Comparison of two approaches for the tensile test of single roving in polymer matrix

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Abstract: High performance concrete is becoming more and more popular material. For extremely subtle structures are used as reinforcement durable composite materials, such as technical textiles. Elements made of this combination are called textile reinforced concrete. Modeling and designing from this material is very sensitive for boundary conditions. This study is focused on the two different methods of approaches for the determination of tensile strength and elasticity modulus of composite reinforcement using two different types of fixing to the testing machine.

Keywords: roving; polymer matrix; tensile test; modulus of elasticity.

1 Introduction

Rovings from different materials in polymer epoxy matrix are used for technical textiles formation. This advanced material is often applied as reinforcement for fine grained high performance concretes. For this particular application are used hard, durable and chemically resistant fiber materials like alkali resistant glass, basalt or carbon. This resulted in a new group of silica materials called textile reinforced concrete (TRC). TRC is used for new construction and is also possible to use this material for structures strengthening [1]. Determination of the basic mechanical parameters of each component is very important for elements designing and numerical modeling. Some types of testing are not clearly prescribed in standards. For this article about basic tensile parameters was chosen and adapted the procedure according to ACI 440.3R-04 [2] about the test methods for fibre-reinforced polymers (FRP) for reinforcing or strengthening concrete structures. This adapting is because this standard describes the same material, but with lower cross sectional area. On both ends of specimens are installed steel sleeves using epoxy resin. Because specimens preparation is very demanding and fragile during preparation and installation and specimens are susceptible to damage so the test procedure modification has been found. The method is described in [3] and has been developed for the tensile testing of single rovings without polymer matrix. The same testing procedure was applied for the tensile testing of single rovings with polymer epoxy matrix. Measured and calculated mechanical properties were the tensile strength and static elastic modulus using method [4].

2 Experimental part

2.1 Materials used for experiment

One type of roving Cem-FILL 5325 used for both approaches is made from the infinitely long alkali-resistant glass fibers. Each of them contained five specimens of composite reinforcements. From the most important properties, the roving used for experiment had a length weight (titer) of 2400 g/km (= 2400 tex), tensile strength of 1700 MPa and a modulus of elasticity of 72 GPa. Specific gravity of fibers material is 2.68 g/cm^3. From the technical data sheet it is possible to calculate theoretical maximal tensile force before breaking of all fibers in one moment and it is 1.522 kN [5]. As epoxy resin was used for experiment two part solvent free epoxy Sikafloor 156. The ratio of Part A and Part B was used 1:3 to assemble the epoxy resin according to technical data sheet. From the most important properties, the epoxy resin used for experiment had a tensile strength of 15 MPa, a modulus of elasticity of 2.0 GPa and specific gravity 1.10 g/cm^3 [6].

2.2 Tensile test

The only experiment for this work was the direct tensile test of composite reinforcement, single alkali resistant roving in matrix of epoxy resin. During test all required values for determination of tensile strength and modulus of elasticity were measured. It means the time, force, crosshead displacement and elongation of specimen using small external potentiometer [4]. For this work was chosen and adapted the procedure according to ACI 440.3R-04 [2] about the test methods for fibre-reinforced polymers (FRP) for reinforcing or strengthening concrete structures. So both ends of specimens were fitted with steel sleeves using epoxy resin because of fixing to the testing machine. The length of the specimen between steel sleeves was 300 mm and the length of each steel sleeve with diameter 20 mm was 150 mm. Specimens preparation is very demanding and fragile during preparation and installation and specimens are very susceptible to damage the test procedure modification was found. Another method for specimen preparation [3] has been originally developed for the tensile testing of single rovings without polymer matrix. Both ends of specimens are fixed to the small epoxy prims 8 x 8 x 80 mm without steel sleeves. For the epoxy prisms casting was used the silicon mold. The distance between prisms was also 300 mm.

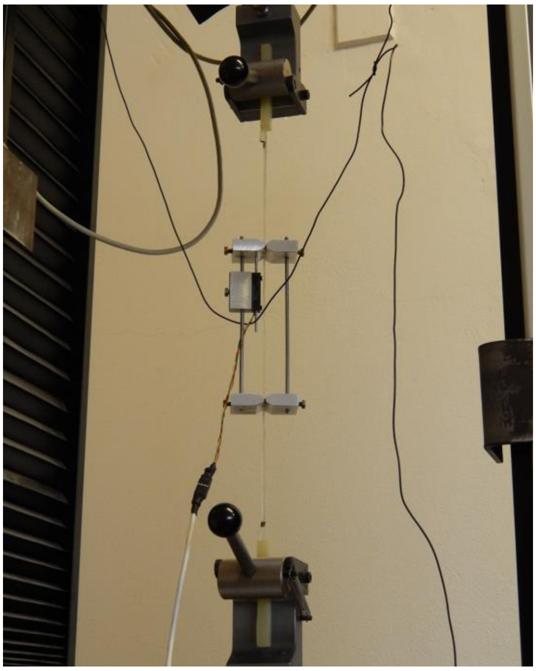

Fig. 1: General view of the specimen in sleeves made from epoxy prisms before testing.

Fig. 2: General view of the specimen in the massive steel sleeves with epoxy inside just after testing.

2.3 Results and calculations

Testing of specimens was performed in LabTest 100 testing machine. This testing machine was additionally provided with data acquisition system using external card because of using small external potentiometer for elongation measurement. The speed of loading was 2.0 mm/min. It corresponds approximately to the increase of stress 2.0 MPa/s. Specimens were loaded until the failure. The views on small potentiometer are presented in Fig. 1 for the case of epoxy prisms 8 x 8 x 80 mm on the end of specimen and in Fig. 2 for the case of steel sleeve with epoxy resin inside. The course of the test was monitored using data acquisition system that monitored the relationship of the acted force to the time of the test and deformation course. Graphical outputs were made from the courses of the tests. Three typical curves from five were chosen for each group of specimens. Force displacement curves are resented in Fig. 3 and stress-strain diagram from calculated values is presented in Fig. 4. Curves are very similar for each group of specimens.

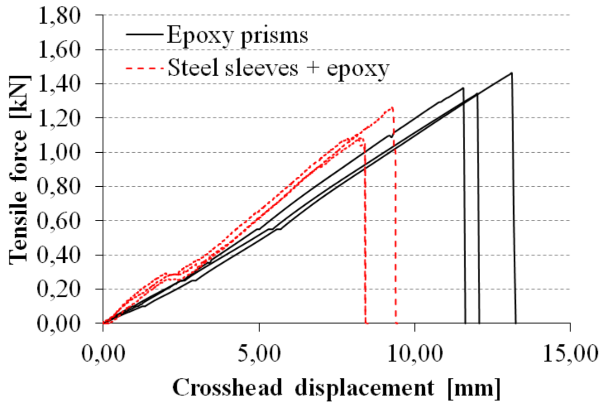

Fig. 3: Force-displacement curves using data from testing machine, both types of specimens.

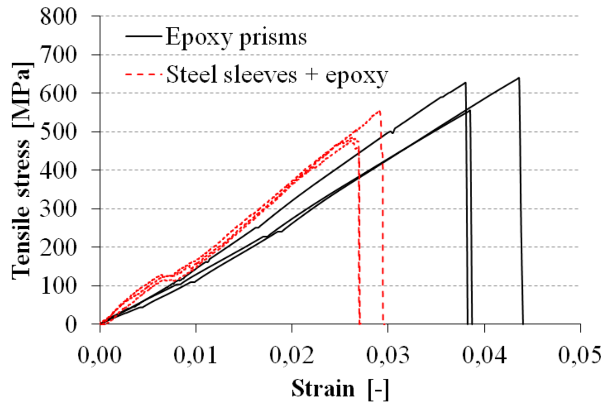

Fig. 4: Stress-strain curves using data from testing machine, both types of specimens.

Damage of specimens was similar for both types epoxy prisms and steel sleeves. They were broken always correctly approximately in the middle. Epoxy prisms were not visibly damaged during testing procedure and worked correctly. There was no visible pulling out of composite material from epoxy prisms. Specimens after testing procedure are presented in Fig. 5 and Fig. 6.

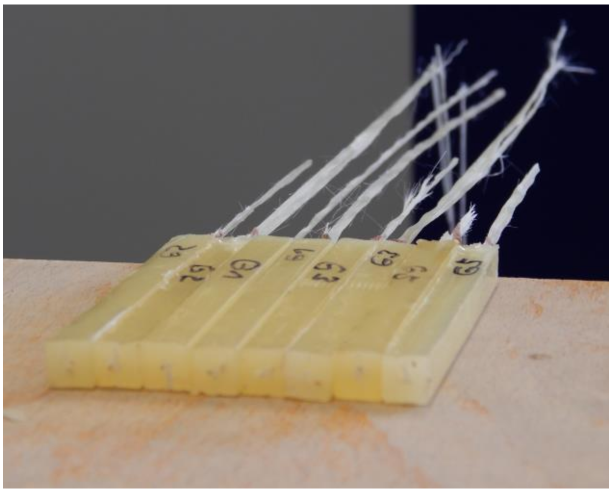

Fig. 5: View of the broken specimens in sleeves made from epoxy prisms 8 x 8 x 80 mm.

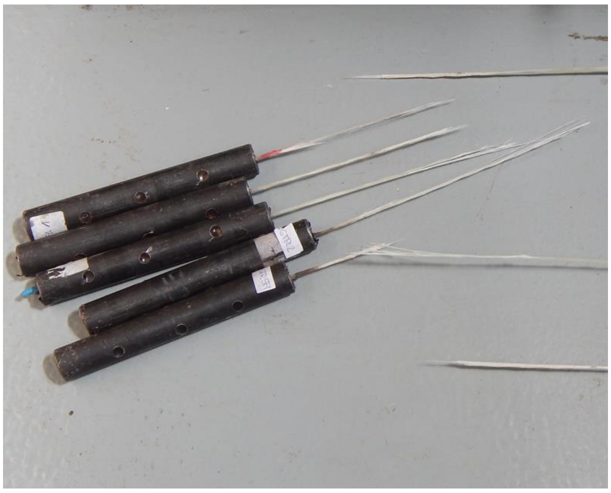

Fig. 6: View of the broken specimens in the massive steel sleeves 20/2.5 mm with epoxy inside.

Basis tensile parameters of used composite reinforcement were calculated from all measured values. All calculated results are presented in Table 1. Specimens with epoxy prisms have indication *E* and specimens with steel sleeves and epoxy inside have indication *S*. Symbol m in the Table 1 means the weight of specimens with length 100 mm and m_e means the calculated weight of pure epoxy, because it is known the weight of pure roving from defined length weight 2400 tex [5]. Symbol A and A_e mean the calculated cross sectional area of composite and pure epoxy using specific gravity of materials [5,6]. F_{max} is maximum measured tensile force just before breaking of specimen and f_t is calculated tensile strength. Elongation ε was measured using small external potentiometer monitoring the distance change between two edges of sensor with base of 130 mm. Elongation was monitored in the range of forces ΔF. Based on these results could be calculated the modulus of elasticity E.

Tab. 1: Results of measurement and calculations for each specimen, maximum tensile force and strength, static elastic modulus.

spec. [mm]	E 1	E 2	E 3	E 4	E 5	aver.	S 1	S 2	S 3	S 4	S 5	aver.
m [g]	0.385	0.386	0.407	0.417	0.440	**0.407**	0.398	0.405	0.405	0.428	0.420	**0.411**
m_e [-]	0.145	0.146	0.167	0.177	0.200	**0.167**	0.158	0.165	0.165	0.188	0.180	**0.171**
A [mm^2]	2.191	2.195	2.286	2.327	2.417	**2.283**	2.248	2.277	2.277	2.371	2.339	**2.302**
A_e [mm^2]	1.296	1.300	1.390	1.431	1.522	**1.388**	1.352	1.382	1.382	1.475	1.443	**1.407**
F_{max} [N]	1374	1205	1462	1283	1342	**1333**	1087	1262	1104	1132	1280	**1173**
f_t [MPa]	627	549	640	551	555	**584**	484	554	485	478	547	**509**
ε [-]	$4.234 \cdot 10^{-3}$	$4.821 \cdot 10^{-3}$	$4.066 \cdot 10^{-3}$	$4.486 \cdot 10^{-3}$	$4.678 \cdot 10^{-3}$	**$4.457 \cdot 10^{-3}$**	$3.255 \cdot 10^{-3}$	$2.842 \cdot 10^{-3}$	$2.913 \cdot 10^{-3}$	$3.003 \cdot 10^{-3}$	$2.739 \cdot 10^{-3}$	**$2.951 \cdot 10^{-3}$**
ΔF [N]	299.9	307.2	300.0	300.0	300.0	**301.4**	200.4	199.4	199.8	200.0	198.1	**199.5**
E [GPa]	32.3	29.0	32.3	28.7	26.5	**29.8**	27.4	30.8	30.1	28.1	30.9	**29.5**

3 Conclusion

Mechanical properties in this experiment are for both approaches very similar. Fig. 3 and Fig. 4 show that specimens with epoxy prisms have higher values of elongation. This is due to lower rigidity of the small epoxy prisms compared to the steel sleeves. Specimens with epoxy prisms also achieved higher maximum force just before damage. This may be due to bad sample with steel sleeves handling. They are heavy and fragile and they can be easily damaged before testing. Damage of specimens may not be visible. Prisms are lightweight and handling is much easier. Results and higher tensile strength indicates that use of the epoxy prisms gives more accurate results compared to the steel sleeves. Results of this work will be used as boundary conditions for numerical modeling.

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