Microstructure, Porosity and Hardness of Spray Deposited Cold Rolled Al-6Si Alloy

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Abstract—Al-6%Si alloys were prepared by spray deposition technique and then cold rolled to various thickness reduction. Hardness, porosity and microstructural characteristics of the alloy were studied from top to centre and from centre to periphery of the deposit for different percentage of thickness reduction. Hardness was found to increase and porosity was observed to decrease with the increase in percentage of thickness reduction. Aluminum grains were observed to be elongated in the rolling direction after 80 % thickness reduction.

Keywords — Al-Si, alloy, deposition, hardness, microstructure, porosity, rolling, spray.

I. INTRODUCTION

The excellent properties of aluminum-silicon alloys like light weight, low density, high strength, toughness, corrosion resistance and low cost have led to extensive use of these alloys in engineering applications. However, the conventional ingot metallurgy leads to coarse primary Si phase which detroits the properties of Al-Si alloy. One approach that has been utilized to suppress the formation of the coarse, brittle, primary Si phase is rapid solidification. Spray deposition process involves relatively high cooling rates combined with the ability to produce a preform in a less number of processing steps [1, 2]. The spray deposited preform generally results in exclusive microstructure exhibited spheroidal or equiaxed grains [3, 4]. In fact, this 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. Though, a certain amount of porosity always exist in spray deposited preform which detroits the mechanical properties [1]. Therefore, the spray deposited preform must further be densified and deformed plastically to prepare fully dense metal sheets with high mechanical properties. To achieve the required mechanical properties as well as to eliminate porosity, extrusion, forging, rolling, etc. are the effective methods [2]. Out of these, rolling is an effective fabrication process for obtaining a full density product from spray deposition preforms [3]. During rolling, densification of porous metal occurs under a generalized stress field having both hydrostatic and deviatoric components.

The microstructure of spray deposit Al–Si–Cu–Pb alloy were investigated by Rudrakshi et al. [5]. 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 globular silicon particles in Al matrix. The size of Si particles varied from 0.5 to 5 µm with variation in deposition distance. Analysis of cold densification rolling of a sintered porous metal strip has been studied by Deshmukh et. al [3]. The density was observed to decrease for greater thickness reduction (25 % and above). The strip developed longitudinal cracks for a thickness reduction of 30 % or greater in a single pass. Tripathi et. al [4] have studied the rolling behaviour of steel backed spray deposited Al-Sn strip and they found that during rolling, both densification and deformation in the Al-Sn deposit and as well bonding between the deposit and the steel substrate take place simultaneously.

In the present work Al-6Si alloys were spray deposited in the form of a disc and then cold rolled. The change in porosity, hardness and microstructural studies with distance from centre to periphery of deposit are reported for different percentage reduction in thickness.

II. EXPERIMENTAL

The details of the spray deposition process have been described elsewhere [6]. In brief, the spray deposition set up consisted of a melting unit, spray assembly to produce spray of fine droplets and an atomization chamber. A convergent-divergent nozzle was used in the spray assembly. The melting was carried out in a graphite crucible placed inside a resistance-heating 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. 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 and then samples were cut from different locations of the preform as shown in Fig.1. After that, these samples were cold rolled in a two-high mill where the speed of the rolls was 8 rpm and the diameter of the rolls was 110 mm.
For the microstructural study, samples from the central and peripheral regions of the preform were cut down and then cold rolled to different percentage of thickness reductions. These samples were polished using standard metallographic technique of polishing. Then samples were examined with Letiz optical microscope and scanning electron microscope after etched with Keller’s reagent.

To measure total porosity at different locations of the deposit, the measured density was determined by Archimedes principle and followed by the ASTM B 328-96 practice. Mean value of three measurements was taken and reported in the present work.

Hardness investigations were carried out on samples cut from central and peripheral regions of preform. Before commencement of a test, samples were ground and polished using standard metallographic technique. A Brinell-cum-Vicker’s hardness tester of model HPO 250 was used to measure the Vicker hardness at 5 Kg load. Indentations were taken at different locations of central and peripheral regions of each sample.

III. RESULTS AND DISCUSSION

A. Microstructure

Fig. 2 shows the optical micrographs of spray deposit Al-6Si alloys. These micrographs were taken at three different locations of the deposit viz. (a) top (sample #1), (b) centre (sample #3) and (c) peripheral (sample #6) regions for without and with 80% thickness reductions. For without reduction, the microstructure exhibits fine equiaxed grain morphology of the primary Al phase. The identification of phases in spray deposited alloy was carried out by EDS analysis. The results indicate that the gray contrast region corresponded to Si phase whereas the bright region predominantly contained the Al matrix. The spray deposit of Al-6Si alloy shows uniform distribution of primary Si phase with a particulate morphology. The average Al grain size is about 15-25 µm and the size of Si particles is about sub-micron to 5 µm.

It can be seen that the size of aluminum grains is almost same for sample #1 i.e. top region and sample #3 i.e. centre region whereas it is lower for sample #6 i.e. peripheral region. The aluminum grain size is about 5-10 µm at peripheral region.

Wherever there is Si phase along the grain boundary, the width of the grain boundary increases due to the spread of Si on rolling. As usual grains are elongated in the rolling direction with the thickness reduction of the sample. Also, the aspect ratio of the Al-grains increases with 80% thickness reduction. No cracks were observed in the reported microstructure after rolling of the samples.

The microstructural features of the spray deposit material are due to the rapid solidification effect achieved during atomization of the melt in to the fine droplets. The high impact velocity of the droplets and the turbulent fluid flow conditions on the growing deposit give rise to fragmentation of dendrite arms [7] and thus refinement of the primary phases and homogeneity in the microstructure. The Si phase solidifies at an early stage due to its high freezing temperature.

B. Porosity

It is well known that there exists a certain amount of porosity in the spray deposit preform. The variation in porosity as a function of thickness reduction for (a) sample #1 to 3 (i.e top to centre) and (b) sample #3 to 6 (i.e. centre to periphery) of the preform are shown in Fig 3. It can be seen that porosity decreases up to 20% thickness reduction and then it increases up to that of 40%. Afterwards, the porosity decreases at a faster rate up to a thickness reduction of 60% than that of 20% and again a small decrement in the porosity occur up to that of 80% for all the samples.

In Fig 3(a), the porosity decreases from sample #1 to #3 i.e. from top to centre and in Fig 3(b), the porosity decreases from sample #3 to #6 i.e. from centre to periphery. The turbulent flow on the preform surface during deposition of the droplets entraps air causing porosity [9] in the resulted preform.

The variation in porosity level depends on the melt percentage variation in the spray [8]. In the initial stage of rolling (i.e about 20% thickness reductions), the metal flow in the Al-Si deposit is mainly in the thickness and as well length direction resulting in the removal of porosity by rearrangement and restacking of spray deposited particles. At 40% thickness reduction, cracks are formed in the sample. Due to which porosity increases. Beyond this much deformation, cracks filled by the metal flow and porosity again decreases.

C. Hardness

The effect of thickness reduction on Vickers hardness of the spray deposited Al-6Si alloy for (a) sample #1 to 3 (i.e top to centre) and (b) sample #3 to 6 (i.e. centre to periphery) of the preform are shown in Fig 4. For samples #1 to 3 (fig. 4a) and samples #3 to 6 (fig. 4b), hardness increases continuously up to 80% thickness reduction.
Without reduction

With 80 % reduction

Fig. 2 Microstructure of different samples #1, #3 and #6 of spray deposited Al-6Si alloy for without, and with 80 % thickness reduction
Fig. 3 Variation in porosity as a function of thickness reduction for (a) sample #1 to 3 and (b) sample #3 to 6, of the preform.

Fig. 4 Variation in hardness with thickness reduction for (a) sample #1 to 3 and (b) sample #3 to 6, of the preform.

However, from 20 to 40 % thickness reduction, increment is marginal or it can be said that hardness remains constant. Also, it is highest for sample # 3 and lowest for sample # 1 in fig 4a while in fig 4b, hardness is highest for sample #6 and lowest for sample #3.

During the cold rolling of the materials, the number of dislocations per materials volume increase significantly [9]. Thus, the nucleation and movement of new dislocations is hindered by the existing dislocations, causing an increase of hardness of the material.

IV. CONCLUSIONS
1. Grains are elongated in the rolling direction after 80 % thickness reduction. The Si phase is located mainly at the grain boundaries and the width of the grain boundary increases due to the spread of Si on rolling.
2. Porosity decreases with the increase in thickness reduction and it is minimum for 80 % thickness reduction. However, at 40 % thickness reduction, porosity increases due to crack formation.
3. Hardness increases with the increase in thickness reduction and it is maximum for 80 % thickness reduction.

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