Effect of Solidification on Microstructure and Mechanical Properties of Aluminium - Silicon Alloys

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Abstract—Microstructures are the key features that provide the backbone for the wear characteristics of all the materials. Structure can be changed by changing the solidification rate. Considering this aspect, two different compositions were prepared, which are Al-Si alloys (5 wt % Si and 12 wt % Si). The specimens were cast by sand casting, chill casting and melt stirred with chilled casting. After that the specimens were prepared for microstructural examination, Brinell hardness test and wear test on pin on disc apparatus was done. In order to understand the distribution of silicon phase, different solidification conditions were used. These influence the development of varieties of structure. It had been observed that the structure, hardness and wear properties were significantly influenced by solidification conditions. Fast cooling, as in chill mould, gives a refined structure which results in finer Si needles. Such a structure provides higher hardness and better wear properties in the alloys. Since Si also acts as a strengthening element, Al-12% Si alloy gives higher hardness.

Key words: Microstructure of the Material, Aluminium - Silicon Alloys

I. INTRODUCTION

The microstructure of the material is the strategic link between material processing and its behavior. Microstructural control is therefore, essential for any processing activity. Various microstructures can be achieved by various casting techniques. Al-Si alloys being non faceted-faceted eutectics make up one of the main bulks of cast alloys and are thus of great practical importance. In terms of mechanical properties, such a microstructure is undesirable because it reduces them. The mechanical properties can be increased, however, by refining the silicon phase through a modification treatment.

M. A. Savas et al. [1] had studied the control of mechanical and wear properties of a commercial Al-Si (ETIAL 140) eutectic alloy in relation to microstructural modifications induced by strontium and lithium additions. It was found that in terms of mechanical properties, the intermetallic size should not increase whilst the silicon phase was being modified. C.H. Caceres et al. [2] had studied the effect of Mg on the microstructure and mechanical behavior of Al-Si-Mg Casting Alloys. The increase in strength with the Mg contents seems to be less than expected due to the formation of γ-phase particles. K. Raju et al. [3] had studied the evolution of microstructure and its effect on wear and mechanical properties of spray cast Al–12Si alloy. They found that the spray casting followed by hot iso-static pressing has refined the microstructure of Al–12Si alloy and the microstructure consisted of fine particles of Si in the Al–matrix in contrast to the coarse microstructure consisting of an eutectic mixture of α-Al and Si needles in chill cast alloy.

A. K. Gupta et al. [4] had studied the effects of T6 heat treatment on mechanical, abrasive and erosive corrosive wear properties of eutectic Al-Si alloy. The as-cast Al-Si alloy exhibit higher hardness, tensile strength and elongation as compared to the conventional Al samples. Abrasive wear resistance (inverse of material loss) of the Al-Si alloy is higher than that of the conventional Al samples. Chen Zhen-Hua et al. [5] had worked on solid-liquid mixed casting of Al-Si alloy. They observed that solid-liquid mixed casting technology is similar to semisolid metal processing, and much simpler than spray forming technology. However, the microstructure of materials prepared by this technology is finer than that by the other two technologies. Waled Khalefa et al. [6] had worked on the microstructure and wear behavior of solidification sonoprocessed B390 hypereutectic Al-Si alloy. The UST has a potential refining effect on the primary Si and Fe-intermetallic phases. The primary Si particles become smaller in size as the pouring temperature decreases from 1033 K to 938 K. The pouring and UST at temperatures below the start of primary Si precipitation result in coexistence of large and fine Si particles in microstructure.

Tevfik Kucukomeroglu [7] had worked on the effect of equal-channel angular extrusion on mechanical and wear properties of eutectic Al-12Si alloy and to reveal the mechanisms responsible for possible changes in these properties. This processing led to the fragmentation of the needle-shaped eutectic silicon plates into smaller and more uniformly distributed particles. Md. Aminul Islam et al. [8] had worked on the effect of porosity on dry sliding wear of Al-Si alloys. The amount of porosity and the size and shape of pores have a great impact on material removal during wear. Vijeesh V. K. Narayan Prabhu [9] had done review of microstructure evolution in hypereutectic Al-Si alloys and its effect on wear properties. It was found that the hypereutectic alloys have properties such as low coefficient of thermal expansion, high wear resistance, and high stiffness. These properties have been exploited for high temperature applications, like piston materials, in the automobile industry. The property of high hardness and wear resistance is due to the high silicon content of the alloy.

In present work, aluminium-silicon alloys with different weight percentages of silicon (5 & 12 wt %) were prepared by sand casting, chill casting and melt stirring with chill casting. Sand casting was done in order to obtain a slow rate of solidification. Chill casting in water cooled mould was done to have a faster rate of solidification which should result in a refined structure giving better mechanical properties. Melt stirring employed during solidification would fragment the micro constituents and further chill casting should result in a still more refined microstructure. The microstructures using optical microscope was studied. The hardness was measured using Brinell hardness testing machine. The Wear behaviour was studied using Pin-On-
Wear disc apparatus. The effect of various solidification parameters on resultant microstructure and mechanical properties and the wear behaviour under different conditions of solidification were studied. It is expected that a study would help in determining the optimum solidification conditions for best wear properties in industrial applications.

II. EXPERIMENTAL PROCEDURE

In the present work, the casting technique has been utilized to prepare the specimens of aluminium-silicon alloys. The alloy compositions that were selected for present study are Al-5wt% Si and Al-12wt% Si alloys. The alloys were prepared using Al and Si metals of commercial purity. The alloys were cast in sand moulds as well as in chilled (water cooled) moulds. Sand casting was done to obtain slow cooling where as chill casting was done in order to have a fast rate of cooling. Alloy Al-12 wt% Si alloy was also subjected to melt stirring and the chill cast. Melt stirring imposed during solidification is expected to refine the microstructure. A total of 5 specimens were prepared. Specimen I (Al-5Si) & specimen III (Al-12Si) were made using sand Casting (slow cooling). Specimen II (Al-5Si) & Specimen IV (Al-12Si) were made using chill casting (fast cooling). Specimen V (Al-12Si) was made using melt stirred with chilled casting.

After this, the cast samples were cut in the transverse direction with the help of hack-saw in the four equal parts. The one of the piece of the cut sample is used for sample preparation. The cut samples had an uneven surface. So those were then taken for the grinding/polishing operation. The sample was first held over a grinding machine with a moving belt to obtain a smooth surface. The grinding was done in such a way so that all the scratches were in the same direction and the grinded surface becomes flat. After this, sample was polished properly using different grits of emery paper. Because the aluminium being soft, it was rubbed over the 400 and 1000 grit emery paper for a small time. Then it was rubbed over an emery paper of 1500 grit and then over a very fine emery paper of 2000 grit for a considerable time in order to get a smooth and clear surface of the sample. The sample was then polished on a fine polishing machine using an alumina polish. This was done to get a well polished and a smooth surface required for the further characterization of the samples. Similarly all the samples were polished for a considerable time, over and over again until a very fine and smooth surface was obtained.

Before taking the micrographs, etching of all the samples is done using Kellers Reagent. It consists of distilled water, hydrochloric acid, nitric acid and hydrofluoric acid. The well-polished samples were then observed under an optical microscope. Micrographs were taken with the help of CCD camera attached to the optical microscope and was further viewed on computer with optical image analyzer software at magnification of 200X and 400X for all the different specimens.

The Brinell scale characterizes the indentation hardness of materials through the scale of penetration of an indenter, loaded on a material test-piece. It is one of several definitions of hardness in materials science. For Brinell hardness tests a load of 500 kgf and a 10 mm diameter steel ball indenter were used.

The Pin on Disc Tribometer was used to perform wear testing of given metal and study the effect of lubrication of different lubricants on that particular metal under different loading conditions. The specific wear rate was calculated, the specific wear rate helps in determining wear resistance provided by the metal under running conditions.

III. RESULTS AND DISCUSSIONS

A. Microstructure using Optical Microscope

The microstructural observations were made at 200X & 400X magnifications, shown in Fig. 1 - 5. The microstructure of specimen I (Al-5% Si sand cast) had a coarse grain structure of alpha matrix & the silicon needles. At few locations even some amount of eutectic of α + Si was also seen. The microstructure of the chilled alloy shows finer grains and finer size of Si needles. This results from a faster rate of cooling in chilled casting which accelerate the rate of nucleation which results in finer grain size & finer Si needles.
One important observation from optical microscopic study was the existence of porosity in the castings. The casting solidified under melt stirring with chilled casting (Specimen V) gives maximum porosity as compared to other castings. It was seen that porosity was maximum in Al-Si alloy subjected to melt stirring and chill cast. Al alloys had a high tendency to absorb gases, especially hydrogen in the liquid state. Imposition of melt stirring causes more exposure of melt surface with the environmental gases and thus more hydrogen was trapped in the specimen V. The entrapped hydrogen was not able to escape fully during solidification and remains as blow holes in the solidified casting. No degassing agents were added during the melt and therefore porosity was observed in all the specimens, the specimen solidified under melt stirred giving maximum porosity.

**B. Hardness Measurement**

Microhardness of each sample was measured. The reason for this was to see the feasibility of providing hard matrix with proper distribution of the softer phase into it. Hardness measurement was done to see the feasibility of this material as hardness and wear characteristics are related to each other up to a greater extent. The Brinell Hardness Number (BHN) of specimens I, II, III, IV & V are 41, 45, 53, 63 & 66 respectively. It was observed that specimen V (Al-12% Si melt stirred with chill cast) gives maximum hardness. In general hardness of Al-12% Si alloy was higher than that of the Al-5% Si alloy. Since Si is a hardening phase and more primary Si was seen in Al-12% Si alloy, its hardness will be more than in Al-5% Si alloy. In both the alloys the chill cast condition gives higher hardness as compared to sand cast since chill casting was associated with higher rate of cooling leading to higher rate of nucleation.

**C. Wear Measurement**

The following parameters were taken using a pin on disc apparatus:
- **Velocity** = 1 m/sec, **Speed** = 382 (RPM)
- **Load** = 5 N
- **Time (in sec.)** = 300, 600, 900, 1800, 3600
- **Distance (in m)** = 300, 600, 900, 1800, 3600
- **Track Diameter** = 50 mm.

The wear behavior of all the specimens is shown in Fig. 6 - 8, in terms of successive and cumulative weight loss at various stages of wear test.

It was observed that Al-12 wt% Si alloy in sand cast condition (Specimen III) shows minimum wear (0.0065 gm after 60 min). The alloy Al-12 wt% Si melt stirred with chill cast (Specimen V) undergoes maximum wear (0.181 gm after 60 min). All other specimens exhibit almost same wear behavior and give a wt loss in the range 0.0071 – 0.0079 gm after 60 min of wear test. Maximum wear in specimen V occurs due to excessive porosity entrapped in this alloy due to stir melt condition. The porosity makes the matrix weak and reduces the wear properties of the material.
The porosity holes have a high stress concentration at their interface with the matrix. These high stresses significantly reduce the wear resistance of the alloy. Minimum wear loss in the specimen III (Al-12 wt% Si alloy sand cast) was due to strengthening by high Si content and low level of porosity due to slow rate of solidification. In slow solidification chances of gases to escape from the melt become high resulting in low porosity and better wear properties.

Fig. 8 gives weight loss per minute in various stages of wear test. The zigzag nature of the curves shows that there was no well-defined trend of wear loss as a function of time. This is basically due to the fact that wear is a complex problem and depends on many structural parameters of the materials. In Al-Si alloys, there are extensive structural in homogenities like size of Si needles, eutectic size, grain size, porosity and the characteristics of the Si-alpha interfaces. Thus an uniform rate of wear is not possible in such alloys. There appears some trend of declining wear loss in the initial stages of the wear test followed by an accelerated rate of wear during later stages. In the beginning the wear loss is slightly reduced due to work hardening of the matrix. However later on the contributions of other parameters prevail and the wear rate becomes non uniform.

IV. CONCLUSIONS

1) Al-Si alloys solidified under different casting conditions exhibit different microstructures. The microstructures are refined in chill cast condition as compared to sand cast condition. The Al-12 wt % Si alloy exhibit a high content of alpha + Si eutectic structure since this composition is close to the eutectic point.

2) Imposition of melt stirring followed by chill casting further refines the microstructure.

3) The hardness increases with rate of cooling as shown by chill casting of the alloys. Stir melt and chill cast alloy further enhances the hardness.

4) Pin porosity is observed in all alloys. Porosity is maximum in melt stirred, chill cast Al-12% Si alloy.

5) Maximum wear is observed in stirred melt, chill cast Al-12% Si alloy and minimum in Al-12% Si alloy in sand cast condition.

6) Wear rate is non uniform through the entire wear test, which was due to complexity of the microstructures in Al-Si alloys.

REFERENCES


