Measuring Mechanical Properties at the Scale of Watch Components

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Mechanical properties of materials are often considered as size independent. However, once the size of a component gets smaller at some point this assumption does not hold anymore [1]. For example, as the size of a material sample gets smaller, features that had a very little effect at macroscopic scale – grain size relative to the sample size, surface roughness, individual voids, and other defects – start to play an important role and may significantly influence the mechanical properties. The length scale at which the response of most materials becomes size dependent is influenced by several factors (class of material, microstructural factors) but, as a rule of thumb, it becomes significant between one millimeter and several tens of micrometers. This so-called mesoscopic scale lies between the macroscopic and microscopic one corresponding very much to the scale of watch components.

In MEMS, watch components and more general in any component with the characteristic size between several tens of micrometers and one millimeter, the effect of surface quality on mechanical behavior is significant [2]. Defects that are often introduced during the sample preparation, treatment, and handling are disproportionately larger than in the case of macroscopic samples relative to the sample cross-section. Therefore, characterization and understanding of material behavior at mesoscale is crucial for improving the performance of watch and mesoscale components in general.

This problematic has been addressed by ASRH in the framework of a joint industrial project. As a project partner, CSEM promoted the technology transfer and implemented novel and unique characterization capabilities to investigate and improve mechanical properties of materials for mesoscale components. In particular, a mesoscale tensile test bench shown in Figure 1 was developed to characterize Young's modulus, yield strength, ultimate tensile strength, and ductility of mesoscale material samples with cross-sections of 100 µm to few millimeters in the longer axis and applied force from 1 N up to 400 N. Alongside, a mesoscale compression test bench has been developed with similar technical specifications shown in Figure 2.

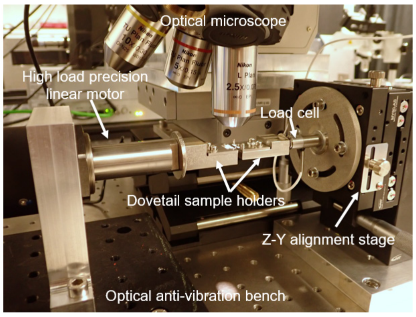

Figure 1: Mesoscale tensile test bench.

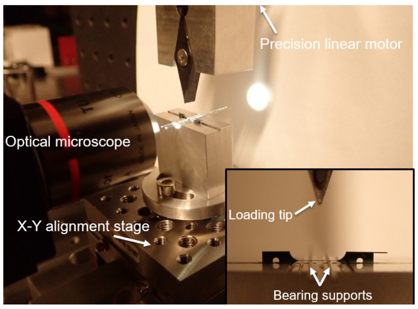

Figure 2: Mesoscale compression test bench in 3-point bending setup.

Both tensile and compression test benches can be precisely aligned using optical microscopes and micrometer precision stages. The set-up is optimized for high throughput testing when large amount of samples has to be tested to obtain statistically relevant data for example in the case of brittle materials. The setups are controlled by custom-made Labview code that enables to perform tests while acquiring optical microscopy images. These images are then used in a Digital Image Correlation (DIC) software to calculate deformation of tested samples thus enabling to construct the whole stress-strain curve.

Figure 3 below shows an example of characterization of a 3D printed stainless steel mesoscale specimen. Each point in the obtained stress-strain curve represents one image taken during the test while image acquisition is being synchronized with the force acquisition. Deformation measurement via image acquisition and DIC has several advantages and is especially well suited for small scale tests as any deformation measurement that requires contact with the tested sample is difficult to implement and may itself influence results.

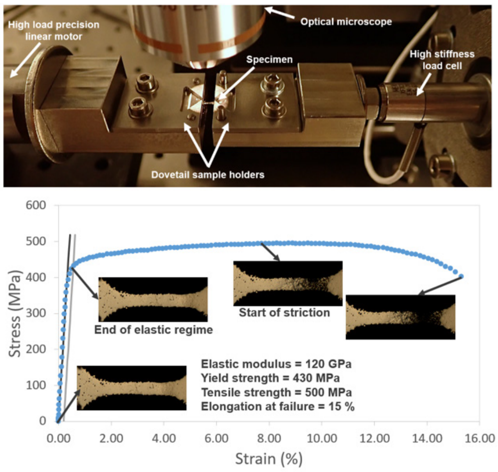

Figure 3: Specimen in the tensile test setup. Images taken during the test using optical microscope are used in DIC to calculate deformations.

Thanks to the novel state-of-the-art characterization capabilities, CSEM is working on understanding the behavior of mesoscale components and improving their performance as the acquired data are used to have a better material selection (*e.g.*, supplier) and better selection of the component manufacturing processes. For example, CSEM is using this platform to develop high-precision 3D printed parts with mesoscale size features as the mechanical behavior of such parts shows significant sensitivity to the process related defects and microstructural features.

[1] J. Krebs, *et al.*, “Cast aluminium single crystals cross the threshold from bulk to size-dependent stochastic plasticity,” Nature Materials, vol. 16, p. 730, May 2017.

[2] J. Prokop, *et al.*, “Mechanical testing of micro samples produced by a novel LIGA related process chain,” Microsystem Technologies, vol. 17, no. 2, pp. 281–288, Feb. 2011.