www.czasopisma.pan.pl PAN www.journals.pan.pl

ARCHIVES
of
FOUNDRY ENGINEERING

10.24425/afe.2020.133359

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (2299-2944)
Volume 2020
Issue 4/2020

133 – 138

19/4

Investigation of SiC Particle Size Variation on the Tribological Properties of Cu-6Sn-SiC Composite

K. V. Shankar [a,*], A. M. Chandroth [a,b], K. J. A. Ghosh [a], C. B. Sudhin [a], A. S. Pai [a], A. Biju [a], K.R. Sriram [a]
[a] Department of Mechanical Engineering, Amrita Vishwa Vidyapeetham, Amritapuri, India
[b] Department of Industrial and Material Science, Chalmers University of Technology, Sweden
* Corresponding author. E-mail address: karthikvs@am.amrita.edu

Received 01.09.2020; accepted in revised form 27.11.2020

Abstract

Copper have always been an important material and incorporation of elements into copper for property enhancement. Bronze is a relevant cuprous alloy which is important for many industrial and automotive applications like bearings and machineries. The present research is directed towards the fabrication and tribological analysis of regular bronze (Cu-6Sn) and metal matrix composites reinforced with varying particle sized SiC ceramic reinforcement (30, 35 and 40 µm). The developed specimens were subjected to wear analysis according to ASTM standards, to identify the tribological properties utilizing a pin on disk tribometer. It was noted that the wear rates of developed MMC's phenomenally decremented with an increase in size of SiC particle reinforcement. Also, the test parameters were influential in altering the wear rates to notable margins. The standard scanning electron microscopy techniques aided in identifying the influence of adhesive wear on the specimen surface.

Keywords: Cu-6Sn, SiC, Metal matrix composite, Wear

1. Introduction

In the modern era, selection of materials plays a vital role in increasing the efficiency of parts and quality improvisation of the product. Alloys were preferred for all major terrestrial and extraterrestrial applications earlier. The conventional materials have always had its drawback considering the mechanical, tribological, thermal and electrical properties which made them unsuitable for several complex and important applications. This led the researchers to think about new modified materials having exceptional properties that satisfies the customer demands. Recently, the interest is being shifted towards Metal Matrix Composites (MMC). MMC's are consolidation of specific materials which results in the enhancement of base material properties. More systematic development methods are being structured by researchers which allows to design the composites according to the relevant engineering properties. Such enhanced composites can be utilised to develop automotive products like wear plates, bearings and bushings which are subjected to immense mechanical and thermal loads. In accordance with the literature, the tribological and mechanical properties of metal matrix composites is extensively depended on the ceramic particle size and particle volume fraction of reinforcement [1], [2] . Certain MMC's have numerous applications including linings of cylinders, automotive parts, spacecraft and aircraft applications are also having increased thermal stability and strength which makes them suitable for various critical aerospace and defense applications [3].

Copper and cuprous alloys have always been existing as the most preferred material due to its extensive material properties which makes it exploitable for various critical applications. However, the incrementing necessity of materials with enhanced material strength to weight ratio and stiffness resulted in development of alloys and composites of copper. From the literature survey carried out, it has been found out that, various reinforcements effect the material property in different ways. Copper when alloyed with Sn was found to show an intensive increase in properties like hardness which also improves the wear resistance of the material [4]. However, addition of reinforcements like Al_2O_3, SiC and B_4C resulted in marginal surge in material density values as a result of increased sinterability with the addition of reinforcement [5]. An approach from M. Asnavandi et al. [6], investigated on the effect of reinforcements like graphite and SiC which results in some alluring conclusions. The hardness value of the manufactured composites were found to escalate with a surge in the wt-% percentage of SiC particle and decremented with the graphite content due to lowering of the composite density [7]. Various investigations were also carried out on the influence of SiC addition in Cu-Cr matrix and was found to increase the wear resistance due to successful reduction in coefficient of friction with incrementation in percentage of reinforcement [8].

The reinforcement type also influences the properties of composites accordingly. Many complex and mechanically stable structures can be created with different types of reinforcing material. Nevertheless, the studies on aluminium MMC with different types of reinforcements revealed that the wear resistance was not generally influenced by the type of reinforcements [9], [10]. The reinforcement percentage had positive and adverse effects on the MMC developed but the effect of reinforcement ceramic particle size was still uncertain.

In the present investigation, the experiments were carried out with SiC reinforcement having different particle size (30, 35and 40 *µm*) in Cu-Sn matrix to develop bronze specimens suitable for bearing applications. From the literature, it was evident that bronze is a suitable material for developing wear resistant components [9].

There are numerous manufacturing techniques for composites like friction stirring, powder metallurgy, centrifugal casting etc. Centrifugal casting techniques and the effect of SiC particles size in wear resistance of developed Cu MMC is least studied. This present investigation includes the development of Cu MMC with SiC reinforcement having varying particle sizes (30, 35 and 40 *µm*) using metal die stir casting method. The developed composite material was subjected to numerous mechanical tests based on ASTM standards.

2. Experimental Procedure

2.1. Materials and methodology

The experiments were conducted by choosing Cu-Sn as the matrix due to its improved wear resistance compared to pure Cu and cuprous alloys. Also, the percentage of Sn added effects the tribo-mechanical properties of the matrix. The composite was fabricated by reinforcing 10 wt-% SiC particles of varying particle sizes (30, 35 and 40 µm) having enhanced wettability with copper alloys [9].

2.2. Fabrication of composites

The MMC was fabricated using stir casting method as shown Figure 1. The manufacturing of the composite rods was done by reinforcing SiC particles of varying particle size. As per the literatures, this method is found to be useful in ensuring uniform distribution of particles throughout the base matrix and enhancing the particle-matrix interfacial bonding [11] .

The melting was conducted in an inert Argon atmosphere to prevent oxidization of the cast specimen. A graphite crucible was loaded with pure copper and was heated till the melting point of copper was attained (approx. 1100 °C). This was followed by the addition of tin (6wt-%) and preheated 10 wt-% of SiC particles having a particle size of 30 µm. The preheating of the reinforcement particle will assist in drastic reduction of thermal unevenness between the matrix and reinforcement [9]. The parameters for the stir casting process as shown in Table 1 were chosen accordingly to ensure uniform distribution of particulate reinforcement in the matrix.

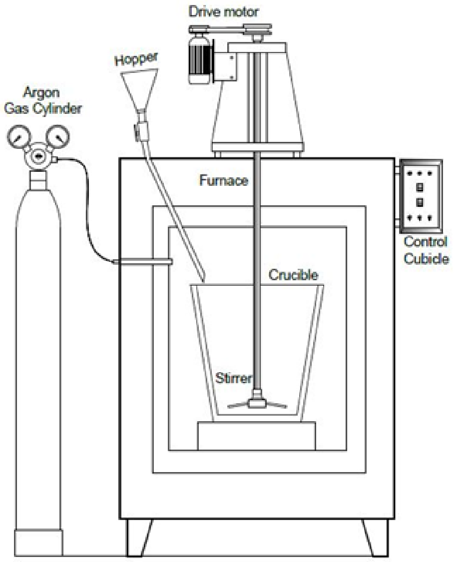

Fig. 1. Schematic sketch of electric arc furnace

The developed melt was transferred into a die made of Oil Hardened Non-Shrinkage Steel (OHNS Steel) which was preheated to a temperature of 300 – 350 °C to obtain cast rods of 150 mm long × 16 mm dia. The developed as- cast specimens were demolded from the metal die after solidification process. The procedure mentioned above was conducted for 35 µm and 40 µm SiC particle size to develop the required cast rods.

Table 1.
Parameters for stir casting [9]

Stirrer speed	150 rpm
Time	20 – 25 min

Tests were carried out to analyze the tribological aspects of the developed MMC, which are detailed in the trailing content. The presence of SiC particle in the Cu-Sn was validated using standard energy dispersion spectroscopy techniques which is generally used for the purpose. From the analysis reports shown in Fig 2-4, it can be concluded from the figure that the particles were present in the matrix in all the specimens of varying SiC particle sizes.

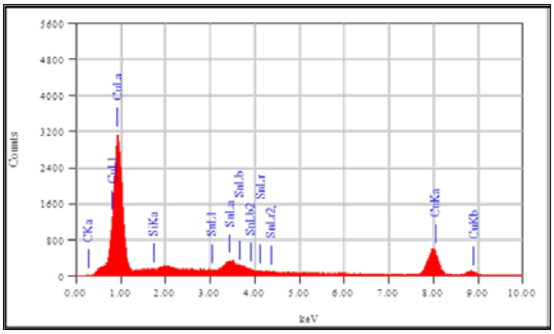

Fig. 2. EDS spectrum of Cu-Sn-SiC MMC with a SiC ceramic particle size of 30 µm

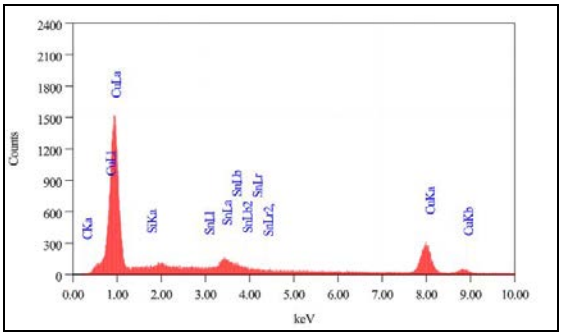

Fig. 3. EDS spectrum of Cu-Sn-SiC MMC with a SiC ceramic particle size of 35 µm

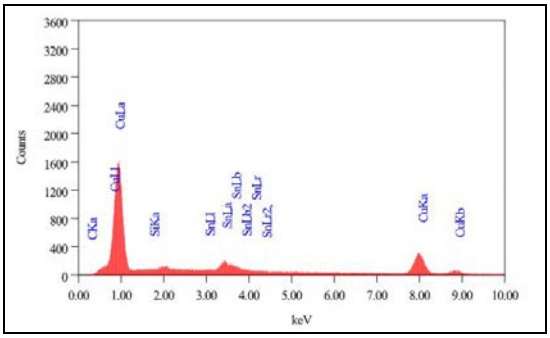

Fig. 4. EDS spectrum of Cu-Sn-SiC MMC with a SiC ceramic particle size of 40 µm.

2.3. Wear Test

The wear specimens were prepared asper ASTM G99 standards and the test was performed using a pin on disk Tribometer as shown in Fig.5 [12]. The prepared pin shaped dry sliding wear test specimens were of dimensions 20 mm x 10 mm and was tested on a counter face disk made of EN - 31 steel. Initial and final weight difference of the test specimens were noted down prior and after each experiment to determine the sample mass loss. Each experiment was conducted at varying loads (10, 20 and 30 N), varying sliding velocities (1, 2 and 3 m/s) and a constant sliding distance of 1000 m.

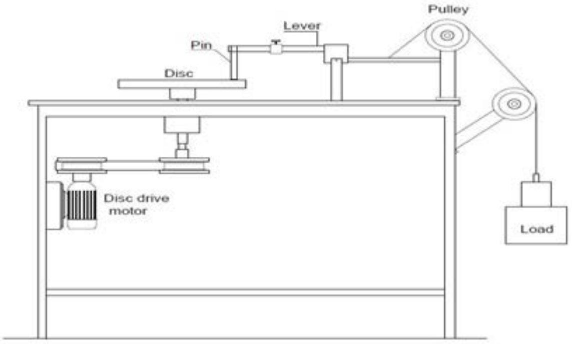

Fig. 5. Schematic sketch of pin on disc tribometer

3. Results and Discussions

In this investigation, the wear rates were analysed by utilising the pin on disc tribometer and the observed results were tabulated and calculated in order to find the enhanced effects of reinforcement addition.

3.1. Effect of load on wear behaviour of developed MMC

The material wear rates of the developed Cu-Sn and SiC reinforced Cu-Sn metal matrix composite samples were determined at a constant sliding velocity of 3 m/s, constant sliding distance (1000 m) and varying loads of 10, 20 and 30 N were determined and depicted in the trailing figure (Figure 6). It is evident from the figure (Figure 6) that the wear rates show phenomenal incrementation with increase in loads. This influence of load on the material removal rate of the specimens can be attributed to the increase in clustering of frictional forces, which are generated as a result of interaction between the EN 31 steel counter disk and test specimens [13]. The decrease in wear resistance properties after subjecting to loads above 20 N might be due to the generation of Mechanical Mixed Layer (MML) which acts as a protective shield against material removal [9], [14].

From the figures (Figure 6), it can be identified that the wear rate of regular bronze is higher compared SiC reinforced MMC’s. This enhancement in wear resistance can be due to the presence of hard phase SiC particles which imparts a resistance to material removal [9]. Also, as a result of this enhancement in wear resistance, the hardness values of the developed specimens were found to be satisfactory according to previous investigations [15]. Nevertheless, a notable increase in wear rate is identified in MMC specimens reinforced with SiC ceramic particles of size 40 μm. From the conducted literature survey, it is evident that this reduction in wear resistance can be a result of agglomeration of SiC ceramic particles in the bronze matrix. From the analysis, it was inferred that the MMC's reinforced with SiC particles of size 35 μm shows enhanced properties compared to other specimens. This can be attributed to the enhanced bonding properties improved wettability and uniform distribution of SiC particulate phases in the Cu-Sn matrix [9], [15].

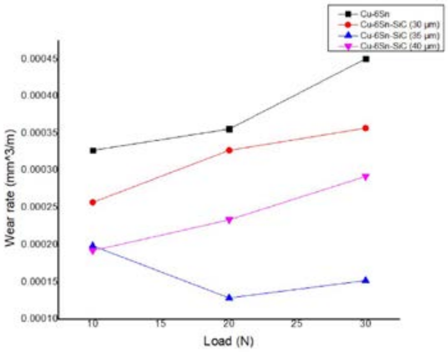

Fig. 6. Plot depicting the influence of varying mechanical load on wear rate

3.2. Effect of sliding velocity on wear behaviour of developed MMC

Material wear rates of developed Cu-6Sn and MMC reinforced with ceramic particles of varying size (30, 35 and 40 μm) SiC reinforced Cu-Sn subjected to a consistent mechanical load of 30 N and sliding distance of 1000 m and varying sliding velocities (1, 2 and 3 m/s) were determined and plotted for further analysis (Figure 7). From Figure 7, it is evident that the material wear rates of regular bronze (Cu-6Sn) shows a surge in values with an incrementation in sliding velocity up to 2 m/s. Nevertheless, the developed MMC's showed a satisfactory contradiction in wear rates at sliding velocities 1 and 2 m/s. This characteristic shown by the developed MMC might be due to the increase in hardness as a result ceramic particle reinforcement [16] . An optimum material removal rate is observed in the case of MMC reinforced with SiC particles of size 35 μm. This can be associated with the improvement in material hardness of MMC due to hindering of dislocation motion by reinforced SiC ceramic particles. An undesirable surge in the wear rate values of 40 μm SiC particle reinforced MMC can be associated to the clustering of SiC ceramic particles in the metallic matrix [9], [17].

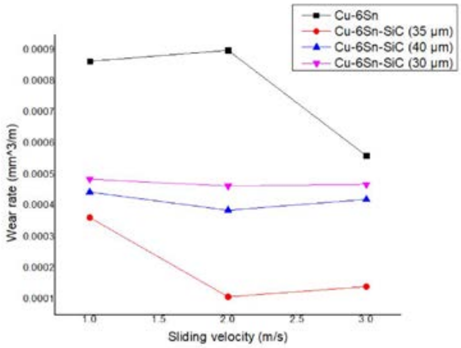

Fig. 7. Plot depicting the effect of varying sliding velocities on wear rate

3.3. Effect of particle reinforcement size on wear behaviour of developed MMC

The Figure 8 depicts the calculated material wear rate values of developed Cu-6Sn alloy along with MMC's strengthened with SiC ceramic particulate phases of different sizes (30, 35 and 40 μm), subjected to varying load of 10, 20 and 30 N at a consistent sliding velocity of 3 m/s and sliding distance of 1000 m. The figure clearly portrays the decreasing trend of wear rate values of MMC's with increase in size of reinforced ceramic particles up to 35 μm. However, a marginal surge in wear rate values is noted in developed MMC with 40 μm SiC ceramic particle reinforcement. From, the literatures, this can be related to the wettability of SiC reinforcement particles in the bronze matrix and agglomeration of reinforced hard phase ceramic particles [1], [13].

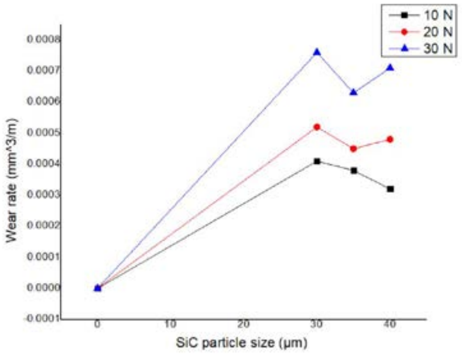

Figure 8: Plot depicting the influence of varying SiC ceramic particle size on wear rate.

3.4. Wear surface Analysis

The wear analysis of surface subjected to wear test experiment was conducted out using standard electron microscopy (SEM) techniques. Figures 9 – 12 depicts the worn-out surface morphology of developed Cu-6Sn and SiC reinforced

MMC's subjected to wear analysis. Figures 9 - 12 clearly portrays the presence of deep and shallow pores. The size and number of pores are larger in the wear surface of normal bronze (Cu-6Sn) as a result of coarse adhesive wear which can be related to the improvised hardness of SiC reinforced MMC's compared to regular bronze [13]. The wear surface images of SiC reinforced MMC's depicted mild debris formation and trivial grooves which indicates the occurrence of reduced wear with increase in SiC ceramic particle size [9].

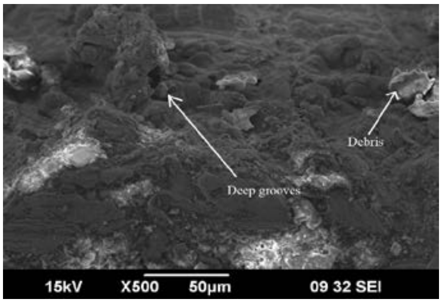

Fig. 9. Wear surface micrograph of regular bronze (Cu-6Sn)

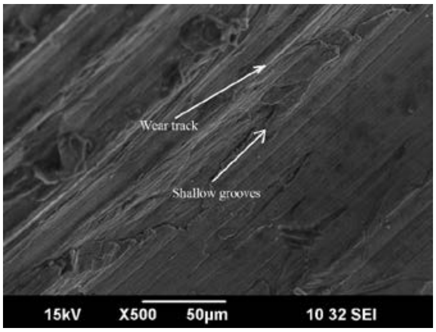

Fig. 10. Wear surface micrograph of Cu-Sn-SiC MMC with SiC ceramic particle size of 30 µm

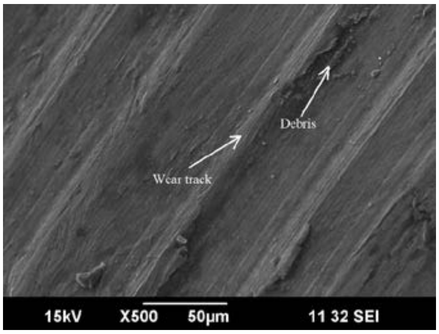

Fig. 11. Wear surface micrograph of Cu-Sn-SiC MMC with SiC ceramic particle size of 35 µm

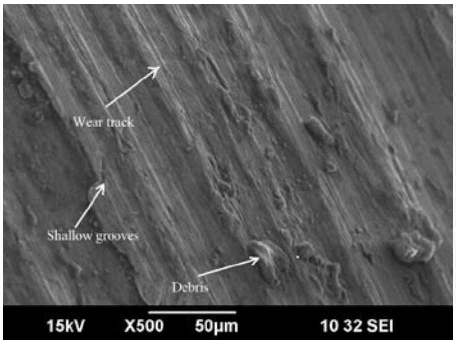

Fig. 12. Wear surface micrograph of Cu-Sn-SiC MMC with SiC ceramic particle size of 40 µm

4. Conclusion

The present investigation was carried out in order to evaluate tribological characteristics exhibited by MMC's reinforced with SiC ceramic particles of varying sized particulate phases. The trailing denouement can be formulated from the analysis of quantified results.

It is evident from the results that the wear rates of the developed regular bronze and SiC reinforced MMC's showed a notable depletion in values with increase in particle size of reinforced SiC ceramic particles up to 35 μm. A contradicting observation noted in the case of 40 μm SiC reinforced MMC was found out to be due to the agglomeration of dispersed ceramic particles. The test parameters were found to be effective in controlling the wear rates of developed MMC both beneficially and adversely. The variation in load was found to be affecting the increase in wear rates due to cumulative frictional forces. The sliding velocity of the counter disk was found to alter the wear rates adversely. Nevertheless, a decrementation in wear rate noted at a sliding velocity of 3 m/s indicates the generation of MML on the specimen surface. The wear analysis of the developed specimens pointed out the formation of shallow and deep groves, debris and wear tracks due to adhesive wear between MMC test specimen surface and counter disk manufactured using EN 31 steel.

Acknowledgement

The authors would like to thank Carborundum Universal Ltd, a part of Murugappa Group, India for providing us with the ceramic reinforcement used in this research.

References

[1] Tjong, S.C. & Ma, Z.Y. (2000). Microstructural and mechanical characteristics of in situ metal matrix composites. *Materials Science and Engineering: R Reports.* 29(3), 49-113. DOI: 10.1016/S0927-796X(00)00024-3.

[2] Krishnan, R.U. *et al.*(2019). Development of bronze metal matrix composite for automobile and marine applications. *Materials Science Forum.* 969 MSF, 415-420.

DOI: 10.4028/www.scientific.net/MSF.969.415.

[3] Hooker, J.A. & Doorbar P.J. (2000) Metal matrix composites for aeroengines. *Materials Science and Technology*. 16(7-8), 725-731, DOI: 10.1179/026708300101508414.

[4] Paul, C. & Sellamuthu, R. (2014). The effect of Sn content on the properties of surface refined Cu-Sn bronze alloys. *Procedia Engineering.* 97, 1341-1347. DOI: 10.1016/j.proeng.2014.12.414.

[5] Öksüz, K.E. (2015). A Study on Al_2O_3/SiC/B_4C Reinforced Cu-Sn Matrix Composite by Warm Compaction Powder Metallurgy. *Advanced Materials Research.* 1128, 123-126. DOI: 10.4028/www.scientific.net/amr.1128.123.

[6] Asnavandi, M., Ghorbani, M. & Kahram, M. (2013). Production of Cu-Sn-graphite-SiC composite coatings by electrodeposition. *Surface and Coatings Technology*. 216, 207-214. DOI: 10.1016/j.surfcoat.2012.11.042.

[7] Gautam, R.K., Ray, S., Jain, S.C. & Sharma, S.C. (2008). Tribological behavior of Cu-Cr-SiCp in situ composite. *Wear.* 265(5-6), 902-912. DOI:10.1016/j.wear.2008.01.023.

[8] Korkut, M.H. (2004). Effect of particulate reinforcement on wear behaviour of aluminium matrix composites. *Materials Science and Technology.* 20, 73-81.

[9] Radhika, N., Karthik, R., Gowtham, S. & Ramkumar, S. (2019). Synthesis of Cu-10Sn/SiC Metal Matrix Composites and Experimental Investigation of its Adhesive Wear Behaviour. *Silicon.* 11(1), 345-354. DOI: 10.1007/s12633-018-9848-6.

[10] Bhatija, K.A. & Radhika, N. (2017). Studies on sliding wear characteristics of aluminium LM25/silicon dioxide functionally graded composite and optimisation of parameters using response surface methodology. *Materwissenschaft und Werkstofftechnik.* 48(6), 600-610. DOI: 10.1002/mawe.201600560.

[11] Nithesh, R., Radhika, N. & Shiam Sunder, S. (2017). Mechanical properties and adhesive scuffing wear behavior of stir cast Cu-Sn-Ni/Si3N4 composites. *Journal of Tribology*. 139(6). DOI: 10.1115/1.4036185.

[12] ASTM Compass, “Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus1,” 2020. https://compass.astm.org/EDIT/html_annot.cgi?G99+17#s00008 (accessed Apr. 17, 2020).

[13] Akshay, M.C., Aravind Senan, V.R., Vignesh Surej, K.S., Akhil, B., Shankar, K.V. & Shankar, B. (2019). Determination on the effect of ti addition on the microstructural, mechanical and wear behavior of Cu–6Sn alloy in as-cast condition. *Transactions of the Indian Institute of Metals.* DOI: 10.1007/s12666-019-01835-5.

[14] Rosenberger, M.R., Schvezov, C.E. & Forlerer, E. (2005). Wear of different aluminum matrix composites under conditions that generate a mechanically mixed layer. *Wear*. 259(1-6), 590-601. DOI: 10.1016/j.wear.2005.02.003.

[15] Shankar, K.V., Ghosh, K.J.A., Sudhin, C.B., Pai, A.S., Biju, A. & Sriram, K.R. (2020). Investigating the significance of SiC particle size on the mechanical properties of Cu-6Sn-SiC composite. *Int. J. Materials Engineering Innovation*. 11(4), 323–337.

[16] Mahesh Kumar, V. & Venkatesh, C.V. (2018). Effect of ceramic reinforcement on mechanical properties of aluminum matrix composites produced by stir casting process. *Materials Today. Proceesings.* 5(1), 2466-2473. DOI: 10.1016/j.matpr.2017.11.027.

[17] Hou, K.H., Ger, M.D., Wang, L.M. & Ke, S.T. (2002). The wear behaviour of electro-codeposited Ni-SiC composites. *Wear.* 253(9-10), 994-1003. DOI: 10.1016/S0043-1648(02)00222-3.