Towards high strength and high ductility 6XXX and 7XXX aluminium alloys

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In high performance Al alloys, the yield stress rises up to approximately 400 MPa and 500 MPa in the T6 hardest state for the 6XXX series and 7XXX series, respectively. The main limitation is that strengthening of the Al matrix comes at the expense of a lower ductility, i.e. a lower fracture strain.

In sheet bending operations, the limiting condition for formability is fracture and the fracture strain measured in a tensile test is an appropriate indicator of the formability. Bending of high-strength Al plates is thus usually restricted to moderate bend angles at room temperature.

Friction stir processing (FSP) is a severe plastic deformation technique. The rotating tool leads to the formation of a nugget zone, where grain refinement is significant, as well as breakage of large second-phase brittle particles [1]. However, FSP leads to unavoidable softening of the material due to the heat generated during the process, dissolving strengthening precipitates in the matrix and leading to lower yield strength compared to T6 base material. Recent work has highlighted a procedure to restore the T6 hardening precipitation by post-FSP heat treatments on 7475 alloy [2]. Applying FSP and heat treatments on a 6056 and a 7475 alloys, this work aims at reaching higher ductility and thus bending limit at room temperature on (peak) aged conditions.

Cold rolled plates base material (BM) of Al 6056 T4, 2.5 mm thick and Al 7475 T7, 12 mm thick were used. Up to 6 overlapping FSP passes were performed on 6056 alloy while maximum 2 FSP passes are applied on 7475 material. A solution heat treatment (SHT) followed by water quenching and artificial aging (AHT) have been applied on Al 7475 BM and 7475 FSPed. Only artificial ageing (AHT) was applied on both Al 6056 BM and 6056 FSPed. Macro hardness measurements were performed on the base material (BM) and FSPed material (FSPM). For Al 6056, the hardness of as-FSP material was decreased by ≈15% compared to BM in the same aged condition. For 7475 material, the hardness of FSPM + SHT/AHT material is homogeneous and equivalent to SHT/AHT 7475 BM, the T6 hardening precipitates are well restored after the post-FSP heat treatments.

Tensile properties are investigated using 2 mm Ø (6056) and 6 mm Ø (7475) cylindrical specimens taken inside the nugget zone refined microstructure, parallel to the processing direction. FSP increases the fracture strain of 6056 alloy by 100% (from BM + AHT to 6 passes FSP + AHT), while the T6 7475 FSP+SHT/AHT material increases the fracture strain, by 38% and 63% for 1 pass and 2 pass FSP respectively in comparison with the T6 rolled material. This improvement is related to the refinement of the microstructure obtained by multi-pass FSP, delaying the damage mechanisms under loading.

Bending tests were then performed on 2.5 mm thick coupons on both alloys and both BM and FSP microstructures. It was shown that crack initiation occurs systematically at larger punch displacement for the FSP samples and similar maximum bending force (compared to BM) for the 6056 and 7475 Al, following the fracture strain evolution observed on tensile samples.

This work highlights the ductilization potential of age-hardenable aluminium alloys. In both investigated materials, i.e. Al 6056 and Al 7475, significant improvement of the ductility is obtained by the use of FSP and heat treatments. Formability is subsequently increased; the bending tests revealed the exceptional improvement of the bend angle. These results pave the way to even higher performances aluminium alloys by the local microstructural refinement demonstrated in this work.

[1] F. Hannard , S. Castin, E. Maire, R. Mokso, T. Pardoen, A. Simar, Ductilization of aluminium alloy 6056 by friction stir processing, Acta Materialia 130, 2017, 121 - 136
[2] Matthieu B. Lezaack, Aude Simar, Avoiding abnormal grain growth in thick 7XXX aluminium alloy friction stir welds during T6 post heat treatments, under review