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Influence of Heat Treatment Processing Parameters on the Hardness and the Microstructure of Semi-Solid Aluminum Alloy A356

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Abstract

The objective of this research is to study the influence of heat treatment parameters on the mechanical properties and the microstructure of semi-solid aluminum alloy A356. The cast specimen were heat treated by using T6 heat treatment processes.

T6 treatment condition was as follows: solubilizing at 520 and 540° C for 4 hr. before quenching and aging at 135°C, 165°C and 195°C for 4,8,12 and 16 hr .

Mechanical properties of semi-solid aluminum alloy A356 were investigated by hardness tests and by using OM.

The process in preparation called Gas Induced Semi-Solid (GISS) utilizes the combination of local rapid heat extraction and agitation achieved by the injection of fine gas bubbles through a graphite diffuser to create semi-solid slurry. In the GISS process, the die casting machine and the process cycle remain little changed from those of conventional die casting. The GISS unit creates a low solid fraction of semi-solid slurry in the ladle during the ladle transfer to the shot sleeve. The semi-solid slurry is then poured directly into the shot sleeve.

Key words ; Semi-solid, A356, Heat treatment

Introduction

Aluminum-silicon alloy is known for its good castability and good corrosion resistance. In this alloy series, A356 (Al-7%Si-0.3%Mg) has a very good properties for cast aluminum and was used to produce many important parts which require high strength, elongation and light weight. The automobile industries increase the use of aluminum alloy because of the greater demand for lightweight and high strength materials resulting in reduction of fuel consumption. Magnesium addition makes this alloy heat treatable and hence improves its mechanical properties by forming Mg_2Si phase. During heat treatment process, solution treatment makes large Mg_2Si particles in the aluminum alloy dissolved and diffuse throughout the matrix as solid solution. Upon rapid quenching the solution-treated sample, magnesium stays in the matrix as the supersaturated solid solution, and ready to precipitate out during aging process. These intermetallic precipitates enhance the mechanical properties by precipitation hardening. Therefore, the mechanical properties of these alloys are significantly influenced by the present of the ß (Mg_2Si) phase and distribution of eutectic Si. The precipitation sequences are shown below:

GPZ (rods) $\longrightarrow$ ß'(rods) $\longrightarrow$ ß (Mg_2Si)(plates)

The Gas Induced Semi-Solid (GISS) process applies the knowledge that the semi-solid structure can be efficiently formed by the combination of local rapid heat extraction and agitation.[1] In the GISS process, the local rapid heat extraction occurs at the surfaces of the porous graphite diffuser when it is submerged in liquid aluminum. At the same time, vigorous agitation is

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induced at the chill surfaces by the flow of very fine inert gas bubbles out of the porous graphite. Figure 1. shows the schematic of the GISS process.

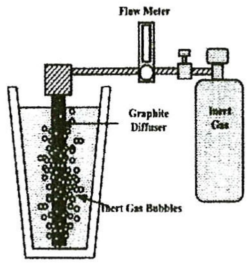


Figure 1. Schematic of the Gas Induced Semi-Solid (GISS) process.

In the GISS die casting process, the die casting equipment and the process cycle remain little changed from those of conventional die casting. The only added step occurs during the ladle transfer when a graphite diffuser is immersed for about 10 seconds to create semi-solid slurry with a low solid fraction of about 10%. The semi-solid slurry is then poured into the shot sleeve for a die casting injection to produce a semi-solid casting part. Figure 2 shows the schematic of the GISS die casting process.

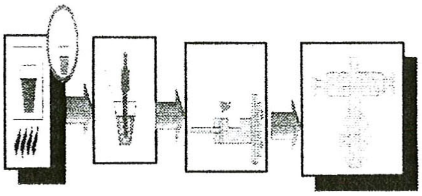


Figure 2. Schematic of the GISS die casting process.

Forming in the semi-solid state may be attractive in this regard as it helps with the porosity and segregation problems inevitable in conventional casting and provides a sound, globular microstructure with relatively higher hardness and ductility values.[2]

Heat treatment can be use for improving the mechanical properties of SSM. These studies identified the following precipitation sequence: (i) aluminum supersaturated solid solution, (ii) cluster of Si and Mg atoms. (iii) dissolution of Mg cluster and formation of Mg/Si co-cluster (GP-zone), (iv) ß' rod precipitates, (vi) ß (Mg2Si) stable plates.[3]

It has been suggested that the increase in strength of Al-Mg-Si alloy during the early stage of aging is due to the increase in energy required for the dislocations to break the Mg-Si bond as they pass through GP-zone precipitates. As the aging time increases, GP zone transform to larger ß' precipitates, and the alloy becomes stronger and harder but less ductile. If aging is continued so that the intermediated precipitates coalesce and coarsen to form ß equilibrium phase, the alloy becomes overaged and weaker than in the peak aged condition. A maximum strength (peak aged condition) is eventually reached if the aging temperature is sufficiently high, and is usually associated with the formation of an intermediated metastable precipitate.

Materials and Experimental Procedures

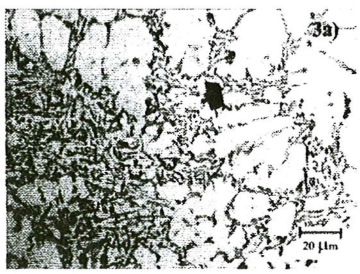
Methodology

The material used in this study was semi-solid aluminum alloy A356 produced by new rheocasting (NRC). Its nominal composition is show in Table 1.

Table1. Nominal composition of the A356 alloy

Al	Si	Mg	Fe	Cu	Mn	Zn	Ti
bal	7%	.35 %	.20 %	.20 %	.10 %	.10 %	.230 %

T6 was used as the heat treatment process with the solution treated temperature and time of 520 and 540°C and 4 hours, respectively. After quenching the specimens were aged at 135°C, 165°C and 195°C. The microstructure of the as-cast and heat-treated specimen was examined using the optical microscopy. The hardness was measured from three specimen for each condition, and from nine different points in each specimen by using Vickers micro-hardness test. The test head load was fixed at 100 grams.



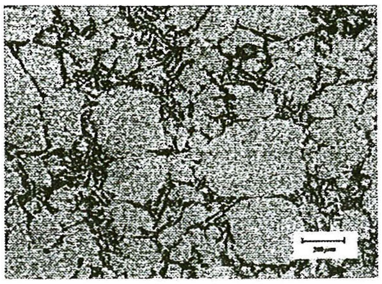


Figure 3. A typical dendritic liquid-cast structure (3a), compared to a semisolid-cast structure of A356 alloy (3b)

Figure 3a. Shows the dendritic structure of conventional cast A356 while Figure 3b illustrates the globular structure of SSM cast A356. Both structures consist of primary phase α-Al and eutectic mixture of Al and Si along the grain boundaries.

Results and Discussion

Figures 4 and 5. Show the microstructure of semi-solid A356 after solution-treated at 520°C and 540°C for 4 hrs. The structure consists of α-Al and Mg_2Si phases in which Mg_2Si phase along the grain boundary becomes discontinuous and round in shape suggesting that solution treatment dissolve Mg_2Si phases into the Al-matrix. However, there is not much difference in the microstructure between the two samples with different solution treated temperatures.

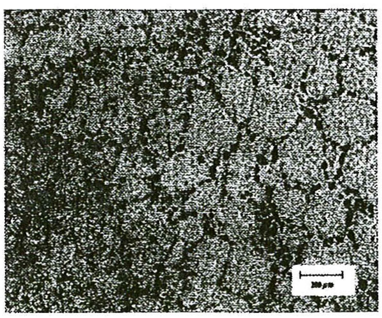


Figure 4. Optical micrograph of semi-solid A356 alloy solution-treated at 520°C for 4 hours.

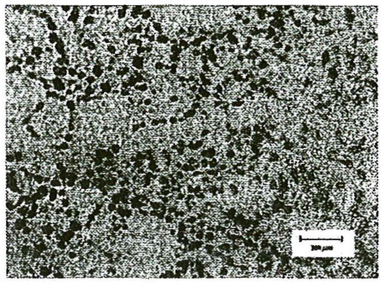


Figure 5. Optical micrograph of semi-solid A356 alloy solution-treated at 540°C for 4 hours

After quenching, the solute atoms in the matrix are in the supersaturated condition and tend to precipitate out during aging. It can be observed from Figures 6 and 7 that as the aging time increases, but less than 12 hours, the numbers of Mg_2Si phase increase. Moreover, the numbers of Mg_2Si phase is highest at the aging temperature of 135°C.

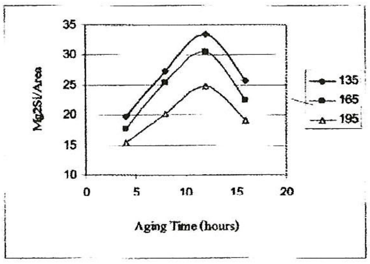


Figure 6. % Mg2Si of semi-solid A356 alloy solution-treated at 520°C for 4 hours and aged at 135, 165 and 195°C for 4,8,12 and 16 hours.

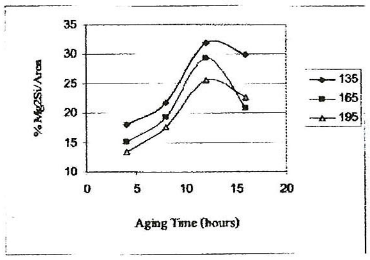


Figure 7. % Mg2Si of semi-solid A356 alloy solution-treated at 540°C for 4 hours and aged at 135, 165 and 195°C for 4,8,12 and 16 hours.

The variations of hardness when exposed to different aging temperatures for different aging times are shown in Figures 8 and 9. These are correlated with the numbers of Mg_2Si phase in which the hardness increases with increasing the number of Mg_2Si phase. The peak hardness is achieved at the aging time of 12 hours in every condition. Although not including in this study, it is observed from Figure. 8 and 9 that the optimum aging time seems to be shorter at higher aging temperature. The shorter aging time is due to the higher diffusion rate of the solute atoms at higher aging temperature, and hence the peak hardness is achieved after shorter aging time.

It is also found in Figures 8 and 9 that the hardness of the specimen increases with increasing aging time until the peak hardness is attained. Then the hardness tends to decrease upon further aging. This result could be explained by the precipitation hardening process of aged specimen which depends greatly on the aging time and aging temperature. The initial increase in hardness is attributed to the diffusion assisted from second phase particles. At the beginning of aging treatment the solute atoms diffuse and locally cluster to from the GP zone throughout in the matrix. The GP zone form the mechanical properties improve due to the high stress required to force dislocation through the coherent zone. With increase aging time the intermediate ß' precipitate will form and replaces the GP zone. It is interesting to note that the size of the ß' phase is larger than that of the GP zone. Therefore, dislocation must be forced through highly strain matrix resulting in the increase of hardness. However, aging has effect to the growth of the ß' phase and transformation of ß' phase to the stable and finally ß' phase transformation to ß phase incoherent. As the ß phase grow its decrease in number of dislocation bowing easier and the hardness is loss.

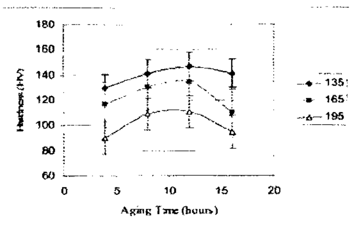


Figure 8. The average hardness of semi-solid A356 alloy solution-treated at 520°C for 4 hours and aged at 135, 165 and 195°C for 4,8,12 and 16 hours.

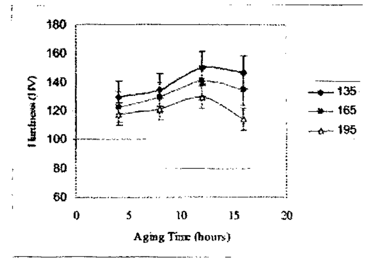


Figure 9. The average hardness of semi-solid A356 alloy solution-treated at 540°C for 4 hours and aged at 135, 165 and 195°C for 4,8,12 and 16 hours

Figures 10 to 12 show the microstructure of semi-solid A356 specimens aging for 12 hours at 135, 165 and 195°C, respectively. Referring to Figure 7 and Figure 9, the maximum hardness and the densiest Mg2Si phase is derived for aging at 135°C. This is due to the change in precipitation sequence at high aging temperature in that the GP zone will not form at the early state of aging. The lack of GP zone formation contributes to lower density of the ß' phase because the GP zone is potent to be nucleation site for the ß' phase as described in Figures. 10 to 12 in which the numbers of Mg_2Si phase decrease as the aging temperature increases.

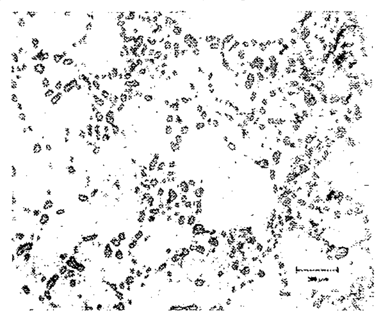


Figure 10. Optical microstructure of semi-solid A356 alloy solution-treated at 540°C for 4 hours and aged at 135°C at 12 hours.

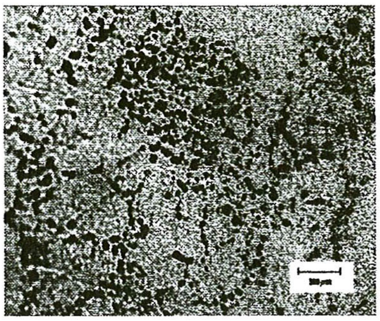


Figure 11. Optical microstructure of semi-solid A356 alloy solution-treated at 540°C for 4 hours and aged at 165°C at 12 hours.

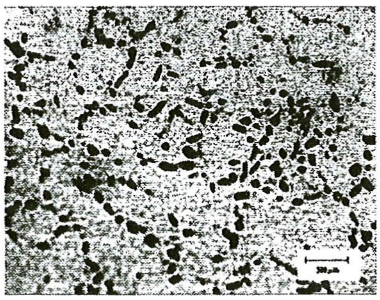


Figure 12. Optical microstructure of semi-solid A356 alloy solution-treated at 540°C for 4 hours and aged at 195°C at 12 hours.

Conclusions

1. As the aging temperature increase the optimum aging time is shorter and the maximum value of hardness decrease.

2. The shorter aging time at higher aging temperature is due to the higher diffusion rate of the solute atoms.

3.As the aging temperature decrease to proper temperature, the numbers of Mg2Si phase increase.

Acknowledgements

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References

1. Flemings, M.C. and Martinez, R.A. 2005. Evolution of particle morphology in semisolid processing Metall. Trans A-*Phys. Metall, Mater. Sci.* **36A(8)** : 2205-2210.

2. Yucel Birol, 2008. *Semi-solid processing of the primary aluminium die casting alloy A356* . Tubitak, Kocaeli : Materials Institute, Marmara Research Center.

3. Evangelista, E., Cabibbo, M. and Spigarelli, S. 2003. A TEM investigation on the effect of semi-solid forming on precipitation processes in an AL-Mg-Si Alloy. *Mater. Charact.* **49** : 193-202.