# DEFORMATION AND FRACTURE OF FIBROUS POLYMER COMPOSITES IN THERMO-MECHANICAL IMPACT CONDITIONS

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## Abstract

A non-standard method of mechanical tests at high and low temperatures by tension unidirectional fiberglass specimens with high reinforcement (70%) by fragile high-modulus fibers was substantiated, developed and approved. Stress-strain diagrams were made. Temperature influences on mechanical properties of unidirectional fiberglass were estimated.

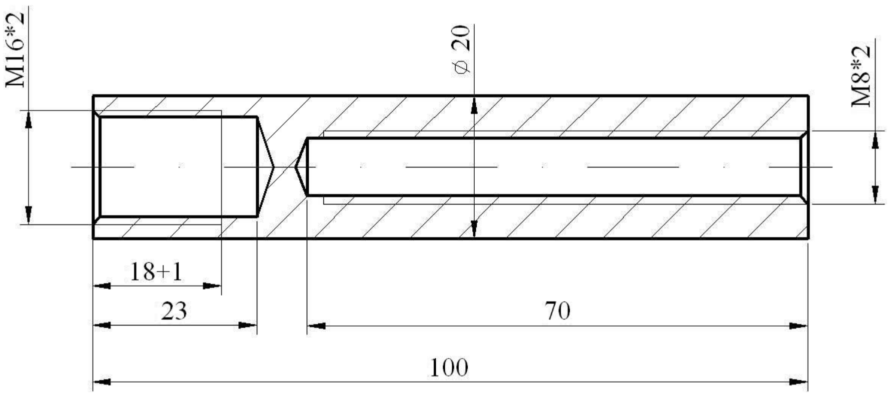
## 1. Introduction.

Usage of fiber-reinforced polymers (FRP) in industry and engineering is becoming more and more topical nowadays. That’s why definition of FRP mechanical properties is really significant goal.
A research aim was substantiation, development and approval of the non-standard method of mechanical tests at high and low temperatures by tension unidirectional fiberglass specimens with high reinforcement by fragile high-modulus fibers. A feature of this material is a high (70%) content of reinforcement. An increase of fiber volume fraction leads to an increase of material strength along reinforcement direction and to an edgy decrease transverse direction. This material is produced in the form of unidirectional tape with transverse size 40×5 mm. These circumstances narrow usage for testing this material by standard approaches and methods (ASTM D 3039/D 3039M-08).

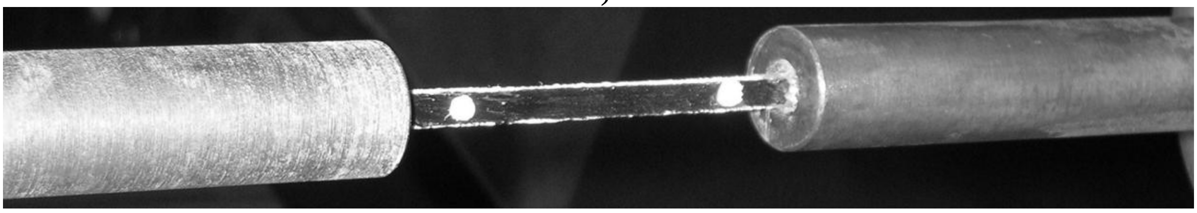
## 2. Uniaxial tension testing of unidirectional fiberglass

### *2.1 Tests at room temperature (22°C)*

A gripping device was designed and produced. The main idea of the construction is that specimen is executed in the form of constant cross section rod. Gripping parts have steel sleeve form, figure 1(a). In that case gripping steel sleeve length limited by working area of the temperature chamber. One end of the sleeve is fixed in the testing machine grip and there is a deep “blind” hole on the other side of the sleeve, which is made for fiberglass immersion. A fixation of the fiberglass specimen in the “blind” hole of the steel sleeve is performed by epoxy adhesive without transverse compression. Adhesive properties and immersion depth define textile of this construction. Preparation of the fiberglass specimens included production of constant cross section rods (5×5 mm) possibly without any external defects (detachment, fractures, binder cleavage) from tape. Then was made pasting rods into sleeves with help of epoxy adhesive and also tags were inserted on the specimen gage length by marker, for using non-contact extensometer Instron AVE, as shown at the figure 1(b).




a)



b)

**Figure 1.** Rough draft of the gripping part (a) and appearance of the highly filled fiberglass specimen for uniaxial tension testing with made tags for using non-contact extensometer Instron AVE (b)

Tension tests of the unidirectional fiberglass along reinforcement direction at room temperature were held by multipurpose electromechanical system Instron 5882 with usage of the videoextensometer Instron AVE. Climate chamber Instron 3119-407 was used at high and low temperature testing. Figure 2 shows a testing complex Instron 5882 (1) with video-extensometer (2) and climate chamber (3) and gripped modificated specimen tensile at room temperature ($22^0$C).[1,2]

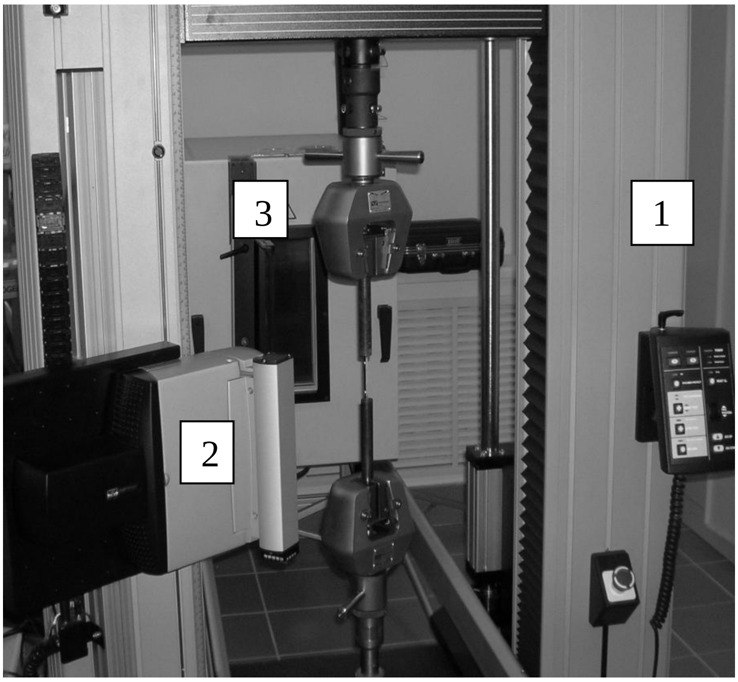



**Figure 2.** Gripped unidirectional fiberglass at tension test: testing complex Instron 5882 (1), videoextensometer (2), climate chamber (3)

Necessity of application non-contact extensometer is due to nature of this material specimen failure. Figure 3 represents a stress strain diagram model type of unidirectional fiberglass at tension test.

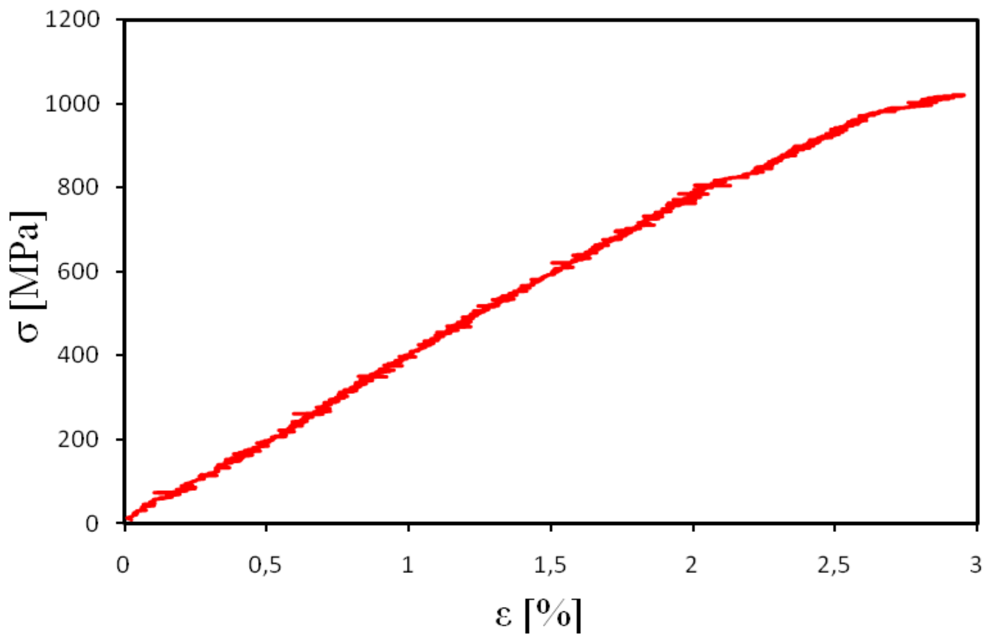



**Figure 3** – the model stress strain diagram of unidirectional fiberglass at tension test

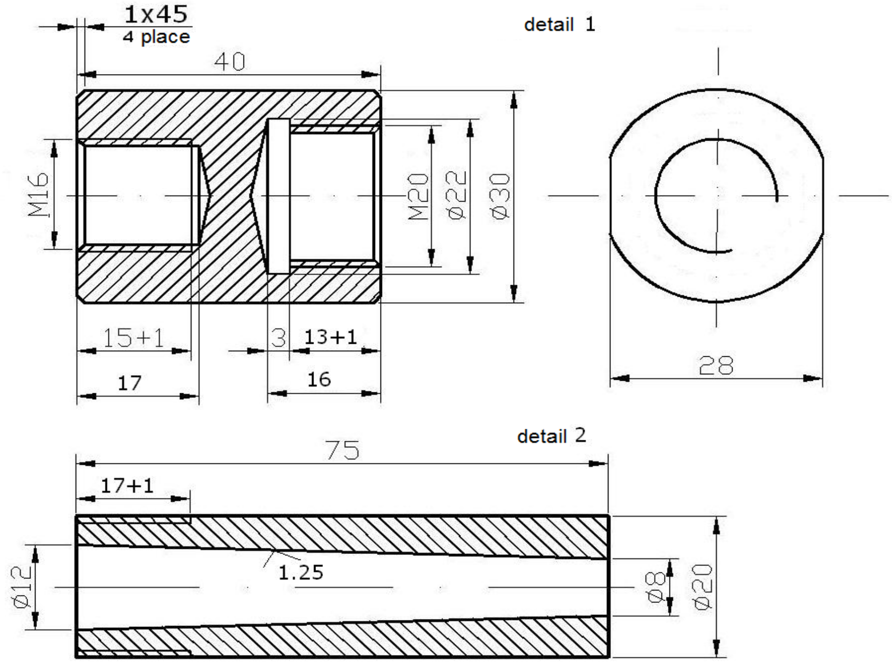
Results of tension tests at room temperature are shown at table 1.

| Specimen № | Young's modulus at elongation E, [GPa] | Tensile strength $\sigma_B$, [MPa] | Tensile strength $\sigma_B$ with confidence probability 0,95, [MPa] | Young's modulus at elongation *E* with confidence probability 0,95, [GPa] |
|---|---|---|---|---|
| 1 | 40,7 | - | | |
| 2 | 42,4 | 700,3 | | |
| 3 | 46,0 | - | | |
| 4 | 53,0 | - | | |
| 5 | 44,0 | 952,4 | | |
| 6 | 50,0 | - | 987,14±164,58 | 47,80±2,68 |
| 7 | 49,0 | 1165,0 | | |
| 8 | 48,1 | 1170,1 | | |
| 9 | 48,4 | - | | |
| 10 | 47,8 | 1100,0 | | |
| 11 | 47,6 | 1065,3 | | |
| 12 | 51,5 | 1118,2 | | |

**Table 1.** Testing results of unidirectional fiberglass at room temperature tension test.

*2.2 Low(-30°C; 0°C) and high(40°C; 50°C) temperature testing*

For testing unidirectional fiberglass at low and high temperature were produced gripping sleeves with a taper hole, a rough draft is shown at figure 4 (a). Specimen appearance is at figure 4(b). The main idea if this sleeves construction concludes following: with increasing tensile load, clamping force at transverse direction is growing.




a)

б)

**Figure 4.** Unidirectional fiberglass specimen is pasted in specific gripping sleeve, which is made for high and low temperature testing.

Results of unidirectional fiberglass specimens tension tests at – 30 $^0$C and 0 $^0$C are shown at table 2.

| Specimen № | Test temperature, [°C] | Tensile strength, [MPa] | Young's modulus at elongation *E*, [GPa] | Tensile strength $\sigma_B$ with confidence probability 0,95, [MPa] | Young's modulus at elongation *E* with confidence probability 0,95, [GPa] |
|---|---|---|---|---|---|
| 1 | -30 | 696,1 | 35,8 | 922,11±91,54 | 34,15±2,54 |
| 2 | | 1144,2 | 40,1 | | |
| 3 | | 917,5 | 32,6 | | |
| 4 | | 930,7 | 28,1 | | |
| 1 | 0 | 1021,4 | 39,3 | 980,22±21,58 | 36,83±2,38 |
| 2 | | 959,4 | 35,5 | | |
| 3 | | 1010,4 | 41,7 | | |
| 4 | | 929,7 | 30,8 | | |

**Table 2.** Testing results of unidirectional fiberglass at low temperature tension test.

8 unidirectional fiberglass specimens were tested at low temperatures: 4 specimens at temperature -30 $^0$C, 4 specimens at 0 $^0$C.
A stress strain diagram of unidirectional fiberglass at tension test at -30 $^0$C and at 0 $^0$C have similar nature with diagram at room temperature.
All unidirectional fiberglass specimens, which were tested for uniaxial tension, at low temperature -30 $^0$C and 0 $^0$C failed at the working area (figure 5). This type of failure happens because of fiber delamination and full matrix distraction.[3]

**Figure 5.** View of destroyed unidirectional fiberglass specimens after low temperature uniaxial tension

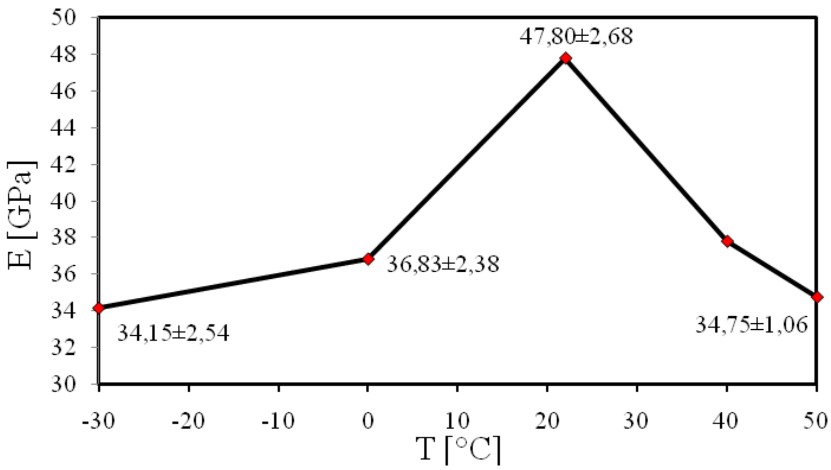
As a result of trial test at high temperatures 40°C and 50ºC, specimen failures were in the gripping sleeve. Using diagrams, which were obtained as a result of these tests, it is impossible to determine tensile strength however Young's modulus was defined.

Results of unidirectional fiberglass specimen tension tests at high temperatures are shown at table 3

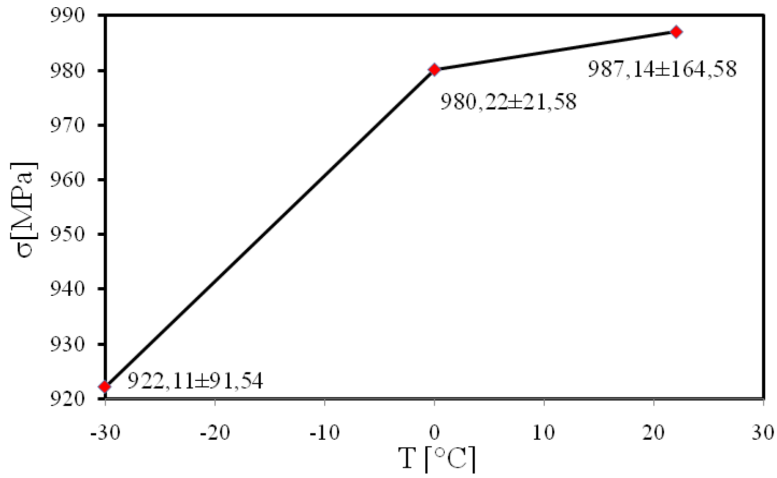
| **Specimen №** | **Test temperature, °C** | **Tensile strength $\sigma_B$, MPa** | **Young's modulus at elongation *E*, GPa** |
|---|---|---|---|
| 1 | 50 | - | 35,5 |
| 2 | 50 | - | 34,0 |
| 3 | 40 | 690,5 | 37,8 |

**Table 3.** Trial testing results of unidirectional fiberglass at high temperature tension test

## *2.3 Assessment of the impact of high and low temperatures on unidirectional fiberglass mechanical properties*




a)




b)

**Figure 6**. Dependence of the influence high and low temperature on Young's modulus (a) and tensile strength (b) of unidirectional fiberglass at tension test

Obtained dependence shows great influence of high and low temperature on unidirectional fiberglass elastic modulus. The value of elastic modulus at high and low temperatures decrease by 25-30% from results that were received at room temperature.

## Summary

Thus, 23 unidirectional fiberglass specimens were tested at uniaxial tension along reinforcement direction: 12 specimens were tested at room temperature (22ºC); 2 specimens at 50 ºC; one specimen was tested at 40ºC; 4 specimens at -30 $^{0}$C and 4 specimens at 0 $^{0}$C. For specimens, which were tested at low and room temperature, were determine tensile strength and Young's modulus. Temperature dependencies of mechanical properties can be defined on the basis of this methodology if specimen working area is improved and additional tests at high temperatures are carried.

Experiments showed that test method of unidirectional fiber-reinforced composites, with using specific (non-standard) gripping parts and specimen form, gives acceptable result at room (normal) and low temperature. Construction of specimen gripping part requires improvement at high temperature tests.

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