MANUFACTURING METHOD FOR BICYCLE SADDLE FROM CARBON/EPOXY COMPOSITE MATERIALS

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Abstract. The fiber reinforce polymer in the last decades had a very impressive development. Currently, it is used in almost all of the areas from fashion to aerospace. In this paper, a new method is proposed for design and manufacture of bicycle seat post from carbon fiber reinforced polymer (CFRP) Starting to design piece, to final prototype by CFRP is presented. The design procedure using an anatomical analysis of the ischoion bone and the cycling position are presented. In the seat post design CATIA V5 packages was used, where finite element analysis of the applied loads was performed, as well. The manufacturing method using autoclave curing and vacuum bag technology to obtain the seat post prototype from CFRP was presented. The weight of bicycle seat post obtained is 43 grams and 73 grams including the fixation bars. This represented 4 times lighter like plastic/leather performance saddle. Using this method the number of the CFRP layers and the corresponding reinforced materials architecture were determined.

Key words: bicycle saddle, Carbon fiber reinforced polymer, composite materials.

1. INTRODUCTION

During the last decades, bicycles benefited manufacturing of several parts produced out of very sensitive, light, special, and ultra-performance materials. One of these categories is fiber reinforced polymer (FRP), which finds rapidly growing application area. Migrated from aerospace domain practically, FRP materials covered a wide domain, bringing special properties to the component. Several authors studied special applications of FRP materials, from medicine to aviation, from Formula One to wind turbine, enabling FRP materials to continue becoming a dominant material in the entire product design and manufacture domain. Dziedzic et al. in [1] studied application of FRP materials on dental industry, where they focused on the tribological properties of the FRPs.

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The application of FRPs in aviation industry is related in [2]. The author proposed to use continuous carbon-fibre-reinforced/poly-ether-ether-ketone (CCF/PEEK) composites for manufacture of complex structural parts in aerospace to replace metal components. From bicycle application the authors studied the frame design [3]. The fiber direction and stacking sequence design for the bicycle frame were analyzed. They traded the load application from theoretical point of view, where the experimental verification and manufacturing practices were missing. 3D printing of carbon fiber reinforced polymer (CFRP) is presented in [4]. The mechanical properties of the CFRP and the FDM process parameters were investigated. They used in this case a thermoplastic material for matrix, and CFRP powder material. The effects of process parameter on the tensile properties of materials are investigated.

In [5–7] comfort the authors treated the cyclist's based on vibration determination. Position on the bike during seated sprint cycling is evaluated in [8,9]. The authors studied the optimization of lower limb joint kinematics while participants undertake sub-maximal intensity cycling.

In this paper, it is aimed to propose a new design for race bicycle saddle. This new prototype brings a CFRP lighter piece and a comfortable position of the rider. Starting from market trends, human anatomy, and new manufacturing processes, a new model made from carbon fiber/epoxy reinforced polymer (CFRP) is proposed. The design stages for the new geometry were performed using the Catia V5 software package. In order to make a CFRP piece, a rigid mold is required. The CFRP is applied in the unpolymerized state on this mold. The CFRP is pressed in the mold cavity and polymerized at a certain temperature, through various manufacturing processes. After the polymerization, CRFP is removed from cavity mold, so that the composite part is obtained. In general, molds are devices that have high costs due to complex surface processing. There are several ways and materials for mold manufacturing. The important specifications for molds are the cost, the manufacturing time, the dimensional precision obtained, and the lifetime.

The solution chosen for mold manufacturing assumes to use of a rapid prototyping (RP) process. In our case using a master model realized by Fused deposition modelling (FDM) technology and a composite mold were done. The FDM process is not relatively new, its use in fast master model making from different plastic polymers. In the manufactured mold, a new seat post of bicycle was manufactured from CFRP Prepreg.

2. DESIGN AND THE MANUFACTURING METHODOLOGY OF THE BICYCLE SADDLE

2.1. Design of the new prototype

In the design of the seat post, its fastening element was considered in accordance with the bicycle production standards. More specifically, the position of the cyclist should be as comfortable as possible and the seat post to be lighter and more rigid. It was considered the fact that performance cyclists are of low height (160–175m) and generally people that weighing up to 70 kg. Thus, the design was performed to carry a maximum weight of 80 kg. For heavier cyclists, additional layers of composite material can be applied to provide proper mechanical characteristics. The bicycle seat post model corresponds to the movements and demands for a circuit on the road. Following discussions with performance cyclists, they have shown interest in making the bicycle seat post as rigid as possible, so that all their energy is transferred to the pedals. The shock absorption to the anatomical parts of the body is achieved by the protection (sponge) placed in the pants used in cycling.

For the current bicycle seat post, a size of 12 was chosen, that is, a width of 120 mm and a length of 250 mm. It is noteworthy to state that, the size does not provide comfort for every individual because the position of the ischion bone differs from one person to another. In some cases, other sizes may be used that provide a greater or lesser width of the seat depending on the anatomical position of the cyclist.

Starting from the anatomy of human bones and the position of the cyclist on the bike, a curve defining the contact points of the cyclist with the top has been set in the longitudinal plane. The same was done in the transverse plane, considering the pressing of the lower bones of the pubis on the contact surface (Fig. 1).

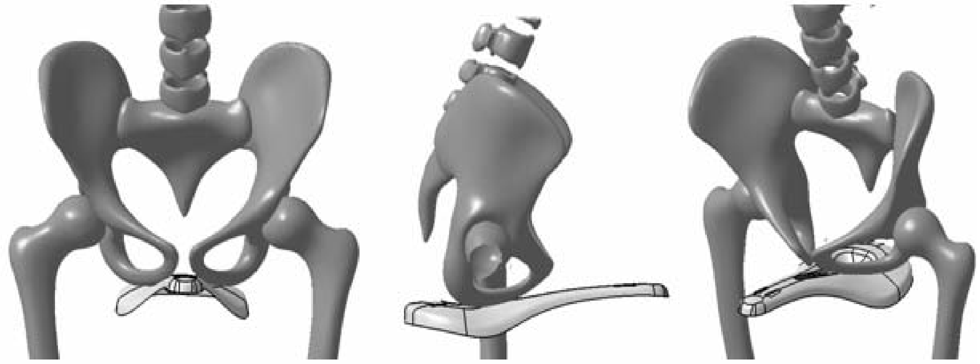
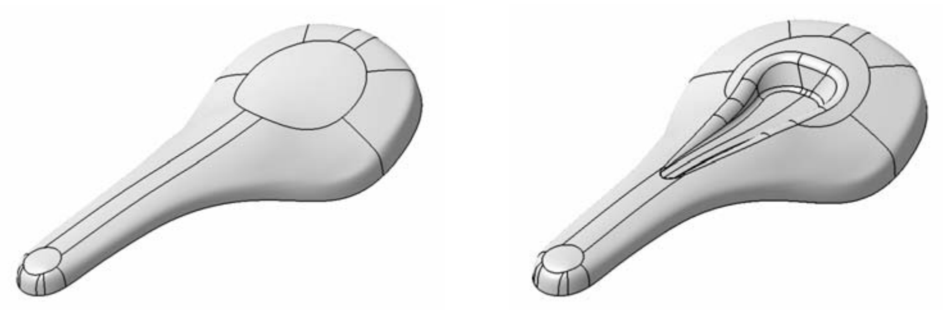


Fig. 1 – Determination of the longitudinal and transverse curves of the bicycle saddle.

Then, the fixing area of the two bicycle seat rods that fixes the seat position the center rod is set. After the two curves were generated and the fixation area of the two rods was established, it went on to create the new model of the bicycle seat. After setting the outer shape (Fig. 2a) on the central part a longitudinal middle channel (Fig. 2b) was made to release the pressure on the prostate if the cyclist is male.



a) b)

Fig. 2 – Bicycle seat post CAD model.

By making a longitudinally disposed cavity in the middle of the cyclist's area, the pressure applied to the prosthesis during pedaling was eliminated. When designing the new model, the problems that may occur in the lower zone of the basin's bones and in the perineum area were considered. It was desired to release the pressure generated in the area of the pubic arch and the pressure in the area of the tissues that make up the perineum. It should be noted that this model is customized only for some individuals with the anatomical configuration and basal bones specific to the design conditions.

2.2. Designing and manufacturing of the mold

Reducing bike mass is the main objective for performance cycling. Therefore, it has been chosen to manufacture the bicycle seat post made of CM. This being the main objective, it was chosen to make bicycle seat post using CFRP. The CFRP benchmarking technology involves manufacturing the piece in a mold using certain manufacturing processes. To obtain maximum mechanical characteristics, it was chosen to manufacture the CFRP piece by the vacuum bag forming process.

In order to reduce the manufacturing time of the new bicycle seat post prototype, a new solution was chosen. The solution is making a mold ass quick is possible. A plastic master model using the CAD designed prototype was manufactured. This rapid manufacturing process greatly reduces manufacturing time and saddle costs. Considering the fact that the FDM process produces a surface of parts with a certain roughness that is not suitable for the manufacture of CFRP mold, it was considered that the active part of the prototype was coated with a gelcoat layer which will then be machined until polishing the active surface of the master model.

For this, an ABS thermoplastic material was chosen to be used in order to make the RP of the saddle. This material is sensitive to solvents from polyester gelcoat and makes very good coupling between these two materials.

To obtain the bicycle seat post from CFRP, several mold design variants have been considered. The simplest option involves making a master model piece, and making a composite mold using the master model piece. The method consists in using a rigid master model of the piece. This will be cover by different CM in order to obtain a rigid mold. The methodology supposed to have an additional step in manufacturing process and this is master model manufacturing.

In order to eliminate this step, it is possible to consider designing a CNC milling machine from an Epoxy or Aluminum block. The process involves high manufacturing costs in milling, material and subsequent processing. Molds made of metal blocks are generally for large series of manufacturing. Thus, a method of making the molds by rapid prototyping master model and composite mold was chosen. Generally, the CFRP pieces are made larger at the edge to avoid areas where the fabric is falling apart. This additional part is cut at the end, producing a composite material with a structure of the homogeneous reinforcement material at the edge. Taking this into account, the area of the bicycle seat has been extended by 10 mm. A separation plane was established in the edge area and the whole surface was integrated into a material block, obtaining a cavity (Fig. 3). A surface check was performed in the mold design phase to determine possible complex geometries or negative angles that could prevent piece extraction from the mold.

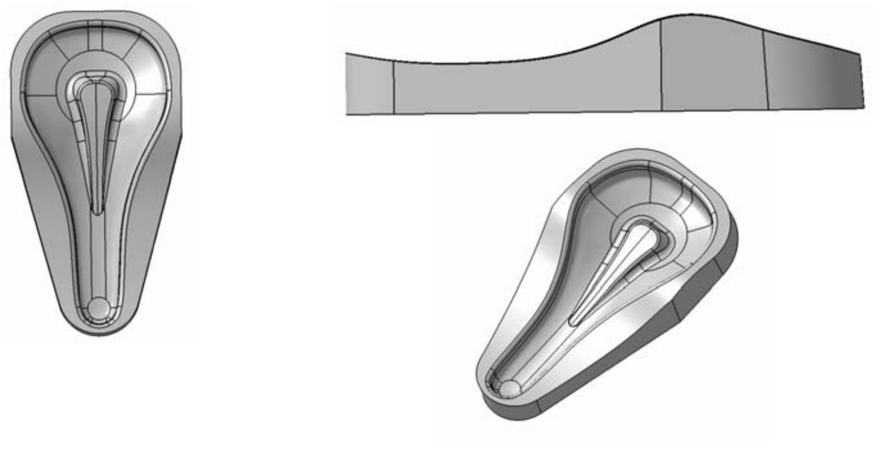


Fig. 3 – The CAD model of the mold.

An inspection was done to ensure there are no corners or planes between which there is an angle of less than 90°. At intersections between the planes, connecting rays were applied. Thus, CFRP can be applied without creasing.

The printer used to manufacture this master model was the LeapFrog printer, the Creart HS XL model; its print size is 280 × 270 × 590, being able to print multiple pieces in the same piece. Due to the size of the machine table the master model of the saddle was arranged on the machine table. To create the G slicing code used to make the prototype; we used the Ultimaker software, Cura 4.0.

The material used to manufacture the saddle is ABS LEAPFROG MAXX Essentials. The material is provided by the manufacturer of the 3D printer. The printing temperature was 245 for the material and 80 for the printer heated bed, 1.75 mm filament thickness, 0.4 mm extruder head nozzle diameter.

The CURA 4.0 software has estimated the printing time, more specific: 38 hours and 43 minutes. The layer thickness is 0.2 mm, and as the internal structure of the piece we have: wall thickness: 4 layers; piece infill (filling): 75%; structure of infill "grid". The printing speed is 60 mm/s. For printing the exterior wall, a lower speed of 30 mm/s was chosen to achieve better dimensional accuracy and roughness.

After the master model was manufactured by RP, in order to improve the quality surface a layer of T35 Polyester Gelcoat was applied on the active side of the prototype. This procedure was through spraying, and the polymerization was made in the oven at 50° C for 4 hours. The active surface of the FDM prototype was machined with abrasive paper having from 80 grit to 1200 grit. The procedure was followed by polishing with 1 µm diamond paste solution. In Fig.4 the master model of the saddle are presented.

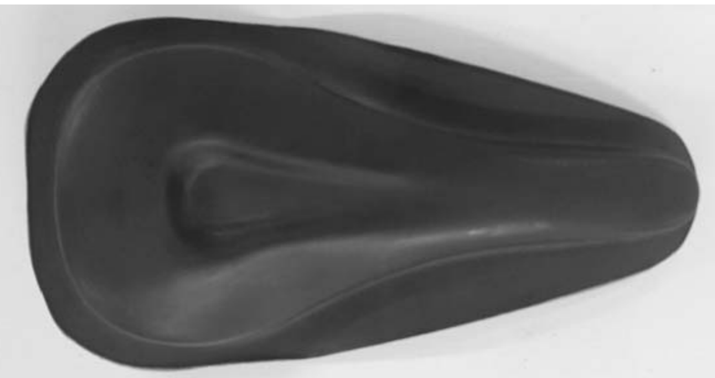


Fig. 4 – Master model of the bicycle saddle manufactured by FDM process.

Using this prototype a CM mold were done. The surface of the prototype was covered by different CM in epoxy matrix. On the surface of the prototype 5 layers of release agent in order to prevent the adhesion of composite to saddle prototype surface were applied. Different layers by glass fiber/epoxy using hand lay-up technology were applied on obtained prototype in order to obtain a CM mold. The mold was introduced in the oven for polymerization. The temperature cycle was 40°C – 8 hours', 60°C – 8 hours' time. Considering the temperature at which the mold is exposed during CFRP polymerization, additional treatment was applied at 110°C for 8 hours.

2.3. Simulation and design of composite material for the manufacture of bicycle saddle

In order to determinate the stress level and the proper stacking sequence of the CFRP layers a FE analysis of the saddle were performed. Were used ANSYS Workbench software. The FE analysis considers the bicycle seat loaded under the forces of given by the cyclist weight. The boundary conditions are presented in Fig. 5. The boundary conditions in form of fixed supports have been applied to the seats in the area of support bars that connect the structure with the bicycle frame. A total force of 800 N is applied on upper faces in contact with the human body.

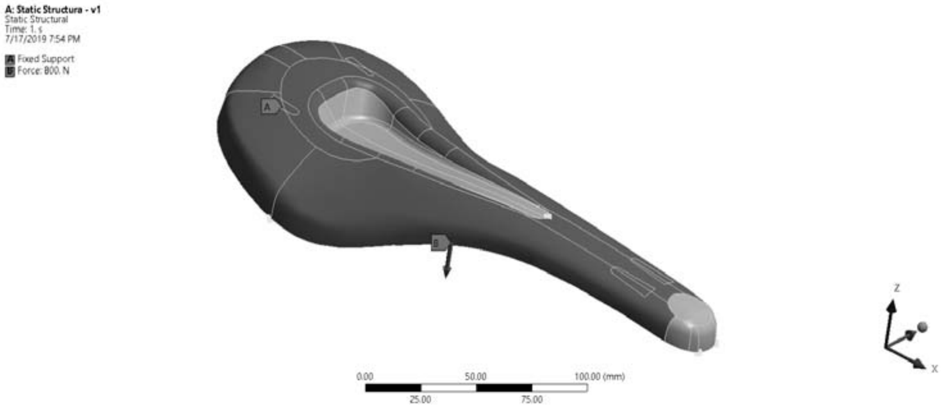


Fig. 5 – Static load application.

The composite material has three layers with the following stacking sequence [0/90/+45/−45/0/90] and is made of twill fabric with a density of 240 g/m². The values of elastic constants obtained by experimental tensile tests of composite samples are: E_x=79 505 MPa, E_y=78 915 MPa, G_{xy}=35 433 MPa and Poisson ratio, ν=0.268. From the point of view of the material, a conclusion shows us that the two-layer orchid made of two layers of T245 material does not withstand the stresses.

In Fig. 6 is presented the total displacement of the bicycle seat for the two geometrical variants. The maximum principal stress is shown in Fig. 7. The stress values are higher in the fixation areas, which were additionally fixed by gluing the fixation frames. As a general observation it can be noticed that the full seat is stiffer than the seat with the median channel.

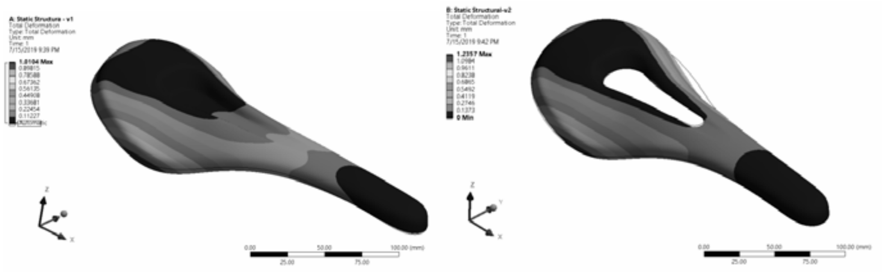


Fig. 6 – Total displacement.

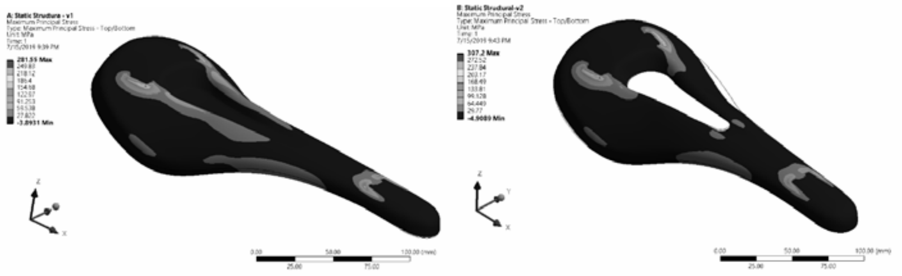


Fig. 7 – Maximum principal stress.

2.4. Manufacturing of the prototype from CFRP

Materials used. For the manufacture of CFRP parts, prepreg material type GG245T-DT806W-42 was used from the DeltaPreg part of Toray Group. The fabric consists of a twill fabric (T) by 245g/m^2 carbon fiber. The epoxy matrix is type DT 806W and weight fraction ratio of resin is 42%. This matrix can also be used for oven polymerization processes without requiring polymerization in the autoclave at high temperature. The polymerization process according to the manufacturer's specifications allows polymerization at different temperatures as indicated in Table 1. The producers are recommended cycles up to 120°C.

Table 1

The producers are recommended cycles up to 120°C

Cure Cycle	Time [Hours]	Temperature [°C]	Time [Hours]	Temperature [°C]
Cycle	16	65	1,5	100
Cycle	10	70	1.0	110
Cycle	5	80	1.0	120
Cycle	3	90		

We had an option to choice one of this cure cycle to polymerized this type of resin. Preparing the mold was performed by applying successive layers of release agent LOCTITE®FREKOTE700-NC ™ type. Ten coats were applied by means of a cotton swab. Drying time between layers was 20 minutes at 20° C. After drying each layer the surface was polished. The prepreg composite material was removed from the freezer at −17° C and kept at 20° C for 24 hours. The application of the prepreg composite material has been achieved layer by layer (see Fig.9) by hand lay-up procedure. The material was heated to 40 degrees to avoid creasing using a portable industrial blow dryer at 40^{o} C on the areas that had a more complex geometry.

Fig. 9 – Application of CFRP layers on the mold.

After the first layer of CFRP applied on the mold cavity, a vacuum pressure was applied to –0.9 bar. The CFRP applied on the mold was covered with a release film and a layer of Peel Ply. After that, the mold and first composite layer was placed in a vacuum bag where –0.9 bar was applied over 30 minutes. The procedure helps to stick and remove air bubbles from the surface of the mold, especially in the area of complex surfaces or corners.

After finishing this treatment, the next step is to apply the other layers according to the results set in the design phase of the material.

Three CFRP T 240 layers by sequence [0–90 / ± 45/0–90] were used in the present case. The CFRP prepreg mold assembly was covered with a release film and a breather fabric. The Assembly was inserted into a vacuum bag. It was sealed to the edges and with a vacuum coupled a vacuum pressure of -0.9 bar for 30 minutes at 20 ° C was applied (Fig.10). CFRP polymerization was done in the oven at 90° C for 24 min. After polymerization, the part was removed from the mold. Its outer surface was observed to be non-porous with well material compaction.

Fig. 10 – Applying vacuum pressure through mold and composite material.

In order to obtain the same dimension of the CFRP prototype the excess of the border were cat. The surface was processed by glass paper from 400 grit.

3. RESULTS AND DISCUSSIONS

3.1. Design of the saddle results

Designing the new seat post for high performance bicycle using the new design methods greatly reduces manufacturing time. The new proposed concept considers the health issues that an incorrectly designed bicycle seat could cause. A new concept has been sought that could improve the design to eliminate. One of this problem is the geometry of the saddle are not comfortable or not proper for cyclist. Other problems are dimension of the saddle or the geometry. This can applied the pressure on the prostate gland.

A RP method and a new material were chosen in order to create the master model prototype and a composite mold to obtain CFRP piece. The manufacture of the ABS saddle prototype offers the possibility of machining the active part of the piece. On the obtained surface, gel coat layers can be applied and then can be polished. Thus, the polished area is a perfect surface that provides an area where CFRP does not adhere to this surface. Not all the thermoplastic materials can be use from this considering.

3.2. Manufacturing of the prototypes results

The obtained roughness on the active surface of the saddle prototype after machining on FDM was $R_a = 0.2$ mm and after application of the polyester gelcoat layer and it's processing $R_a = 0.05$ μm.

The obtained mold made by CM is shown in Fig. 10. This is used to manufacture the bicycle seat prototype in CFRP.

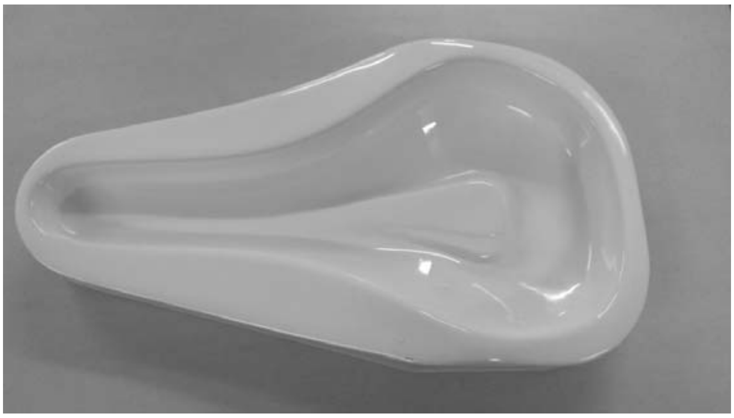


Fig.10 – Composite mold obtained by hand lay-up technology.

The obtained bicycle saddle has a mass of 43 g. Subsequently, using a 3M ™ Scotch-Weld DP 420 structural adhesive, the fixing rods are glued.

In Fig. 11 are presented the obtained CFRP bicycle saddle.

Fig.11 – The CFRP saddle obtained.

3.3. Economical analysis

Considering the amount of material estimated by the Ultimaker software, Cura 4.0, that is, 595 g of material used, this is consistent with the prototype obtained. The cost price on the market for the respective benchmark of 11 Euros / 100 g of material can be calculated as an estimate. The estimated cost of the mold made through FDM prototype and CM mold is 100 euro. The outer surface of the CFRP is glossy copying the surface of the mold. No areas with defects or excess resin are observed.

An important factor to underline is the behavior of the CM mold made by CM that did not suffer deformations by exposing it to temperature and pressure. This was measured and the initial dimensions correspond to the original dimensions. No cracks or deformations in the active area of the mold are observed. Twenty pieces with different configurations of the reinforcement material were made for their testing.

The CNC milling machines of the mold, having an operation cost of 25 to 45 Euros/hour. It's takes about 12 hours, which costs minimum of 400 euros of machining cost including the material. This is a significant reduction in mold preparation when the mold material is CM.

In aluminum case of the mold the estimate weight is 2 000 g. The CM obtained mold has 600 g including Gelcoat layer.

3.4. Dimensional measurements

The dimensional evaluation of the CFRP seat post made in the CM mold was done using a portable co-ordinate measuring machine (Fig. 13).

Fig. 13 – Dimensional evaluation of CFRP seat post.

The comparison between real part and CAD model was made in 131 points acquired manually in various areas of the bike saddle as shown in Fig. 14, where the green color represents a very small difference between the CAD model and the real one as the shades go to the blue it the difference increases. Figure 15 shows the deviation of the points from the nominal size (top) and the normal distribution of errors of physical model related to the CAD model.

Fig. 14 – Points acquired on CFRP seat post.

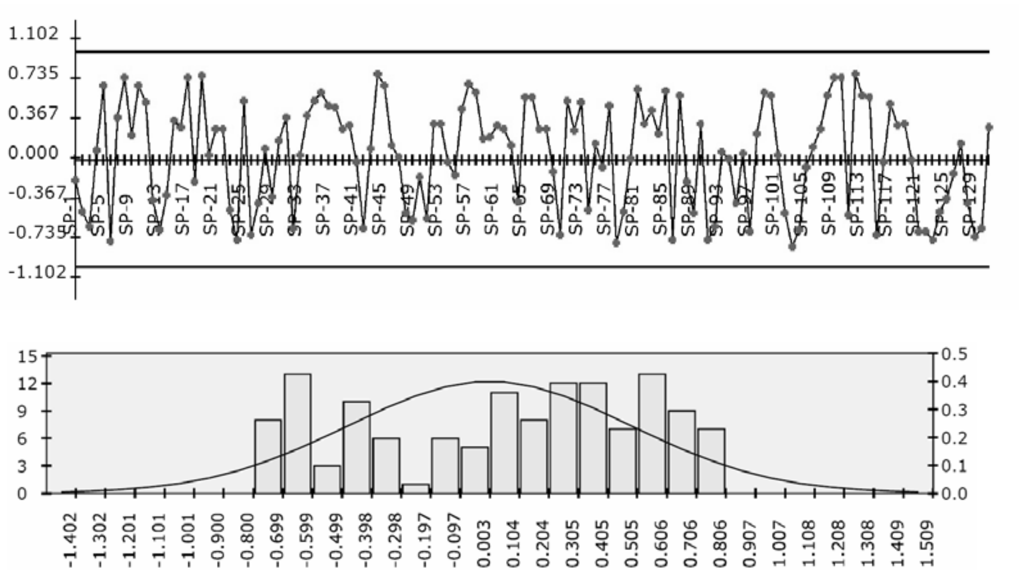


Fig. 15 – Deviation of the points from the nominal dimension (top) and the normal distribution of the physical model errors to the CAD model (bottom).

The differences between the real part and CAD models in ranges of ± 0.8 mm, considering these deviations and the functional role of the part it can be stated that the piece is dimensionally precise. The difference between CAD model and final CFRP saddle prototype can be attributed to the layer of gelcoat applied to the FDM saddle prototype surface and in the same time, surface processing preparation.

5. CONCLUSIONS

Applied on CFRP in high performance bicycle components bring a lot of benefits. The most important are the mechanical behavior and weight of the components.

The new application of the RP technologies in the CM manufacturing process reduced the cost of the mold by 4 times compared CM mold by CNC aluminum milling mold.

The weight of CM mold is 3.36 times lower like aluminum case. The obtained CM mold can be used to prepare the CFRP components. Twenty pieces were obtained and the mold is not affected, it can be used for a next pieces.

The FE analysis using the ANSYS software indicates the 3 layers of the CFRP for the final piece. Different stacking sequence of the layers can be applied to obtain a comfortable cyclist position and the elastic deformation. Depends of the road the saddle must to absorb a little the vibration coming from a bumpy road.

The standard deviation between CAD model and obtained CFRP saddle is in ranges of ± 0.8 mm. Considering the application of the piece this can be dimensionally precise. The precision can be improved in the designing stage considering the gelcoat layer dimension. We must to mention that this mold solution is proposed for prototyping of CFRP piece.

The lifetime of the aluminum mold can be not compared by CM mold. This mold can be applied in the mass production case.

The weight of the obtained bicycle saddle is 75g including the fixing bars, which is 4 times lighter like plastic/leather performance one.

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