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Influence of layers lay-up on the mechanical properties of hybrid composites in field of aeronautics

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Summary

Polymer composites have been used in industry for more than fifty years, from shipbuilding all the way to aviation and vehicles. Numerous excellent properties of these materials, low costs and simplicity of production have resulted in large expansion of their application area. In the application in aviation industry materials have to be of low density, high strength and rigidity regarding density, as well as of excellent physical properties. The paper presents the procedures and the conclusions regarding the fabrication of laminated hybrid composite plates composed of carbon and glass fibres and the testing of their mechanical properties. In the former case, the central layer of the composite plate is made of glass fibres and the external layers are made of carbon fibres, but in the latter case, the central layer is made of carbon, and the external layers of glass fibres. As result, the impact of laying up of such hybrid polymer composites on mechanical properties (tensile and flexural properties) has been tested. The paper concludes with a parallel with some materials that are implemented in aviation (aluminium alloys and laminated composite materials with only one type of reinforcement).

KEY WORDS:
aeronautic industry
flexural properties
hand lay-up
polymer composite
tensile properties

KLJUČNE RIJEČI:
polimerni kompozit
rastezna svojstva
savojna svojstva
slaganje slojeva kompozita
zrakoplovna industrija

Utjecaj slaganja slojeva na mehanička svojstva hibridne kompozitne tvorevine u zrakoplovnoj industriji

Sažetak

Polimerni kompoziti u industriji se primjenjuju više od pedeset godina, od brodogradnje pa sve do zrakoplovstva i vozila. Mnogobrojna odlična svojstva ovih materijala, niski troškovi te jednostavnost proizvodnje razlozi su velikog širenja područja njihove primjene. Pri primjeni u zrakoplovnoj industriji uvjetuje se za materijale niska gustoća, visoka čvrstoća i krutost s obzirom na gustoću, kao i odlična fizikalna svojstva. U radu su izneseni postupci i zaključci vezani za izradu slojevitih hibridnih kompozitnih ploča sastavljenih od ugljikovih i staklenih vlakana te za ispitivanja njihovih mehaničkih svojstava. U prvom slučaju središnji sloj kompozitne ploče načinjen je od staklenih, a vanjski slojevi od ugljikovih vlakana, a u drugom slučaju središnji sloj načinjen je od ugljikovih, a vanjski slojevi od staklenih vlakana. Kao rezultat, provedeno je ispitivanje utjecaja slaganja takvih hibridnih polimernih kompozita na mehanička svojstva (rastezna i savojna svojstva). Na kraju rada dana je i usporedba s nekim materijalima koji se primjenjuju u zrakoplovstvu (aluminijske legure i slojeviti kompozitni materijali sa samo jednom vrstom ojačanja).

Introduction

Composite materials are a combination of two or more materials of different properties that when combined produce a material with the properties different from any individual component. Composites consist of a matrix and reinforcement agents that are added primarily in order to increase the strength and rigidity of the matrix, with reinforcement agent being usually in the form of fibres. There are many different composites, but the usual ones are those with polymeric matrix reinforced with glass, carbon, aramid or polyester fibres. Compared to "traditional" materials, composites feature numerous advantages: corrosion resistance, low density and low mass, favourable strength-to-density ratio (specific strength), favourable relation of module of elasticity and density (specific rigidity), possibility of fabrication of parts of complex shapes, simple and inexpensive maintenance, longer life-cycle, and possibility of "designing" the properties.[1]

Various innovations in the area of developing the existing materials and the creation of new types of materials have enabled the development of numerous areas including aviation which has therefore significantly improved from its original beginnings till today. The wish for higher quality and simpler life has given incentive to people to produce increasingly complex products, whose new functions and properties cannot be realized using classical materials.[1,2] Aircraft is an example of a product where today more than ever new materials are in mass use. The reasons lie in the improvement of the utility characteristics of aircraft regarding size, mass, speed, load capacity, safety and durability, change of operating conditions and requirements from the engine part or design element, failures during the use caused by material – deformations, fractures, excessive wear or corrosion, implementation of new laws, regulations and standards, reduction of costs and achievement of better competitiveness.[1]

Composites are, as already emphasized, one of the increasingly present materials in aviation owing a properties as high strength and low mass which gives them extremely favourable specific strength, thus becoming an alternative to classical metal materials of higher density and greater mass.[1,3] By the use of composite materials in the production of aircraft constructions, the aircraft mass can be substantially lowered, hence realizing lower fuel consumption or increasing the payload at the expense of lower mass which in turn has favourable effect on the cost-efficiency. Another advantage of composites is the possibility of their shaping into the products of complex shapes, thus reducing not only the number of positions of an assembly, but also the need for fastening and joining. The advantages are twofold: with the smaller number of positions the time necessary for mounting is shortened, and also the number of potentially dangerous points for crack initiation may increase, since the elements such as bolts and different bores act as stress concentrators. In relation to conventional engineering materials composites are less sensitive to the appearance of different forms of damage which contributes to their durability. And finally, it should be emphasised that these are the materials that can be designed in order to realize precisely the properties that are required in certain application, and which are not feasible in component materials. Therefore, composites represent a successful alternative to conventional metal materials in making engineering elements such as aircraft wing and fuselage fairing and numerous other aircraft elements. The development of modern aircraft is greatly conditioned by the application of precisely the composite materials whose share is constantly rising as presented by Table 1 on the example of three types of Boeing aircraft. As a rule composite parts have 20% to 30% lower mass in relation to identical metal parts. The total mass of composite materials embedded in *Boeing 777-200* amounts to 7,540 kg out of which 71% are carbon-reinforced polymer composites (CFRP), and the rest are glass-fibre-reinforced composites (GFRP).[1]

TABLE 1 – Application of polymer composite in *Boeing*[1]

Airplane type	*Total mass of polymer composites, kg*	*Save on weight, kg*
Boeing 737	681	272
Boeing 757	1516	676
Boeing 767	1535	636

Historically carbon fibre has been used extensively in secondary structures such as fairings, floor panels and interior. The manufacturing process for CFRP parts is very expensive, due to the high price of raw materials and the special tools needed for manufacturing.[4] But nevertheless Andersson, F. et al. described that SAAB's aircraft manufacturing adapt extensive use of carbon fibre reinforced plastics because of better mechanical properties which is in success factors (strategic, tactical, operational) of firm that contribute to a more cost-efficient product development process and aircraft design (reduction of weight with good mechanical properties).[5] In paper Guermazi, N. et al. authors investigate the influence of hygrothermal conditions on performance of glass-epoxy (G-E), carbon-epoxy (C-E) and hybrid laminated bidirectional composites in aircraft repairs. The C-E composites exhibited the best mechanical behaviour when they are subjected to tensile, flexure and wear.[6] On the other hand, over prolonged periods of immersion, water induced a noticeable degradation and resulting structural changes were recorded indicating that the durability of these composites was affected. In particular, G-E composites showed higher sensitivity to aging in comparison with C-E and hybrid composites. In all cases, the reduction in mechanical properties is caused by matrix plasticization due to moisture and temperature.

Through the literature review it can be concluded that there are lots of application and testing of carbon and other composite materials in aeronautic industry. The main goal is to reduce the weight by keeping the satisfactory mechanical properties. Carbon fibre composites are commonly used in aircrafts due to the highest specific strength and rigidity. However, for some less demanding applications, their production cost is not acceptable so it is necessary to design some new materials or combinations of materials with the reduced costs and satisfactory mechanical properties like hybrid composites.[7-11]

Hybrid composites are composites containing at least two types of reinforcements in a common unique matrix. A comprehensive review of hybrid composites and their mechanical properties is given in paper form author Swolfs, Y., et al.[12] This paper is focused on use of hybrid composites (combinations of carbon and glass fibres with different layers lay-up) in aeronautic industry.

Production of composite plate

In manufacturing hybrid composite plates, epoxy resin has been used as matrix and carbon and glass fibres as reinforcing agents. The plates were made manually, by lay-up technology. Two composite plates were made, of similar dimensions, same construction elements, the first plate being carbon-glass-carbon (CGC) reinforced by carbon fibres externally and glass fibres inside, and the second plate was glass-carbon-glass (GCG), on external side reinforced by layers of glass fibres and the central part made of two layers of carbon fibres as shown in Figure 1.

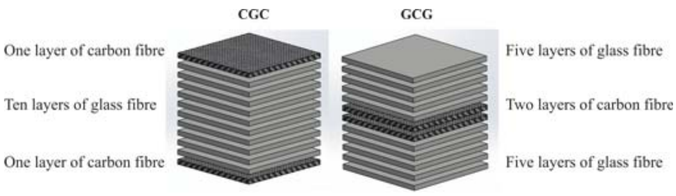


FIGURE 1 – Structure of CGC and GCG plates

The mould (Figure 2) is made of aluminium due to its excellent properties of heat transfer (by conduction) which is essential for best possible networking of composite plate constituents, and because of the possibility of good finishing of the mould plate reverse side (side on which the composite is to be laid). Good finishing of the mould plate reverse side is essential due to the quality of the external surface of the end product, since all the irregularities (damages) of the mould are mapped onto it. The mould is made of two aluminium plates, of dimensions 300 × 300 × 20 mm. They are machined, first by removing a layer of 2 mm thickness by a plane in order to obtain a perfectly flat contacting surface on both parts of the mould, and then the reverse sides are polished to obtain maximally smooth, high-quality surface.

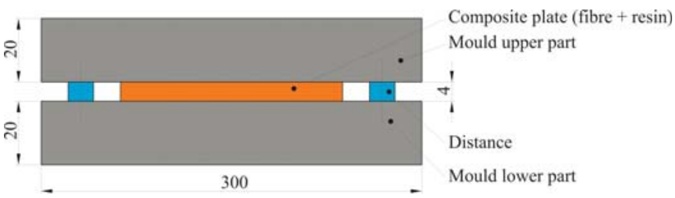


FIGURE 2 – Mould for production of composite plates

As preparation for the manufacturing of both composite plates, it was necessary to use a release agent, which is applied to mould plates, in a single layer. After hardening, it represents a thin protection film that facilitates separation of finished, hardened composite plate at the end of the production procedure. The experiment uses *Trennlack PVAL blau*, manufactured by *Lange Ritter*. It refers to a water-alcohol solution based on poly (vinyl-alcohol), with excellent properties regarding the formation of the protection film, with excellent emulsion and adhesive properties.

For the fabrication of both plates, 1st plate – CGC (carbon-glass-carbon) and 2nd plate – GCG (glass-carbon-glass), epoxy resin *HEXION™ Specialty Chemicals L 285* was used, manufactured by *G. Angeloni*, in combination with compatible crosslinking agent, also the fastest among those that can be used, *HEXION™ Specialty Chemicals H 285*, of the same manufacturer. Together, these two elements (epoxy resin and crosslinking agent) form a unique matrix of composites. Epoxy resin *HEXION™ Specialty Chemicals L 285* has the certificate issued by the *German Federal Aviation Authority* for use in aviation. Glass fabrics with the surface mass of 390 g/m^2, and carbon fabric with the surface mass of 220 g/m^2 were used. Thickness of one layer of glass fibres amounts to 0.33 mm, and of carbon fibres 0.40 mm. A total of ten layers of fabrics of glass fibres and two layers of carbon fibre fabrics were used for each plate. Fibre fabrics are tailored to the size of 320 x 320 mm, at an angle of 45°. The reason for using a smaller number of carbon fibre fabric layers, in relation to glass fibres, lies in the fact that they are much more expensive. Glass fibre fabrics are woven by twill method, and carbon fibres by satin weave. Fibre orientation of these biaxial fabrics is 0°/90°. Biaxial fabrics consist of fibres oriented in longitudinal (0°) and transversal (90°) direction. These fabrics are obtained by interweaving of longitudinal and transversal fibres in a regular pattern. Properties of used glass and carbon fibres are shown in Table 2.

TABLE 2 – Properties of used glass and carbon fibres

	Glass fibre	*Carbon fibre*
Fabric surface mass, g/m^2	390	220
Fabric pattern	Twill	Satin weave
Number of fibre bundles in longitudinal direction of the length 10 mm	6	7
Number of fibre bundles in the transverse direction of the length 10 mm	6	7
Fibre thickness, mm	0.33	0.4

The manufacturing procedure of composite test plates can be generally broken down into five steps: cleaning, application of release agent, application of layers of resin and fibres, crosslinking and removal of the product from mould.

In order to remove some possible residual or newly created irregularities on the aluminium mould plates (majority of irregularities is removed by the very treatment of mould plates by planing and polishing), such as scratches, impurities and others, minimally three layers of beeswax are applied using a small sponge. An even more important task of applying beeswax on the mould plates is to prevent absorption of the release agent that is later applied on the mould, into the very mould material.

The next step in manufacturing is the application of the separating agent on the mould plates. The release agent is necessary since, after having cured, it forms a thin protective film which later facilitates the separation of the finished, hardened composite plate at the end of the production procedure. The separating agent takes 20 minutes to cure, more precisely to form the protective layer on the mould, at the temperature of 45 ± 2 ºC.

For the possible removal of the formed protective layer of the release agent from the mould plates one can use only water (possibly by stripping from the surface).

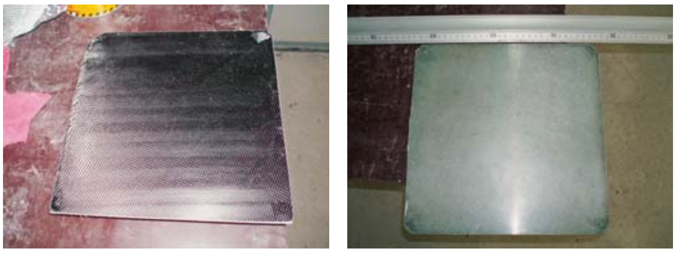
Mixing of matrix materials consists of weighing and mixing of two components of the two-component epoxy resin. The resin and the crosslinking agent are mixed in the mass ratio of 2.5:1 which follows from the calculation of the epoxy and amine equivalents. They need to be properly mixed in order to realize proper crosslinking. The crosslinking of epoxy resin takes four hours, in a furnace at the temperature of 50 ± 2 ºC.

The fabrication procedure of composite plates is a procedure of hand lay-up moulding – lamination (the oldest method of lamination in open moulds). The initial step of the lay-up procedure (lamination) of composite plates was to spread a prepared two-component epoxy resin (already mixed with the crosslinking agent) on the pre-prepared mould (applied wax and a layer of the separating agent) in order to avoid possible bubbles of resin or air. Then follows the lay-up of the fist layer of fabric of fibres on the mould plate on which previously resin had been applied, and then the fabric is rolled by a brush in order to absorb the resin. Then the resin was re-applied on the first layer of fabric, followed by the procedure of alternate laying up of the remaining layers of fabric of fibres and applying resin between them (layer by layer with removal of air pores – each layer of resin must be hand-rolled using a brush in order to impregnate resin in the best possible way with fibres and in order to remove air bubbles), until all layers of fibre fabrics are used thus realizing the desired thickness of the composite with adequate number of fabric layers.

When impregnating the layers attention should be paid that the resin is uniformly and completely distributed along the entire layer, and that no resin or air bubbles are formed. This is realized by careful spreading of resin by brush over the surface, and subsequent, even higher-quality spreading of resin on the surface.

Since the plates are intended for testing of flexural and tensile strength of composites, the height of the required test specimens has been taken as the plate thickness, which is indicated in the standards and amounts to 4 mm. With the very selection of the number of fibre fabric layers (knowing the thickness of the layers of the fabrics of glass and carbon fibres) the limits of the required plate height have already been reached, but because of safety and more precise fabrication, on the very edges (on the four corners) of the mould plates four distances (limiters) of 4 mm high have been set. After having set the limiters the upper mould plate was set and it closed the mould cavity and pressed the composite plate. Since the limiters ensured the necessary height of the plates, it should be ensured that there is no shear between the layers. This is achieved by clamping the upper and the bottom mould plate by clamps, and thus the composite plate inside the mould achieved the necessary thickness of 4 mm. The fabrication of one plate takes approximately 20 minutes.

The excess of the applied two-component epoxy resin leaks then out of the mould, and thus ensures better impregnation of resin and fibres. After the excess resin has leaked out of the plate, it is placed (together with the mould and clamps) into the furnace for four hours at a temperature of 30 ºC to 35 ºC which is determined on the experience basis. Figure 3.a shows the first manufactured plate – CGC (carbon-glass-carbon), and Figure 3.b shows the second plate – GCG (glass-carbon-glass).



a) b)

FIGURE 3 – Composite plate: a) first – CGC (carbon-glass-carbon), b) second – GCG (glass-carbon-glass)

Test specimen and procedure of testing mechanical properties

The test specimens were prepared according to the standard for testing the flexural properties HRN EN ISO 14125:2005[13] and tensile properties HRN EN ISO 527-4:2008[14] according to which a minimum of five test specimens need to be tested.

The flexural test specimens (Figure 4) are l = 80 mm long, b = 15 mm wide and h = 4 mm thick, whereas tensile test specimens (Figure 5) are of the length l = 250 mm, gauge length l_g = 50 mm, width b = 25 mm and thickness h = 4 mm.

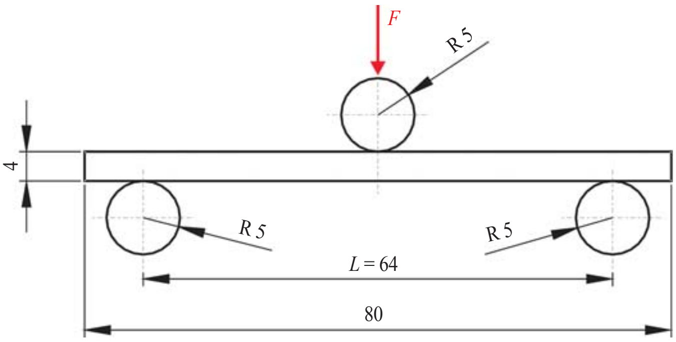


FIGURE 4 – Dimensions and shape of flexural test specimen[13]

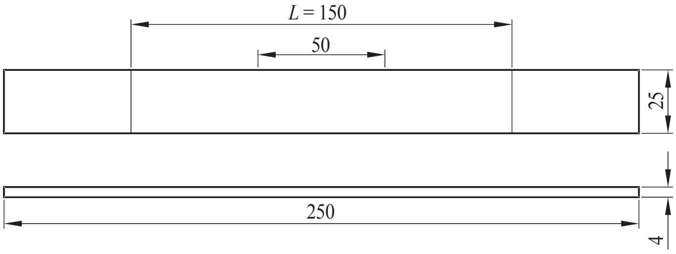
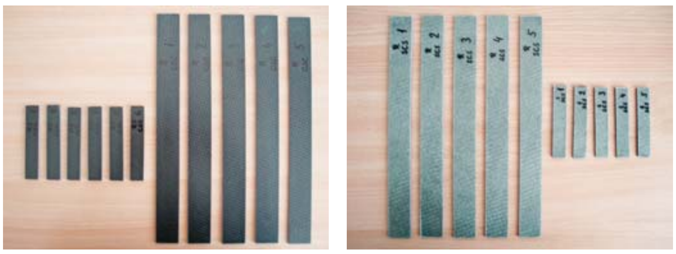


FIGURE 5 – Dimensions and shape of tensile test specimen[14]

Figure 6 shows the flexural and tensile specimens machined to standardised dimensions from produced CGC and GCG plates.



a) b)

FIGURE 6 – Flexural and tensile test specimen: a) CGC, b) GCG

All tests were carried out at room temperature of 23 °C on the Messphysik BETA 50-5 tester with the maximum force of 50 kN, at a velocity of 5 mm/min.

In the experimental part the flexural strength, flexural modulus, tensile strength, and tensile modulus have been tested. Additionally, mass and content of fibre of test specimens were measured.

Flexural strength is calculated by equation:[13]

$$\sigma_{\mathrm{fm}} = \frac{3 \cdot F_{\max} \cdot L}{2 \cdot b \cdot h^2} \tag{1}$$

Where: σ_{fm} [MPa] – flexural strength, $F_{\max}$ [N] – measured force, L = 64 mm – gauge length, b [mm] – width of test specimen, h [mm] – thickness of test specimen

Flexural modulus is calculated by equation:[13]

$$E_{\mathrm{f}} = \frac{F_{\max} \cdot L^3}{4 \cdot s \cdot b \cdot h^3} \tag{2}$$

Where: E_{f}, [MPa] – Flexural modulus, s [mm] – deflection of test specimen, $F_{\max}$ [N] – measured force, L = 64 mm – gauge length, b [mm] – width of test specimen, h [mm] – thickness of test specimen

For the flexural properties, strain $\varepsilon_{\mathrm{fm}}$ and maximal deflection $s_{\max}$ are also measured.

Tensile strength is calculated by equation:[14]

$$R_{\mathrm{m}} = \frac{F_{\max}}{b \cdot h} \tag{3}$$

Where: R_{m} [MPa] – tensile strength, $F_{\max}$ [N] – maximal measured force, b [mm] – width of test specimen, h [mm] – thickness of test specimen

Tensile modulus is calculated by equation:[14]

$$E = \frac{\sigma_2 - \sigma_1}{\varepsilon_2 - \varepsilon_1} \tag{4}$$

Where: E [MPa] – tensile modulus, σ_1 [MPa] – stress measured at the strain ε_1 = 0.0005, σ_2 [MPa] – stress measured at the strain ε_2 = 0.0025.

Results and discussion

Values of flexural properties for all test specimens are given in Table 3 while the values of tensile properties for all test specimens are given in Table 4. Average values of flexural and tensile properties are shown in Figure 7 and 8.

Experimental results of flexural properties of tested composites have shown that higher values of flexural strength are featured by the test specimens of the first plate (CGC). In this plate the external layers are reinforced by carbon fibres, what indicates that the better properties result from the fact that majority of load is taken over by carbon fibers. Since the carbon fibres actually have better flexural properties than the glass ones, the entire plate also features better properties. Also the values of flexural modulus of elasticity are higher in test specimens of the first plate due to the higher rigidity of carbon fibres.

These results are consistent with the results of papers Naik, N.K., et al.[15] and Zhang, J. et al.[16] that concluded that hybrid composites laminated in a way that the high stiffness carbon fibres are placed away from the neutral axis and the low stiffness glass fibres at the neutral axis have higher flexural modulus.

This also confirms the theory that the carbon fibres feature the highest specific rigidity and highest specific strength of all fibre reinforcing agents.[2] Placing the carbon layers at highly stressed regions is beneficial[15] and resulting in better properties of the plate whose external layers are reinforced by carbon fibres and this is the first plate – CGC (carbon-glass-carbon).

As with the results of flexural properties, during the tensile testing similar results were obtained. Test specimens with carbon layer outside (CGC) showed higher values of tensile strength and tensile modulus then the test specimen with the glass layer outside (GCG). On the other hand, GCG test specimens have slightly higher tensile strain then the CGC test specimens. From tensile stress-strain behaviour of both CGC and GCG composites it can be concluded that the tensile properties are mainly affected by the carbon fibre strength and rigidity.

Additionally, mass and content of fibres in test specimens of each type of composite plates were measured. Mechanical properties are also dependent on the content of the reinforcement and matrix, i.e. content of individual components. For composite materials the rule is to make a product with good mechanical properties with the lowest content of resin. Table 5 shows the content of fibre in specimens. Content of fibre is calculated as a ratio of mass of fibre after the melting of resin and mass of fibre and resin before the melting. The results show that the both plates have almost the same fibre content (about 95%), and that there is no difference in plates composition and production procedure. It can be concluded with

TABLE 3 – Test specimen dimensions and results of flexural properties

Test specimen	*h, mm*	*b, mm*	*σ_{fm}, MPa*	*ε_{fm}, %*	*E_f, GPa*	*F_{max}, N*	*s_{max}, mm*
CGC-1	3.88	15.40	394.7	2.7	19.1	953.1	4.75
CGC-2	4.06	15.50	449.9	2.7	18.6	1197.0	4.50
CGC-3	3.70	15.30	434.2	2.7	21.3	947.5	5.01
CGC-4	4.14	15.50	392.8	2.7	16.3	1087.0	4.50
CGC-5	3.80	15.21	423.0	2.6	20.9	967.7	4.65
CGC-6	4.03	15.10	399.5	2.8	16.4	1021.0	4.82
CGC $\bar{x}$	*3.93*	*15.34*	*415.7*	*2.7*	*18.8*	*1028.9*	*4.71*
S	0.169	0.162	23.635	0.083	2.143	97.788	0.195
GCG-1	3.70	15.49	351.9	2.8	15.2	777.3	5.15
GCG-2	3.59	15.28	343.4	2.7	16.5	704.4	5.20
GCG-3	3.46	15.49	353.0	2.7	17.3	681.9	5.24
GCG-4	3.47	15.29	374.9	2.9	18.7	719.0	5.63
GCG-5	3.42	15.27	356.2	2.6	18.4	662.8	5.27
GCG-6	3.76	15.53	358.2	3.1	17.1	819.2	5.66
GCG $\bar{x}$	*3.57*	*15.39*	*356.3*	*2.8*	*17.2*	*727.4*	*5.36*
S	0.140	0.123	10.452	0.177	1.301	59.599	0.228

TABLE 4 – Test specimen dimensions and results of tensile properties

Test specimen	*h, mm*	*b, mm*	*F_{max}, N*	*R_m, MPa*	*E, GPa*
CGC-1	3.34	25.52	26921.0	315.8	23.9
CGC-2	3.23	25.47	25929.0	315.2	22.1
CGC-3	3.57	25.40	26054.0	287.3	23.1
CGC-4	3.56	25.13	26706.0	298.5	21.4
CGC-5	3.18	25.37	25856.0	320.5	19.6
CGC $\bar{x}$	*3.38*	*25.38*	*26293.2*	*307.5*	*22.0*
S	0.182	0.151	486.194	14.020	1.680
GCG-1	3.63	25.08	20457.0	224.7	16.6
GCG-2	3.26	25.48	20602.0	248.0	19.1
GCG-3	3.32	25.30	21137.0	251.6	14.0
GCG-4	3.56	25.13	20540.0	229.6	17.6
GCG-5	3.27	25.17	20371.0	247.5	19.7
GCG $\bar{x}$	*3.41*	*25.23*	*20621.4*	*240.3*	*17.4*
S	0.174	0.161	301.070	12.213	2.252

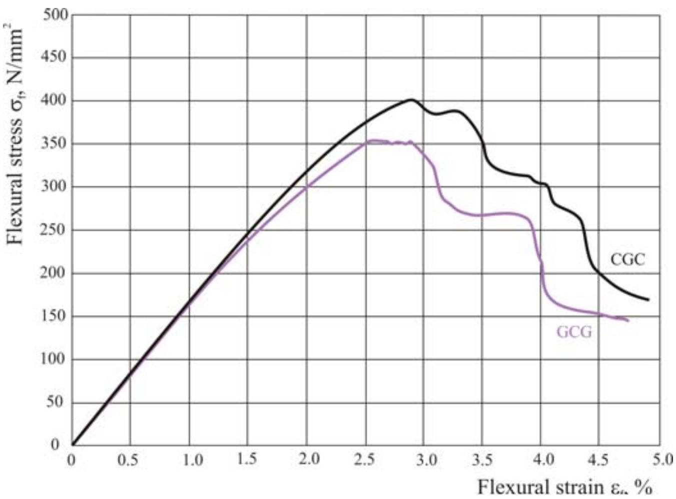


FIGURE 7 – Flexural properties of CGC and GCG test specimens

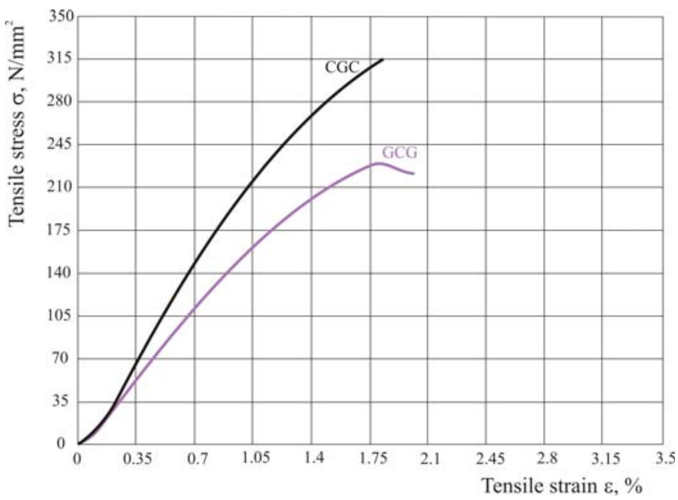


FIGURE 8 – Tensile properties of CGC and GCG test specimens

this, i.e. we confirmed the theory of the production of composites with small share of the resin.

Although the properties of the pure carbon fibre or pure glass fibre composites were not tested in this study, according to the literature[12,16,17] and results obtained, it can be concluded that the tensile strength of hybrid composites should be higher than the tensile strength of glass composite, but lower than the strength of pure carbon composites. Likewise, tensile strain of hybrid composites should be intermediate between the tensile strains of carbon only and glass only reinforced composites.

Results of flexural properties of tested hybrid CGC and GCG composites coincide with the results given in literature[12,15,16,17]. Compared with glass fibres only, flexural strength and modulus are higher, but not higher than the results of composites reinforced with carbon fibres only.

According to[18] the composite reinforced only by carbon fibres has all the properties, flexural and tensile strength, module of elasticity and flexural modulus, better in relation to the composite reinforced only by glass fibres. However, the high price difference of carbon and glass fibres (between 10 and 20 times higher price of carbon fibres) limits the use of carbon fibres only.

The difference in the mass of composite reinforced only by carbon fibres in relation to hybrid composite with combined reinforcing agents (glass and carbon fibres) is practically negligible.

Hybrid composites combined form carbon and glass fibres and laminated in appropriate order can significantly reduce the costs while maintaining satisfactory tensile of flexural properties.

If the obtained results are compared with the properties of traditionally used materials in aviation industry, and these are aluminium alloys, the most used alloy Aluminium 6061-T6, according to[19], it may be concluded that CGC and GCG composites feature higher values of flexural strength ($\sigma_{fm,Al}$ = 310 MPa), lower value of the module of elasticity (E_{Al} = 68.9 MPa). The specific strength (strength-to-density ratio) of hybrid composites reinforced by carbon and glass fibres is even up to four times higher than the one featured by aluminium and titanium alloys. Likewise specific rigidity (ratio of module of elasticity and density) of hybrid composites is two times higher. Most importantly in aviation industry, lower density of hybrid composites, i.e. equivalently lower mass, represents an advantage which is certainly the main reason why today composites are slowly substituting traditional materials.

TABLE 5 – Content of fibre

Test specimen	*Fibre + resin mass, g*	*Fibre only mass, g*	*Fibre content, %*
CGC-1	21.6244	20.5952	95.24
CGC-2	23.6601	22.6105	95.56
CGC-3	23.1837	22.1397	95.50
CGC $\bar{x}$	*22.8227*	*21.7818*	*95.43*
CGC S	1.0648	1.0542	0.17
GCG-1	17.9853	17.0524	94.81
GCG-2	18.3725	17.443	94.94
GCG-3	24.5018	23.597	96.31
GCG $\bar{x}$	*20.2865*	*19.3642*	*95.35*
GCG S	3.6557	3.6711	0.83

Conclusion

Mechanical properties, flexural and tensile, of two hybrid composite plates were compared to show the differences in the properties of composites that are made of the same materials (the same epoxy resin as matrix, and the same number of layers of glass and carbon fibres as reinforcing agents), but with the different order of laying up of the layers. In the first case material reinforced externally by carbon and internally by glass fibres, and vice versa, with external layers of glass fibres and the central part made of two layers of carbon fibres.

Results of flexural and tensile properties showed that better mechanical properties are obtained with the CGC composite plate, meaning that although the same materials were used, properties of hybrid composites depend on layers lay-up order.

Compared to classical composites reinforced by only one type of fibres, advantage of hybrid composite is that with appropriate selection of reinforcement fibres and their lay-up order, production of composites of desired properties at reasonable costs can be achieved.

After considering the results of tensile and flexural properties of CGC and GCG composites it can be concluded that hybrid composite reinforced by carbon and glass fibres represent an alternative to conventional metal materials and they could find possible application in modern aircrafts for the fabrication of aircraft parts such as doors, side panels, floor panelling, and their supports, wing edges, flaps, spoilers, aircraft radome, stabilizer and their fairings, rudder, elevator, and engine housing.

For further research in the field of aeronautic industry it is necessary to test compressive properties and impact strength of hybrid composites.

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