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Mechanical Characterization of Rapid Solidified Alsicumg Alloys by New CRSS Casting Method Under T6 Condition

N.D.Malleswararao.K, I.N.Niranjan kumar

Abstract: Aluminum-silicon alloys acquiring extensive industrial attention due to their superior resistance to rate of wear and elevated strength to weight ratio properties. Though the properties of the materials substantially depend on the manufacturing process they involve. Thus many industries focusing on new manufacturing methods to produce high-performance alloys. In this present study, AlSi (16-18) alloys were prepared by new CRSS (combined rheo stir squeeze) casting method with rapid-solidification process under T-6 condition. CRSS-T6 as casting process enhances the microstructural and mechanical properties significantly by 40-70%. Whereas, the maximum value of hardness (179.37) was found with AlSi17Cu3.5Mg0.8 with CRSS-T6. The improvements in hardness and elastic properties were mainly ascribed to size, distribution, and morphology of Si-particles because of its manufacturing process. SEM, advanced metallurgical microstructure and EDS analysis techniques are used for the surface morphologies observation. Moreover, Brinell hardness tester and Tensometer are used for the characterization of mechanical properties.

Keywords : CRSS method, Hardness, HAS alloy, Mechanical properties, Tensometer.

I. INTRODUCTION

Aluminum alloys are the trending materials in most of the automobile and industrial sectors because to their low weight, ductility, high-strength, less COF (coefficient of friction) and great wear resistance properties. The aluminum alloys are reinforced with ceramic particles has prominent merits, such as stiffness, higher-level dimensional stability and superior wear resistance [1-2]. Though Si-particles in Al alloys can remarkably strengthen the material without losing the ductility [3-4]. Moreover, Hypereutectic Aluminum Silicon (HAS) alloys which are prepared from new manufacturing processes obtaining substantial industrial importance due to their excellent mechanical and wear properties [5]. Normally alloys (MMC) are prepared by two methods such as liquid state casting method and solid state casting method [6-8].

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***** Correspondence Author
N D Malleswararao K*, Research Scholar, Marine Department, Andhra University, Visakhapatnam, India. Email: nottymalli@gmail.com
Dr. I N Niranjan kumar, Professor, Marine Department, Andhra University, Visakhapatnam, India. Email: neeru.@yahoo.com

Whereas, the manufacturing technique of the solid state casting process (powder metallurgy) is very costly compared to the methods [6]. Therefore most of the industries prefer to fabricate the MMC by the liquid state casting method, in which the reinforcements are added in the molten metal directly by stirring and casting [7]. Although adding Si reinforcements in the molten metal possess some difficulties like wettability and poor dispersion because of higher surface area [8]. So the wettability and poor dispersion problems are overthrown by adopting new manufacturing methods [9].
Zhao-Hua HU et.al. performed research on Al-Si alloy and reported that the mechanical and microstructure of the MMC are significantly improved by rheo manufacturing route [10, 15]. Though Mohit Kumar Sahu et.al. in their study explained that the properties of the reinforcements and metal matrix depend on the stirring parameters of the casting process [11]. In the experiments of Alireza Hekmat-Ardakan et.al. reported that the alloy microstructure finer for high cooling rate contrasted to the low rate of cooling. Moreover, the solid-fraction of primary silicon improves remarkably with the incorporation of magnesium particulates and also good improvement observed in wear properties [12-13]. Ramesha V et.al. [14] performed a series of experiments by varying ZrSiO4 reinforcements weight percentages and concluded that the stir casting route greatly improves the tensile and hardness properties. Therefore the preparation of AlSi alloy through stir fabrication route enhances the microstructures and mechanical properties with the uniform distribution of Si-particles and wettability [16, 17, 18 - 19]. Further, the investigation continued by adding ultrasonic treatment to the stir casting procedure (RSC). Here M. da Silva et.al. conducted experiments on 6061 alloys with the addition of Al2O3/SiC nanoparticles by ultrasonic stirring technology (UST) and reported that a remarkable increase in elongation achieved with UST treatment [20]. Moreover, Poovazhagan Lakshmanan et.al. [21] concluded with their experiments that the tribomechanical properties of Al MMC are extensively improved by ultrasonic cavitation-assisted casting route. The fabrication of Al-Si MMC with the new process (mechanical stirring and ultrasonic vibration) improves the dispersion stability and weight fraction of SiC particles. Additionally, physical and mechanical properties were significantly increased [22-23].

Several researchers described that the Al-Si MMC properties are improved by the squeeze casting technique compared to the regular techniques such as stir and sand casting [24-28]. Yuan-Ji Shi et.al. [24-25] conducted a series of experiments on squeeze cast (AlSi17.5Cu4Mg0.5) Al-Si MMC and noted that the mechanical and microstructure properties are greatly improved. Though Yang Zhang et.al. prepared AZ91-Ca alloy with rheo-Squeeze casting under heat treatment, concluded that the new casting process significantly improves the wear and mechanical properties [26]. Furthermore, the investigation continued by adding UV to the squeeze casting technique. Though Wei Dai et.al. [27] produced the semi-solid composite of Al5CuMnTi alloy by UV (indirect) and explained that the mean diameter of grain reduced with the increased weight (pressure) and also remarkable changes in the tensile and harness properties were observed with the higher mold temperature. Moreover from the studies of Chong Lin et.al. it is observed that the wear and mechanical properties of HAS alloys are remarkably increased by high-pressure squeeze casting with UV technique [28].

Later the alloys are prepared by using novel stir-squeeze casting technique for prominent merits. In the research of Pooja Verma et.al. reported that the low porosity, fine grain structure and even distribution of Si-C particles are obtained by the stir-squeeze casting process [29-30]. Also Vineet Tirth et.al. [31] conducted experiments on AA_2218-5 alloy of Wt-Pct-Al_2O_3_(TiO_2) with the effect of Squeeze Pressure on aging and described that the aging (heat treatment) and increasing squeeze pressure improves the hardness and tensile values greatly. Whereas, S. Ghosh et.al. [32] expressed that the squeeze cast Al-SiC composites have high hardness and less tribological properties compared to the sand cast alloy. Therefore it is clear that the rapid solidified (Al-Si) alloys prepared by stir-squeeze casting process under T6 condition have excellent tribological and mechanical properties compared to the regular casting methods [33-39].

From the above literature it is clear that no one explored the effect of CRSS-T6 casting on mechanical properties of AlSi (16-18) Cu3.5Mg0.8alloys, therefore the present research study investigates the influence of novel CRSS-T6 casting method on tensile and harness properties of rapid solidified Al-Si (16-18) alloys. First of all Al-Si (16-18) alloys are prepared using two stage CRSS casting method with rapid solidification, then the mechanical properties of HAS alloys are investigated under T6 heat treated condition. Energy Dispersive Spectroscopy (EDS), advanced metallurgical microscope (AMM), and electron microscope (SEM) were used for material characterization. Also, Brinell hardness tester and Tensometer were used to find out the harness and tensile properties of AlSi (16-18) Cu3.5Mg0.8alloys.

II. EXPERIMENTAL PROCEDURES

The preparation of AlSi (16-18) Cu3.5Mg0.8alloys are carried out by novel two-stage combined rheo stir-squeeze (CRSS) casting technique (Fig. 1) whereas in stage one the master alloy (Table. 1) is prepared by using stir casting with ultrasonic vibration treatment later it was continued by squeeze casting technique.

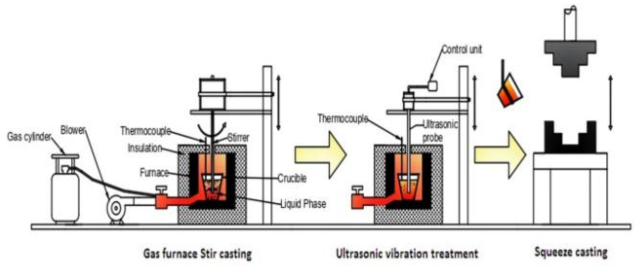

Fig. 1.CRSS casting process

Table 1 Chemical composition of Al-Si alloys

Alloy	Fabrication Technique	Chemical Composition (wt %)			
		Si	Cu	Mg	Al
AlSi16	RSC & CRSS	16	3.5-4	0.6-0.8	Balance
AlSi17	RSC & CRSS	17	3.5-4	0.6-0.8	Balance
AlSi18	RSC & CRSS	18	3.5-4	0.6-0.8	Balance

The process begins by melting the pure aluminum (99.9%) and pure copper (99%) in a graphite crucible of the gas furnace. Simultaneously Si-particles are also heated at 270^0C in the pre-heated furnace (powder) before being mixed with the composite. When the MMC (alloy) was totally liquified at 1100^0C, it was chilled off to 720^0C and stirred mechanically. Pre-warmed Si-particles and Mg granules were included into the mixing vortex (stirring) by maintaining the speed of 300 rpm about 15 min. when the mechanical-stirring operation was completed, the compound (HAS alloy) was warmed up to 1100^0C and held for 20 min. Later Ultrasonic vibration (UV) was introduced into the melted alloy about 5min for dispersing of SI particles. The UV equipment contains a titanium alloy horn with 20kHz frequency and 2.8kW maximum power output. After stage one processing (stir with UV), the liquified compound was poured into a pre-heated (200^0C) mold of steel and then stage two (squeeze casting) operation was performed. In stage two, the melted alloy was squeeze cast at 200MPa and achieved a rapid solidified casting ingot with 40X40mm square of 100mm length. Further, the prepared rapid solidified Al-Si (16-18) alloys were undergone through the heat treatment process with T6 condition. The T6 condition contains a solution heat treatment at 500^0C with soaking time of 4 hours by rapid quenching in water not more than 50^0C later it was continued by artificial-aging treatment at 165^0C for 4 hours and then cooled in air.

Whereas to understand the effect of a new casting process on Al-Si (16-18) alloys the microstructural and mechanical properties were also investigated. The billets of Al-Si alloys (40X40X100 mm) sliced into 40X40X10 mm and then EDS testing was conducted on the samples to reveal the composition of the alloy. Moreover, VFM-9100 Metzer Metavision advanced metallurgical microscope (AMM) and S-3700N SEM were used to study the Si-particles distribution.

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The samples of SEM and AMM were polished with 800 and 1000 grit size Si-C papers later the final finishing (mirror finishing) achieved with 1 µm diamond paste. Later the samples were cleaned benzene and acetone to extract any debris that may have been left during polishing and machining.

The hardness tests of all the Al-Si samples have been done using Brinell hardness equipment. Though, the applied force (load) during the testing was 250 kgf, with a ball diameter of 5mm. The Brinell-hardness-number (BHN) is determined from the following equation:

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

Tensile properties of the HAS alloys were analyzed by Tensometer with a capacity of 20N. Though the Tensometer tests (tensile) were conducted with a experiment speed of 0.5 mm/min and the corresponding load-displacement values are recorded by induced Tensometer software. Fig. 2 & 3 explains the dimensions of the test piece used for this test.

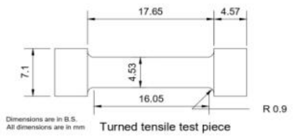

Fig. 2.Tensile test specimens dimensions

Fig. 3.Al-Si (16-18) tensile test specimens

III. RESULTS AND DISCUSSION

To explore the results of CRSS casting technique on mechanical properties of HAS alloys different tests were carried out and the experimental effects were discussed in following segments.

This investigation contains two types of tests:

a. Al-Si (16-18) alloys by stir casting with UV treatment (RSC), and

b. Al-Si (16-18) alloys by CRSS casting under T6 condition (CRSS-T6).

A.Microstructural Observations

Advanced metallurgical Microscopy and EDS Analysis: Figs. (4-6) represents AMM and EDS micrographs of rapid solidified Al-Si (16-18) alloys. Fig. 4(a-b) shows (AMM) micrographs of RSC and CRSS (T6) casted AlSi16Cu4Mg0.8 alloy, whereas Fig. 4(a) exhibits the existence of polygon-shaped like primary Si-particles, which which gather bringing about a non-finished distribution in the alloy matrix. On the other hand, Fig. 4(b) demonstrates an improvement in distribution of the primary Si-phase and morphology. EDS analysis (Fig. 4(c)) represents that HAS alloy elements (Al, Si, Cu, and Mg) are observed in polygon shaped meld, while the meld is AlSiCuMg phase, as shown in Table 2. Similarly Fig. 5(a-b) and 6 (a-b) shows the micrographs of AlSi17Cu4Mg0.8 and AlSi18Cu4Mg0.8 alloys, Though Fig. 5(a) and 6(a) images exhibit that the alloys prepared with RSC contain a non-finished distribution of Si-particles with irregular polygon shaped structures.

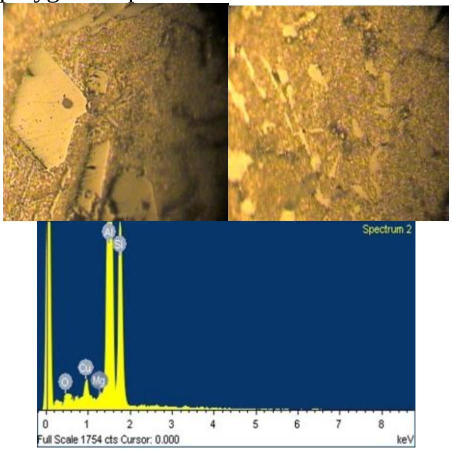

Fig. 4(a).AMM micrograph of RSC AlSi16Cu3.5Mg0.8 alloy, (b) AMM micrograph of CRSS-T6 casted AlSi16Cu3.5Mg0.8 alloy and (c) EDS analysis of AlSi16Cu3.5Mg0.8 alloy

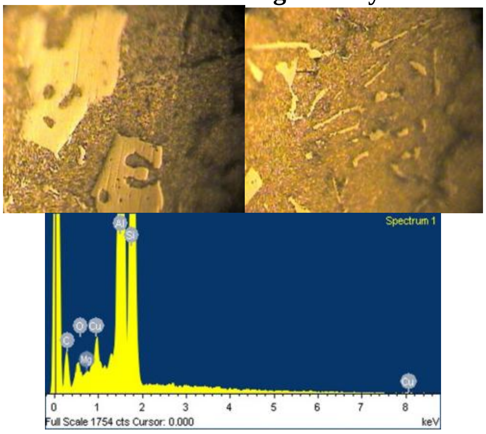

Fig. 5(a).AMM micrograph of RSC AlSi17Cu3.5Mg0.8 alloy, (b) AMM micrograph of CRSS-T6 casted AlSi17Cu3.5Mg0.8 alloy and (c) EDS analysis of AlSi17Cu3.5Mg0.8 alloy

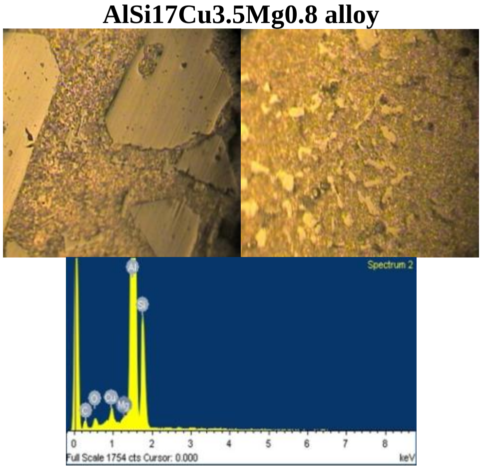

Fig. 6(a).AMM micrograph of RSC AlSi18Cu3.5Mg0.8 alloy, (b) AMM micrograph of CRSS-T6 casted AlSi18Cu3.5Mg0.8 alloy and (c) EDS analysis of AlSi18Cu3.5Mg0.8 alloy

Moreover, there is a noteworthy improvement observed in the dispersal of primary Si-particles and morphology by CRSS (T6) casting method (Fig. 5(b) and 6(b)). EDS analysis shows that the irregular polygonal compounds in Fig. 5(c) & 6(c) contain the similar components of HAS alloy (Al, Si, Cu, and Mg) as exhibited in Table 2.

Table 2 EDS analysis of HAS alloys

S.no	Alloy	Elements (wt %)					
		Si	Cu	O	Mg	C	Al
1	AlSi16	14.89	3.46	0.92	0.52	-	80.21
2	AlSi17	15.98	3.61	1.12	0.47	4.99	73.83
3	AlSi18	16.45	4.43	2.46	0.32	6.79	69.55

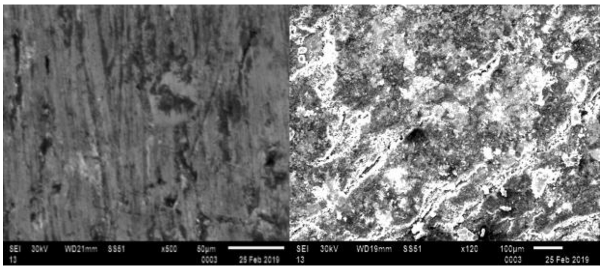

Fig. 7(a).SEM micrograph of RSC AlSi16Cu3.5Mg0.8 alloy and (b) SEM micrograph of CRSS-T6 casted AlSi16Cu3.5Mg0.8 alloy

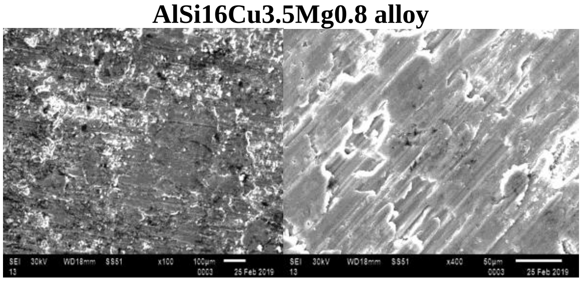

Fig. 8(a).SEM micrograph of RSC AlSi17Cu3.5Mg0.8 alloy and (b) SEM micrograph of CRSS-T6 casted AlSi17Cu3.5Mg0.8 alloy

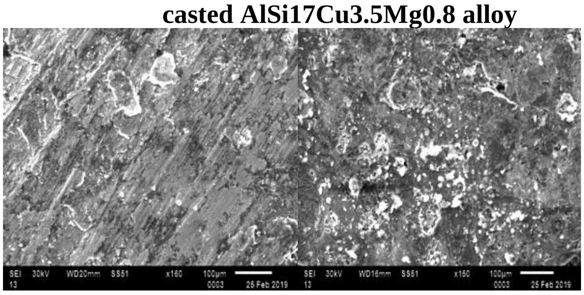

Fig. 9(a).SEM micrograph of RSC AlSi18Cu3.5Mg0.8 alloy and (b) SEM micrograph of CRSS-T6 casted AlSi18Cu3.5Mg0.8 alloy

SEM analysis: Figs. (7-9) exibits the SEM images of Al-Si (16-18) alloys. Though Fig. 7(a-b), 8(a-b) and 9(a-b) shows micrographs of RSC and CRSS (T6) casted AlSi16Cu4Mg0.8, AlSi17Cu4Mg0.8 and AlSi18Cu4Mg0.8 alloys. Micrographs (Fig. 7(b), 8(b) and 9(b)) reveal that the CRSS-T6 casting technique gives low agglomeration and even distribution of Si-particles in the meld compared to the RSC casted alloys (Fig. 7(a), 8(a) and 9(a)). The images indicate that the CRSS-T6 fabrication technique causes the development of grain refining, reduced porosity, grains orientation and the microstructural densification in the squeezed way, finally gives the sound casting product.

B. Mechanical characterization of Al-Si (16-18) alloys

Hardness: Table. 3 demonstrate the results of the calculated hardness of Al-Si (16-18) alloys for the RSC and CRSS (T6) casting processes. The hardness values of the CRSS-T6 fabricated alloys are increased compared to the RSC alloys due to the variation in the morphology of the eutectic-network of a meld and the uniform distribution of Si-particles. Moreover, the CRSS-T6 technique provides a considerable development in hardening of entire HAS alloys which is most noteworthy for the AlSi17Cu4Mg0.8 alloy. The experimental values of Fig. 10 also indicate that the hardness of 16% Si alloy is the most minimal for the both RSC and CRSS-T6 fabricated specimens. Increasing the Si weight percentage to 1% again increases the hardness.

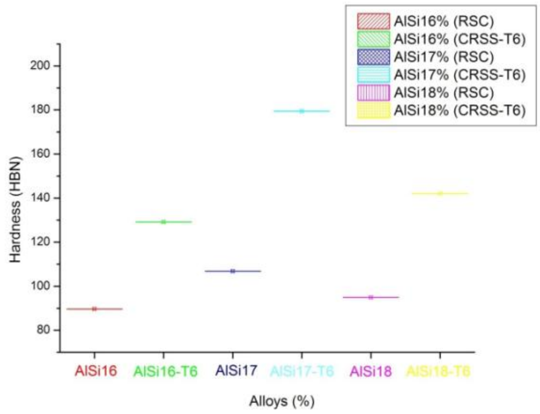

Fig. 10.Hardness values of hyper-eutectic Al-Si (16-18) alloys

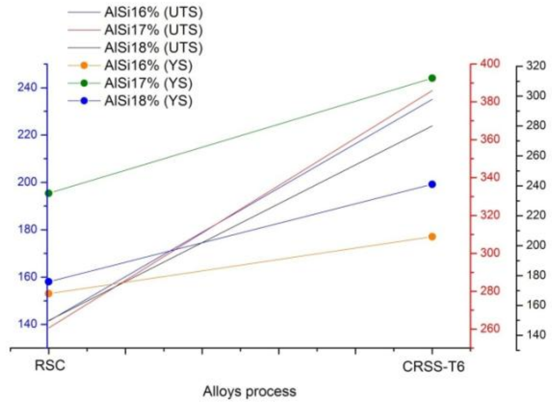

Fig. 11.UTS and YS values of hyper-eutectic Al-Si (16-18) alloys

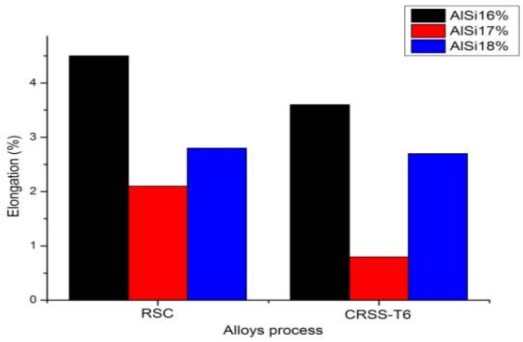

Fig. 12.Elongation (%) of hyper-eutectic Al-Si (16-18) alloys

Tensile strength: The tensile results of Al-Si (16-18) alloys at room temperature are given in Table. 4. Fig. 11 & 12 shows that the CRSS-T6 casting process lead to superior strengthening effects for all Al-Si alloys. Whereas AlSi17Cu4Mg0.8 alloy achieved higher tensile values compared to other two alloys in both cases (RSC and CRSS-T6) because of the presence of well-dispersed Si in the matrix. It is obvious that in the both cases very low results obtained for AlSi16Cu4Mg0.8 alloy, since less content of Si-particles causes to the non consistency of the MMC. Though, when the substance of Si is 16wt%, UTS and YS of the materials are 141MPa and 168MPa, which are enhanced by 66% and 22% individually, contrasted with the RSC alloy. Similarly, the elongation percentage reduced to 25% in the case of CRSS-T6 casting compared to RSC alloy. The reinforcing impact of 17wt% Si/Al is greatly improved than 16wt%. Though, the UTS and YS of the alloys are 261MPa and 235MPa, respectively, about 47% and 33% higher than the RSC alloy but elongation is lower in case of CRSS-T6 casted alloy (16%). While adding 18wt% Si to the Al grid, the UTS, YS, and EI of the composites are 150MPa, 176MPa and 2.8%, which are improved by 86%, 36% and 0%, individually. It merits referencing that the Al alloys are reinforced by the Si-particles while keeping up ductility on account of CRSS-T6 casting method.

Table 3 Hardness values of Al-Si alloys

Composition	Load (kgf)	Ball diameter (mm)	RSC		CRSS-T6	
			Indentation diameter (mm)	Hardness (BHN)	Indentation diameter (mm)	Hardness (BHN)
AlSi16	250	5	1.85	89.67	1.55	129.18
AlSi17	250	5	1.7	106.82	1.32	179.37
AlSi18	250	5	1.8	94.91	1.6	121.02

Table 4 Tensile properties of Al-Si alloys

Composition	UTS		YS		Elongation (%)	
	RSC	CRSS-T6	RSC	CRSS-T6	RSC	CRSS-T6
AlSi16	141	235	168	206	4.5	3.6
AlSi17	261	386	235	312	2.1	0.8
AlSi18	150	280	176	241	2.8	2.8

IV. CONCLUSION

In this research, we explored the mechanical properties of the rapid solidified AlSi (16-18) Cu3.5Mg0.8 alloys under T6 heat treated condition, where Novel CRSS casting method is used for the manufacturing of HAS alloys.

The results specify that the CRSS casting with T6 heat treatment condition gave a notable effect on microstructure improvement. Though, SEM, AMM and EDS examination of alloy top faces exhibit that the microstructure and dispersion of Si-particles improved greatly. Moreover, Brinell hardness tester and Tensometer results reveal that the mechanical (tensile and hardness) properties of AlSi (16-18) Cu3.5Mg0.8 alloys increased significantly about 40-70%. This shows that the CRSS-T6 casting process helped not only in the refinement of microstructure but also in mechanical properties enhancement. This study gives a new perception of the relationship between the HAS alloys and CRSS-T6 casting process as a self-properties improvement, in automotive/industrial applications.

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AUTHORS PROFILE

N.D.Malleswararao.K Research scholar at Andhra University, Visakhapatnam. He has published many papers in national and international Journals and member of various professional Bodies.

Dr.I.N.Niranjan Kumar is working as Professor in the Department of Marine Engineering of Andhra University, Visakhapatnam. He is having experience more than 20 years to teach UG/PG courses in Mechanical/Marine Engineering. He has published many papers in national and international journals and member of various professional bodies.