Al 7075reinforced with SiC and B_4C nano particles fabricated by ultrasonic cavitation method. *Journal of Scientific & Industrial Research*.

[2] Kannan C., Ramanujam R., (2017): Comparative study on the mechanical and microstructural characterisation of AA 7075 nano and hybrid nanocomposites produced by stir and squeeze casting. *Journal of Advanced Research.*

[3] Kumar Premvrat, Katiyar Sandeep, (2018): Effect of Mechanical Mould Vibration on the Properties of Sand Casting Aluminium (A-1100) Alloy, *International Journal of Engineering Research & Technology* (IJERT) Volume 07, Issue 06 (June 2018)

[4] Vinoth Babu 1 N., Dr. Moorthy T.V., (2014): Synthesis and characterization of Al7075/SiC composite by Stir casting,

Applied Mechanics and Materials Vol.5 592-594.

[5] Mishra S.S., Sahu S.S, Ray V. (2015):Effect of mold vibration onmechanical and metallurgical properties of al-cu alloy. *International Journal For Technological Research In Engineering* Vol.3, Issue 1.

[6] Girisha K.B., Dr. Chittappa H.C., (2013): Preparation, characterisation and wear study of aluminium alloy (al356.1) reinforced with zirconium nano particles, *International Journal of Innovative Research in Science, Engineering and Technology.*

[7] Suryanarayanan K., Praveen R., Raghuraman S., (2013): Silicon Carbide Reinforced Aluminium Metal Matrix Composites for Aerospace Applications: A Literature Review, *International Journal of Innovative Research in Science, Engineering and Technology.*

[8] Gowrishankar T P, Manjunath L H, Jegadeeswaran N (2017): The Properties of an Aluminium Metal Matrix Composites: A Review, *International Journal of Advances in Scientific Research and Engineering*.

[9] Venkatachalam G. and Kumaravel A., (2017): Mechanical Behaviour of Aluminium Alloy Reinforced With SiC/Fly Ash/Basalt Composite for Brake Rotor, *Polymers & Polymer Composites*, Vol. 25, No. 3.

[10] Bharath V, Nagaral Madev, Auradi V and Kori, S. A. (2014): Preparation of 6061Al-Al2O3 MMC's by Stir Casting and Evaluation of Mechanical and Wear Properties, Procedia Materials Science 6 1658 – 1667.

[11] Abugh A., Kuncy I.K, (2013): Microstructure and mechanical properties ofvibrated and weldments, , University of agriculture, P.M.B 2373, Makurdi-Nigeria, pp.7-13.

[12] Mr. Suragimath Prashant Kumar, Dr. Purohit G. K., (2013): A Study on Mechanical Properties of Aluminium Alloy (LM6) Reinforced with SiC and Fly Ash, *IOSR Journal of Mechanical and Civil Engineering* (IOSR-JMCE).

[13] Ravi B., (2017): Fabrication and Mechanical Properties of Al7075-SiC-TiC Hybrid Metal Matrix Composites, *International Journal of Engineering Science Invention.*

[14] Singh Gurlabh, Singh Sidhu Gurpreet, (2017): Development and Analysis of Aluminium Based Alloy A356 Reinforced with Aluminium Nitride and Magnesium by Stir Casting Technique, *International Advanced Research Journal in Science, Engineering and Technology.*

SEPARATION OF GANGUE FROM LIMESTONE USING GLCM, LBP, LTP AND TAMURA

(Continued from page 33)

24. Ojala, T. and Pietikinen, M. (1999): Unsupervised texture segmentation using feature distributions. *Pattern Recognition.* 32 477–486.
25. Ojala, T., Pietikinen, M. and Harwood, D.A. (1996): Comparative study of texture measures with classification based on feature distributions. *Pattern Recognition*. 19(3) 51– 59.
26. Perez, C.A., Estévez, P.A., Vera, P.A., Castillo, L.E., Aravena, C.M., Schulz, D.A. and Medina, L.E. (2011): Ore grade estimation by feature selection and voting using boundary detection in digital image analysis. *International Journal of Mineral Processing.* 101(1) 28-36.
27. Reddy, K.G.R. and Tripathy, D.P. (2013): Separation of gangue from coal based on histogram thresholding. *International Journal of Technology Enhancements and Emerging Engineering Research*. 1(4) 31-34.
28. Riedel, F. and Wotruba, H. (2004): Pre-concentration by sensor-based sorting devices in mineral processing. *Proceedings of Mineral Processing Technology*. 37-44.
29. Salter, J.D. and Wyatt, N.P.G. (1991): Sorting in the minerals industry: past, present, and future. *Minerals Engineering.* 4(7-11) 779-796.
30. Sanchez, M.S. and Sarabia, L.A., (1995): Efficiency of multi-layered feed-forward neural networks on classification in relation to linear discriminant analysis, quadratic discriminant analysis and regularized discriminant analysis. *Chemometrics and Intelligent Laboratory Systems*. 28(2) (1995) 287-303.
31. Singh, N., Singh, T.N., Tiwary, A. and Sarkar, K.M. (2010): Textural identification of basaltic rock mass using image processing and neural network. Computational Geosciences. 14(2) 301-310.
32. Singh, V. and Rao, S. M. (2005): Application of image processing and radial basis neural network techniques for ore sorting and ore classification. *Minerals Engineering*. 18(15) 1412-1420.
33. Song, X. R. and Wang, F. J. (2007): Research on coal gangue on-line automatic separation system based on the improved BP algorithm and arm. Sixth International Conference on Machine Learning and Cybernetics. 5 2897-2900.
34. Tamura, H., Mori, S. and Yamawaki, T. (1978): Textural features corresponding to visual perception. IEEE Transactions on Systems, Man, and Cybernetics. 8(6) 460-473.
35. Tan, X. and Triggs, B. (2010): Enhanced local texture feature sets for face recognition under difficult lighting conditions. *IEEE transactions on image processing*. 19(6) 1635-1650.
36. Tessier, J., Duchesne, C. and Bartolacci, G. (2007): A machine vision approach to online estimation of run-of-mine ore composition on conveyor belts. *Minerals Engineering*. 20(12) (2007) 1129–1144.
37. Wang, R. and Liang, Z. (2011): Automatic separation system of coal gangue based on DSP and digital image processing. 2011 Symposium on Photonics and Optoelectronics (SOPO). IEEE. 1-3.
38. Zhang, C., and Zhang, C. (2012): Coal gangue separation system based on density measurement. IEEE International Conference on Computer Science and Automation Engineering (CSAE).1 216-218.
39. Zhang, Z., Yang, J., Ding, L. and Zhao, Y. (2012): Estimation of coal particle size distribution by image segmentation. *International Journal of Mining Science and Technology*. 22(5) 739-744.

Printed by Pradip Kumar Chanda at The Indian Press Pvt. Ltd. 93A Lenin Sarani, Kolkata 700 013 and
published by him for Books & Journals Pvt. Ltd. from 62 Lenin Sarani, Kolkata 700 013.