UTILIZATION OF INNOVATIVE TECHNIQUES IN ULTRA-LIGHT AUTOMOBILE PRODUCTION

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Abstract: *The paper presents the results of research focused on the use of innovative processes in the production of composite materials. The experimental work was focused on the use of Vacuum Bag Molding technology in the production of the prototype of the Shell Eco-marathon formula. The car body was designed with 3D modeling and optimized with airflow simulation. Carbon fibers have been used to reduce the vehicle's weight. Some complementary parts were produced using 3D printing.*

Keywords: COMPOSITE MATERIALS, CARBON FIBERS, VACUUM BAG MOLDING TECHNOLOGY, 3D MODELING, AIRFLOW SIMULATION

1. Introduction

The Faculty of Engineering of the Technical University in Košice has been actively participating in the Shell Eco Marathon since 1994. Over the past years the vehicle body has evolved significantly. Initially, it was a monopost construction of iron frame, vehicle body served as a cover. The further effort in vehicle body development was to reduce the weight of the vehicle, reduce rolling resistance and resistance in wheel bearings.

The vehicle underwent facelift since 2006, where the top cover was relocated as close as possible to front axle and drivers compartment. Vehicle B&S 3 facelift at Paul Armagrac circuit in Norgama reached performance of 783.1 km/l of fuel and ranked 47th out of 263 participants.

Since 2016 in vehicle construction a lightweight, carbon fiber-based top cover is used. It is lighter and better in terms of aerodynamic resistance.

Fig.1 *Experimenal vehicle Prototype 2017*

During the development of new body model, current information were evaluated and used to design new vehicle. These findings led to a design of new vehicle called *Prototype 2017*. Composite sandwich body was equipped with carbon frame, that was central and carrying element of the whole vehicle. Steering was improved by reduced friction when cornering. New ceramic bearings that have minimal rolling resistance and high inertia contributed to improved driving performance. Vehicle was also equipped with new engine with capacity of 35 cm^3 and power of 1 kW.

The design of new body was carried out in CAD program CATIA V5/R16. Vehicle body was adapted to already designed frame, which ensured perfect rigidity and safety of the vehicle.

The shape of the body was designed based on the optimization of the air flow, Fig.2. Aiflow testing was performed in SolidWorks program and CFD analysis was also processed in Ansys program. Two variants of body vehicle were tested, based on the CFD analysis results better variant was selected, Fig. 3-5.

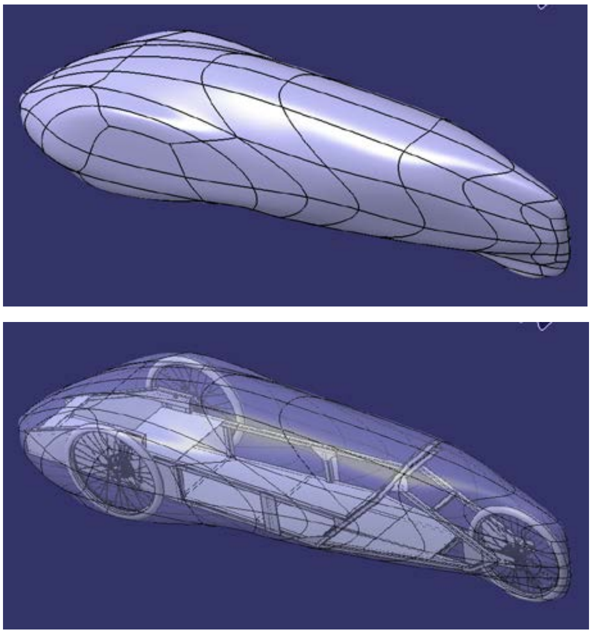

Fig.2 CAD design of body vehicle a) the vehicle bonnet, b) the vehicle internal support frame

For the improvement of body shapes consecutive testing of designed proportional shapes was carried out. Several designs of vehicle body shapes were tested. Although each component of the vehicle influences its performance, attention has been paid mostly to airflow, reducing the weight and increasing body strength. All designed variants of body were tested and the best result was chosen. The resistance force of the best model represents 25% of the resistance force of the previous model from year 2016.

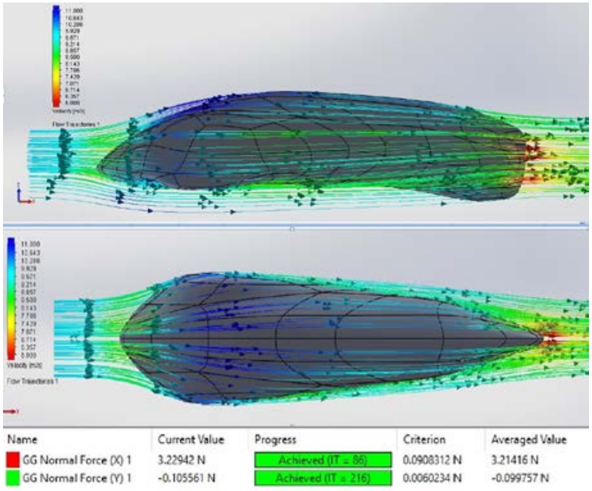

Fig.3 *Testing of experimental vehicle*

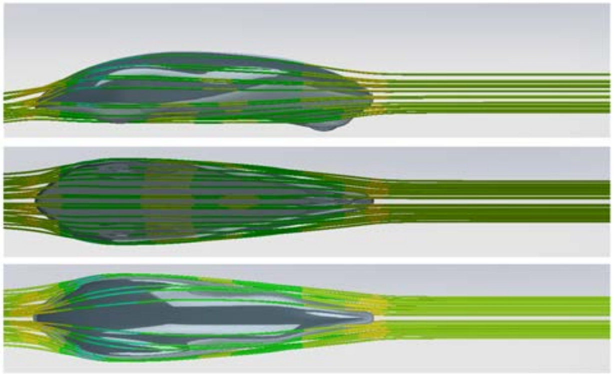

Fig.4 *Airflow of the vehicle - side view, lower part, top view*

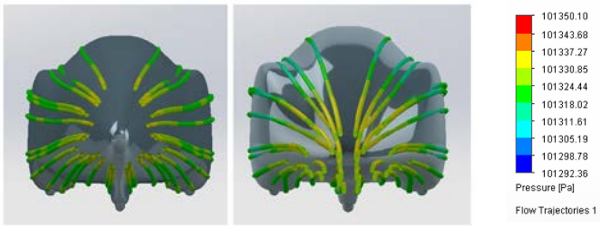

Fig.5 *Airflow - view of the rear and front part of vehicle; scale of pressure*

2. Production of a vehicle model

This process is based on designed 3D model, based on which a model with dimensions corresponding to the final shape of the vehicle was produced. For the mold manufacturing a method of manual deposition was chosen. The principle lies in manual deposition of glass fibers pre-treated with epoxy resin. This method was chosen due to its lower difficulty and low price. The beginning of model production was carried out in a machining centre, where individual parts of the model were milled from excruded polystyrene. After completion all parts were joined together using a polyurethane adhesive.

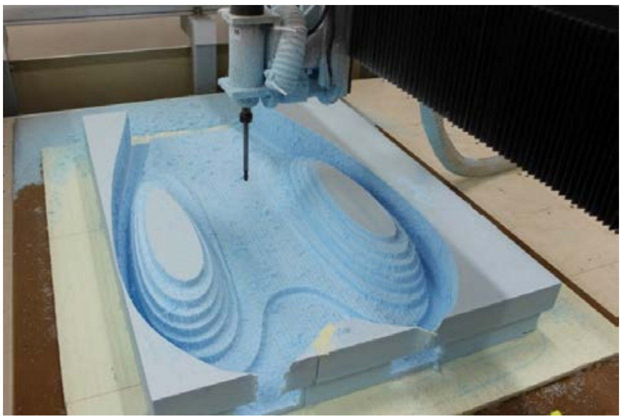

Fig.6 *Rough milling of one model part*

Fig.7 *Experimental vehicle - milled model*

Body requirements for Shell Eco - Marathon vehicle

Shell company sets the rules for Shell Eco - Marathon vehicle competition. Bodywork requirements are rigidity, low vehicle weight, safety of driver, airflow, manufacturability, surface quality of upper sandwich structure and overall body price. Every team must present technical drawings or overall animation respectively for the project approval. No mechanical part of the vehicle can be visible. The wheels must be placed under the body of the vehicle.

Choosing a sandwich core for Shell Eco - Marathon body

When selecting appropriate material, several aspects had to be taken into account. Material had to be strong enough, but also light to achieve low consumption of the experimental vehicle. Sandwich structure application achieved the mean of these properties. Core of sandwich structure allows the body to be lightened by glass fibers, which are heavier compared to PVC foam and nonwoven polyester by 30%. Experimental vehicle body was composed of two parts, the lower and upper part of body. For the production of body Coremat XM 2mm material was chosen.

This type of material is based on a nonwoven polyester, which was optimized for improved tensile strength properties achieved by resin saturation through hexagonal cells of this material. Microspheres, which prevent excessive imbibition of resin into the polyester, are part of the material as well. Hexagonal structure under the layer of resin stays invisible. The manufacturer indicates reduction of resin by 1000 g.m^{-2} per layer thickness. Compared to glass fibers, up to 30% of weight in one composite layer is saved. Using Coremat reduces production time. It is flexible and easy-to-shape material and is suitable in technology of manual composite deposition. It is not suitable for technology of infusion of resin into a closed space. Its application is mostly found in RC models and smaller boat trunks. Coremat XM is available in 2 to 4 mm thickness.

Table 1: *Mechanical properties of material Coremat XM 2mm*

Typical mechanical properties of Lantor Coremat® XM*
impregnated with unsaturated polyester resin

Mechanical properties	unit	value	test method
Flexural strenght	MPa	8,5	ASTM D790
Flexural modules	MPa	1250	ASTM D790
Tensile strenght across layers	MPa	4	ASTM C297
Compression strenght: 10% strain	MPa	10	ISO 844
Shear strenght	MPa	3	ASTM C273-61
Shear modules	MPa	25	ASTM C273-61
*Lantor Coremat®XM 3			

3. Process of production of experimental vehicle Shell Eco Marathon – Prototype 2017 body

In the production of experimental vehicle body the sandwich composition of carbon fiber fabric and material Coremat XM was used. Among the first steps of production of the lower part of body was the degreasing of the mold. This step was necessary also due to the prior smoothing of the surface using wool polishing wheels combined with abrasive 3M polishing paste. After degreasing, lower part of produced vehicle body was waxed using application microfibre wipes with basic wax in several layers. After waxing the last layer using basic wax, PVA coating was sprayed on the surface of lower part of produced body vehicle. This coating served as an interlayer, which prevented the joining of two arbitrary coatings with each other. After application of PVA coating, accelerator transparent HAVELpol 1 resin was applied for better bonding with the epoxy resin.

Fig.8 *Interconnecting resin HAVEL 97*

After hardening of connecting resin, other type of resin was applied. This type of resin is characterized by lower viscous density. Its task is to secure connection between deposited fabrics and sandwich core. Epoxy resin was applied separately on both layers. An uniform layer was formed over the entire lower part of the finished mold. The first application of this type of resin was important mainly in terms of better deposition of fabric and molding into desired shape. This process of resin application firstly into the mold is better in terms of improved oversaturation of fabric by resin.

Fig.9 *Depostion of carbon fabric into front part of the mold*

The fourth layer was formed by Coremat XM material. This material in sandwich structure acts as a sandwich core. Material was not applied to the space reserved for wheels. Similar to the previous layers, resin was applied on top. Gaps between the Coremat bands were enhanced by carbon roving. The Coremat layer was closed by glass fabric.

Fig.10 *Fourth layer Coremat XM*

This way was used to form all layers of composite structure. After completing the seventh final layer, the lower part of body was moved to foil sleeve. The suction of resin to fabric was carried out using Vacuum Bag Molding technology over 12 hours.

VBM technology (Vacuum Bag Molding) uses a similar procedure to manual wet deposition. On the last layer perforated separating foil is deposited. Next layer is formed by suction layer (absorbent fabric), purpose of which is to absorb excess resin. Mold layered this way is then inserted into space, from which air is sucked out. Vacuum ensures the reduction of pores in composite, compression of reinforcement layers by atmospheric pressure and extrusion of excess resin.

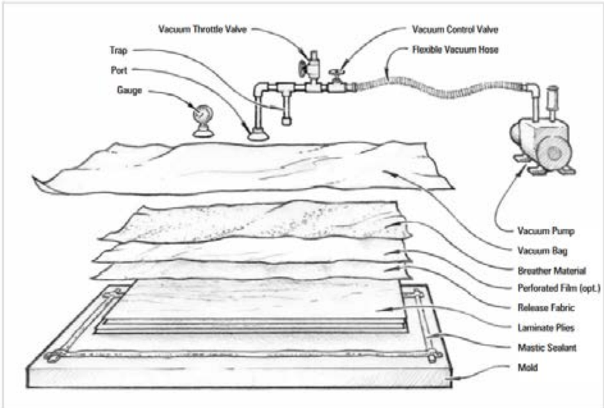

Fig.11 *Typical components of a Vacuum Bag Molding Proces*

In the production of upper part of experimental vehicle body, formation of air bubbles occured during the deposition of first carbon layer. These air bubbles are classified as white spots, that can not be removed even by polishing. The cause is an uneven layer of resin and weak contact of first carbon layer with experimental vehicle mold. In the production of lower part of body these errors did not occur due to the smaller surface area and more uniform application of epoxy resin.

The indisputable advantage of the manual deposition of these sandwich compositions is mainly affordability. Technology is very applicable in prototype production, which was used to produce also described experimental vehicle. However, in the production of experimental vehicle body, functional nature of the vehicle was more important than cosmetic errors on the bodywork.

Negative side of this technology is subjective impact on the quality of produced parts. Another error in the production process of experimental sandwich bodywork was the formation of uneven surface and depressions on the rear rounding.

The resulting body of experimental vehicle without carbon frame, engine and accessories weighed about 20 kg. The total weight of the Shell Eco Marathon experimental vehicle was reduced compared to previous experimental model by one third. Current vehicle has a strong carbon frame, but also solid sandwich body. To achieve lower fuel consumption in the next stages of the vehicle development, it is necessary to use sandwich materials. Lower part of the body would have to go through optimization of the sandwich composition to increase the strength of the self-supporting body.

Fig.12 *Final experimental vehicle body*

4. Conclusion

Components that are made from composite materials can be manufactured using multiple technologies. The choice of technology depends on the shape of produced component, requirements for its mechanical properties, structure and surface quality, expenses available for production and desired productivity. With a variety of technologies there is a room for choosing such technology, that will meet the exact specified requirements for the final product. There are many technologies available, from quite simple technologies, such as manual wet deposition to more or less sofisticated production methods, that depend on specific technological equipment.

The use of composites in automotive industry has an increasing tendency. The greatest credit for the rising use of these progressive materials lies with large automotive companies focused on production of luxury and electric automobiles. They collaborate with different factories, which focus on development but also the production of carbon fibers itself. More available are also technological production methods of sandwich materials. The greatest potential lies in technologies that are fully capable of series production. 3D trial printing of sandwich structures is also at the forefront of technological options. Evidence is also the new collaboration of automobile manufacturer Honda with one of companies, that deals with these 3D printing technologies. In the process of experimental vehicle production the most available technological method was chosen, namely manual deposition of sandwich structure. Sandwich structure of experimental vehicle has a strength of 70 MPa. Experimental vehicles are great tool for testing a variety of materials and manufacturing processes. The process of manual deposition and using the sandwich structure itself might not be directly applicable in current automobile generation, but it is an inspiration for addressing the topics of fuel-reduction and related new emission limits. The process of manufacturing of experimental vehicle can be improved by proposed solutions such as enhancing the suction of epoxy resin and change of technology to a vacuum infusion. Strong sandwich body has a great potential for creating self-supporting body of experimental vehicle.

The development and production of experimental vehicle Shell Eco Marathon was also attended by students of Faculty of engineering, TUKE. In 2017 they participated with this vehicle in international Shell Eco-marathon Europe race in London and officially achieved a distance of 586 km per liter of fuel. In the category of combustion engines they ranked 18th. Race took place at the Queen Elisabeth Olympic Park in London on May 25.-28. Students from Košice competed with nearly 200 teams from 28 countries.

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