



## Mechanical properties of Al-Si17Cu3.5Mg0.8 alloy fabricated by stir casting with UV and new CRSS casting process with and without T6 condition

N.D.Malleswararao.K<sup>a</sup>, Dr. I.N.Niranjan Kumar<sup>b</sup>

<sup>a</sup>Scholar, Andhra University, Visakhapatnam, A.P, India.

<sup>b</sup>Professor, Andhra University, Visakhapatnam, A.P, India

### Abstract

Aluminum-Silicon metal matrix composites are the popular materials in the vast majority of the car and modern industries on account of their low weight, high mechanical properties, and incredible wear opposition properties. In the present study, Al-Si17Cu3.5Mg0.8 alloy is fabricated by two casting processes such as stir casting with ultrasonic vibrations (RSC) and merged-rheo-stir-squeeze (CRSS) casting with and without heat treated (T6) condition. Microstructural and material characterization was explored by advanced metallurgical microscope (AMM), SEM and EDS. Though, tensile and hardness tests were executed by Tensometer and hardness tester (Brinell). The casting process (CRSS) greatly improves the mechanical properties than rheo stir casting about 30%. The micrograph results display uniform distribution of Si-particles in CRSS cast workpieces than the regular casting. Furthermore, mechanical values revealed that the addition of heat treatment (T6) process led to the development of hardness and tensile strength.

*Keywords: Al-Si alloy; Stir casting; Squeeze casting; EDS; SEM; Tensometer*

### Introduction

Al alloys are getting more attention due to high ductility and low weight. However, with the addition of particles like ceramics, the alloys attain good wear resistance and stiffness [1]. Moreover, the aluminum alloys extraordinary strengthen with the reinforcement of Si particles without losing ductility [2]. The metal matrix composites (MMC) (Hyper-eutectic Al-Si) made from most recent techniques are getting modern consideration because of their predominant wear and mechanical properties [3]. From the previous years, the MMC is manufactured by two techniques, for example, solid-state casting strategy and fluid state casting technique [4-6]. Be that as it may, solid-state casting process (powder metallurgy) isn't conservative [4] contrasted with different techniques so the manufacturing industries concentrated on making parts utilizing fluid state casting strategy, where the alloys are straightforwardly mixed in the liquid metal by mixing and then cast [5]. In Al-Si alloys when Silicon particles mixed in the liquid metal own some difficulties like poor dispersion and wettability [6] because of more surface area. [7] Therefore the casting problems (poor dispersion and wettability) can be overthrown by choosing new casting procedures.

Various reports have been described on the physical properties of Al-Si alloys. T V S Reddy et.al. examined the microstructural and tribological behavior of Al-Si-Cu alloys and found that the hyper-eutectic alloys have good wear resistance with improved microstructure by rheo manufacturing route [12]. Whereas Zhao et.al. conducted experiments on aluminum-silicon MMC

and described that the microstructure and mechanical of the alloys are greatly enhanced by liquid state casting route [8].

Alireza et.al. described that the MMC microstructure changes from thinner to contrasted with the rate of cooling and also the primary silicon particles with magnesium particulates improve the wear resistance properties [9, 10]. [11] Ramesha et.al. conducted numerous studies by changing ZrSiO<sub>4</sub> (wt%) percentages and announced that the liquid-state casting with stirring notably enhances the tensile and hardness properties. From the above literature, it is clear that the manufacturing of AlSiCuMg alloy through the stir casting course enhances the micro-structural and tensile properties [13 -16]. M. da Silva et.al. [17] reported the properties of Al alloys (6061) with the addition of Al<sub>2</sub>O<sub>3</sub>/SiC particles under UV and concluded that the notable changes have been observed in microstructure and mechanical properties. Moreover, Poovazhagan et.al. described by their studies that the properties of Al-alloys like wear greatly enhances by UV-assisted casting route at lower loads [18-20]. Further from the above literature, the stir casting with the UV casting route possesses the poor dispersion of Si particles in the alloy matrix which causes the low wear rate at higher loads.

Many researchers reported that the dispersion stability of Al-Si alloys is improved by squeeze casting route [21-25]. Yuan-Ji Shi et.al. performed experiments on AlSi17.5Cu4Mg0.5 alloy by squeeze casting route and reported that the microstructure properties are greatly improved at different loads [21, 22]. Besides Yang et.al. made MMC (AZ-91-Ca) with the Squeeze casting process

with T6, detailed that Squeeze-casting method surprisingly improves the tribological properties [23]. In spite of the fact that Wei Dai et.al. and Chong Lin et.al. described by their tests that the noteworthy changes in the harness and tensile properties were seen with the enhanced form temperature by high squeeze pressure (UV) system [24-25]. Moreover Yang et.al. manufactured alloy (AZ-91-Ca) with the Squeeze-casting route with T6, reported that the squeeze casting route remarkably enhances the tribo properties [23]. Though Wei Dai et.al. and Chong Lin et.al. described by their studies that the notable improvements in the physical properties were seen with the increased melt temperature by high squeeze pressure casting (UV) technique [24-25].

Furthermore, the manufacturing of the alloy was continued by squeeze casting with string technique for important merits. Pooja Verma et.al. [26-27] conducted experiments on squeeze cast alloy and reported that the good distribution of Si-C particles and fine grain structure was obtained by stir-squeeze casting technique. Whereas Vineet Tirth et.al. from their experiments concluded that the increasing squeeze pressure improves the mechanical properties greatly [28]. Additionally S. Ghosh et.al. seen the squeezed MMCs with Al-Si have great mechanical and low wear characteristics contrasted with the natural processes [29]. Hence the MMC (Al-Si) which are made utilizing both squeeze and stir processes with heat treatment method have great mechanical and wear properties contrasted with the conventional procedures [30-33].

It is clear that nobody investigated the impact of CRSS technique on tensile and hardness properties of Al-Si17 MMC, hence the present examination performed to discover the impact of CRSS process on physical properties of Al-17Si-T6 composite. EDS, AMM, and SEM were utilized for characterization of MMC. Additionally, Brinell hardness analyzer and Tensometer were utilized for mechanical properties of AlSi17Cu3.5Mg0.8alloy.

### 1. Experimental procedure

The MMC (AlSi17Cu3.5Mg0.8) was manufactured utilizing CRSS process, (Fig. 1) though in step one the MMC matrix is made by stir casting (UV) (Table. 1) later it was kept utilizing high pressure squeeze casting.

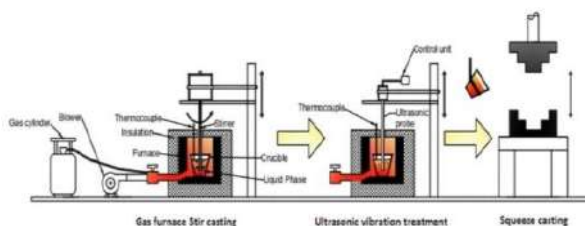


Fig. 1. Combined rheo stir squeeze casting process.

Table 1 Al-Si17 alloy chemical composition

Alloy	Fabrication Process	Composition (wt %)			Al
		Si	Cu	Mg	
AlSi17	RSC & CRSS	17	3.5	0.6	Balance

The procedure begins by melting the Al-Cu in a ceramic container of the gas furnace. At the same time Si powder warmed at 270°C in the pre-warmed heater before adding to the composite. The MMC was completely liquified at 1100°C, and cooled to 720°C with stirring. Si powder (pre-heated) and Mg particles were incorporated into the stirring liquid by keeping up the RPM of 300 around 15 min. at the point when the stirring mixing activity was finished, the MMC was heated again upto 1100°C and maintained for 20 min. Further Ultrasonic testing was brought into the ceramic container melt about 5min for scattering of Silicon particles. After step one (UV with stirrer), the MMC liquid was transferred into a pre-warmed (200°C) shape of steel mold and afterward step two (squeezing) activity was performed. In step two, the liquefied MMC was squeezed with a pressure of 200MPa and formed a 40X40mm square of 100mm length casted square block. Though, the manufactured Al-17Si MMC (Rapid solidified) is experienced the T-6 heat treatment state. The T-6 state have a 500°C solution heat-treatment with soaking time of 4 hours then the specimen was (<50°C) quenching in water rapidly and then continued by 4 hours of artificial-aging treatment at 165°C afterward cooled in air.

Moreover the prepared square blocks are cut into 10 mm thick plates and afterward EDS testing was performed. In addition, SEM and AMM (VFM-9100 Metzer Metavision) were utilized to examine the distribution of primary Si reinforcements. The specimens were surface finished with Si-C papers (800, 1000 sized) later the final finishing (mirror) accomplished with diamond paste (1 μm). Specimens were cleaned acetone and benzene to remove any foreign particles that may remained during cleaning and finishing operations.

Hardness of samples was performed using BHN equipment (Brinell hardness) with a load of 250 kgf and 5mm ball diameter, later the BHN number is acquired from equation-1. Furthermore to investigate the tensile properties, Tensometer (20N capacity) is used with a test speed of 0.5 mm/min (Fig. 2&3).

$$BHN = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2})}$$





## International Symposium on Marine Design and Construction 2019 (SMDC 2019)



treatment (T6) the MMC experiences higher UTS and YS values i.e. 261MPa and 235MPa.

Table 3 Hardness results of Al-Si17 alloy

Composition	L (kgf/cm)	Ball diameter (mm)	RSC				CRSS-T6			
			Indention diameter (mm)	Hardness (BH N)	Indention diameter (mm)	Hardness (BH N)	Indention diameter (mm)	Hardness (BH N)	Indention diameter (mm)	Hardness (BH N)
AlSi17	250	5	1.7	106.82	1.32	179.37				

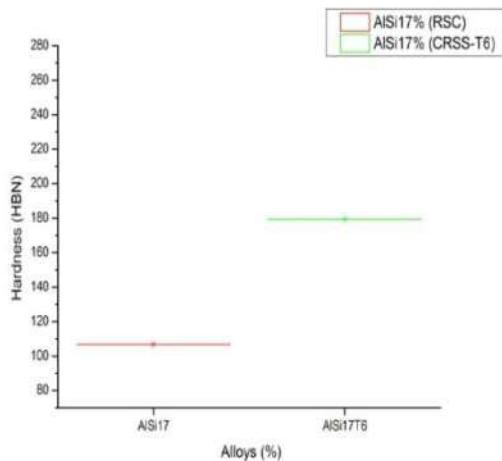


Fig. 6. Hardness values of Al-Si17 alloy

Table 4. Test results of Al-Si17 alloy tensile properties

Composition	UTS		YS		Elongation (%)	
	RS C	CRS S-T6	RS C	CRS S-T6	RS C	CRS S-T6
AlSi17	261	386	23	312	2.1	0.8

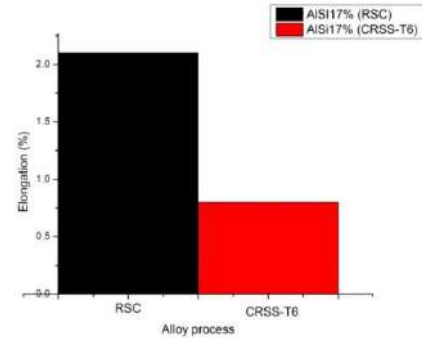
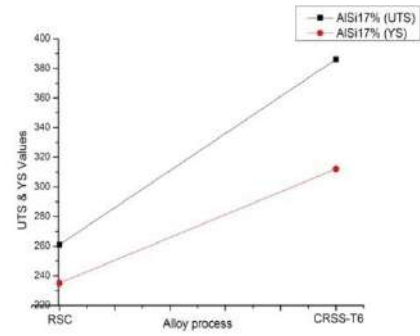


Fig. 7. Ultimate tensile strength and Yield Strength values of hyper-eutectic Al-Si17 alloy

Fig. 8. Elongation values of hyper-eutectic Al-Si17 alloy

### 3. Conclusion

The investigation performed on AlSi17Cu3.5Mg0.8 alloy to find the mechanical and microstructure properties under age hardening heat treated (T6) condition. The alloy was prepared using two casting methods i.e. RSC and CRSS, though the results described that the CRSS-T6 process gave superior effect on mechanical properties. Moreover AMM and SEM micrographs confirm the well dispersed Si-particles are seen at the top faces of the CRSS casted alloy which in turn enhances the hardness and tensile properties greatly.

### References

- [1] V. Kavimani et.al. (2018), "Tribo-Surface Characteristics and Wear Behaviour of SiC@r-GO/Mg Composite Worn under Varying Control Factor", Silicon.
- [2] K.K. Deng et.al. (2010), "Effect of submicron size SiC particulates on microstructure and mechanical properties of AZ91 magnesium matrix composites", Journal of Alloys and Compounds 504 (2010) 542–547.
- [3] N. Beigi Khosroshahi, R. Taherzadeh Mousavian, R. Azari Khosroshahi and D. Brabazon. (2015), "Mechanical properties of rolled A356 based composites reinforced by



## International Symposium on Marine Design and Construction 2019 (SMDC 2019)



- Cu-coated bimodal ceramic particles”, *Materials & Design* 83 (2015) 678–688.
- [4] M. Tavoosi, F. Karimzadeh, M.H. Enayati, and A. Heidarpour. (2009), “Bulk Al–Zn/Al<sub>2</sub>O<sub>3</sub> nanocomposite prepared by reactive milling and hot pressing methods”, *Journal of Alloys and Compounds* 475 (2009) 198–201.
- [5] Ervina Efzan M.N., Siti Syazwani N., and Mohd Mustafa Al Bakri Abdullah. (2016), “Fabrication Method of Aluminum Matrix Composite (Amcs): A Review”, *Key Engineering Materials* 700, pp 102-110, doi:10.4028/www.scientific.net/KEM.700.102.
- [6] M. Nosonovsky and P.K. Rohatgi. (2012), “Tribological Properties of Metal Matrix Composites”, *Biomimetics in Materials Science: Self-Healing, Self-Lubricating, and Self-Cleaning Materials*, Springer Series in Materials Science 152, DOI 10.1007/978-1-4614-0926-7\_8.
- [7] G. A. Kosnikov, O. L. Figovsky and A. S. Eldarkhanov. (2014), “Liquid Phase Production Technologies of Metal Matrix Composites (Review)”, *International Letters of Chemistry, Physics and Astronomy* 6 (2014) 69-77.
- [8] Zhao-hua HU, Guo-hua WU, Jia XU, Wen-fei MO, Yan-lei LI, Wen-cai LIU, Liang ZHANG, Wen-jiang DING, Jonathan QUAN and Yuan-Wei CHANG. (2016), “Dry wear behavior of rheo-casting Al–16Si–4Cu–0.5Mg alloy”, *Trans. Nonferrous Met. Soc. China* 26(2016) 2818–2829.
- [9] Alireza Hekmat-Ardakan, Xichun Liu, Frank Ajersch and X.-Grant Chen. (2010), “Wear behaviour of hypereutectic Al–Si–Cu–Mg casting alloys with variable Mg contents”, *Wear* 269 (2010) 684–692.
- [10] Alireza Hekmat-Ardakan and Frank Ajersch. (2010), “Effect of conventional and rheocasting processes on microstructural characteristics of hypereutectic Al–Si–Cu–Mg alloy with variable Mg content”, *Journal of Materials Processing Technology* 210 (2010) 767–775.
- [11] Ramesha V, Prasad T B, Vighnesha Nayak and Neelakantha V L. (2018), “A Study on Mechanical Properties of Al-17Si Metal Matrix Composites”, *Materials Science and Engineering* 376 (2018) 012100 doi:10.1088/1757-899X/376/1/012100.
- [12] T V S Reddy, D K Dwivedi and N K Jain. (2008), “Effect of stir-casting on the microstructure and adhesive wear characteristics of cast Al–Si–Cu alloy”, *J. Engineering Manufacture*, DOI: 10.1243/09544054JEM1196.
- [13] N. V. Ravi Kumar, B. C. Pai and E. S. Dwarakadasa. (2003), “Microstructural evolution in liquid metal processed Al-alloy/SiCp composites”, *Int. J. Cast Metals Res.*, 2003, 15, 573-579, <http://dx.doi.org/10.1080/13640461.2003.11819543>.
- [14] J. LECOMTE-BECKERS, D. COUTSOURADIS and M. LAMBERIGTS. (1990), “SIC FIBERS AND PARTICLES REINFORCED ALUMINIUM ALLOYS PRODUCED BY STIR CASTING”, *Developments in the Science and Technology of Composite Materials*.
- [15] Manchang Gui, Jianmin Han and Peiyong Li. (2003), “Fabrication and Characterization of Cast Magnesium Matrix Composites by Vacuum Stir Casting Process”, *JMEPEG* (2003) 12:128-134.
- [16] C. Gonzalez-Rivera, J. Baez, R. Chavez, O. Alvarez and J. Juarez-Islas. (2003), “Effect of SiCp content on cooling curve characteristics and solidification kinetics of Al-Si/SiCp cast composites”, *International Journal of Cast Metals Research*, 00110.1179/136404603225006459.
- [17] Shian Jia, Yang Xuan, Laurentiu Nastac, Paul G. Allison & Timothy W. Rushing. (2016), “Microstructure, mechanical properties and fracture behavior of 6061 aluminium alloy-based nanocomposite castings fabricated by ultrasonic processing”, *International Journal of Cast Metals Research*, DOI: 10.1080/13640461.2016.1181232.
- [18] Poovazhagan Lakshmanan, Kalaichelvan K & T. Sornakumar (2015): *Processing and Performance Characteristics of Aluminum-Nano Boron Carbide Metal Matrix Nanocomposites*, *Materials and Manufacturing Processes*, DOI: 10.1080/10426914.2015.1026354.
- [19] L. Z. Zhao, Y. Jiao, Q. L. Wang, J. Zhang and M. J. Zhao. (2014), “Research on in situ Al–Cr/Al composites fabricated by ultrasonic aided casting technology”, *Materials Research Innovations* 18, 4, pp. 473-478.
- [20] Shu-sen Wu, Du Yuan, Shu-lin Lü, Kun Hu, and Ping An. (2018), “Nano-SiCP particles distribution and mechanical properties of Al-matrix composites prepared by stir casting and ultrasonic treatment”, *Research & Development china foundry*.
- [21] Y. J. Shi et al./ *Journal of Iron and Steel Research, International* 24 (2017) 957-965.
- [22] MAO Wei-min, ZHENG Qiu and ZHU Daping. (2010), “Rheo-squeeze casting of semi-solid A356 aluminum alloy slurry”, *Trans. Nonferrous Met. Soc. China* 20(2010) 1769–1773.
- [23] Yang Zang et al. (2017), “Microstructure evaluation and mechanical properties of rheo-squeeze casting AZ91–Ca alloy during heat treatment”, *Research and development china foundry* 14, 6, pp. 485-491.



## International Symposium on Marine Design and Construction 2019 (SMDC 2019)



- [24] Wei Dai, Shusen Wu, Shulin Lü and Chong Lin. (2012), “Effects of rheo-squeeze casting parameters on microstructure and mechanical properties of AlCuMnTi alloy”, *Materials Science and Engineering A* 538 (2012) 320–326. doi:10.1016/j.msea.2012.01.051.
- [25] Chong Lin et.al. (2018), “Effects of high pressure rheo-squeeze casting on Fe-containing intermetallic compounds and mechanical properties of Al-17Si-2Fe-(0, 0.8)V alloys”, *Materials Science & Engineering A* 713 (2018) 105–111,  
<https://doi.org/10.1016/j.msea.2017.12.050>.
- [26] J. Chattopadhyay et al. (eds.), *Innovation in Materials Science and Engineering*, [tps://doi.org/10.1007/978-981-13-2944-9\\_7](https://doi.org/10.1007/978-981-13-2944-9_7).
- [27] Muhammad Hassan Sarfraz, Mirza Jahanzaib, Wasim Ahmed and Salman Hussain. (2018), “Multi-response parametric optimization of squeeze casting process for fabricating Al 6061-SiC composite”, *The International Journal of Advanced Manufacturing Technology*.
- [28] VINEET TIRTH, S. RAY and M.L. KAPOOR. (2009), “Effect of Squeeze Pressure on Aging and Mechanical Properties of AA2218-5 Wt Pct Al<sub>2</sub>O<sub>3</sub> (TiO<sub>2</sub>) Composites”, *The Minerals, Metals & Materials Society and ASM International*.
- [29] S. Ghosh, P. Sahoo and G. Sutradhar. (2014), “Tribological Properties of Al–SiC Metal Matrix Composites: A Comparison Between Sand Cast and Squeeze Cast Techniques”, *J. Inst. Eng. India Ser. D (July–December 2014)* 95(2):161–171, DOI 10.1007/s40033-014-0044-6
- [30] Sarbjit Singh, Inderdeep Singh & Akshay Dvivedi (2017): Design and development of novel cost effective casting route for production of metal matrix composites (MMCs), *International Journal of Cast Metals Research*, DOI: 10.1080/13640461.2017.1323605
- [31] P. Shanmugasundaram and R. Subramanian. (2013), “Wear Behaviour of Eutectic Al-Si Alloy-Graphite Composites Fabricated by Combined Modified Two-Stage Stir Casting and Squeeze Casting Methods”, *Advances in Materials Science and Engineering Volume 2013*, Article ID 216536, 8 pages.
- [32] H. Torabian, J.P. Pathak and S.N. Tiwari. (1993), “Wear characteristics of Al-Si alloys”, *Wear*, 172 (1994) 49-58.
- B. CAN'roR. (1986), “FUNDAMENTALS OF RAPID SOLIDIFICATION”, *Science and Technology of the under cooled Melt*