MICROSTRUCTURE CHARACTERIZATION AND MECHANICAL PROPERTIES OF SEMI SOLID ADC12 AL ALLOY

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Abstract: To investigatemicrostructural evolution and tensile properties of semi solidADC 12 Al alloy under the different input variablesof cooling slope technique in detail. Furthermore, comparisons between the conventional cast and cooling slope cast samples have been made at same pouring temperature. The ingot of ADC12 aluminium alloy was melted in resistance heating furnace at 750^0C. Subsequently, the liquid metal alloy was poured in a holding furnace and set at the desired temperature (585^0C). Liquid molten metal was flow through the cooling slope plate at a fixed temperature with varying slope angle (30^0, $45^0$and 60^0) and slope length (400, 500, 600mm). Obtained results infer that the slope angle and slope length are most significant input variablesof cooling slope techniques, which affects the morphological characteristics of semi solid cast material. From microstructure observation, at the optimum condition (45^0 and 500mm) of these input variables generates the high sphericity and minimum particle size of primary phase of Al alloy. Obtained results also infer that the cooling slope cast samples are having better mechanical properties than corresponding gravity cast samples. The fracture studies reveal the presence of mixed mode fracture to be predominant fracture mode in case of rheocast specimens.

Key words: rheocasting, cooling slope; tensile properties; ADC12 aluminium alloy.

1. INTRODUCTION

Semi solid metal processing (SSM) has potential to be a significant manufacturing technology for automotive industry, aerospace, electrical and construction industry. This processing technology provides various advantages such as better mechanical properties, the high degree of dimensional precision, over the conventional method (Gencalp and Saklakoglu, 2010; TaghaviGhassemi, 2009). The key element of the SSM is the transformation of microstructure from dendritic to non-dendritic along with the reduction in the segregation and porosity levels in the castings (Spencer et. al., 1972; Flemings, 1991). The rheocasting process has become even more popular in the recent decade, as it possesses various advantages over thixocasting, as well as less processing cost, enhancing the casting dimensional accuracy and improvement of die life (Park et. al., 2005) Several techniques such as ultrasonic vibration, electromagnetic stirring, and magneto- hydrodynamic and rapid cooling have been investigated to find out near equixed grain microstructure. Alternatively, the cooling slope process is best techniques that use the formation of semisolid slurry for rheocasting and improves the uniformity of microstructure. Significant works were conducted at semi solid metal processing (liu et. al., 2004; Apelian, 2006; Jorstad and Apelian, 2008) on producing SSM via inclined plate (CRP - Continuous Rheoconversion Process and cooling slope) (Birol,2008; Birol, 2007; Xu et. al., 2011; Haga and Suzuki, 2001). There are several literatures available on semi solid metal processing of most common Al alloy are A356/A357(low Cu %) and A380 (higher Cu 3%) as compared to ADC12 at 1.5% level. In spite of this detail, the widely used material in the automobile industries is ADC12 Al alloy. However, some work about the semi solid metal processing of this alloy has been available to the best knowledge of the authors. This class of (ADC 12) Al alloy is used extensively due to their excellent properties like high corrosion resistance, low thermal expansion and high castbilty. In contradiction, there are several cast defects in conventional die casting components e.g. porosity, surface blister and blowholes. Considering that porosities are obtained especially in die casting because of turbulent flow and defects like surface blister cannot be normally heat treated (Tian et. al., 2002; Zhao et. al., 2009). To resolve this problem in ADC12 aluminium alloy, the rheocasting process is selected for this experimental work. To investigate microstructural evolution and tensile properties of semi solid ADC 12 Al alloy under the different input variables of cooling slope technique in detail.

2. EXPERIMENTAL PROCEDURES

The commercial ADC 12 alloy was selected for this this experimental work and differential thermal analysis result was validate its liquids and solidus temperatures 572°C and 520°C respectively (shown in Figure1). Chemical composition of this class of Al alloy was shown in Table 1.

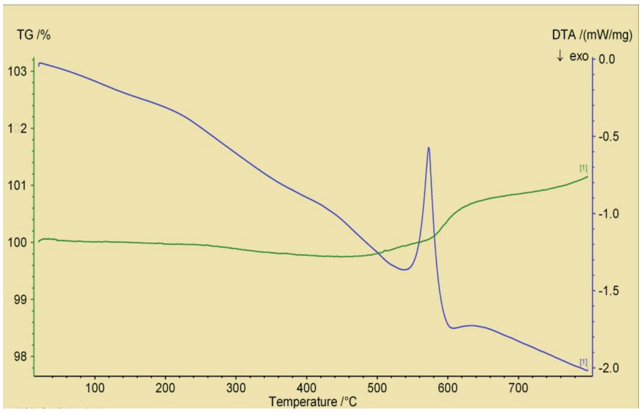


Fig. 1. Differential thermal analysis graph of ADC 12 Al alloy

Table 1. Chemical composition of ADC12 Al alloy

Element	Al	Si	Cu	Fe	Mn	Mg	Zn	Ti
Wt%	Balance	10.57	1.685	0.780	0.314	0.082	0.117	0.021

The cooling slope facility was shown Figure 2. The cooling slope plate was fabricated by stainless steel material because its thermal conductivity was very less compare to the copper material. Low thermal conductivity material has less adhesion therefore; this material is suitable for semisolid slurry generation. ADC 12 ingot was melting in the resistance furnace at 750^{0}C and poured into holding furnace, it was set at 585^{0}C temperature. Cooling slope was preheated (60^{0}C) from inside by circulating heating oil and surface of cooling slope was coated with boron nitride to avoid adhere the liquid melt. Angle of cooling slope plate was adjusted respect to horizontal plane at varying degrees (30^{o}, 45^{o} and 60^{o}). The molten metal was poured from the holding furnace to the cooling slope plate and allowing melt travel on the cooling slope at different slope length (400 mm, 500mm and 600mm). Temperature of flowing melt was monitored by k-type of thermocouple, which were located at three different sections as bottom, middle and exit of cooling slope. Semi solid slurry was collected at end of cooling slope in the preheated copper mould (200^{0}C) and cooled in the atmospheric condition. For the comparative metallographic examination samples are extracted from the gravity cast and cooling slope cast, usingoptical microscope and Field Emission Scanning Electron Microscope.

Fig. 2. Experimental setup of cooling slope techniques

2.1. Mechanical test

Tensile properties of gravity cast and cooling slope cast samples have been evaluated using rounded tensile specimens, fabricated as per ASTM E8 standard. The dimension of the rounded tensile specimen is shown in Figure 3. There are three rounded tensile specimens are machined from solidified billet of each experiment. Experimental tests were performed at ambient condition, at 0.5 mm/sec displacement rate. The broken samples after tensile tests were characterized using Zeiss FESM for fracture surface analysis.

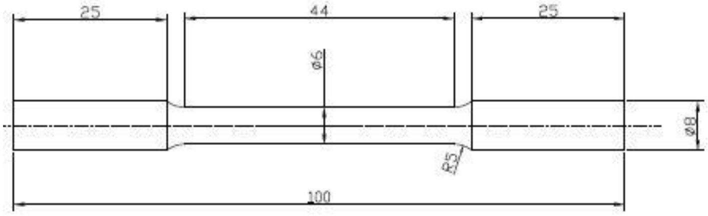


Fig. 3. Dimensions of tensile samples

3. RESULTS AND DISCUSSION

3.1. Microstructure analysis

Figure 4 depicts gravity cast microstructure, which was directly poured into the rectangular copper mould without using the cooling slope. From these observations, microstructure of gravity cast samples revealed the elongated dendritic morphology of primary Al particle along with primary and secondary arms. Micrographs also revealed that long needle type mixture of eutectic phases (Istrate et. al., 2015). Micrograph of cooling slope cast samples shows completely different from the gravity cast microstructure due to generation of heterogeneous nucleation of α-Al phase takes place at contact surfaces between the melt and cooling slope plate. Due to shearing effect, these particles are removedfrom the surface of cooling slope plate and are carried along with flowing melt. The detached particles become spherical in form. Later, it gets converted into semisolid on reaching the exit of slope plate. The difference in the microstructure of conventional cast vis-à-vis rheocast samples in this research work are found similar with few earlier reported work on A356 alloys (Das et al., 2014; Gautam et. al., 2018). In this investigation to analyse the morphological characteristics of cooling slope cast when change in slope angle and slope length.

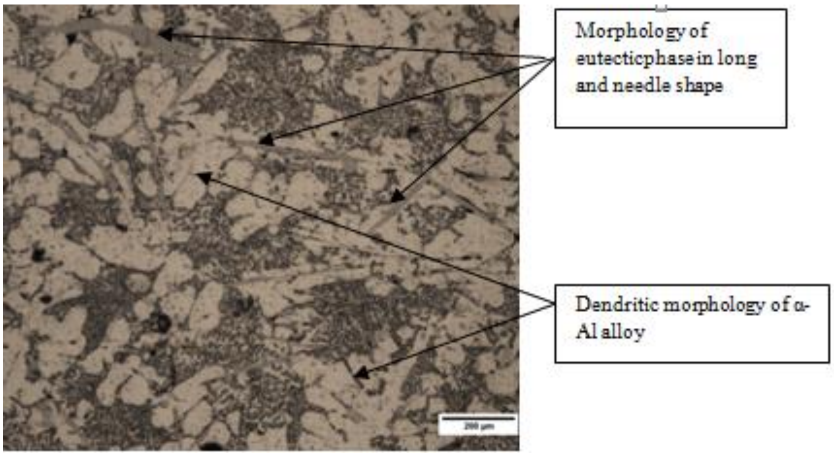
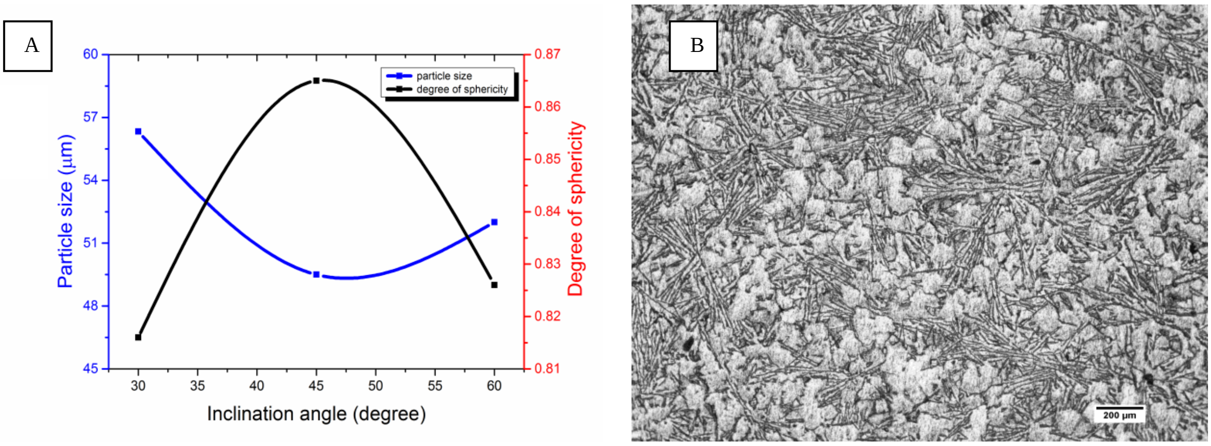


Fig.4. Gravity cast microstructure

3.1.1. Effect of inclination angle

Slope angle is the most significant input variable of cooling slope technique and it governs rate of melt flow and a time spendamong the flowing melt and cooling slope plate surfaces. Figure 5 (A) represents the variation of average particle size and sphericity with different slope angle conditions. At the low slope angle (30 degrees), morphology of primary phase of Al alloy not completely change into the spherical, due to low shear force and low melt velocity (Saklakoglu et. al., 2011). Increasing cooling slope angleupto (45^0) results in an increase the gravity force that assists the shear off the dendritic structure and modified it to nearly globular shape and fine particles (as shown in Figure 5(B) and 5 (C). Further increasethe slope angle (60^o) beyond an optimum value (45^o) molten metal flow over the inclined surface travel at high velocity, decreasing the heat extraction between the slurry and cooling surface plate. Consequently, collectedslurry has mixture of low solid fraction and high liquid percentage, which is unwanted (Nourouzi, 2013). Figure 5 (D) shows the micrographs at 60^0 slope angle.



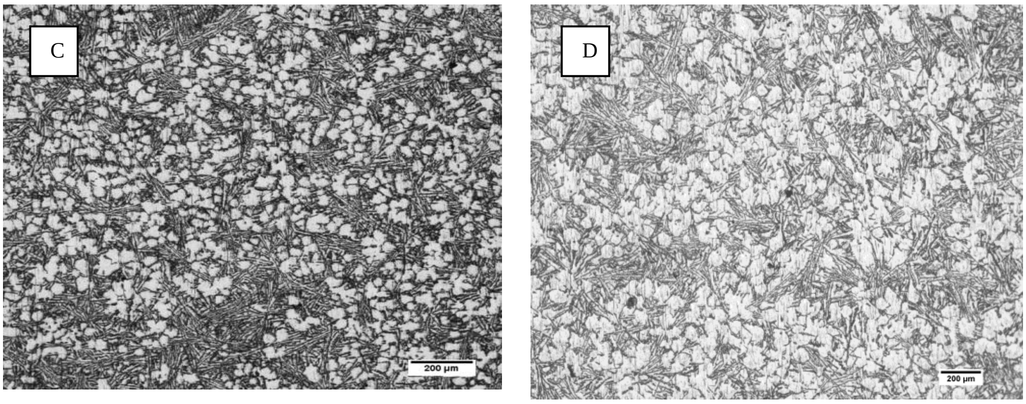


Fig. 5. Micrographs of cooling slope cast samples at constant pouring temperature (585°C) and slope length (500mm): (A) variation in (slope angle); (B) 30^0; (C) 45^0; and (D) 60^0

3.1.2. Effect of slope length

The microstructures of cooling slope cast samples at different cooling slope lengths of 400, 500 and 600mm at 45-degree slope angle are shown in Figure 6. It can be clearly seen from Figure 4 and Figure 6 that the morphological changes are significant with and without using cooling slope. The dendritic morphology of the gravity cast sample is replaced with equixed grains using cooling slope technique; which facilitates heterogeneous nucleation due to rapid heat exchange and successive detachment of the formed crystals from the surface due to the shear has driven the flow of the melt through the slope (Salafar, 2004). The optimum microstructure having equixedfine grain and the high degree of sphericity is obtained at 500 m length. Further, increment in slope length, it enhanced the average the grain size and sphericity of primary phase Al alloy. This phenomenon can be attributed to the fact that the increase in slope length leads to the thickening of the solid layer formed between the melt and the inclined slope. As a consequence, the rate of heat transfer along with the rate of cooling of the melt flowing on the surface of the inclined plate decrease, which leads to lowering of the nucleation rate of primary solid phase. Therefore, size of primary solid phase available for the final microstructure solidified into the mould increases (Taghaviand Ghassemi, 2009).

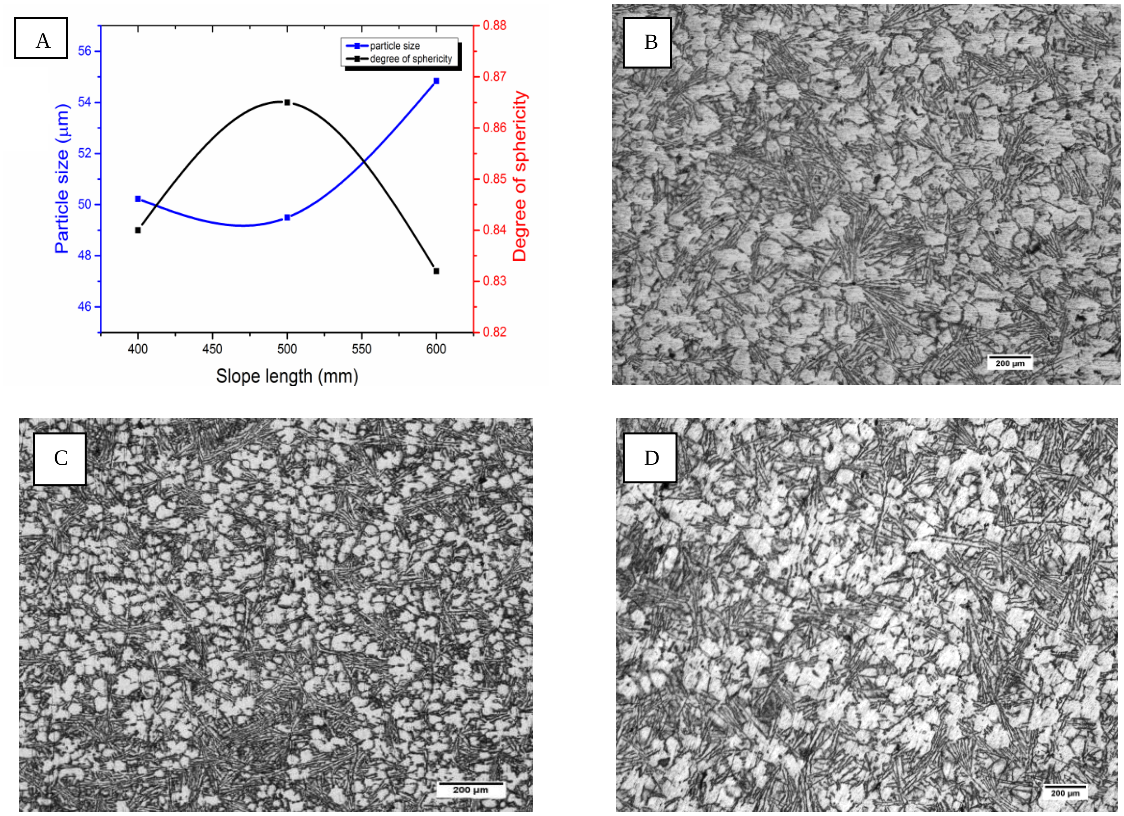


Fig. 6. Microstructure of cooling samples at constant pouring temperature (585^0C) and slope angle (45^0): (A) direct effect of processing parameter (slope length); (B) 400mm; (C) 500mm; and (D) 600mm

3.2. Tensile results

Figure 7 shows the comparison of tensile results obtained experimentally from the conventional cast and cooling slope cast at different processing conditions. Morphology of microstructure is having more effect on tensile strength and elongation (Das et. al., 2012; Nedelcu et al., 2009; Nedelcu et al., 2010). The conventional cast of ADC12 Al alloy has large and elongated particles (dendritic).This dendritic structure of α-Al effects on mechanical properties because of high strain hardening and micro-porosity.

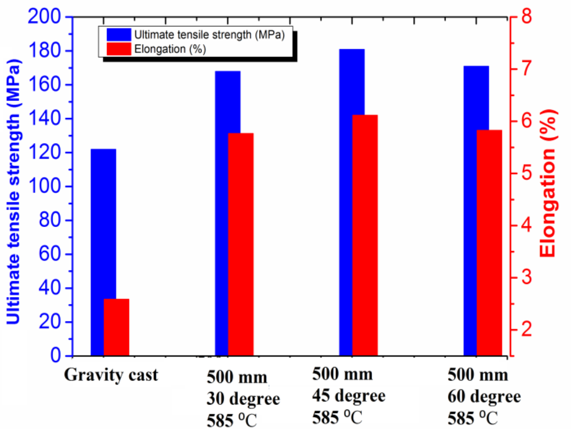


Fig. 7.Tensile strength and % elongation of ADC12 alloy of gravitycast and cooling slope cast at different processing conditions

During the solidification, the formation of microporosity within melt takes place which creates a solid slecton reducing the fluidity of melt. It also adversely affects mechanical properties (ultimate tensile strength and ductility) of cast materials. In cooling slope process, micrographs revealed that morpholgy of primary phase Al alloy nearly spherical and fine grain size which improves the mechanical properties(ultimate tensile strength and ductility) of cast samples. Thus, in cooling slope casting a likelihood transition of fracture manner from intergranular to transgranular is seen. Few earlier investigators have compared conventional cast and the rheo cast of Al alloys (Baltaescu et al., 2013; Cosic et. al., 2012; Lu et al., 2010).

3.3. Fracture surface analysis

The fracture surface of the gravity cast of tensile sample is shown in Figure 8A. A crack initiation point in gravity cast depends on intermetallic structure. It causes the structural defect such as porosity. A crack initiation structure of these intermetallic phases is plate and long needle type shape. Crack initiation, it is propagated by cracking of eutectic Al-Si particles and Fe-based intermetallic compound; this is responsible for facets of the fracture surface.

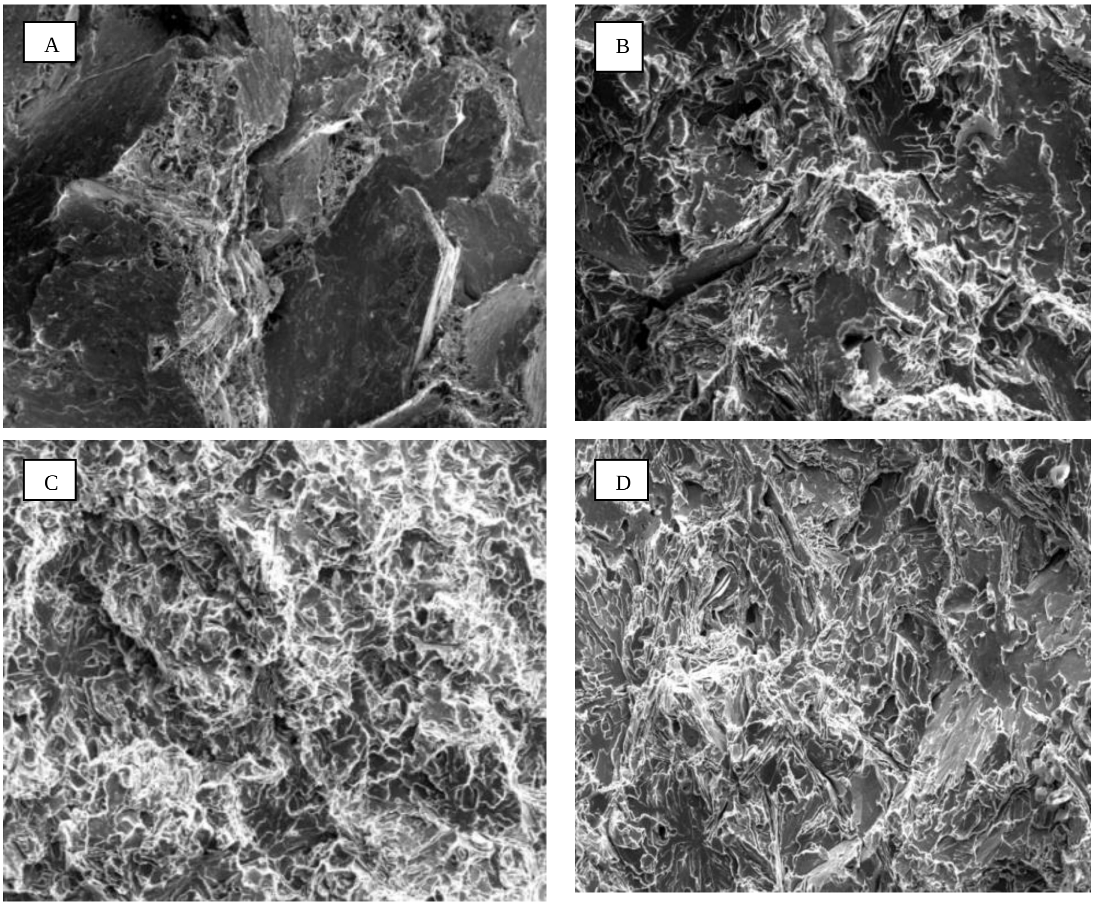


Fig. 8. FESM fractographs of tensile fracture surfaces at different magnification 1000x. (A) gravity cast. cooling slope cast at different processing condtions (B) angle 30 degree, length 500mm and pouring temperature 585^{o}C. (C) angle 45 degree, length 500mm and pouring temperature 585^{o}C. (D) angle 60 degree, length 500mm and pouring temperature 585^{o}C

Figure 8B, C, D show the factrography of cooling slope cast under different processing conditions. Generally, mixed mode fracture manner occurs in cooling slope cast alloy due to void initiation at globular eutectic silicon particles and is responsible for facets in the fracture.

4. CONCLUSIONS

The obtained result of this investigation infers the following:

Morphology of α-Al phase in gravity cast sample readily changes from dendritic to the non-dendritic structure while flowing through the cooling slope channel which facilitates heterogeneous nucleation due to rapid heat exchange and consecutiveseparation of the nucleated grains from the surface due to the gravity force applied on flowing melt through the channel.

Since the slope angle and lengths influence the heat extract for the molten metal and thus the cooling rate, which thus controls the ability to obtain globular alpha aluminium. It is observed that the most favourablecondition of slope length (500mm), which generates the fine grain size and high globular, is obtained at the constant slope angle of 45^0. Also, the most favourable condition of slope angle (45^0) (fine grainsize and the high globular) is observed at constant slope length of 500mm.

An increase in tensile strength and elongation were obtained in cooling slope cast samples at the optimum value of cooling slope parameter 45^0, 585^{0}C, 500mm than gravity cast.

5. ACKNOWLEDGEMENTS

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