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Modification of Eutectic Silicon Under The Influence Of Mold Vibration During Solidification Of LM6 Alloy Castings.

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Abstract

The properties of Al-Si alloy are dependent on the grain size and distribution of silicon particles which can be affected by grain refinement and modification. Techniques to carry out grain refinement include addition of grain refiners to the melt, addition of modifiers, subjecting the molten melt to vibration during solidification. In the present work, mold containing the solidifying melt is subjected to mechanical vibration which is considered as one of the process parameters. Other parameters considered were mold material and pouring temperature. Factorial design of experiment technique was used to conduct the experiments. It was observed that inducing vibration to the mold containing molten metal resulted in fragmentation of silicon needles thereby improving the hardness and wear properties of the alloy.

Keywords- Factorial design of experiments, mechanical mold vibration, silicon morphology.

1. Introduction

Aluminum-Silicon alloys are one of the most commonly used foundry alloys because they offer many advantages such as good thermal conductivity, excellent cast ability, high strength to weight ratio, wear and corrosion resistance etc. Therefore they are well suited to automotive cylinder heads, engine blocks, aircraft components etc. The mechanical properties of Aluminum-Silicon alloys are related to the grain size and shape of silicon.

Imposition of vibration on liquid Al-Si alloy during solidification has shown improvements like grain refinement[1], reduction in shrinkage pipe[2], fragmentation of dendrites and transition of eutectic structures from flakes to fibrous[3], reduction in average size of silicon needle [4] resulting in improved properties. Thus it is clear that subjecting the liquid molten metal to vibration during solidification promotes changes in microstructure and consequently in the properties.

Different methods of inducing vibration into the molten metal like electromagnetic vibration [5], Ultrasonic vibration [6] and mechanical mold vibration [7] have been tried.

In the present work, mechanical mold vibration technique has been used to bring changes in the alloy considered. Also other process parameters likely to affect the solidification process such as mold material [1] and pouring temperature have been considered. The properties under study are hardness and dry sliding wear of the as cast alloy.

2. Experimental

A simple mechanical vibrator set up was used to subject the mold to vibration. The set up consists of a power oscillator on which the mold is mounted as shown in Figure 1. The frequency of vibration can be changed in the range of 1Hz - 10 KHz with a maximum displacement of 12mm peak to peak. In the present study, frequency and amplitude of vibration was kept constant at 25 Hz and 0.05 mm amplitude. Commercial grade LM6 alloy was melted in a graphite crucible in a 3 phase, 12 KW electrical resistance furnace to a temperature of 850°C. After proper degassing with hexachloroethane and removing the slag, the melt was poured into the vibrating mold. Temperature of the charge was measured using chromel-alumel thermocouple just before pouring. The vibration was maintained until the melt was completely solidified. After solidification the castings were removed and specimens were prepared for testing. Molds preheated to 200°C were used to produce the castings. Cylindrical castings of diameter 30 mm x 200mm length were produced.

Table 1 shows the factors selected and their levels and experiments were conducted as per the design matrix [8] of full factorial design as shown in Table 2. For each combination of input factors two replicates were considered.

The ingots were split into two halves. One half was used to study the microstructure. The other half was used to conduct wear and hardness test. The microstructure examination was made on the middle part of the castings, as per ASTM-E407 standard. Nikon make optical metallurgical microscope was used. Size of silicon particles and the interparticle spacing were measured.

The outputs measured were Brinell hardness and dry sliding wear. The BHN hardness of the specimen was obtained with a 10mm ball indenter and applying 500kg load. The wear test specimen from each casting was prepared with the dimension of diameter 5mm x 20 mm length. Computerized pin on disc wear testing machine having integrated software for data collection was used to conduct the wear test. The test was conducted for duration of 1 hour at speed of 300 rpm under a normal load of 1 kg.

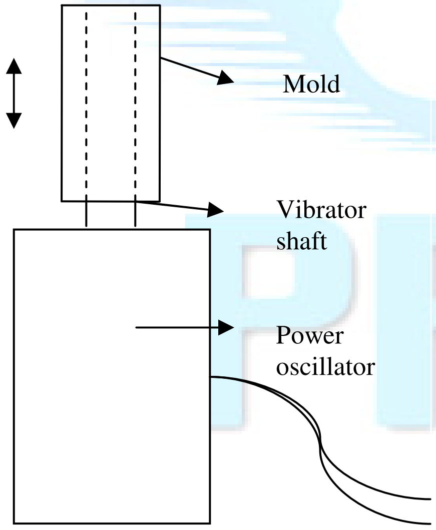

Fig. 1 Vibration set up arrangement.

Results and Discussion

The experimental data collected is shown in Table 3.

Table 1 Factors and their levels

Notation		*Levels*	
Factors considered	***Code***	***Low level (-1)***	***High level (+1)***
Mold material	A	Cast Iron	Graphite
Vibration	B	Without vibration	With vibration (Frequency 25 Hz and Amplitude 0.05mm)
Pouring temperature	C	700°C	800°C

Table 2 Design Matrix

		Factors		
Experiment Number	***Label***	***A***	***B***	***C***
1	(1)	-1	-1	-1
2	a	1	-1	-1
3	b	-1	1	-1
4	c	-1	-1	1
5	ab	1	1	-1
6	bc	-1	1	1
7	ac	1	-1	1
8	abc	1	1	1

Table 3 Experimental data

Trial Number	***Input Parameters***			***Responses***			
				Wear (μm)		***Hardness BHN***	
	A	***B***	***C***	***Trial 1***	***Trial 2***	***Trial 1***	***Trial 2***
1	-1	- 1	-1	460	473	63.55	63.88
2	1	- 1	- 1	500	520	63.66	63.25
3	-1	1	-1	670	650	60.01	60.95
4	-1	- 1	1	750	735	59.95	60.06
5	1	1	- 1	520	500	64.82	64.91
6	-1	1	1	540	550	62.27	61.34
7	1	- 1	1	770	750	58.14	58.38
8	1	1	1	425	432	66.62	65.67

3.1 Microstructure Study

The results of microstructure examination of samples cast as per table 1 and table 2 are shown in figure 2 to figure 9. The microstructure reveals the presence of needle like particles of eutectic silicon in a matrix of aluminum solid solution. LM6 is of slightly hypo - eutectic composition and solidifies with a small amount of primary aluminum as seen in the micrographs.

The microstructure for specimen cast in static mold shows presence of dendritic growth. For the specimen cast in vibrated mold, the aluminum dendrites have broken into

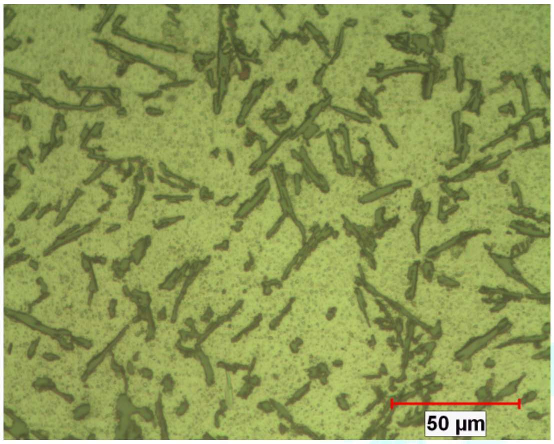

Fig. 2 Microstructure of specimen for experiment number 1

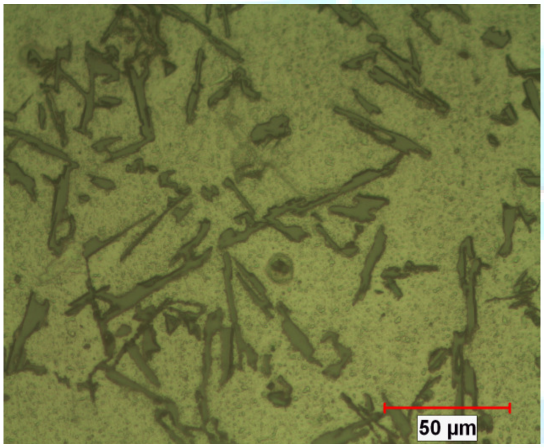

Fig. 3 Microstructure of specimen for experiment number 2

small islands. Inducing vibration fragments the dendrites thereby resulting in less dendritic growth.

The microstructure of specimen cast at lower pouring temperature in static mold also exhibits fragmented dendrites as compared to specimen cast at higher pouring temperature. This may be due to less time being available for the dendrites to grow when cast at lower temperature. But when alloy is poured at higher temperature in molds subjected to vibration, it is seen that the effect of vibration is more pronounced as compared to alloy poured at lower temperature. Higher pouring temperature provides more time for vibration to take its effect in causing fragmentation.

The microstructure of specimen cast in cast iron molds shows dendritic growth as compared to specimen cast in graphite mold. Alloy poured in cast iron mold freezes at slower rate as compared to graphite mold, due to the thermal characteristics of cast iron mold.

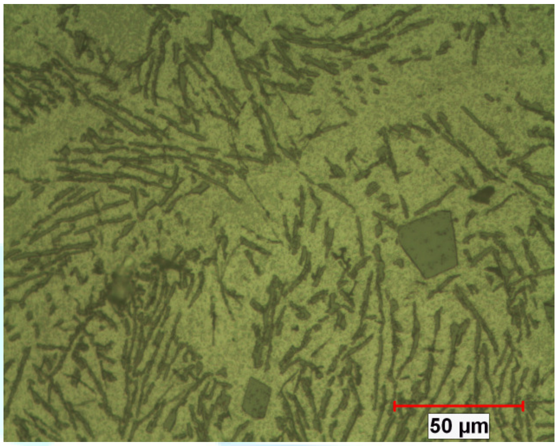

Fig. 4 Microstructure of specimen for experiment number 3

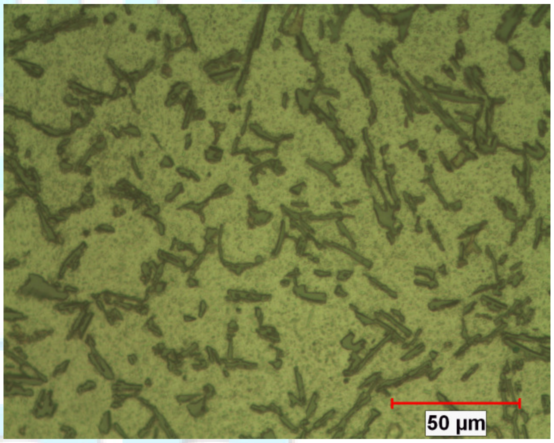

Fig. 5 Microstructure of specimen for experiment number 4

3.2 Study of Silicon morphology

The average silicon particle size and average interparticle spacing are shown in table 4. From the table it can be seen that the imposition of vibration during solidification causes a significant reduction in silicon particle size and interparticle spacing.

There is also a tendency for the silicon needles to get rounded in appearance as a result of vibration. The refinement of silicon can be attributed to the solidification process of Al-Si eutectic, which is known to freeze endogenously, that is from the surface to the center of casting. Under such conditions, the leading phase in this case silicon can easily fracture by stirring action or by viscous friction caused by relative movement between the liquid metal and solid eutectic already formed.

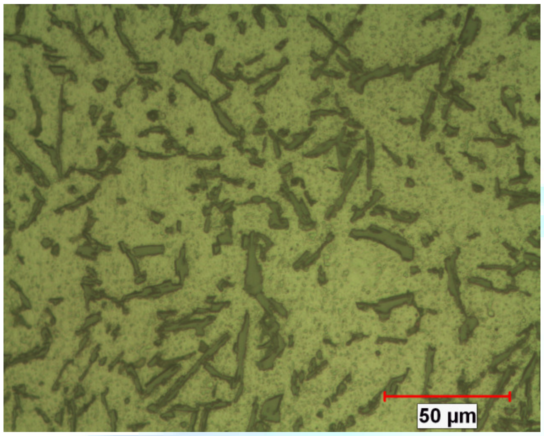

Fig. 6 Microstructure of specimen for experiment number 5

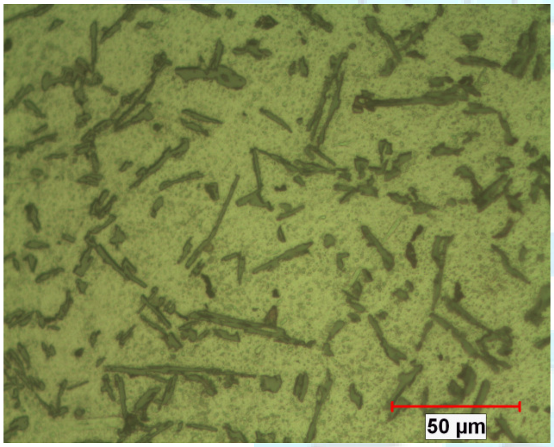

Fig. 7 Microstructure of specimen for experiment number 6

From table 4, it can be observed that particle size and inter particle spacing of specimens cast in static cast iron mold is lesser than specimen cast in static graphite mold for the same pouring temperature, whereas it is observed that particle size and inter particle spacing of specimens cast in vibrated cast iron mold is more than specimen cast in vibrated graphite mold for the same pouring temperature. The reason could be difference in cooling rates of different mold materials.

Similarly increase in pouring temperatures, increased the particle size and inter particle spacing in specimens cast in static condition, but with vibration, other parameters remaining same, there was reduction in particle size and inter particle spacing. The lower pouring temperature provided finer microstructure in static condition whereas higher pouring temperature was found beneficial in vibrated mold. It is also seen that particle size and inter particle spacing of specimen cast in molds subjected to vibration is less for all test conditions. The particle size of specimen cast in vibrated graphite mold at pouring temperature of 800 °C is the lowest.

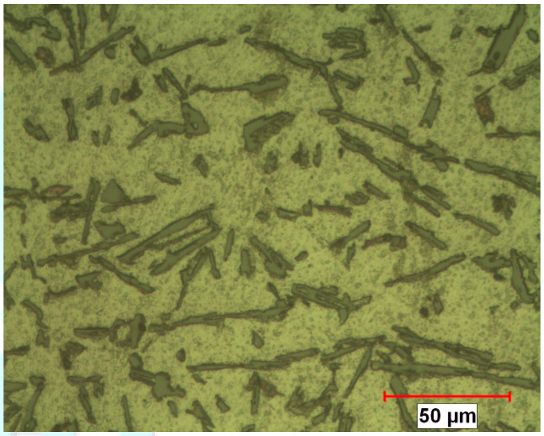

Fig. 8 Microstructure of specimen for experiment number 7

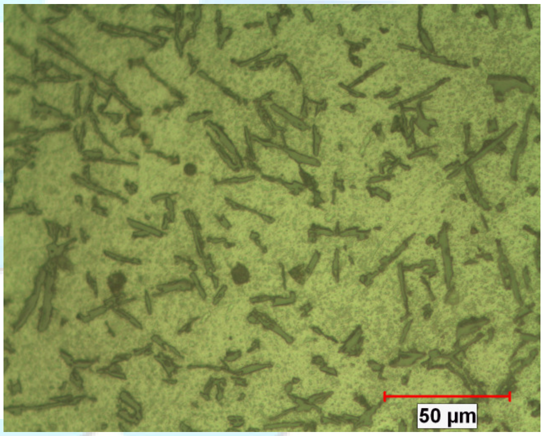

Fig. 9 Microstructure of specimen for experiment number 8

The energy of mechanical vibrations promotes microstructure refinement during solidification. Also vibration induces a higher heat transfer along the mold walls due to the alternated movement of liquid molten metal. This could be the reason for change in the particle size and inter-particle spacing.

From the above discussion it can be concluded that the test variables such as Mold material, Pouring temperature,

Table 4 Average Silicon particle size and Interparticle spacing of as cast specimen

		Factors			*Average Silicon flakes Size (μm)*	*Interparticle spacing (μm)*
Experi-ment No.	***Label***	***A***	***B***	***C***		
1	(1)	-1	-1	-1	36.3	5.86
2	a	1	-1	-1	37.3	15.23
3	b	-1	1	-1	37.8	4.33
4	c	-1	-1	1	55.6	10.64
5	ab	1	1	-1	29.7	10.34
6	bc	-1	1	1	32.2	6.24
7	ac	1	-1	1	60.7	13.21
8	abc	1	1	1	27.7	4.62

Vibration influenced the Silicon particle size and inter-particle spacing. These microstructural changes in turn influenced the mechanical properties such as hardness and wear properties.

3.3 Hardness

From the values of hardness in table 3, it is seen that in general the hardness of specimen cast in vibrated mold is high as compared to those specimen cast in static mold. The increase in hardness of specimen cast in vibrated mold is due to the presence of refined silicon and uniform distribution of silicon particles in Al- matrix. It may be noted that uniform distribution of silicon particles will lead to higher constraint in the localized deformation of softer matrix under the application of indentation load. The eutectic silicon phase provides an appreciable impediment to plastic deformation caused by indentation.

3.4 Wear

From the values of wear in table 3, it is seen that in general the wear of specimen cast in vibrated mold is low as compared to those specimen cast in static mold. Silicon contributes substantially to the wear resistance. The wear behavior of Al- Si alloys depends in general on the size and shape of Si particles and the nature of dispersion. Inducing vibration to the mold during solidification of the alloy leads to the fragmentation of silicon needles which improves the wear resistance of the alloy.

4. Conclusions

Applying vibration to the solidifying LM6 alloy leads to microstructural changes to both the dendritic structure and eutectic silicon. Vibration successfully broke the dendritic structure into small islands of Aluminum. Inducing vibration also resulted in fragmentation of silicon needles and uniform distribution of silicon flakes resulting in improved properties.

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