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DESIGN AND MANUFACTURE OF THE REAR WING BRACKET OF A FORMULA STUDENT RACING CAR

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Abstract: Polymer composite materials have found widespread application in race vehicles. By reducing the weight of parts without compromising on strength, it is possible to enhance the dynamic performance of race cars. The aim of this research is to reduce the weight of a rear wing bracket. Carbon fiber plastics have a specific strength and stiffness that is several times higher than the same properties of aluminium alloys. However, the effectiveness of using composites significantly decreases if the load does not follow the fiber's direction. In contrast, metals are isotropic, meaning they do not change their properties when the loading direction is altered. However, in cases of grid structures, unidirectional composites outperform metals. Grid structures are constructed in such a way that the materials function mainly along the reinforcements, allowing the unique properties of composites to manifest in the structure. Therefore, it was decided to design a lattice composite bracket. Wet winding was selected as the production technique. During the work, processes of designing and manufacturing of a rear wing bracket for a Formula Student car were considered. The technological process of manufacturing this product was developed. A prototype weighing 386 grams was more than twice lighter than the previous version of this bracket (900 grams).

Key words: composite materials, filament winding, lattice structure.

1. INTRODUCTION

In the 70s, the speed of F1 cars increased significantly, along with the requirements for the strength and stiffness of the chassis. The aluminum construction of the monocock could not cope with these requirements. The solution was found in the aircraft industry, and the first car with a carbon fiber monocoque took part in the race in 1974. Since that, composite materials have become widespread in motorsport. Modern carbon-epoxy composites have high specific strength and stiffness which are 3 times higher than the corresponding characteristics of aluminum alloys. However, the effectiveness of using composites significantly decreases if the load does not follow the fiber's direction. In contrast, metals are isotropic, meaning they do not change their properties when the loading direction is altered. However, in cases of grid structures, unidirectional composites outperform metals. Grid structures are constructed in such a way that the materials function mainly along the reinforcements, allowing the unique properties of composites to manifest in the structure.

Formula student is a competition which challenges teams of university students to conceive, design, fabricate, develop and compete with small, formula style, race cars. Competition is held in accordance with the Formula Student Germany rules. The competition tracks have many turns, which requires additional downforce to maintain control. Team engineers pay special attention to the aerodynamic elements during the design of the car. The rear wing of the vehicle generates the majority of the downforce and its supporting structure is subjected to significant loads. There are a variety of bracket design options available, the most common are metal lattice structures and composite sandwich structures.

Metal lattice brackets are produced by milling on CNC machines made of aluminum plate, Figure 1. This production method is the most accurate, so the geometry of the bracket can be the closest to the optimization results. However, the specific stiffness and strength characteristics of metal alloys are significantly lower than the corresponding characteristics of carbon-epoxy composites.

Composite sandwich brackets consist of structural foam filler and carbon fibre cladding. Brackets are manufactured using the manual method of vacuum infusion. This method has lower precision, therefore the geometry of the bracket differs from the optimization results and has a larger safety factor. The full potential of composites has not been realized due to the use of multidirectional fabric.

Fig. 1. Metal lattice bracket

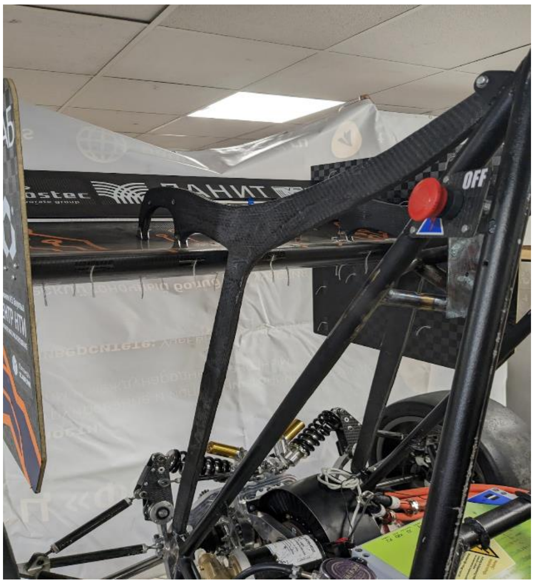

Fig. 2. Composite sandwich bracket

The composite lattice bracket combines all the advantages of composite materials and optimized geometry. The main method of manufacturing lattice structures is filament winding. It is the process of continuous fiber winding on a rotating mandrel. There are two main types of winding: wet and dry. The dry process uses pre-impregnated fibers. It is a cleaner but more expensive process. In the wet process, the impregnation of the fiber takes place immediately before winding. It provides an opportunity of choice from a wide range of resins and reinforcing materials and makes this technology much cheaper.

A bracket model was created based on the optimization results, taking into consideration the specificities of the manufacturing process. The triangle was selected as the basic design element, as it is a concave shape and greatly simplifies triangulating the product. An upper cross piece was also added to counteract lateral loads, Figure 3.

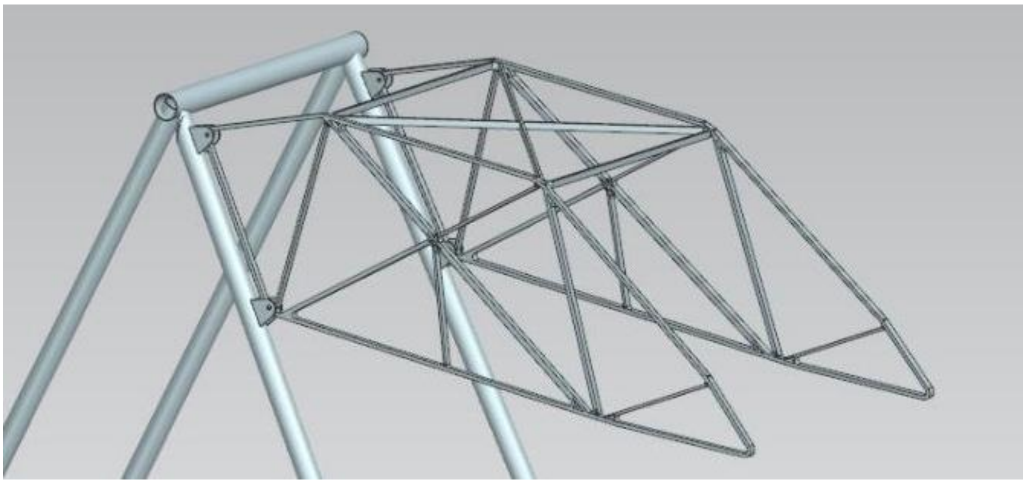

Fig. 3. Model of the bracket

2. MATERIALS AND METHODS

2.1 Materials

Carbon fiber roving was chosen as the reinforcing material. A carbon fiber roving is a type of yarn that consists of many individual carbon fiber filaments. A roving with an index of 24k was chosen, as it has an optimal thickness. An epoxy resin with a low viscosity and a lifetime of more than 1,5 hours was chosen as the binder. All parts of the mould were made by 3d printing from ABS plastic.

2.2 Method

The production method consists of sequentially winding the parts of the mould. The bracket is far from a rotation figure. It has a flat, spatial shape, so it was decided to divide the bracket into 3 flat parts that are produced separately. The two side parts are produced on a complex mould consisting of eight triangular sections. These sections follow the shape of triangles that can be built on the sides of the bracket. On the sides of the triangles, there are grooves (troughs), where the fiber is placed, i.e., the winding around the triangle takes place. Each individual triangular section of two symmetrical halves with respect to the plane of the bracket, ensuring the disassembly of the tooling. Triangles are connected together using separately manufactured fasteners.

The production method consists of 4 stages:

Stage I: Fixing the roving into each section with embedded elements. Winding each individual triangle with three layers of roving (Figures 4 and 5). Installation of the embedded elements in sections 1 and 8 after winding the second layer. Tension is applied by means of special embedded elements, most of which are subsequently removed. The remaining embedded elements are later used for attaching to the wing and frame (Figure 5).

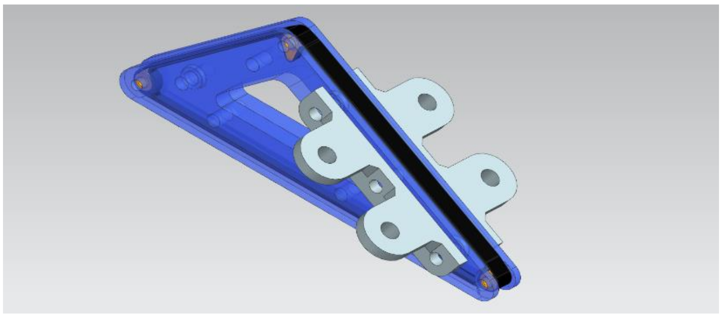

Fig. 4. Stage I

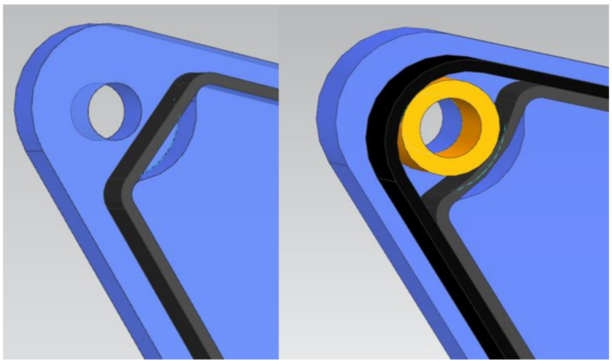

Fig. 5. Embedded element used to connect the bracket to other parts of the car

Stage II: Pairwise connection of triangular sections 1-2, 3-4, 5-6 and 7-8. Winding pairs with 2 layers of roving, Figure 6.

Stage III: Pairwise connection of pairs of triangular sections 12-34, 56-78. Winding pairs with 2 layers of roving. At this stage, blanks of two halves of the side part of the bracket have been obtained, Figure 7.

Stage IV: Connection of two halves of the side part of the bracket. Winding along the outer contour with 3 layers of roving, Figure 8.

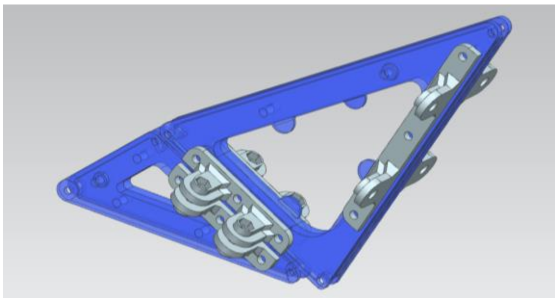

Fig. 6. Stage II

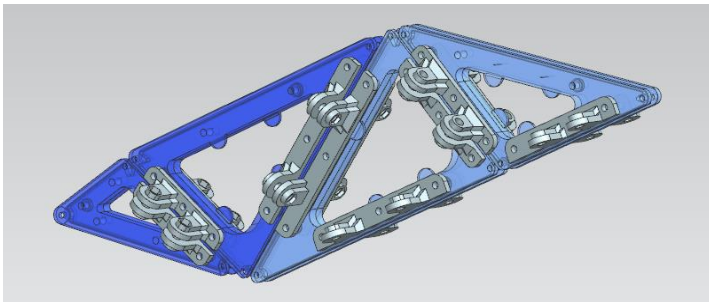

Fig. 7. Stage III

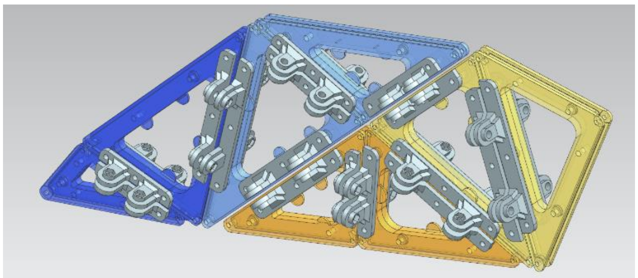

Fig. 8. Stage VI

After the winding process is completed, the product is cured at room temperature. Then it is removed from the mould, post-curing and subsequent machining are carried out. Figure 10 shows the finished side parts of the bracket, Figure 9.

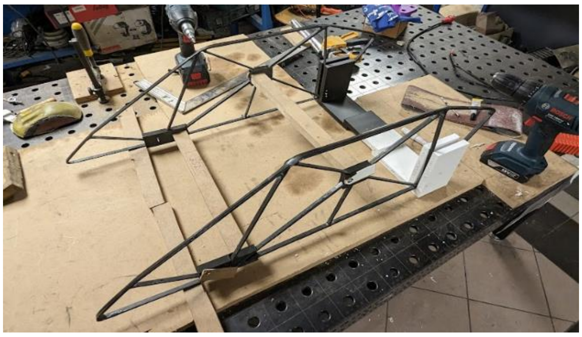

Fig. 9. Finished side parts of the bracket

Fig. 10. Pre-marked plane

No separate tooling was provided for the manufacture of the crosspiece. Instead, it was wound around four cylinders, which were installed at appropriate points behind a pre-marked plane, Figure 10. Then the crosspiece was cured at room temperature and cylinders were taken out.

At the last stage, all the parts of the bracket were assembled together on the stocks and wound to each other. The finished bracket is shown in Figure 11.

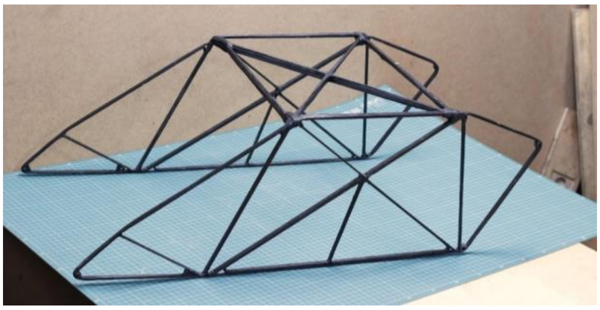

Fig. 11. Metal lattice bracket

2.3. Mould

Three iterations of the rigs were created to refine the production technology.

The first iteration was developed in isolation from the geometry of the mesh bracket consisted of two triangular sections, each triangular section consists of two symmetrical halves. Their shape is symmetrical except for the centering elements: on one half there are 3 projections, on the other 3 holes. Two triangular sections are connected together by 4 fasteners (Figure 12). All three angles differ, thereby determining the need for embedded elements and their shape. The first is a drop-shaped embedded element, it is needed to fix the fiber at the beginning of winding and create tension. The second embedded element (cylinder) remains in the part at the mounting points of the bracket. The groove section is round.

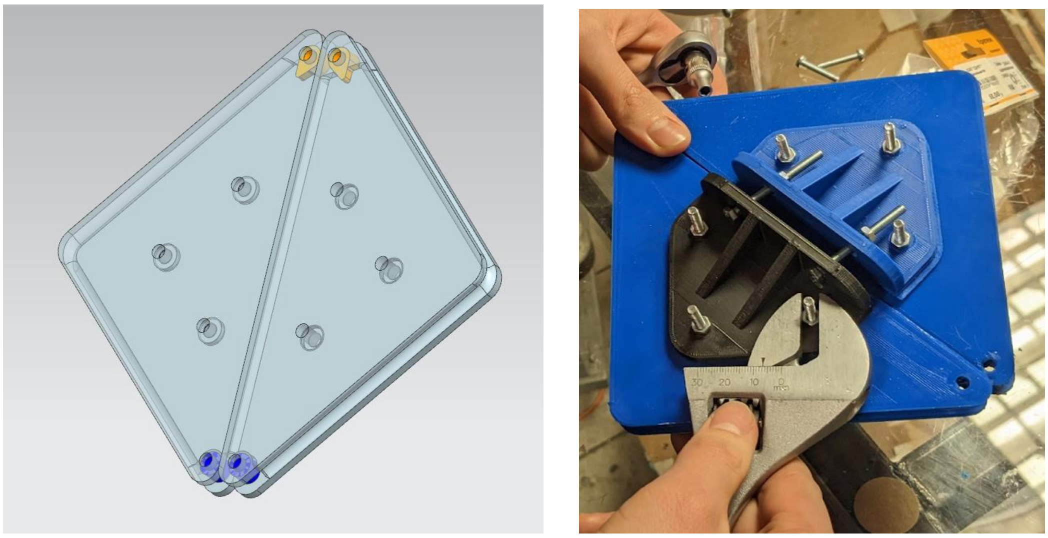

Fig. 12. First iteration of the mould

According to the results of the first iteration, it was decided to change the shape of the grooves to a rectangular one, change the shape of the fasteners to save plastic (changing the mounting points of the brackets allowed cutting out the central part) and accelerate assembly (the recess in which the nut will be placed with tension), add elements that facilitate disassembly of the mould. The second iteration of the mould was based on the geometry of the bracket (its two largest triangles), similar to the first iteration consisting of two halves connected by four brackets, Figure 13.

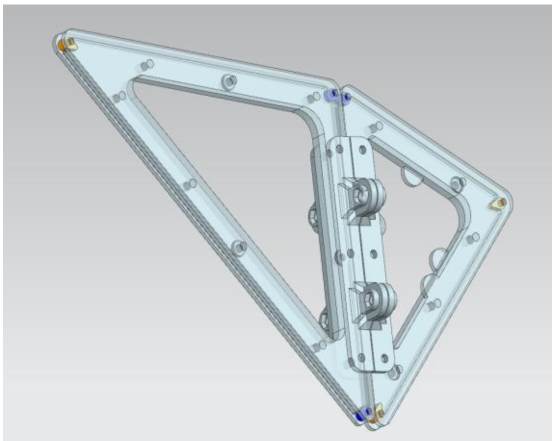

Fig. 13. Second iteration of the mould

Fig. 14. Third iteration of the mould

The third iteration is a bracket-scaled version of the second iteration with increased groove depth, reinforced elements for disassembling and the addition of a wedge-shaped groove on the inside of the triangular sections to facilitate disassembly. The equipment consisted of 8 triangular sections (each section consists of 2 halves), and 32 brackets. (Figures 14 and 15)

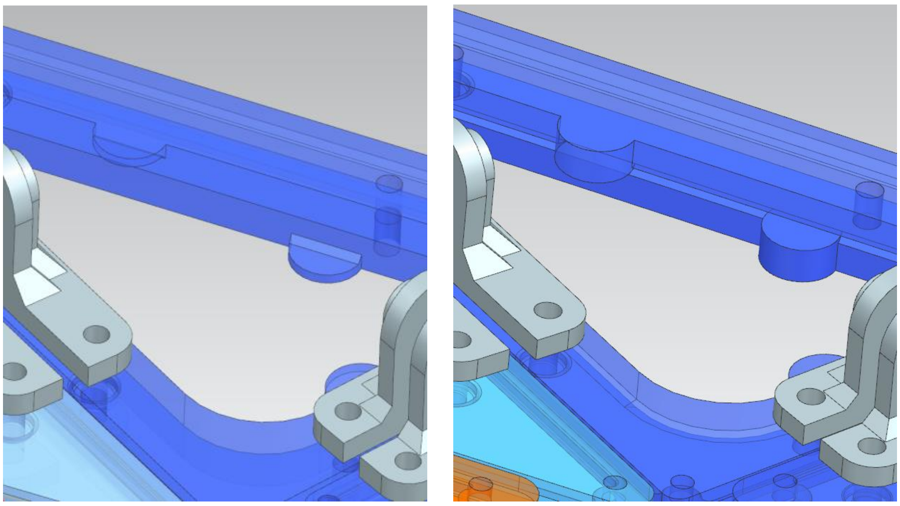

Fig. 15. The third iteration of the mould. Changes to the design of the elements for disassembling and the addition of a wedge-shaped groove

3. RESULTS AND DISCUSSION

In 4 months, the technology of manufacturing a composite lattice bracket by winding was developed. Special equipment was developed and manufactured using 3D printing. A composite lattice bracket was made, which weights 386 g. The bracket was produced by a large team of engineers from the composite structures and related departments.

As a result of the work, a bracket was produced that is 2.3 times lighter than analogues. But the production of the mould and the product took quite a long time. The 3D printing of the tooling took more than 50 hours and consumed more than 2 kg of plastic. These costs can be reduced by modifying the shape of the sections and fasteners of the mould. It is also worth considering the possibility of manufacturing the side parts of the tooling using a technology similar to the production technology of the central section. It will reduce the number of assembly operations and significantly speed up production.

4. CONCLUSIONS

After The analysis of the existing bracket designs was carried out. The winding technology was investigated. The production process for the composite lattice structure of the rear wing for the Formula Student car has been developed and implemented. The weight of the bracket has been significantly reduced. Further work will be aimed at simplifying the technological process and changing the configuration of the bracket rods in order to improve the rigidity and strength properties of the structure.

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Conflicts of Interest: There is no conflict of interest.

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