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Development of an Aluminum Semi-Solid Extrusion Process

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Abstract

Semi-solid extrusion process is a new forming process that is quite promising because the process requires lower forming pressure than conventional solid extrusion. In addition, semi-solid extrusion does not require large machines, which results in lower production costs. The aim of this article is to study the feasibility of an aluminum semi-solid extrusion process. The semi-solid technique selected for usage in this study was the Gas Induced Semi-Solid (GISS) process. The laboratory extrusion system was developed in this work. In the experiments, nitrogen gas was injected into aluminum melt for about 5 seconds. After that, the obtained semi-solid slurry was poured into the shot sleeve. The plunger then pushed the slurry through the extrusion die at different speeds of 2, 4, and 6 centimeter per second. In this study, the effect of holding time of the slurry in the shot sleeve was investigated. The results show that the plunger speed and holding time parameters affected the final extruded parts.

Key words: Aluminum alloys, Aluminum extrusion, Semi-solid metal, Extrusion process, Microstructure, Gas Induced Semi-Solid (GISS) process

Introduction

Extrusion is normally used to create parts of homogeneous cross-section and is done by forging a metal billet through a die under high pressures. There are several advantages for the extrusion process in that it can form products that are near net shape and long. Products from an extrusion process are then widely used in many applications in the forms of bars, solid and hollow sections, tubes and wires.(1) However, limitations of the current extrusion process also exist. It requires a high-pressure machine to force the metal which is in the solid state. Moreover, defects such as surface defect and piping may be found in the products. (1)

Semi-solid rheo-extrusion is a new extrusion process that has several advantages such as low extrusion force, high fluidity of materials, and low friction force between the die and the materials.(2) In a rheo-extrusion process, the metal alloy is melted in a furnace and then extruded at a temperature between the solidus and liquidus temperature of the metal alloy. The slurry is forced through a die orifice to form a desired part.

Several previous studies have been reported regarding the behaviors of the rheo-extrusion process. However, no complete research in the rheo-extrusion process has been published.(3-5) To apply the rheo-extrusion process in the production of commercial parts, it is important to conduct further studies. This research paper reports a preliminary research and development work of a new rheo-extrusion process using the Gas Induced Semi-Solid (GISS) technique. In this study, the effects of the plunger speeds and solid fractions on the extrudability of an aluminum 356 alloy were investigated.

Materials and Experimental Procedures

The raw material used in this work is aluminum 356 alloy. The chemical composition of the alloy is shown in Table 1.

Table 1. Chemical composition of aluminum 356 alloy.

Element	Si	Fe	Cu	Mn	Mg	Zn	Ti	Al
Weight%	6.9	0.42	0.05	0.04	0.42	0.01	0.10	Bal.

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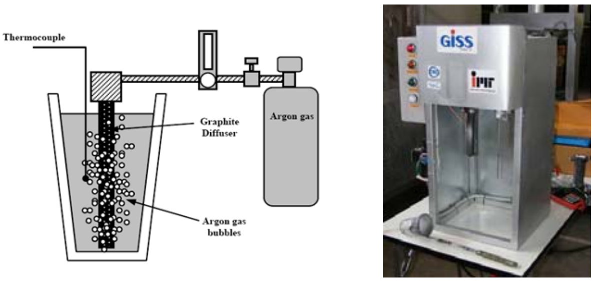
Preparation of Semi-Solid Slurry

The aluminum 356 alloy was melted in an electric furnace at the temperature of about 650°C. Approximately 300 grams of the molten aluminum were taken from the crucible by a ladle. When the temperature of the molten aluminum was about 620°C, a graphite diffuser was immersed to inject nitrogen gas for 5 seconds. Semi-solid slurry with the solid fraction of about 10% was then obtained. A schematic drawing of the GISS technique and the GISS machine is shown in Figure 1.



(a) (b)

Figure 1. (a) Schematic drawing of the GISS technique [6] and (b) the GISS machine to prepare semi-solid slurry

Rheo-Extrusion Test

The semi-solid slurry from the GISS machine was then poured into a shot sleeve with the inner diameter of 40 mm. The shot sleeve was preheated to about 350°C-400°C. Next, the slurry was forced by a plunger at various speeds of 2, 4, and 6 cm/s through a die, a graphite support and a water-cooled tube. The inner diameter of the die was 12 mm. The schematic drawing of this rheo-extrusion process is shown in Figure 2. The holding time of the slurry in the shot sleeve, 0 second and 5 seconds at each plunger speed was also studied in this work. Figure 3 shows the extrusion die and the laboratory-scale extrusion machine. This machine has a 20-ton capacity with a hydraulic system.

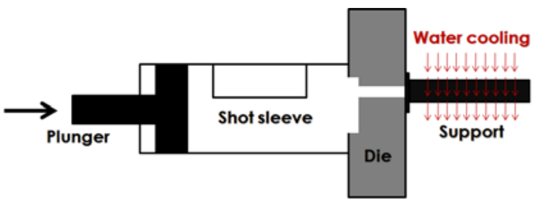


Figure 2. The schematic drawing of this extrusion process.

Figure 3. The extrusion die and laboratory-scale machine used in this study.

Result Analysis Methods

The extruded samples were analyzed using three criteria to determine the extrudability. The methods can be briefly described as follow:

Length of the samples: The length of the samples was measured after the extrusion test. In this work, the criterion for the required length was 15 cm. Shorter samples than set by this standard were rejected.

Surface quality: The surface of the samples was also examined. Samples with smooth surfaces across the complete area would pass the requirement.

Microstructure uniformity: The microstructure of samples was observed using an optical microscope. The samples were cut and obtained from two positions as shown in Figure 4. The samples were then prepared for metallographic analysis using the standard grinding, polishing and etching procedure. Good extruded parts should have uniform microstructure throughout the length.

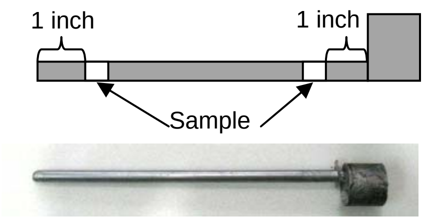
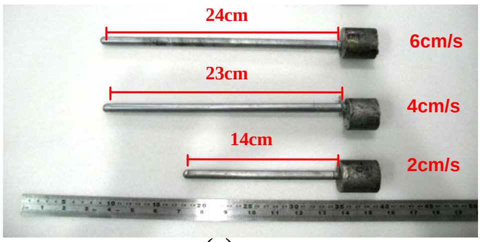


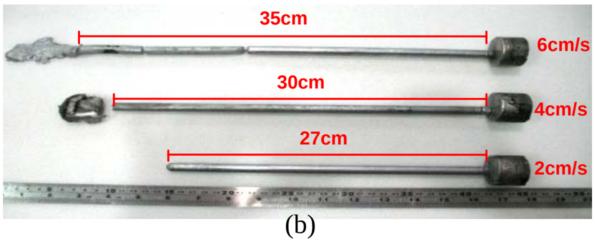
Figure 4. The sampling position.

Results and Discussion

The representative extruded samples from the experiments are given in Figure 5. The results show that faster plunger speed and lower holding time yield longer samples. Only the sample with a low plunger speed of 2 cm/s and a longer holding time of 5 seconds did not pass the length criterion. (see Table 2.)



(a)



(b)

Figure 5. The samples from GISS extrusion at (a) each plunger speed and 5 seconds of holding time and (b) each plunger speed and no holding time.

Table 2. The semi-solid extrudability of 356 Al-alloy.

	0s		5s	
	length	Surface	length	Surface
2 cm/s	✓	x	x	✓
4 cm/s	✓	x	✓	✓
6 cm/s	✓	x	✓	x

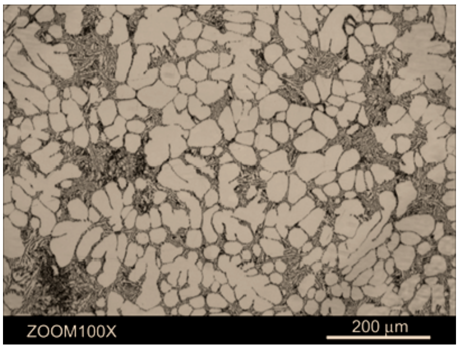
The results suggest that conducting the rheo-extrusion process with a high speed and with the low-solid-fraction slurry (no holding time) gives the longest length as expected since the slurry can flow easier and faster.


(a) (b)

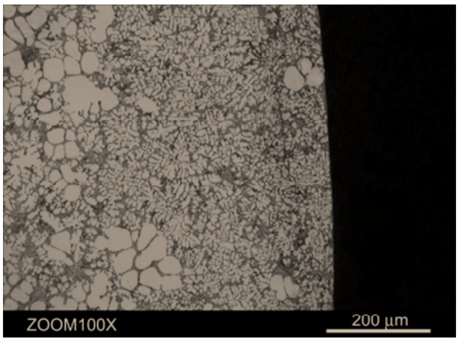
Figure 6. The finished surface of samples of (a) 4 cm/s of plunger speed and holding time is 5 seconds and (b) 4 cm/s of plunger speed and no holding time.

However, when the surfaces of the samples were examined, the samples produced by fast speed and at a low solid fraction have surface defect as shown in Figure 6(b). Only the samples produced by lower speeds (2-4 cm/s) and at a higher solid fraction pass the surface quality requirement. The fast flow speed of the slurry may cause turbulent flow causing the surface defect. By increasing the viscosity of the slurry through increasing the solid fraction, the slurry will have laminar flow at the same flow speed.

From these results, only samples produced by the conditions of 4 cm/s plunger speed and holding time of 5 seconds pass the requirements of length and surface quality.



(a) Middle



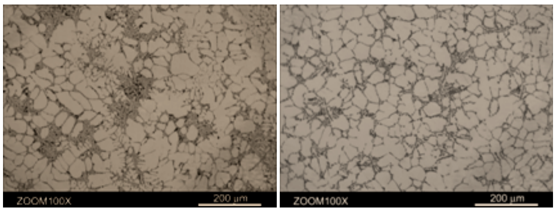
(b) Edge

Figure 7. The representative microstructures of the cross section of the samples.

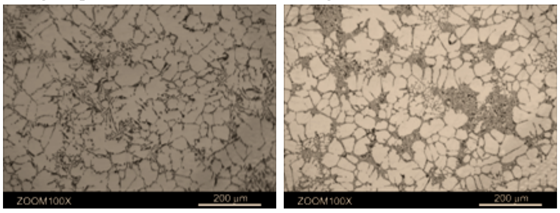
For all the samples, the microstructures at the edge and the middle are similar. Figure 7 shows representative microstructures at the edge and the middle of the samples. The micrographs show that the solid particles are concentrated near the center of the channel during the flow.

Representative microstructures of the samples at the tip and the base of the rods at various plunger speeds and holding times are given in Figures 8-9.

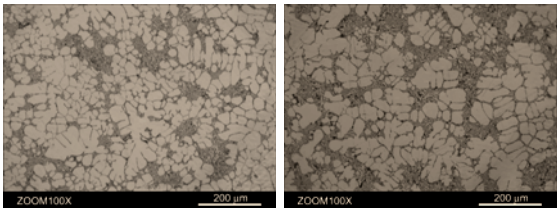
At tip of samples	At base of samples



Plunger speed is 2 cm/s and no holding time



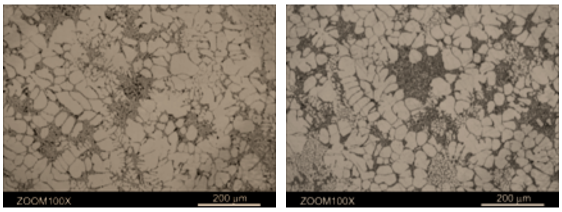
Plunger speed is 4 cm/s and no holding time



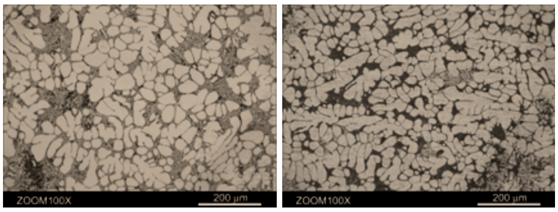
Plunger speed is 6 cm/s and no holding time

Figure 8. The microstructure of each sample with no holding time.

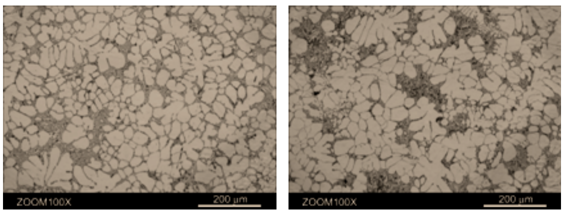
At tip of samples	At base of samples



Plunger speed is 2 cm/s and 5 seconds of holding time



Plunger speed is 4 cm/s and 5 seconds of holding time

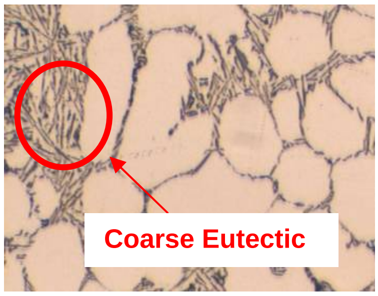


Plunger speed is 6 cm/s and 5 seconds of holding time

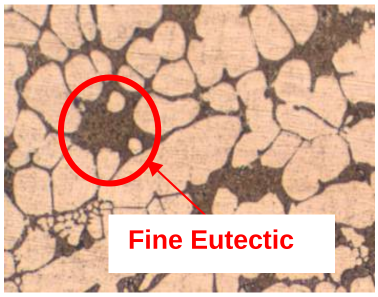
Figure 9. The microstructure of each sample with 5 seconds of holding time.

In general, the amount and distribution of the primary α phase in all the samples are quite uniform. However, the eutectic structures in the samples at the tip and the base of the rods are different. The eutectic phase at the tip has a coarse structure, as shown in Figure 10. A fine eutectic structure is observed at the base of the rod.

The results show that the metals near the tip have longer solidification time so that the eutectic structure can grow larger. To improve this, a better cooling system should be applied in the rheo-extrusion system.



(a) Tip



(b) Base

Figure 10. The different eutectic structures at each position.

Conclusions

From this study, the following conclusions can be drawn:

1. The extrusion behavior of an aluminum 356 alloy using the GISS technique is influenced by the plunger speed and the solid fraction of the slurry in the shot sleeve.

2. The higher solid fraction of the slurry helps reduce the surface defects of extruded parts.

3. The non-uniformity of the eutectic microstructure is caused by inefficient cooling of the extruded samples. This problem can be improved by adding a better cooling system along the die.

4. This preliminary study gives important information for the development at the rheo-extrusion machine using the GISS technique in the future.

Acknowledgements

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