Effect of Ti Addition and Mechanical Alloying on Mechanical Properties of an AA7050 Extruded Aluminium Alloy

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Keywords: mechanical alloying, extrusion, aluminium alloy, Ti, dispersion hardening.

Abstract: Aluminium alloys are the major materials used in the aeronautic sector that continuously claims for improvement in properties. This improvement has been obtained by modification of chemical composition, strict control of processes, development of new processing routes (mechanical alloying, rapid solidification, severe plastic deformation). In this work, powder of an aluminium alloy based on commercial AA7050 was produced by mechanical alloying with titanium addition with the aim to produce a dispersion-hardened alloy by Al₃Ti particles. Mechanical alloying, in the same process conditions used to produce the dispersion-hardened alloy, was also utilised to obtain a reference powder of the AA7050 aluminium alloy without titanium addition. The mechanically alloyed precursor powders were hot extruded and the consolidated samples were characterised by tensile testing. The microstructure was characterised by electron microscopy. Results of both materials were compared to infer the effect of Ti addition and particle dispersion on mechanical properties. The effect of mechanical alloying on properties of the AA7050 alloy was assessed comparing experimental results with the mechanical properties of the commercial alloy obtained from literature.

Introduction

Aluminium alloys are the major materials used in the aeronautic sector that continuously claims for improvement in properties as strength, toughness, corrosion resistance and density. Property improvement of aluminium alloys has been obtained by modification of chemical composition and strict control of processes, besides development of new processing routes, as rapid solidification and mechanical alloying [1,2].

Structural applications at high or moderate temperatures require aluminium alloys that are dispersion hardened by a fine and homogeneous distribution of particles, which are stable until the temperatures of use. Intermetallic phases of high melting point formed by elements presenting low solid solubility and low diffusivity in aluminium, such as the transition metals, comply with these requisites. Al₃Ti is very attractive among all intermetallics, because it has a high melting point (~1350°C) and relative low density (~3.3g/cm³)[3]. Particle dispersion can be obtained by conventional ingot metallurgy, by mixing the dispersoids to the cast matrix alloy or by in situ formation of the intermetallic phase by adequate addition alloying [4,5].
However, problems as formation of coarse intermetallic particles and segregation during the ingot solidification, usually take place. These problems can be overcome by using the powder metallurgy and more specifically the mechanical alloying as processing route [3, 6-8]. Mechanical alloying is a solid-state process that permits refining of the microstructure, homogenisation and extension of solid solubility [9,10]. The possibility of higher solubility could be interesting to enhance precipitation of equilibrium phases in the heat treatable aluminium alloys.

Among all aluminium alloys with application in the aircraft industry, the highest strength alloys are those of 7xxx series. In this work, a commercial AA7050 based aluminium alloy was chosen to be produced by mechanical alloying with titanium addition with the aim to produce a dispersion-hardened alloy by Al3Ti particles. Mechanical alloying, in the same process conditions used to produce the dispersion-hardened alloy, was also utilised to obtain a reference powder of the AA7050 aluminium alloy without titanium addition. The precursor powders produced by mechanical alloying were hot extruded and the consolidated samples in the as extruded condition were characterised. Results of both materials were compared to infer the effect of Ti addition and particle dispersion on mechanical properties. Comparing experimental results with literature values of mechanical properties of the commercial alloy assessed the effect of mechanical alloying on properties of the AA7050 alloy.

Experimental procedure

Powder of an AA7050 based alloy with nominal composition Al -2,4 Cu - 2,4 Mg - 6,2 Zn (weight %) with addition of 1 wt % titanium was produced by mechanical alloying with a milling time of 100 h. The same alloy at the same milling conditions was produced without titanium addition. Further information about powder production was reported elsewhere [11]. The precursor powders were consolidated by hot extrusion at 400°C in a horizontal press with an extrusion ratio of 37:1 and extrusion rate of 0,3 mm/s. Samples in the as extruded condition were characterised by scanning and transmission electron microscopy. Mechanical properties were determined by tensile tests using an Instron testing machine at a strain rate of 6,7 x 10^{-4} s^{-1}. The tensile specimens, machined parallel to the longitudinal axes of extruded bars, were of gauge length 25 mm and diameter 5 mm.

Results and Discussion

The extrusion of the AA7050 mechanically alloyed powders, with and without Ti addition, resulted in high quality bulk bars as shown in Figure 1 where no evidence of the primary powder particles or porosity can be seen. SEM observations show also no evident differences in the microstructure of samples of the AA7050 alloy with and without Ti addition. Besides precipitates of different sizes, some holes can be seen that could have been left by particles that probably were torn off during the sample preparation.

Figure 2 shows the fine grain size of extruded alloy, ranging from 200 to 500 nm, and the presence of precipitates of different sizes and shapes. The rod-like precipitates although could not be identified by electron diffraction, are suggested to be η or η’ phase (MgZn2), responsible for precipitation hardening of these aluminium alloys. The coarser particles
showed in Figure 2c could not be identified by electron diffraction, as they were very thick. EDS analysis showed that they were composed by Al and Ti, what suggests that these particles are Al₃Ti phase.

Figure 1. SEM micrographs of the AA7050 alloy extruded at 400°C (a) without Ti addition, (b) with 1% Ti addition.

Tensile tests results obtained from extruded bars are showed in table 1 as well as the minimal specified values for commercial AA7050 alloy in the T76 condition. Comparing the values of mechanical properties of commercial AA7050 aluminium alloy obtained from literature with experimental results obtained by tensile tests of mechanically alloyed and extruded samples shows that the milling process increases both yield and ultimate strength. The increase in strength due to mechanical alloying process can be explained by structural changes that the milling produces as refining grain size to nanometer scale and increase in defects density especially dislocations density. Ti addition increased still more the strength of
the mechanically alloyed aluminium alloy and had a pronounced effect on elastic modulus, as shown in table 1. These results are due to the formation of Al₃Ti particles, a hard intermetallic phase with high modulus that additionally originates the dispersion hardening effect. It is valuable to note that the values of mechanical properties for commercial alloy were obtained from heat-treated alloys to T76 condition, an overaging state. In this way, for a better understanding of effects of process and alloying addition, heat treatments must be effectuated in these alloys, that is a matter for a next work.

![Microstructures by TEM of AA7050 –1% Ti alloy extruded at 400°C](image)

Figure 2. Microstructures by TEM of AA7050 –1% Ti alloy extruded at 400°C

<table>
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<tr>
<th>Table I. Tensile properties of AA7050 aluminium alloy, with and without 1% Ti addition, obtained by hot extrusion of mechanically alloyed powders, and 7050 T7 commercial alloy</th>
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<td>Elastic Modulus (GPa)</td>
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<td>As extruded mechanically alloyed AA7050 – 1% Ti alloy</td>
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<td>As extruded mechanically alloyed AA7050</td>
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<td>*Commercial 7050 T76 alloy</td>
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* Minimal value specified according to SAE-AMS 4340
Conclusions

Mechanical alloying of an aluminium alloy based on commercial AA7050 increased the mechanical properties when compared to the commercial one due to strengthening mechanisms resulting from the milling such as grain size refinement to nanometric scale and increase in dislocation density due to severe deformation caused by the process. The addition of titanium produced additional increase in strength in the mechanically alloyed and extruded sample due to the Al3Ti formation that added another strengthening mechanism: the dispersion hardening. The formation of Al3Ti phase also had a pronounced effect on the elastic modulus that attained the highest value in this alloy.

Acknowledgements

The authors acknowledge Alcoa for the aluminium powder, and the financial support by FAPESP and CNPq under projects 00/05353-9 and 490111/2003-3, respectively, and the Scientific Cooperation Programme of the Spanish Ministry for Education and Culture and MAT2003-00722.

References