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THE EFFECT OF ADVANCED TECHNOLOGIES ON LIGHTWEIGHT DESIGN AND MANUFACTURING OF A SAE STEERING WHEEL

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Abstract: *The steering wheel of the formula student car (SAE) represents an important component that the driver interacts with car, through a fully mechanical steering system. This paper proposes a lightweight steering wheel manufactured in two versions based on the advanced technologies such as water jet cutting, autoclave vacuum bagging, and 3D printing. Lightweight design procedure used in this paper involves an optimal shape of the steering wheel based on size constrains and lightweight materials. The steering wheel was manufactured in two versions, one from 6082-T6 aluminum alloy and the other from carbon fiber reinforced polymer (CFRP). Both product versions have side grip components 3D printed using fused deposition modeling (FDM) technology. A new design of SAE steering wheel was proposed, and validated by static structural analysis using finite element method (FEM). The results have showed a significant mass reduction of 40.8% for CFRP steering wheel version, it having also superior performance in mechanical characteristics.*
Keywords: *lightweight; SAE; steering wheel; CFRP; static structure analysis; manufacturing; 3D printing.*

1. INTRODUCTION

Formula Student is one of the most established and widely-held engineering competition for students. In the early 1980s, the Society of Automotive Engineers (SAE) organized the competition in Austin, Texas, after which it quickly spread to Europe, Asia and Australia [1]. The competition aims to test engineering, management and business knowledge, with the objective of the competition being to design and build a single seat racing car.

The steering system is one of the main interfaces between the driver and the vehicle and is used to transfer steering input and steering torque to the rest of the steering system.

There are some steering wheels types used in Formula Student, made of different materials. Thus, it can mention the following types [1-3]: a classic round shape design with spoked, rectangular shape made of aluminum and 3D printed handles, rectangular shape and hollow construction made of carbon fiber and with integrated electronics, and rectangular shape made by 3D printing with integrated electronics. These types of SAE steering wheels have advantages but also disadvantages. The classic round shape design with spoked it is heavier than other models. The steering wheels with integrated electronics are expensive due to the electronic elements and the manufacturing costs of the molds [2]. Additive manufacturing technology makes possible obtaining a lightweight construction if it is properly optimized [3].

Lightweight design can be defined as “the science and the art of making things parts, products, structures as light as possible, within constraints” [4].

A lightweight design of the steering knuckle using the topology optimization approach for the Formula Society of Automotive Engineers competition considering two different mass constraints and steel alloy materials was proposed in [5], but a customizable design was not necessary to be done.

In the study [6], it was performed an application of finite element algorithms for formula racing steering wheels on a steering disc assembly having a complex structure composed of a magnesium and aluminum alloy skeleton, polyurethane foam, plastic parts, and electronic components. It was proposed in [7] a methodology for creating 3D virtual model of a car steering wheel but not lightweight design or manufacturing method was performed.

The main goal of this research was to minimized the mass and simplified the shape of the SAE steering wheels. Lightweight design procedure used in this paper involves an optimal shape of the steering wheel based on size constrains of strict SAE rules and selection of lightweight materials. The paper main contribution is to propose a methodology validated by case studies about the interconnecting between advanced technologies and new materials on the lightweight design of a customizable steering wheel.

2. METHODS AND MATERIALS

2.1 Methodology for lightweight design of products

The proposed methodology for lightweight design of a SAE steering wheel consists in some steps according to the Figure 1 based on computer aided technologies (CAT). Computer aided technologies use computer as an indispensable tool to solve a problem in a certain field [8, 9]. Two targets were taken into consideration, a lightweight product and a customizable product. Thus, the steering wheel is customizable regarding the hands of the driver. Constraints based on the SAE rules [1], meaning mainly the shape size of the steering wheel were taken into consideration.

The main goal of lightweight design is to reduce the product weight which can be achieved in the following ways, by replacing traditional materials with alternative lightweight materials and product design changes. The method used suppose a shape product optimization based on the driver hands size and shape.

The advanced manufacturing technologies have a higher influence on the steering wheel being also interconnected with the proper selection of the materials.

The steering wheel is an assembly composed by structural and electronics components.

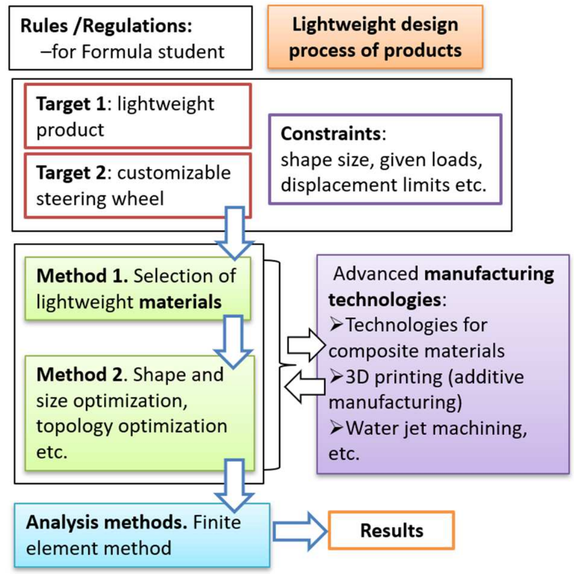


Fig. 1. Methodology for lightweight design of a product

This paper is focused on the lightweight design and manufacturing of the structural components of the steering wheel. The proposed main structure of the steering wheel contains a central main plate and two side grip components. The central plate has a circular shape with some optimized cutouts.

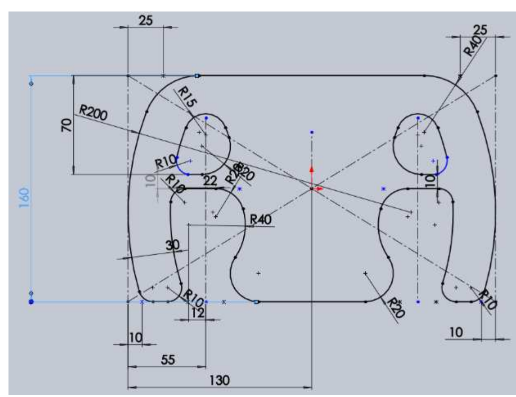


Fig. 2. The conceptual design.

The SAE steering wheel was designed using SolidWorks 2016 software.

The conceptual design was started by making a rectangle with dimensions of 260mm x 160mm into which a near circular shape of the steering wheel was designed, according to the Formula Student rules. On the side areas of the steering wheel a radius of 200mm was applied, as is shown in Figure 2. Four cutouts for easy accessibility of the fingers and to provide the most comfortable position of the hands on the steering wheel were created.

The preliminary design process for the steering wheel shape consisted of several steps and shape design versions. Thus, three prototype versions, at a scale of 1:1, were analyzed by cutting out the drawing sketch obtained in SolidWorks from a plywood and manually checked the hands accessibility by the driver (Figure 3). Thus, an optimal and customized shape design was performed.

Fig. 3. Preliminary design and Prototype

After the final shape of the steering wheel was established, the three holes for attaching the quick coupler were positioned in the center of rotation of the steering wheel. The steering wheel must be attached to the column with a quick disconnect [1]. The procedure of the quick disconnect while in the normal driving position with gloves on should be done by the driver.

Two product variants were proposed for the SAE steering wheel, keeping the same CAD geometry and changing the materials and manufacturing technologies with the focus on a lightweight product.

A static analysis of the steering wheel was performed using the finite element method (FEM) with the help of Ansys R18.2 software. Its aim was to evaluate the stability and safety of the steering wheel during use. The FEM analysis of the steering wheel, in both design versions, has followed the next processing steps:

- Import the 3D model of the steering wheel in STEP file format in Ansys software;
- Apply the material to 3D model;
- Discretization of the model using tetrahedral mesh elements of 3mm to 0.0015mm for highly stressed areas;
- Setting the boundary conditions on the 3 holes in the central part of the steering wheel;
- Applying the loads on the steering wheel, to simulate the forces during a rotation and a frontal impact. The forces for the analysis were determined considering a safety factor of 2.5 and the 100 Nm torque required by bevel gears included in the steering system. Thus, forces of +250N and -250N were applied to the model on the Y axis and -250N on the Z axis.

2.2 Manufacturing methods and materials

Two steering wheel variants have been proposed, the first one based on a lightweight alloy metal and the second one manufactured by a CFRP composite material. The particular materials were chosen based on their low density and their use in many engineering applications.

In the first version the steering wheel has been manufactured from a 5mm plate of 6082-T6 aluminum alloy using abrasive waterjet machining. The second version of the steering wheel was made from carbon fiber prepreg layers using autoclave vacuum forming process and cut to final shape using abrasive waterjet machining. The CFRP plate consists in 10 layers of Zoltek PX35 prepreg tapes. The CFRP plate has 5.2mm thick.

A mold made of MDF was used. A layer of Teflon was applied over this mold, to facilitate the demolding of the final piece after it comes out of the autoclave. The CFRP material was placed in the mold, and then covered with a release film, a breather woven and placed inside a vacuum bag. The autoclave heat treatment of the CFRP plate consisted in a curing process which included a stage of 3 h at 40°C and -0.8 bar pressure, followed of a curing stage of 5 h at 110°C and -3 bar pressure.

The manufacturing process of the main structure of the steering wheel consists of three main steps. In the first step the main plate was manufactured by two different materials and using different technologies. Then, the side grip components were obtained by 3D printing, and in the final step the grip components were glued by the main plate. The side grip components were manufactured by material extrusion additive process using fused deposition modeling (FDM) technology, from PLA material on the Prusa i3-MK2 3D printer.

The 3D models of the side grip components were saved as STL files and imported in Prusa slicer. Prusa slicer 2.9 was used to simulate the 3D printing process, estimate the material and time consumption and finally generate the G code file. The simulation process of 3D printing is presented in Figure 4.

The 3D printed parts were made from PLA, setting an infill of 20%, 1.7mm wall thickness, and a layer thickness of 0.15mm.

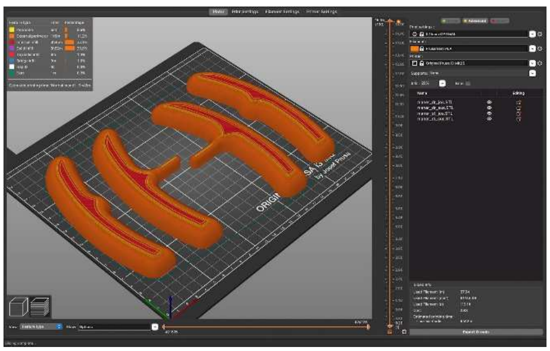


Fig. 4. The simulation process of 3D printing

The 3D printed grip components were glued to the aluminum steering wheel with super glue, and for the carbon fiber steering wheel using VM100 Methyl Methacrylate Adhesive. After the adhesive was added on each handle, they were fitted into place on the sides of the main plate. Special vise grips (Figure 5) were used during bonding process to secure the handles.

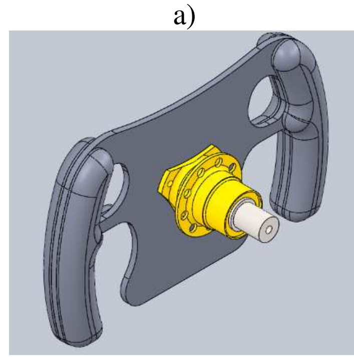
Fig. 5. Special vise grips.

3. RESULTS AND DISCUSSIONS

3.1 Results of 3D design and analysis of the steering wheel

The components of the SAE steering wheel was 3D modeled. Then all the parts such as central main plate, front side grips components, rear side grips components, and the quick coupler positioned in the center of rotation were assembled. The 3D assembly of the proposed SAE steering wheel is shown in Figure 6.

a)



b)

Fig. 6. 3D assembly of the steering wheel.

The results of FEM analysis, consisting in total deformation and equivalent stress is shown in Figure 7 and 8 for aluminum steering wheel and Figure 9 and 10 for CFRP steering wheel.

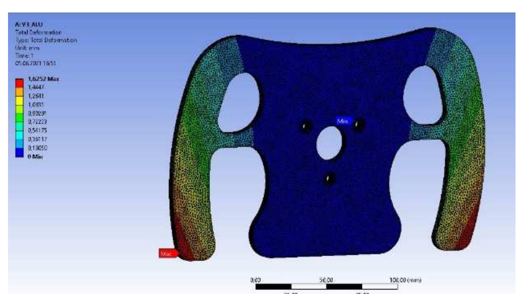


Fig. 7. Total deformation for aluminum steering wheel

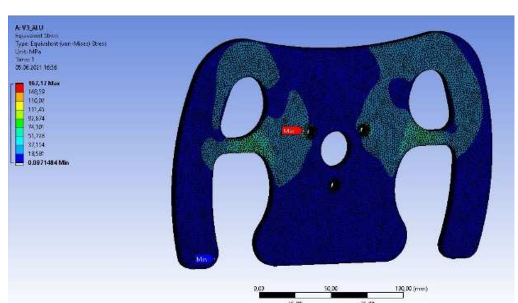


Fig. 8. Equivalent stress for aluminum steering wheel

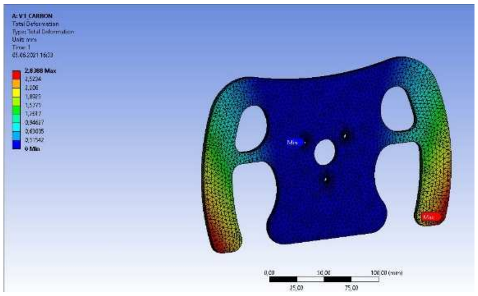


Fig. 9. Total deformation for CFRP steering wheel

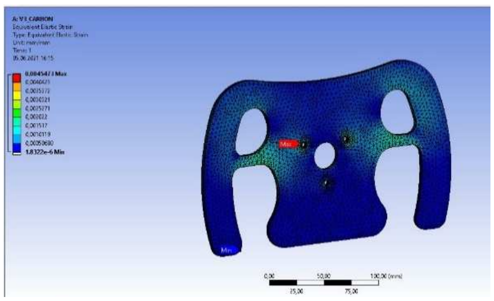


Fig. 10. Equivalent stress for CFRP steering wheel

The results of FEM analysis have shown that higher equivalent elastic strains were obtained in the case of composite plate than aluminum plate. The fact that the composite material is slightly more elastic than aluminum is a beneficial thing, because it takes over the vibrations transmitted through the steering column to the pilot's hands. The maximum total deformations of 1.62mm and 2.82mm were determined for aluminum plate, and CFRP plate, respectively.

The maximum equivalent stress obtained in the case of aluminum plate was 176 MPa which is lower than the admissible material stress of 300 MPa. Also, a 180 MPa maximum stress was obtained in the case of composite plate which is lower than the admissible stress of 1850 MPa.

3.2 Results of manufacturing process of the steering wheel

The main plate of the steering wheel was manufactured in two versions according to the procedure presented in the methods section. Both steering wheel plates were weighed, as shown in the figures 11 and 12. The results shown that the aluminum plate weight 392 grams, and the CFRP plate 232 grams. It was found a 160 grams weight difference between the CFRP plate and the aluminum plate.

Fig. 11. Aluminum plate weight.

Fig. 12. CFRP plate weight.

Two sets of grip components were 3D printed for each main plate version (Figure 13). The 3D printing time for a set of four grip components was 9 hour and 42 minutes, and the material consumption 113g of PLA.

Fig. 13. 3D printed grip components.

Fig. 14. Version 1 of the assembled steering wheel.

Fig. 15. Version 2 of the assembled steering wheel.

The final assemblies of the steering wheel in both versions are shown in the Figures 14 and 15. A launch button and a radio button were inserted into the structure of the steering wheel.

4. CONCLUSIONS

Lightweight design procedure used in this paper involves an optimal shape of the steering wheel based on size constrains of SAE rules and selection of lightweight materials. The following conclusions can be drawn:

- A new methodology for lightweight design of a SAE steering wheel having two targets such as lightweight design and a customizable product was proposed. Three advanced manufacturing technologies were taken into consideration in correlation with the proper selection of the materials.
- A new design of SAE steering wheel was proposed, and validated by static structural analysis using finite element method.
- A significant mass reduction of 40.8% and superior performance mechanical characteristics was obtained for CFRP steering wheel version compared with aluminum version.

Future research directions will be focused on lightweight design of others components.

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Efectul tehnologiilor avansate asupra proiectării pentru masa minima si a fabricării unui volan SAE

Volanul mașinilor din formula student (SAE) reprezintă o componentă importantă prin care șoferul interacționează cu mașina, printr-un sistem de direcție pur mecanic. Această lucrare propune un volan cu masa minimala fabricat în două versiuni bazate pe tehnologii avansate, cum ar fi tăierea cu jet de apă, formarea sub vid in autoclavă și imprimarea 3D. Procedura de proiectare de tip "lightweight" utilizată în această lucrare implică o optimizare a formei volanului pe baza constrângerilor dimensionale și a materialelor ușoare. Volanul a fost fabricat în două versiuni, una din aliaj de aluminiu 6082-T6 și cealaltă din compozite armate cu fibre de carbon (CFRP). Ambele versiuni au componente de prindere laterală imprimate 3D folosind tehnologia FDM. A fost propus un nou design al volanului SAE și validat printr-o analiza structurală statică folosind metoda elementelor finite (FEM). Rezultatele au arătat o reducere semnificativă a masei de 40,8% pentru versiunea de volan din CFRP și performanțe superioare privind caracteristicile mecanice.

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