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TOPOLOGY OPTIMIZATION APPLIED TO TOOLING PLANTS IN THE AUTOMOTIVE INDUSTRY

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Abstract.

The growth of the automobile industry leveraged the development of the toolmaking branch, although this sector had been producing tools for the most diverse purposes. From the inception of the tooling industry, the understanding of the structural response of the designed tools was very limited, so sizing of all the devices and machines ended up in a rather oversized configuration. Over the years it was noted that the competitiveness of the automotive segment can be evaluated by the performance and quality in the production chain, therefore, optimization techniques are used to increase these parameters and to provide tooling quality improvements for the automotive industry, resulting in cost and time reduction. In order to eliminate, or at least alleviate the oversizing problem, the Topological Optimization (TO) approach emerged, which is the result of improved parametric and shape optimization that performs internal and external boundary changes without violating the design conditions. The present work assesses topological optimization analysis of stamping dies for the automotive industry, aiming at cost reduction and improvements in the construction and production processes. The objective of this study is to perform static analyses of automotive stamping tools, for drawing operation, followed by topological optimization. For this purpose, the commercial software of topological optimization Virtual.Pyxis developed by VirtualCAE will be used, which has integration with the Siemens NX package as a solver to perform the modeling and to obtain the design responses. The process loads used as an input of the optimization simulations were obtained by the assembler that owns the tool, in this case the Fiat Chrysler Automobiles (FCA). The goal is to obtain a significant reduction of material due to an optimized design, simultaneously maintaining the quality in the operation process, considering that the removal of material can affect the stiffness of the part as a whole, making it more flexible, thus inducing problems of accuracy in the final formed product.

Keywords: topology optimization, metal forming, numerical simulation

1. INTRODUCTION

The need for greater competitiveness in the global market leads to ever growing industrial demands such as cost reduction, increased efficiency, innovation and greater reliability, all of which may be met by the creation and implementation of new technologies. The development of new technologies and their application in manufacturing over the decades led to the proposal of new methodologies to improve the process as a whole, such as the study and development of Topology Optimization (TO). Some scientific works have been done with the purpose of performing optimizations in cold sheet metal forming tools. One of these studies is the subject of the thesis of Birath (2006), who made a study of topological optimization in the die tool for the production of the Volvo S80 trunk lid, reducing the weight by 20% and increasing the stiffness by approximately 30%.

The development of computer simulations, notably the Computer Aided Design (CAD) and the Finite Element Method (FEM), are associated with the main applications for TO in practical engineering problems. Briefly, TO is a numerical method designed to refine the layout of an object, aiming at the optimal positioning of material under certain design criteria, through multiple FEM analyses. This process has been gaining a lot of space in additive manufacturing because of the complex shapes that result from the optimization process, but it can also be applicable to traditional manufacturing processes such as casting and machining, which are common in automotive tools (Bahia, 2005).

The TO methodology consists in defining a certain project domain, then performing the discretization of the body under study by approximate methods, applying on it the proper boundary conditions. Only then the domain information is processed in the TO algorithm through an interactive procedure, in which the material is distributed in order to maximize or minimize the desired objective function. The result of the analysis obtained after post-processing is the optimal topology (Liu, 2018).

The development of layout optimization emerged around the beginning of the 20th century with studies by Michell (1904). However, due to the inexistence of a tool that could help such an approach by processing data, the methodology was without any application in the industry. Only after years of study and software development did topological optimization spread and found its applications in the most unusual engineering purposes as a whole.

Throughout the development of TO some material models for obtaining the desired results were elaborated: SIMP, TSA, ESO and SESO. The technique developed by Bendsøe (1988), Simple Isotropic Material with Penalization (SIMP), consists in using a material of artificial feature in order to impose penalties. In view of the need to determine the empty regions, the material has its constitutive behavior determined by a parameter related to the density, where the solid is represented by artificial density equal to one, whereas the void is represented by density equal to zero. The Topological Sensitivity Method (TSA) has its operation based on a scalar function declared as topological derivative that provides at all points of the problem domain the sensitivity of the cost function associated with the creation of the void. The conventional Evolutionary Structural Optimization (ESO) technique developed by Xie and Steven (1993), which in essence occurs through a process called "hard-kill", consists of removing material in which stresses with small values act in a discrete manner, since this element is used inefficiently. Finally, the Smoothing Evolutionary Structural Optimization (SESO) technique was proposed by Simonetti (2009), which represents a smoothing of the classic ESO, aiming to reduce the impact of the latter. Its procedure consists in reducing the stiffness contribution in each interaction of each element that does not suffer the action of stresses with high values in a process called "soft-kill", instead of removing the material completely.

Topology optimization seeks to minimize or maximize a given functional that respects determined constraints, in order to distribute the material in the best feasible way within the design domain. The fundamental components for the optimization process described by Secchi (2001), are basically three: objective function, design variables and the constraints. The objective function is designed to represent and quantify the object by mathematical bias to be minimized or maximized according to the design purpose. The design variables are the project parameters that can be changed in order to search for topological optimization of the structure. The design variables describe the way how the equations are assembled to determine the objective function. Finally, the constraint functions are basically the limits imposed on the design variables, and can be represented by equations of equality, inequality or side (Bendsøe, 2003).

In the Virtual.Pyxis software the design responses that represent the constructive constraints applied to the project are divided into two groups. The first is the standard design response which can work as objective function or as constraints, being composed by frequency, volume, mass and compliance. The second group of design responses is the manufacturing design responses that work only as optimization constraints, divided into casting, symmetry and extrude. The present study is going to use the standard design response compliance and volume.

In the present work, topology optimization of a stamping tool used in a manufacturing process of the automotive sector was performed aiming for significant mass reduction, bringing substantial advantages to both the tool's construction and its operation, and consequently cost reduction.

2. MATERIAL LAW FOR TOPOLOGY OPTIMIZATION

The material model is designed to determine the structure within the design domain and is required for material characterization among void, intermediate stage and solid. The material law that Virtual.Pyxis has in its source code is the Simple Isotropic Material with Penalization (SIMP). In essence, the SIMP model predicts the optimal material distribution over the design domain using discrete functions for the defined load cases, respecting the design constraints.

The approach of this topological optimization model consists in discretizing the domain, in a finite element mesh. The distribution of the material pseudo-densities within the design domain is given by binary values, with one being assigned for presence of material and zero for its absence. In order to avoid the discrete nature due to the binary order problem of element activation and deactivation, a continuous relative pseudo-density distribution function is introduced, disfavoring the appearance of intermediate densities. The ideal topology is composed of regions with or without the presence of material (Bendsøe, 2003).

Knowing that, each element has its relative density (pseudo-density) equivalent to the density distribution function ρ_e associated with the modulus of elasticity of an isotropic material E_0 . The relationship between the two is calculated by a power law as shown in Eq. (1) (Bendsøe, 2003).

$$E(\rho_e) = (\rho_e)^p E_0 \quad (1)$$

The penalty factor p is intended to reduce the occurrence of elements with intermediate densities, bringing the values of the pseudo-densities closer to one or zero according to their arrangement. Studies of numerical experiments have shown that the penalty factor equal to three presents more satisfactory results (Duysinx and Sigmund, 1998; Rozvany and Lewiński, 2012). Using higher values can create excessive penalties making the continuous problem tend to become a discrete problem, thus bringing numerical instability resulting from the sudden variation in the values of pseudo-densities (Bendsøe, 2003).

Some problems inherent to the application of TO relate to the numerical instability of the methodology, and can be divided into three categories. The first is mesh dependence, where different mesh discretizations do not necessarily result qualitatively in the same solution, but rather end up creating a topology with more holes and numerous details. The second problem is the formation of local minima that refers to the problem of obtaining different solutions when different parameters of the algorithm are chosen. Finally, the third category, checkerboard instability, is one of the most common problems, which is the formation of regions with alternating solid and empty material. In order to circumvent such issues a number of techniques have been developed, such as the use of filters and the relaxation of the numerical problem (Bendsøe, 2003).

According to Arora (2004) an optimization algorithm must possess its structure, its inherent precision, ease of use and efficiency. In addition, it should be able to converge to the optimal point regardless of the initial estimate, and it should handle both equality and inequality constraints, so that a good final result is achieved in the optimization process. In the present paper Virtual.Pyxis commercial software was used, which presented itself as a highly reliable software, being on the market since 2015.

3. OPTIMIZATION METHOD

The process of interaction between finite element software and topological optimization software is introduced starting from the FEM analysis, in which the structure is discretized into a mesh of small elements, as refined as desired, in order to obtain better results in the optimization analyses. The data regarding geometry, loads, boundary conditions and refinement of the structure's mesh, in addition to material properties such as the modulus of elasticity are passed on to the TO software. Once the objective and constraint functions are available, their respective sensitivities are obtained, which are basically the derivatives of these functions. However, the objective and constraint functions are not always feasible to obtain their respective derivatives directly. Therefore, approximation functions are applied as an intermediary mechanism in order to make it possible to calculate the derivatives of the objective and constraint functions in a more simplified way. The sensitivities generated by the approximation functions, which are basically the derivatives, enter in the non-linear optimization method, which works with the deformation energy of the elements, returning in the output new updated pseudo-densities that will be returned to the finite element solver. This iteration is repeated until convergence is obtained in the desired topological optimization criterion or the maximum number of iterations is reached (Bonnans, 2006).

The optimization can be divided into three classes depending on the type of function. It is considered linear when both the objective function and the constraints are linear functions. It is considered non-linear when both, objective and constraints are nonlinear functions. Finally, it is considered quadratic when the objective function is quadratic and the constraints are linear (Afonso, 1995). Among the constrained nonlinear optimization methods there are three: feasible-point methods, barrier methods and penalty methods. The barrier method transforms the constrained problem into an unconstrained problem, subsequently introducing constraints into the objective function through a barrier parameter, which prevents the approximation of a feasible point to the boundary of the admissible region. The penalty method is a model that transforms the constrained optimization problem into an unconstrained optimization problem by introducing a penalty that grows as the deviation in meeting the admissible regions increases. While the barrier method works from

inside to the edge, the penalty method works from outside to the edge. Finally, the feasible-point method works with the change of the design variable always within the admissible region (Griva, 2009). The methods of explicit approximations available in the literature to obtain the approximation function are Sequential Linear Programming (SLP), Sequential Quadratic Programming (SQP), Convex Linearization (COLIN), Optimality Criteria (OC) and Method of Moving Asymptotes (MMA). Among these, the Virtual.Pyxis has implemented in its work routine the MMA and OC optimization functions, being MMA considered a more general function demanding more processing time, while OC is a more specific function demanding less processing time.

Each optimization function model has its advantages and disadvantages. The Method of Sequential Linear Programming (SLP) works with the linearization of the objective and constraint functions, being the simplest method of all. However, its main disadvantage is the fact that it does not ensure convexity of the function. Therefore, it may not ensure convergence to an optimal value. The Method Sequential Quadratic Programming (SQP) is based on applying the Newton-Raphson method to the minimization of an approximation of the Lagrangean function of the problem, where the model adds to the objective function a quadratic term that ensures the convexity of the function. The Convex Linearization (COLIN) method can be applied to systems of equality or inequality constraints, where the model aims to ensure the convexity of the approximation function by means of reciprocal variables, and its main disadvantage is that it is very conservative. The MMA has similar characteristics to COLIN, but has the advantage of imposing upper and lower bounds on COLIN so that the functions are asymptotes, thus ensuring that it is closer to the minimum or maximum besides ensuring the convexity of the function by reducing the conservatism of the model. The last method is a variation of the COLIN, the Optimality Criterion (OC). It has a specific constraint function and linear behavior, while the objective function can be non-linear (Bonnans, 2006). Figure 1 shows the flowchart for a single iteration of the work routine between the FEM solver and the topological optimization solver.

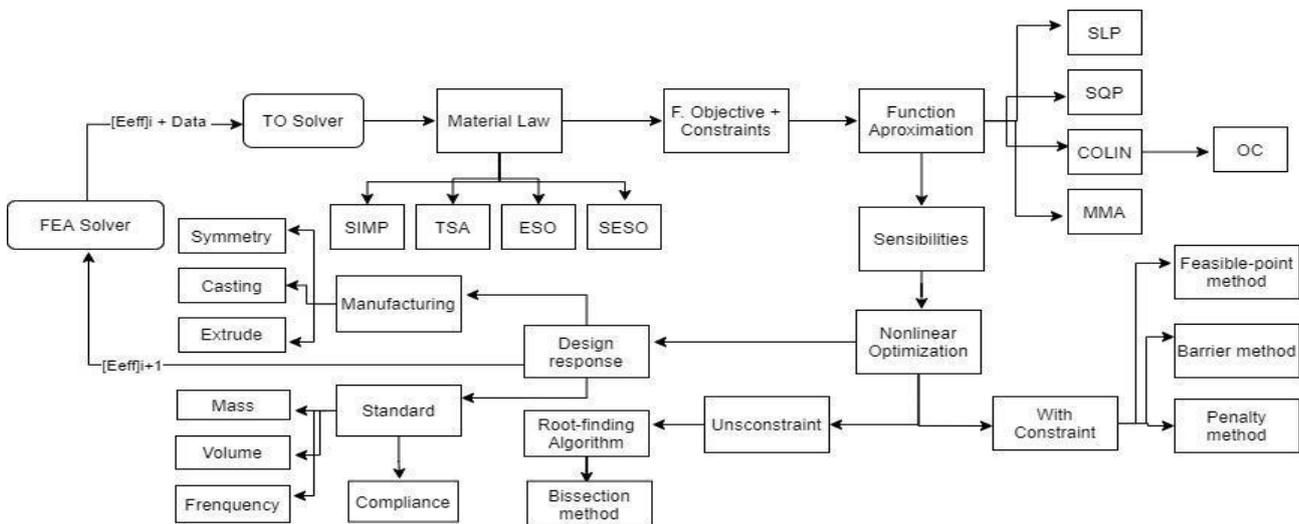


Figure 1. Flowchart of the work routine in topology optimization.

4. METHODOLOGY

The sheet metal forming is the process of converting a flat sheet of metal into a part of desired shape without fracture or excessive localized thinning. There are many types of forming: bending, stretching, plane-strain stretching, coining, and drawing. The operation of drawing sheet metal causes compression in one direction and elongation in the perpendicular direction. The easiest example for understanding this process is a flat-bottomed cylindrical cup. In this process a circular disk is held between two flat annular dies and impacted in the center by a flat-bottomed punch, drawing the edges of the disk inward to form the wall of the cup. The metal is stretched radially by the tensile forces produced by the punch (Taylor, 2006).

The stamping tool for the deep drawing operation came from a Fiat Chrysler Automobiles (FCA) project, and was designed for the production of the B structural column of a conventional vehicle model. The tool under study is presented in Figure 2. This tool fits into the double effect category, characterized by the separate movement of the upper elements, where the binder is the first to come into contact with the blank, followed by the punch that touches the plate in sequence.

Some constituent elements of the drawing tool suffer greater stresses during load application due to their position in the tool such as the punch, the die and the binder, in addition to the contact regions between elements. These will not be considered for this optimization study, in view of the level of criticality to enable an optimization in them, which could lead to a reduction in the rigidity of the part, resulting in plastic deformations in the tool, which would bring as a major disadvantage a conformation of the blank outside the project dimensions. Thus, the tool elements over which optimization

will be conducted are the upper and lower tool shoes. For analysis purposes, two loading conditions are considered. The first considers the application of the load provided by the hydraulic press for the entire system of tool components, while the second case of loading considers the tool during transportation, in which all the self-weight is concentrated on the tool's support handles. The results from the topology optimization analyses are obtained in the Virtual.Pyxis software. Care is taken to ensure that no plastic deformation occurs so that the tool does not keep deforming, which may cause irregular blank drawing.

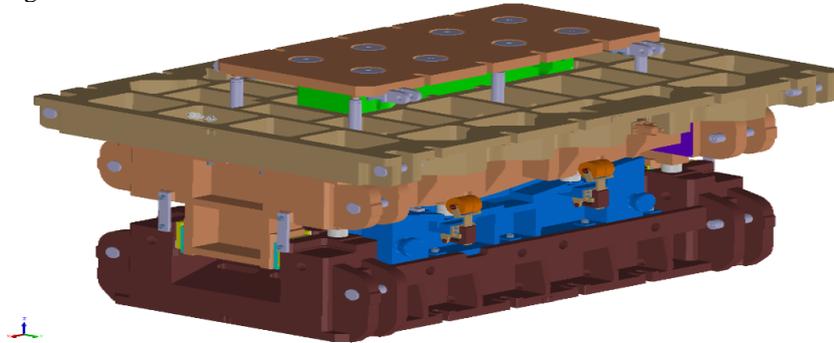


Figure 2. Tool of the drawing operation.

The main objective of the present study is to perform the topological optimization of the top and lower shoes of the automotive stamping tool for the drawing operation. For this purpose, the objective function stipulated was to maximize the stiffness, with the restriction of reducing the volume of the optimized components up to 50%. Figures 3a and 3b show the shoes.

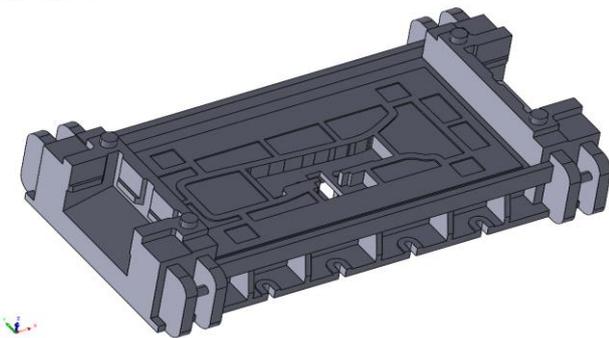


Figure 3a. Lower shoe of the drawing operation.

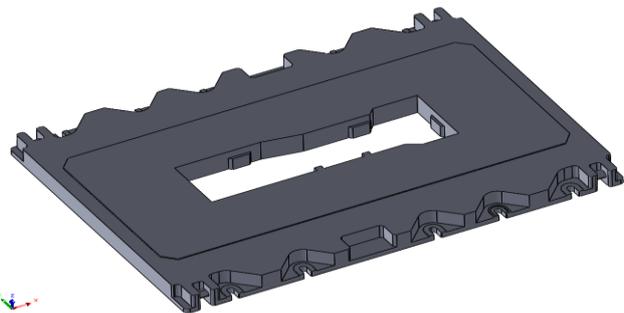


Figure 3b. Top shoe of the drawing operation.

The following modeling considerations were made in the FEM software: the imposition of restricted displacement in the three axes along the lower contact surface of the shoes, considering it as simply supported. With respect to the loading coming from the hydraulic press, it was admitted that the lower shoe received a load in the contact area with the die of 220t and a load of 110t of the attachment points coming from the punch, totaling the load of 330t applied to the shaded blue area in Fig. 4a. The top shoe receives 220t of the binder on the contact surface and 110t along the six cylinders that perform the return of the punch to its original floating position. Figures 4a and 4b show the application points of the loads on the lower and upper shoes respectively by the press.

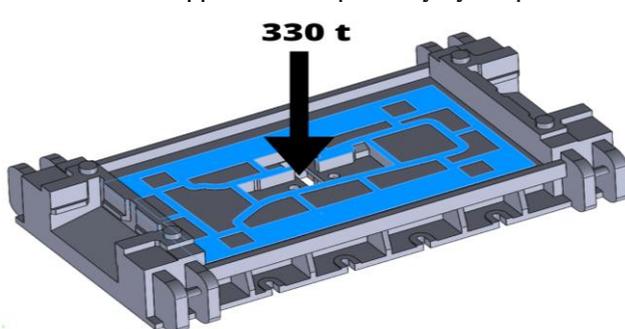


Figure 4a. Loads applied to the lower shoe.

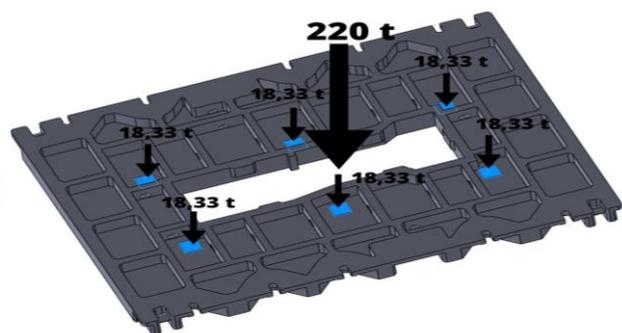


Figure 4b. Loads applied to the top shoe.

Finally, for the case of transport loading, the self-weight of the entire spinning tool distributed on the lower table body was applied, this value being equal to 12t. However, a common practice during the transport process is to overlap one tool over the other in order to speed up the transport. Taking this information into consideration an increase factor equal

to two was adopted, so the total load became 24t. For this specific loading case, the restrictions were applied to the four pins located on the sides of the lower shoe that are used for lifting and are connected to the transport trunnions.

Regarding the material properties used to characterize the mechanical behavior of the structure under study, the GG25 cast iron material properties were used according to the DIN 1691 standard: $E = 125 \text{ GPa}$, $\nu = 0.33$, $\rho = 7.2 \text{ g/cm}^3$. Linear elastic mechanical behavior was assumed since plastic deformation is not allowed in these structures. A mesh composed of parabolic tetrahedron elements was created, since FEMAP could not mesh hexahedral elements in view of the multifaceted geometry. The average element size of the mesh was set to 15 mm. After linking the mesh of the geometry to the support conditions, loading and material properties, the topological optimization of the tool was performed considering one loading case for the top shoe and two service cases for the lower shoe discussed in the methodology topic. In order to be able to perform the optimization of the central block and the side blocks of the lower shoe, two different meshes were set up to perform the optimization separately through their respective meshes.

5. RESULTS

In this section the result of the optimized geometries of the drawing tool components are presented, these being the top and lower shoes. It is described how the final optimized shape of the parts were obtained and the parameters analyzed in order to validate the mass reduction, stiffness gain and simultaneously ensure that the component is not subjected to more stress than it can resist, therefore some failure criteria were evaluated.

For all topological optimization analyses performed in Virtual.Pyxis software, the optimization results satisfied the constraints and objective functions. For the lower shoe in the first loading case the convergence was achieved with 36 iterations, with the focus on maximizing the stiffness and constraining the volume. Figure 6 shows the result of the lower shoe structure obtained from the topology optimization, for the case of service loading, where the press applies the pressure to make the stamping. This result of topological optimization will be used as a reference to redesign a new lower shoe.

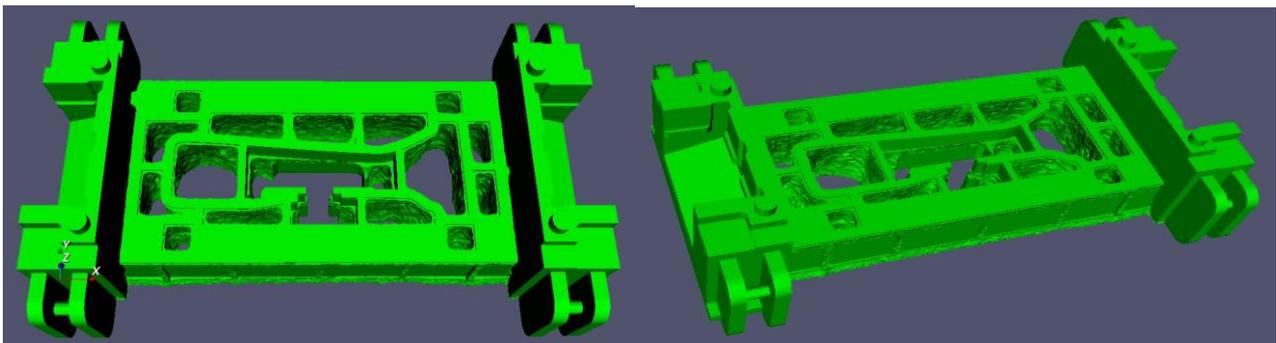


Figure 6. Result from the optimization of the lower shoe for the first loading case.

When the topology optimization result is evaluated, it is important to emphasize that this result for a given loading configuration may not be optimal for another loading case. In other words, the optimal design is not necessarily the same for all the possible loading configurations that a structure may be subjected to. For this reason, the topology optimization was performed for the case of self weight loading, which occurs during the tool transport process causing the bending of the lower shoes. Figure 7 shows the optimization result for the lower shoe considering the second loading case. Convergence was achieved with a total of 63 interactions.

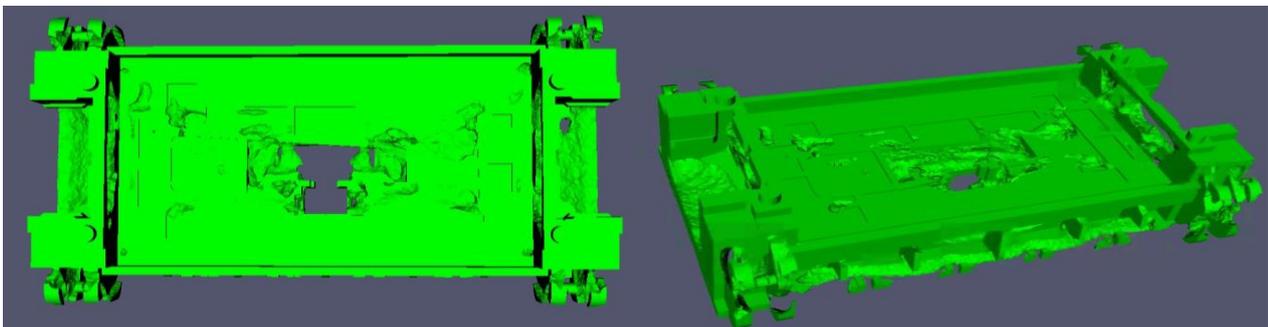


Figure 7. Result from the optimization of the lower shoe for the second loading case.

Following the same procedure, the optimization of the top shoe was performed. Results converged after 44 iterations. Figure 8 shows the result of the top shoe optimization.

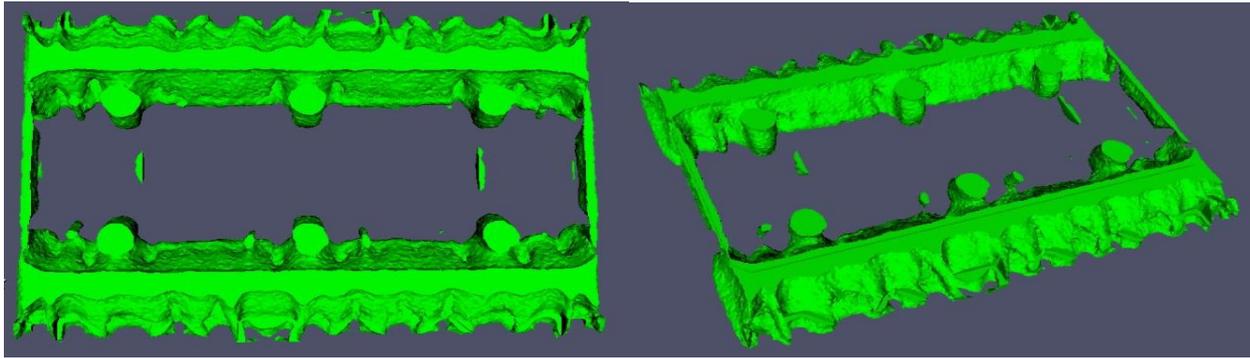


Figure 8. Result from the optimization of the top shoe.

5.1 Redesign of the shoes

After analyzing the optimization results it is possible to observe that the resulting geometry is extremely irregular, without a well defined shape, resembling an organic structure. The geometry is not feasible to be manufactured in the casting process and does not simultaneously respect in some points the non-optimizable areas. Therefore, it must be redesigned to meet the design requirements of the project. A CAD model is created from the pattern obtained in the results of the topology optimization in the software Virtual.Pyxis, which generates a file in stl format. The stl file was used for the purpose of redesigning in the software Solid Works together with NX. The non-optimizable regions were respected, which were the support contacts, load application regions and support areas for the other components of the stamping tool.

It is worth noting that the redesign step, although following as a reference the pattern recommended by the optimization result, can be interpreted in different ways by the designer in some peculiarities that can influence the final result of the geometry. Figure 9 shows the result of the CAD in an isometric view of the top and lower of the lower shoe for the first loading case. Following the optimization result, material was removed from the recessed perimeters located in the central part where there is a small step. The contours of the ribs in the lower region were also recreated.

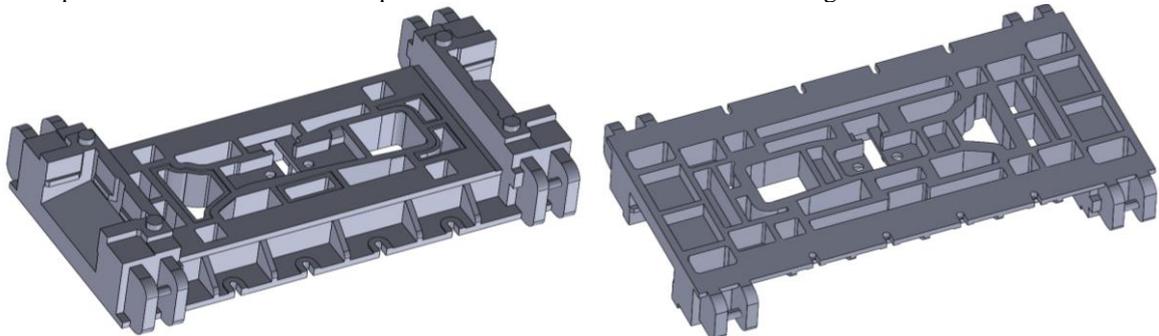


Figure 9. Model of the redesign optimized lower shoe for the first load case.

Figure 10 shows the result obtained after redesigning the lower shoe for the case of tool transport loading. It should be noted that the optimization was performed only on the side blocks; the central block maintains its original geometry, since in this loading case the optimization located on the sides was set.

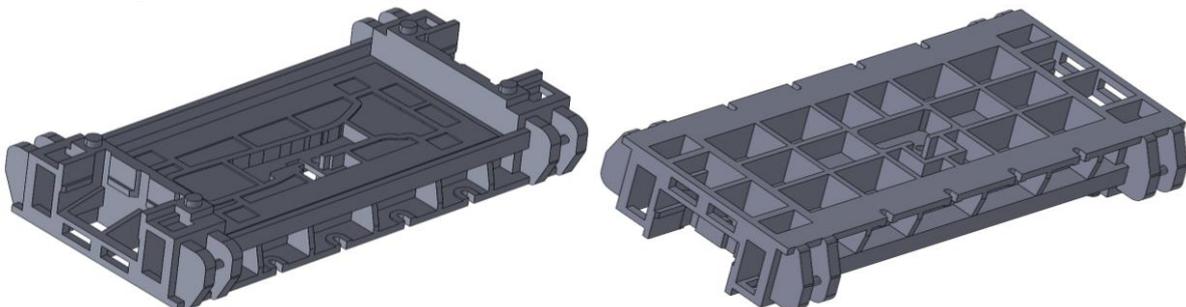


Figure 10. Model of the redesign optimized lower shoe for the second load case.

The optimization of the lower shoe's center block from the first loading case and the side blocks for the second loading case were combined, resulting in the final geometry of the lower shoe shown in Figure 11.

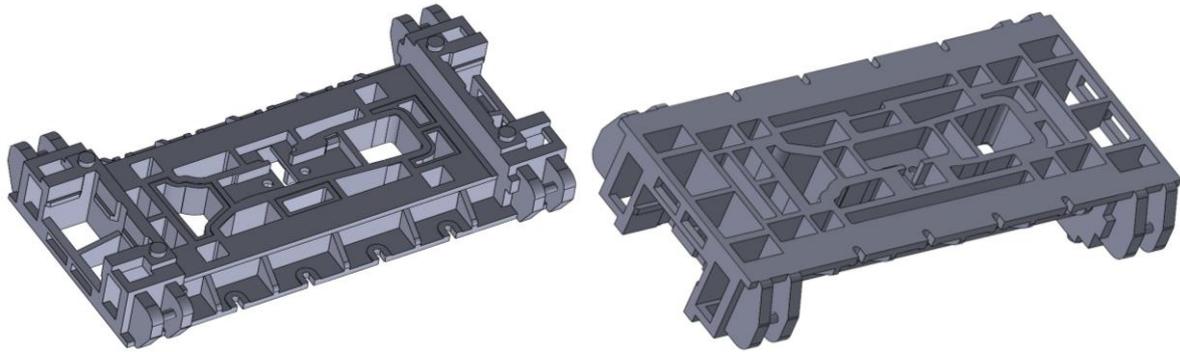


Figure 11. Model of the redesign optimized lower shoe combined both loading cases.

Using the same reasoning, the top shoe was redesigned. It can be inferred from the optimization result that the central part of the shoe is not essential to ensure the stiffness of the component. However, one cannot simply remove all the central material since many support areas for some components pass through the central region. After working on the shoe redesign, Figure 12 shows the CAD model of the new optimized top shoe.

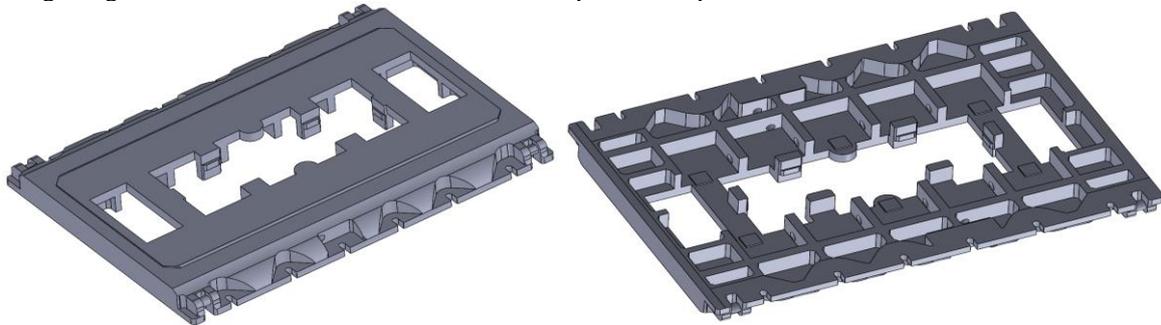


Figure 12. Model of the redesign optimized top shoe.

5.2 Displacement and stress analysis

After the redesign of the lower and top shoes based on the optimization results, FEM simulations with the same boundary conditions were performed in order to establish a comparison with the original structure behavior. The metrics for the comparison can be the maximum displacement to assess the stiffness of the structure, maximum Von Mises stress and the maximum shear stress according to the Tresca failure criterion to evaluate safety. The Tresca criterion is more assertive for brittle materials, which is precisely the case of the GG25 cast iron used to produce the tool shoes.

When reading the metrics obtained from the FEM simulation after the redesign of the lower shoe for the case of press loading, it is observed that the mass remained almost the same, with a reduction of only 4.5%, while there was a significant increase in stiffness of around 54%. This result was intentionally obtained throughout the redesign development process, in order to present a solution where what is desired is the reduction of maximum deflection rather than the reduction of mass. In the redesign optimization what should be evaluated as predominant are the design criteria that best suit the proper functioning and purpose of the component. Considering that this is the lower shoe of the drawing tool, a steeper reduction of the maximum deflection will imply a more assertive stamping, since the displacement components along the drawing tool will accumulate. Finally, the maximum Von Mises stress and maximum shear stress values remained well below the ultimate stress values for tensile and shear.

Table 1. Comparison between original lower shoe and optimized for the first loading case.

| Measured Parameters | Lower Table | | |
|----------------------------|-------------|-----------|------------|
| | Original | Optimized | Difference |
| Maximum displacement (mm) | 0.0515 | 0.0236 | -54.2% |
| Maximum Von Mises (MPa) | 57.6 | 34.7 | -39.7% |
| Maximum shear stress (MPa) | 30.86 | 18.04 | -41.5% |
| Mass (kg) | 3240 | 3096 | -4.5% |

Table 2 shows the values obtained after modeling in FEMAP, for the lower shoe considering the case of loading from self weight. It can be seen that the stiffness of the component remained almost the same with a reduction of 8.5% of the total mass of the shoe. However, if one takes into account that only the side blocks were optimized and compare only the

original side blocks compared to the optimized, there was a reduction of 20% of mass. Finally, it is observed that the failure criteria are below the strength limit of the material.

Table 2. Comparison between original lower shoe and optimized for the second loading case.

| Measured Parameters | Lower Shoe | | |
|----------------------------|------------|-----------|------------|
| | Original | Optimized | Difference |
| Maximum displacement (mm) | 0.215 | 0.218 | +1.4% |
| Maximum Von Mises (MPa) | 160.7 | 168.9 | +4.8% |
| Maximum shear stress (MPa) | 91.79 | 93.24 | +1.5% |
| Mass (kg) | 3240 | 2960 | -8.6% |

Finally, a general compilation was made considering the redesign obtained from the combination after the optimization of the lower shoe for the two loading cases. A comparison of this optimized geometry was performed for the two service cases and compared to the original table, as shown in Table 3.

It is interesting to note that, for the first loading case, the stiffness remained the same, i.e. the removal of material due to the optimization for the other loading condition did not affect the stiffness of the structure. However, the stress values had a small increase when compared to the optimized shoe only with geometry update of the center block show in Table 1. While for the second case of loading, there is a reduction of 10.4% in the table stiffness, it is inferred that the first case of optimization contributed to the attenuation of the optimization of the second case. It is also observed that there was an increase in the stresses compared to the case of optimizing only the side blocks of the table, as seen in Table 2. Finally, the grouping of the optimized lateral and central blocks generated a reduction of 12.2% in the total mass of the lower shoe.

Table 3. Comparison between original and optimized bottom shoe combined both loading cases.

| Measured Parameters | Lower Shoe - 1st loading case | | | Lower Shoe - 2st loading case | | |
|----------------------------|-------------------------------|-----------|------------|-------------------------------|-----------|------------|
| | Original | Optimized | Difference | Original | Optimized | Difference |
| Maximum displacement (mm) | 0.0515 | 0.0236 | -54.2% | 0.215 | 0.240 | +10.4% |
| Maximum Von Mises (MPa) | 57.6 | 37.46 | -34.9% | 145.4 | 169.7 | +14.3% |
| Maximum shear stress (MPa) | 30.86 | 20.01 | -35.1% | 82.4 | 96.79 | +14.8% |
| Mass (kg) | 3240 | 2844 | -12.2% | 3240 | 2844 | -12.2% |

Table 4 shows the comparison of the parameters evaluated for the top shoe. It is possible to observe that there was a significant increase in the stiffness of the component, which can be interpreted by the reduction in the maximum displacement, which for the application in the component was approximately 16%. Therefore, it can be stated that the objective function was reached. According to the same Table 4, there was a significant increase in the maximum Von Mises stress, however the optimized shoe stress remains below the maximum tensile stress for the GG25 material, which is in the range (250-350 MPa) according to (DIN 1691, 1985). Regarding the Tresca criterion, evaluated by the maximum shear stress, even with the increase around 17.5% in the shear stress the value is still below the maximum shear stress that for GG25 (280 MPa) according to (DIN 1691, 1985). Finally, the last parameter to be commented on is the mass of the component in which 18.7% reduction in mass was obtained.

Table 4. Comparison between original top shoe and optimized.

| Measured Parameters | Top Shoe | | |
|----------------------------|----------|-----------|------------|
| | Original | Optimized | Difference |
| Maximum displacement (mm) | 0.325 | 0.272 | -16.3% |
| Maximum Von Mises (MPa) | 130.8 | 170.8 | +23.4% |
| Maximum shear stress (MPa) | 73.61 | 89.18 | +17.5% |
| Mass (kg) | 3287 | 2671 | -18.7% |

6. CONCLUSION

The present work presented the topology optimization of two components of a stamping tool of the automotive sector. Optimized structures were obtained with mass reduction while maximizing the stiffness according to a service loading case of a drawing tool. This work reveals the enormous potential of the optimization tools to bring gains for the automotive tooling manufacturers enabling significant cost reduction.

It was observed that during the development of the redesign it is possible to improve different parameters of interest, in the case of the present study the maximization of stiffness or the reduction of mass. It is convenient to evaluate which

parameter is more relevant for the application of the component. It is concluded that the topology optimization solution for a given structure under certain loading configuration, when evaluated under another loading scenario, can result in a solution that becomes non-optimal and can be indeed dangerous or unsafe.

Suggestions for future works are to perform more localized optimization steps in regions where the acting stresses are low in order to obtain greater reductions in the mass of the components. It is also interesting to conduct a more refined study in order to investigate to what extent the optimization of a given region compared to another area of interest when subjected to different stresses within the same component can influence the structural responses to each other, improving the objective function. Another suggestion is to perform a viability analysis on the casting process of the shoes in order to ensure that the result of the optimization does not result in a bottlenecks. For instance, very thin ribs can be difficult or even impossible to manufacture through casting.

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8. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.