Preparation of SiC based Aluminium metal matrix nano composites by high intensity ultrasonic cavitation process and evaluation of mechanical and tribological properties

N V Murthy[1*], A Prasad Reddy[2], N Selvaraj[3], C S P Rao[4]

[1]Research Scholar, Mechanical Engineering Department, NIT Warangal, Telangana, India.
[2]Research Scholar, Mechanical Engineering Department, NIT Warangal, Telangana , India
[3]Professor, Mechanical Engineering Department, NIT Warangal, Telangana , India
[4]Professor, Mechanical Engineering Department, NIT Warangal, Telangana, India

E-mail: nvm.nitw@gmail.com

Abstract Request augments on a worldwide scale for the new materials. The metal matrix nano composites can be used in numerous applications of helicopter structural parts, gas turbine exit guide vane's, space shuttle, and other structural applications. The key mailman to ameliorate performance of composite matrix in aluminium alloy metal reinforces nano particles in the matrix of alloy uniformly, which ameliorates composite properties without affecting limit of ductility. The ultrasonic assisted stir casting helped agitation was successfully used to fabricate Al 2219 metal matrix of alloy reinforced with (0.5, 1, 1.5 and 2) Wt. % of nano silicon carbide (SiC) particles of different sizes 50nm and 150nm. The micrographs of scanning electron microscopy of nano composite were investigated it reveals that the uniform dispersion of nano particles silicon carbide in aluminium alloy 2219 matrix and with the low porosity. How the specific wear rate was vary with increasing weight percentage of nano particles at constant load and speed as shown in results and discussions. And the mechanical properties showed that the ultimate tensile strength and hardness of metal matrix nano composite AA 2219 / nano SiC of 50nm and 150nm lean to augment with increase weight percentage of silicon carbide content in the matrix alloy.

Keywords: Nano composites, Al 2219, Nano SiC(50nm and 150nm), Ultrasonic assisted stir casting, Mechanical Properties, Microstructure.

1. Introduction

Aluminium based metal matrix composites have been used in aerospace, automobile, military, gas turbine engine, space shuttle and structural applications, because of their high strength to weight ratio, low density, and good wear resistance, corrosion resistance and high stiffness. The ceramic reinforcements such has tungsten carbide [1], alumina [2], silicon carbide [3], boron carbide [4], silicon nitride [5], and titanium carbide [6] etc., have been added to the aluminium based matrix by the researchers. Al-MMCs reinforced with Al2O3 have shown improved stiffness and strength over the alloys but effected on ductility and fracture toughness. The Al2O3 possesses important characteristics good wear resistance, easy availability and low cost. The micron size ceramic reinforced composite was shown better the yield strength and ultimate tensile strength, but reduces the ductility with increase of weight percentage of reinforcements in the matrix. Many of the researchers have been identified the improvement of properties with the addition of nano size ceramic reinforcement without affecting the ductility. The tensile strength and hardness of Al/4vol% Al2O3 nano composite was improved compared to its base alloy [7]. The nano composites of Al 2024/ 1wt. % Al2O3 resulted ultimate tensile strength and yield strength by 37% and 81% respectively to its base matrix alloy [8]. Researchers were developed solid state and liquid state fabrication techniques for production of Al-MMNCs composites from the last two decades. The uniform dispersion of nano ceramic reinforcements in the metal matrix composite were shown good properties. The uniform dispersion of nano size reinforcements in the liquid molten metal is difficult by using mechanical stirring.

However, among all methodologies the uniform dispersion of nano particles occurs in ultrasonic assisted stir casting. In the present work, Al 2219 alloy as base matrix material reinforced with nano size silicon carbide (SiC) particles with a mean size of 50 nm and 150nm. The fabrication of Al 2219-MMNCs has been done using ultrasonic assisted stir casting and tested its mechanical properties like ultimate tensile strength and hardness and proved uniform dispersion of nano particles with the analysis of microstructures for different weight percentages of nano silicon carbide reinforcement content.

2. Materials and Experimental Method

AA2219 alloy was selected as base matrix material, because of its excellent weldability and used in aircraft defense and automobile applications. The physical properties of AA2219 and sillicon carbide(SiC) are shown in table 1.The Al 2219 alloy was supplied by Rohit Super Forge Private Limited, Hyderabad, India. Chemical composition of Al 2219 alloy is shown in table 1.

Table 1. Physical property of AA2219 and SiC.

Material	Density (g/cm^3)	Melting point(°C)	Modulus of elasticity(GPa)	Thermal conductivity(W/mK)	Co-efficient of thermal expansion(/°C)
AA2219	2.85	550	80	170	22.1X10-6
SiC(50nm &150nm)	3.21	2730	410	120	4 x 10-6

Table 2. Chemical composition of AA2219 alloy

AA2219	Cu	Fe	Mg	Mn	Si	Ti	V	Zn	Zr	Al
	6.1	0.3	0.02	0.4	0.2	0.1	0.15	0.1	0.25	Bal

The ceramic nano reinforcing material silicon carbide(SiC) of different sizes 50 nm and 150nm was taken in this research work. Silicon carbide has excellent dielectric properties, high wear resistance, good thermal conductivity and good stiffness. Its melting point 2730˚C temperature and of density 3.21g/cc. The silicon carbide was characterized using Philips (XRD) X-ray diffraction sepctometer to verify the phases of the particles and purity, as shown in Fig. 1(a). The nano silicon carbide powder was supplied by Sigma Aldrich, Hyderabad, India. AA2219 alloy melt was reinforced with 0.5, 1, 1.5 and 2 weight percentages of silicon carbide nano particles. The nano composites were fabricated using ultrasonic assisted stir casting. The Experimental setup is shown in Fig. 1(b) which includes various parts of ultrasonic probe, ultrasonic control unit, ultrasonic generator, electric resistance heating furnace, furnace control unit, mechanical stirring unit, cooling unit and pre-heating electric furnace. The temperature limit of the furnace is up to 1000˚C. The frequency of the ultrasonic probe was used 20Khz for fabrication of aluminium based nano composites of various weight percentages.

Al 2219 alloy rectangular pieces were taken and measured its weight exactly 700g and placed in a graphite crucible having capacity 2.5 kg. The crucible was placed in electrical resistance furnace and gets melted to 760˚C. The required weight of the nano silicon carbide (SiC) particles of different sizes 50nm and 150nm was measured and kept in an aluminium foil and prepared pallets by wounding aluminium foil. The aluminium foil pallets were placed in a pre-heating furnace and heated up to 760˚C temperature. The mechanical stirrer was placed in a liquid molten alloy and stirred at a speed of 600 rpm. The pre-heated alumina pallets were dropped into a vertex of a molten alloy at low speed. The mechanical stirring was continued for 15 minutes. After completion of mechanical stirring the

IOP Conf. Series: Materials Science and Engineering **149** (2016) 012106 doi:10.1088/1757-899X/149/1/012106

ultrasonic probe was dipped into a liquid molten alloy up to 25mm depth. The liquid molten Al 2219 alloy was processed with ultrasonic waves for optimized 15 to 9 minutes with increasing weight percentage to break up the clustered nano alumina reinforcements. After ultrasonic processing, the crucible was removed immediately from the furnace using tongs, and the molten slurry was poured into the split mould. The mould is pre-heated up to the 780˚C temperature before pouring of the molten alloy.

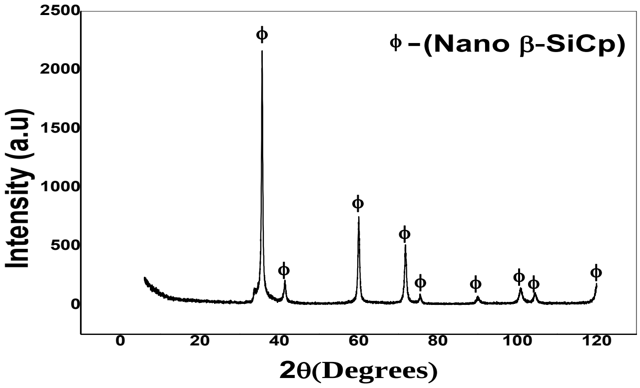


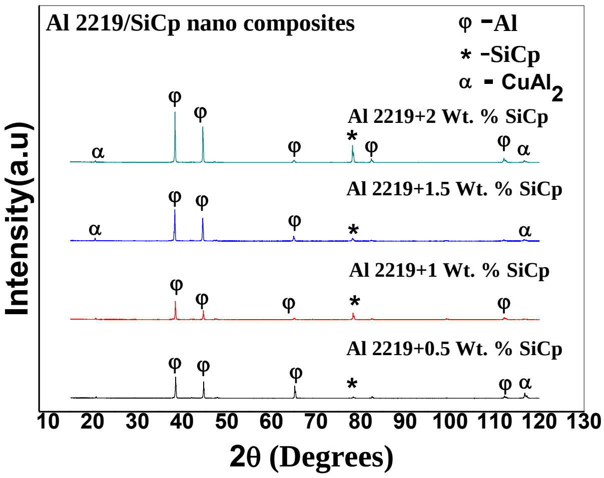
Figure1(a). XRD Pattern of nano SiC

Figure1(b). Ultrasonic assisted stir casting setup

Tensile test specimens were made according to ASTM E8 standard and carried out on Electro Mechanical Tensile Testing Machine of capacity 20kN(Civil Engineering dept., NITW). In this paper the tensile properties were reported on average of four tensile tests. The hardness of the nano composites was analyzed using a Vickers micro hardness tester. The dwell time and applied load for the hardness measurement were 15 s and 1000gf. Wear height was calculated by using pin on disc test machine available in Department of mechanical Engineering, NIT Warangal and specific wear rate was calculated by using mathematical formula which is shown in equation form.

3. Results and discussion

The X-ray diffraction pattern of the fabricated Al 2219/nano silicon carbide(50nm) and 150nm composites are shown in Fig. 2(a&b).



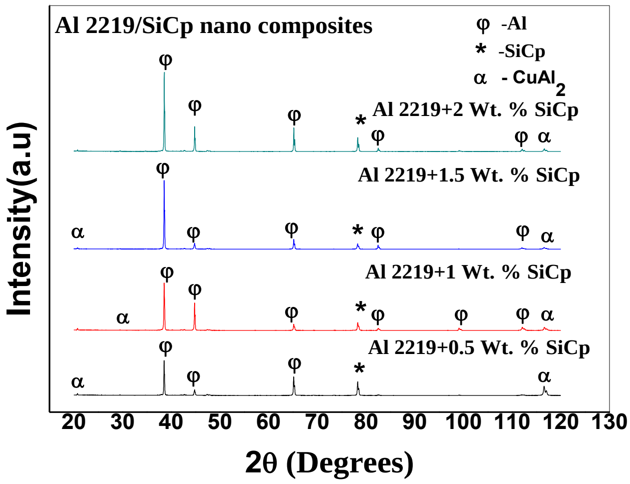


Figure 2(a). XRD pattern of Al 2219/SiC(50nm)

Figure 2(b). XRD pattern of Al2219/SiC(150nm)

The analysis of XRD peaks resulted in the presence of aluminium (Al), silicon carbide(SiC) and intermetallic compound $CuAl_2$. The Al 2219/ (0.5, 1, 1.5 and 2 wt. %) silicon carbide of different sizes 50nm and 150nm nano composites fabricated through ultrasonic assisted stir casting, the morphology of nanocomposites investigated by using Scanning Electron Microscope (SEM). The

IOP Conf. Series: Materials Science and Engineering **149** (2016) 012106 doi:10.1088/1757-899X/149/1/012106

SEM micrographs shown in Fig. 3 (a) & (b) reveals uniform dispersion of nano siliccon carbide particles and dendrite shape was exsiting at grain boundaries.

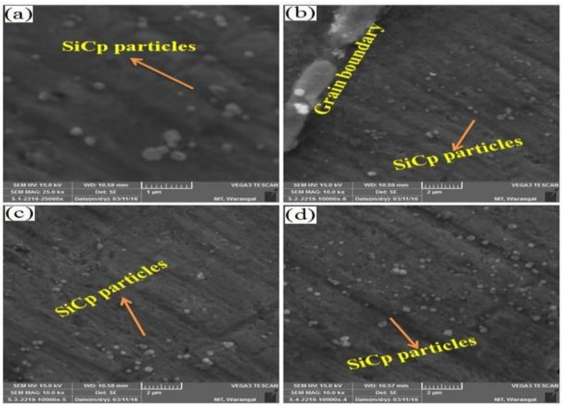


Figure3(a). SEM micrographs of AA2219/ SiC(50nm)

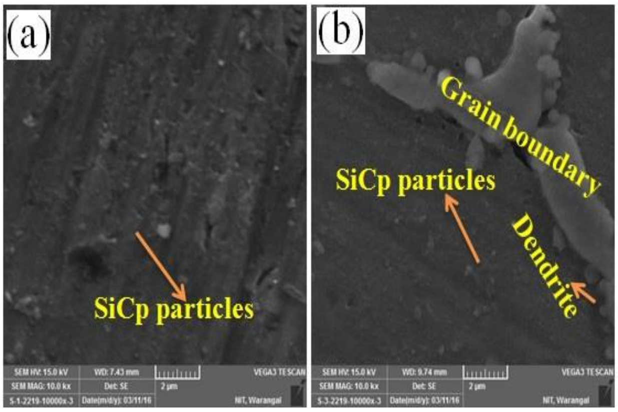


Figure3(b).SEM micrographs of AA2219/ SiC(150nm)

The micro hardness of the Al 2219/ (0, 0.5, 1, 1.5 and 2 wt. %) SiC nano composites 50nm and 150nm as shown in Fig. 4 (a). The vicker hardness value is maximum (260 HV) at 2 wt. % of metal matrix nano composite. The increase of hradness is due to the formation of intermetallic compound ($CuAl_2$) at the grain boundaries.

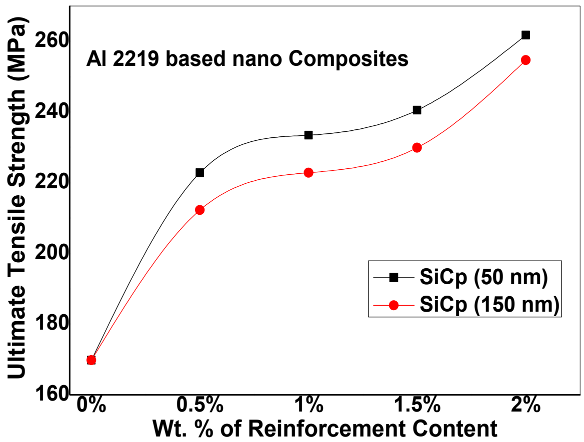


Figure 4(a). Ultimate tensile strength Vs Wt.%

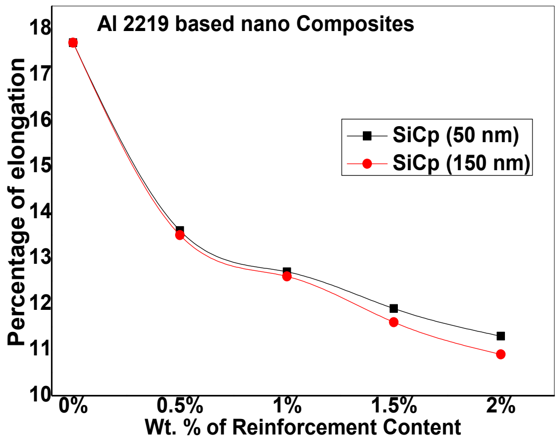


Figure 4(b). Percentage of elongation Vs Wt.%

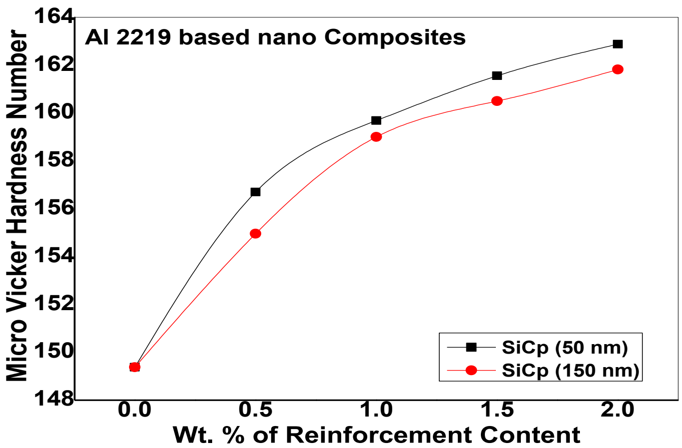


Figure 5. Vicker's Hardness Number Vs Wt.% of Reinforcement

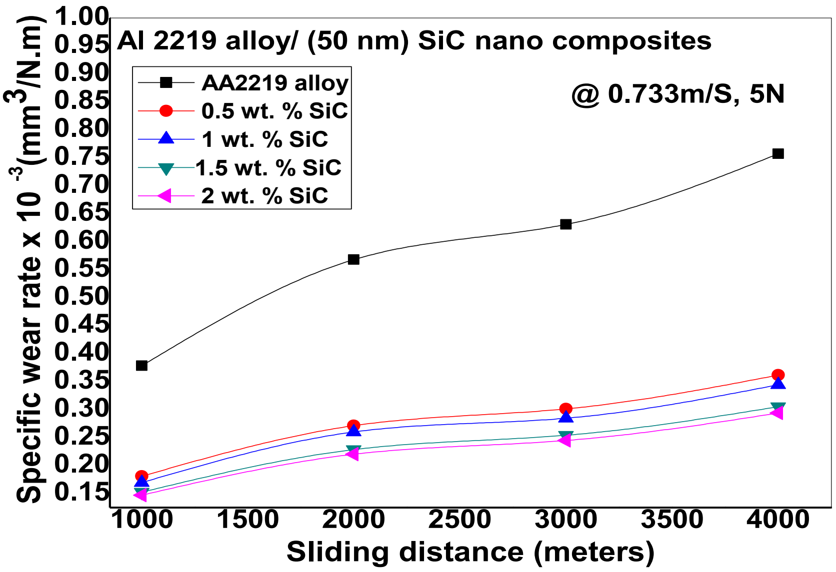


Figure 6(a). Specific wear rate Vs Sliding distance

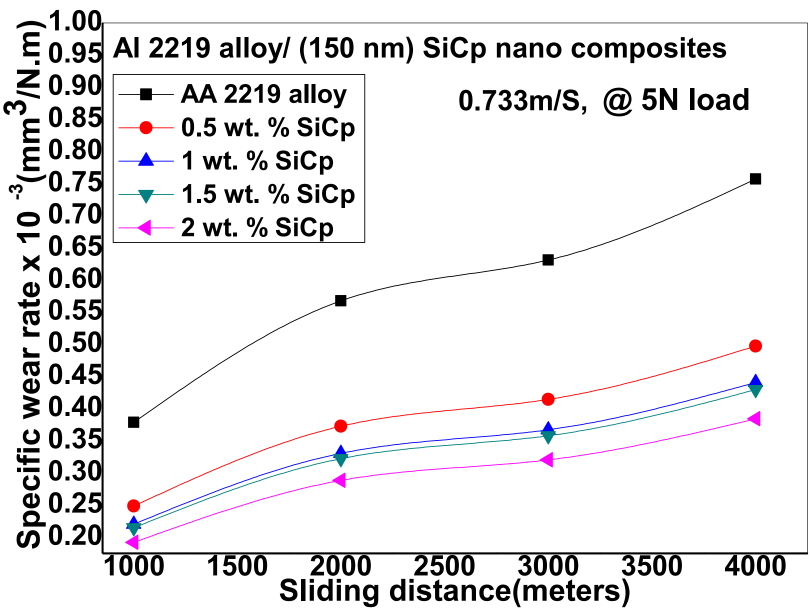


Figure 6(b). Specific wear rate Vs Sliding distance

Fig. 4,5&6 Analysis of AA 2219/ (0, 0.5, 1, 1.5 and 2) wt. % of nano silicon carbide(50nm & 150nm) composites Fig.4(a) shows the ultimate tensile strength Vs weight percentage of reinforcement, Fig.4(b) shows the percentage of elongation Vs weight percentage of reinforcement ,Fig.6(a & b) shows the specific wear rate Vs sliding distance at constant speed 0.733m/s and constant load 5N of 50nm and 150nm respectively.Fig.5 shows the Vicker's hardness number Vs wt.% of Reinforcement content.

The Fig. 4 (a) shows the ultimate tensile strength (UTS) of Al 2219 alloy/ (0, 0.5, 1, 1.5 and 2 wt. %) silicon carbide nano composites. The ultimate tensile strength (UTS) of the Al 2219 alloy/silicon carbide nano composites is enhanced compared to the base alloy. Due to the grain refinement and degasification, there is an increase of the grain boundary area [8, 9]. Due to the increase of the grain boundary area causes induceses thermal stress at the interface, there will be a coefficient of thermal expansion variance in betweeen the nanosilicon carbide reinforcement, $CuAl_2$ phase and Al 2219 alloy matrix and also revealed low porosity. The addition of 0.5 wt. % nano silicon carbide(SiC) of 50nm reinforcement to the base alloy, the ultimate tenslie strength was 225Mpa, it was increased by 28.88% and the maximum ultimate tensile strength showed 260MPa at 2 wt. % of nano silicon carbide, it was increased by 36.53%. The addition of 0.5 wt. % nano silicon carbide(SiC) of 150nm reinforcement to the base alloy, the ultimate tenslie strength was 210Mpa, it was increased by 21.43% and the maximum ultimate tensile strength showed 250MPa at 2 wt. % of nano silicon carbide, it was increased by 34%. The weight % of nano silicon carbide increases, the ultimate tensile strength is also increasing, and maximum at 2wt.%. The nano silicon carbide size increases the tensile strength decreases. Figure4(b) shows the ductility decreases as the reinforcement content increases. Figure6 shows the hardness value increases as the reinforcement content increases, and base matrix reinforced with 50nm gave higher hardness value than 150nm reinforcement. From figure 6(a&b) shows the specific wear rate increases as the sliding distance increases at constant load 5N and constant speed 0.733m/s. And specific wear decreases as the reinforcement content increases this phenomenon happened because of increasing of surface area of nano silicon carbide.It clearly evident that as compared 50nm composite with 150nm, the specific wear rate was low in 50nm and more in 150nm.

4. Conclusions
AA2219 alloy based metal matrix nano composites (Al-MMNCs) have been fabricated successfully by using ultrasonic assisted stir casting method. The nano ceramic particles were distributed uniformly in the AA2219 alloy matrix.The following conclusions were made after testing and characterization.

- The XRD analysis of the AA2219 alloy /SiC(50nm &150nm) nano composites revealed that the aluminium, intermetallic ($CuAl_2$) and silicon carbide(SiC) phases.
- The SEM micrographs revealed the dendrite shape of ($CuAl_2$) intermetallic phase at grain boundaries, nano silicon carbide(SiC) particles.
- The hardness of the nano composites increases with the increase of weight % of nano silicon carbide reinforcement content and found that maximum at 2wt.%
- The ultimate tensile strength of the nano composites increases with incease of weight % of nano SiC. The (UTS) is raised by 36.53% at 2 wt. % of nano silicon carbide(50nm) reinforcement content. The ultimate tensile strength of the nano composites increases with incease of weight % of nano SiC. The (UTS) is raised by 34% at 2 wt. % of nano silicon carbide(150nm) reinforcement content.
- shows the specific wear rate increases as the sliding distance increases at constant load 5N and constant speed 0.733m/s. And specific wear decreases as the reinforcement content increases this phenomenon happened because of increasing of surface area of nano silicon carbide.It clearly evident that as compared 50nm composite with 150nm, the specific wear rate was low in 50nm and more in 150nm.

Acknowledgment
The authors are grateful to the Department of Mechanical Engineering, National Institute of Technology, and Warangal, India for providing the ultrasonic assisted and stir casting equipment and laboratory facilities.

5. References
[1] Kaftelen, Hulya., Unlu, Necip., Gultekin, Goller., Lutfi, Ovecoglu., Hani, Henein., 2011. Comparative processing-structure property studies of Al-Cu matrix composites reinforcewith TiC particulates. Composites: Part A. 42, 812-824.
[2] Yang, Yongbiao., Zhang, Zhimin., Zhang, Xing., 2012. Processing map of Al2O3 particulate reinforced Al alloy matrix composites. Materials Science & Engineering A. 558, 112-118.
[3] Umasankar, V., Anthony Xavior, M., Karthikeyan, S., 2014. Experimental evaluation of the influence of processing parameters on the mechanical properties of SiC particle reinforced AA6061 aluminium alloy matrix composite by powder processing. Journal of Alloys and Compounds. 582, 380-386.
[4] Nie, Cunzhu., Gu, Jiajun., Liu, Junliang., Zhang, Di., 2008. Investigation on microstructures and interface character of B4C particles reinforced 2024Al matrix composites fabricated by mechanical alloying. Journal of Alloys and Compounds. 454, 118-122..

[5] Ramesh, C.S., Keshavamurthy, R., Madhusudhan, J., 2014. Fatigue behavior of Ni-P coated Si3N4 reinforced Al6061 composites. Procedia Materials Science. 6, 1444-1454.

[6] Shyu, R. F., Ho, C.T., 2006. In situ reacted titanium carbide –reinforced aluminium alloys composite. Journal of Materials Processing Technology. 171, 411-416.

[7] Chang Kang, Yung., Lap. Ip Chan, Sammy., 2004. Tensile properties of nano metric Al2O3 particulate-reinforced aluminum matrix composites. Materials Chemistry and Physics. 85, 438-443.

[8] Su, Hai., Gao, Wenli., Feng, Zhaohui., Lu, Zheng., 2012. Processing, microstructure and tensile properties of nano-sized Al2O3 particle reinforced aluminum matrix composites. Materials and Design. 36, 590-596.

[9] Zhang, X. P., Ye, L., Mai, W. Y., Quan, G. F., Wei, W., 1999. Investigation on diffusion bonding characteristics of SiC particulate reinforced aluminium metal matrix composites (Al/SiCp-MMC). Composites: Part A. 30, 1415-1421.