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The influence of temperature on the mechanical properties of a glass fiber reinforced polymer made by an infusion method

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ABSTRACT

Composite materials are increasingly used in the aerospace industry, among which laminates seem to be the most commonly used ones. They often replace conventional materials, such as metals due to their superior properties and performance. Composite materials help reduce fuel consumption and improve aircraft performance. It is important for the composites used in aircraft structures to have very high creep resistance and strength, due to high loads that they carry. Composites with the highest mechanical properties can be obtained using an infusion method. In the infusion process, the mould is prepared together with the reinforcement made of the material from which the composite is made, e.g. glass fibre. It is tightly closed in a vacuum bag, and the equipment supplying the previously mixed resin with hardener is connected to the injection points. This study describes the main issues related to composites. It characterizes in detail the infusion method and the laminate manufacturing process. Layered composites using an infusion method can be made at various temperatures. This work describes the effect of the applied different temperatures on the obtained mechanical properties from a composite reinforced with fibre glass. During the research, tensile strength, impact strength and bending tests were carried out. It turns out that the best strength properties of the material are obtained when it is manufactured at high temperature, while manufacturing at low temperature causes a significant decrease in strength and other material parameters. The authors also wanted to show the advantages of the infusion process with controlled (higher) temperature in the context of increasing strength factors of the composite.

Keywords: layered composites, composite manufacturing processes, infusion method, GFRP (glass fiber reinforced polymer).

INTRODUCTION

A composite is a material consisting of two or more chemically and physically different components that are combined in such a way as to exhibit better properties than when they are separate. Composite materials expand the possibilities for designers in all branches of engineering [17, 25, 26]. This family of synthesized materials offers a possibility of new solutions to difficult engineering problems. Materials are combined in a way to make the most of their advantages while minimizing their disadvantages [3, 5]. This allows constructors to use more durable and lighter materials, the properties of which can be tailored to specific design requirements. Furthermore, due to the ease of manufacturing complex shapes, this can lead to cheaper and more efficient solutions [13]. Composites are produced by a variety of methods, and the most commonly used ones in industry include the hydraulic press method, the vacuum bag method and the infusion method [1].

The method of composites manufacturing using a vacuum bag uses atmospheric pressure as a medium maintaining pressure until the resin hardens. This process combines elements of the contact technique (manual percolation of fibers) with forming using negative pressure.

In practice, subsequent reinforcing layers are percolated with resin mixed with a hardener, then a layer of delamination fabric, perforated foil and a drainage fabric are laid on them. The semi-finished product prepared in this way is sealed in a vacuum bag, to which an air extraction system is connected. Sucking out the air and maintaining a constant negative pressure allows the atmospheric air surrounding the bag to exert pressure evenly over the entire surface of the laminate. This method is very universal, cheap and leads to obtaining materials of medium strength.

The technique using a hydraulic press allows for obtaining high smoothness of both surfaces, as well as a very good ratio of the amount of reinforcement to the amount of matrix. Most often, the composite production process using this method is carried out by placing suitably saturated reinforcement layers in a mold and pressing under an appropriately high pressure. In order to improve the quality of the product, molds equipped with heating systems and venting channels are very often used. The hydraulic press allows for very precise and efficient production of composites. The quality of the products obtained by this method predisposes it for serial production (but only simple shapes elements). What is more, it also provides the possibility of repairing composite structures, which makes it a method of wide application [28].

The vacuum infusion method, used in composite manufacturing, uses the pressure difference, between the closed mould and atmospheric pressure, as the driving force to infuse the resin mixture (resin mixed with hardener) into the mould and further press the composite into the mould [16, 24]. This process significantly increases the ratio of reinforcement fibres to matrix in the finished composite, generating additional benefits not available with traditional manual lamination methods. Starting the process, dry reinforcing material (e.g. glass fibre) is placed on the surface of the mould. This is followed by a layer of delamination fabric and mesh to facilitate the flow of resin. A tube is placed inside and an item is placed at the top to allow tight sealing (often a polyolefin film), which must be properly attached to the mould to form a hermetically sealed unit. The vacuum pump removes air, which creates a pressure difference between the low pressure in the mould and the higher atmospheric pressure, sucking the resin into the mould. During this process, the laminate is saturated with the resin mixture until the reinforcement layers are completely covered.

The vacuum infusion method provides a number of advantages over traditional methods. One advantage is better reinforcement to matrix base ratio. Hand lamination usually results in the introduction of more matrix base than reinforcement itself in the mass produced composite. This is different in the infusion method, where only a minimal amount of liquid matrix is introduced into the mould, maximizing the properties of combined composite components (i.e. reinforcement fibres and matrix).

Although the concept of the infusion process appears simple, its successful application requires careful planning and design to ensure that the mould is filled in a timely manner without areas that are not saturated with the liquid matrix [12, 15]. The infusion rate is determined by the viscosity of the resin [19], the distance it has to flow, the permeability of the elements and the vacuum level. It is, therefore, important to properly select the materials and flow elements, resin flow layout and location of vacuum ports, which is crucial to achieve a high quality manufactured piece.

Glass fibres and glass fibre products are commonly used as reinforcement in composites [9, 10, 11]. The most popular fibres are made from the so-called E-glass, which is glass with low alkali content. They can operate at temperatures up to 350 °C.

Glass fibres are most commonly used in the form of roving, i.e. strands of fibre joined without twist and coated with a special preparation, as well as in the form of fabrics in a variety of weaves, chopped roving and chopped roving mats. Glass fibre reinforcement phases have high tensile strength, low Young's modulus (low stiffness), but high shear modulus. It can be considered that, apart from the price, the main advantage of glass fibres in polymer composites is their higher energy absorption capacity compared to carbon fibres and their very high tensile strength [4, 7, 27].

The matrix of polymer composites is often an epoxy resin composition with known characteristics, as long as it is used under the conditions specified by the manufacturer in the safety data sheet (in terms of weight ratio resin to hardener). However, it may happen that standard composite manufacturing conditions cannot be maintained, which is likely to be the case with their manufacture in the field. The article presented here attempts to determine the effect of the infusion method composite manufacturing temperature on its mechanical properties.

PREPARATION OF MATERIALS FOR TESTING

The composite material for the study was made from nine layers of 390 g/m^2 glass fibre twill fabric [2, 7, 8] – the dimension of the laminates (Fig. 1) produced was 200 × 300 mm (the dimension of the 400 × 300 mm mould was conditioned by the size of the climate chamber (Fig. 1) in which the infusion process was carried out). The reinforcing fabrics in the mould were arranged without rotation, so the reinforcing fibers in all layers were parallel to the edge of the mould. The matrix was MGS L285 epoxy with H287 hardener [20]. The epoxy resin and hardener were mixed together in 100:40 weight ratio. In order to conduct the tests, 3 composite panels were produced using the same technology, differing only in the value of the manufacturing temperature: 5 °C, 23 °C and 50 °C. The manufacturer recommends temperatures between 20 °C and 40 °C for the manufacture of composite materials [23]. The temperature of 5 °C was used to check and verify the possibility of field repairs of composite structures, e.g. those used in aviation.

Figure 1. WEISS-Technik climate chamber WKL 64/40 including vacuum installation

The manufacture of laminates was conducted in accordance with the technology described in the available literature. In the final step, after the mould was sealed and the lines connecting the mould to the liquid matrix tank and the vacuum pump were connected, the valves placed on the tubing were opened, causing the resin composition to seep through the previously laid reinforcement layers. Once this process was complete (the mould was completely filled with the liquid matrix), the resin-hardener supply valve was closed. After 24 hours when the material had fully cured, the composite plate was removed from the mould.

The time required for matrix supersaturation of all laminate layers varied with temperature, reaching the following values:

- at a temperature of 5 °C for approximately 5 hours;
- at a temperature of 23 °C for approximately 15 minutes;
- at a temperature of 50 °C for approximately 5 minutes

The difference in mould filling times is related to the change in viscosity of the liquid matrix with the change in temperature at which the process took place [22].

After the composites were removed from the mould, a visual inspection of their quality was carried out, during which it was noted that the composite layers were properly supersaturated and the matrix had cured adequately. The structure of the composites was visually correct.

RESULTS OF EXAMINATION

A set of samples was cut out (high pressure water cutting) from each laminate for strength testing using a waterjet cutting machine (Fig. 2). The samples were used for tensile, bending and impact strength tests. The samples were cut so that the reinforcing fibres were parallel and perpendicular to their long edge.

Prior to testing, the surface weight of the composites, the reinforcement content of the composite and the average thickness of the samples were calculated (Table 1). The thickness of each sample used in the tests was measured at three points – the results were averaged.

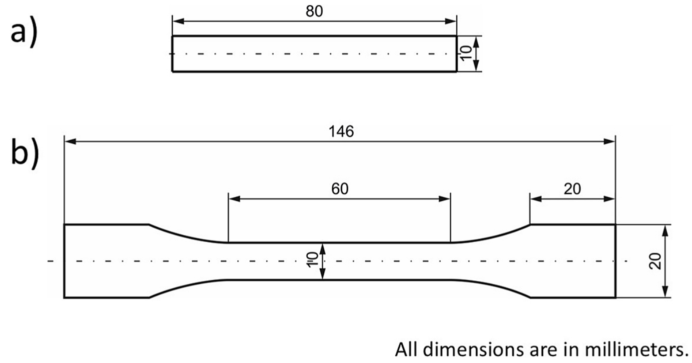

Figure 2. Specimen shape: a) sample for impact and bending strenght test, b) sample for tensile strenght test

Table 1. Composite parameters of the manufactured composites

Composite production temperature (°C)	Surface weight (g/m²)	Volume of reinforcement in laminate (%)	Average thickness (mm)
5	5243.1	67	3.80
23	4965.2	70	3.02
50	4972.2	70	2.85

Visual examination (Figs. 3–5) shows that, in terms of internal structure, the best laminate is the one made at 50 °C with the fewest air voids in the structure [14, 18, 21], which is very favourable for the composite material. The composite made at 23 °C is not much different - it has the correct external and internal structure and only slightly more air voids. The internal and external structure of the composite made at 5 °C is the worst. Significantly more air voids can be seen in the internal structure. Also areas of heterogeneous surface cross-linking are clearly visible in the external structure under magnification.

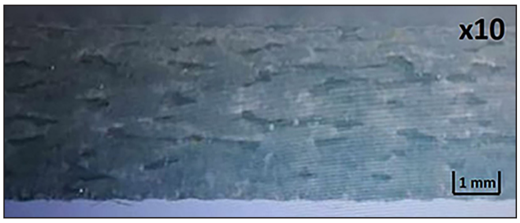

Figure 3. Internal structure of the laminate made at 5 °C (x10 magnification)

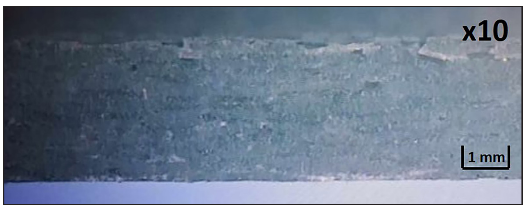

Figure 4. Internal structure of the composite made at 23 °C (x10 magnification)

Figure 5. Internal structure of the composite made at 50 °C (x10 magnification)

The static tensile strength test was performed in accordance with EN ISO 527-5982 standard using the INSTRON 5982 machine. The test was performed to determine the tensile strength (Fig. 6) and the Young's modulus (tensile) (Fig. 7). During the test, 15 samples (5 samples from each composite) in the shape of a paddle with a gauge length of 150 mm were tested. The speed of the traverse movement equalled 2 mm/min.

When analyzing the results, it was observed that the laminate made at 50 °C achieved an average tensile strength of 422.53 MPa, a result approximately 40% higher than the composite made at 5 °C. The composites made at 23 °C and 50 °C showed similar tensile strengths.

A triple support bending tests was conducted in order to determine the bending strength (Fig. 8) and Young's modulus (bending) (Fig. 9). The test parameters were set in accordance with the DIN EN ISO 178 standard. Fifteen samples (5 pieces per composite) measuring 80 × 10 mm were used for the test, the traverse movement speed during the test was equal to 10 mm/min, distance of

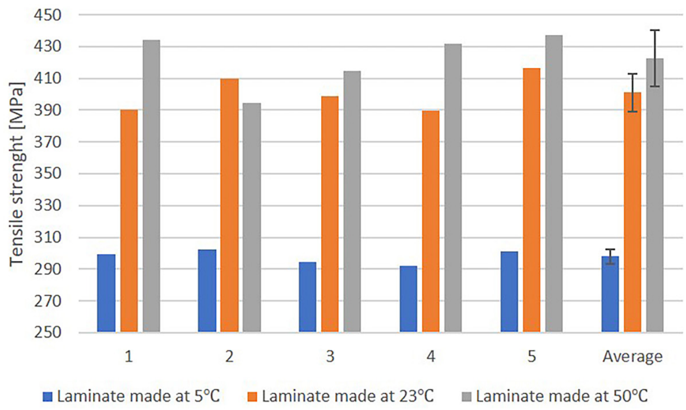

Figure 6. Diagram of tensile strength of tested materials

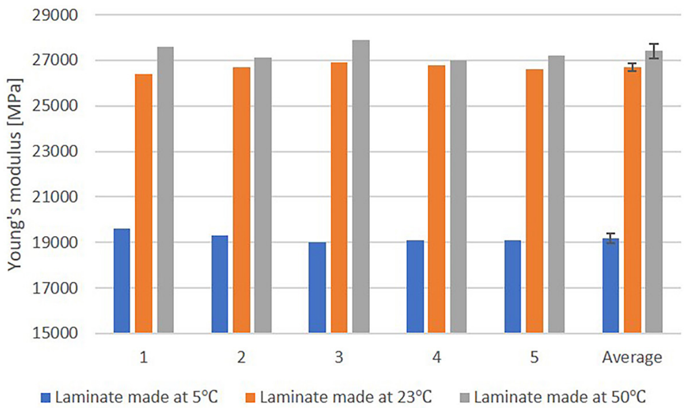

Figure 7. Diagram of Young's modulus (tensile) of tested materials

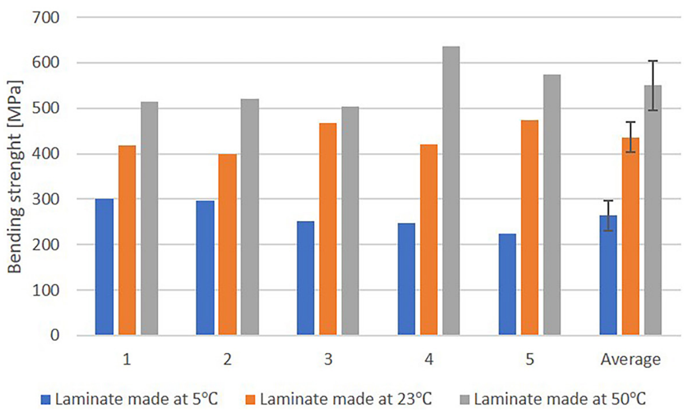

Figure 8. Diagram of the bending strength of the test materials

supports was equal to 60 mm, initial force speed was equal to 5 mm/min.

In terms of bending strength, there are significant differences in the composites tested. From the graphs (Figs. 8–9), it can be deduced that the composite made at 50 °C has the highest bending strength average (549.8 MPa) and that when it is made at 5 °C, it has 108% lower bending strength (264.0 MPa) than the one made at 50 °C. In contrast, the Young's modulus (bending) of the laminate made at 5 °C is 48% (21.5 GPa) lower compared to the composite made at 23 °C (31.8 GPa).

The determination of the impact strength was carried out using the Charpy method with an SW-5 pendulum hammer [6]. The samples of the fabricated composites were surface and edge loaded. For the needs of the tests, the authors used 60 samples sized 80 × 10 mm.

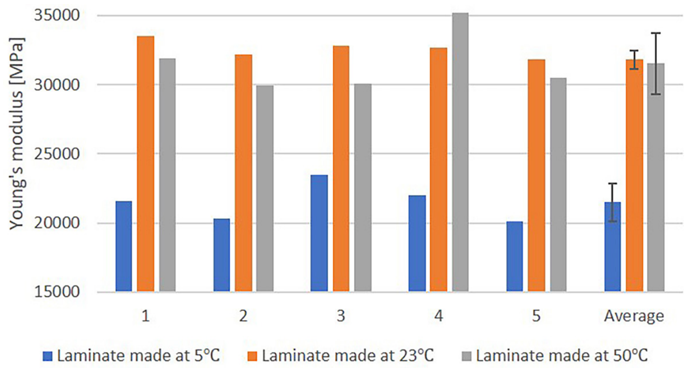

Figure 9. Diagram of Young's modulus (bending) of tested materials

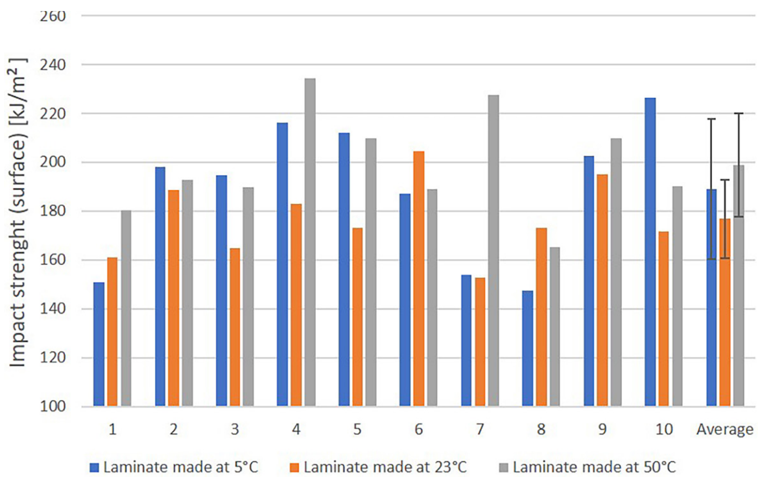

Figure 10. Impact strength of laminates under surface load

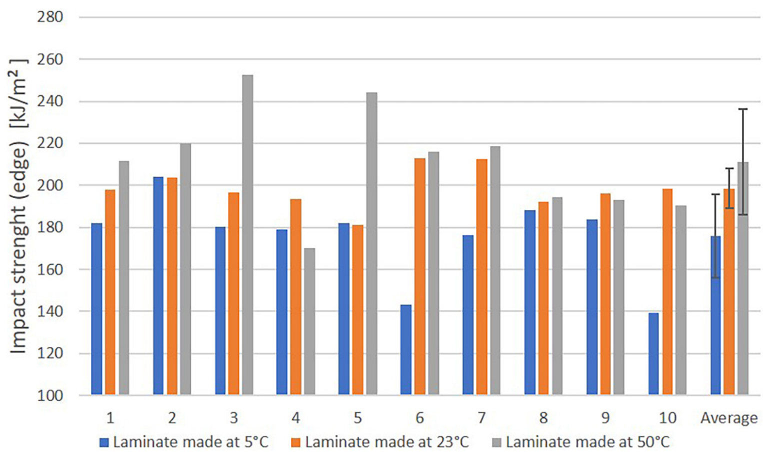

Figure 11. Impact strength of laminates under edge loading

The laminate, made at 50 °C, achieved the highest impact strength average (211.062 kJ/m^2) in the edge impact test (Fig. 11). In the case of surface impact strength (Fig. 10), the laminate made at 50 °C also shows the best impact strength average (198.847 kJ/m^2). The composite made at 50 °C has approximately 12% higher impact strength than the composite made at 23 °C, and approximately 5% higher impact strength than the material made at 5 °C when comparing surface impact strength. On the other hand, when comparing edge impact strength averages, a composite made at 50 °C has an impact strength average approximately 6% higher than a composite made at 23 °C and approximately 20% higher than a laminate made at 5 °C.

CONCLUSIONS

An analysis of the tests carried out on laminates made of glass fibre with a 390 g/m^2 twill weave and a matrix consisting of a mixture of epoxy resin and hardener, manufactured by means of the infusion method, made it possible to assess such strength parameters as impact, tensile and bending strength.

The performance properties such as surface mass, laminate thickness and percentage of reinforcement in the laminate were also determined. The best performance is shown by composites made at 23 and 50 °C, containing around 70% reinforcement in the laminate, with the composite made at 50 °C having the lowest number of internal 'voids'.

The composite made at 50 °C shows the best mechanical properties, although similar to the composite made at 23 °C (differences of up to 5%).

The composite material made at 5 °C is characterized by the lowest performance among all the tested properties. This is partly due to the low temperature, which caused the composite to take several hours to supersaturate, much longer than the other two laminates, which did not favour the propagation of the resin mixture, making it more difficult to extract the excess matrix. As a result this laminate is almost a millimetre thicker than the others. The low manufacturing temperature also affected the cross linking process of the matrix, which also translates into low values for the tested mechanical properties of this composite.

Based on the tests of composites produced in the temperature range 5–50 °C, it was found that the composite material made by the infusion method has better strength and performance properties, the higher the temperature at which it was made. However, increasing the manufacturing temperature of the composite requires additional tooling, which, in view of the small increase in mechanical strength, may not be justified.

REFERENCES

1. Boczkowska A., Krzesiński G. Kompozyty i techniki ich wytwarzania, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2016.
2. Krzyżak, A., Mazur, M., Gajewski, M., Drozd, K., Komorek, A., & Przybyłek, P. Sandwich structured composites for aeronautics: methods of manufacturing affecting some mechanical properties. International Journal of Aerospace Engineering, 2016.
3. Godzimirski J., Materiały lotnicze, WAT, Warszawa 2008.
4. Staszewski W., Boller Ch., Tomlinson G. Health Monitoring of Aerospace Structures. John Willey & Sons, Ltd, 2004.
5. [5] Boczkowska A, Kapuściński J., Puciłkowski K., Wojciechowski, S. Kompozyty, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2000.
6. Ochelski, S. Metody doświadczalne mechaniki kompozytów konstrukcyjnych, Wydawnictwa Naukowo-Techniczne, Warszawa 2004.
7. Konsztowicz, K., Kompozyty wzmacniane włóknami. Podstawy technologii, Wydawnictwo AGH, Kraków 1986.
8. Heng, H., Belouettar, S., Potier-Ferry, M. Review and assessment of various theories for modeling sandwich composites. Composite Structures 2008, 84(3).
9. Goraj, Z. Struktury kompozytowe w lotnictwie. Prace Naukowe Politechniki Warszawskiej. Mechanika 2007, 219.
10. Seneńko, K. Badanie właściwości lotniczych struktur kompozytowych. Diss. Instytut Techniki Lotniczej i Mechaniki Stosowanej, 2010.
11. Karpowicz, A.S. Metody wytwarzania kompozytowych struktur płatowca. Diss. Instytut Techniki Lotniczej i Mechaniki Stosowanej, 2016.
12. Popham, N. Resin infusion for the manufacture of large composite structures. In Marine Composites: Design and Performance; Pemberton, R., Summerscales, J., Graham-Jones, J., Eds.; Woodhead Publishing: Amsterdam, The Netherlands, 2019.
13. Lunn, P. Cost-effective resin infusion. Reinf. Plast. 2009.
14. Mehdikhani, M., Gorbatikh, L., Verpoest, I., Lomov, S.V. Voids in fiber-reinforced polymer composites: A review on their formation, characteristics, and effects on mechanical performance. J. Compos. Mater. 2019.
15. Correia, N., Robitaille, F., Long, A., Rudd, C., Šimáček, P., Advani, S. Analysis of the negative pressure infusion moulding process: I. Analytical formulation. Compos. Part A Appl. Sci. Manuf. 2005.
16. Hashim, N., Majid, D.L.A., Baitab, D.M., Yidris, N., Zahari, R. Tensile properties of woven intra-ply carbon/kevlar reinforced epoxy hybrid composite at sub-ambient temperature. In: Encyclopedia of Materials: Composites, ed. Dermot Brabazon, Elsevier. 2019.
17. Markuszewski D., Wądołowski M., Gorzym M., Bielak M. Concept of a composite frame of a

Martian vehicle. Advances in Science and Technology Research Journal. 2021, 15(4), 222–230. https://doi.org/10.12913/22998624/141213

18. Juan, J., Silva, A., Tornero, J.A., Gámez, J., Salán, N. Void content minimization in vacuum infusion (VI) via effective degassing. Polymers 2021, 13, 2876. https://doi.org/10.3390/polym13172876
19. Abidin, M.K.A.B.Z., Anuar, M.K. The effect of resin viscosity in vacuum infusion process. Universiti Teknologi PETRONAS, 2010.
20. Święch, Ł., Kołodziejczyk, R., Stącel, N. Experimental analysis of perimeter shear strength of composite sandwich structures. Materials 2021, 14, 12. https://doi.org/10.3390/ma14010012
21. Shevtsov S., Zhilyaev I., Chang S.H., Wu J.K., Huang J.P., Snezhina N. Experimental and numerical study of vacuum resin infusion for thin-walled composite parts. Applied. Sciences. 2020, 10(4), 1485. https://doi.org/10.3390/app10041485
22. Hutera, B. Wpływ wybranych czynników na lepkość żywicy epoksydowej stosowanej jako spoiwo mas formierskich. Archiwum Technologii Maszyn i Automatyzacji 2003, 23(1), 53–61.
23. Technical Information (Laminating resin MGS L285, Hardeners MGS 285, 286, 287), Hexion, 2006.
24. Janiszewski J., Komorek A., Bakuła M., Bieńczak R., Pękala B. The influence of pressure in the infusion method upon mechanical properties of polymer composites. Adv. Sci. Technol. Res. J. 2023, 17(6), 217–227.
25. Czyż, Z., Karpiński, P., Gęca, M., Ulibarrena Diaz, J. The air flow influence on the drag force of a sports car. Adv. Sci. Technol. Res. J. 2018, 12(2), 121–127.
26. [26] Kłonica, M., Kubit, A., Perłowski, R., Bielawski, R., Woś, S. Selected methods of modifying the surface layer of a carbon composite. Advances in Science and Technology Research Journal 2024, 18(1), 270–277. https://doi.org/10.12913/22998624/183101
27. Kłonica, M., Bielawski, R., Żokowski, M. Comparative tests of shear strength of adhesive lap joints after thermal shocks. Advances in Science and Technology Research Journal 2021, 15(4), 364–375. https://doi.org/10.12913/22998624/143270
28. [28] Brodzik R., Komorek A., Janiszewski J., Przybyłek P., Rośkowicz M., Komorek Ł., Sobieski zu Szwarcenberg M. The influence of manufacturing technology on the mechanical properties of the layered composite, Aviation and Security Issues, 2023, 4(2), https://doi.org/10.55676/asi.v4i2.69