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# Effect of Temperature on the Interlaminar Strength of Carbon Fibre Reinforced Thermoplastic

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**Abstract.** Application of thermoplastics composites (TPCs) in aircraft constructions is growing. Thermoplastics have the greatest potential in the interior and in the secondary construction, where they can fully replace aluminum parts and glass laminate parts. In the aircraft interior, they are used mainly for excellent fire, smoke and toxicity properties and on exterior mainly for their excellent impact resistance. Thanks to thermoplastics, today we can talk about real recycling of composites. The most used TPCs in aircraft constructions is polyfenylensulfid (PPS). This material was also chosen for our experiment where we compared two most used test method (ASTM and AITM) which are used for measuring of the interlaminar shear strength by the loading of the curved beam. The aim was to find out whether the results measured according to different standards are comparable (whether it is possible to neglect the influence of the method when comparing interlaminar shear strength, measured using these two standards). For more complex results, the tests were performed at three different temperatures. At room temperature, at 70°C and at –50°C. Both the selection of the test method and the test environment had a significant influence on the measured values of the interlaminar strength.

## Introduction

More than 95 percent of composites used in aerospace industry are thermosets [1]. However, the share of high-performance thermoplastic composites (TPCs) in aeronautical industry is rising year after year even at the expense of the thermosets. It is given by attractive properties such as fracture resistance [2, 3, 4] formability[5, 6], welding [7, 8], self-healing possibilities [9, 10] and recyclability [11]. With regard to modern trends and requirements, we can say that the recyclability of composites belongs and will belong (compared to metals) among their weakest aspects. Thanks to thermoplastics, today we can talk about real recycling of composites. Thermoplastics soften when heated and become more fluid as additional heat is applied. The curing process is completely reversible as no chemical bonding takes place. This characteristic allows thermoplastics to be repeatedly cured and recycled without negatively affecting the material’s physical properties. Softening by heating further enables the welding of subcomponents. This leads to the eliminating of fasteners and adhesives as is showed in [12]. The requested performance of structural TPCs parts can be easily achieved by using stacking of tailored blanks with combination of thermoforming process – this is, for example, demonstrated on thermoplastic rib in Ref. [13].

This paper present results of curved beam strength of PPS samples at different temperatures, concretely at room temperature (RT), at –55 °C (CT) and at 80°C (HTA). Before these tests started, a comparison of two most used test methods was performed (ASTM D6415 - Standard test method for Measuring the Curved Beam Strength of Fiber-reinforced Polymer-Matrix Composite [14] and AITM 1-0069 - Determination of curved-beam failure load [15]).

## Experiment

PPS thermoplastics resin samples (see Fig. 1) with T300 3K, 5HS, 280 gm$^{-2}$ FAW, 43% RC (50% BY VOLUME) carbon fabric 280 gm$^{-2}$ were tested. Used lay-up was: [[(0,90)/(±45)]$_4$]. The coupons were manufactured by thermoforming. Thermoforming is used to convert a flat consolidated continuous fibre reinforced laminate into a complex shape with no change in original laminate thickness. The laminates were heated to the required temperature and then quickly formed by pressure with a few minutes dwell time. Average width of the tested samples was $w$ = 25.14 mm, average thickness $t$ = 4.95 mm and average angle $\alpha$ = 89.5 deg.

The tests were performed on electro-mechanical loading machine Instron 55R1185 with installed load cell with the capacity of ±10 kN. The test setup is shown in Fig. 2. Test specimen was placed on the bottom cylindrical bars. Then, extensometer Instron 2620-604 with a base of 50 mm was installed. Extensometer recorded axial displacement between the upper and lower parts of the fixture. The specimen was loaded by constant crosshead speed of 2 mm/min and test was ended when the loading went rapidly down.

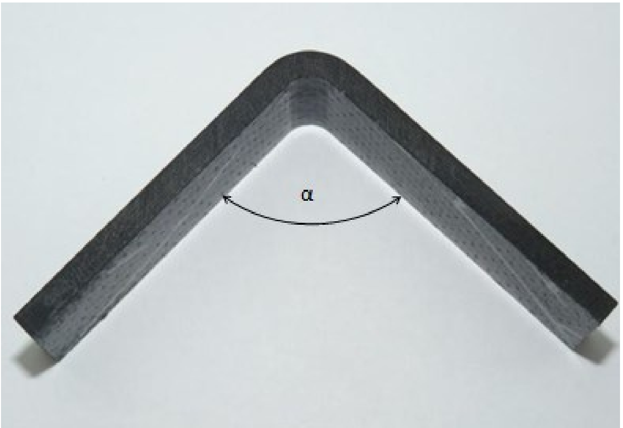



Fig. 1: Curved beam strength sample

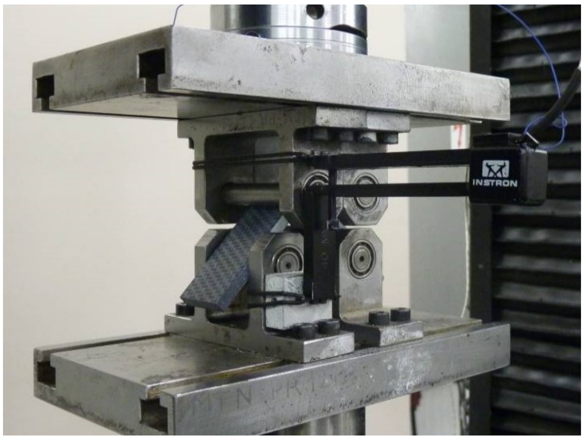



Fig. 2: Curved beam strength test

At first, test methods were compared. Three test set-ups were used, see Table 1. The main difference between the test methods is, that the ASTM method used fixed distances between the lower/upper rollers. In contrast, AITM method defines span length of the fixture based on sample geometry – Equations (1) to (4):

$$l_t > 2 \cdot \left( \left( (R_i + t + \frac{D}{2} \right) \cdot \sin(\varphi) + \left( \frac{t}{4} + 1 \right) \cdot \cos(\varphi) \right) \quad \pm 0{,}5 \tag{1}$$

$$l_t < 2 \cdot \left( \left( (R_i + t + \frac{D}{2} \right) \cdot \sin(\varphi) + \left( \frac{t}{2} + 1 \right) \cdot \cos(\varphi) \right) \quad \pm 0{,}5 \tag{2}$$

$$l_b > l_t + t + 10 \quad \pm 0{,}5 \tag{3}$$

$$l_b < l_t + t + 20 \quad \pm 0{,}5 \tag{4}$$

where: $l_t$ is span of top fixture, $l_b$ is span of the bottom fixture, $R_i$ is inner radius, $t$ is thickness of sample, $D$ is roller diameter, and $\phi$ is angle from horizontal of the sample legs.

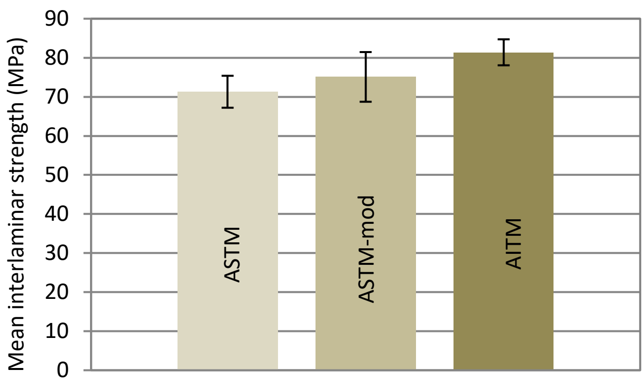
Table 1: Tests set-up, overview

| Test method | Distance of lower rollers [mm] | Distance of upper rollers [mm] |
|---|---|---|
| ASTM | 100 | 75 |
| ASTM mod | 75 | 50 |
| AITM | 51.3 | 26.35 |

**Results**

All measured data (see Fig. 3) were tested by Dixon's test for outliers and on the basis of this evaluation, the lowest measured value of 63.5 MPa from the AITM respectively RT set was excluded.

| | PPS | | |
|---|---|---|---|
| | ASTM | ASTM mod | AITM |
| | 69.3 | 70.1 | 83.6 |
| | 70.8 | 85.6 | 84.7 |
| | 72.9 | 71.4 | 80.0 |
| | 72.0 | 68.9 | 63.5* |
| | 78.8 | 78.7 | 77.4 |
| | 65.4 | 75.9 | - |
| | 70.0 | - | - |
| **Mean** | **71.3** | **75.1** | **81.4** |
| S.D. | 4.09 | 6.36 | 3.33 |
| C.V. | 5.73 | 8.47 | 4.09 |
| Min. | 65.4 | 68.9 | 84.7 |
| Max. | 78.8 | 85.6 | 77.4 |




* outlier, not included into the statistical evaluation

Fig. 3: Measured mean interlaminar strength σ (MPa) - test methods comparison.

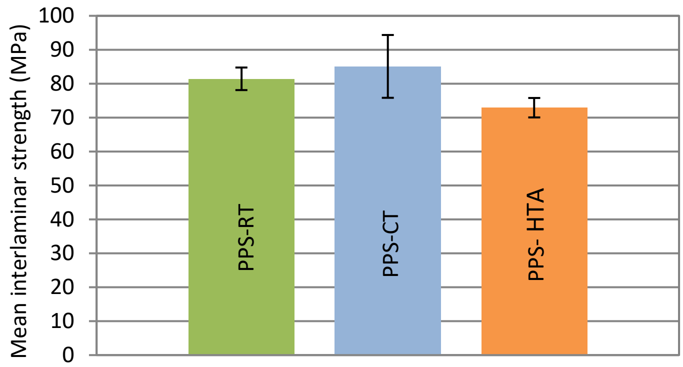
The statistical analysis of data showed that the test method have statistically significant effect (p-value = 0.05), see Table 2. Specifically, AITM data were statistically significantly different from the other two sets. For ASTM and ASTM-mod sets was the difference evaluated as statistically insignificant.

Table 2: Statistical comparison of test methods. D files are different, ND files are not different, p-value = 0.05.

| | RT | | |
|---|---|---|---|
| | ASTM | ASTM-mod | AITM |
| ASTM | - | ND | D |
| ASTM-mod | ND | - | D |
| AITM | D | D | - |

For further testing (influence of temperature), the AITM test method was chosen. The main reason was to take sample geometry into account for test fixture setting (span length). All measured data are shown in Figure 4.

| | PPS | | |
|---|---|---|---|
| | RT | CT | HTA |
| | 83.6 | 89.8 | 76.4 |
| | 84.7 | 89.5 | 71.4 |
| | 0.0 | 95.3 | 68.9 |
| | 63.5* | 73.1 | 74.2 |
| | 77.4 | 77.8 | 73.8 |
| **Mean** | 81.4 | 85.1 | 72.9 |
| S.D. | 3.33 | 9.26 | 2.86 |
| C.V. | 4.09 | 10.89 | 3.93 |
| Min. | 84.7 | 73.1 | 68.9 |
| Max | 77.4 | 95.3 | 76.4 |




* outlier, not included into the statistical evaluation

Fig. 4: Measured mean interlaminar strength by AITM method, $\sigma$ (MPa) – temperature effect.

The statistical analysis of data showed that the temperature have statistically significant effect (p-value = 0.05), see Table 3. Specifically HTA (80 °C) data were statistically significantly different from the others two sets. For RT and CT (–55 °C) sets was the difference evaluated as statistically insignificant.

Table 3: Statistical comparison of temperature effect. D- files are different, ND files are not different, p-value = 0.05.

| | RT | CT | HTA |
|---|---|---|---|
| RT | - | ND | D |
| CT | ND | - | D |
| HTA | D | D | - |

**Conclusions**

The measured values clearly demonstrated the influence of the temperature on the interlaminar strength. Furthermore, it has been shown that the choice of test method has a significant effect on the measured values.

Comparison of the test methods showed that the selection of the test method has a significant influence on the measured values of interlaminar strength. The highest values were measured in tests where the test set up was set according to the AITM 1-0069 method. This method was chosen to determine the effect of temperature on interlaminar strength values. The main reason was to consider the geometry of the test specimen for setting up of the test assembly.

The highest interlaminar strength values were measured on specimens tested at cold temperature. Mean value was approximately 5% higher than the interlaminar strength measured at room temperature. The difference between these two sets was evaluated as statistically insignificant. The samples tested at hot temperature showed a 12 % decrease in strength compared to RT set. The HTA set was evaluated as statistically significant different from the other two sets.

This paper showed that it is not possible to compare values measured on the same material tested by different methods, although the differences in the methods may seem to be insignificant.

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