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Homogenization and Hot Ductiility of Aluminum Alloy AA 6063

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Abstract

Several homogenization treatments were applied in DC ingots of aluminum alloy AA 6063, in order to analyze the microstructures developed in the homogenized conditions and their effects on the hot workability of this alloy. Microstructures of as-cast samples and samples homogenized in different conditions were analyzed by means of optical metallography, X-ray diffraction and in the scanning electron microscope (SEM with EDS). The changes in distribution and morphology of second phase particles (AlFeSi and Mg2Si), due to the different homogenization treatments, could be assessed. Samples were selected for hot tensile testing, in temperatures between 470 and 650ºC, so that hot workability (here meaning hot ductility) could be assessed in different conditions of strain rate. The homogenization treatments enabled the transformation of the undesirable intermetallic β-AlFeSi phase, which is present in the as-cast condition, to α-AlFeSi particles, which are not detrimental to the extrudability of the alloy. Hot tensile tests could show that homogenization can change the hot ductility response of the alloy.

1. Introduction

Alloy AA6063 has been gaining continuous popularity in industry mainly due to the combination of high extrudability (and consequently high productivity), and high strength. Largely used in the transportation as well as in construction industry, this is the most widely used of all extruded aluminum alloys [1-3].

This alloy's extrudability (or hot workability) strongly depends on chemical composition, solidification conditions and homogenization heat treatment, which determine the material's microstructure before mechanical working. It is well known that the final properties of a component are dictated by its microstructure, which in turn is the result of the processing conditions used [4, 5]. Consequently, the study of the evolution of the microstructure during homogenization of alloy 6063 and the effects on the hot workability are the objectives of the present work.

It is widely recognized that homogenization makes the mechanical working easier, so that semi-finished products such as rolled plates, sheet or extrudates can be easily and more efficiently produced.

The beneficial effects due to this heat treatment is a result of the attenuation of the microsegregation intensity and of the solutionizing and re-precipitation reactions of coarse primary constituent particles, originated during solidification [6, 7].

In this work, as-cast samples and homogenized samples have had their microstructures characterized by electron microscopy (SEM) and EDS microanalysis. Thus, changes concerning distribution and morphology of second phase particles (intermetallics of AlFeSi and Mg_2Si), due to different treatments have been analyzed. The hot ductility was evaluated via hot tensile tests, and the effects of homogenization treatment of the hot ductility of the alloy could be studied.

2. Experimental Procedure

An industrial scale DC ingot of alloy 6063, of 6” in diameter with chemical composition (wt%) 0.44% Mg; 0.36% Si; 0.20% Fe; 0.036% Mn; 0.008% Cr; 0.007% Ti, was used for the experimental work.

Samples cut from as-cast ingot were given different homogenization heat treatments according to table 1, below:

Table 1: Nomenclature of homogenization conditions.

Condition	Temperature (^oC)	Time (h)	Cooling mode (to room temp.)
2A	585	2	in AIR
2H	585	2	in WATER
8A	585	8	in AIR
BF	AS-CAST		

Samples thus heat treated were characterized by means of optical metallography, SEM/EDS microscopy and X-ray diffraction techniques.

Hot tensile tests were carried out in a testing machine Gleeble-1000 HAZ, and the cross head speed used was of 25 mm/s, corresponding to a initial strain rate of 0.83 s^{-1}. These tests were done at temperatures ranging from 470 to 600^oC (which are within typical hot working range for the alloy studied). After testing, reduction in area of fractured test pieces was obtained by measuring the fracture diameter in a profile projector, which gives an accuracy of 10^{-3} mm.

3. Results and Discussion

The microstructures developed during the homogenization treatments used are shown in figure 1, where the interdendritic phases’ distribution can be observed. Prior to homogenization, as seen in figure 1A, the as-cast microstructure is composed by aluminum matrix and interdendritic β-AlFeSi in the form of an almost continuous film of plate-like morphology. Also, eutectic Mg_2Si can also be found coupled with the β-AlFeSi particles. The continuous film of β-AlFeSi is known to have a deleterious effect on the hot workability of alloy 6063, and the use of homogenization heat treatment promotes the transformation to α-AlFeSi which is not damaging to the workability of the alloy. When homogenized sample 2A is analyzed, it can be seen that the interdendritic film is significantly changed to a broken configuration, as shown in figure 1C. Also, in this case, the presence of intergranular Mg_2Si particles was observed. A fine precipitation can also be seen within the grains, and these are small Mg_2Si precipitates that form during the cooling from the homogenization temperature.

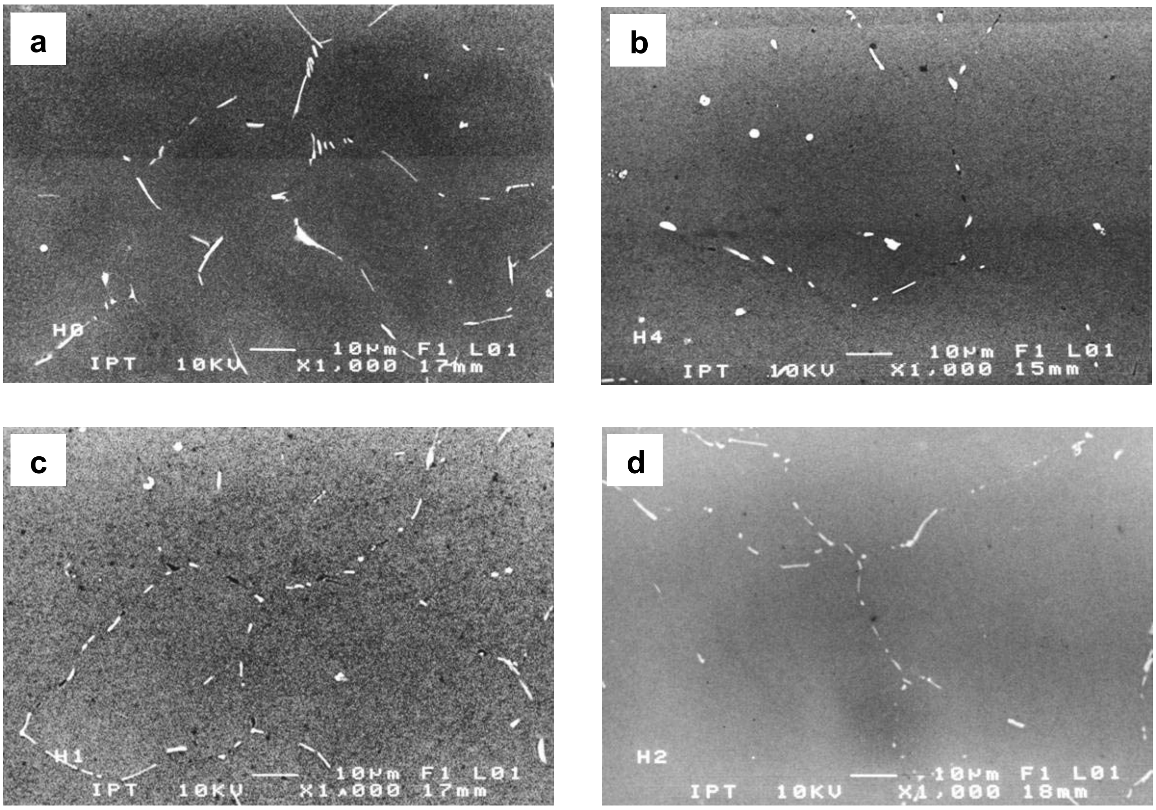

Figure1: Al 6063 micrographs/ SEM of condiitions : (a) BF, (b) 8A, (c) 2A, (d) 2H.

As during homogenization of the alloy there is the transformation of β-AlFeSi to α-AlFeSi, there is a consequent increase in Si into solution in the Al matrix because the ratio of Si to Fe in the particles is decreased when α-AlFeSi is formed. Therefore, the greater availability of Si causes the formation of greater amount of Mg_2Si when homogenization takes place, provided that the cooling from homogenization temperature allows for the formation these precipitates. Thus, when homogenization is applied, not only transformation of the AlFeSi particles takes place, but also a consequent increase in volume fraction of Mg_2Si occurs.

When the time of homogenization was increased to 8 hours, the effect of spheroidization of the α-AlFeSi particles was evident, as observed in figure 1B. Also, the presence of intergranular Mg_2Si could still be noticed. With extended homogenization time there was a noticeable change in morphology of the interdendritic AlFeSi particles, as longer times of heat treatment causes the spheroidization of the α particles.

The effects of increasing the cooling rate from the homogenization temperature can be observed in figure 1D, where sample 2H, that was water quenched after homogenization, is shown. In this case the intergranular α-AlFeSi is shown to present similar features as for the condition 2A, being the network somewhat broken and discontinuous, in comparison with the as-cast condition. The presence of Mg_2Si, however, was not detected in this sample, as water quenching prevents precipitation of Mg_2Si during cooling. Thus, for this condition of homogenization the Mg (and Si) was kept in solid solution in the Al matrix, and no Mg_2Si was observed.

It also important to note that the large particles of Mg_2Si were always found intergranularly for all conditions except for the sample 2H, and such particles were frequently formed at or close to AlFeSi intermetallics.

Analysis of these samples using X-ray diffraction was done and results could confirm the characterization of phases done with the SEM/EDS and revealed that the β-AlFeSi phase was totally transformed to α-AlFeSi for all homogenization conditions, independently of cooling condition or time of homogenization. The detection of the β-AlFeSi was only present for the as-cast conditions, while for all other conditions only α-AlFeSi was found. These findings are in accordance with literature [8, 9] that points out the accelerating effect of low levels of alloying with Mn (0.04 wt%) on the kinetics of transformation of β to α-AlFeSi. Indeed, when the Mn content is higher than 0.04% the time necessary for complete transformation of β-AlFeSi is around 1 hour at 580°C. Therefore, the transformation from the monoclinic β-Al_5FeSi phase to the hexagonal α-Al_8Fe_2Si phase is supposed to have occurred to completion for all samples homogenized shown in the present paper. Due to the low volume fractions (and relative small size) of the Mg_2Si particles, they could be detected via X-ray diffraction of the material studied here, although their presence could be detected from the microstructural SEM/EDS studies.

Tensile tests were carried out so that hot ductility could be assessed relatively to the homogenization condition used: BF, 2A, 2H and 8A. Such homogenization conditions produced very different microstructures in terms of second phase particle distribution (and also of in terms of solute content in the matrix) as previously shown in figure 1. Before presenting the results of the hot tensile tests, it is interesting to point out that DCS analysis on these samples indicated melting (solidus) temperatures of 673, 676, 673 and 676°C were found for conditions BF, 2A, 2H and 8A, respectively.

Figure 2 shows the results of hot ductility in graphs relating reduction in area of fractured specimens as a function of testing temperature. Temperatures were chosen to cover typical range of hot working for the alloy studied and the initial strain rate was 0.83 s^{-1}, which is also of interest for hot working processes. These results show that hot ductility of this alloy is very high in temperatures up to 550°C. For higher temperatures there is a continuous decrease in ductility for all conditions. However, the material that was homogenized (2A, 2H and 8A) presented similar behavior showing gains in relation to the as-cast material for all testing temperatures. A more detailed analysis of the results can indicate that the as-cast material presented a sharp decrease in ductility when testing temperature was greater than 510°C, whereas for the samples which have undergone homogenization treatment the decrease in ductility only took place for temperatures higher than 550°C. Also the decrease in reduction of area of sample BF is more pronounced than those for samples 2A, 2H and 8A, and when testing temperature was of 575°C, sample BF presented no ductility (reduction in area and elongation were negligible), while homogenized samples presented reductions in area of around 55%. Thus, results have shown that the use of homogenization heat treatment caused the increase in the overall level of ductility and also resulted in a less pronounced decrease in ductility when testing was done at higher temperatures (above 510°C). It is important to remember that all homogenized samples have shown enhanced ductility in comparison to the as-cast sample. As the full transformation from β-AlFeSi to α-AlFeSi must have occurred, one can conclude that this is the most important transformation if better workability is to be achieved.

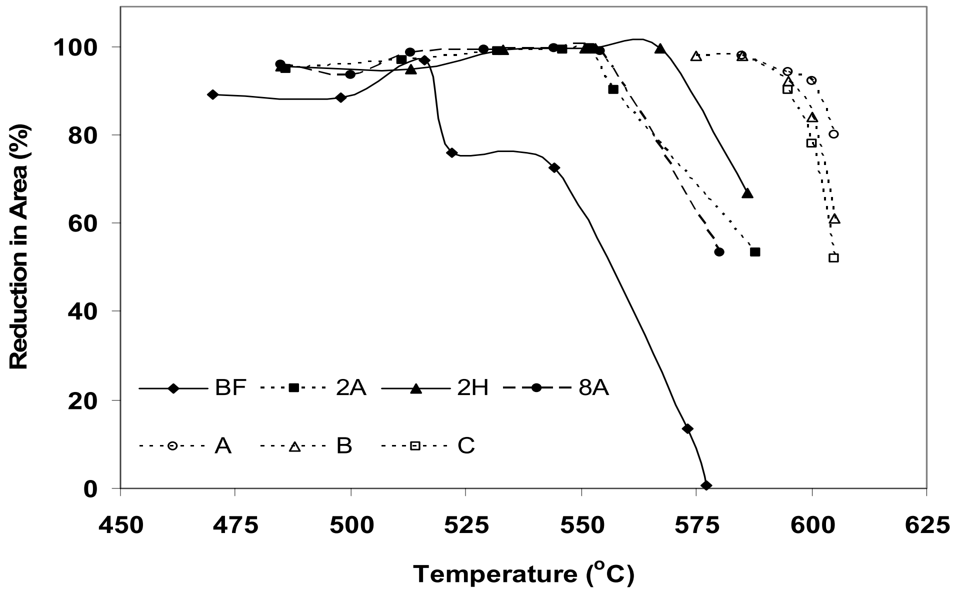

Figure 2: Results of hot tensile tests: BF, 2A, 2H and 8A from present work; A, B and C from references [8, 9].

Apparently, this transformation is more important than other changes such as the spheroidization of the α phase or the dissolution of Mg in the Al matrix.
By analyzing in more detail the results of figure 2, the abrupt drop in ductility when test was carried out at higher temperatures (higher than 510°C) must be a consequence of incipient melting of intergranular eutectic phases located in grain boundaries. It is known that for Al-Mg-Si alloys there are several possible low temperature reactions involving β-AlFeSi and/or Mg_2Si and/or Si phases:

Al + Mg2Si → Liquid; at 587-590°C
Al + Mg2Si + Si → Liquid; at 550-550°C
Al + β-AlFeSi + Si → Liquid; at 578°C
Al + Mg2Si + β-AlFeSi → Liquid + α-AlFeSi; at 576-578°C

In the present case α-AlFeSi particles were present in the homogenized conditions and β-AlFeSi in the as cast condition. As the fastest and most abrupt drop in ductility took place for the as-cast material, then it can be concluded that the presence of β-AlFeSi phase is causing the deleterious effect during hot tensile testing. It is interesting to point out, however, that the homogenized samples also presented a decrease in hot ductility at temperatures higher than 570-580°C, and as these samples had not β-AlFeSi in their microstructures the decrease in ductility can only be attributed to the presence of the Mg_2Si particles, which were present in the microstructures and that could not be dissolved during the rapid re-heating prior to the hot tensile tests. Other studies [10] have shown that when re-heating was slow, and therefore dissolution of Mg_2Si could take place, then high hot ductility could be preserved high, up to temperatures of 650°C. Thus, it can be proposed that when α-AlFeSi particles are present after homogenization, still, the presence of Mg_2Si can be deleterious to the hot ductility as it can undergo low temperature eutectic reactions during hot deformation. The fact that sample 2H presented the best ductility results emphasize the prejudicial effect of Mg_2Si on the hot workability, as this sample was water quenched after homogenization, and therefore no Mg_2Si precipitation could take place during cooling from homogenizing temperature. The detrimental effect associated to Mg_2Si in hot extrusion has recently been reported, and it is shown that tearing defect in extrudates could be associated with intergranular fracture occurring close to Mg_2Si particles [11]. Such an effect due to Mg_2Si is also likely to occur for as-cast material in which large primary Mg_2Si particles are always present.

In figure 2, results presented in this work are compared with results from literature [8, 9] which were obtained from hot tensile tests at the temperature range of 550 to 605°C for homogenized samples of three variations of alloy 6063, using a nominal strain rate of 10 s^{-1}. In these experiments, the reheating rate of samples was such that dissolution of Mg_2Si could be fully attained prior to testing. In these samples [8, 9] the incipient melting of β-AlFeSi was the predominant cause for the decrease in hot ductility, and as the eutectic reaction involving β-AlFeSi phase occur at temperatures around 578°C, the sharp drop in ductility in these samples occurred for higher temperatures than those for the homogenized material studied in the present work, in which the predominant reaction for incipient melting involves Mg_2Si at lower temperatures (550-560°C).

4. Conclusions

Synthetically, the results obtained have shown that: a) β-AlFeSi particles are very detrimental to hot ductility of alloy 6063; b) homogenization effectively increases the hot ductility by causing an efficient (complete) transformation from β-AlFeSi to α-AlFeSi phase; c) the distribution of such α particles (their size and rounded shape) and the effect of Mg in solid solution caused no evident change in the hot ductility; d) when there id the complete transformation to α-AlFeSi during homogenization, the ductility can still be negatively influenced by incipient melting reactions involving Mg_2Si particles. From the results presented above, the best hot ductility would occur if during homogenization all β-AlFeSi could be transformed to α AlFeSi and no Mg_2Si would be present in the microstructure of the alloy during hot deformation (this can be achieved by controlled fast cooling after homogenization).

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