

On the mechanical behaviour of SLM AlSi10Mg and its improvement by friction stir processing

Juan Guillermo Santos Macías, Jean-Yves Buffière, Eric Maire, Jérôme Adrien, Chola Elangeswaran, Antonio Cutolo, Brecht Van Hooreweder, Frédéric Lani, Pascal Jacques, Aude Simar

Great expectations have been placed in the additive manufacturing (AM) technologies, coming from countless different sectors and fields. Potential applications are very diverse, in part due to the flexibility the technique offers.

When aiming at high performance mechanical properties for structural applications, metals are frequently the best if not the only available option. In the transport industries AM of lightweight metal alloys is therefore attractive for structural parts manufacturing. Nevertheless, there are some aspects of mechanical behaviour of AM metal parts that are hindering their industrial implementation. Anisotropy and heterogeneities, porosity, surface quality, reproducibility, etc. are problems that frequently occur regardless of the AM technique or the metal alloy used. Other issues can be more serious depending on the method, like residual stresses, which are more significant in selective laser melting (SLM), the most popular metal AM technique, than in e.g. electron beam melting (EBM).

In applications where good mechanical properties, especially good fatigue resistance, are sought, the anisotropy and heterogeneities, porosity, surface quality and residual stresses issues can become critical. A representative example could be SLM AlSi10Mg, the most used AM Al-alloy. Despite its static mechanical strength well above the cast reference owing to its very fine microstructure typical of SLM high cooling rates, both ductility and fatigue resistance are fairly low and exhibit anisotropy. These issues are directly linked to microstructural defects (inhomogeneities, porosities and Fe-rich intermetallics, some of them significantly larger than the α -Al+Si-rich eutectic microstructure).

Considering the phenomena behind this underperformance, a good way to improve mechanical behaviour of SLM AlSi10Mg parts could be to perform friction stir processing as a post-processing technique. This method derives from friction stir welding and consists in introducing a rotating tool composed of a shoulder with a pin at the tip into the part to treat, traversing the desired area of the part in order to produce at the same time severe plastic deformation, a forging and a thermomechanical effect on the material. The benefits of FSP in cast parts are proven and include microstructure refinement, homogenization and porosity elimination, resulting in significantly enhanced ductility and fatigue resistance.

The application of FSP on SLM AlSi10Mg plates has yielded homogenization, porosity elimination, Fe-rich intermetallic particles breakage and redistribution, all the while little affecting the initial fine microstructure. This has been analysed through imaging techniques, including SEM and X-ray (laboratory and synchrotron) microtomography, the latter allowing for 3D porosity studies.

Static mechanical testing has shown the significant 400% ductility improvement brought about by FSP. Fatigue testing has also yielded promising fatigue life behaviour improvement after FSP. In situ tensile and ex situ fatigue testing performed in the synchrotron X-ray facilities of the ESRF (Grenoble) have allowed to study monotonic and cyclic damage mechanisms in the bulk of AlSi10Mg samples to understand the changes introduced by FSP and their impact on the mechanical behaviour.