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Influence of Temperature Change on Young Modulus of Elasticity of CFRP

B. Kropík[1,*], M. Matušů[1], Z. Padovec[1], T. Mareš[1]

[1] *Department of Mechanics, Biomechanics and Mechatronics, Faculty of Mechanical Engineering, Czech Technical University in Prague, Technická 4, 160 00, Prague, Czech Republic*

[*] *bohumil.kropik@fs.cvut.cz*

Abstract: Repeated tensile testing at low stress level was done at different temperature levels to estimate the temperature influence on the Young modulus of the composite material. Testing was done for temperatures higher than the room temperature and also for lower temperatures with use of liquid nitrogen cooling. Tests were held for two different types of fibres and the results indicate change in the Young modulus depending on the temperature.

1 Introduction

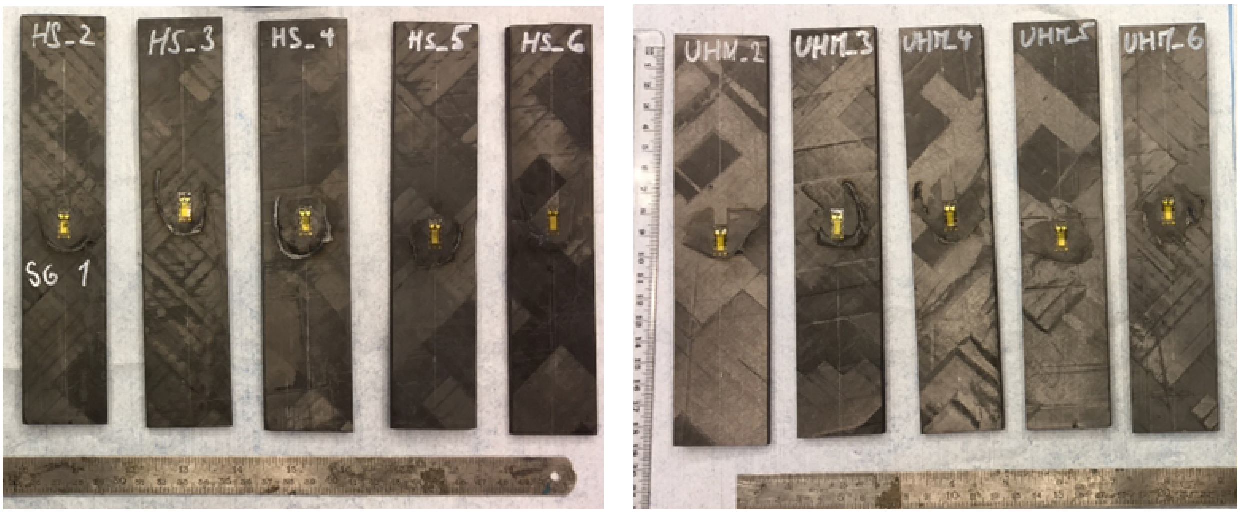
Composite materials, which in this context refer to a Carbon Fibre Reinforced Polymers (CFRP), are often designed to enhance the mechanical strength of structures with the aim of reducing the assembly weight or increasing structural potential. Operating temperatures often do not differ significantly from room temperature, but in some cases they may vary considerably. Some information on temperature-related behaviour regarding the mechanical properties of CFRP can be found in [1] for temperatures higher than room temperature and in [2] for temperatures lower than 0 °C. Therefore, for our design purposes, it was decided to measure the relationship between the Young modulus of elasticity and temperature. The CFRP used in this study comprised two types of carbon fibres: High Strength (HS), partially documented in [3], and Ultra-High Modulus (UHM) fibres. These specimens were subjected to repeated measurements during the elastic phase of the tensile test to determine whether the temperature variations affect the stiffness of the composite material and to what extent, particularly in our case.

2 Specimens

The composite used for the specimens was made using a filament winding process on a square cross-section mandrel. Of this, flat planes of about 1000x120x5 mm were cut and delivered by the manufacturer. Specimens were manually cut to an approximate size of 200x40x5 mm, representatives are shown in Fig. 1. In total, 10 specimens were made using High Strength (HS) fibres and 8 using Ultra High Modulus (UHM) fibres, both with the epoxy resin and almost identical lay-up. In the centre of each specimen, 1 linear Strain Gauge (SG) was installed on each side orientated in the direction of loading.

3 Loading Scenario

Specimens were loaded during the tensile test on the TIRA 2300 testing machine with a displacement of 1 $\frac{\mathrm{mm}}{\mathrm{min}}$. With the idea of using the specimens repeatedly at different temperature levels, the loading was limited to not damage the specimens. After the installation of the specimen on the loading machine, three loading cycles between 1 and 10 kN were performed at each temperature level. Measurements were first performed at 20 °C. Using a thermal chamber, we continued at 60 °C and then at 100 °C. The next step was the identification of the behaviour at lower temperatures. The specimens were cooled with the use of liquid nitrogen in our thermal chamber, at least 30 minutes before loading. The plan was to measure behaviour at 0 °C, -20 °C and -40 °C.



(a) representatives of HS specimens

(b) representatives of UHM specimens

Fig. 1: Specimens.

The SGs installed on the specimens were connected in a quarter-bridge connection, so only the tensile strain ε_T was evaluated using Eq. (1) assuming the ε_1 and ε_2 being the signals from each SG. From each cycle, the linear section between 4 and 5.5 kN was used for the evaluation to neglect any clearances of the loading setup.

$$\varepsilon_T = \frac{\varepsilon_1 + \varepsilon_2}{2} \tag{1}$$

4 Results

The results are presented separately for the elevated and decreased temperatures. Young modulus is presented related to the temperature level of 20 °C for each material. In Fig. 2 the results for the HS specimens at elevated temperature levels are presented in a typical form of a box plot. The green triangle represents the average value and the orange horizontal line shows the median. The box is sized between 1. and 3. quartiles and whiskers are up to 1.5 times the size of the box, depending the position of measured values. It could be seen that the data vary a lot between the specimens but there is a decreasing trend of stiffness of the specimens with the rising temperature level. A similar result is with the UHM specimens presented in Fig. 3 that appeared to decrease stiffness more significantly at the temperature level of 100 °C. The scatter in the measured data is attributed to the manual division of the specimens which resulted in a width variation of up to 3 mm. This difference in the design leads to the differences in the SG position according to the layup of the composite and also affects the measured signal. Other influences could be the surface of the composite material itself, which varied on each side of the specimen, considering the inner (mandrel) and outer surfaces, and the error of installation of the specimens in the loading machines, which was done manually.

As the measurements at the decreased temperature levels with liquid nitrogen cooling were done for the first time, it was decided to pick two representative specimens of each type for the measurement at 0 °C. This measurement showed that it is necessary to protect the SG from the condensed moisture, which was not done for the increased temperature levels. After SG protection, the specimens were loaded at room temperature again to inspect the behaviour. As they were considered not damaged, the temperature levels of -20 °C and -40 °C were measured with the jaws rotated by 90 °to have the outlet of liquid nitrogen from the side. The results of this measurement are not presented in more detail, as there was again a decrease in the stiffness of the specimens with decreasing temperature, which was unexpected. Repeated measurement at room temperature showed a decrease in stiffness of approximately 20 % for HS specimens and 30 % for UHM specimens after measurements at lower temperature levels. We assume that the specimens were damaged during measurement. The damage to the specimens was probably caused by two main factors. The first could be the frozen moisture from condensed air that could damage the outer layers of the composite. Specimen loaded at 0 °C is presented in Fig. 4 but considering that there was no damage after this loading, the main factor is considered

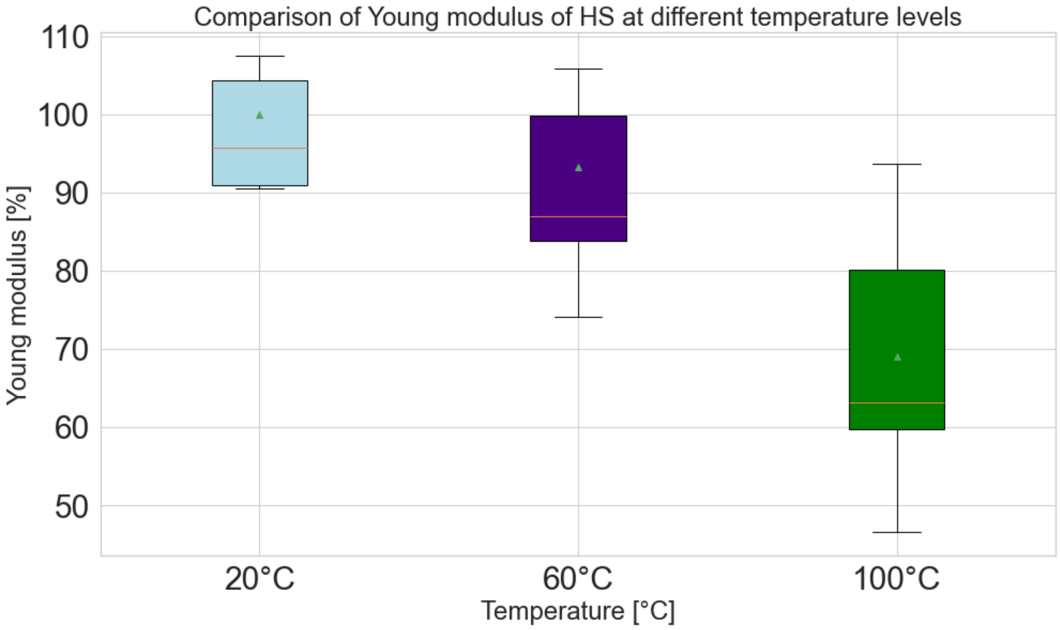


Fig. 2: HS results.

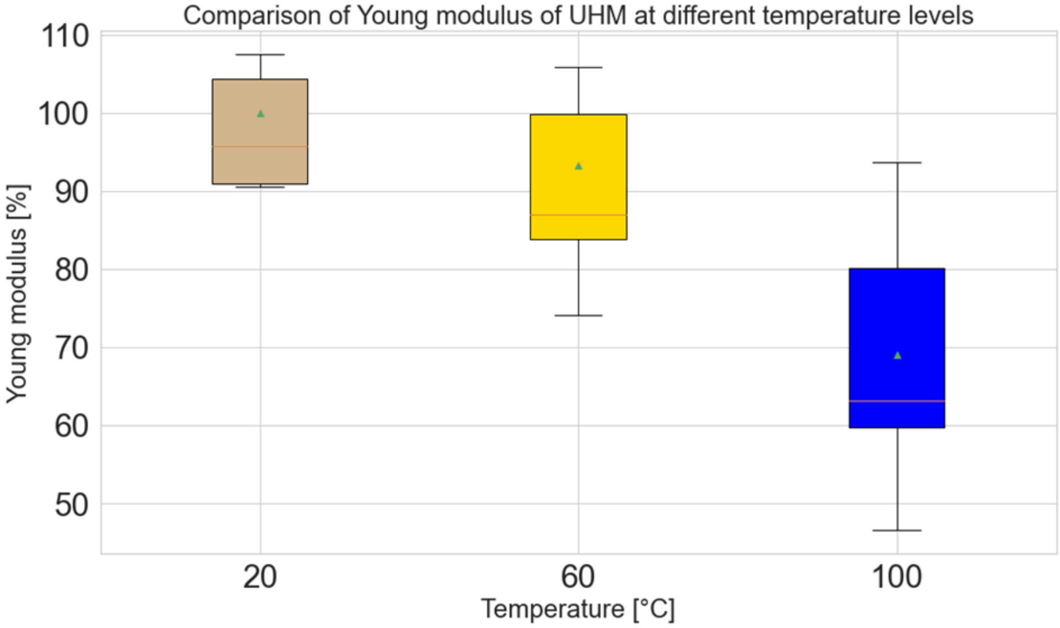


Fig. 3: UHM results.

Fig. 4: Specimen during lower temperature loading.

to be the injection of liquid nitrogen into the chamber. The chamber was not perfectly sealed, which resulted in a continuous injection of liquid nitrogen. The construction of the chamber has an outlet that aims strictly at the specimen from a close distance. The thermal chamber used was not specially designed for the tests of composite materials. As liquid nitrogen is often used successfully for the cooling of composites, we assume that the chamber needs to be perfectly sealed to minimise the amount of injected nitrogen and to control the cooling to be slower, preferably with outlet not in the direction of specimens or with some protection.

5 Conclusion

A decrease in stiffness was observed for increased temperature levels of approximately 9 % (60 °C) and 15 % (100 °C) for the HS composite and about 8 % (60 °C) and 31 % (100 °C) for the UHM composite. Although the scatter of the measured data, decrease in stiffness could be considered an expected behaviour considering the literature, but more tests, especially on more precise specimens, should be done to get more representative values. The measurement with liquid nitrogen cooling proved to be more complicated. To obtain useful results, the experimental setup and cooling, especially liquid nitrogen injection, must first be solved to avoid damaging the specimens. However, the operating conditions proved to be important to take into account during design.

Acknowledgement

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