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MICROSTRUCTURE AND TENSILE DATA OF A VERY DUCTILE AS CAST Al-21%Si-1.5% Ba HYPER-EUTECTIC ALLOYS

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Abstract

The microstructure and tensile properties of as cast Al-20%Si-1.5%%Ba hyper-eutectic alloys are presented. All sample alloys in as cast condition showed\ microstructure that is comprised of an almost primary Si free Al-Si eutectic. The eutectic silicon appears as flake/fiber in morphology and assumes the width of flake/fiber in the range of sub-micron. The alloys show a very high ductility of about 7% and exhibit UTS of 130 MPa.

Introduction

The ever-increasing demand for materials with advanced properties has inspired investigators to develop newer and newer ideas and production methods to remain competitive. For automotive, aerospace and defense industries, the properties of the materials most sought after are reduced weight, good machinability, low thermal expansion, good electrical properties and excellent wear resistance at elevated temperatures. Hypereutectic Al-Si alloys that have a high volume fraction of a very fine morphology silicon phase in the order of (100 nm) uniformly distributed in the matrix of the aluminum adequately meet such requirements. For the commercial viability and economic success it is desirable that components made of such alloys be produced by conventional casting processes.

In an Al-Si binary system [1] as shown in Figure 1, the hyper-eutectic range exists for a silicon composition that is higher than 12.2 at% (12.7 wt%) of silicon. The microstructure of hyper-eutectic alloys contains two major components: the primary phase and the eutectic phase. The primary phase is of virtually pure silicon and assumes the morphology of mainly large idiomorphs that are embedded in the matrix, while the eutectic phases are comprised of aluminum based solid solution of silicon and virtually pure silicon and forms the matrix of the microstructure. These large idiomorphs of primary silicon usually cause considerable tool wear and machining difficulties [2]. The toughness of alloys containing such large idiomorphs of primary silicon is rather low [3]. Therefore, these alloys have to be modified to convert the idiomorphs into small and uniformly distributed particles.

Recently, based upon the concept of the solubility of barium (Ba) metal in the silicon phase Shamsuzzoha and his coauthors [4-6] have demonstrated that hyper-eutectic alloys containing up to 17-wt% Si can be produced by directional solidifications without a primary silicon phase being present in the microstructure. The procedure has

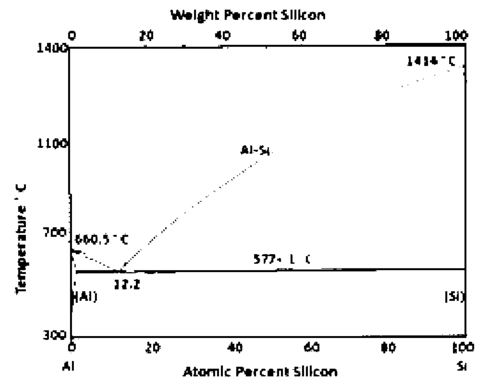

Figure 1. Al-Si phase diagram [1].

resulted in a shift to the normal eutectic point from 12.7 wt% to 17wt% Si (Figures 2). The silicon in these alloys appears as nano- and close-to-nano-size fibers at high growth rate (2500µm/sec) and moderate growth rate

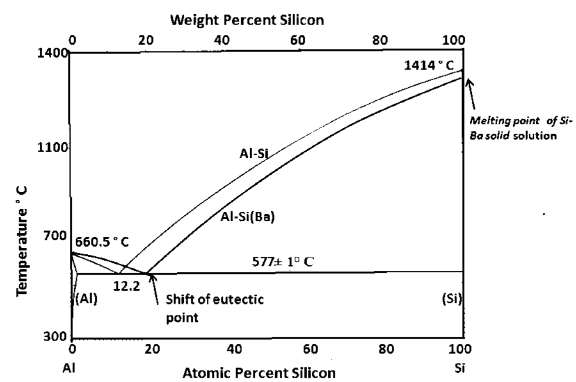

Figure 2. Schematic representation of the liquid-solid tie lines and a shift of eutectic point due to solid solution of Ba in Si as imposed in the Al-Si phase diagram.

(250µm/sec) respectively. It basically involves the addition of Ba into a melt of hyper-eutectic alloys. Similar treatment in the shape casting of the hyper eutectic Al-17-wt% Si alloy also revealed [7] a microstructure in which Si phase assumes a close to nano-sized flake morphology silicon. The same concept has now been applied to develop primary Si free high strength and ductility hyper-eutectic Al-Si alloys by conventional permanent mold castings. This paper deals with the development of such Al--21%Si hypereutectic alloys that exhibit primary Si free microstructure with a nano or sub-micron sized flake/fibrous morphology eutectic Si.

Experimental Procedures

The process involves melting of alloys that have composition of Al-21wt%Si in an argon-rich environment. Starting materials used in these experiments are aluminum and silicon of 99.7% and 99.2 % purity respectively. The furnace used for melting is a resistance furnace, in which temperature is kept to 850℃ for Ba treatment. After Ba treatment the resulting melt was poured into the sprue of a standard ASTM B-108 mold that was preheated at 450℃. After pouring, the mold was allowed to cool down to room temperature. Longitudinal and transverse section specimens taken from near the center of the grown samples were used to determine the microstructure. Directly cast cylindrical tensile samples as provided by ASM mold were subjected to tensile testing. The microstructure of the alloys was investigated using a JOEL JSM-7000F SEM. For microstructure investigation, samples of cast alloys were deep etched to remove surface aluminium and to expose the topography and morphology of silicon phase.

Result and Discussions

The microstructure of the alloys could not be well-resolved by optical microscopy, and therefore investigated by scanning electron microscopy to study the morphology of silicon and aluminium phases. Energy dispersive x-ray spectrometry equipped with the SEM for the alloy showed an overall composition that is close to that of Al-21 wt% Si.

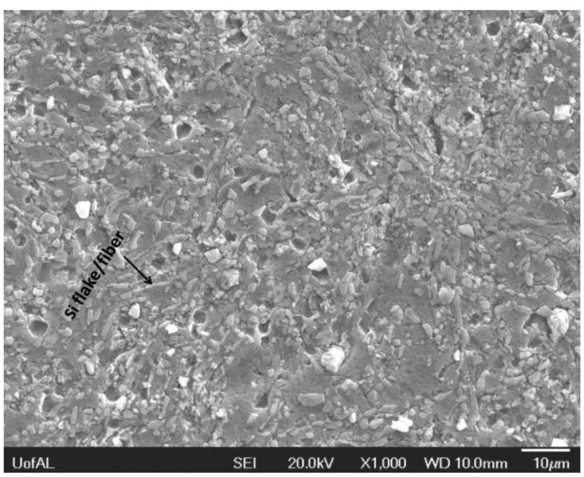

Figure 3. SEM micrograph of a deep etched permanent mold cast Al-21% Si-1.5% alloy, showing a microstructure of completely free primary silicon.

Figure 3 shows a SEM micrograph of a typical microstructure found in a resulting cast alloy. Simple examination of the micrograph reveals that the microstructure of the alloy solely consists of eutectic, and is free of any primary silicon phase. This feature of the microstructure is expected with addition of Ba, which causes eutectic point to shift towards higher Si content [7]. The eutectic silicon crystals found in the microstructure of the alloy assumes very fine flake/fiber morphology. The width of the eutectic silicon as in the microstructure assumes nanometer in scale, which is at least several order magnitude thinner than that found in other Al-18-25%Si alloys that grown either impurity modification using Sr or by other techniques like solid –liquid duplex casting and Rheo casting [8-10].

Presence of a very refined Si phase and absences of large sized particles of primary Si in the microstructure of these Al-21%Si-1.5%Ba alloys suggests that the alloys are likely to exhibit marked improvements in physical and mechanical properties over the existing hypereutectic alloys of similar composition. Tensile tests were therefore performed on the present as cast Al-21%Si-1.5%Ba alloys.

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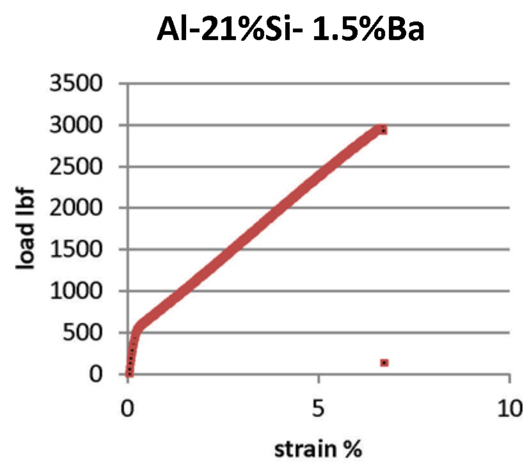

Figure 4. A stress versus strain plot for the Al-21%Si-1.5%Ba alloy.

The results of these tests revealed an average ductility and UTS of 6.8(5)% and 130(5) MPa respectively. A typical stress vs strain plot of a sample from Al-21%Si-1.8%Ba alloy is shown in Figure 4. Presence of an almost linear relationship between stress versus strain as seen in the plot is interesting. The refined microstructure of these alloys is expected to produce higher strength than that shown in the plot of Figure 4. The alloy probably failed prematurely during initial stage of plastic deformation. The failure could be due to voids or impurity regions developed due to the impurities present in the starting materials. A very high fraction of Si in the matrix can also renders failures because silicon is very brittle and prone to premature fracture. Further work for determining the reasons for the failure is under progress Metallographic examination of failure samples revealed a cup and cone fracture, which is a fundamental characteristic of ductile fracture The 6.5(4)% ductility exhibited by the alloy is consistent with the ductile fracture failure of the alloys. Even more the observed ductility is much higher than that of 1-2 % found in similar Al-Si alloys developed by various forms of castings [8-10].

Conclusion

The microstructure of the presently developed permanent mold-cast high-strength cast hyper-eutectic Al-Si alloy discussed in this paper reveals that the entire silicon content of the alloy appears as similar in size and assumes nano or sub-micron flake/fibrous morphology. Appearances of such morphology of Si phase reveals that either the primary Si phase did not form during solidification or the eutectic point has shifted towards higher than 21% Si in the hyper-eutectic alloy. The later idea is more plausible as the addition of Ba, which forms solid solution with Si may have shifted the eutectic point and also alters the crystallization behavior of silicon. Presence of nano or sub-micron sized flake/fiber morphology of silicon phase in the alloy helps to increase the ductility. However, further investigations are needed to acquire understandings of why the occupancy of such a refined silicon phase in the microstructure has lead to failure of the alloy at moderate UTS value during tensile testing.

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