Loading tests of adhesively bonded joints of glass-fibre reinforced plastic composite members

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Abstract: - There is generally a tendency of using various types of composite members across the whole spectrum of civil engineering branches. As one of the possibilities it can be taken an application of these members in case of bridge structures (for example as a part of a bridge deck or of a guardrail), where it can be advantageously used their load-carrying capacity together with a relatively small self-weight. A design of connection between composite members made of the glass-fibre reinforced plastic (GFRP) is a very important problem in this event. To get information about an actual behaviour of such kind of construction details, several series of the loading tests of adhesively bonded joints subjected to a loading force have been recently realized on the authors' workplace. This paper deals with some particular results of mentioned experiments and describes the test evaluation as well as the subsequent verification of the load-carrying capacities by the help of the design assisted by testing method given by Eurocode.

Key-Words: - adhesively bonded joints, loading tests, tension loading, actual behaviour, mode of failure, load-carrying capacity, experimental verification

1 Introduction

Several research projects focused on the problems of the using of different types of composite members have been realized in the recent period on the author's workplace, which is the Institute of Metal and Timber Structures of the Faculty of Civil Engineering of Brno University of Technology.

During them some particular experiences and knowledges about the failure mechanisms and modes of failure have been obtained in case of design of the composite member connections. One of the latest of these research projects is still continuing and it is focused on the adhesively bonded composite joints. In terms of this project five series of the GFRP specimens with slightly different geometric parameters have been firstly selected for testing. These "pilot" tests have been performed for the verification of the specimen load-carrying capacities and for the determination of theirs characteristic and design values according to Eurocode method – design assisted by testing [1].

2 Loading tests configuration

In context of the information mentioned above, i.e. in order to get the information about the actual behaviour as well as to obtain the values of the characteristic or design load-carrying capacities, the loading tests with using of a tension force in all selected joint specimens (with their own different geometric configurations) have been performed. This tension force, in fact, caused the shear loading and the shear stress in planes of the connection.

During all the loading tests the values of the tension forces were recorded. The displacements were also measured and finally, for the selected specimens, they were recorded the values of a shear stress through the use of the strain gauges. The used specimens are shown in Fig. 1.

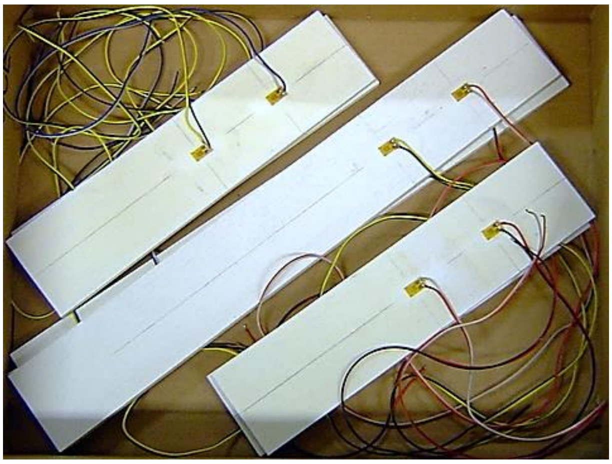

Fig. 1 Prepared specimens with the strain gauges

2.1 The description of the arrangement and equipment of the loading tests

In the event of the realization of all the loading tests the electromechanical high-capacity four-column testing machine LabTest 6.1000 (up to 1000 kN) have been used, see Fig. 2. The sizes of the forces have been controlled by the appropriate software (Catman Easy by HBM) and then, the obtained data of the forces along with the longitudinal and transversal displacements have been recorded by the measuring centre (MGC plus by HBM). The illustration of the entire loading test arrangement is shown in Fig. 3.

Fig. 2 Testing machine used for loading tests of the adhesively bonded joints

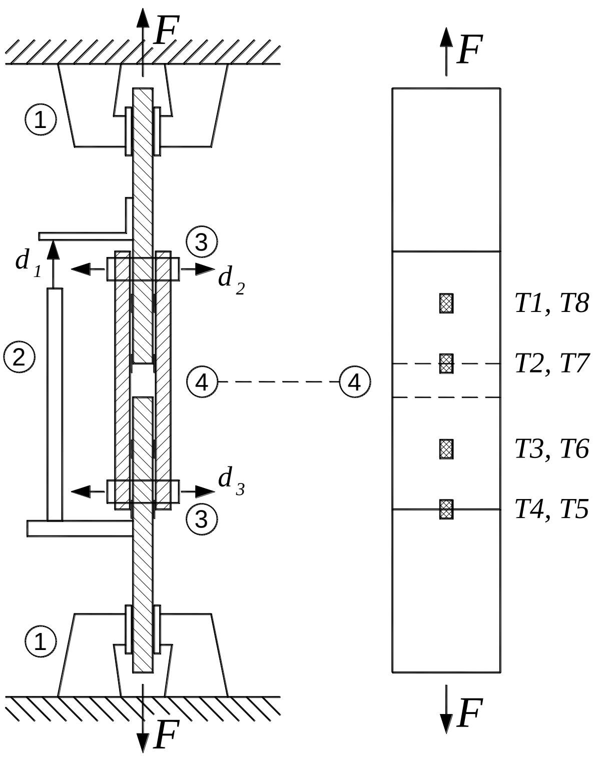

Fig. 3 Scheme of the loading test arrangement

The testing equipment consisted of following parts (see the numbers used in the Fig. 3): 1 – the testing machine LabTest 6.1000 by LaborTech; 2 – the inductive displacement transducer WA-T 10 mm and WA-T 50 mm by HBM; 3 – the displacement transducer transducers with the strain gauges LY11-3/350; 4 – the resistance strain gauges LY41-3/120 and LY41-1,5/120.

2.2 Configuration and dimensions of tested specimens

The test specimens of the GFRP composite member connection have been designed as the weighted double-lap adhesive joints, which (at the both ends) consisted of two cover adherents with the thickness t_1 and of one middle adherent with the thickness t_2 (Fig. 3 and Fig. 4), [2] - [5]. Then, a thickness of the adhesive t_a was 2 mm for the each specimen. The width of the adherents was selected as the value w and the distance of the overlapping of the adherents was l_o (the same values at the both ends of the joint).

Two specimens with the strain gauges in each series were used, whereas eight strain gauges marked from T1 to T8 were used for each specimen in this case and placed on the specimens into the centre of shear area of all the adherents and at the adherent's edge, see Fig. 3).

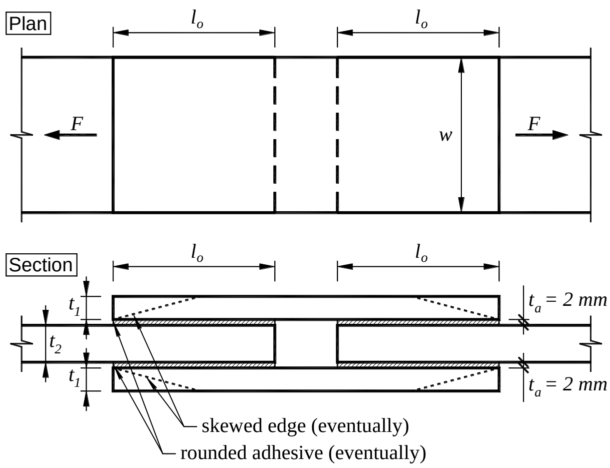

Fig. 4 Geometry and parameters of the tested adhesively bonded connection specimens

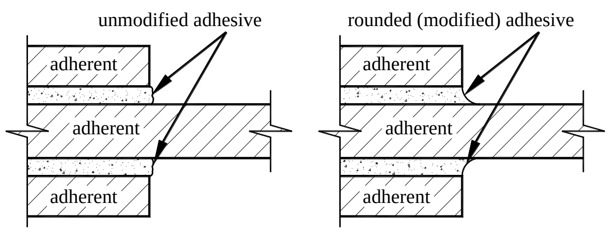

Fig. 5 Illustration of the adhesive modification

In one of the series skewed ends of the cover adherents have been used to get the information of their eventual influence on the value of the load-carrying capacity. By the same reason the adhesive was rounded in the area of the contact between adherents in the event of one of the series, too. Both of these described modifications can be found in the pictures on Fig. 4 and Fig. 5.

The Table 1 shows all the selected dimensions and parameters of the bonded joints in the event of 5 used series of specimens.

Table 1 Parameters of the adhesively bonded joint specimens (the dimensions according to Fig. 4)

Series of joints	w	l_o	t_1	t_2	Skewed edge	Rounded adhesive
	[mm]					
1	50	50	6	9	no	no
2	50	50	6	9	no	yes
3	25	50	6	9	no	
4	25	50	6	9	yes	no
5	50	100	6	7	no	

2.3 Loading tests realization

They were performed altogether loading tests on 99 specimens in five series marked as S1 to S5 (by 21 tests in the series S1 to S4 and then 15 tests in case of the series S5).

During all loading tests it was used the tension force F until the test specimen failed. To get the values of a tangential stress the member dimensions have been chosen in such a way so that all the specimens have failed in the shear area of the bonded joint and not in the composite member cross-section.

Next, just for the illustration, there are some pictures of performed loading tests shown in Fig. 6 and Fig. 7.

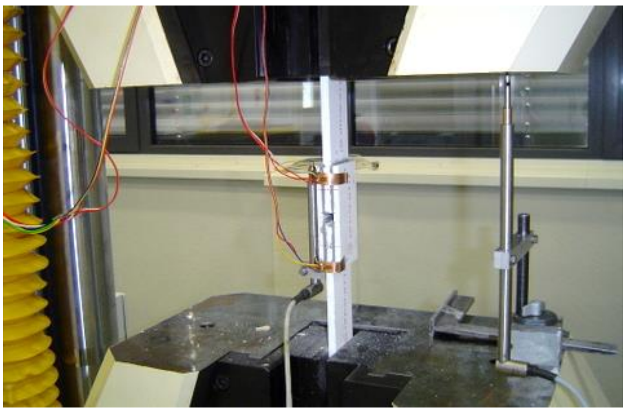

Fig. 6 Illustration of the loading tests realization

Fig. 7 Illustration of the loading tests realization

3 Test results

On the basis of 99 realized loading tests of the adhesively bonded composite joints, the elaboration of the test results has been subsequently performed.

First, from the “force F – time t” relationships the intervals of relevant measured data have been obtained. Then, for the chosen recorded values the relationships of “force F – displacement w” as well as “force F – relative displacement ε” have been evaluated and elaborated to the graphic form.

As an example, there is the chart of the relative displacements ε in dependence on the force F shown in Fig. 8 for the series S4.

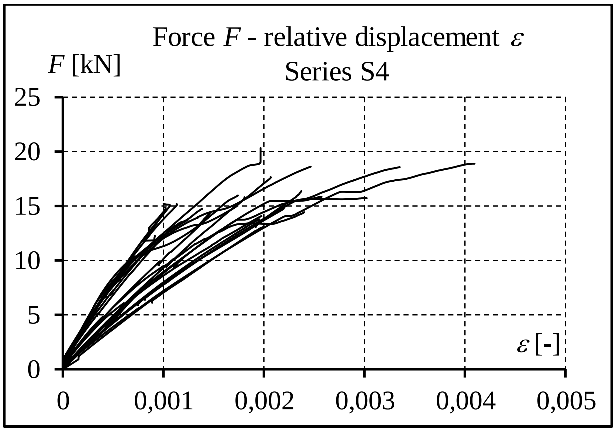

Fig. 8 Force to displacements relationships in case of series of specimens S4

3.1 Modes of failure

Simultaneously, the modes of failure have been classified, whereas, altogether 7 classes of failure modes exist; for example an adhesive or cohesive failure, then a thin-layer cohesive failure (TLCF), a fiber-tear failure (FTF), a light fiber-tear failure (LFTF), etc.

All these classes can be taken according to rules given by ASTM [6].

3.2 Load-carrying capacity verification

Table 2 shows the results for all series of specimens in case of the achieved maximal ($F_{max,test}$) and minimal ($F_{min,test}$) values of a shear force at the moment of the failure. Then it shows also mean values $F_{mean,test}$ and the variation coefficients v for each series. Then, the method "design assisted by testing" [1] was used for the determination of characteristic ($F_{ult,test,k}$) and design ($F_{ult,test,d}$) values of the ultimate load-carrying capacity in case of the shear force in the joint; see Table 2, where the corresponding values of factors γ_f are written, too.

Table 2 Determination of a load-carrying capacity in case of a shear force F in the connection

Series	S1	S2	S3	S4	S5
$F_{min,test}$ [kN]	26,65	28,10	11,83	13,07	34,35
$F_{max,test}$ [kN]	35,06	37,28	19,32	20,33	52,44
$F_{mean,test}$ [kN]	29,77	32,48	14,7	16,21	40,31
v [-]	0,084	0,089	0,125	0,126	0,139
$F_{ult,test,k}$ [kN]	24,15	26,35	11,48	12,64	30,00
$F_{ult,test,d}$ [kN]	16,86	18,40	8,06	8,85	17,48
γ_f [-]	1,432	1,432	1,425	1,428	1,717

The same procedure of data evaluation was used in case of the determination of characteristic and design shear resistances of the bonded joint, see Table 3. The shear stress has been obtained for the shear area, which has been taken as:

$$A_v = l_o \cdot w \tag{1}$$

and the value of the shear stress can be written:

$$\tau_{ult} = F_{test} / (2 \cdot A_v). \tag{2}$$

The resultant values subsequently evaluated from the loading tests are shown in Table 4 in comparison with the expected ultimate resistance $\tau_{ult,num}$ obtained from the numerical FEM models of the connection. The actual shear resistances are about 5-10 % higher in case of a skewed edge or rounded adhesive.

Table 3 Shear resistances of the composite joint

Series	S1	S2	S3	S4	S5
$\tau_{ult,num}$ [MPa]	4,72	6,45	5,96	6,57	4,06
$\tau_{mean,test}$ [MPa]	5,98	6,57	5,96	6,57	4,06
$\tau_{ult,test,k}$ [MPa]	4,85	5,33	4,77	5,13	3,00
$\tau_{ult,test,d}$ [MPa]	3,39	3,72	3,52	3,59	1,70
γ_f [-]	1,43	1,43	1,36	1,43	1,76

4 Conclusion

Altogether 99 loading tests have been performed in case of adhesively bonded joints. Some their results have been mentioned above as partial conclusions. All the values of the actual load-carrying capacities in case of shear loading are used for the verification of the numerical models, too.

Besides, the experiences and knowledges about the actual behaviour (process of loading, failure modes, technology of the adhesive bonding, etc.) are subsequently used for the design and verification of another series of GFRP specimens in case of the continuing research project, in which connections with a combination of composite members and steel parts are presently planned.

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