Improve the finite element predictions by using more accurate material properties obtained from Digital Image Correlation

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Abstract An accurate estimation of the mechanical properties of engineering materials is critical to comprehend their behavior under extreme conditions such as impact and high deformation levels. In this work, mechanical characterization of additively manufactured stainless steel samples is done using an innovative approach with digital image correlation (DIC) method in uniaxial tensile tests. For this, two 2D-DIC cameras were synchronized to monitor the specimen cross-section up to high deformation levels, defining the stress level up to the material failure, so-called current stress. The specimen true stress was also extracted for comparison purposes. The material constitutive parameters were extracted from both approaches and fed into a finite element model of a Triply Minimal Periodic Surfaces (TPMS) lattice under impact loading. It was noticed that the mechanical properties extracted using the DIC approach could enhance the FE prediction by up to 7.4%.

1. Introduction

The Digital Image Correlation (DIC) method is a versatile technique that allows for non-contact, real-time, and full-field measurements. It is frequently used in experimental mechanics since it can precisely define and estimate strain behavior through two-dimensional displacement distribution analysis. This technique has seen considerable advancements in registration accuracy, matching strength, computing efficiency, and application breadth since its inception in the early 1980s [1]. The DIC's core concept compares the grayscale intensity of pictures of a specimen surface under various loading situations to evaluate deformation using specific preset correlation criteria [2].

2. Methodology

Specimens made of atomized 316L stainless steel powder were manufactured using selective laser melting technique with dimensions defined by the ASTM E8 standard. Uniaxial tests were performed at universal testing machine Instron 3369, and two synchronized VIC-2D Correlation Solutions were used. The system was set up as illustrated in Fig. 1a, to monitor the frontal and through-thickness strain fields. Therefore, the frontal DIC provided ε_1 and ε_2 data, meanwhile the thought thickness system provided ε_1 and ε_3 .

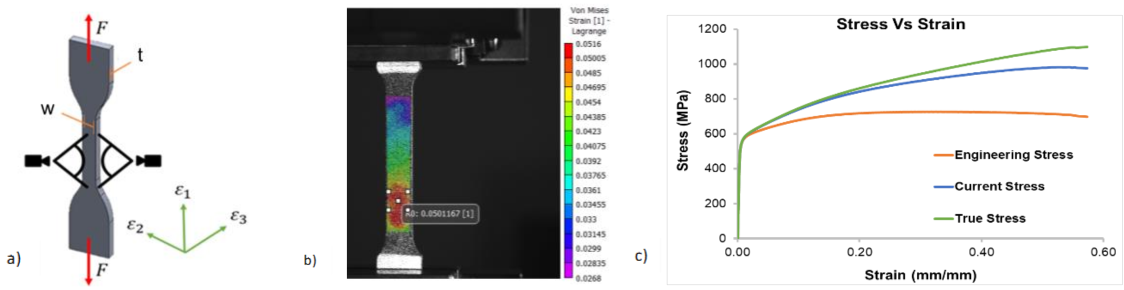

Figure 1: a) System set up for uniaxial tests, b) Data extraction using DIC approach, c) stress-strain curves of stainless steel 316L under quasi-static load.

Thus, the current stress, σ_c, and true stress, σ_t, can be defined as:

$$\sigma_c = \frac{F}{w(1+\varepsilon_2)*t(1+\varepsilon_3)}, \qquad (1) \qquad\qquad \sigma_t = \frac{F}{w*t}(1+\varepsilon_1) \qquad (2)$$

where, w and t is the initial specimen width and thickness, respectively, and F is the load applied to the specimen.

3. Results and discussion

3.1. Material characterization

As shown in Fig.1b, the DIC method was utilized to obtain the stress-strain data. The so-called current stress and the true stress were calculated as explained beforehand and presented in Fig.1c. Although the current stress and true stress curves were identical in the elastic region as seen in the graph, a notable variation in how the two stresses behaved as the test got closer to failure would create distinct characteristics from the two. The Johnson-Cook plasticity model has been employed which can be expressed as:

$$\sigma_{flow} = \left[A + B\varepsilon_p^n\right]\left[1 + Cln\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_o}\right)\right] \qquad (3)$$

where σ_{flow} is the flow stress, A is the yield stress, ε_p is the dimensionless strain, B and n reflects the strain hardening effect, C is the strain rate sensitivity parameter, $\dot{\varepsilon}$ and the $\dot{\varepsilon}_o$ are the strain rate and the reference strain rate as defined by the user, respectively. From the stress- strain curves shown in Fig.1c, two sets of Johnson-Cook parameters were computed based on the two stresses and demonstrated in Table1.

Table 1. Johnson-Cook parameters obtained from both approaches.

	A [MPa]	***B [MPa]***	***n***
Form True stress	471$\pm$11	839$\pm$53	0.63$\pm$0.02
From Current stress	471$\pm$11	717$\pm$39	0.59$\pm$0.02

3.2. Numerical modelling evaluation

A finite element model of Schwarz Diamond Lattice with a relative density of 27% subjected to impact load was developed using ABAQUS/Explicit Software and validated against experimental tests. The same model was used with the constitutive parameters extracted from two different approaches: one with the material constitutive parameters derived from the current stress-strain curve, and other with the constitutive parameters from the true stress-strain. The results of the two models were compared to some experimental data, as shown in the graph in Fig 2. The current stress technique has clearly improved the FE model prediction compared to the experimental data. The plateau stresses for the three stresses were computed as shown in Fig.2. A deviation of 9% was noticed between the current stress and the experimental results, whereas a 16.4% deviation was there between the true stress and the experimental data. This emphasized that the DIC technique and the current stress approach Enhanced the FE model prediction by 7.4%.

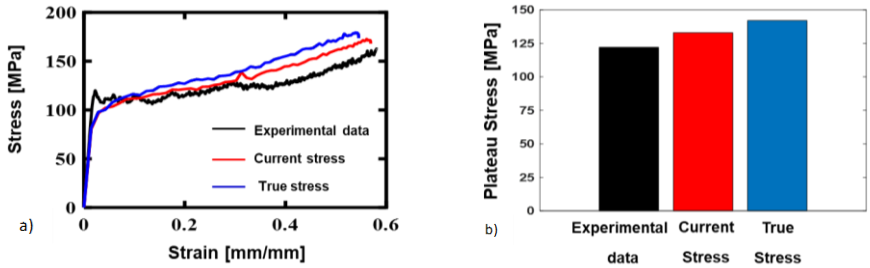

Figure 2: a) Stress - strain curves for the three different scenarios and b) plateau stress.

4. Conclusions

The current stress and the true stress were computed for the stainless-steel specimens tested under quasi-static strain rate, yielded two sets of Johnson-Cook parameters, which were input into a explicit finite element model. The outputs of the two models were compared, along with some experimental data and an improvement of 7.4% was noted in the FE model prediction when using the current stress instead of the true stress.

References

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