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Weight reduction by topology optimization of an engine subframe mount, designed for additive manufacturing production

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Abstract

Additive Manufacturing (AM) technologies are getting more and more strategic for different purposes in many industrial fields. Among the most outstanding are part prototyping, single part to small batch production, relatively reduced manufacturing times and investments costs, reduced material consumption, and innovative and efficient shapes. The considerable advantages these technologies offer, compared to subtractive ones, make additive manufacturing a potentially industry-leading process in almost all domains - from aeronautics to the medical industry. Under these circumstances, the inspiration given by topology optimization tools can lead to feasible industrial parts, with fewer constraints in comparison to traditional manufacturing processes.

The paper presents the development and the results obtained using topology optimization and design for AM technology on an automotive part: an engine mount sub-frame component for a rear middle engine sports car. The final design enables a significant weight reduction.

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1. Introduction

The emergence of additive manufacturing (AM) technology has opened up previously unprecedented possibilities to produce parts with integrated/improved functionalities and extremely lightweight designs. By additive manufacturing technology it is possible to obtain parts with complex geometries and features, impossible to be produced by other processes. Lately, a number of studies have been undertaken in the field of AM manufacturing technology and of its possible implementation in various industries [1 - 10].

AM is defined by the BS-ISO /ASTM 52900:2015 standard as “the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies.” Powder Bed Fusion is the standard designation of processes where powder is layered in a bed and selectively fused by means of a high-energy beam, either laser or electron beam. To obtain metal parts, a laser beam with power between 20 and 450W is generally used [11-13].

Initially developed for rapid prototyping purposes, AM has grown rapidly and today the most significant use regarding the production of final parts is especially related to the high-tech industries (aerospace and the automotive industry), as well as in medicine and electronics.

The outstanding degrees of freedom offered by additive fabrication, as compared to traditional manufacturing, allow obtaining the best benefits from the topology optimization results [14-16]. According to the definition, topology optimization is a “mathematical approach that, within a given design space, and a set of loads and boundary conditions, provides a solution that respects certain constraints (i.e. displacements, accelerations, stresses) and either minimizes or maximizes the objective variable (i.e. mass, compliance, volume, displacement)”.

With the explosive development of computing, topology optimization has become a fundamental tool for designing lightweight components. A number of large software companies have developed either topology optimization programs or various extensions of design programs for this purpose. As a consequence, new complex shapes resembling organic structures are obtained.

Powder bed fusion (PBF) processes are an increasingly frequent choice for many components in Si, Mg aluminum alloys, traditionally obtained by casting. Typical examples are brackets, carters and stands. The quality standards of high-performance cars require the adoption of expensive solutions, mainly gravity and low-pressure permanent mould casting, with the use of cores. While outstanding in terms of mechanical and dimensional quality of parts, as well to absence of defects, such processes suffer from high investment costs, long time-to-market and very low flexibility. All these characteristics mismatch production types characterized by very small batches, where variable costs, still high, can be much easier to be attributed than fixed ones. PBF is still at the first stages in this field, due to the scarce maturity, mostly in terms of reliability and predictability, of a technology that only recently included aluminum alloys among the options.

The paper deals with the application of topology optimization and design for additive manufacturing of an engine mount sub-frame component for a rear middle engine sports car, with the main objective of mass reduction.

2. Experimental details

The benchmark selected is an engine subframe mount, shown in Figure 1. The part, produced by permanent mould casting with the AlSi10Mg alloy, serves the function to support the engine. Maximum predicted stress for durability is 70 MPa. Each current casting weighs 2.2 kg and box dimensions are 390×339×166 mm³. According to the data provided by the powder supplier [17], the mechanical characteristics of the parts obtained by PBF technology are equal or better than that of the cast-alloy [18].

In order to perform the topology optimization, a simplified design space has been created. To have greater freedom in optimization, the procedure started from a 3D volume that included the initial design, as seen in Figure 2. Specific areas, where the part has to be attached to the rest of the frame and the engine bushing, are excluded from the design space.

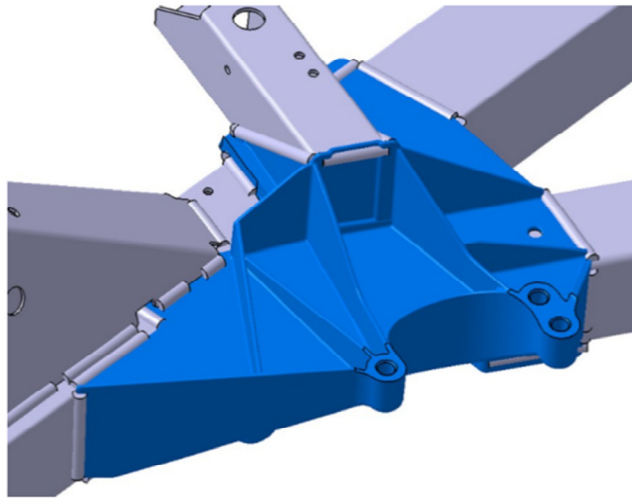


Fig. 1. Engine sub-frame mount.

The volume has been meshed with first order tetrahedral elements and load and boundary conditions have been applied. In the definition of the optimization problem, the constraints were the maximum displacements and stress allowed, and the target was to minimize the mass.

The topology optimization was possible using an extension of the Solidworks software, namely TruForm, GRM Consulting Ltd. The result is a parameterized shape, from which the low stressed areas have been eliminated.

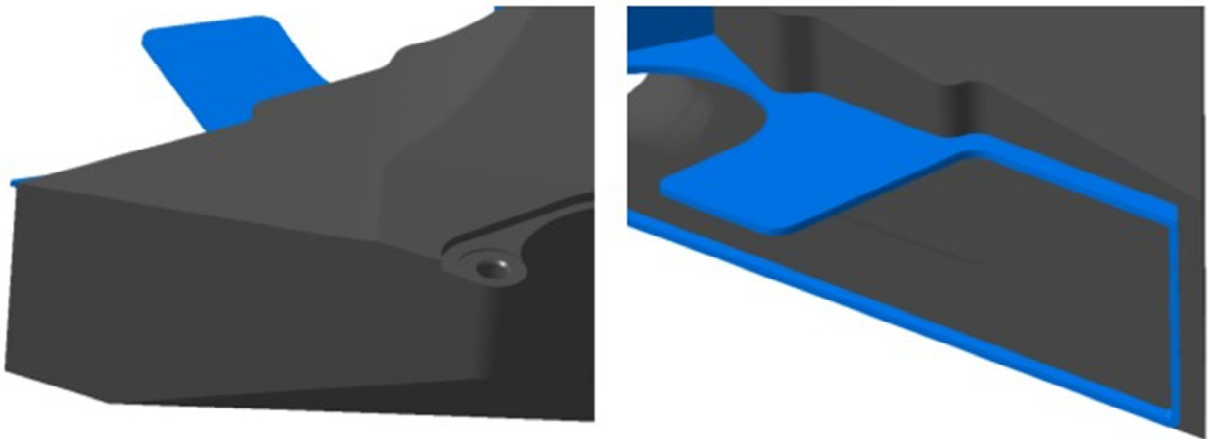


Fig. 2. Portions of the design space (black) and the surfaces to be preserved (out of design space – blue).

3. Results and discussions

By solving the optimization problem, TruForm software provides a resulting model, marked in green in Figure 3a, which highlights the areas that can be removed from the design space (dark grey). The result from TruForm are suggestions that can be used to inspire the new design, through an interpretation of the designer, who has to follow as much as possible the shape proposed by the optimization software. In building the new parameterized CAD

model, the designer usually includes manufacturing considerations and constraints, which hamper the full exploitation of the optimization and can potentially lead to compromise solutions. In the case of AM, the great design freedom allows to remove extra-mass and to achieve the best benefits from the optimization process. The redesign of the part (using SolidWorks 2016) conducted to a weight reduction of the part from 2.2 kg to 1.52 kg, meaning around 30% from the original component, as seen in Figure 3b.

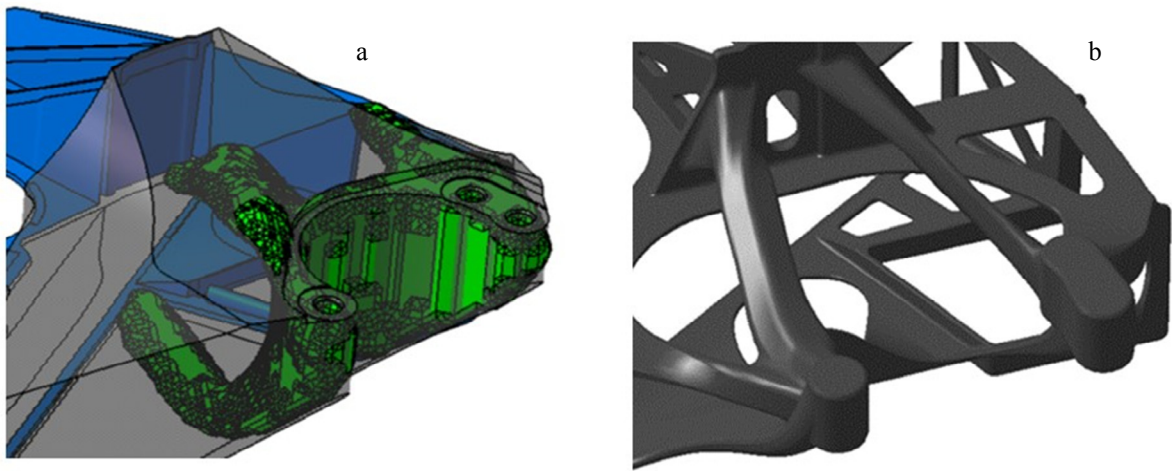


Fig. 3. a) TruForm generated results. b) The optimized CAD model.

The proposed design has been verified in further load cases such as static, dynamic, durability, including non-linear crash load cases. The results showed that a slight increase in stiffness and strength was required. Consequently, certain locations were further reinforced, by adding trusses or walls. The final design weights 1.71 kg, achieving an overall weight reduction of about 20%. Overlaying the optimized geometry of the engine mount over the original shape – figure 4 – clearly shows that the optimized model requires less material than the original. The organic optimized design can be considered unusual, however, considering the trends in automotive design, such shapes will become virtually common in car components.

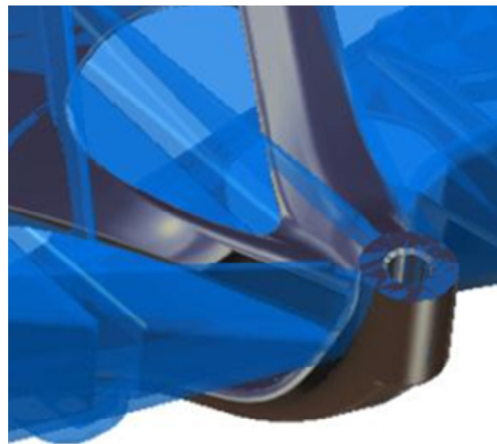


Fig. 4. Optimized model (black) superimposed over the original (blue).

The further step will be analysing the optimized component in terms of design for additive manufacturing. Orientation of the part in the PBF machine, as well as position and type of supports, need to be studied and used for

possible further improvements of the geometry, in order to achieve better quality or lower manufacturing costs [19, 20].

4. Conclusions

The activities carried out and presented herein, have demonstrated that the use of topology optimization, to be further applied in additive manufacturing technologies, in the redesign of parts for, but not limited to, the automotive industry has a clear beneficial effect on weight reduction, while maintaining the structural requirements. The weight reduction is associated with material economy, coupled with reduced energy consumption in the manufacturing stages, and as a secondary consequence, a reduction in fuel consumption of the car.

Topology optimization is not self-sufficient, but requires a further re-design step, in which more complex structural analyses as non-linear load cases need to be considered. A result as impressive as a weight reduction of 20% has been obtained, by considering the same material properties of the cast alloy. In this study the possible benefits to have higher mechanical properties of the AM material have not been considered and could turn into further opportunities concerning final part mass reduction.

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