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Microstructural Evolution and Strengthening Mechanisms in a 2xxx Series Modified Al Alloy.

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The 2xxx Al series (Al-Cu-Mg) is widely used for the aircraft and aerospace industry, it has low density and presents excellent mechanical properties such as high fracture toughness, high tensile strength, and good damage tolerance. Identifying and understanding the strengthening mechanisms of these alloys to improve their strength, is the aim of several research works [1, 2]. At present study is analyzed the microstructure and the microhardness of a 2xxx modified Al alloy to identify the strengthening mechanisms involved.

The modified alloy was produced by conventional casting. Cu and Mg of high purity (and Al-5Ti-B as grain refinement) were added to a 1350 Al alloy to obtain a nominal composition of Al-4Cu-4Mg, the melt was degassed with argon atmosphere for 5 minutes and poured into bar-shaped molds of 4 cm in diameter. The thermo-mechanical process was as follows: first, the bars were hot extruded at 480°C using an extrusion ratio of 16. Later, a solution heat treatment (hereafter SHT) was carried out at 495°C for 7 h continued by a water quenching at room temperature. Finally, the extruded and solution treated samples were plastically deformed by cold-rolling to obtained both, 30% thickness reduction (CR 30%) and 40% thickness reduction (CR 40%). The microstructural characterization was performed by an SEM Hitachi, model SU3500. The mechanical properties were evaluated in terms of Vickers microhardness, the tests were made by a LECO microhardness tester, model LM300AT, using the ASTM standards and a 50 g load. The reported value ($HV_{0.05}$) was the average obtained from 12 indentations. Each indentation was carefully placed in the matrix, avoiding indenting rich-solute areas.

Figure 1 shows the microstructural evolution of the Al-4Cu-4Mg alloy throughout its processing and the distribution of the main alloying elements. In the as-cast condition can be appreciated the typical dendritic grains and an interdendritic region rich in Cu and Mg. The extrusion modified the interdendritic in such a way that it is no longer continuous and is now homogeneously distributed. It appears like the SHT barely dissolved some solute. The cold-rolling processes aligned the rich-solute areas along the rolling direction.
Furthermore, the Mg is more homogeneously distributed into the matrix than Cu in every processing stage, suggesting that is easier for Mg to form a solid solution with Al since both alloying elements are present in the same content.

The microhardness results at the processing stages that were relevant for strengthening the Al-4Cu-4Mg alloy are presented in Figure 2(a). It demonstrates the effectiveness of SHT and cold-rolling to (i) increase the HV value and (ii) to homogenize mechanical properties since the standard deviation decreased. Figure 2(b) shows the contribution to the total hardness that every processing stage had, and the main strengthening mechanisms found: solid solution hardening (SSH) and strain hardening (SH). The microhardness value of 99.99% pure Al in the annealing condition is 27 HV [3], while the microhardness value of Al-4Cu-4Mg alloy in the as-cast condition of the present study was found to be 121 HV. The SSH per alloying increased the hardness by 94 HV. The SHT further increased the hardness by 19 HV. It was much more significant the SSH obtained per alloying than the one obtained per SHT. On the other hand, cold-rolling to 30% thickness reduction increased the hardness by 22 HV, while CR 40% increased it by 33 HV. It can be concluded that the most effective strengthening mechanism for Al-4Cu-4Mg alloy was SSH per alloying, followed by SH per CR 40%, SH per CR 30%, and SSH per SHT.

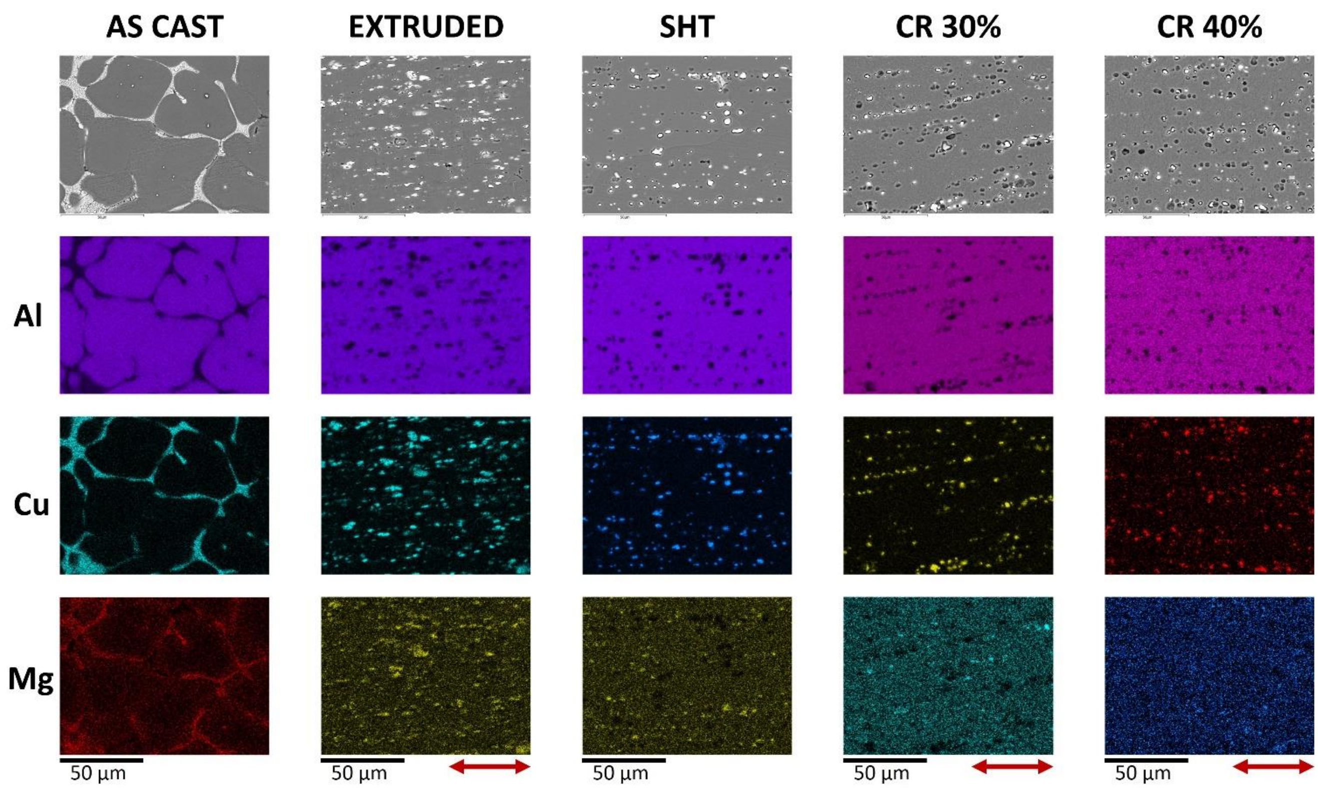

Figure 1. SEM BSE images of the Al-4Cu-4Mg microstructure at each processing stage (from left to right, as cast, extruded, SHT: solution heat-treated, CR 30%: cold-rolled to 30% thickness reduction, CR 40%: cold-rolled to 40% thickness reduction). SEM-EDS elemental mapping images are also included (from top to bottom, Al, Cu, Mg). The red arrows indicate the extrusion and cold-rolling direction.

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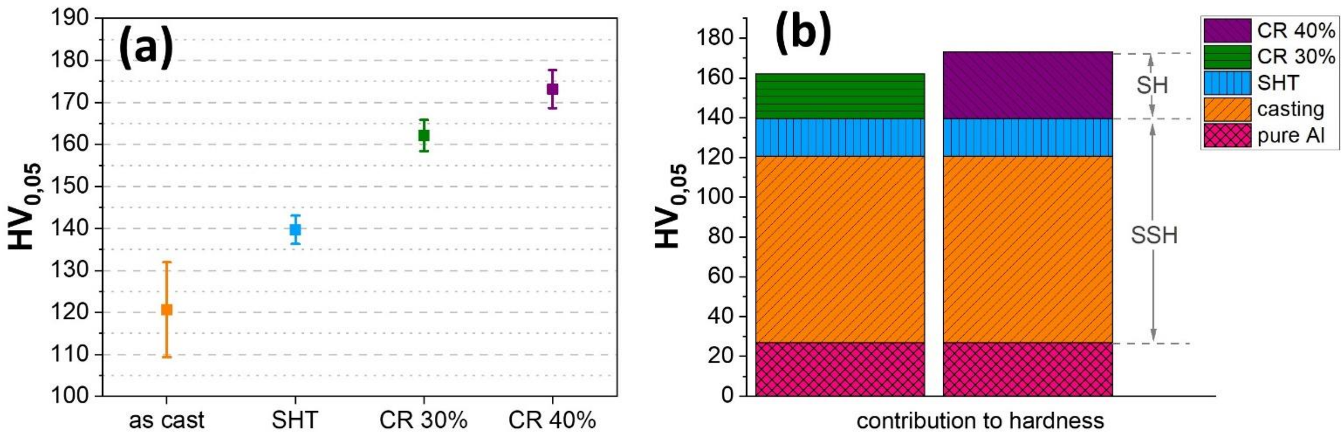

Figure 2. (a) Microhardness Vickers of Al-4Cu-4Mg at each processing stage. (b) Contribution to total hardness of every processing stage and the identified strengthening mechanisms (SH: strain hardening, SSH: solid solution hardening).

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