TOPOLOGY OPTIMISATION AND MODEL VALIDATION OF SELECTIVE LASER MELTED COMPONENTS USING DIGITAL IMAGE CORRELATION

M. Faes[1,a], Y. Wang[2], P. Lava[2] and D. Moens[1]

[1]KU Leuven - Mechanical Engineering Technology TC,
Jan De Nayerlaan 5, 2860 St.-Katelijne-Waver, Belgium
[a]matthias.faes@kuleuven.be

[2]KU Leuven - Materials Technology TC
Gebroeders De Smetstraat 1, 9000 Gent, Belgium

Abstract. This paper applies Topology Optimization (TO) to a design study of a component manufactured by Selective Laser Melting. The resulting optimal design is validated using Stereo Digital Image Correlation (DIC). A constitutive material model for Ti6Al4V ELI was defined by performing tensile tests. TO was performed, reducing the overall weight of a car suspension component by ∼65%. The model was produced via SLM and the used Finite Element (FE) models were validated through DIC measurements in a realistic loading situation for the component. In this regard, a dedicated test-setup was designed. In general, good agreement was found between the DIC measurement and FE simulation. Some mismatch was found and is attributed to the constitutive model, boundary-effects in the image processing and misalignments during the testing.

Introduction

Due to the low time-to-market, large freedom in design and efficient usage of materials and resources, Additive Manufacturing (AM) receives and increasing industrial interest, especially in sectors where weight reduction plays an important role, such as Automotive and Aerospace. An example of such an AM process that receives growing attention, is Selective Laser Melting (SLM) [1]. SLM builds up complex parts based on a digital model through a layer-by-layer approach. A fine layer of metallic powder is deposited and selectively melted by a laser source, binding to previously melted layers. Thus the desired product is formed [2]. Due to the layer-by-layer nature of this process, complexity can be added to the design without increasing the cost of the production [3].Therefore, the combination of this production concept with Topology Optimization (TO), a powerful numerical technique for the determination of an optimal material distribution within a defined 'design-space', is expected to induce a large step forward as typical constraints of more conventional subtractive and formative processes can be neglected. These typical constraints include e.g. tool access in subtractive processes and part removal and thermal issues in injection moulding [4,5]. First steps in combining these two concepts are already made by e.g. Almeida & Bartolo (2010) [6], Bracket et al (2011) [5] and Tomlin & Meyer (2011) [7], who achieved a decrease in weight of up to 64%, while improving the structural response of the components. However, no validation of the used Finite Element (FE) models or built components was made. This paper therefore aims at combining TO with AM, based on a validated FE model. An important issue in the validation of these FE models is the complexity of the occurring stress and strain fields under realistic loading situations of optimized components. In this regard, Digital Image Correlation (DIC) is a powerfull technique which enables the validation of FE models by comparing measured deformation and strain fields with FE-computed fields. This is possible because of the contactless full-field character of the measurements obtained by DIC [8].

Methodology

In order to validate the previously described concept, a case study was performed on a rocker of a Formula Student race car. Using the material selection method proposed by Ashby & Cebon (1993) [9], Ti6Al4V ELI (grade 23) was found to be the most performing material taking strength, stiffness, producibility and specific mass into account. The constitutive model, which is needed to perform the FE calculations in the framework of the TO, was initiated by performing standard tensile tests on Selective Laser Melted (SLM) Ti6Al4V ELI) samples. Two different orientations of the material (Flat and Edge, see also Figure *1*) were built. The samples were tested at 10 mm/s using an Instron 5900R tensile tester with a linear extensometer and a load cell of 100kN. Topology Optimization was performed using the commercial TO software "solidThinking Inspire®". In a first step of the TO, a functional model is built in the software, including the needed connections of the rocker, while keeping the needed dynamical freedom in mind. These connections are no part of the design space, where the software will optimize the distribution of the material. The optimal mesh size for the TO was selected using a sensitivity analysis taking the resulting mass and calculation cost into account. The optimized geometry was subsequently exported to PTC Creo® CAE software and produced using SLM, assuming an isotropic constitutive model. Subtractive finishing steps were performed for critical areas in the part to achieve desired tolerances. Validation of the used FE model was made through an experimental investigation where a realistic loading situation of the component was simulated. The occurring deformation fields were captured at different loadings using two 2MP cameras and analysed using the DIC software platform MatchID®. The DIC measurements were finally compared to the results of the FE analysis to validate the used FE model for the TO.

Results and Discussion

The results of the tensile tests performed on the SLM samples are shown in Table *1*. As can be observed, there exists a slight difference in mechanical properties between the two built directions. It is assumed that this is due to the directions of the scan vectors in the SLM process [2] and the influence of the thermal process history of the part on its microstructure [10]. This is because the Flat specimen remains longer on an elevated temperature in the production volume, which gives rise to different crystallization speeds.

		Flat	Edge
E-Modulus	[GPa]	111.9 (0.75)	120.11 (0.83)
Tensile Stress	[MPa]	961.5 (34.6)	925 (21.21)
Tensile Strain	[%]	1.41 (0.07)	1.13 (0.28)

Table 1 – Results of the tensile tests

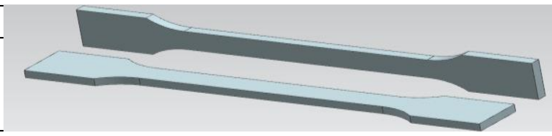

Figure 1 – Orientations of the test samples

Using the TO methodology as described before, an optimized rocker was designed achieving a reduction of the total weight by 64.8% while maintaining the mechanical integrity of the component. The results of the validation are shown in Figure 2. The figure on the right-hand side shows the comparison between the simulated and measured maximum principal strains along a predefined line on the component (denoted A-B in the DIC picture on the left-hand side). The used DIC parameters are indicated in Table 2. In general, good agreement between the simulation and experiment was achieved. Some important differences however occur, which can be attributed to both the DIC measurement itself as to the used constitutive model. As concerns the DIC measurement, boundary-effects and misalignment of the applied load play an important factor in the analysis. On the other hand it is assumed that heterogeneity and anisotropy in the mechanical properties of the SLM material have also an influence. Future work will focus on improving the simulations and test set-up by improving the constitutive models and alignment of the load.

Parameter	Value
Criterion	ZNSSD
Subset	21
Step	3
Strain window	29
Prefiltering	Gaussian 5x5
Interpolation	BL
Transformation	Affine

Table 2 – Parameters of the DIC set-up

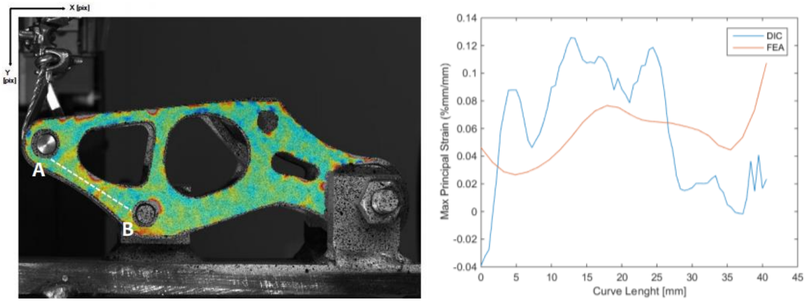

Figure 2 - Comparison between FEA and DIC

Conclusion

This paper shows that a combination of Topology Optimization, Selective Laser Melting can give rise to important weight reductions in functional components. It was shown that a weight reduction of up to 64.8% can be achieved by combining the strengths of Topology Optimization and Selective Laser Melting. Validation of the used Finite Element models was made using Digital Image Correlation. Good agreement was achieved in general. Differences between the experiment and simulations were found and are attributed to both the measurement set-up as the used constitutive model.

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