EXPERIMENTAL AND NUMERICAL CHARACTERIZATION OF SINTERIZED MATERIALS WITH SPECKLE INTERFEROMETRY AND OPTIMIZATION METHODS

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1. Introduction

The traditional approach to mechanically characterize materials is to perform destructive tests. When material properties are known, the displacement field of a specimen generally loaded and constrained is univocally defined. This paper suggests an innovative methodology in order to determine mechanical characteristics (E, ν) of new materials for an inverse solution of the elastic problem. A hybrid approach based on the combination of phase-shifting electronic speckle pattern interferometry (PS-ESPI) and finite element analysis is utilized. An innovative algorithm, implemented in the numerical model, automatically executes several optimization loops varying E and ν in order to minimize the objective function based on the difference between displacements evaluated by means of ESPI and the same predicted by FEM analysis. Three-point-bending experimental tests are carried out on titanium alloy and Selective Laser Melting (SLM) specimens.

2. Experimental Tests

Preliminary tests on isotropic and homogeneous titanium alloy were planned in order to define the experimental set up and to validate the numerical model that could be used to study new materials, as SLM. SLM parts are composed overlapping layers of metal powder. A focused laser beam selectively fuses powdered material by scanning cross-sections generated from a 3D CAD model of the part on the surface of a powder bed. In order to obtain high density parts the powder mixture and SLM process parameters are optimized.

Electronic Speckle Pattern Interferometry (ESPI) [1,2] is a non-contact optical technique, which accurately measures displacements in real time, gathering full field information without altering specimen conditions. ESPI can measure displacement components u(x,y,z), v(x,y,z) and w(x,y,z) for each point (x,y,z) of the specimen surface. Fringes will appear on the specimen surface and each fringe represents the locus of an iso-displacement region. The frequency distribution of fringes can be used to evaluate strain fields.

Three-point bending tests were carried out on prismatic samples at various loading step. Figure 1 shows the loading apparatus. It connects a 2 kg loading cell to the wedge, in order to measure the applied load. The load was transferred by a micrometric translational stage, which pushes the loading wedge against the specimen. Preloading beams ensures to minimize rigid body motions, which may cause speckle decorrelation. Data were recorded by the Micro Measurements System 5000 acquisition system. The optical set-up used for measuring u-displacements consists of a double illumination Leendertz interferometer [1,2].

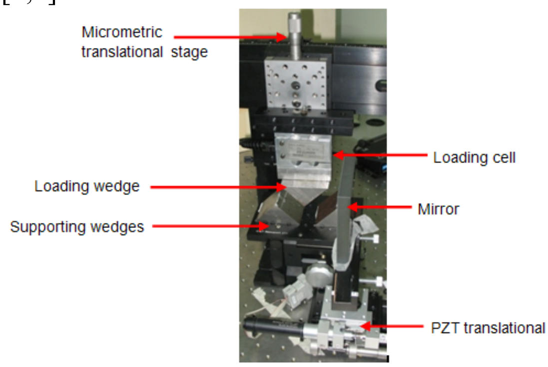

Fig. 1: Loading apparatus

3. Numerical Model

A finite element model, with real sizes of the specimens tested, was realized. Kinematic constraints were imposed in order to correctly reproduce the mechanism of loading. FE analysis was carried out with the ANSYS® 10.0 commercial software [3]. The specimen was modeled with SOLID45 three-dimensional elements. Although specimens' thickness is small compared to length, the specimen under 3-point-bending was however modeled as a 3D specimen in order to account for asymmetries eventually occurring in the loading process or related with constraint conditions.

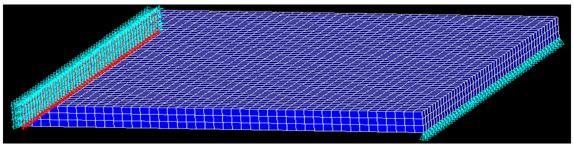

Fig. 2: Finite element model of the 3-point-bending test numerically simulated

Specimen materials were assumed as isotropic and linearly elastic. This assumption is obviously more realistic for the titanium specimen than for the sintered one, because SLM specimens are realized by random strategy on each layer, so each layer could be considered as isotropic. The experimental evidence seems to confirm this assumption: in fact, the u_x displacement measured through the thickness became null at the specimen midplane. The mesh included 293112 nodes and 265232 elements. (Figure 2 with indications of loads and constraints is representative of both materials). Mesh size was consistent with sampling of the speckle pattern. All finite element analyses were run on a standard PC equipped by an Intel® Core™ i7 processor and 8GB RAM memory. The structural analysis supplies E and ν values and was completed in about 10 hours.

4. Experimental Results

The horizontal displacement measured by ESPI was taken as target value of FE analysis.
The algorithm implemented compares these values with the same calculated numerically for each optimization loop, until the gap was minimized. The area monitored during experimental test was located 500 nm far from the constraint wedge and far enough from the region where the load is applied, in order to avoid the influence of local phenomena. Starting values of Young's modulus and Poisson ratio for both materials in numerical models were respectively 180 GPa and 0.3. After FEM validation of titanium specimens, SLM component was analyzed by the same code changing only geometrical dimensions. Young's modulus and Poisson coefficient obtained for titanium alloy by means of the proposed hybrid procedure were respectively 109 GPa and 0,299.

Figure 3 summarizes the convergence procedure on titanium specimen for one loading step, in order to validate the algorithm function used in the optimization procedure.

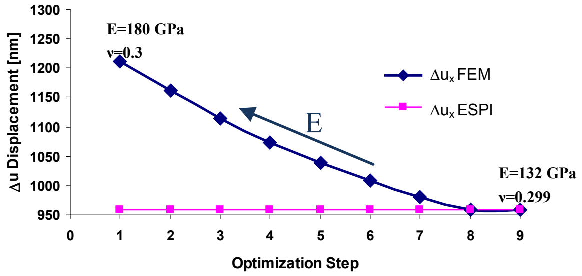

Fig. 3: Algorithm function of the optimization cycle

Table 1 shows experimental and FEM results for SLM specimen. The proposed methodology seems to work well. The residual error on displacements is minor than 1%.

Load [g]	Δu_x Exp fit [nm]	Δu_x FEM [nm]	Error %*E-05	E [GPa]	ν
293	489,78	489,780	2.5	131.33	0.299
330	550,73	550,729	0.29	131.54	0.299
504	837,34	837,340	0.026	132.13	0.299
529	878,52	878,520	0.015	132.19	0.299
695	1151,95	1151,950	0.052	132.45	0.299
706	1170,07	1170,069	0.22	132.46	0.299
810	1341,38	1341,382	0.12	132.56	0.299

Tab. 1: Percentage displacements' difference on SLM specimen

Mechanical properties calculated for SLM specimen were: Young's modulus 132 GPa and 0,299 Poisson coefficient. The experimental pattern is in excellent agreement with FE results. It results important that the weight of Poisson's ratio in FEM optimization is absolutely inferior than the Young's modulus.

References

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[2] Sciammarella C., Overview of optical techniques that measure displacements: Murray Lecture, Exp. Mechanics, Vol. 43(2006), Issue 1, P. 1-19
[3] The ANSYS® 10.0 Users' Manual, Swanson Analysis System Inc., 2005