Bending Properties of Glass-Polyester Composite Pipes

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Abstract. In process industry today with success are used the pipes of glass-polyester composite materials. In construction of complex pipelines, except typical loading because of internal pressure, pipes also can be subjected to bending. In that case the overload on outer layers (surface) damage and finally crack of pipes can occurr. The aim of this paper is the determination of bending strentgh, bending module of elasticity and deflection of stated composite pipes, by use of standard procedure of mechanical tests on bending. Pipes were produced by Cooperation "Poliester" a.d. Priboj. Also, having in mind the mechanisms of crack on bending, bending strentghs were compared with test results of the ultimate tension strentgh and according to that some conclusions were made. Micromechanical analysis on breaking surfaces helped to introduce the influence of structure on bending properties. This analysis confirmed all models and mechanisms during bending of pipes.

Introduction

Intensive development of polymer engineering, as well as specific capabilities of polymers to form new, synthetic structures with improved mechanical properties, led to expansion in usage of composite materials followed by continuous improvement of technology of their fabrication. Development of technology of composites was speeded up also in the area of design and production of big structures which will have low price and adequate reliability. Due to good mechanical properties, low mass and relatively simple fabrication, composites represent main competition to classical constructional materials [1,2], so today in the facilities of process industry more and more pipes, tanks, pressure vessels, and even reactors, are made of these materials.

Depending on the purpose, composite pipes, especially in constructions of complex pipelines can be subjected to bending. In that case exceeding of allowed stresses can cause failures which are seen in cracked fibers, crack of matrix and delamination. In dependence on the structure of pipes different models of failure are developed. In constructions of complex pipelines, except classical loading because of inner pressure, pipes can be subjected to bending. In the case of exceeding of allowed tensile strength on outer surfaces it causes damages that lead to cracking of pipes. Therefore, it is important to establish a reliable criteria of behavior of composite pipe exposed to bending, based on machanical testing and micromechanical analysis on surfaces of cracking, in order to evaluate which models and mechanisms on this loading occur and how they influence weakening of construction.

Experimental

The pipes were tested on bending by producer 'Poliester' from Priboj. The producers of glass fiber reinforcement A.D. 'OHIS' and 'Vidoe Smilevski-Bato' from Gostivar-Macedonia prove by certificate 'E' glass with 1% alkali.

As matrix was used thermo-active resin from Slovenian producer 'Color'-Medvode. Certificate was given for 'COLPOLY 7510' that is for the type: US\SOM- highly reactive, low viscose unsatiated polyester based on ortoftal acid in standard glycol.

Pipes were produced by method 'Filament Winding', composition of glass fibers was with angle ±55°. Dimensions of the pipes were ϕ70x500x6,5 mm (samples B2) and ϕ60x500x6,5 mm (samples M10). Pipes were measured before testing with flaw of ±1%. Three pipes were tested from each group.

By testing on bending the bending strength, modulus of elasticity on bending and deflection were determined. The tests were done on devices with tools adjusted for these tests. The procedure of tests, shape and dimensions were defined by standard ASTM D 790 [3,4]. The testing was done in three points (one, central loading on pipe supports on 2 points). Pipes were tested to bending on servo-hidraulic testing machine INSTRON 1332 with controller INSTRON FAST TRACK 80800, with the usage of hydraulic jaws. The loading rate was υ=5mm/min. During the testing the pipes were set on carrier with lining which represented supporters.

To assure accurate values of measuring it must be secured that crack of sample is in middle of bending and not in the middle of interlaminar shear stress which was achieved by proper choice of distance between the supports. Considering the length of pipes the distance between the supports was chosen l=300 mm.

Results and Discussion

On Fig.1 are shown characteristic diagrams force-deflection (*P-D*) which were received directly through the plotter during the testing of pipes samples B2-1 i M10-1.

The bending strength R_f, that is equal to maximal stress in outer layer in the moment of failure of pipes, was determined according to maximal load P_{max}, by the Eq.1.

$$R_f = \frac{P_{\max} \cdot l \cdot D_s}{2 \cdot I_x} \tag{1}$$

where:

R_f	-	Bending strength, [MPa]
P_{max}	-	Maximal load, [N]
L	-	Distance between supports, [mm]
D_s	-	Outer diameter of pipe, [mm]
I_x	-	Moment of inertia, [m^4]

Moment of inertia I_x was calculated according to the Eq.2.

$$I_x = \frac{\left(D_s^{\,4} - d_u^{\,4}\right)\pi}{32} \tag{2}$$

where:

D_s	-	Outer diameter of pipe, [mm]
d_u	-	Inner diameter of pipe $d_u = D_s - 2 \cdot s$ [mm]
s	-	Thickness of pipe wall, [mm]

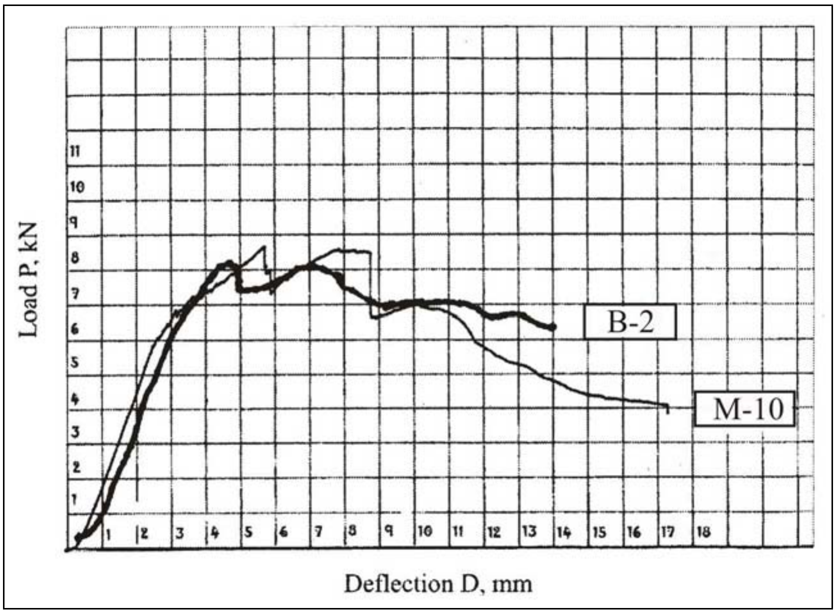


Fig. 1 Diagram force-deflection (F-D) received by bending in three points of samples B-2 and M-10

Modulus of elasticity on bending E_f was determined from the plot force (*P*)- deflection (*D*), from numerous values *P* and *D*, by method of smallest squares.

Maximal deformation of outer layer *(r)* was determined by achievement of maximal sum of force (made on the middle of distance between supports) and calculated by Eq.3.

$$r = \frac{6D_{\max} d}{l^2} \tag{3}$$

The received results were shown in comparison for all tested pipes of serial B2 and M10 in Table 1. In the right column are shown average values, and on Fig.2 and Fig.3 by diagram are shown average values in comparison of strength on bending and modulus of elasticity on bending for samples B2 and M10.

Table 1 Bending test results of pipes in serial B2 i M10

Sample	Bending strength R_f (MPa)		Modulus of elasticity E_f (GPa)		Maximal deflection *D* (mm)		Max. deformation of outer layer *r* (mm/m)	
		$R_{f,\,av}$		$E_{f\,,\,av}$		$D_{,\,av}$		$r_{,\,av}$
B2-1	105.8	108.4	2.7	2.5	6.9	8,0	3.9	3.5
B2-2	110.1		2.5		9.2		3.2	
B2-3	109.2		2.3		8.1		3.5	
M10-1	65.1	64.8	3.1	3.0	4.7	4.7	1.4	1.5
M10-2	66.2		2.75		4.2		1.4	
M10-3	63.1		3.2		5.1		1.7	

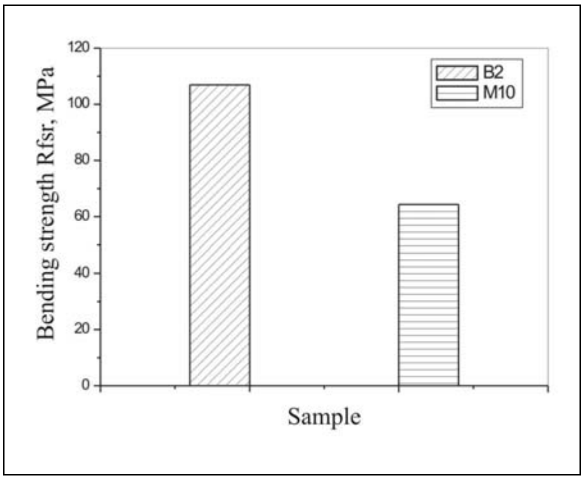


Fig.2 Average value of bending strength $R_{f, av}$ for tested samples

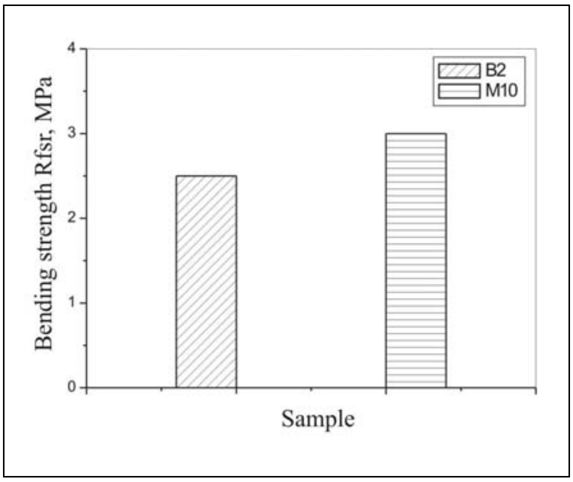
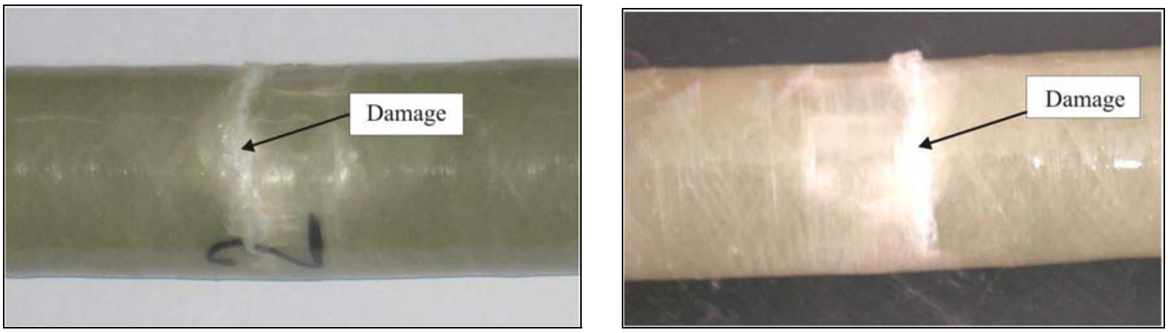


Fig.3 Average values of modulus of bending $E_{f, av}$ for tested samples

The pipes of type B2 compared with pipes M10 have higher bending strength, together with smaller modulus of elasticity. That is why we have higher deflection than with the samples M10. At pipes M10 the higher modulus of elasticity is characteristic, leading to higher stiffness and smaller deflection than the pipe B2.

It is known that during the testing on bending the outer side is always exposed to tension and inner on pressure [5,6]. Therefore it is very important to have data related to the tension properties in longitudinal and transversal direction of pipe, which is the subject of another test and paper. Micromechanical analysis on broken pipes has huge importance for the determination of all models and mechanisms during the break which directly influence bending properties [7].

The failure surfaces obtained during the tests on bending of pipes B2 and M10 are given on Fig.4.



a) *b)*

Fig.4 Damages made on tests on bending of pipes of serial B2 (a) i M10 (b)

The crack is initiated in all test tubes on the side of outer layer which is subjected to tension. Occurrence of the failure was at the moment of reaching critical state of stress in the material which causes the occurrence of critical value of crack and its unstable growth. The place of critical crack is related to fiber-matrix debonding after which the fibers cracked. It is obvious that on the spot where the first break appeared (outer layer) exist more broken fibers which were previously debonded and pulled out from the matrix. Crack propagation leads through to the inner surface of test tube in transversal direction. Lateral on this crack, in test specimens appeared cracks and delamination as result of shear stresses in the layers. Existence of shear stresses is characteristic for bending test, specially in the case when orientation of glass woven reinforcement is different (in our case ±45°).

In further experiments it is necessary to increase the number of samples to get more accurate and precise results. Also, the knowledge needs to be completed by data about straining and deformations, that is, hardness in vertical and transversal direction of pipes caused by tightening and pressure. In that way there would be set a connection between hardness on bending, tightening and pressure, considering that that is the basic model according to which the pipes and bent and broken: outer surfaces are tightened and inner pressured.

Conclusion

Basic mechanical characteristics were received by testing of composite pipes glass-polyester in three point bending test. Bending strengths and modules of bending were received for two types of pipes, B-2 and M-10, of diameter of 70 and 60mm. Three samples were tested of each group and average values of the results were shown. It is obvious that results of bending strength are better with samples B-2 and average values are $R_{f,av}$=108,4 MPa, while with samples M-10 they are much lower and are $R_{f,av}$=64,8 MPa. However, if modules of elasticity are observed it could be concluded that average received values of both samples are similar, that is, there is not some bigger deviation. Module of elasticity on bending with samples B-2 is $E_{f,av}$=2,5 GPa, while with samples M-10 it is $E_{f,av}$=3,0 GPa. It is obvious that with enlargement of bending strength the hardness of pipes enlarges which can be seen from the received results of maximal deflections, and they were D=8,0 mm and D=4,7 mm for samples B-2 and M-10, respectivelly. Also, it is interesting to compare diagrams force-deflection (P-D) received directly from the devices for testing. It can be said that they are by look relativelly similar, so it can be concluded that similar or even the same mechanisms of break appear that are not dependant of dimensions of cross section or thickness of wall of the pipe. With this experiment, the basis of the devices and related equipment for further tests were set.

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