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# Study on controlled segregation of Al-Sn alloys for bearings

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## Abstract

In this study, Sn particles are finely and uniformly distributed in the Al-Sn alloy through a strong pulse treatment on the molten alloy. The Sn particle size in the conventionally cast Al-25%Sn alloy is about 80 $\mu$ m while that in the pulse-treated alloy is reduced to 45 $\mu$ m with a uniform distribution. Applying a strong pulse to an Al-Sn alloy causes a fine and uniform microstructure and the pulse-treated Al-Sn alloy is preferable for a metal bearing material where an excellent lubricity with a proper wear resistance are necessary.

**Key words:** Segregation, distribution, microstructures, particles, bearing materials

## Introduction

Most engine bearings have layered structure, which provides optimum combination of the bearing material properties: fatigue strength, seizure resistance, wear resistance, conformability, embedability, corrosion resistance, and cavitation resistance. The main functional bearing materials can be a mono-metal, a bi-metal, a tri-metal or a multi-layered clad metal and most of engine bearings are in the form of either bi-metal or tri-metal. Recently, enhanced properties of bearings are required with a development of the engine performance such as speed, compactness, and light weighting. The Al-Sn alloy should have an excellent corrosion resistant, thermal conductivity, and abrasion resistance. The Al-Sn alloys containing harmful Pb are cheaper than the Cu containing alloys and an economical technology should be applied to a manufacturing of bearing alloys.

Typical engine bearings structures are presented in the Fig. 1. The bearing alloy has been developed to meet the demands such as the fatigue strength, lubricity, excellent thermal conductivity, wear and corrosion resistance as well as economical materials [1-3]. In order to improve the lubricity, the bearing material contains 10-14% of Sn in aluminum alloy. For a further improvement in lubrication, a higher Sn concentration is adapted with Al-20%Sn and Al-40%Sn alloys.

Aluminum based bearing alloys commonly contain Sn (6-40%) as a soft component. Tin is distributed in aluminum matrix as a separate phase in a reticular structure along the edges of aluminum grains. Tin element imparts to the material anti-friction properties such as compatibility, conformability, embedability. Silicon has very high hardness and Si-related inclusions distributed through the aluminum matrix can serve as abrasive particles polishing the mating journal surface. During the engine operation, Si particles included in the aluminum matrix remove the ragged edges from the shaft surface. Aluminum matrix of engine bearing alloys can be strengthened by an addition of alloying elements such as Cu, Ni, Cr, Mn, Mg, and Zn.

The Sn particles are crystallized with eutectic silicon phases, resulting in a uniform distribution of Sn particles with the addition of Si in an Al-Sn alloy. The addition of Cu and Si in an Al-Sn alloy increases the tensile and yield strength of the alloy. Wear resistance of the Al-Sn alloy having large network structure of Sn particles exhibits better anti-friction characteristics compared to that of the elongated Sn structure. Cu and Si elements are known to enhance the strength of the Al-Sn alloy and improve the bearing properties such as wear resistance and the performance in seizure resistance. In the as-cast condition, the AlSn20Cu material is characterized by an interdendritic distribution of the low melting point Sn-based phase which forms a three-dimensionally connected network around the Al-based dendrite arms.

Tin in an aluminum is hardly dissoluble and the melting point of aluminum is 660 $^{\circ}$ C which is about 3 times higher than that of Sn. The density of Sn is 7.28g/cm<sup>3</sup> which is about 3 times higher than that of aluminum. Mushy zone of the Al-Sn alloy is very wide through the whole content of Sn and wider in a low Sn content alloy (Fig. 2). Therefore, grains of Al-Sn alloy become coarser and severe segregation is easily found in this alloy when it is produced by conventional melting and casting processes. Segregation in an Al-Sn alloy is caused by insoluble Sn phase and huge difference in melting temperature and density. Therefore, investigations on the manufacturing method for finely and uniformly distributed Sn particles in the Al-Sn alloy are required. This alloy can be produced in a strip form by the continuous casting but segregation problems have not been solved completely. As the Sn content increases, the lubricity is improved. However, increase in Sn content causes weakening of the grain boundary segregation of Sn in Al matrix, which can decrease the fatigue strength rapidly [4-5]. Electro hydro pulse treatment (EHPT) [6] and electromagnetic stirring process are able to influence the size and distribution of the intermetallic particles.

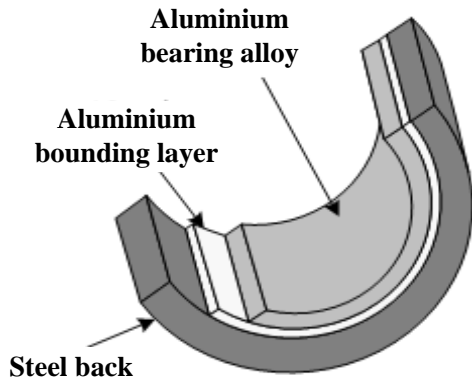


Fig. 1: Typical structure of metal bearing with Al-Sn alloy

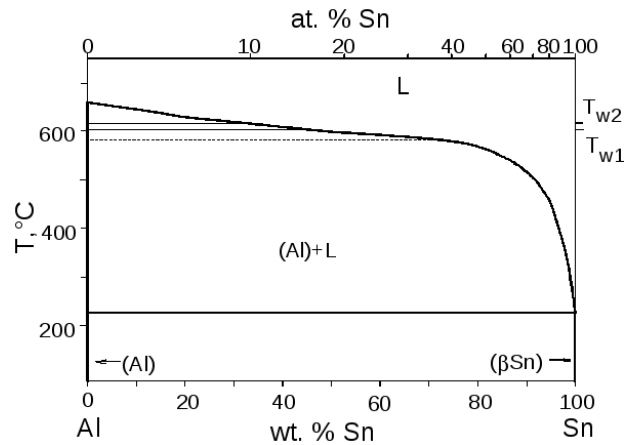


Fig. 2: Phase diagram of Al-Sn alloy

**Results and discussions**

Uniform distribution of Sn particles and little segregation of Sn with a network structure along the aluminum grain boundaries are important in Al-Sn alloys. Tin in aluminum bearing alloys is harmful for an adhesion of bonded strips between the steel back and Al-Sn alloy. The most popular method to avoid the unfavorable effect of Sn is cladding Al-Sn strip with a bonding layer of pure aluminum prior to cladding onto a steel back.

Fig. 3 shows the pulse equipment which is used for making fine and uniform distribution of Sn particles by applying a strong pulse into the molten aluminum alloy. Fig. 4 is a schematic diagram of electromagnetic stirring equipment which can prevent segregation and porosity formation during casting. As an electromagnetic method for a binary alloy liquid, an alternating magnetic field and current of industrial frequency are applied. The first step of this task is to study the complex influences of MHD-process emulsification, with widespread qualitative and quantitative analysis of hydrodynamic power, mechanical, acoustic, vibrational and electro-physical MHD-effects.



Fig. 3: Pulse equipment

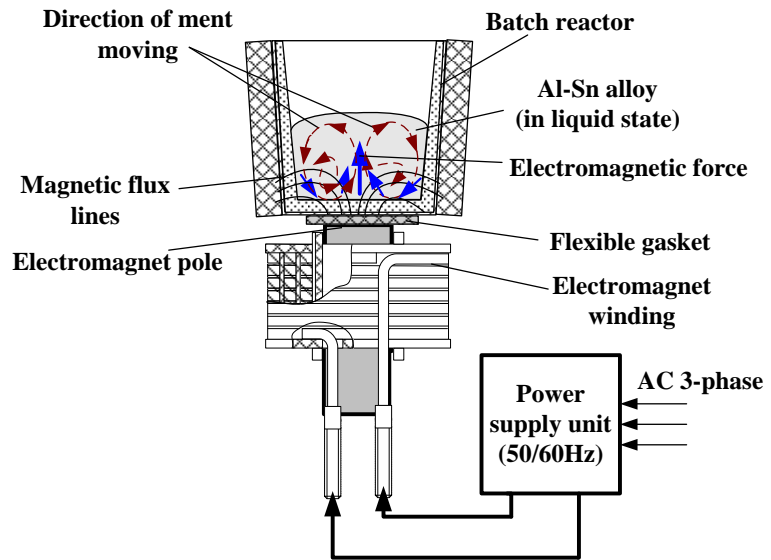


Fig. 4: Equipment of electromagnetic stirring

This research is mainly focused on a fine and uniform distribution of Sn particles through the strong pulse process in a molten Al-Sn alloy. Fig. 5 is SEM micrographs of as-cast Al-25%Sn alloys showing the effect of pulse treatment on the distribution of Sn phases. The size of Sn particles in the conventionally cast Al-25%Sn alloy is somewhat coarse with an average diameter of 80µm (Fig. 5a). However, Sn particles in the pulse-treated specimens are greatly reduced to 45µm with a uniform microstructure (Fig. 5b). By applying a strong pulse into an Al-Sn alloy, a fine and uniform

structure was obtained and this alloy and it is applicable to an Al-Sn alloy for a metal bearing which requires excellent lubricity and wear resistance. The pulse treatment can be also applied to a conventional Al-Si-Mg-Fe casting alloy in which the size and distribution of the hard phases such as primary Si and Al-Fe-Si intermetallics are important. Especially, the Fe-containing compounds are harmful for the soundness of the casting. The pulse treated alloy shows shorter intermetallic compounds through the Al matrix (Fig. 6), which can improve the mechanical properties of the alloy.

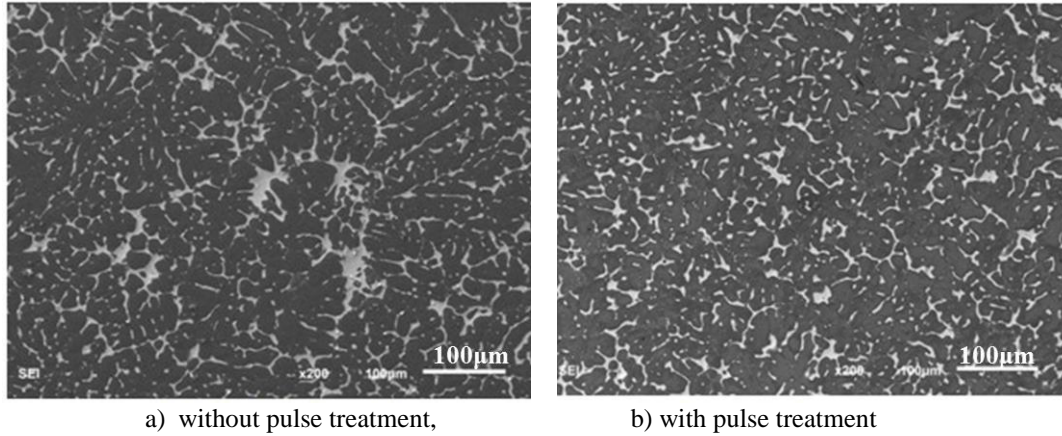


Fig. 5: Microstructure of Al-25%Sn alloy for metal bearing with pulse treatment

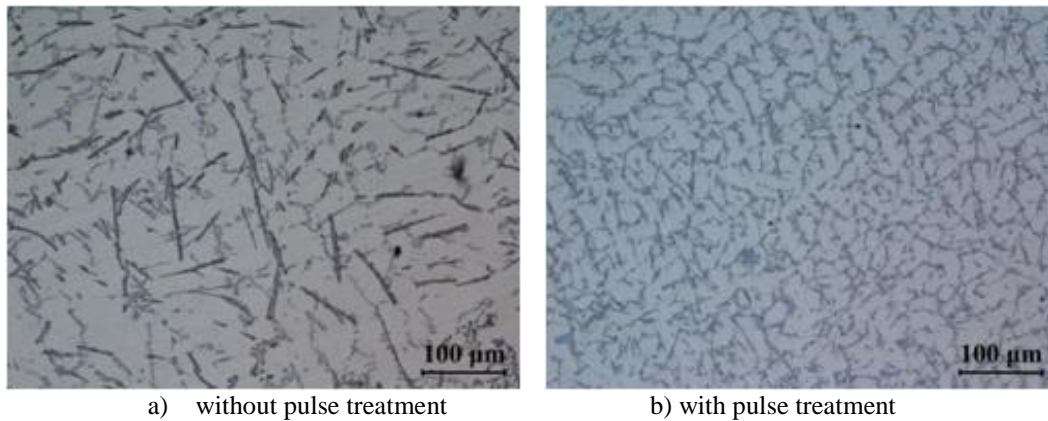


Fig. 6: Microstructure of Al-Si-Mg-Fe alloy with pulse treatment

A microstructural analysis was done for the typical conditions of moderate heat removal in the mold with a low solidification rate and overheating above the melting point of metals. It is found the formation of semi dendrites of  $\alpha$ -Al, and a cluster of  $\alpha$ -Sn in the grain boundary with different sizes and shapes. Application of mechanical mixing with gas bubbling provided a moderate dispersion of Sn up to 60 vol.% of interdendritically distributed form, with a large size of Sn particles between 50 to 85  $\mu\text{m}$ . In this method, it is inevitable to form residual gas porosity during casting. However, application of an EMS-PMF showed a deeper mixing in particle dispersion of Sn with dense structures incorporating Sn of 5-40  $\mu\text{m}$  in an interdendritic distribution (Fig. 7).

According to the multiple additional electromagnetic stirring (20-30 cycles of stirring for 1 minute, at speeds of 0.5 to 2 m/s) the mass flow rate in the pulse processing zone is 0.5 to 2 kg / s due to electromagnetic forces (frequency 120 Hz) for a binary Al-Sn alloy. In a high Sn containing Al-Sn alloy such as Al-40%Sn, the pulse processing (1.25 kJ with a frequency range of 1 to 3 Hz) can significantly increase the efficiency of the treatment by enhancing the processed volume (without EMP only 20 kg over 1-3 minutes) which is associated with an output pulse in relation to the effective volume of the melt to process.

Compared with an electromagnetic stirring only, typical advantage of the pulse processing is deeper efficiency on mechanical and acoustic effects of compression-dilatation waves on redistribution, homogenization, crushing solids and inclusions containing silicon, iron and other complex heterogeneous phases (needle-like intermetallic compounds) (Fig. 6), as well as non-metallic inclusions in the molten alloy. Based on the idea of combining the pulse treatment with

simultaneous contactless mixing of melts, segregation of the constituent phases can be successively prevented. Furthermore, it is possible to create novel equipment with an efficient technology for dispersion and stabilization of the emulsion of finely distributed Al-Sn alloys with production quantities (from 50 to 500 kg).

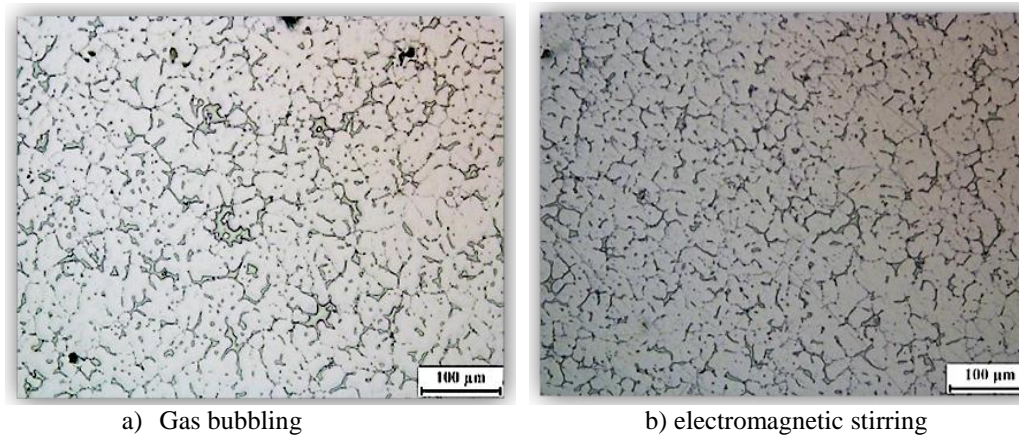


Fig. 7: Microstructure of Al-25%Sn alloy for metal bearing with pulse treatment

Compared with the pulse-only specimen without electromagnetic stirring, the specimen processed with a combination of the pulse treatment and the electromagnetic stirring has smaller Sn particles with a more uniform distribution. In this specimen, the partitioning of the alloying elements within the parent Al phase and the Sn-rich regions is essentially the same as in the as-cast material.

### Conclusions

Tin particles of Al-25%Sn alloy which is produced by conventional melting and casting are coarse to 80 $\mu$ m but those of the pulse-treated specimens are exhibited fine as 45 $\mu$ m with homogeneous microstructures. By adding a strong pulse in an Al-Sn alloy, fine and uniform structures are obtained. This alloy can be used for a metal bearing material which requires excellent lubricity and wear resistance. The best manufacturing method of Al-Sn alloy for a bearing material can be applied with a combination of strong pulse treatment and electromagnetic stirring at the same time in the molten alloy.

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