Title:
Case study of lightweight design of a fixture using GD tools

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Introduction:
This paper presents the state of the art in the field of lightweight design of industrial components and fixtures for measuring an automotive wheel suspension arm. The application is carried out using the Generative Structural Design method in 3DEXPERIENCE software where three case studies were subjected to the process. In the first case study the nylon PA12 material designed for MultiJet technology was used to construct the component. In the second case study, ASA material designed for fused deposition modeling (FDM) was used to construct the part. In the third case study, AlSi10Mg aluminum alloy designed for direct metal laser sintering (DMLS) has been investigated. All components were subjected to the same process of topological optimization (TO) and generative design (GD) process in the current innovative software. The main parameters evaluated in the design process are production time and cost.

The possibilities for designing and manufacturing parts using additive manufacturing (AM) are in the current stage limitless, leading to further development of next-generation software programs that allow designers and engineers to create parts for a wide range of different industries. Increasingly, modelling methods such as TO can be used to achieve alternative parts that provide advantageous solutions in terms of strength-to-weight ratio.

TO and GD can be considered as next-generation design tools that improve workflows and processes while pushing simulation capabilities to an earlier stage of product development and subsequently providing reliable design models. The main fundamental difference between GD and TO is in the process of generating and creating the final shape, whereas in GD a volume is gradually created in space and in TO it is taken from an already existing and predefined volume [1,2,3]. GD sometimes referred to as Generative CAD or Bionic Design and it is an important part of the design for AM.

Application of the Structural Generative Design:
Structural Generative Design is module in the 3DEXPERIENCE software which offers a wide range of applications. It uses TO commands to generate component concept or final shape, while the result is based on load conditions provided in the beginning of the process. However, 3DEXPERIENCE software has several modular solutions in terms of optimization and also includes Flow Driven Generative Design whose results are used to find flow paths that create complex networks through the component. As a consequence of this fact, the module performing the TO based on the strength and

power conditions is referred to as structural to unambiguously distinguish the function of these two modules.

The process in the software to achieve the optimum shape of the part while maintaining sufficient rigidity at minimum or reduced weight is the same for all three materials. The process begins by defining the basic shape of the component, which has been influenced by the following limiting factors:

- Dimensions of the suspension arm of a car wheel
- Functional areas fixing the arm
- Minimum height of the fixture
- The range of the measurement device

Topology optimization in 3DEXPERIENCE software

The first step in this process is to define the volume that represents the boundary space (exploration envelope) of the fixture placement. The result is an object in the space of the form of a cube-shaped object with recesses that allow gripping handles and contact measurement of the functional areas of the component using the measuring arms. The functional surfaces on which the part will be placed are subsequently cut. These areas must remain untouched from the TO point of view and must be designed with maximum precision. Pre-prepared functional areas are set like „Region to preserve" in the Structural Generative Design in the 3DEXPERIENCE software shown in the Fig. 1(a) and Fig. 1(b). The result of this part is a configured model, the so-called semi-finished model with radius, which represented the largest design space required for the part shown in the Fig. 1(c).

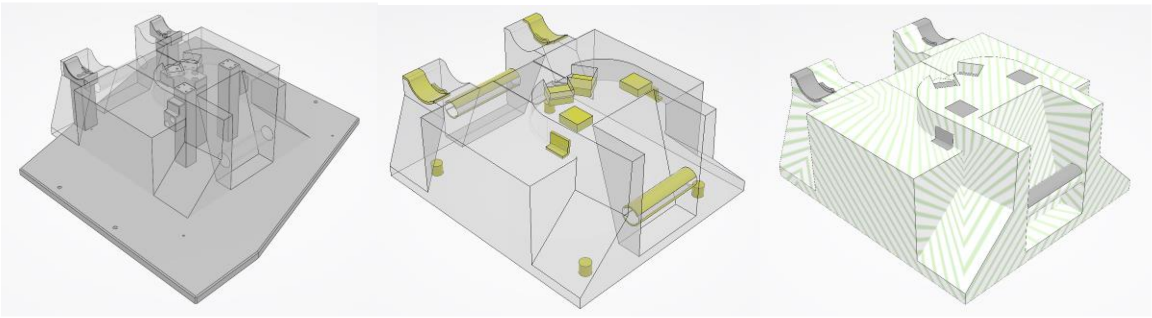

Fig. 1: (a) Regions to preserve, (b) Preserved regions with functional areas only (c) Semi-finished model.

The second step is to apply loads and constraints as shown in the Fig.2 (b). The software allows us to specify different boundary conditions, which are further combined in different load cases as required. When applying loads, functional areas must be omitted, and loads can only be applied using static quantities. Dynamic loads are only used to a limited extent in the AM process due to the fact that this area is not sufficiently researched. Dynamic loads and gravity present a limitation with respect to a system solution, the results of which could converge to incorrect values.

The third are the user settings, which depend mainly on the desired result and the shape of the optimized part. This part of the procedure involves the creation of a network that divides the component into smaller units. The size of the mesh elements for all the above materials was increased to 9 mm, so that the total number of mesh elements was optimal, and the simulation time was only a few hours. The model further takes into account the weight of the fixture itself as well as the weight of the component intended for the fixture while maintaining the fixture dimensions of 330x330x150mm. The coefficient of friction varies depending on the material. This step also involves evaluating and determining the possible situations to which the fixture will be subjected, such as 90 to 180 degree rotation, tilting and other manipulations. In the following sections, the design of the fixture shown in Fig. 2(a)., will depend on the material chosen for manufacture, which will significantly affect the weight and final shape.

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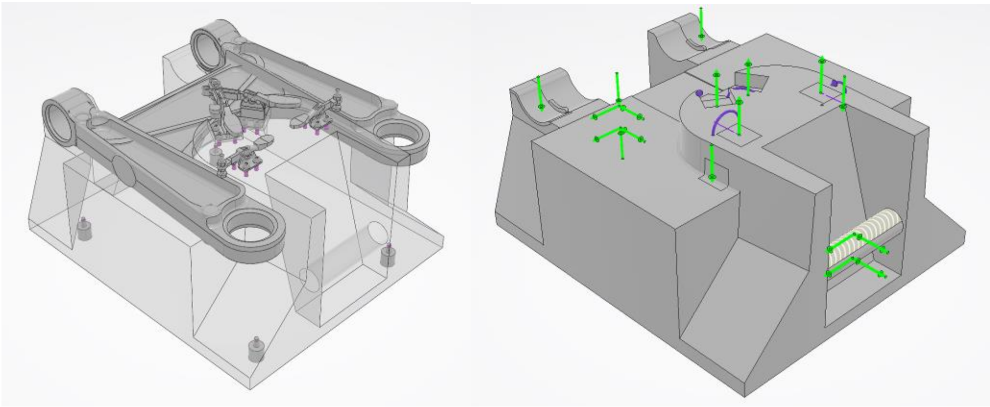

Fig. 2: (a) Application of wheel suspension arm (b) Load application.

The fourth step is to start the TO process after defining all the necessary parameters. The result of the TO is a raw fiber model that will be used in the following steps. The model is then modified not only to reduce weight and simplify the shape, but also to make the resulting design attractive to the customer.

Since the result of the optimization is a raw component shape with the number of unnecessary materials, it is necessary to modify the model in the last step. The basis of the modification is to create surfaces with circular diameters that are an approximation of the fibers of the raw model. For clarity and simplification of the process, the raw model is divided into several parts. The method of generating individual fibers is based on drawing lines of approximate diameter of the support circle on the fibers of the raw model to form an irregular cylinder surface. The individual surfaces can be modified by sliding portions of the support surface mesh. In order to achieve a smooth connection of the fibers with the functional surfaces of the model in the final modeling steps, approximate surfaces representing the functional areas for an automotive wheel suspension arm placement were created.

To implement and use the fixture, the functional fixing surfaces would need to be adjusted to the exact dimensions for all materials. In real production it is possible to use e.g., a milling cutter suitable for the selected material for this process. In order to achieve the best material properties, it is necessary to remove the material gradually and with a small layer height in the machining process of the part to avoid damaging the 3D printed part. The smaller the layer that is removed, the lower the forces generated during machining and the less likely the part is to be damaged. The tool must have suitable parameters for machining the material to avoid damaging it.

Nylon PA 12

Nylon Pa 12 is often used in AM due to its pliability and ease of melting in the manufacturing process. In addition to being environmentally friendly, it also has advantageous mechanical properties such as good durability, flexibility and surface smoothness, while maintaining good precision and excellent abrasion resistance. The disadvantage of the material is that it is hydroscopic and material anisotropy which severely limits its use for more complex applications. The combination of Nylon Pa 12 with multi jet fusion printer brings advantages in terms of speed and accuracy [5]. In optimizing this material, the weight of the component was changed from a raw blank weighing 10.4 kg to 2.5 kg. The advantage is the strength of the parts printed with this technology, but also the flexibility that the material is able to retain. The length of the subsequent post-processing shown in the Fig. 3. can be set at 4 hours to obtain the optimum shape. The Fig. 3(a). shows the TO process as a raw component without any modification. The Fig. 3(b). and Fig. 3(c) shows the result of TO after adjustments using the 3DEXPERIENCE software.

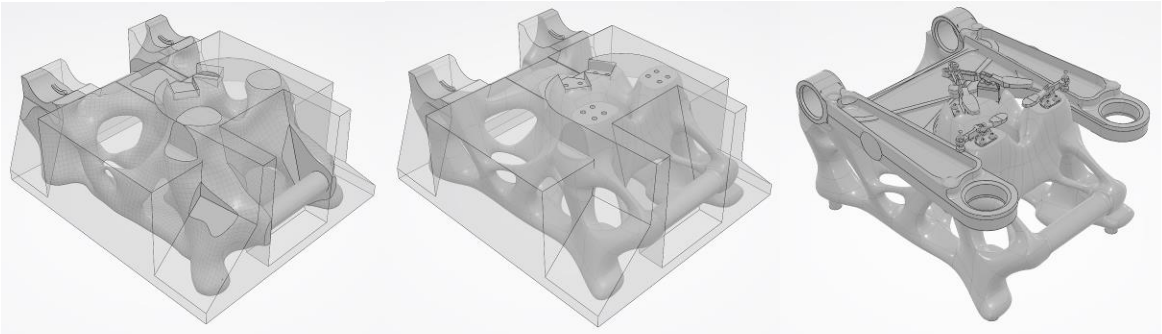

Fig. 3: (a) Raw component after TO (b) Component after TO and modifications (c) Application of the fixture.

ASA

The material, referred to as ASA, stands for acrylonitrile-styrene-acrylate, which is a substitute for ABS material for use in 3D printed parts, with its main advantage being better resistance to temperatures at which the material does not degrade during cooling [4]. The material is used in combination with FDM technology, in which the filament is essentially heated to a temperature just above the melting point of the material. When the filament reaches the molten state, the material is extruded through the nozzle of the 3D printer [6]. In optimizing this material, the weight of the component changed from a raw blank weighing 11.1 kg to 2.97 kg. The fixture was after optimization subjected to modifications as shown on Fig. 4.

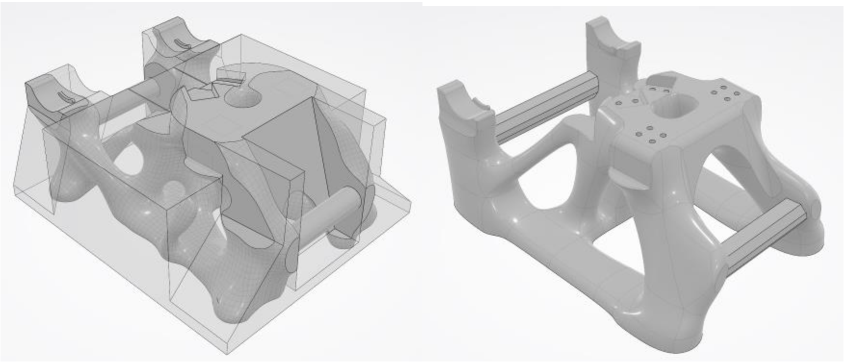

Fig. 4: (a) Raw component after TO for ASA material (b) Component after modification for ASA material.

Aluminum alloy

3D printing of aluminum is achieved using DMLS technology, combining good thermal properties, while the weight of the printed parts is lower compared to steel. The aluminum parts are created by sintering the powder using a powerful laser beam, which ensures excellent bonding of the layers, but the disadvantage is the explosiveness of the aluminum powder in the 3D printing process. In optimizing this material, the weight of the component changed from a raw blank weighing 27.3 kg to 3.4 kg, so the greatest weight reduction can be observed with this material. The reduction of the material and the modification of the raw component is shown in the Fig. 5.

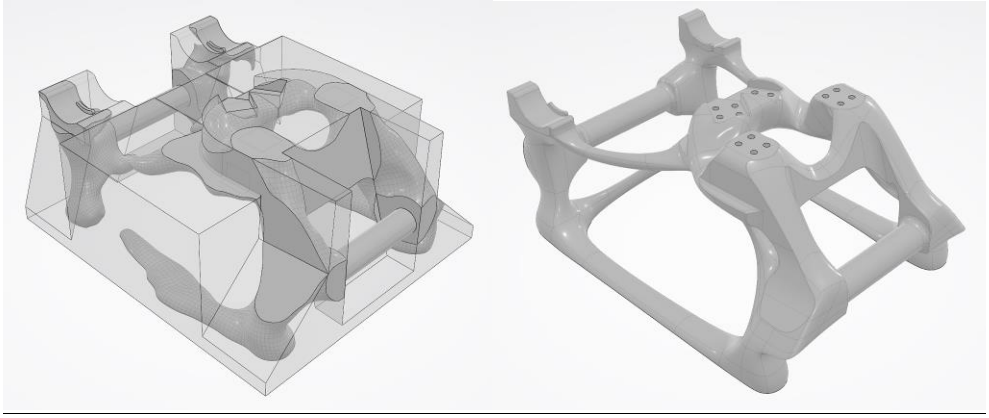

Fig. 5: (a) Raw component after TO for Aluminum Alloy (b) Component after modification for Aluminum Alloy.

Conclusion:

The aim of the study is to illustrate the impact of advanced tools and programs in TO on real applications. The achieved results clearly show the possibility of accelerating the development of formulations at their current reduced weight. FDM printing remains the cheapest technology to produce a wheel suspension arm, but the disadvantage of this technology is clearly the high height of the deposited layer. The largest difference in weight between the raw blank and the final optimized component can be observed especially in the case of aluminum materials and DMLS technology. The study has demonstrably confirmed the possibilities and advantages when using topological shape optimization.

Problematic from the process point of view is the limitation of the software to work with only four cores, which considerably lengthens the simulation process and the length of the computation. This problem can be solved by purchasing a license to work with more cores but this affects the resulting price for the use of the software. Another problem in terms of software setup concerns linear network elements. The software also offers the option of using a linear mesh, but this does not accurately display curved edges and surfaces. Therefore, for better convergence of the results, it is preferable to use a quadratic mesh, which is relatively less sensitive to deformation of the elements and gives better results. However, the disadvantage is that it is computationally demanding.

The last limiting factor in terms of settings is the restriction of the optimization to low maximum voltages. Although aluminum can have a relatively high yield strength, the optimization option is only set to 5 MPa. This is influenced by the large difference between the stress induced by the applied load and the actual stress that the material would be able to withstand. In order to load a given material to larger stress values that approach the inter-material yield stress, we would also need larger emergent forces acting on the fixture in service.

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