

# Spray Forming of Al-10Si-20Pb, Al-10Si-20Sn and Al-20Sn alloy: A Comparative study of their microstructure and wear characteristics

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**Abstract**-In this work an attempt has been made to evaluate the microstructural and wear characteristics of spray formed Al-10Si-20Pb, Al-10Si-20Sn and Al-20Sn alloys. The spray forming method was employed for preparation of samples. The microstructural features of spray formed alloys were studied under optical microscope. The microstructure of alloys shows uniform distribution of lead and tin particles along the grain boundary of base alloy. The wear characteristics of alloys were investigated under dry sliding condition by pin on disc type wear testing machine. Also the influence of applied load, sliding speed and frictional coefficient are determined. Worn out surface of pins are studied under optical microscope to determine the type of wear mechanism. The wear test results of all alloys shows increase in wear rate with applied load and sliding speed. The spray formed Al-10Si-20Pb alloy exhibits better wear resistance and lower coefficient of friction as compared to Al-10Si-20Sn and Al-20Sn alloy.

**Keywords:** Aluminum base alloy; Frictional coefficient; microstructure; Spray forming; Wear rate

an attempt has been made to investigate the microstructure and wear properties of spray formed Al-10Si-20Pb, Al-10Si-20Sn and Al-20Sn alloys.

## 1. INTRODUCTION

Spray forming is an advanced material processing technology that converts stream of molten metal into a near-net-shape solid. In spray forming, inert gas (Nitrogen or Argon) is used to atomising the molten metal and to achieve rapid solidification of deposited on copper substrate. Aluminum, copper and lead-tin based bearing alloys are widely used in tribological applications as bearing materials [1]. Al-Si based systems with Sn and Pb as soft phase materials possess good tribological, mechanical properties, high thermal conductivity and high corrosion resistance and are widely used in engineering applications, such as plain bearings, IC engine pistons, cylinder liners and aerospace industries [2]-[5]. The processing of immiscible alloys with conventional casting is associated with the segregation due to large density difference in liquid state. From the last 40 years, numbers of techniques have been developed for processing these alloys, such as powder metallurgy, stir casting, co-deposition, rheocasting and spray forming. Among these techniques the spray forming method provides better result in distribution of lead and tin particles along the grain boundary of alpha aluminum phase [6]-[7]. The addition of lead and tin into the Al-Si alloy increases the wear resistance property [8].

Earlier days Rudrakshi et al. [9]-[11] have studied the microstructure and wear characteristics of several spray-formed Al-Si-Pb alloys. However, the wear and microstructure of spray formed Al-Si-Sn alloys have not been systematically investigated. Therefore in this present study,

## 2. EXPERIMENTAL WORK

### 1. Spray forming process

The procedures of the spray forming process used in the present work have been described elsewhere [12]. The schematic diagram of spray forming is shown in fig.2.1. The forming process has been carried out for three compositions such as Al-10Si-20Pb, Al-10Si-20Sn and Al-20Sn. The melting was carried out in graphite crucible by resistance heating furnace. For each run, 3 Kg of alloy was charged in crucible. Initially the hole at the bottom of crucible was plugged with stopper rod before heating of alloy. The heating of alloy has been carried out for 120 minutes at above the melting temperature of (850°C) base alloy. The melt was promoted to flow through annular convergent-divergent nozzle to produce a spray of melt down by lifting the stopper rod at the top of the furnace. The additives in the form of granular of size 3-5 mm were added to the melt at the vertex from the top of the furnace.

The atomization of the melt has been carried out by the nitrogen gas at a pressure of 1.0 MPa and substrate distance 0.45m from nozzle. The sprayed material was deposited on the copper substrate in the form of bell shape of 200 mm diameter and 25 mm thickness at the centre of the preform. The similarly the spray forming was carried out for the other alloy compositions.

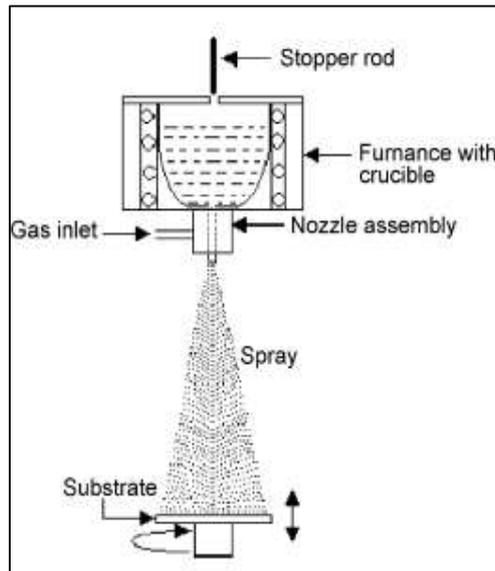


Fig.2.1: A Schematic diagram of spray forming process.

## 2. Microstructural Examination

The specimens of 5-8 mm height were cut from the preform. The samples were initially polished using different series of emery papers with increasing fineness grade. The final polishing was done on disc polishing machine using 400-mesh alumina paste, until the scratch free and mirror surface is obtained. Then the polished samples were etched with Keller's reagent (94 ml water, 3 ml nitric acid, 2 ml HCl and 1 ml HF) for 30 seconds and studied the all samples under optical microscope for microstructure.

## 3. Wear Testing

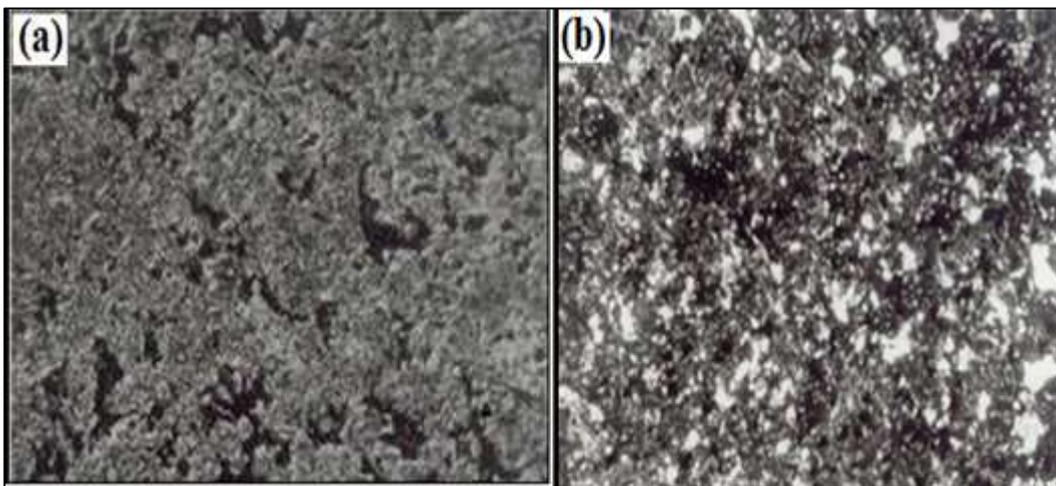
The wear test were conducted on pin on disc wear testing machine (TR-20, DUCOM) as shown in fig. 2.2. The samples of 30 mm length and 8 mm diameter pins were machined from the preform using lathe machine and single point cutting tool. The frictional force on sliding surface was measured with the help of load cell attached to the lever arm in terms of newton. The weight loss of the pin was measured using electronic balance

having an accuracy of 0.0001 kg. Tests were carried out for different loads (10 to 90 N), different sliding speeds (1m/s, 1.5 m/s and 2 m/s) and keeping sliding distance (1000 m) constant. The wear rate was calculated by the ratio of wear mass to sliding distance. The frictional force was measured with the help of load cell. The frictional coefficient was calculated by the ratio of frictional force to the applied normal load on specimen and worn-out surface of wear specimens were studied under optical microscopy.

## 4. RESULT AND DISCUSSION

Experimentation work carried out on the Al-Si-Pb, Al-Si-Sn and Al-Sn alloys. The experiments were conducted with the help of optical microscope for the microstructural study and pin on disc type wear testing for investigating the wear behaviour of all alloys.

### 1. Microstructural features



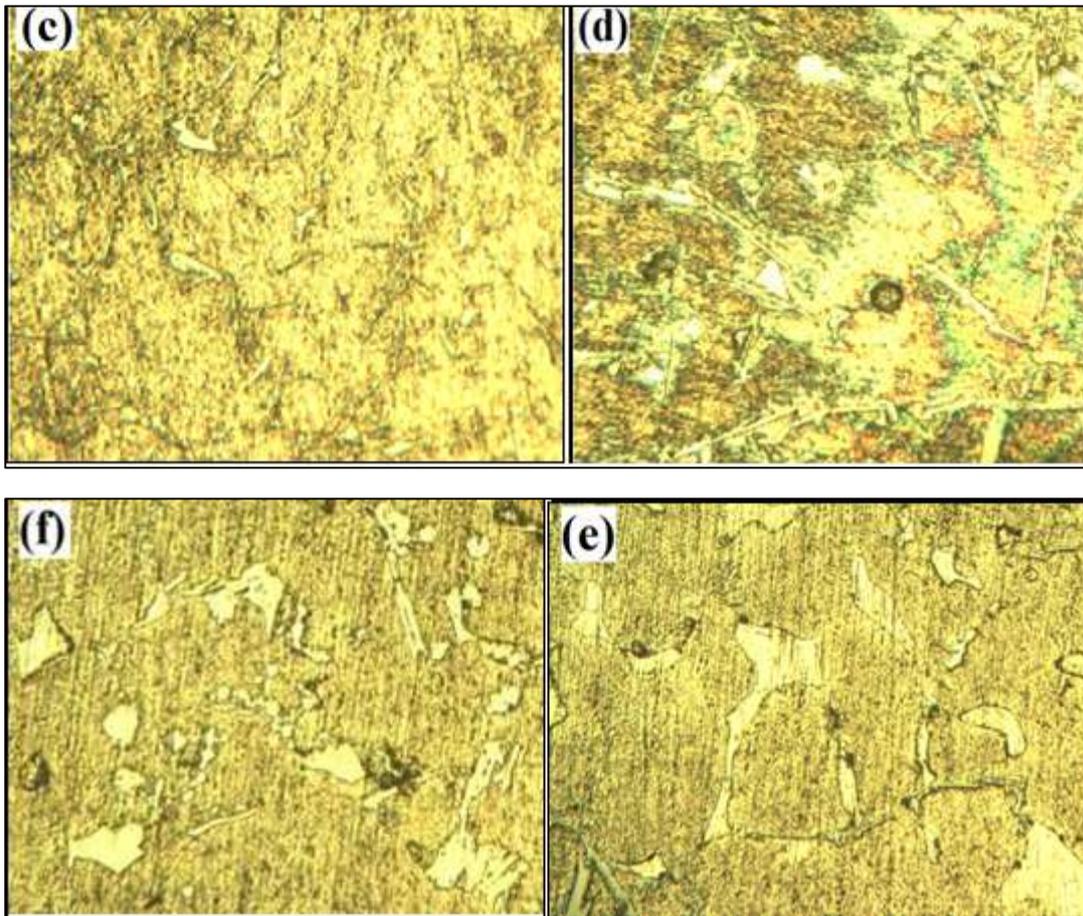


Fig.3.1: Optical micrographs of Al-10Si-20Pb (a, b), Al-10Si-20Sn(c, d) and Al-20Sn alloys (e, f).

The microstructure of the spray formed Al-10Si-20Pb, Al-20Sn and Al-10Si-20Sn are shown in fig.3.1. The microstructure of spray formed Al-10Si-20Pb alloy invariably exhibited grain morphology of the primary  $\alpha$ -phase with uniform distribution of Si particles and lead particles along the grain boundary. The size of Si particle was 10 micron and several sub-micron size particles were noticeable in the intra granular regions. The fig.3.1 (a) shows

## 2. Wear characteristics

The experimental results of Al-10Si-20Pb, Al-10Si-20Sn and Al-20Sn alloys under dry sliding condition for different applied loads, different sliding speed and constant sliding distance (1000 m) were shown in Fig.3.2. The result graphs have been plotted between the wear rate and applied loads for different speeds. From the graphs the wear rate of leaded alloy is lower as compared to the tin content alloys. The wear rates of all the alloys were increased with increasing the applied load. The wear rate was lower between the loads of 10N-30N and quickly increased after the load of 30N. The wear rate was more in Al-20Sn system as compared to Al-10Si-20Pb, Al-10Si-20Sn system due to the absence of Si in the alloy.

that the distribution of lead particles along grain boundary in dark phase. It has been observed that the Si particles formed fine structure in the Si rich phase shown in fig.3.1 (b). The microstructure of spray formed Al-10Si-20Sn exhibited uniform distribution of tin along the grain boundary as shown in fig.3.1(c and d). The fig.3.1 (e and f) shows that the distribution of tin in grain boundary of Al-20Sn alloy.

The effect of applied load on coefficient of friction has been investigated by plotting the graphs between applied load and coefficient of friction as shown in the fig.3.3. The coefficient of friction was high initially due to the effect of surface roughness and sharply decreased up to the load of 30N and subsequently become almost constant up to the load of 90N. The coefficient of friction was lower in the case of leaded alloy compared to the other alloys. The addition of silicon and lead to the aluminum was reduced the wear coefficient as compared to the addition of tin and silicon to the aluminum for the same composition of alloy.

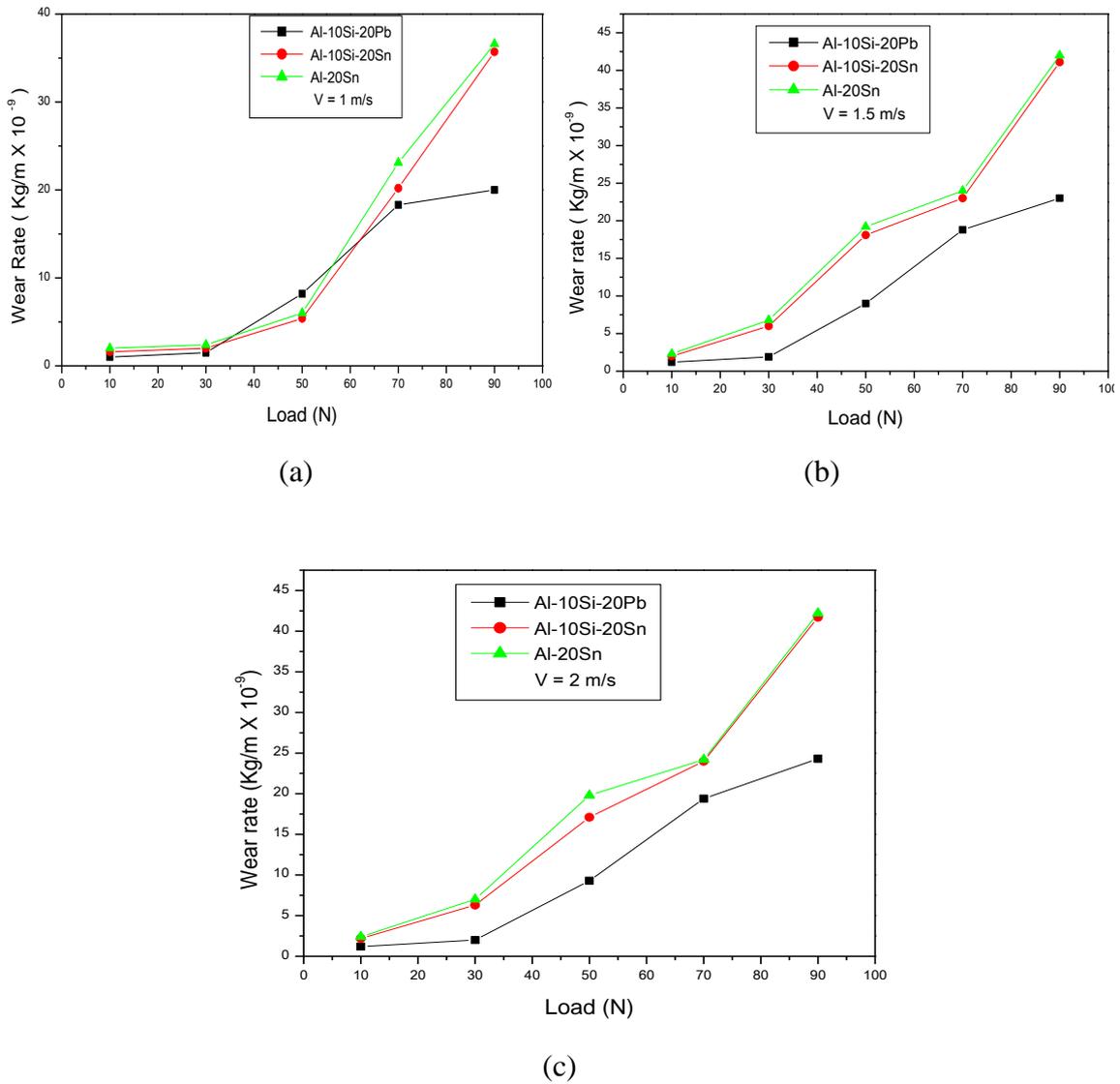
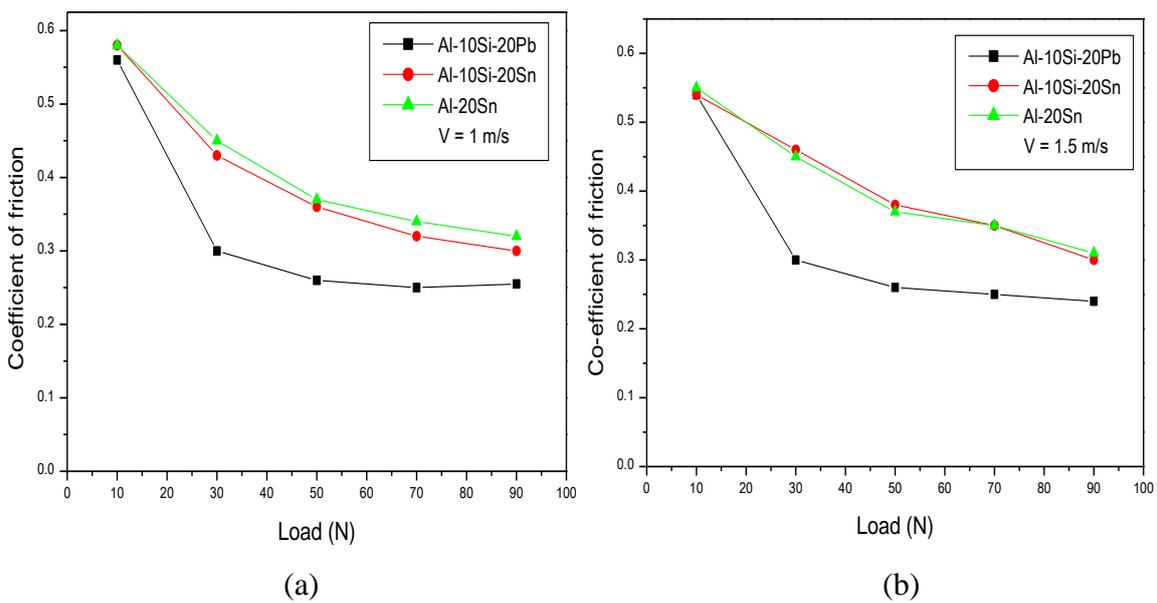
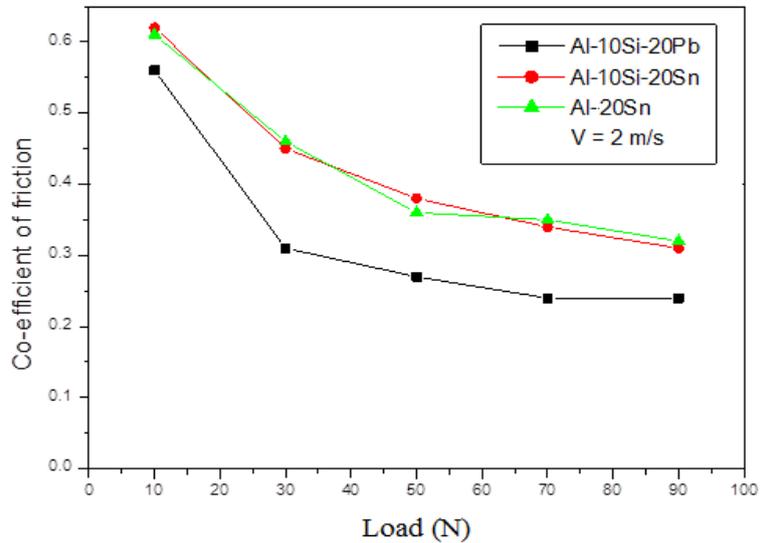


Fig. 3.2: Effect of applied load on wear rate in all alloys at sliding velocity (a) 1 m/s, (b) 1.5 m/s and (c) 2 m/s.





(c)

Fig. 3.3: Effect of applied load on coefficient of friction in all alloys at sliding velocity (a) 1 m/s, (b) 2 m/s and (c) 2 m/s.

### 3. Nature of worn out pin surface

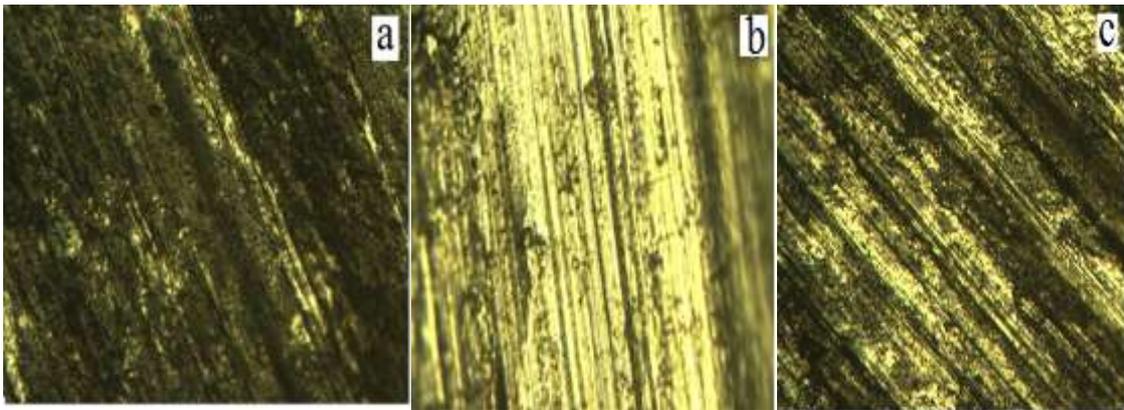


Fig.3.4:Optical micrographs of worn out pin surface of (a) Al-10si-20Pb, (b) Al- 10Si-20Sn and (c) Al-20Sn alloys.

One of the same feature observed in all micrographs was form of grooves, ridge running parallel to the direction of sliding and repetitive ploughing marks in all the alloys and the form of grooves indicates that the abrasive type of wear in all the alloys. Comparing fig.3.4 (a, b and c), it has been found that the shining surface more in Al-Si-Sn alloy due to the presence of silicon and tin and lower in other two alloys. Also it was observed that the wear grooves were fine and few dimples on the worn surface of Al-Si-Pb alloy compared to other alloys. It indicates that the wear rate in this alloy should be lower compared to other alloys.

### 4. CONCLUSIONS

The study of the Spray formed aluminum based Al-10Si-20Pb, Al-10Si-Sn and Al-20Sn led to following conclusions:

1. The spray forming method provides a significant microstructure modification in all alloys. The grain morphology of the spray formed alloys exhibits

### REFERENCES

2. equiaxed grain with uniform dispersion of lead and tin particles along the grain junctions.
3. The grain size of primary alpha-phase is depending upon the process variables employed during the spray deposition.
4. The wear properties of the spray formed alloys influenced by the microstructural feature.
5. The wear test results of all alloys showed increase in wear rate with applied load.
6. The spray formed Al-10Si-20Pb alloy exhibits better wear resistance properties compared to Al-10Si-20Sn and Al-20Sn alloys.
7. In all the three alloy systems the wear coefficient of friction has been found initially high and subsequently become almost constant after the load of 30N.
8. The wear coefficient of friction for Al-10Si-20Pb alloy shows lower as compared to Al-10Si-20Sn and Al-20Sn alloys.

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