TuijinJishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 44 No.4 (2023)

Microstructure and Mechanical Properties of Hypo and Hypereutectic Al-Si Alloy Processed through Die and Centrifugal Casting

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***Abstract*:**

The hypo and hypereutectic alloys of Al-Si for the silicon percentage of 6 and 18 % Si respectively produced through die casting and centrifugal casting for the research work. The samples of ascast and centrifugal casting from the casted billets prepared as per the ASTM standards for the microstructure analysis, to determine mechanical and tribological properties. The surface topography of the samples revealed spherical and needle morphology and uniform distribution of the secondary phase within the Al matrix material. The density of the samples are measured using water displacement method and density of the ascast and reciprocating samples of hypoeutectic alloy were found to be reported as2.6793± 0.0075and 2.6392 ± 0.0016 g/cc respectively, whereas the density of hypereutectic ascast alloy is reported as 2.6265 ± 0.002and centrifugal hypereutectic alloy is 2.6226 ± 0.0086 g/cc. The micro hardness of the ascast and centrifugal casting hypo and hypereutectic Al-Si alloys are measured using Vickers hardness testing machine. The ultimate tensile strength of the ascast and centrifugal casting of both hypo and hyper eutectic alloys were carried out using quasistatic tensile test. The UTS of ascast hypoeutectic alloys is 148.552 ± 4.774 MPa and centrifugal casting hypoeutectic alloy is 154.512 ± 7.949 MPa.The UTS of hypereutectic ascast and centrifugal casting alloys are reported as 140.40 ± 32.23 and 159.807 ± 21.145 MPa respectively. The variations in the properties of hypo and hypereutectic alloy of ascast and centrifugal Al-Si alloy could be attributed to different strengthening mechanisms of the alloys.

Keywords*: hypoeutectic, hypereutectic, mechanical properties, tribological properties.*

1. Introduction:

Al-Si alloys are extensively used in automobiles, aerospace, electronic industry and general engineering works due to high strength to weight ratio. Al-Si alloys have excellent wear resistance, corrosion resistance, low coefficient thermal expansion and good castability [1, 2]. The aforementioned properties of the Al-Si alloy depending on the silicon phase present in an alloy [3]. The properties of the Al-Si alloys are varied by chaining the processing methods from ingot metallurgy to powder metallurgy. The conventional casting processes normally produce the inferior mechanical and tribological properties. Therefore, the properties of the Al-Si alloy are enhanced by adding sodium and the rear earth elements like strontium [2, 4]. The solid solubility of silicon in aluminum is limited to 0.02 wt.% in aluminum. The Al-Si alloy exhibit high mechanical strength and excellent wear resistance as the silicon content is increased above the eutectic composition. However, large Si phase and coarse needles present in an ascast alloy produced through conventional casting route result in inferior mechanical properties [5]. The solid solubility of silicon in aluminum is increased and the morphology of the silicon is changed when the alloy is processes through rapid solidification process. The process involves melting of alloy, atomization of melt and consolidation of the droplets to form an ingots for near net shape perform [6]. The microstructure and wear performance of spray formed alloys obtained for different process parameters were studied and are compared with ascast counterpart [7-10]. The microstructure of the spray formed deposit revealed equiaxed grain morphology in contrast to ascast deposit. The variations in microstructure and porosity of the spray deposit are depending on the amount of liquid fraction present in the spray. The wear rate of the spray formed sample is varied at different applied loads with sliding speed of 0.75 m/s. The wear properties of spray formed Al-10 wt. % Si is found to be better than the wear properties of spray formed Al-6 wt.% Si alloy [11]. The study was focused on microstructural variations with respect to different deposition distances from substrate to top surface of the deposit. The microstructure for smaller distances of the spray deposit was found to be observed as Si coexisting primary phase and needle type eutectic Si phase. The formation Al-α phase dendrites is related to undercooling of the melt before solidification of the alloy. The particles are embedded uniformly in a matrix of aluminum with fine microstructure for a large deposition distance [12]. There are several studies were focused on microstructural, mechanical and tribological properties of both hypo and hypereutectic alloys of Al-Si alloy processed through die casting and spray atomization. However, the investigation on comparative study of centrifugal and die casting of Al-Si alloys are not reported in the literature as per the authors knowledge. The present work focused on microstructure, mechanical and tribological properties of hypo and hypereutectic alloys of Al-Si alloys processed through die casting and centrifugal casting. The comparative investigations have been made in the light of cooling rate on microstructure, mechanical and tribological properties of hypo and hypereutectic of Al-Si alloy.

2. Experimental

The hypo and hypereutectic alloys of Al-Si for the silicon percentages of 6 wt. % and 18 wt. % have been melted for die casting using electrical resistance furnace. The electrical coils in the electrical resistance furnace were made of Kanthal electrical coils. The clay graphite crucible was used to melt 1 kg of Al-Si alloy each to produce the hypoeutectic and hypereutectic alloy. The alloy was heated up to 700 ˚C for melting and the melt was transferred into metallic die size of 200 mm x 150 mm x 10 mm.The K type thermocouple was used to measure the temperature of the melt in ˚C. The mechanical stirrer is employed to stir the melt at low rpm 0f 50 rpm for uniform mixing of elements. Similarly, hypo and hypereutectic Al-Si alloy was prepared through centrifugal casting. The diameter and length of the centrifugal casting die was 85 mm and 100 mm respectively. The optimized speed of 900 rpm was employed for centrifugal casting process.The hypo and hypereutectic Al-Si alloy of 1 kg each is melted in an electrical furnace and the melt is transformed into the centrifugal casting machine to produce the cylindrical sample of dimensions of outer diameter 85 mm, inner diameter of 45 mm, length of 100 mm and the thickness of 20 mm. The speed of the centrifugal casting machine was measured with automatic speedo meter connected to the machine. The samples for microstructure from ascast (outer, inner and centre region) and centrifugal casting (outer, inner and centre regions) cut at different places as per the ASTM standards.All the samples are polished as per the standard metallographic procedure. The standard metallographic procedure consists of four grades of emery paper followed by disc polishing of alumina and diamond polishing. The alumina powder, diamond paste and spray respectively used for alumina and diamond polishing using velvet cloth. The speed of the disc was 250 rpm and ten minute polishing was done on each sample. The polished samples of hypo and hypereutectic Al-Si alloys etched are for 10 s using Keller's (100 ml distilled water, 5 ml HNO_3, 3 ml HCl and 2 ml HF) etchant. The density of the ascast and centrifugal hypo and hypereutectic Al-Si alloy were measured using CONTAC electronic balance by applying Archimedes principle(water displacement method). The microstructural investigations were carried out using Olympus, BX53M optical metallurgical microscope. The microhardness hardness of the samples was obtained using Wilson VH1102 BUEHLER Vickers hardness testing machine. The load of 10 N and dwell time of 10 s has been employed for each indentation. For each sample, six indentations were taken and average hardness value was calculated with the standard deviations. The quasistatic tensile test was carried out to determine the yield and ultimate tensile strength using BISS UT-01-0025 nano tensile cum fatigue testing machine. The tensile test was done on the flat samples prepared as per the ASTM E8/E8M-04 for the strain rate of 0.016/s. The fractured surface of the tensile test samples were analyzed using FEI Quanta 200, USA scanning electron microscope.

The cylindrical samples of size 6 mm diameter and 50 mm height were prepared for wear tribological testing. The wear rate of hypo and hypereutectic Al-Si alloys were done usingTR 20LEpin-on-disc DUCOM wear testing machine.

3. Results and Discussions

3.1 Physical and microstructural characterization

The average density of the hypoeutectic ascast Al-Si alloy was 2.6793± 0.0075g/cc and centrifugal casting sample was2.6392 ± 0.0016 g/cc. The average density of ascast and centrifugal casting of hypereutectic alloys were reported as 2.6265 ± 0.002g/cc and2.6226 ± 0.0086 g/cc respectively.It is found from the results that, there is no much variations in the density of ascast and centrifugal hypo and hyper Al-Si alloy. In all the cases, uniform density of the samples is achieved.The optical micrographs of hypoeutectic Al-6 wt. % Si and hypereutectic Al-18 wt.% Sialloys of ascast and centrifugal casting are shown in Fig.1.The hypoeutectic Al-6 wt. % Si alloy processed through the die casting is indicated in Fig.1a. The distribution of secondary phase is revealed in the micrograph. The continuous and discontinuous phase distributed in the micrograph could be attributed cooling rate of the casting.The cooling rate of casting process is in the order of 10^3 C/s and the surface topography and distribution of the secondary phase is depending on cooling rate. The same alloy was processed through centrifugal casting and is depicted in Fig. 1b.The distribution of the secondary phase in the micrograph is revealed that the needle like morphology is distributed within the Al phase.

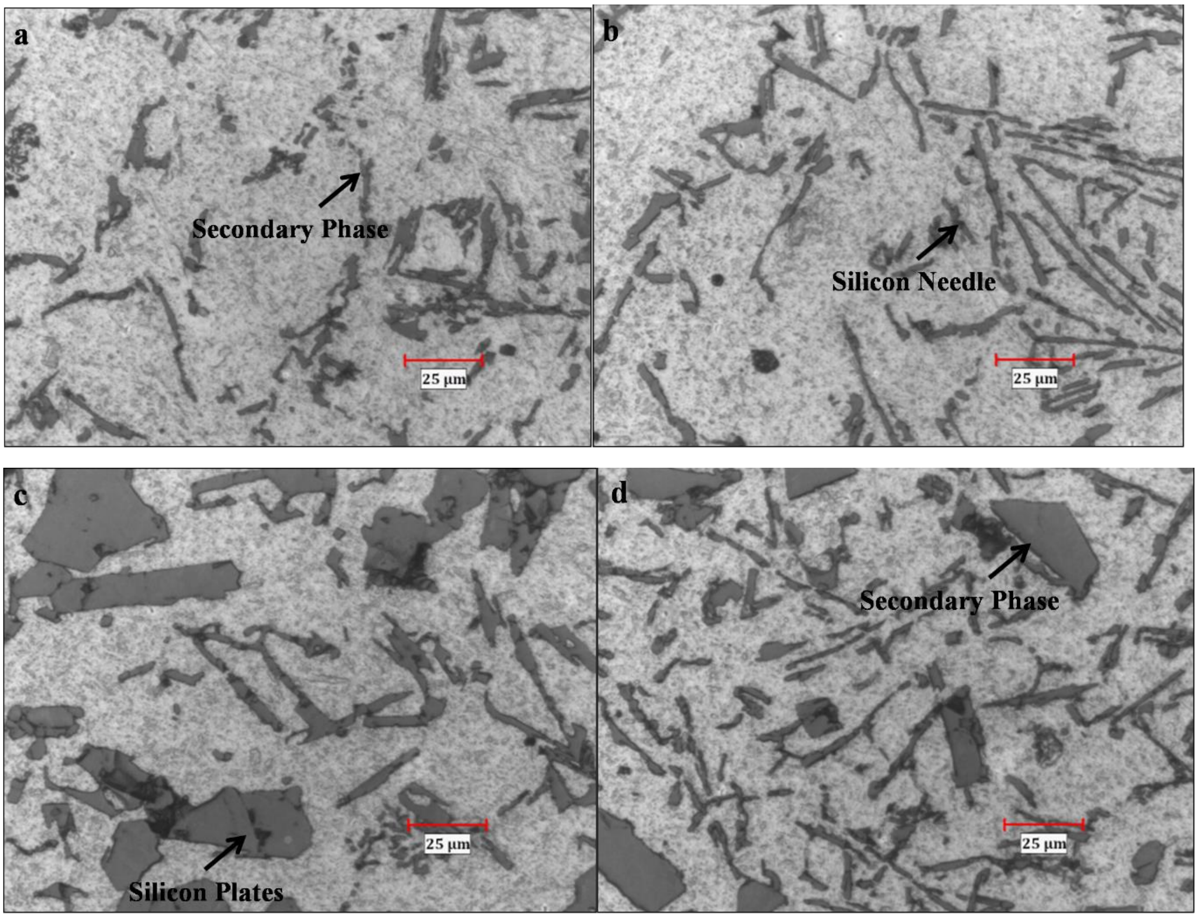


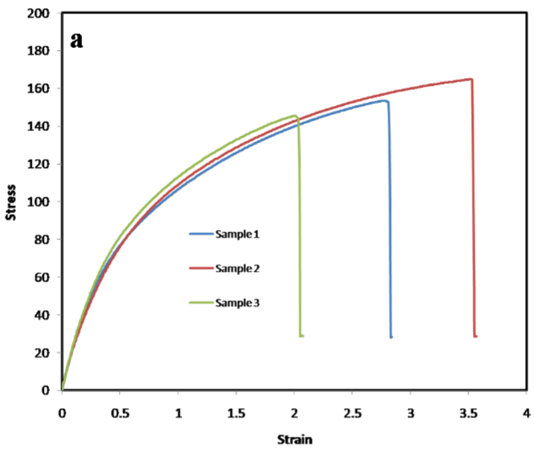
Fig.1 Optical micrographs (a) ascast hypoeutectic Al-6 wt. % Si alloy, (b) centrifugal hypoeutectic Al-6 wt. % Si alloy, (c) ascast hypereutectic Al-18 wt. % Si alloy and (d) centrifugal hypereutectic Al-18 wt. % Si alloy.

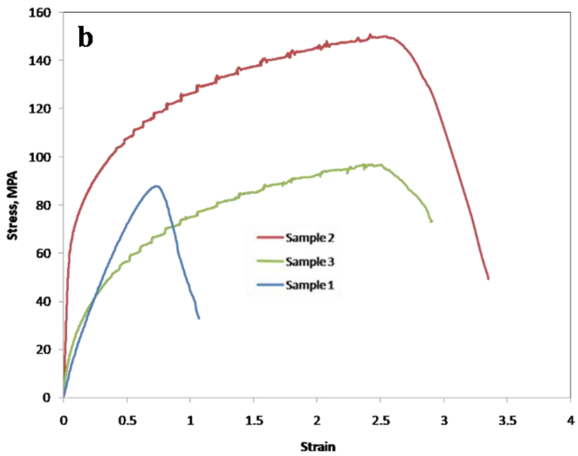
The cooling rate in case of centrifugal casting is high compared to its counterpart. The secondary phase is uniformly distributed due to the centrifugal force developed at 900 rpm employed during centrifugal casting process. Secondary Si phase in the form of powder could be observed only in few locations of the micrograph.

Fig.1c indicates the hypereutectic Al-18 wt.% Si alloy processed through die casting process. The quantity of secondary phase observed in the micrograph is found to be increased. The silicon secondary phase is embedded within the soft aluminum phase. The surface topography indicates the quantity of silicon plates are more the quantity of the silicon needles. The micrograph shown in Fig.1d indicate the morphology of hypereutectic Al-18 wt.% Si alloy silicon phase processed through the centrifugal casting. The silicon secondary phase found to be decreased by increasing the silicon needles. The effect of silicon needles on mechanical properties is higher than the effect of Si plates. The silicon phase distribution depends on the cooling rate of the alloy. The cooling rate is increased in case of centrifugal casting than the die casting process due to the centrifugal force developed during the process.

3.2 Mechanical properties

The microhardness of hypoeutectic ascast Al-6 wt. % Si and centrifugal casting Al-6 wt.% Si alloy are 46.66 ± 2.77 HV1 and 45.45 ± 2.44 HV1 respectively. There no much variation in micro Vickers hardness of hypoeutectic Al-6 wt. % Si alloy processed through die casting and centrifugal casting. The marginal variations in hardness of the ascast and centrifugal casting Al-6 wt. % Si alloy could be attributed to the distribution of secondary Si phase shown in Fig. 1a and 1b.The micro Vickers hardness of hypereutectic Al-16 wt. % Si alloy processed through die casting is reported as 51.46 ± 1.63 HV1 and centrifugal casting hypereutectic alloy is 47.21 ± 5.37 HV1.In case of hypereutectic Al-18 wt. % Si ascast and centrifugal casting observed the marginal variations in micro Vickers hardness. However the standard deviations in micro Vickers hardness of hypereutectic centrifugal casting alloy is higher the ascast counterpart. The hardness of the alloy either ascast or centrifugal casting is depending not only on the distribution of the silicon phase, also depending on size and shape of the silicon phase. From the results it is observed that, the microhardness of hypoeutectic ascast alloy is increased from 46.66 ± 2.77 HV1 to 51.46 ± 1.63 HV1 as the silicon percentage is increased from 6 wt. % to 18 wt. %.The Vickers hardness of centrifugal casting Al- 6 wt. % Si hypereutectic alloy is 45.45 ± 2.44 HV1 and is increased to 47.21 ± 5.37 HV1 when the silicon weight percentage is increased to 18 %. The tensile test stress and strain diagram of hypoeutectic alloy processed through die casting and centrifugal casting is shown in Figs. 2a and 2b. Similarly the stress and strain diagram of ascast and centrifugal casting of hypereutectic alloy is depicted in Figs.2c and 2d. The yield strength of the hypoeutectic Al-6 wt. % Si alloy of ascast and centrifugal casting are 73.5606 ± 1.6505 MPa and 89.609± 3.3318 MPa respectively.





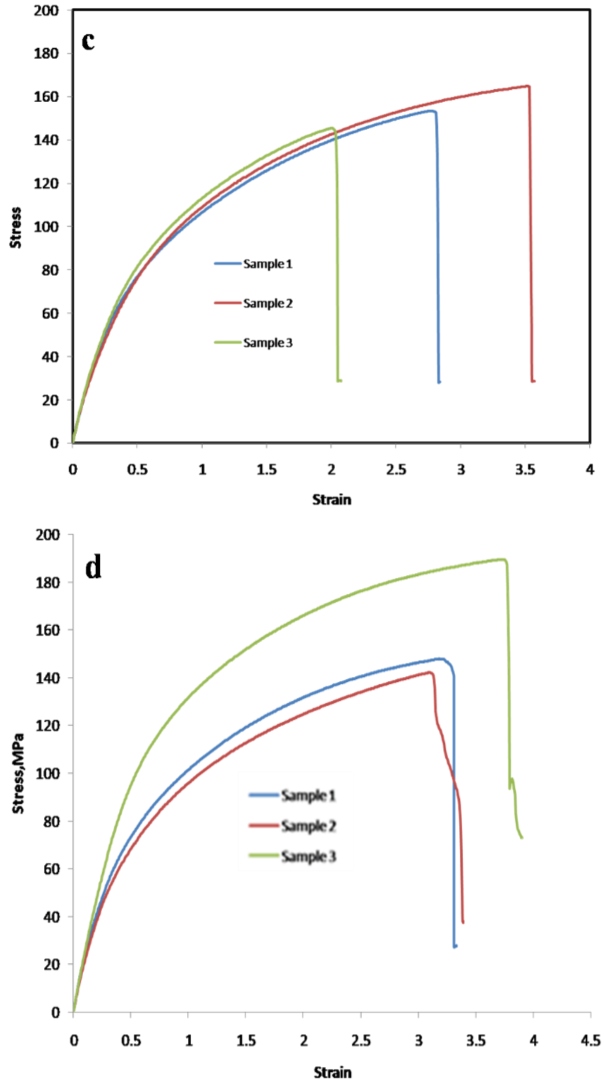


Fig. 2 stress strain diagrams of Al-Si (a) ascast hypoeutectic, (b) centrifugal hypoeutectic, (c) ascast hypereutectic and (d) centrifugal hypereutectic alloy.

The ultimate tensile strength of hypoeutectic alloy of ascast is 148.552 ± 4.774 MPa and centrifugal casting is 154.512 ± 7.949 MPa.The increase in yield strength of hypoeutectic and hypereutectic ascast and centrifugal casting is depending on the silicon needles and plates present in an alloy. The silicon needles and platesact as a barrier for the dislocation movement. The effect of silicon needle is more than the effect of silicon plates on the yield strength of the alloy.The yield strength of ascast and reciprocating hypereutectic alloy are found to be reported as 89.609± 3.3318 MPa and 91.1823 ± 16.4205 MPa respectively.The tensile test also revealed that the ultimate tensile strength of ascast hypereutectic alloyis 154.512 ± 7.949 MPa and centrifugal hypereutectic alloy reported as 159.807 ± 21.145 MPa. The marginal variations in yield and ultimate strength of ascast and centrifugal casting of hypereutectic alloy are found to be reported from the tensile test results. In the cases, the solid solution strengthening and the movement of the dislocation with respect to silicon phase could be one of the reason for showing marginal variations in the strengths.

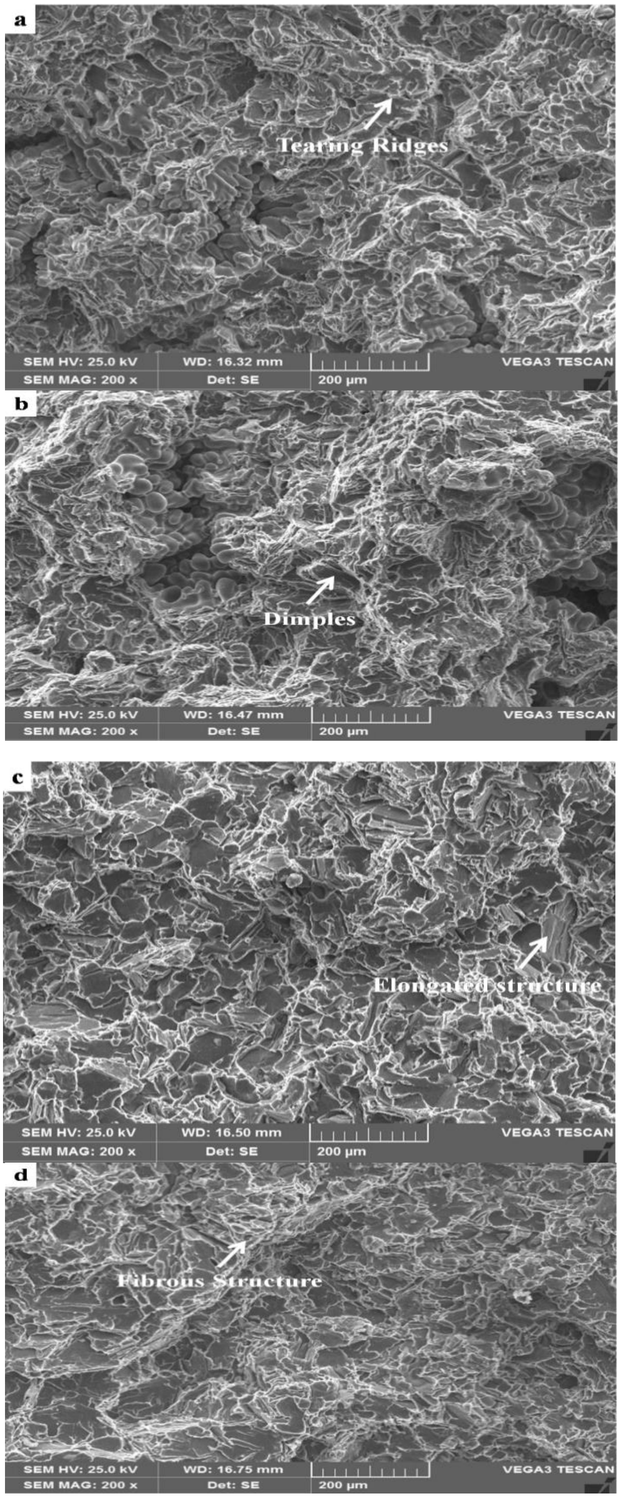


Fig.3 scanning electron micrographs of fractured surface (a) Al-6 wt.% Si ascast hypoeutectic alloy, (b) Al-6 wt.% Si centrifugal hypoeutectic alloy, (c) Al-18 wt.% Si ascast hypoeutectic alloy and (d) Al-18 wt.% Si centrifugal hypoeutectic alloy.

The scanning electron micrographs of fractured surfaces of Al-Si hypo and hypereutectic alloy processed through diecasting and centrifugal casting is depicted in Fig.4. All the fractured surfaces of ascast hypoeutectic, centrifugal hypoeutectic, ascast hypereutectic and centrifugal hypereutectic Al-Si alloys are shown in Figs.3 a-d respectively. The fractured surfaces of the scanning electron micrographs shown in Figs.3a-d revealed the tearing ridges and the dimples on the surface. The tearing ridges and the dimples on the fractured surface is the indication of showing the hypoeutectic and hypereutectic alloys are ductile fracture. The ascast hypereutectic and centrifugal hypereutectic alloys shown in Figs. 4c and 4d exhibit elongated and course fractured surface. The course and elongated fractured surface depend on the volume of silicon present in an alloy. The fibrous structure shown in Fig.4d is also indicating the hypo and hypereutectic alloys processed through die casting and centrifugal casting are ductile in nature.

Conclusion:

The Hypoeutectic and hypereutectic Al-6 wt.% Si and Al-18 wt.% Si alloy were processed through die casting and centrifugal casting. The marginal variations in density of hypereutectic and hypoeutectic alloy could be attributed to fewer defects encountered during the processing of the alloy. The microstructure of the alloy is significantly changed the morphology of the silicon phase from plate like structure to needle morphology when the processing method changed from die casting to centrifugal casting. The microhardness of the hypoeutectic ascast is enhanced by 3 % compared to centrifugal casting, whereas ascast of hypereutectic alloy is increased by 8 % in contrast to centrifugal casting. The increase in hardness of hyper eutectic alloy is due to increase in silicon content in an alloy. The yield strength and ultimate tensile strength of ascast is enhanced by 18 % and 4 % respectively by increasing the silicon content from 6 wt. % (hypoeutectic) to 18 wt.% (hypereutectic). Similarly the yield strength of centrifugal casting is enhanced by 16 % and ultimate tensile strength is increased by 12 % as the silicon percentage is changed from 6 wt. % to 18 wt. %. The strength of the alloy processed through die casting and centrifugal casting are enhanced due to increase in silicon percentage of the alloy.

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