Topology Optimization of a Motorcycle Swing Arm Under Service Loads using Abaqus and Tosca

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In research and development environment and concept design, people involved in new projects often need to design a completely new shape for the structure target of the analysis. The loading conditions and constraints are usually known but the designer hardly knows how to create the geometry of the structure that meets the requirements of the project and that can be manufactured at the same time respecting the target costs.

The weight is known to be one of the main factors that impacts on the performance and on the costs, and for this reason its reduction often becomes the main objective to achieve. Often geometries are realized based on experience or on similarity to previous projects, but this approach can be long and expansive, without the certainty of being able to reach the optimum. The use of the CAE (Computer Aided Engineering) is strategic in this environment, in order to verify and virtually simulate different types of geometries avoiding the cost and time of prototyping and testing. A FEM model is the starting point for the optimization process and provides, where appropriate, the subsequent integration of the results with different physical disciplines, such as CFD or Heat Transfer.

In this paper is presented the topology optimization of a motorcycle swing arm, starting from a design space which takes into account the overall dimensions, and trying to minimize the mass while maximizing stiffness. The use of Tosca Structure, that drives the FEM simulation of the swing arm performed with Abaqus, allowed to obtain a shape that can be manufactured in compliance with the requirements of the project.

Keywords: *Topology optimization, Nonlinear Analysis, Motorcycle, Swing arm*

1. Introduction

SACMI IMOLA is the Italian parent Company of an international Group that includes over 80 Companies. Over the years, the core business of designing and building machines and complete plants for the ceramic industry has been flanked by other businesses, to form an efficient organization that joins Companies and technologies in the following sectors: Ceramics, Beverage, Food e Plastics.

PROTESA is a Company of SACMI Group and offers technological and organizational services in support of business processes. Its dynamic workforce of 100 consultants and technicians combines top-level professionalism with experience in the intensive use of modern technologies, offering full support for the entire manufacturing process to its customers.

In research and development environment and concept design, people involved in new projects often need to design a completely new shape for the structure target of the analysis. The loading conditions and constraints are usually known but the designer hardly knows how to create the geometry of the structure that meets the requirements of the project and that can be manufactured at the same time respecting the target costs. In this scenario CAE and Topology Optimization fulfill all the requirements described. In particular, if used before a real prototype, CAE technologies help to:

- analyse the full design cycle with fast steps
- understand the dominant constraints of the project
- keep all disciplines connected, multi physically, as the real-world complexity requires
- get a preliminary solution that will help technicians to understand in which way they have to realize the engineering shape of the component

This paper describes the simulation steps involved in the CAE process, focused on increasing the performance of a racing motorcycle swing arm taking into account different crucial aspects (structural, weight, casting) and making them converge together. At first, a topological optimization has been performed using Tosca Structure with Abaqus. Then, the optimized shape was submitted for a quick casting analysis.

2. Motorcycle swing arm component

The motorcycle swing arm is the back of the same, which connects the rear wheel to the frame, and that through the use of one or more suspensions controls the movement of the frame relative to the tire and via a damper damps and slows the oscillation.

It is known that under racing conditions the motorcycle swing arm is one of the most important components for the configuration of the bike and its performance. In the following figure a sample of real motorcycle swing arm is shown.

Figure 1. Sample of motorcycle swing arm in production

3. The Topology Optimization Process

Topology optimization is an automated methodology that uses software able to generate a design proposal and it is often used for finding new concept shapes.

In addition, a number of manufacturing constraints can be applied so that the design proposal can be produced with casting technology, molding technology, etc. Concerning constraints, Tosca is able to take into account several boundaries and in particular in this work, casting constraints, member size constraints, freezing, symmetry and coupling constraints have been defined through Tosca Strucutre using Abaqus as FEA solver. The process that has been followed for the activity described in this paper, is resumed in figure 2.

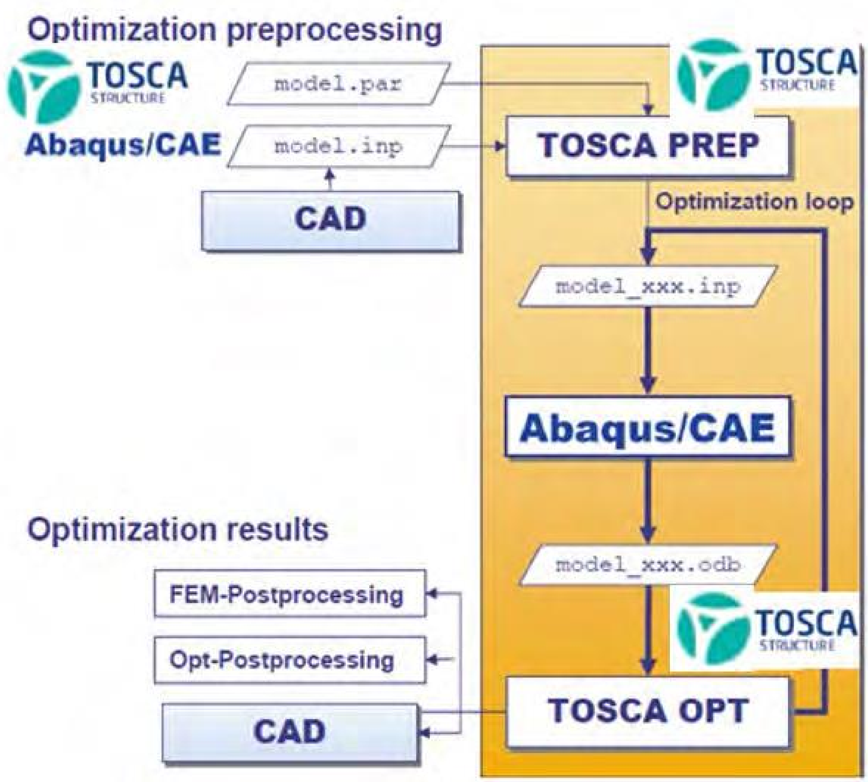

Figure 2. Topology Optimization Process using Tosca Structure and Abaqus (picture based on Tosca Structure documentation[1])

Concerning the topology optimization of the motorcycle swing arm, first of all a finite element model of the design space has been created inside Abaqus/CAE, and element sets to be passed to Tosca has been defined inside the graphical interface. Figure 3 shows the model representing the initial design space in which the swing arm geometry has to be identified by Tosca Structure and the element sets created.

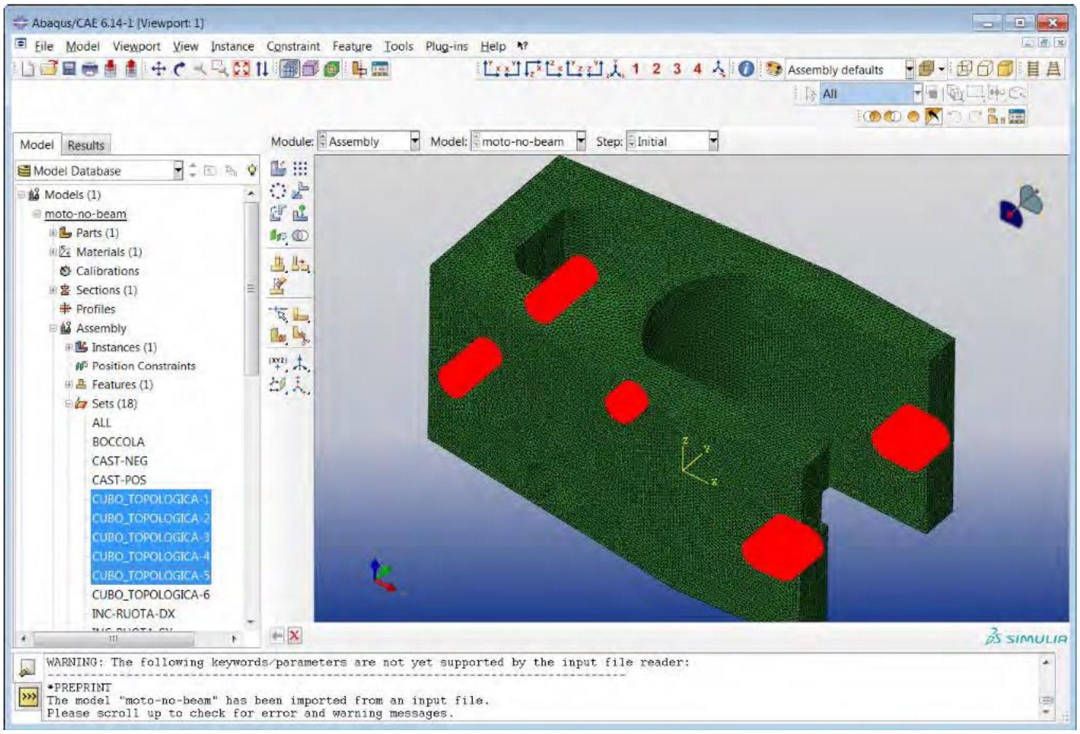

Figure 3. Abaqus Finite Element Model of the Optimization Design space used by Tosca

In Table 1 the material used in the simulation and the dimension of the design space in terms of elements and nodes are listed.

Table 1. Finite element model characteristics.

Material	Al6000
Number of elements	1169311
Number of nodes	1640840
Volume	0.03 m^3

To get a suitable shape of the swing arm, it is necessary to define constraints those take into account forging restriction (material pull direction), frozen area of the design space domain that cannot be modified and the service loads to which the component is subjected. In Figure 4 the defined frozen areas (red) and the material pull direction are shown.

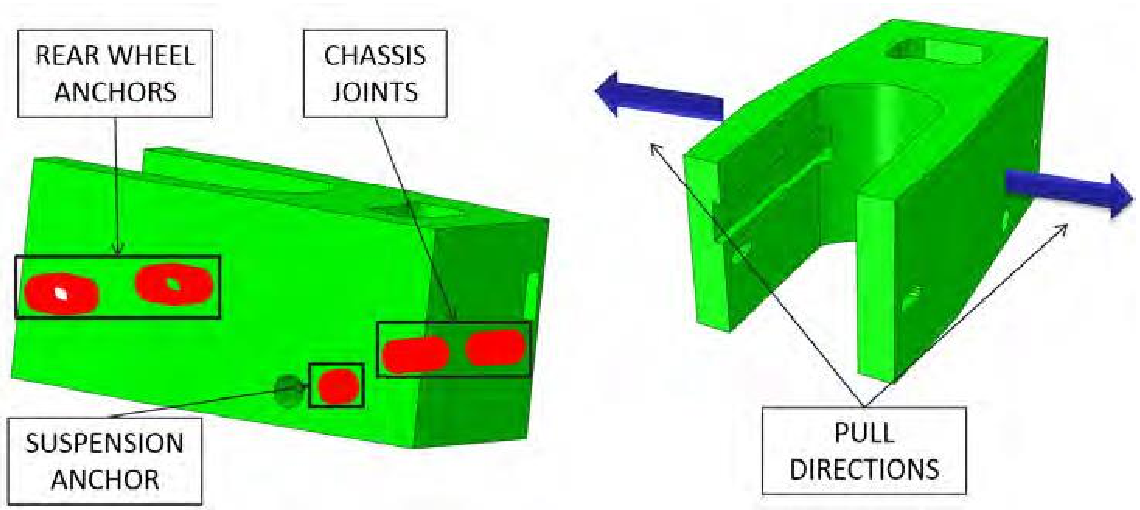

Figure 4. Frozen areas definition (red zones) and material pull direction definition in Tosca Analysis

Figure 5, 6, 7 show the three load cases used in the analysis. Those load cases must be fulfilled by the topology optimization. The final shape of the swing arm in fact, must have the maximum stiffness with the minimum mass, in compliance with all load cases corresponding to service loads.

Figure 5. Load Case 1: Service loads acting on swing arm due to passenger load.

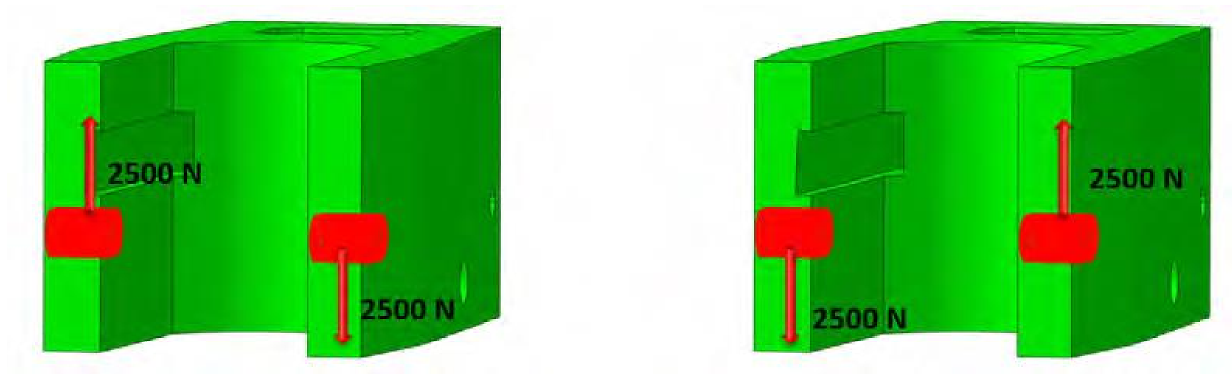

Figure 6. Load Case 2: Service loads acting on swing arm – torsional load

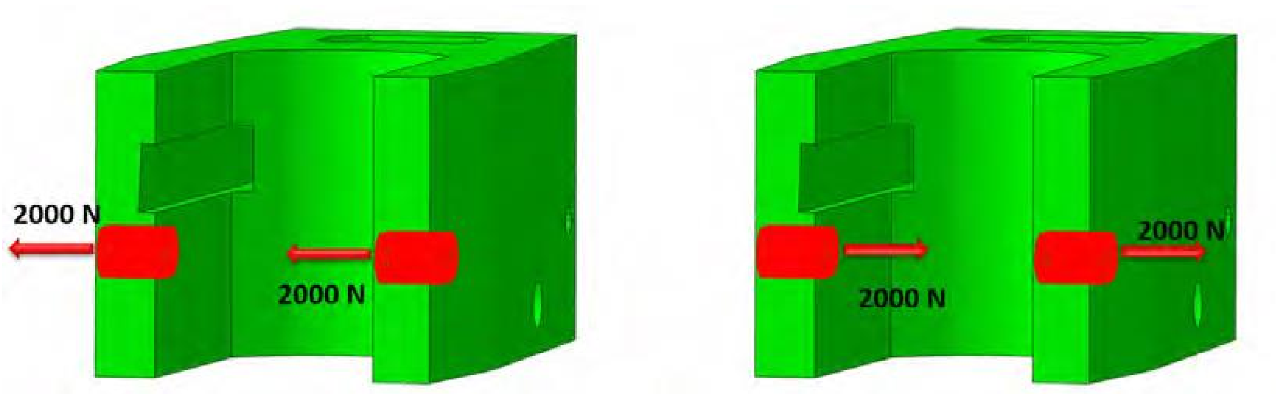

Figure 7. Load Case 3: Service loads acting on swing arm – lateral bending load

The Tosca optimization task set up is to find a shape of the swing arm with the maximum stiffness for the component with a volume or weight restriction. This represents the most common standard optimization task for the topology optimization. The value to be optimized is the compliance which is used as a measure of the stiffness.

The compliance is represented as the sum of the strain energies if the different load scenarios of the complete model. Here, this value has to be minimized. The constraint is the weight or volume constraint which is defined to be 30% of the initial volume/weight of the structure (the available design space).

As manufacturing constraint a casting/forging constraint has to be defined. The idea of the constraint is to ensure that the created structure of the topology optimization has no undercuts and can be remodeled (or removed from the forging die).

In Figure 8 the Tosca Structure panel on which the Casting Design Variable Constraint has been set is shown. Topology Link to control symmetry of the final shape has been added as optimization constraint.

Moreover, to control the maximum and minimum thickness of the final shape, a constraint of maximum member size (16 mm) and minimum thickness (10 mm) has also been defined as shown in Figure 9.

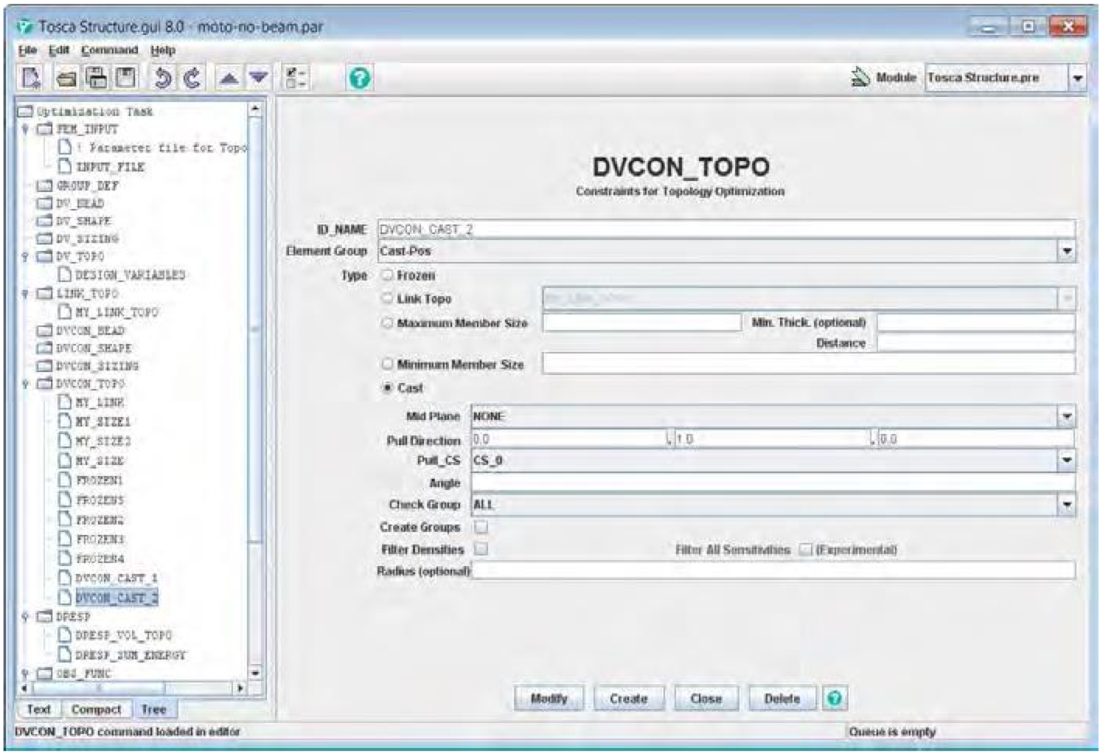

Figure 8. Casting Design Variable Constraint in Tosca Structure

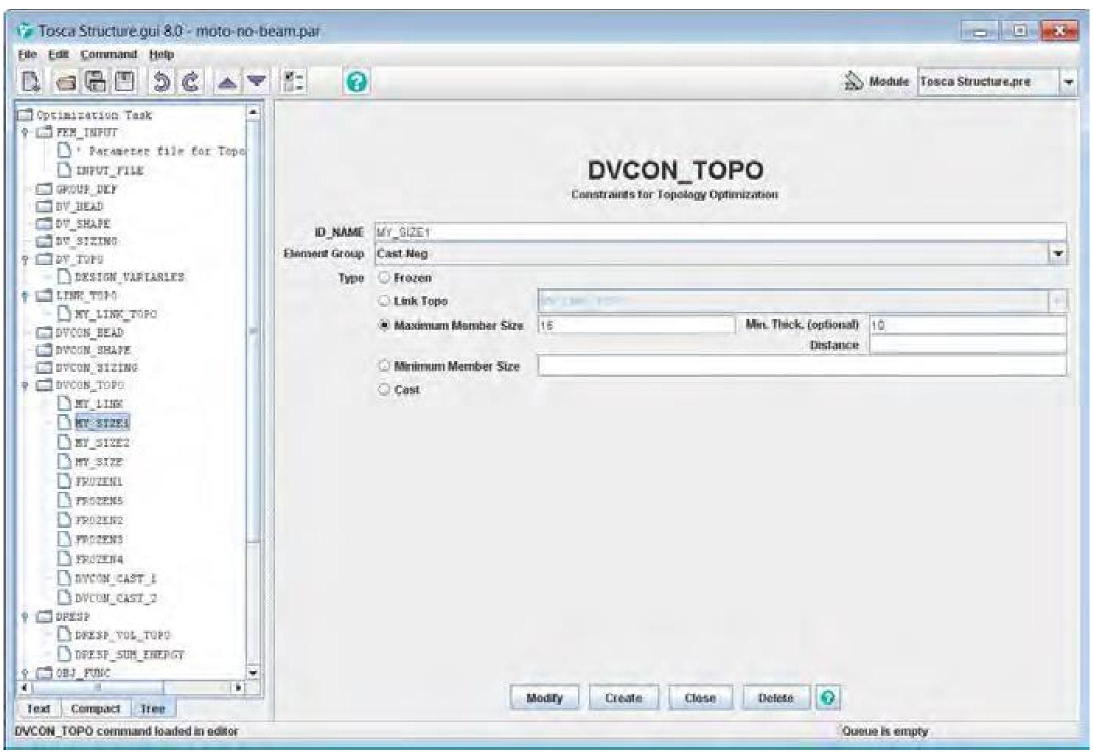

Figure 9. Maximum Member Size Constraint in Tosca Structure

4. Optimization Results

Considering the load cases and the topology constraints defined, after 15 iterations Tosca Structure obtains an optimized shape that is in compliance with the optimization task. The final weight of the optimized swing arm is of 4.7 kg and the shape is shown in Figure 10.

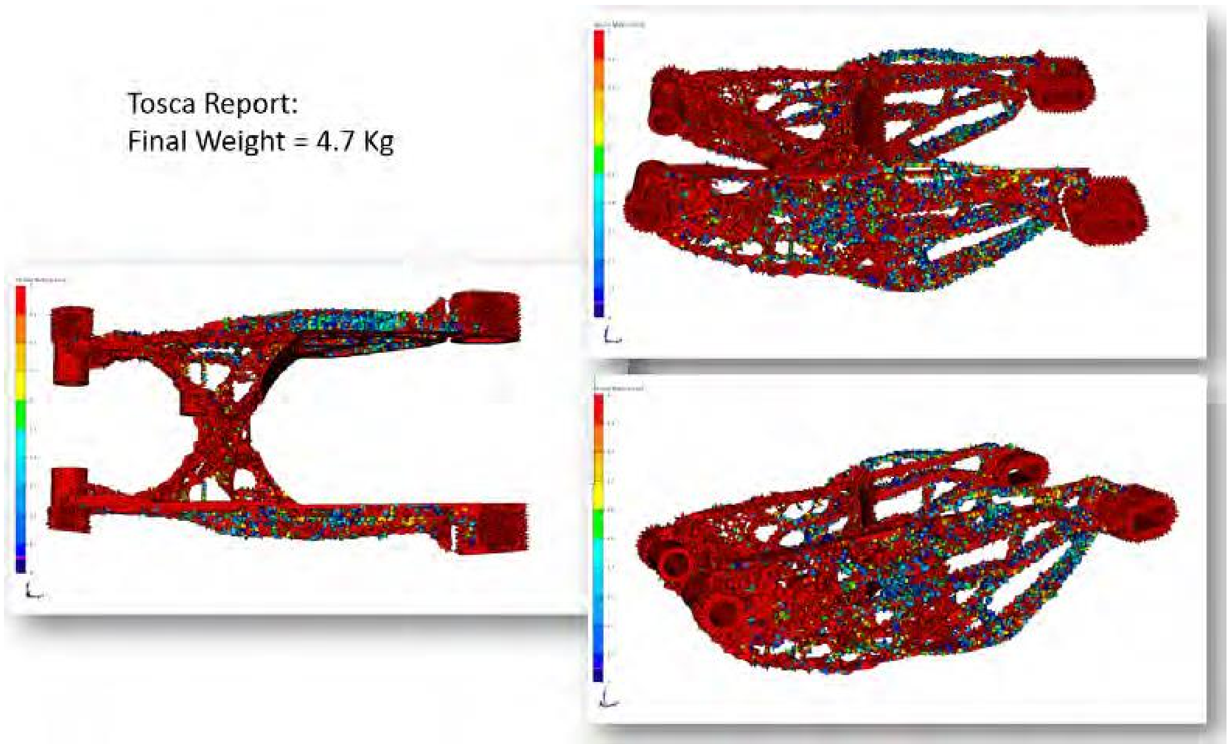

Figure 10. Swing arm optimized shape – Tosca Report View

As result of topology optimization, Tosca shows an "eroded" shape coming from the deactivation of elements that, during the optimization, have assigned a "zero stiffness".

This kind of shape can also be smoothed with Tosca Structure.smooth to get a shape suitable for detailed Finite Element analysis or for the final detailed design.

The smoothed geometry of the optimized shape is shown in Figure 11.

A final Abaqus stress analysis has been performed on the smoothed structure to verify the stress level on the optimized swing arm. The stress contour map is shown in Figure 12.

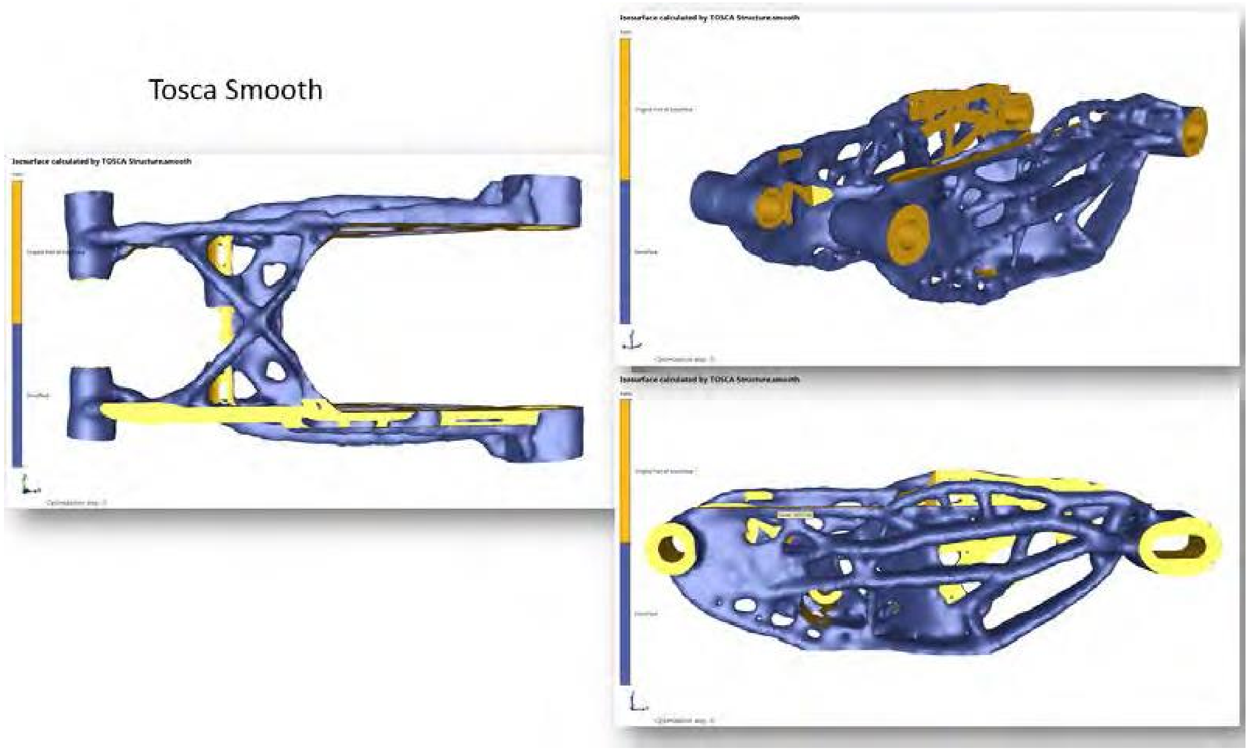

Figure 11. Swing arm optimized smoothed shape – Tosca Smooth View

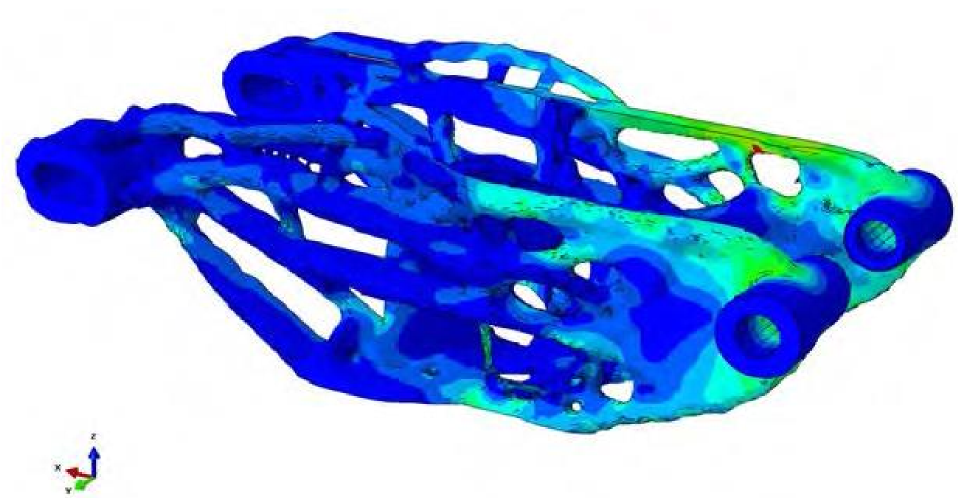

Figure 12. Swing arm optimized smoothed shape – Stress Contour Map

5. Conclusion

The proposed research aims to highlight the great potential that provides the topology optimization for the development of systems to be used in high performance mechanical components.

The benefits using Tosca Structure consists in saving about 30% of the time to market, obtaining shape that meets the requirements of the project and that can be manufactured at the same time respecting the target costs.
Moreover, the technology used in this case skips the CAD creation, using a technology, called Sensable Virtual Clay, able to get a polygonal geometric feasible part directly from STL coming from FEM, using a sort of "virtual sculptor technique" as shown in the following figure.

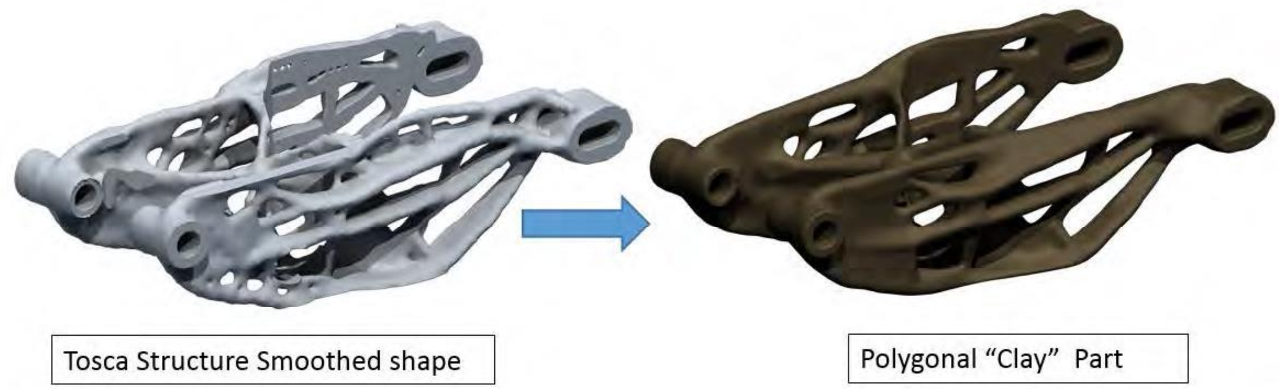

Figure 13. Polygonal clay part obtained from FEM

The polygonal part can be used directly to virtually evaluate casting and to produce the component. The virtual evaluation of casting has already be performed, as shown in figure 14. The core is realized in polystyrene with addictive manufacturing. The component is then produced with quick casting (lost foam technique). In the future the production time will be further reduced using rapid prototyping on aluminum (aluminum sintering procedure), skipping the addictive manufacturing phase to create the core and the lost foam casting.

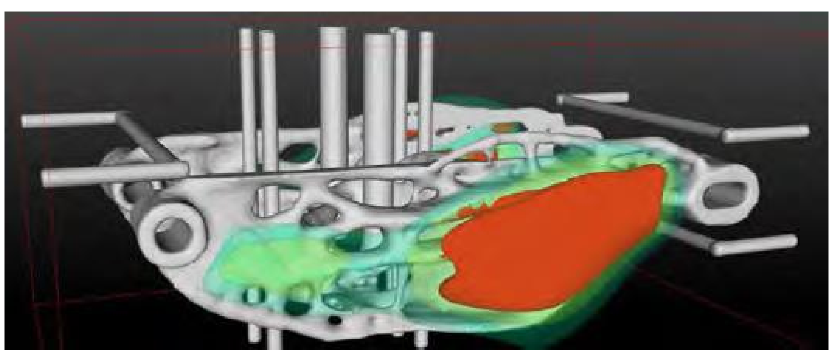

Figure 14. Casting virtual evaluation

Future development: after the realization of the prototype with the shape obtained with Tosca Structure based on static loads, we planned to go on with experimental experience of vibrational dynamic monitoring on track of a rear swing arm with FBG fiber optical sensors. With dynamic load monitoring we will evaluate if the prototype will need a further loop of optimization from the dynamic point of view. In concept phase dynamic loads were not available, and we planned to measure them on the real prototype.

6. References

1. Tosca Structure Documentation 8.0, Dassault Systémes Simulia Corp., Providence, RI.
2. Abaqus Users Manual, Version 6.14-1, Dassault Systémes Simulia Corp., Providence, RI.