Abstract- In the present work, the microstructural studies of Al-6Si and Al-6Si-20Pb alloys were conducted from top to bottom and from centre to periphery of the spray formed preform. SEM and Optical micrographs were taken at three different locations of the preform viz. (a) top (b) bottom and (c) peripheral regions. The size of the aluminum grains was lower at the peripheral region as compared to that of the top and bottom regions. Particles/droplets of two different types were found to deposit on the substrate. First type particles were aluminum rich and the second type were lead rich. Aluminum rich particles were coarser than that of lead rich. Lead particles were observed in inter-dendritic regions of the particle microstructure and it was uniformly dispersed in the spray deposit. The size of lead particles was higher at the centre as compared to that of periphery of the deposit. Some silicon particles were observed to be surrounded by lead at the grain boundary of aluminum phase.

Keywords- Al-Si alloys; microstructure; spray forming

I. INTRODUCTION
Numerous advantages like effective micro structural control together with producing a near net shape [1,2] pre form in a less number of processing steps can be achieved by spray forming technique. The spray deposited pre form generally results in exclusive microstructure exhibited spheroidal or equiaxed grains [3-6]. In fact, spray forming technique exhibits the beneficial characteristics of powder metallurgy processing without the numerous processing concerns, that is, powder production, storage and handling, sintering and hot consolidation.

Spray formed Al–Si–Cu–Pb alloy and the microstructure of the spray deposits were investigated by Rudrakshi et al. [7,8]. The results invariably exhibited an equiaxed grain morphology of the primary α-phase with variation in grain size from 10 to 25 µm in addition to a uniform dispersion of ultra-fine particles of lead and globular silicon particles in Al matrix. The size of Si particles varied from 0.5 to 5 µm and that of Pb particles from 0.1 to 25 µm with variation in deposition distance. Fang and Fan [2] successfully produced immiscible Al–Si–Pb alloys using the rheo-diecasting process (RDC) and the microstructure of alloys was characterized by spherical and fine Pb particles dispersed uniformly in the Al–Si alloy matrix. The size of the α-Al primary phase was approximately 50 µm and the average size of the Pb particles increased with the increase in Pb concentration. The Pb particle size increased from 2.6 µm in Al–7Si–3.8Pb to 14 µm in Al–7Si–17.2Pb alloy.

In the present work Al-6Si and Al-6Si-20Pb alloys were spray formed in the form of a disc and then their microstructure, EDX and SEM were studied.

II. EXPERIMENTAL
Spray forming set up [9,10] was consisted of a spray assembly to produce spray of fine droplets and an atomization chamber. A convergent-divergent nozzle was used in the spray assembly. A graphite crucible was placed inside the furnace which was lying above the atomization chamber. A metal delivery tube was connected with this crucible at its bottom surface, which passed through the central hole of convergent divergent nozzle [11,12]. A disc shape copper substrate of diameter 200 mm was kept at a distance of 400 mm from the nozzle.

The base alloy taken in the present work was Al-6Si. This alloy was melted in a graphite crucible. The atomization of melt was carried out by N2 gas at a pressure of 10 bar. The spray of atomized droplets was subsequently deposited over the copper substrate. Preform was taken off the substrate after the deposition [6].

A. Microstructure
For the micro structural study, samples from the central and peripheral regions of the preform were cut down. These samples were polished using standard metallographic technique of polishing. Then samples were examined with Leitz optical
microscope and scanning electron microscope after etched with Keller’s reagent.

III. RESULTS AND DISCUSSION

A. Spray deposit
At three different locations of the deposit viz. (a) top, (b) bottom and (c) peripheral regions, optical micrographs were taken. These micrographs are presented in Fig. 1 for 0 and 20% Pb content.

![Microstructure of Al-6Si (a, b & c) and Al-6Si-20Pb (d, e & f) alloy prepared by spray forming technique showing top (a & d); bottom (b & e) and peripheral (c & f) regions.](image1)

Microstructure of spray deposited Al-6Si and Al-6Si-20Pb alloy are shown in Fig.1. Fine equiaxed grains of primary Al were observed and within these grains and along the grain boundary Si was present. Gray color in the microstructure represents Si phase as depicted by EDS in Fig.2. The size of the Al grains and Si particles were 15-25 and sub-micron to 5 µm, respectively.

Black color represents the Pb phase (as revealed by EDS in Fig.2). It can be seen that throughout the Al-phase, the Pb distribution is almost uniform. At central (top and bottom) and peripheral regions, the Pb particles size varies from sub-micron to 20 µm and sub-micron to 15 µm. The size of the Al-grains is lower at the peripheral region as compare to that of the top and bottom regions. The Al-grain size at central i.e. top, bottom and peripheral regions are 5-35 and 2-20 µm, respectively.

Atomized droplets deposit over the copper substrate kept at a distance of 400 mm. At this distance the velocity of gas which is 50 m/s [9] is not supposed to disintegrate further the droplets [8] depositing on the substrate. Although, some melts on the deposit could further break by the impact of the momentum of droplets striking the deposit. Semi-solid droplets also break into finer fragments by the impact of this momentum. These fine fragments act as nuclei for the solidification of melt on the surface [5].

![EDS spectrum with analyzed (a) whole region; (b) bright region, indicating Pb and Si phases in spray deposited Al-6Si-20Pb alloy.](image2)

On the deposition surface a semi-solid or semi-liquid mass is continuously depositing and solidifying. Heat will released rapidly to the surroundings having high gas velocity due to this continuously depositing mass. The high gas velocity leads to high rate of heat transfer by convection and previously deposited mass leads to heat transfer by conduction from the depositing mass. Therefore high rate of heat transfer from the melt leads to very high solidification rate of the spray deposit and thereby formation of equiaxed structure (Fig.1). The silicon in the structure is in particulate form, conflicting to that of the...
convectonal cast structure \[12,13\] which also indicates rapid solidification of the deposit \[11\].

The microstructure of the deposit was found to depend on the location of the deposit (Fig 1). More cooling rate at peripheral region was achieved as compared to that of the central region because of the reduced thickness of the deposit at peripheral region which leads to an increase in the heat transfer rate by conduction. The more cooling rate at peripheral region leads to the formation of more fine grains structure as compared to that of the central region.

Fig.2 shows the EDS spectrums with micrographs of the analyzed region for Al-6Si-20Pb spray formed alloy. EDS analysis of black and white regions of the micrograph gives Al, Si and Pb peaks and these two regions are shown in micrographs in the same figure. The EDX analysis of white (bright) region shows that it is the Pb rich phase and so the black (dark) region should be Al rich phase.

IV SPRAY PARTICLES

Fig. 3 shows the SEM micrographs of the spray particles for 20% of lead at two different magnifications viz. (a) 200x and (b) 500x. Particles size is varying from sub-micron to 100 µm. White and black colour particles are Pb and Al rich, respectively (as revealed by EDS analysis in fig.2). The shape of the particles is rounded and having rough surface. Aluminum rich particles are coarser than lead rich particles and these particles are having about 1-3 µm size lead particles on their surface. Silicon phase in these particles could not be identified. Some particles are showing satellite formation and some are showing cracks at their surface. Aluminum or lead rich liquid phase was observed to be solidified on some particles.

V. CONCLUSIONS

1. Particles/droplets of two different types were found to deposit on the substrate. First type particles were aluminum rich and the second type were lead rich. Lead rich particles increases with the increase in lead content. Aluminum rich particles were coarser than lead rich particles. Lead particles were observed in inter-dendritic regions of the particle microstructure.

2. The lead was uniformly distributed in the spray deposit.

3. The size of lead particles was lower at the periphery as compared to that of centre of the deposit.

4. The size of the aluminum grains was lower at the peripheral region as compare to that of the top and bottom regions.

5. In SEM the maximum amount of lead was dispersed along the grain boundaries.

REFERENCES


