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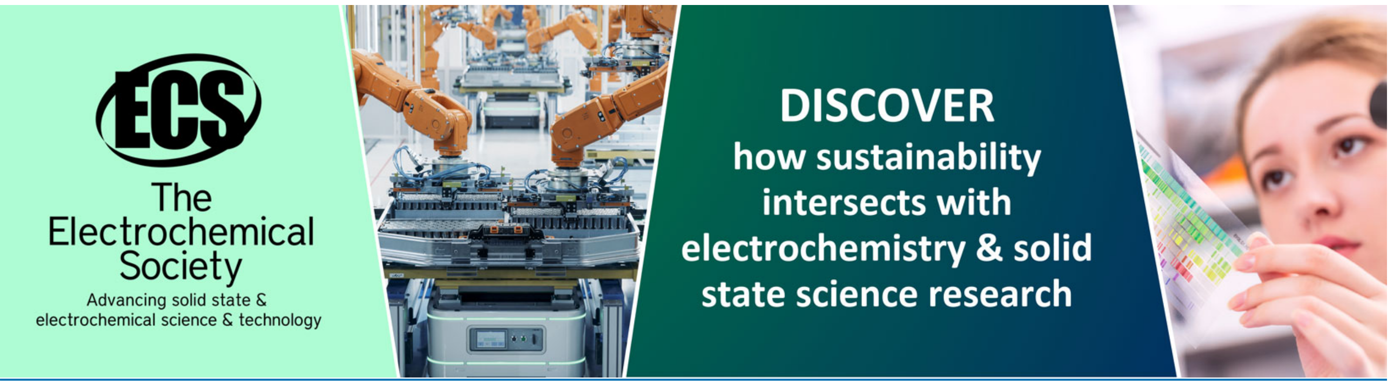

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Developing of the autoclave-free composite manufacturing technology

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Abstract. Nowadays there are numerous ways of making parts of polymer composite materials. The main controlled properties of a part depending on a used technology are porosity and binder percentage, which influence on quality and strength of a part, and also manufacturing cycle time and costs of the used equipment. The main aim of the research was to increase the efficiency of the PCM moulding comparing to the resin infusion method. For reaching the aim there was developed the moulding technology with using elastic diaphragm inflation, as well as there were conducted series of tests by using the dynamo-mechanic analyzer. The way of making the mould and pattern of reinforcing plies layout were offered. For technology approbation there were made a serie of carbon fiber reinforced plastic sport helmets, and got results of time properties of manufacturing. It was discovered that the number of parts made for the time unit by using the inflation method twice exceeds the number of ones made by vacuum infusion method. Specific properties of constructions made by the offered technology also exceed properties of parts made by traditional methods. Inflation technology was successfully put in production and proved its efficiency, reliability and profitability.

Key words: polymer composite materials, composite technologies, autoclave-free moulding, inflating technology, composite materials manufacturing, sport helmet, manufacturing optimization

1. Introduction

Composite materials are widely used in different fields of technics due to their unique properties. At the present moment there exist a lot of ways of making parts of these materials [1-5]. In composite industry there is a trinity of material, technology and construction [6], which means that every composite part requires the unique combination of producing method and the plies layout. Many factors influence on the final quality of the part: the technology of moulding, personnel skills, raw materials and their pre-preparing, environment factors (e.g. temperature, humidity, etc.), facility's equipment [7-9]. Thus while creating a new manufacturing technology negative factors are to be significantly reduced or eliminated. Cycle time of producing the part and the price of the used equipment are also important [10]. Nowadays RTM, autoclave moulding, Compression RTM and experimental technologies such as VARTM with incomplete vacuum are the technologies providing the most optimal ratio of the matrix and filler as well as pores percentage [11-17].

2. Elastic diaphragm inflation technology

As the basis of the method there was taken the process of making composite helmets with thermoplastic binder (figure 1).

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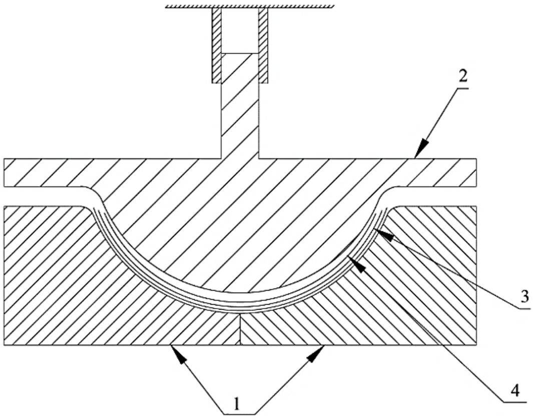

Figure 1. Schematic of motorcycle helmet making:
1 – separating mould, 2 – punch on a hydrocylinder, 3 – layer of the thermoplastic binder, 4 – filler layer

While manufacturing the helmets the separating aluminium mould, divided on the face of symmetry is used. Filler (4) and thermoplastic layers (3) are put in the assembled mould. After that the punch with the inner shape of the helmet (2) is pressed by using the hydraulic cylinder. After connecting the punch and the mould thermoplastic binder is softened by heating. Then, after compressing of all the layers and cooling the part down, the punch removes from the mould and the part ejects.
Due to the relatively high complicity of the technology realization, there was offered the following technology, whose schematic is shown on the figure 2.

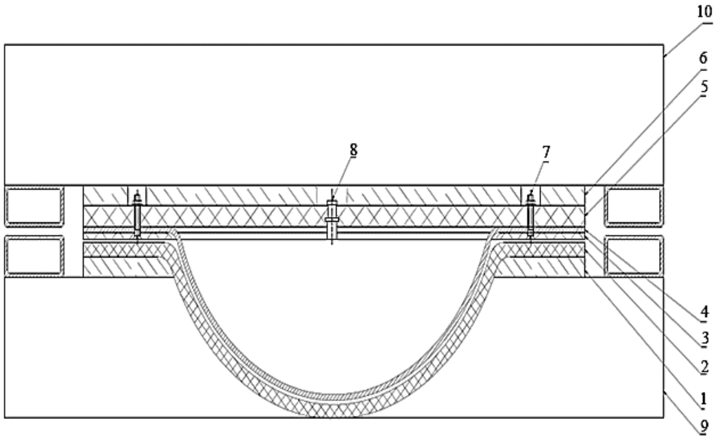

Figure 2. Schematic of the assembled mould: 1 – 15 mm plywood, 2 – fiberglass mould, 3 – lower cover, 4 – silicon bag, 5 – upper plate, 6 – plywood support, 7 – M5 bolts, 8 – air inlet, 9 – lower frame half, 10 – upper frame half

Before being moulded the stack of dry layers lays out on the mould (2) just the same way as for vacuum infusion. For binder spreading and stack compression the silicon elastic diaphragm (4), inflated by the excessing pressure from the air pipeline, is used. Hermetic area is created by the upper plate (5) and silicon diaphragm (4), pressed to each other and held by the lower plate (3). Plates and silicone membrane are pulled together by 16 bolts (7). To avoid displacements of the hermetic area relatively to the mould there are used two halves of the frame: upper (10) and lower (9), which are pulled together by 4 M16x90 bolts. To fit both of the frames parts tight to the mould and the upper cover, 15 mm plywood plates (1), (6) are adhered.

3. Part moulding process

Part making starts from preparing the preform:
Mould surface is covered with Loctite 770NC release agent. Then, filler plies (carbon biaxial tape BT70-20, hybrid carbon-aramid cloth) are laid on the preform mould in reverse order, due to that the first layer would become inner after locating the preform in the mould (table 1).

Table 1. Order of preform's plies layout

Ply no.	Filler material
1	Carbon biaxial tape
2	Carbon biaxial tape
3	Carbo-aramid cloth

During first ply laying out on the preform's mould, the minimal amount of adhesive spray should be used. Moreover, it's better to spray only on the flanges so not have fabric surface glued to the main mould surface, otherwise there may be a risk of strong preform deformation.
Elantas Elantech 152 (80g of resin and 24g of hardener per each helmet) was chosen as the binder. Needed amount of the compound pours in the mould and the helmet's preform locates into the right position (3).

Figure 3. Mould with the poured binder

Figure 4. Assembled mould

For silicon bag's protecting from damaging interacting with epoxy resin, the silicon lubricant is used. When a preform is located in the mould, it's covers with the silicon bag and then these two parts are pulled together by the frame. After both parts of the frame are strongly screwed, thermo-resistant pipe connects to air inlet and pressure applies. Fully assembled mould is shown on the figure 4.
After binder hardening the inlet closes, air releases, the frame unscrews and the silicon bag takes off the mould. To avoid temperature deformations, the helmet cools down to the room temperature, and then ejects. Further, the helmet is cut on the CNC milling machine.

4. Measurements of parts' elastic modules

To compare elastic modules of parts there were cut 5 specimens 5x20 mm off the zones with maximal radius of curvature. For tests the were used one helmet made by each of technology. Cutting out zones' locations are shown on the figure 5.

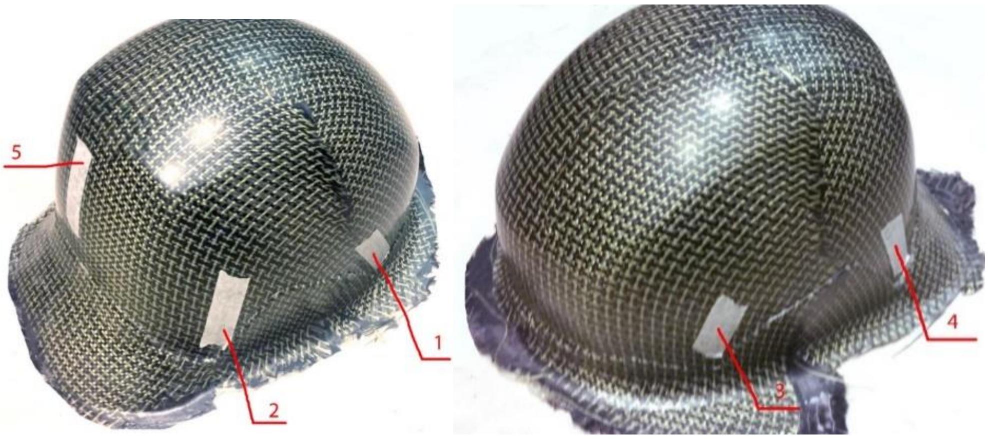

Figure 5. Specimens' cut-out zones on the helmet

Tests were conducted on dynamo-mechanical analyzer (DMA) NETZSCH DMA 242 E [17]. Three-point bending with sinusoidal specimen loading was used as the deformation mode [19],[20]. Results of tests are provided in table 2.

Table 2. Specimen's elastic modules' values

	Silicon bag inflation	Vacuum infusion
Cutting out zone no.	*E*, GPa	*E*, GPa
1	11,22	10,83
2	12,24	11,95
3	11,27	10,57
4	12,16	11,96
5	13,77	12,13

Figure 6 shows the values of specimens' made by vacuum infusion and elastic diaphragm technologies elastic modules.

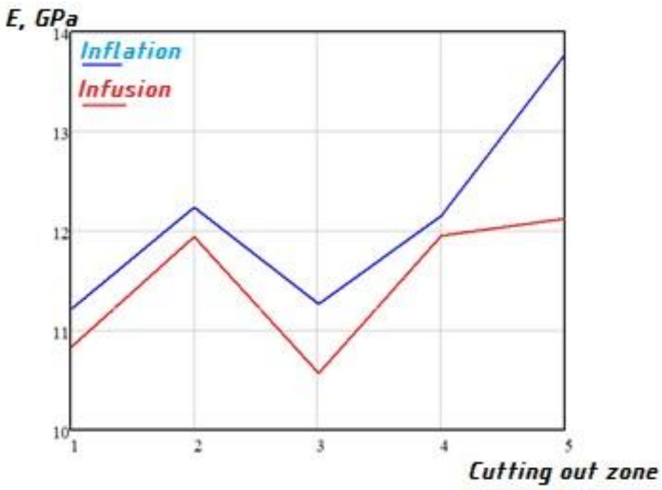

Figure 6. Dependence of parts' elastic modulus on cutting out zone. Blue line – elastic diaphragm inflation, red line – vacuum infusion

For mass comparison there were chosen 15 helmets from each batch made by different methods. Weighing was conducted on the laboratory scales OHAUS SJX3201/E [21], which value of division is 0,1 g and accuracy is ±0,05 g.
Computing the mean values of helmets' mass, equal 148,52 g for vacuum infusion and 138,32 g for membrane inflation, it can be concluded that using the new technology the mass decreased for 6,8%.

Conclusion

1. The new technological process for making composite parachute helmets was developed with efficiency higher than vacuum infusion.
2. The new technological mould for the process was developed.
3. The technology was worked out for helmet manufacturing. During work there were found and eliminated the main defects appeared on parts
4. Trial parts were created. The mechanical properties of specimens and their mass were compared. Based on the received data it was concluded that elastic modules of parts made by using the new technology is 9% higher, filler percentage increased for 4,4% due to binder amount decreasing.

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