A multi-purpose, hygro-thermo-mechanical, *in-situ* x-ray CT tester

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Abstract

A compact, light-weight, climate-controlled, high force and displacement resolution, stationary ROI, multiple loading in-situ CT device has been realized that enables advanced hygro-thermo-mechanical experiments with intermittent high-quality CT characterization. The setup's potential has been convincingly demonstrated by performing an *in-situ* CT experiment during the successive creasing, folding and relaxation of cardboard within a climate-controlled environment. The complete process from design considerations, conceptual design, technical realization, implementation, and device validation will be presented at the BSSM conference.

Keywords: In-situ mechanical testing, X-ray computed tomography, Climate control, Variable loading, Stationary ROI, Micro-mechanics

Introduction

X-ray Computed Tomography (CT) is a powerful non-destructive technique used to obtain high-resolution 3D description of samples. In the past decade, a growing interest has arisen in combining CT scanning with mechanical testing. Hence, several in-situ testing devices have been developed, each with their own merits and limitations, see brief literature review in [1]. However, none of them can perform advanced hygro-thermo-mechanical tests on specimens subjected to multiple loading modes, while accurately controlling and measuring the force, displacement, temperature and relative humidity in real time.

Research goals and strategy

To address these challenges, Therefore, a compact, light-weight, climate-controlled, high force and displacement resolution, stationary ROI, multiple loading in-situ CT device has been realised which allows all of the above-mentioned complex experiments. The device is designed to fit the compact design space of lab-scale CT scanners. The conceptual design is based on a comprehensive literature study in which various possible options were discussed [1]. A stationary ROI is realized with a smart planetary gear to convert rotational motion into both up-and downwards translation, see Fig. 1.

Results and discussion

Accurate force and displacement measurements are attained by, respectively, allowing exchangeable load cells and three accurate extensometers (LVDT's) inside. A maximum stroke of 20 mm was realized along with a maximum applied load of 2 kN, allowing testing of a wide variety of materials. A modular clamping method was realized that allows fixation of rectangular and circular samples which require minimal sample geometry adjustments, while additionally, allowing fixation of specific loading modules such as three- and four-point bending clamps. To enable a controlled climate (temperature and relative humidity) around the sample, an external climate box is connected to the sample tube.
Various validation experiments were conducted.[1] CT reconstruction quality was found to be sufficiently high to characterize delamination in cardboard down to the level of individual fibers, which is known to be challenging. Accurate force and displacement measurements are validated by successfully determining the Young's modulus of three brass shafts. Proper climate control inside the sample tube is realized, well within the specified requirements.
The setup's potential is demonstrated by performing the creasing and folding and subsequently relaxation process of cardboard within a climate-controlled environment, see Fig. 2. Three- and four-point bending clamps are used to, respectively, crease and fold cardboard. Each process is performed in multiple increments and intermittent CT scans on the sample are performed. This allowed full 3D characterization of the material, which can directly be linked to the properly captured mechanical response, allowing identification and analysis of micro-mechanical failure modes, in this case plie delamination during the folding process.[1].

Conclusions

All the requirements that were set for the design of the compact, light-weight, in-situ CT device with climate-control, high force resolution and high displacement resolution, stationary ROI, multiple loading configuration have been met. Currently the device is being brought to commercial production to facilitate access to the device for researchers worldwide.

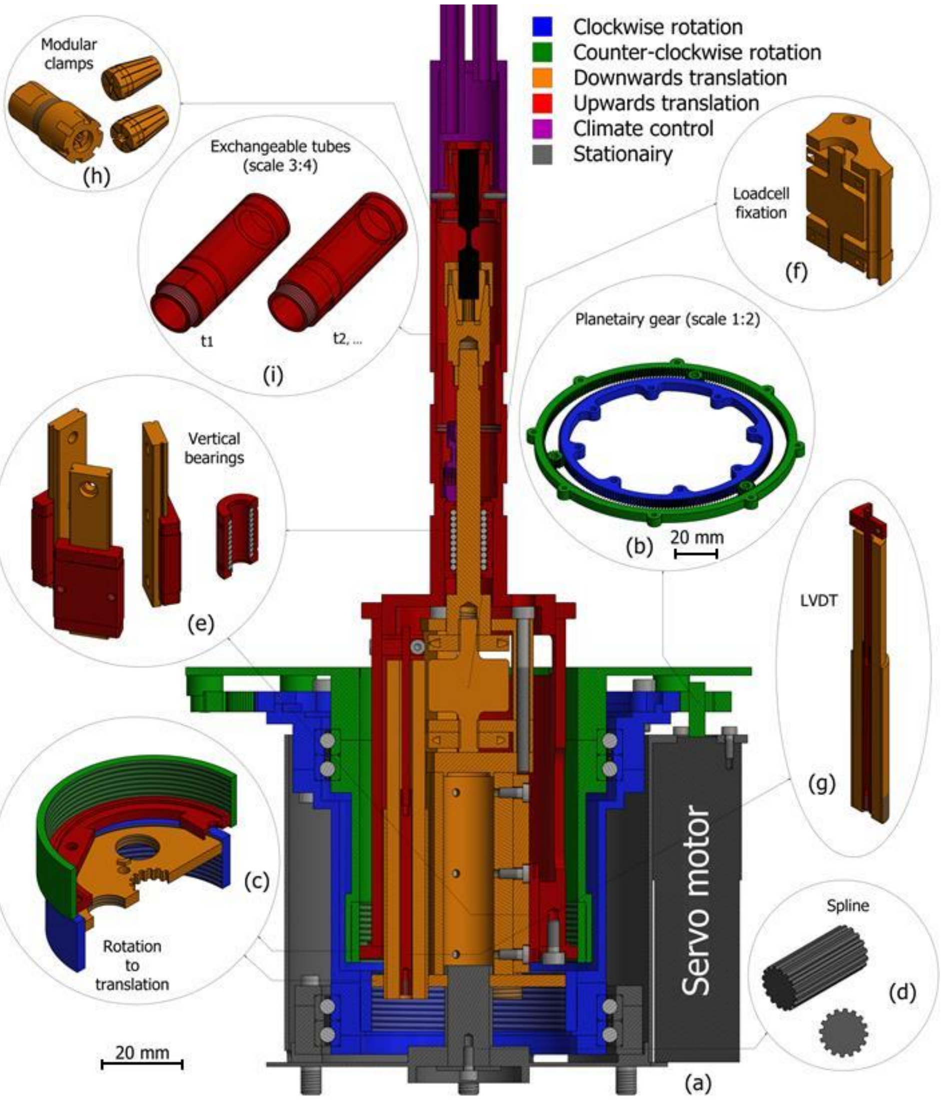

Figure 1: *CAD model of the detailed design of the in-situ CT tester. (a) Section view of the realized setup, (b) planetary gear which is driven by three servo motors, (c) two large threaded cylinders (green and blue) in combination with a spline (d) and vertical bearings (e) to convert the rotational motion into vertical translational motion of the upper (red) and lower (orange) plate which are connected to the sample clamps, (f) exchangeable loadcell which is fixed under the clamp for accurate force measurement, (g) three LVDT's which accurately monitor the relative displacements of the cylinders, (h) exchangeable tubes and (i) universal clamps which are easily exchangeable. Legend: each color indicates a different type of motion.[1]*

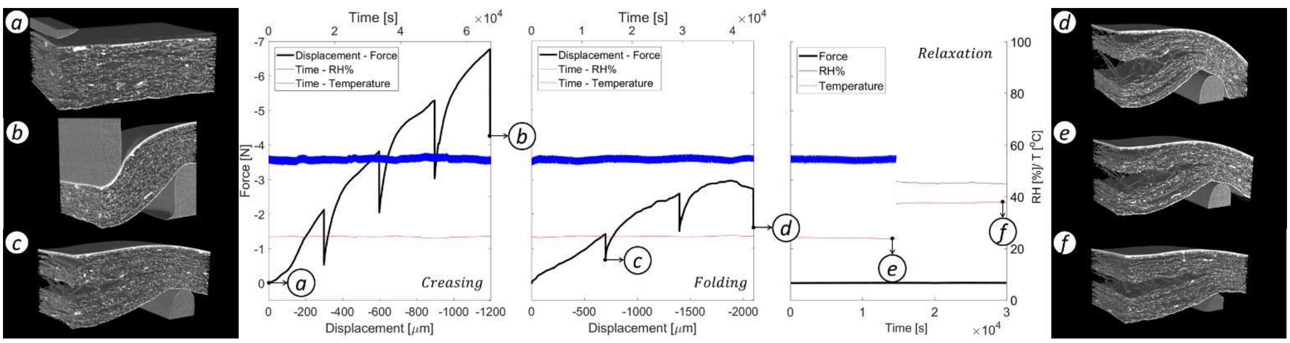

Figure 2: *High-resolution 3D CT characterization of hygro-thermo-mechanical response of cardboard under creasing and folding.[1]*

References

[1] N. H. Vonk, E. C. A. Dekkers, M. P. F. H. L. van Maris & J. P. M. Hoefnagels (2019). A multi-loading, climate-controlled, stationary ROI device for in-situ X-ray CT hygro-thermo-mechanical testing. Exp. Mech., 59(3), 295-308.