Characterization Study of Al Alloy Cast through Strain Induced Melt Activated (SIMA) Process

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Abstract- **The effects of process parameters on microstructure evolution of A356 (Al-7%Si-0.3%Mg) alloy cast by strain induced melt activated (SIMA) process were investigated. Deformation of 20%, 30% and 40% were used by hot working at 380°C (rolling and forging). In order to determine the kinetics of coagulation, some samples were heated to a temperature above the solidus point and maintained in the isothermal conditions at two temperatures (580 and 590°C) for various holding times (15, 30 and 45 min). The metallographic studies were done on SIMA processed alloys Al alloy. Those were compared with as cast A356 alloy. It was observed that SIMA processed alloys has globular morphology. The formation mechanism of globular particles in the process of isothermal treatment also discussed. It has been observed that the solid fraction of the semi solid slurry gradually decreased with temperature or prolonging isothermal time. It was found that increased deformation reduced the time to obtain globular morphology. Effect of SIMA process on mechanical properties of A356 alloy has also been seen. Significant improvement in ductility noticed in SIMA processed alloy in comparison to cast alloy besides some improvement in tensile strength.**

Keywords- 356 aluminium alloy, isothermal holding time, isothermal temperature, partial remelting, semi-solid microstructure

I. INTRODUCTION

The Al alloys produced by the conventional casting methods have dendritic morphology and this dendritic morphology leads to poor mechanical properties. So for better mechanical properties, this dendritic morphology should be changed into non-dendritic morphology. The main aim of semi-solid metal (SSM) processing is to obtain the non-dendritic morphology by stirring the alloy in between the solidus and liquid point **[1, 2].** Semi-solid forming, which has been widely use in the field of automobile, spaceflight and aviation, is a promising method of materials processing **[3, 4].**

Usually, the semi-solid slurry, prepared by stirring process known as rheocasting **[5],** is used directly for forming products. Thixoforming is another two step method where thixoformed feed stock is reheated to semi solid temperature to provide the SSM slurry subsequently used for component shaping. As one of the SSM process, the strain induced melt activation (SIMA) process developed by Young et. al. **[6]** in 1980s is used to produce Mg alloys. This combines both casting and forging/rolling. For this method, residual strain is stored in a billet and a global structure is evolved by the strain energy stored in the billet after reheating **[7].** The process is based on scientific understanding that grain boundaries induced by plastic deformation and recrystallization will be wetted by liquid metal at the semi solid temperature, resulting in a fine and globular structure **[8].** In this study, various parameters which relate the microstructure and mechanical characteristics of thixoformed A356 alloy, such as grain size, solid fraction and shape of primary Al and morphology of silicon particles are addressed. Grain coarsening mechanism has also been discussed.

II. EXPERIMENTAL PROCEDURE

In this study A356 (Al-7%Si-0.3%Mg) alloy is used. The alloy was melted in the electric resistance furnace at 720^0C. To avoid the oxidation of the melt, it was covered with cover flux. After proper mixing, degassing and grain refinement the molten alloy was cast in the form of rectangular strips of size 250mm x 15mm x 10 mm in metallic mould. The ingot was cut breadth wise to get samples of length 25mm.

In order to study the effect of deformation and isothermal process parameters (time and temperature) on semi solid microstructures, the deformed samples (20%, 30% and 40%, by forging and rolling) were heated from room temperature to 580 and 590^0C in an electric resistance furnace. When the respective heating temperature reached to predetermined values, samples were isothermally held for 15, 30, and 45 min. and immediately taken out for water quenching keep microstructure morphology of semi solid slurry at room temperature. Samples for microstructure characterization were prepared by the standard metallographic techniques, followed by etching in a Keller's reagent. The microstructure of samples was observed under metallurgical microscope.

XRD was carried out on a representative samples to identify the phases present and distribution of elements in the alloy. The tensile properties were tested on Material Test System at a constant rate of $10^{-3}S^{-1}$. Averages of three values were taken. SEM analysis was also carried out on selected metallographic samples and fractured tensile samples.

III. RESULT AND DISCUSSION

A. XRD analysis

XRD analysis was carried out to investigate the phases present in the alloy. A representative sample (at 580^0C, 30% predeformation and holding time 30min) was selected for XRD analysis .The XRD analysis detected peaks of Al, Al-Si and Si (Fig.1).

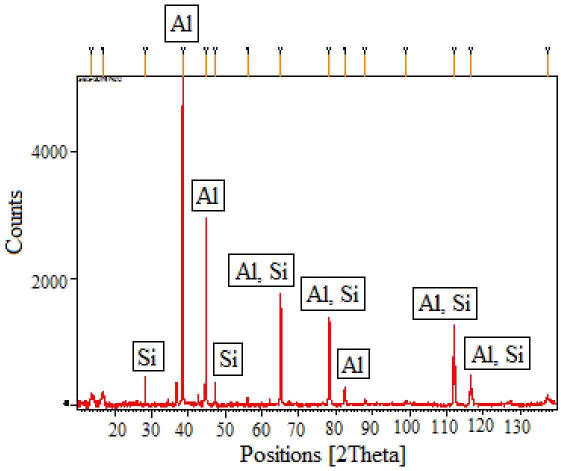


Fig.1: XRD analysis at 580^{0}C and 30% deformation for 30 min.

B. *Line analysis*

Fig.2 shows the distribution of the major alloying elements at the semi-solid temperature range by line analysis. During partial remelting, Si, and Mg redistributes in the matrix and grain boundary. It can be found that distribution of elements Si, and Mg is uniform in the matrix. However, contents of the Si and Mg at the grain boundary are much higher than those in the matrix. The diffusion of atoms is closely associated with the isothermal temperature and the holding time. The contents of the Si and Mg decrease in the matrix and these elements segregate to the grain boundaries with an increase of the isothermal temperature and the holding time. The longer the holding time and the higher the isothermal temperature, the more segregation of Si at the grain boundary would be which results in a decreasing amount of Si in the intragranular regions. The reason is that the different diffusion velocities for Si and Mg atoms in the intragranular and intergranular regions of grains are enhanced by an increase of the isothermal temperature and the holding time.

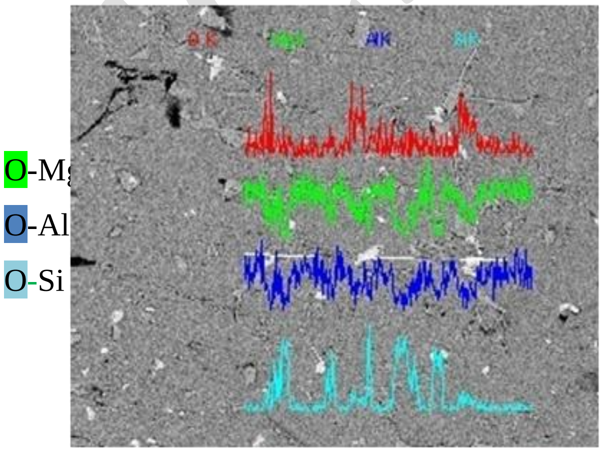


Fig.2: SEM micrograph and line scan for the semisolid Al-7Si-0.45Mg alloy

C. *Microstructure of as-cast and SIMA A356 alloy*

The microstructure of as cast A356 alloy is shown in below Fig.3, and from the Fig it is clear that the alloy has dendritic morphology.

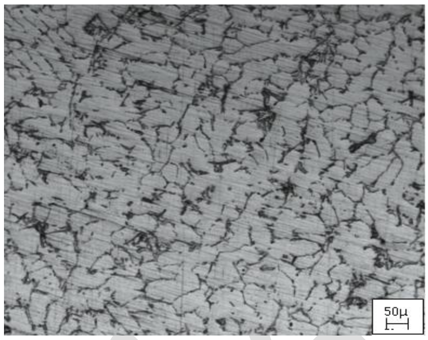


Fig.3: Microstructures of as cast A356 alloy

D. *Effects of deformation and temperature on semi sold microstructure*

Fig.4 (a-c) show the microstructures at 580^{0}C deformed to 20%, 30% and 40% for 30 min. According to this Fig. 4(a-c), it is clear that the grain size decreases as deformation increases. With a large amount of deformation, more energy in the form of residual strain is deposited in the samples. This energy will be released and help to break up the microstructure when the sample is reheated. The more the residual strain, the more the energy is deposited and the smaller the grain size.

The same phenomena also observed at 590^{0}C which was performed for 20%, 30% and 40% predeformed for 30 min. (Fig.4 d-f). However in the later case the average grains size are more than the average grains of alloy at 580^{0}C (Fig 4 a-c). So it is cleared that the average grain size decreases with the deformation.

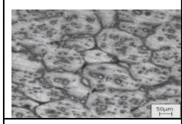
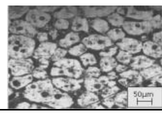
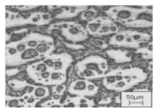
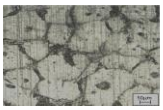
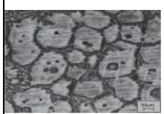
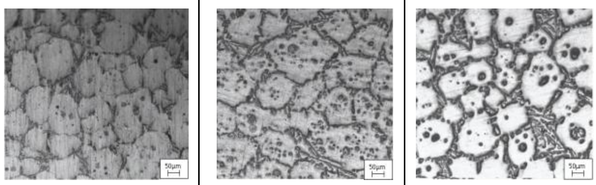
Temp.	Deformation		
	20%	30%	40%
580^{0}C	 (a)	 (b)	 (c)
590^{0}C	 (d)	 (e)	 (f)

Fig.4: Microstructures of A356 alloy at 580^{0}C and 590^{0}C, predeformed to (a) 20% (b) 30% (c) 40% for 30min

E. *Effects of isothermal time on semi solid microstructure*

The effects of holding time on microstructure during partial remelting are shown in Fig. 7 (a-c). The Al-grains coarsen and become some what globular with an increase of the holding time. At the isothermal temperature of 580 °C, the average size of grains increase from 60 to 75 µm, from holding times of 15 to 45 min.



(a) (b) (c)

Fig.5: The microstructures of 40% predeformed A356 alloy heated at 580^{0}C for (a) 15min; (b) 30min; and (c) 45min

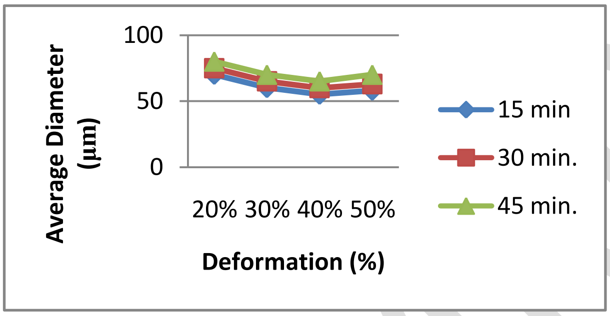


Fig. 6: Effect of holding time on average grain size (at 580^{0}C)

With increasing holding time, many small liquid droplets within grain combine and form several big liquid drops in order to reduce the interfacial energy.

Above the holding time of 30 min, the grain size increases slowly. From Fig. 5(c), it is observed that small grains are merging with large grains. This eventually decreases the quantity of the small grains.

The two main mechanisms of grain coarsening play an important role during partial re-melting. One of the coarsening mechanisms is the coalescence of grains. Grain growth due to coalescence by grain boundary migration is dominant at short times after liquid is formed, at low volume fractions of liquid. Liquid fraction increases with increasing of the isothermal temperature and holding time. Under these conditions, Ostwald ripening is the dominating mechanism of grain coarsening in the stage of high liquid fraction, in which grains continuously coarsen and the small grains gradually melt **[9, 10].**

IV. MECHANICAL PROPERTIES

A. *Tensile testing*

Fig.7 shows the results of 0.2% proof stress, UTS and % elongation of samples with varying predeformation at 580^{0}C for 15 minute holding time. From Fig it is clear that for the constant temperature and holding time as the deformation increases, 0.2% proof stress, UTS, and Elongation also increases when compared with the as cast sample.

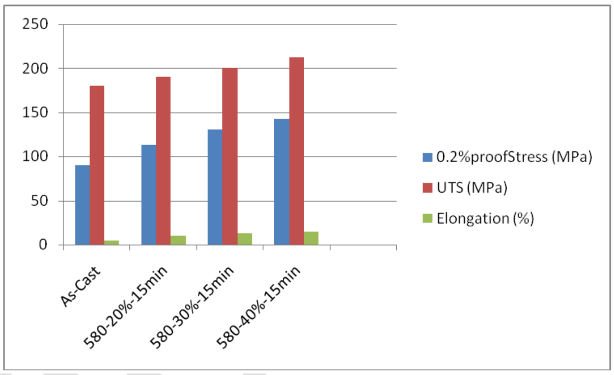


Fig.7: Graphs of SIMA Tensile samples

The maximum UTS value 212.75 MPa and elongation 14.61% is achieved for the sample heat treated at 580-40%-15min. This is attributed to the globularity of primary aluminium morphology, grain refinement and change in morphology of Si particles of Si particles i.e. size and shape.

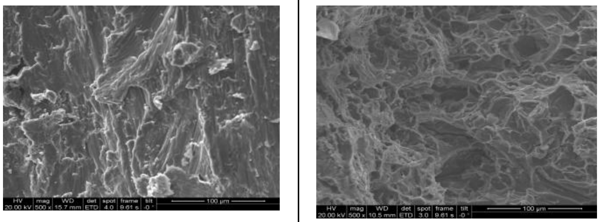
The improvement in strength and elongation, can be understood by the following Hall –Petch equation

$$\sigma_y = \sigma_i + k\,(d)^{-1/2} \qquad (1)$$

Where σ_y and σ_i to the yield stress and normal stress, respectively, d refers to the grain size, k is constant **[11].** From the above equation, the yield strength increases with decreasing grain size because the grain boundary acts as effective obstacle for slip dislocation on initial deformation stage is dominantly affected by the interaction and across of dislocation rather than the presence of grain boundary. The behavior of slip dislocation with decreasing grain size was interrupted by numbers of grain boundaries. Therefore, the yield strength and elongation were improved with decreasing grain size.

B. *SEM analysis of fractured tensile samples*

Fig 8 (a) and (b) show SEM image of A356 alloy at 20% and 40% deformation respectively. Fig (b) shows more dimpled than (a) in the fractured surface, indicates more ductility than 20% deformed sample.



(a)	**(b)**

Fig.8: SEM photographs of 580^{0}C for 15 minutes at (a) 20% (b) 40% deformation.

CONCLUSION

From the above work it can be conclude that as the deformation increases then the average grain size decreases but globularity in the particles increases. But as the holding time increases then coarsening of particles occurs due to Ostwald ripening which can be further given by the LSW theory and more globularity also occur. The mechanical properties of SIMA processed alloy is better than the as cast condition and these mechanical properties also increases as the deformation increases.

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