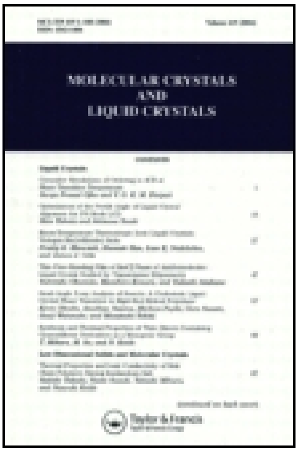

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A New Concept Concerning Phase Transformation to Establish a Good Compromise Between Formability and Mechanical Strength in Aluminium Alloys

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A New Concept Concerning Phase Transformation to Establish a Good Compromise Between Formability and Mechanical Strength in Aluminium Alloys

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Abstract: The formability and mechanical strength are properties, which have a contrary behavior. When the mechanical strength increases the formability decreases, simultaneously. In Al-Fe-Mn alloy system, it has been shown that these concepts are not necessarily true, so a good compromise between these properties could be obtained. Different aspects of phase transformation could be taken into account to explain these anomalous mechanical behavior: kinetic behaviour, diffusion mechanism and mainly, the matrix / particles orientation relationship. Results showed that during heat treatments, the precipitation of AlFe phase leads to a softer decrease in mechanical properties while the formability increases.

Keywords: high formability in Al alloys; formability & mechanical strength; phase transformation.

I. INTRODUCTION

The formability has been investigated by different authors in the Al-Fe-Mn alloys. The relationship between the microstructure and the mechanical properties has been described on the basis of its fine grain size and its hardening ability and texture in the sheet [1-8]. Early studies suggested that, during phase transformation, an orientation relationship between particles and matrix is established to reduce the internal deformation previously produced on the twin-roll casting [3]. In consequence, the lattice parameter decreases as a function of time. Traditionally, the precipitation is followed by an increase in the hardness and a decrease in the ductility. In this alloy system, segregation produces the AlFe particles which lead the aluminium matrix to decrease its hardening. At higher temperatures, while the time of decomposition increases, producing the precipitation, the yield strength decreases and the plastic flow could begin earlier. Nevertheless, if the time of heat treatment prolongs more, the particles could grow and engage the plastic deformation. In this alloy system, the mechanical behaviour can be justified considering both the size of particles and the atomic arrangement of AlFe phase.

II. ALLOY AND EXPERIMENTAL METHODS

A commercial AA 8023 aluminium alloy was decomposed in different conditions to study the kinetics and morphological aspects of the phase transformation to explain the mechanical behavior. After a previous DSC evaluation (slope of 5°C/min), samples of sheet of 5.15 mm thickness, under casting conditions, were heat treated at different temperatures raging from 385 to 510°C. Different times among 3 and 30 hours were investigated during heat treatments. After heat treatments samples were prepared by conventional metallographic techniques. The microstructure of the samples were investigated in a Scanning Electron Microscope (SEM) equipped with an Energy Dispersive x-ray Analyzer (EDS). For x-ray study, a copper target (CuKα ; λ=1.5405Å) was used to obtain the x-ray diffraction patterns, allowing the measurement of the lattice parameters and establishing some aspects of kinetic decomposition. Hardness measurements were made in heat treated simples, in matrix and particles, to correlate their mechanical properties. Tensile tests were made in heat treated samples following ASTM E58-89B standard in order to establish the relationship between the mechanical properties and the microstructure, realizing the mechanism which contributes more to formability or mechanical strength in aluminium alloys.

III. RESULTS

The as-roll cast microstructure is a supersaturated aluminium solution. The heat treatments were made at different times and temperatures to study the microstructural evolution. The results showed that the as-roll cast microstructure decomposes in different ways depending upon the temperature range. A double kinetic was observed during decomposition. At lower temperature, the diffusion is weak and inefficient to modify the as-cast dendritic structure. Earlier results showed that when the temperature is lower than 420°C, the microsegregation increases smoothly after long interval of time (fig.1). Chemical microanalysis data obtained by EDS, showed that in this temperature range, the solute rejection decreased, consequently softening the interdendritic segregation. At higher temperature, the dendritic cell structure becomes a Fe-rich particle structure, which could also be associated as an AlFe phase [1,3].

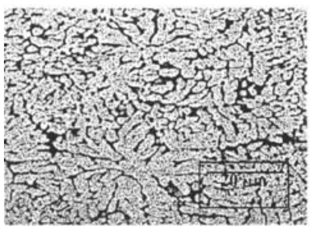

FIGURE 1. Microstructure of sample heat-treated for fifty hours at 250°C.

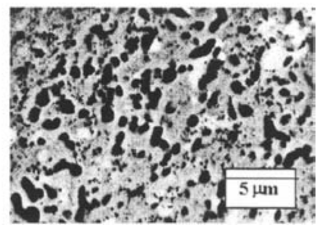

FIGURE 2. Microstructure of sample heat-treated for twenty-four hours at 495°C.

In the beginning of the decomposition at 495°C, the microsegregations of manganese and iron, mainly, produces a fine and dispersed precipitation on the interdendritic zones, having a non-discernible morphology. The precipitation is followed by coarsening and growth. So after twenty-four hours the fine precipitates become particles of Fe-rich or AlFe as observed in figure 2. Microhardness measurements (HK-500g) were made to correlate the individual mechanical properties in the simples heat-treated for twenty-four hours. The results obtained were 155 ± 5 HK for matrix and 162 ± 3 HKfor precipitates (particles of AlFe).

Chemical microanalysis in EDS associated with x-ray diffraction patterns showed that decrease of the lattice parameter could be correlated with the sequence segregation- short range ordering, produced during nucleation and growth of the AlFe phase. Microstructural evolution is always followed by the changes in the mechanical behaviour. Mechanical properties were determined in samples heat treated in different conditions of time and temperature.

The results relating to the uniaxial tensile data plotted against time and heat treatment temperature are shown in figures 3 and 4. Three temperatures of heat treatments relating to the times of three, six and eighteen hours were investigated in this study. It is observed (fig. 3) that the yield strength decreases from three up to eighteen hours for all temperatures of heat treatments.

For lower temperatures (420<T<480°C), the yield strength presents a soft decrease, reaching an asymptotic value near eighteen hours. For higher temperatures (T>480°C), the yield strength decreases continuosly up to eighteen hours. The values of elongation are very different for samples heat treated during three hours at different temperatures (fig 4). After three hours, the elongation increases only for samples heat treated at 480°C. For samples heat treated at 495°C, after three hours, a decrease in elongation followed by a soft improvement up to eighteen hours are observed. For sample heat treated at 510°C, a decrease in elongation is observed between 3 and 18 hours.

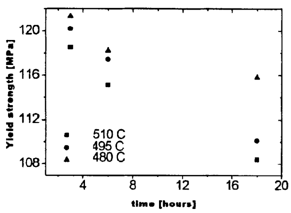

FIGURE 3. Yield strength plotted against time and heat treatment temperature.

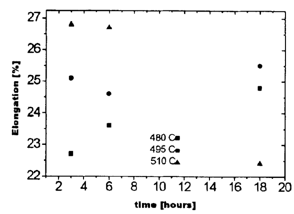

FIGURE 4. Elongation plotted against time and heat treatment temperature.

IV. DISCUSSION

The decomposition can produce either microsegregation on the interdendritic zones without modifying the dendritic structure or to form a particle structure, depending upon the temperature range. These results suggest that different mechanisms of diffusion are produced in two temperature bands, characterizing a double kinetic. At higher temperatures (T>420°C), where the diffusion effects are more intensive the solute is rejected from the dendritic arms to the interdendritic zones [3]. During decomposition, most of the manganese remains in the solid solution. Nevertheless, it is accepted that a few amount of segregated manganese aids the nucleation of AlFe particles [9]. An atom of manganese can eventually replace another atom of iron in AlFe lattice. Following Gray *et al.*[9] the manganese content is important to correct the shape of the AlFe particles, such as observed in an AA 3000 aluminium alloy. At lower temperatures (T<420°C), the diffusion effects are less intensive and the microsegregation is reduced, so the particle structures can not be shaped. At this temperature range, only the segregation content increases smoothly on the interdendritic zones.

The x-ray diffraction patterns showed only streaks relating to the aluminium matrix [3]. It was not able to show neither equilibrium nor transient phases. If the equilibrium phases such as Al_6Mn and $FeAl_3$ do not appear in long times is probably due to the manufacturing condition. The rapid solidification aided by the stabilizer microstrutures assures a metastable condition and hampers the appearance of these phases in times less than twenty four hours. This is in agreement with Moris *et al.* [1] and Rodrigues *et al.* [2] who did not find the intermetallic phases in similar solidification condition in equivalent alloy system.

The decrease of the interplane spacings and the atomic relationship between Al and Fe suggest that an ordering of short range is necessary to form the Fe-rich or AlFe phase. After x-ray measurements and considering the other results, the unique configuration possible for that phase is shown in the figure 5.

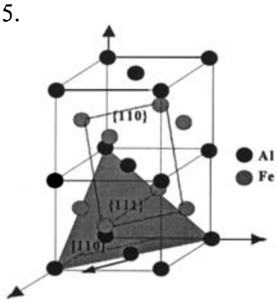

FIGURE 5 - Lattice of AlFe phase showing an Al/Fe atomic relationship.

The ordering of short range could be explained as follows: During decomposition, the aluminium matrix reduces its lattice parameter up to $\mathbf{a}_{Al}$ = 3.9785 Å to shelter inside it a body-centered tetragonal lattice where the lattice parameters must be $\mathbf{a}_{AlFe}$ = 2.8132 Å and $\mathbf{c}_{AlFe}$= 3.9785 Å. Considering the superlattice, as proposed, the orientation relationships are $[110]_{Al}$ // $[100]_{AlFe}$ and $\{111\}_{Al}$ // $\{110\}_{AlFe}$ as represented in figure 5. This ordering of short range is very important to formability and can improve the mechanical properties. While the time of decomposition increases, the yield strength decreases and the plastic flow can begin earlier. Nevertheless, if the time of heat treatment prolongs more, the particles can grow and the elongation reduces during decomposition. At higher temperature (495° C) the particles of AlFe can grow significantly so the elongation decreases while the time increases up to eighteen hours. On the other hand, at 480° C the particles of the AlFe phase are not able to grow and hinder the plastic deformation, so the elongation increases continuously during the decomposition. In this alloy system, the mechanical behaviour can be justified considering both the size of particles and the atomic arrangement of AlFe phase, such as proposed in figure 5. So it is easy to accept that in the first instance of decomposition, the elongation is larger for samples heat treated at higher temperature. In this condition, the matrix is less saturated of Fe and Mn but the AlFe particles do not grow yet to engage the plastic deformation.

V. CONCLUSION

The microstructural evolution of the AA 8023 aluminium alloy is strongly conditioned by the temperature of decomposition. During the heat treatments, only an intermediary phase AlFe is observed after long times of heat treatments. A double kinetic is observed in this alloy system. At higher temperatures (T>420° C), where the diffusional effects are more intensive, the microsegregation increases and the core nucleated on the interdendritric zones coarsens to form the AlFe globular particles after a long interval of time. At lower temperatures (T<420°C), the diffusion is weak and inefficient to modify the as-cast dendritic structure. Mechanical behaviour is conditioned by the segregation of Mn and Fe and nucleation of the AlFe phase. For short times of heat treatments, the size of AlFe phase is small so the elongation can be greater for samples heat treated at higher temperatures, where the matrix is less saturated. Nevertheless, for longer periods of heat treatments at high temperatures, particles of AlFe phase can grow and engage the formability.

ACKNOWLEDGMENTS

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