

Selected Construction Properties of Hybrid Epoxy Composites Reinforced with Carbon Fabric and Alumina

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ABSTRACT

The purpose of this study is to investigate the impact of the introduction of powder modifier into composite reinforced with carbon fabric on selected mechanical properties. The tests were performed on 16 groups of hybrid epoxy composites, including one reference group and 15 groups containing alumina with the grain size of F220, F240, F280, F320 and F360, added in the weight percent of 5%, 10% and 15%. This composite was made of certified components designed for application in the aviation industry. Test results indicated that the increase of alumina content by weight caused the decrease of strength of polymer composites in most tests. The value of the force transferred by the composite in the tensile test increased disproportionately to the cross section. It resulted in decreased strength. The addition of alumina impeded the super-saturation of the carbon fabric, which caused discontinuities in the matrix material.

Keywords: polymer resin, Al₂O₃, powder modifier.

INTRODUCTION

The wide range of application of polymer composites was described in numerous scientific papers, like for instance [1–2]. The increasingly bold modifications, both in terms of the manufacturing technology [3–7] and composition [8–10], translate into promising test results and pave the way for further exploration of achievable improvements [11, 12].

The fibres that are most common as reinforcement for polymer composites are: glass, carbon, aramid, polyethylene and ceramic [13–16]. Polymer composites, which include supplementary modifiers (e.g. powder) in addition to the above-mentioned fibres, are referred to as hybrid composites [17–19]. They are designed primarily to improve selected properties of composites that contribute to their final application character. This is essential particularly in manufacturing areas,

in which the improvement has an impact on the component life, which means financial benefits or contributes to higher safety [20, 22].

In literature there are many studies on the properties of the composites modified with powder additives. They include modifications with granite powder, for example, which contributes to reduced absorption [23], glass powder, which provides high bending strength of the composite material [24], or silicon carbide (SiC), which makes the produced composite ensures that it has very good shock absorption [1].

The authors decided to investigate the possibility of using high grade powdered alumina to improve the tribological properties of layered composites made of carbon fibres and epoxy resin.

Alumina is a synthetic form of corundum. This material is obtained by smelting bauxite in electric arc furnaces [27]. It is primarily used as abrasive material due to the shape of individual

particles (they are far more regular and sharper than the particles of natural alumina). It is also characterised by high hardness and strength. An additional advantage is the option to use various types of admixture that modify its abrasive properties directly.

The purpose of these admixtures is to influence the abrasive properties of the material; they are also selected for specific materials to be machined.

The authors tested powder composites with an admixture of high grade alumina with the five grain sizes (F220, F240, F280, F320 and F360) [28] compliant with FEPA0 42-2:2006, and five weight percent contents (5%, 10%, 15%, 20%, 25%) for every grain size. The obtained results led to narrowing down the group of weight percent contents of physical modifiers with various grain sizes introduced into hybrid composites (carbon fabric was used as the reinforcement and polymer resin L285 with hardener H287 was invariably used as the matrix). Hybrid composites produced this way were then subject to the determination of the impact of the weight percent of alumina on the dynamic response in the form of amplitude and frequency characteristics. In addition to the relationship between the composition of prepared composites (weight percentage/grain size) and the resonance frequency for the first vibration form. A parallel stage of study was the determination of mechanical properties.

MATERIALS AND METHOD

Materials

Composites were produced using Resin L285, approved by German Federal Aviation

Authority. Due to its properties, this resin is dedicated for use in aviation and production of models. Lamination resin L285 (Havel Composites) is certified and therefore used by many manufacturers of aeroplanes and gliders. Combined with the hardener H287 from the same manufacturer, it is the most common system in the aviation industry [29]. The most important features of the resin itself are presented in Table 1, while hardener details are listed in Table 2.

To produce the basic structure of the layered composite, carbon fabric GG 280/T (G. Angelonir, Quarto d’Altino, Italy) with plain weave (twill 2/2, fibre 3K 200 tex, 220 g/m²) was used as the reinforcement. Eight layers of carbon fabric were used in fibre orientation [0/45/90/135/0/45/90/135]. Based on test results so far [28], high grade alumina with the grain size determined as per FEPA 42-2:2006 was used as the second reinforcement material. The grain sizes of the alumina are listed in Table 3. The weight percent of alumina of every grain size was 5%, 10%, 15%. In addition, layered base composite was produced without alumina as reference composite, to determine the impact of the modifier on the selected mechanical properties of the composite. It should be emphasised that the increase of the filler volume did not result in the significant increase.

Manufacture of composite samples

Hybrid composites were produced by manual lamination at the laboratory of the Polish Air Force University in Dęblin. Resin L285 and Hardener H287 were combined in the proportions recommended by the manufacturer (100:40) and then alumina was added to every composite with varying grain size (F220, F240, F280, F320,

Table 1. Specifications of Resin L285 [29]

RESIN L285	
Density at 25 °C	1.18–1.23 g/cm ³
Viscosity at 25 °C	600–900 mPa·s
Epoxy equivalent	165–170
Epoxy number	0.59–0.65

Table 2. Specifications of Hardener H287 [30]

HARDENER H287	
Mixing measurement	100:40 (by weight)
	100:50 (by volume)
Work time at 20–25 °C	4 h
1 mm gelling time at 20–25 °C	5–6 h

Table 3. Information on the grain size of alumina for the grain sizes used as per FEPA 42-2:2006

Parameter	DETERMINATION OF THE ALUMINA GRAIN SIZE				
	F220	F240	F280	F320	F360
Grain size as per FEPA 42-2:2006 [µm]	75.0–53.0	46.5–42.5	38.5–35.0	30.7–27.7	24.3–21.3

F360) and weight percentage (5%, 10%, 15%). At the following stage, the subsequent carbon fabric layers were super-saturated (eight layers of fabric in fibre orientation [0/45/90/135/0/45/90/135]). Finally, the structure was pressed using the hydraulic press PDM – 50S Mecamaq at the pressure of 2.5 MPa. For testing purposes, samples were cut from layered hybrid composites, while maintaining the same fibre direction along the long axis of the samples. The dimensions of specimens for tensile strength tests were as follows: length of 250 mm, width of 25 mm and, depending on the composite type, thickness of 2.0 mm (for base composite) to 3.4 mm (for the samples of composite F360 15% EA). The test specimens for bending strength testing were 25 mm wide and 50 mm long, with a thickness of 2.1 mm to 3.4 mm. The test specimens for interlayer shear strength testing were 20 mm long and 8 mm wide. The samples were obtained by cutting with water jet using COMBO gantry-type cutting machine (ECKERT) designed for cutting with water jet with abrasive admixture in the form of garnet (80 mesh). The prepared samples were placed in a climate test chamber (WKL 64, Weiss Technik), where they were subjected to the thermal processing recommended by the resin manufacturer at 80 °C for 24 hours. The objective was to ensure the proper mechanical strength of the composite matrix.

Mechanical properties of the samples

The first test performed on the samples was the static tension test as per ISO 527-2:2012 [31]. This test was carried out on the 5982

strength testing machine by Instron with the maximum permissible force of 100 kN. The measurement of sample deformation required the use of the extensometer AVE2 for the avoidance of errors related to the potential sample displacement in machine jaws. The measurement length was determined at 100 mm. The samples were clamped in fixtures by tightening with the constant torque of 35 Nm. The cross head travel speed was 2 mm/min. The composites showed the tensile characteristics typical of fragile materials.

Next, three-point bending strength tests were performed as per [32] using the Zwick/Roell Z5.0 strength testing machine. The dimensions of the large sample surface were 50x25 mm (thickness of 2.0 mm - for base composite- to 3.4 mm - for the samples of composite F360 15% EA). The test speed was 1 mm/min, with the support span equal to 16 times the sample thickness. This span was approx. 32 mm to 54 mm for the individual tests. The necessary support span was set before the start of each test. The deflection measurement ended if the composite cracked or the force dropped to 0.2 of the maximum force. The bending stress as per the standard was calculated according to the following formula:

$$\sigma_f = \frac{3F_{max}L}{2bh^2} \tag{1}$$

where: σ_f – bending stress [MPa], F_{max} – maximum load [N], L – support span [mm], h – sample thickness [mm], b – sample width [mm].

The interlayer shear tests were performed based on the short beam test method as per the

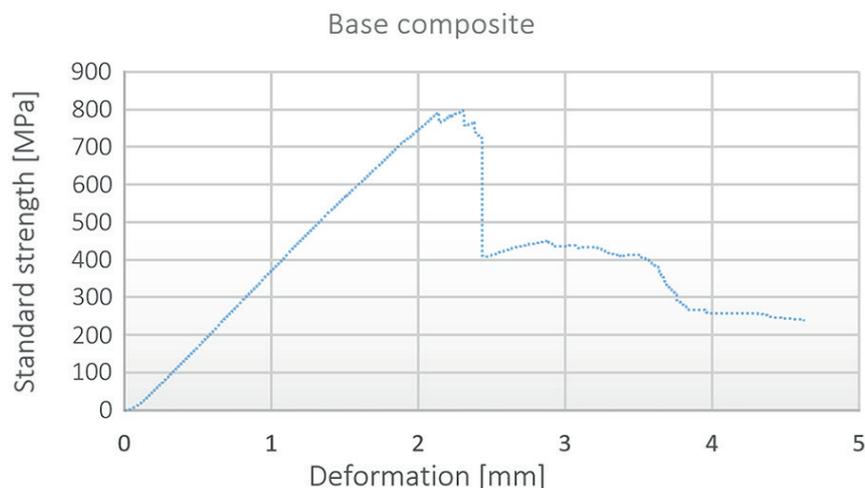


Fig. 1. Base composite bending test diagram

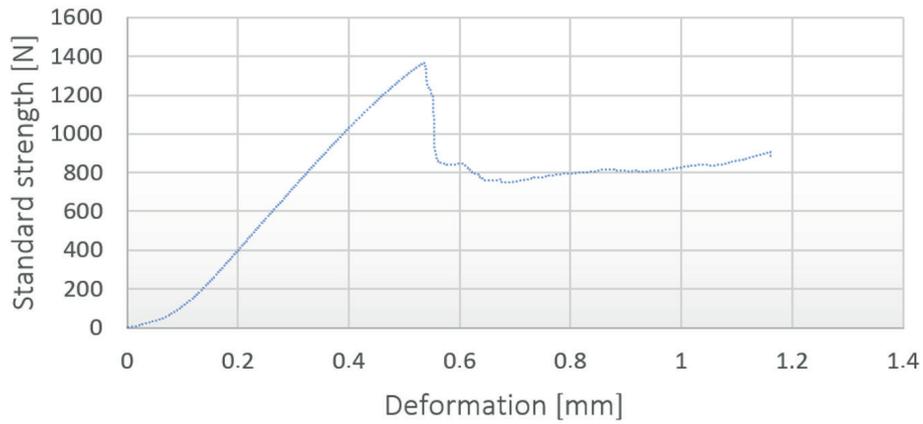


Fig. 2. Base composite short beam shear test diagram

required standard PN-EN ISO 14130 [33] on the Zwick/Roell Z5.0 strength testing machine. The tested specimens were 20 mm long and 8 mm wide. The support span was set every time to the width of five times the composite thickness. The cross head travel speed was 1 mm/min. The example layer shear characteristics is shown in Figure 2 and it is essentially the same as for bending, but higher interlayer shear stress values are obtained, calculated as per the standard according to the following:

$$\tau_M = \frac{3}{4} \times \frac{F}{bh} \quad (2)$$

where: F – maximum sample break force [N],
 b – test specimen width [mm],
 h – test specimen thickness [mm].

RESULTS AND DISCUSSION

The graphical presentation of tensile strength test results is shown in the diagrams (Fig. 3, 4 and 5). The diagrams show the variation of the tensile strength, tensile modulus of elasticity and tensile strength elongation. The percent content of alumina in the composite was marked using colours. The tensile strength increased only for the material reinforced with alumina, marked as F220 (the greatest grain diameter). In this case the strength increase was 12.7% relative to the base composite (0% mass share). For comparison, the greatest strength loss occurred for composite F240 and was 22%. Strength loss could also be observed in other types of alumina, i.e. F280, F320 and F360,

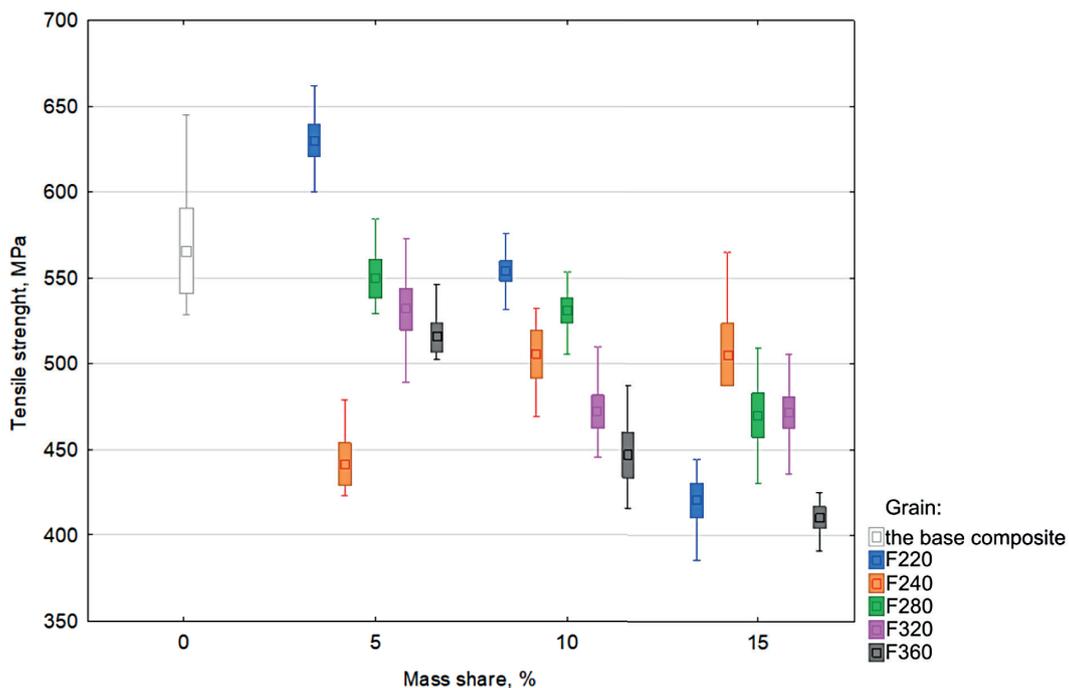


Fig. 3. Characteristics of changes in tensile strength depending on the percentage and grain size of alumina

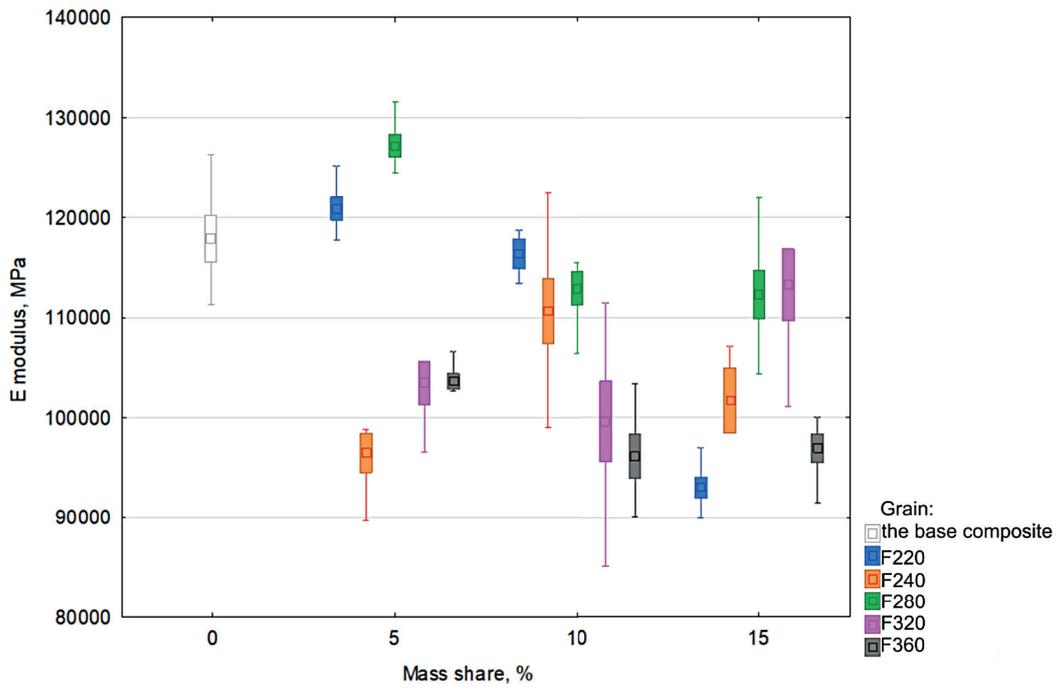


Fig. 4. Characteristics of changes in E modulus depending on the percentage and grain size of alumina

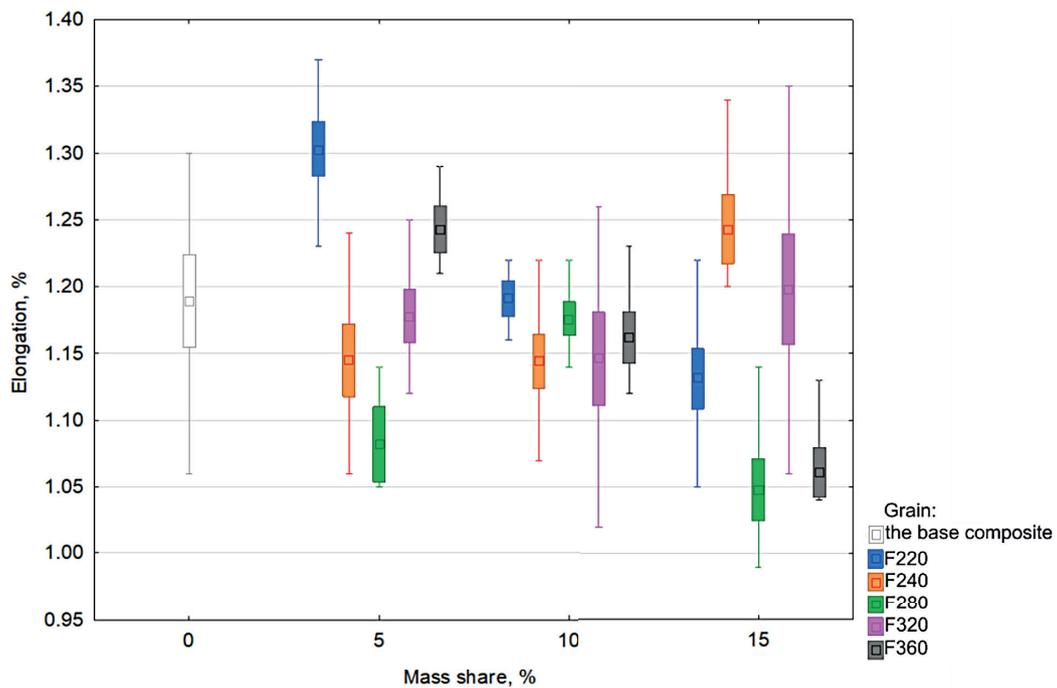


Fig. 5. Characteristics of changes in elongation depending on the percentage and grain size of alumina

and was: 3%, 6% and 9%, respectively. It is not possible to clearly present the relationship between the type of alumina grain and its impact on the tensile modulus of elasticity E. Nonetheless, it can be noticed that with an increase of the filler volume the material's tensile modulus of elasticity E decreased. The only exceptions are tests F220 5% and F280 5%, in which the material showed

an increase of modulus E. However, this change was irrelevant compared to the base composite. In general all tests showed a linear decrease of the tensile strength, which was greater proportionally to the amount of alumina added to the matrix by weight. Therefore, the lowest results were recorded for nearly all types of composite with 15% alumina content. The only case of increased material

strength was the composite with 5% addition of F220 grain. In this situation, the increase was noticeable and the individual tests were highly repeatable. The modulus of elasticity decreased for alumina F240, F320 and F360 grains by: 18.5%, 12.6% and 12.4% relative to the base composite (0% mass share).

However, it may be stated that the alumina volume and grain size had impact only on the

broader range of test results in tensile elongation measurements (Fig. 5). Elongation was found to decrease in case of additional alumina with the smallest grains. This relationship can also be influenced by greater total edge length of alumina (in accordance with the principle that the total surface of particles increase as their size decreases), which during simultaneous elongation along the axis and transverse compression

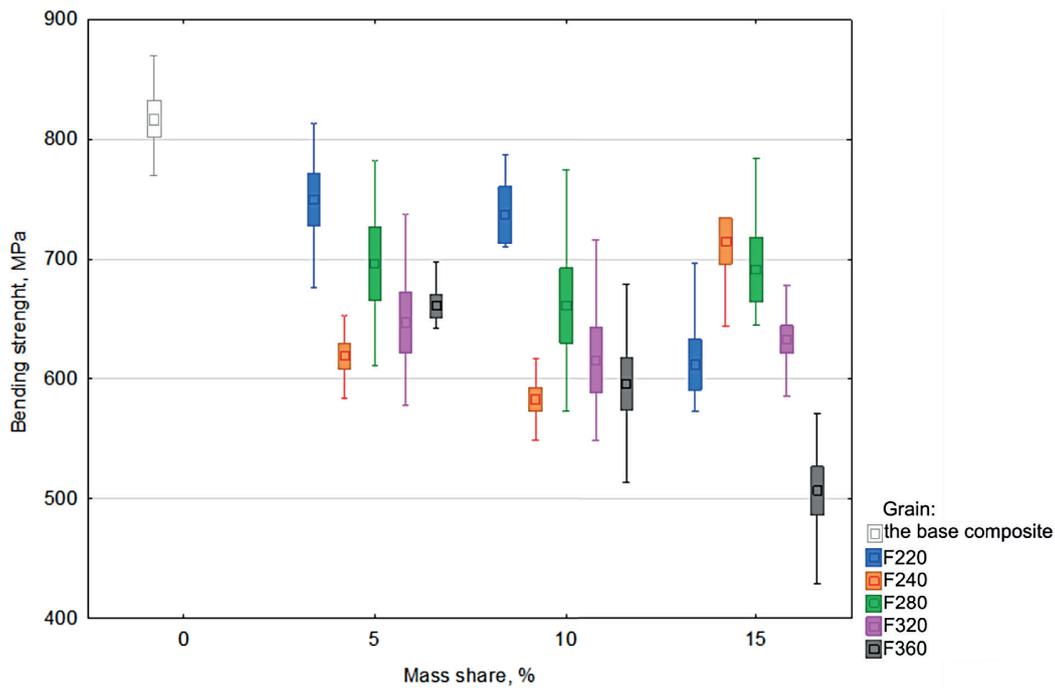


Fig. 6. Characteristics of changes in bending strength depending on the percentage and grain size of alumina

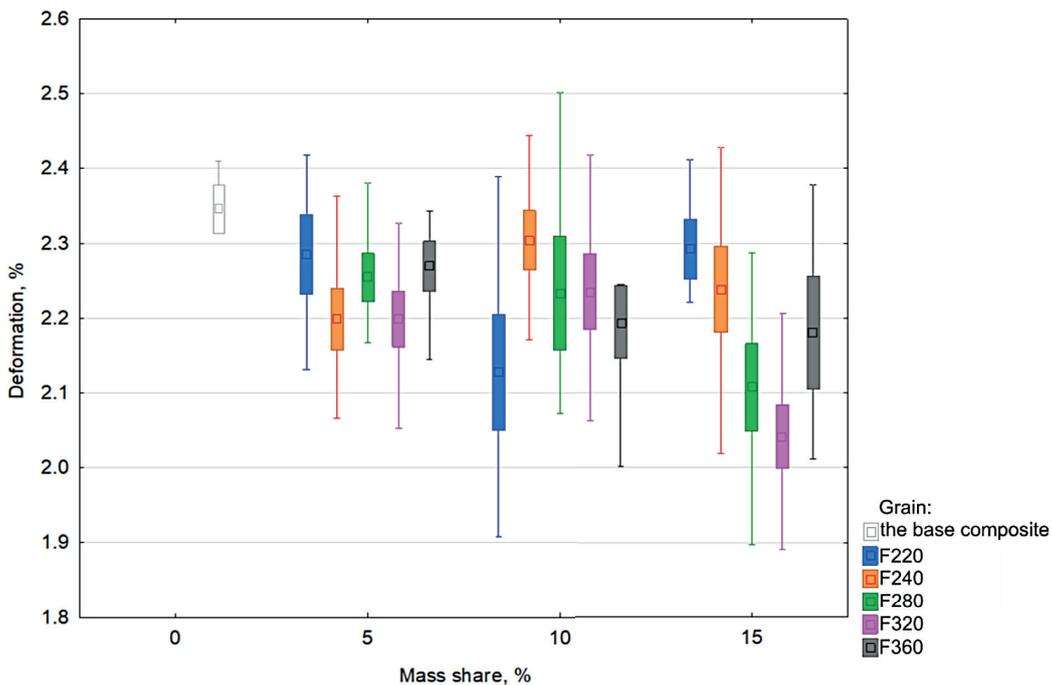


Fig. 7. Characteristics of changes in deformation depending on the percentage and grain size of alumina

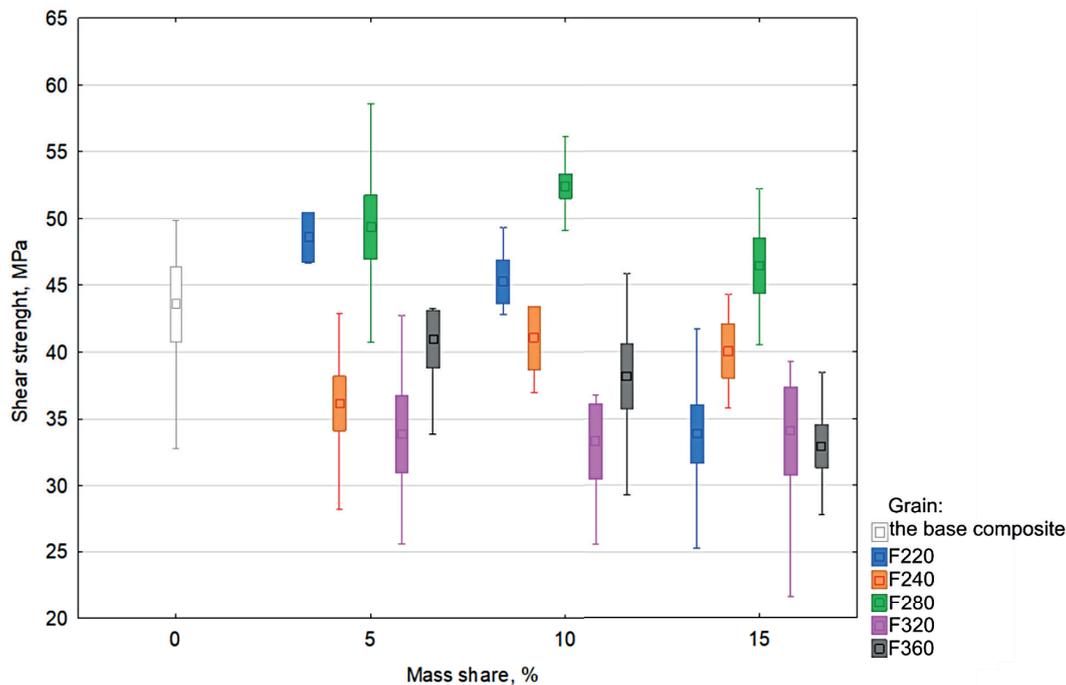


Fig. 8. Characteristics of changes in sear strength depending on the percentage and grain size of alumina

of the sample act as cutting edges and in increasing numbers, causing quicker micro-damage to the matrix and fibres.

Figure 6 shows bending strength test for the particular types of materials. It was found that an increase of the alumina content in the matrix reduced the bending strength of the material. This observation was also confirmed by the result for the composite with F360 grain up to 15% by weight to the matrix, where the bending strength decreased by 37.92% relative to the base composite. The decreasing bending strength was accompanied by a decrease in the maximum deformation of the tested composites types (Fig. 6).

During the assessment of the assumed inter-layer shear strength (Fig. 8), it was found that the higher the alumina content in the composite was, the greater strength decrease. The greatest strength decrease was recorded in the composites with 15% alumina content. This tendency was more noticeable also when the micro-grains had a smaller diameter. The results are comparable to the earlier bending and tensile tests, in which a similar tendency was observed. Nonetheless, for F220 grains with 5% and 10% content and F280 grains with 5%, 10% and 15% content, the recorded strength increased compared to the base composite. The strength increase was clear, however it decreased with an increase in the number of alumina grains.

CONCLUSIONS

The produced polymer composites modified with high grade alumina were tested. The strength drop in the discussed tests was more noticeable with an increase of the alumina weight percent. However, the strength did not decrease in all types of composite. In some tests, the material showed a rise in strength, in particular in the interlayer shear test.

During the static tensile test it was found that despite the tensile strength decrease, the transferred maximum force was cleargreater compared to the base composite. An increase of the maximum force was recorded in the samples reinforced with micro-grains of alumina F320 for all filler percent contents. Thus, the increase of the maximum force was noticeable for samples F220 5%, F240 10%, F240 15% and F280 5%. The test specimens were also characterised by a significant increase of the cross section due to filler addition, which was also observed during the measurements of individual specimens in the pre-test preparation process.

Following the tests performed on the individual sample series, the tensile strength was found to decrease with an increase of the alumina content.

During the bending test, the strength was found to decrease as well. The prepared samples with an addition of alumina were destroyed in a more dynamic and abrupt manner. A visible tendency in this test was the strength reduction as the

filler volume increased. An increase of the alumina content also had a clear impact on the variation of other resulting coefficients. A decrease was also observed in both the bending modulus of elasticity and elongation at maximum tension.

The final completed strength test was the inter-layer shear strength calculation. For examined test series, the strength was found to increase for test specimens of composite F280 with 5%, 10% and 15% content of alumina, and for test specimens of composite F220 5% and 10%. For other groups, the results showed the strength to decrease.

The following conclusions were formulated based on experiments, observations and analyses. Increase of alumina content by weight caused a decrease in the polymer composite strength in most tests. The force transferred by the composite in the tensile test increased disproportionately to the cross section, which resulted in decreased strength. The addition of alumina impeded the super-saturation of the carbon fabric, which caused discontinuities in the matrix material.

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