

Ductilization of aluminium alloy 6056 by friction stir processing

F. Hannard ^a, T. Pardoen ^a, E. Maire ^b, A. Simar ^a

^a Institute of Mechanics, Materials and Civil Engineering, Université catholique de Louvain,

B-1348 Louvain-la-Neuve, Belgium

^b MATEIS UMR5510, INSA-Lyon, F-69621 Villeurbanne, France

Ductile fracture is characterized by the nucleation of microvoids, followed by stable void growth until neighboring voids starts to coalesce. The accumulation of void linkages leads to the formation of a critically-sized crack that finally propagates into the material and triggers final failure. The main source of damage in Al alloys is the micron-sized iron-rich intermetallic particles present in the alloys due to the inevitable iron content of the bauxite ore. Damage nucleation is caused by the fracture or interface decohesion of these particles.

In a previous study [1], ductile failure of three 6xxx series aluminum alloys (6005A, 6061 and 6056) has been characterized and modelled. It was highlighted that the key element setting the fracture strain in these materials is the effect of particle size distribution and spatial distribution on the void nucleation and coalescence processes. The presence of pre-existing voids has also been shown to have a first order effect on the ductility. The goal of this study is thus to perform friction stir processing (FSP) on plates of Al 6056 (up to six passes) in order to break the large second phase particles into smaller and more resistant fragments, closes the existing initial porosity and homogenize the particle spatial distribution, i.e. reduce clustering of particles. The purpose is to positively impact the three main causes of low ductility in wrought 6xxx series Al alloys.

Cold rolled plates of Al 6056 with a 6 mm thickness and initially in T4 condition were used for this study. Up to six overlapping FSP passes were performed with a tool rotation rate of 500 rpm and a traverse speed of 200 mm/min.

X-ray microtomography is performed at the TOMCAT beamline of the Swiss Light Source (voxel size of 160 x 160 x 160 nm³) in order to study the effect of FSP on the microstructure. The microstructural evolution can be summarized as follows [2]: (i) the intermetallic particle size decreases with the number of FSP passes; (ii) initial porosities present in the base material are reduced in size by the increasing number of FSP passes; (iii) FSP homogenizes the particle distribution and this has been demonstrated quantitatively by the tessellation method, a clustering analysis and pair correlation functions.

Tensile testing and interrupted tensile tests of the base material and FSPed samples have revealed the following: (i) The fracture strain of FSP samples is improved up to 90% in best case compared to the base material tensile samples presenting the same yield strength. (ii) The nucleation stress for the fracture of intermetallic particles (i.e. the source of damage in these alloys) is increased in the FSP samples. (iii) Friction stir processing is shown to render isotropy in fracture strain.

In situ tensile tests in X-ray microtomography (voxel size of $0.6 \times 0.6 \times 0.6 \mu\text{m}^3$) have been performed on the base material (BM) and in the FSPed material in order to quantitatively characterize the evolution of the damage process. X-ray microtomography images of these specimens, just before fracture, are shown in Figure 1. It is clear that the ductility of the FSPed specimen is increased compared to the base material.

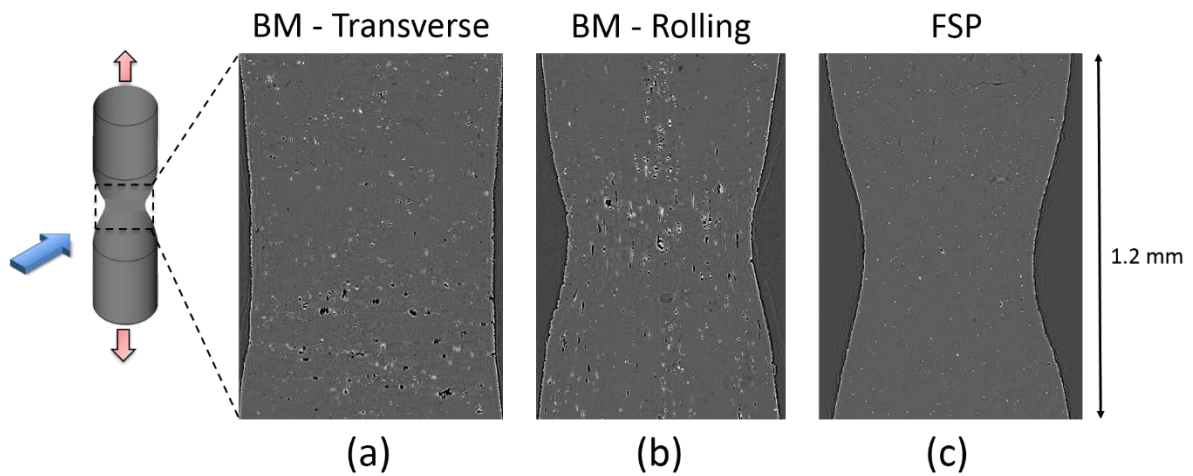


Figure 1. X-ray microtomography reconstructed images, just before fracture, of the tensile test performed on (a) the base material loaded in the transverse direction, (b) the base material loaded in the rolling direction and (c) the FSPed material. Voids are in black and IM particles are in white.

[1] F. Hannard, T. Pardoën, E. Maire, C. Le Bourlot, R. Mokso, A. Simar, *Acta Mater.*, 2016, 103, 558-572.

[2] F. Hannard, S. Castin, E. Maire, R. Mokso, T. Pardoën, A. Simar, *Acta Mater.*, 2017, 130, 121-136.