Additive Manufactured Metallic Compliant Mechanisms and Flexible Structures

H. Saudan, L. Kiener, E. Dominé, K. Vaideeswaran, Y. Zangui, M. Dadras

With its highly promising technology, the application of additive manufacturing (AM) processes for space applications is a constantly growing topic of interest among the main actors in the space industry. While most of the research and development work performed presently is focused on reproducing and optimizing designs of what could be described as "structural or massive parts", little work related to the manufacturing of thin, flexible structures has been published up to now. CSEM is developing a production method based on AM-SLM (selective laser melting) to be applied to the development of its FLEXTEC (flexure structure technology)-based precision mechanisms, a core competency of CSEM that has been widely used in the past 30 years in the framework of space, the watch industry, and scientific instrumentation projects.

FLEXTEC-based mechanisms, also known as compliant mechanisms, can achieve macroscopic linear or rotary motion without friction, wear, or backlash and with extremely high fatigue performances thanks to the elastic deformation of flexible structures arranged in a special manner. In spacecraft, they cover various functions such as launch locking, linear or rotary scanning for ultra-high precision optical instruments, pointing mechanisms for antennas, and more. A notable example is CSEM's corner cube mechanism flying onboard the MetOp satellites, with more than 700 million cycles to date.

Up to now, the complexity of compliant structures has required highly sophisticated and expensive manufacturing methods, with the gold standard being wire electro-discharge machining from a bulk material block with consecutive large material losses and very long and delicate machining procedures. Today, this paradigm is questioned due to the new possibilities offered by additive manufacturing (AM) technologies.

After showing, in 2014, the feasibility of building an elementary compliant structure made of 316L stainless steel (see Figure 1) with AM-SLM (Selective Laser Melting), CSEM successfully developed – in the framework of an internal research project carried out with the company 3D PRECISION – an end-to-end SLM-based manufacturing and post-processing production method for a high-strength stainless steel chemically comparable to the widely known and used 17-4PH.

Figure 1: 316L stainless steel AM-SLM built linear stage.

The optimization of the SLM process was carried out as an iterative task that consisted of producing test samples through a set of well-defined parameters and analyzing them with the aim of minimizing the porosity and optimizing the microstructure and surface roughness. A last optimization phase was carried out to determine the best thermal post-processing strategy, and the best variant was identified through experimental testing of the mechanical performances of several sample groups.

The tensile testing of the various groups of samples produced highlighted the tremendous improvement associated with the Hot Isostatic Pressing (HIP) treatment, with the conclusion that the SLM built material can offer tensile performances similar to those of a commercial grade 17-4 PH stainless steel. The micrograph fracture analysis confirmed the positive influence of the HIP treatment, as shown by Figure 2.

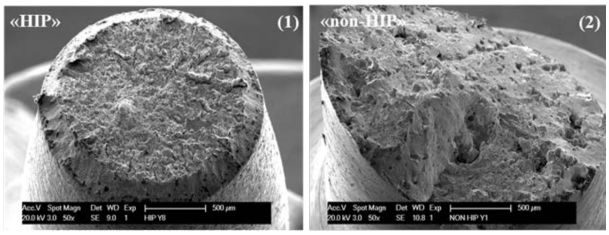

Figure 2: Alternate bending fatigue test results for AM-SLM samples.

The fatigue performances of flexure test samples were investigated in detail through an alternate bending fatigue test campaign covering four different sample groups (the test bench principle is illustrated in Figure 3). The fatigue test data collected helped understand the contribution of key material and surface defects to the final fatigue performances and highlighted the beneficial effect of the HIP treatment on the fatigue performances.

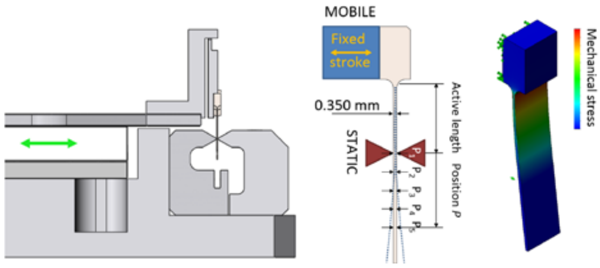

Figure 3: Alternate bending fatigue test principle.

A major conclusion is that despite a 23% loss in fatigue performances observed with respect to flexure elements built from commercial grade material, it is possible to design and produce – provided that a well-adapted sizing, in-depth SLM process mastering, and wise post-processing strategy are used – a compliant structure offering a lifetime of over 15 million cycles. This confirms the high enabling potential of AM-SLM in the domain of FLEXTEC-based precision mechanisms. This potential will be further assessed through a detailed study of the new flexure topologies enabled by SLM. The present work will be presented at the 14th European Conference on Spacecraft Structures, Materials and Environmental Testing.