

EXPERIMENTAL RESEARCH ON LOAD CAPACITY, TREATMENT OF ADHESIVELY BONDED SURFACE AND FAILURE PROCESS OF STRUCTURAL T-JOINT

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Abstract

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In this paper the mechanical behaviour of structural two-component epoxy adhesives in T-joints is experimentally investigated. The aim of this study is to analyse the impact of the adhesive bonded surface treatment on the maximum force required to cause destruction, i.e. bearing capacity of T-joints bonded with various adhesives. Experimental results showed that the type of the adhesive affected the limit values of a force required for the destruction of the adhesive bond. The effect of the bonded surface treatment was also confirmed. From the results of experiment it was proved on five tested two-component epoxy adhesives that the negative effect of the peeling forces can be reduced by mechanical treatment of the adhesive bonded surface e.g. blasting. When there is applied an unsuitable mechanical treatment of adhesive bonded surface, the decrease of the force required for the destruction of the bond was up to about 98%.

Keywords: adhesive bond, elongation, chemical treatment, loading force, mechanical treatment, time of destruction, two-component epoxy adhesives

INTRODUCTION

The adhesive bonding method, regarded as a potential future technology, is now extensively applied in the automotive industry due to its several advantages over other traditional jointing methods such as welded, riveted and bolted joints etc. (Ping Hu *et al.*, 2012).

Adhesive bonds have been widely used in many technologies, e.g. automotive, agriculture machines, marine industry, space and aeronautics, as they offer significant advantages in applications (Müller, 2013; Müller and Herák, 2013; Müller *et al.*, 2013; Salih Akpınar *et al.*, 2013). However, in the design of adhesive bonds, many problems may appear. One of these problems is the stress concentrations occurring in the free edges of the bonding area (Salih Akpınar *et al.*, 2013).

The adhesive bonding technology, however, also includes the specific limitations and disadvantages

which may affect the adhesive itself, the adhesive bond and its durability. It is therefore necessary to ensure conditions that would eliminate the effect of the following factors in the application of the adhesive bonding technology. The main disadvantages of the adhesive bonding technology which are classified by some authors are the following factors (Messler, 2004; Habenight, 2002; Gardon, 1977; Pizzi and Mital, 2003; Müller *et al.*, 2007; Herák *et al.*, 2009; Cidlina *et al.*, 2014; Valášek *et al.*, 2014; Valášek and Müller, 2015):

- The requirement for an appropriate preparation and a surface cleanness of adherents.
- The construction of bonds – an influence of the length and thickness of the adhesive bonds.
- The necessity of various technological devices and equipment which are not normally required with other joining processes.

- A limited pot life, a limited shelf life of adhesives, and relatively long time of a curing.
- Bonds do not allow a direct visual check of the bonded area (if adherents are not transparent).
- A durability of adhesive bonds depends on the environment to which they are exposed, and environmental factors are much more varied and limited than at other methods of joining.
- An existence of peeling forces.

Experimental results showed that increasing overlap length did not improve the maximum load capacity of the bond (Aydin and Akpınar, 2014; Ping *et al.*, 2012). The experimental results showed that one of the options was the increase of the rigidity of adherents. This method is, however, not always possible, due to the requirement of the type of material.

This reason led to the focus of experiments in two directions: Choice of the adhesive and Surface treatment of the adherent.

In this paper the mechanical behaviour of structural two-component epoxy adhesives in T-joints is experimentally investigated. The aim of this study is to analyse the effect of the surface treatment of the bond on the maximum force required to cause the destruction, i.e. a bearing capacity of T-joints bonded with various adhesives.

MATERIALS AND METHODS

Laboratory experiments were performed on standardized test specimens of structural carbon steel S235J0 made according to standard ČSN ISO 11339 (Adhesives – T-peel test for flexible-to-flexible bonded assemblies) by cutting the carbon steel as a sheet with thickness of 1 mm. All the

adherents were bent to 90° by using a bending machine with a 0.5 mm radius.

The following surface treatments were tested:

- Mechanical treatment – grit blasted F 80 (Al_2O_3)/chemical treatment – degreased with Acetone (Marked A).
- Mechanical treatment – grit blasted F 80 (Al_2O_3)/without chemical treatment (Marked B).
- Without mechanical treatment/chemical treatment – degreased with Acetone (Marked C).
- Without mechanical and chemical treatment (Marked D).

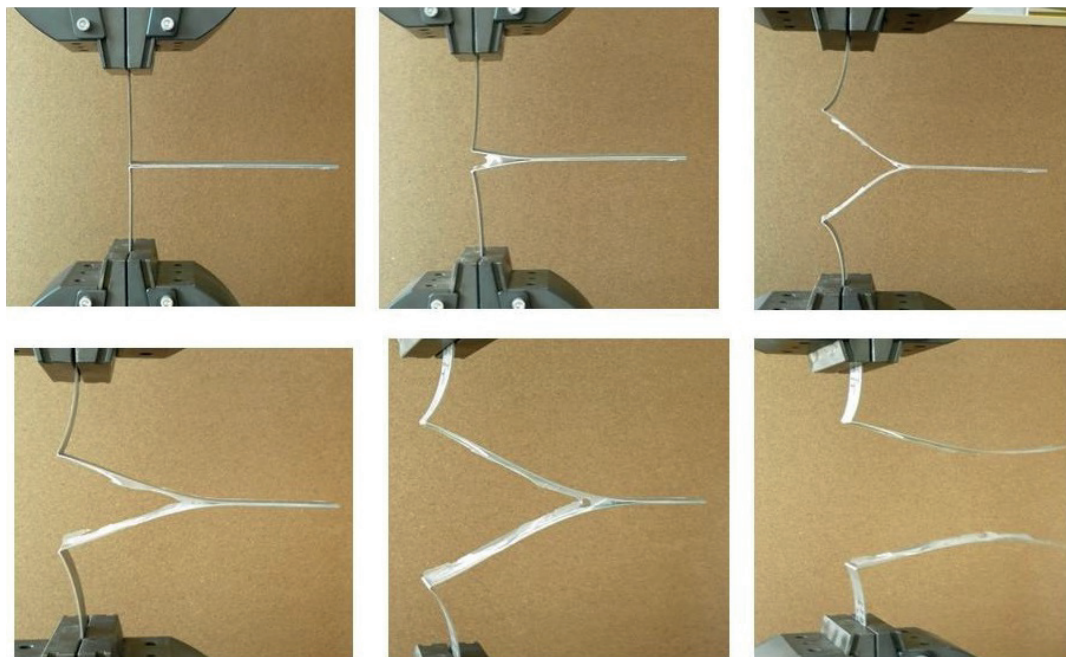
It can be assumed that the impurities (especially preservative wax) on the surface of the adhesive bonded material significantly reduce the loading capacity of the adhesive bond. A similar incidence of dust contaminants can be expected after mechanical surface treatment.

The blasting was performed in manual blasting chamber ITB 65 with foot control of compressed air. On a reciprocating compressor the pressure was set to 3.5 MPa.

On the surface of adherents designed for bonding roughness parameters R_a and R_z were measured. Roughness parameters were measured with a portable profilometer Mitutoyo SurfTest 301. Limit wavelength cut-off was set at 0.8 mm.

Five specimens from each series were prepared. For the research 5 two-component epoxy structural adhesives have been used:

- Bison universal (marked 1),
- Bison metal (marked 2),
- UHU plus 5 min (marked 3),
- UHU plus endfest 300 (marked 4)
- and Altec 3-ton quick 30 minutes (marked 5).



1: The process of test on Universal testing machine

After described surface preparation method, the adhesive material was applied and the adhesive bond was loaded with a weight of 495 ± 5 g under laboratory conditions with the temperature 23 ± 2 °C.

An even thickness of the adhesive layer was reached by a constant pressure 0.5 MPa. The lapping was according to the standard 150 mm.

The failure type according to ISO 10365 was determined at the adhesive bonds. The tensile strength and the elongation test were performed using the universal tensile strength testing machine LABTest 5.50ST (a sensing unit AST type KAF 50 kN, an evaluating software Test & Motion). A loading speed of the deformation corresponded to $100 \text{ mm} \cdot \text{min}^{-1}$. Process of the test on the Universal testing machine is evident from the Fig. 1.

The tested sets were mutually compared using F-test from the point of view of the influence on mechanical properties. The zero hypothesis H_0 presents the state when there is no statistically significant difference ($p > 0.05$) among tested sets of data from their mean values point of view.

RESULTS

The results of the surface roughness are evident from Fig. 2. Using the profilograph SurfTest 301 the following values were determined: the adhesive bond of series A and B – R_a showed higher values of the surface roughness $1.63 \pm 0.19 \text{ } \mu\text{m}$, R_z $9.08 \pm 1.11 \text{ } \mu\text{m}$, the adhesive bonds from series C and D – R_a $0.72 \pm 0.10 \text{ } \mu\text{m}$, R_z $3.75 \pm 0.53 \text{ } \mu\text{m}$. The thickness of the adhesive layer varied depending on the type of the adhesive. The measurement results are as follows: adhesive 1 $0.20 \pm 0.04 \text{ mm}$, adhesive 2 $0.13 \pm 0.01 \text{ mm}$, adhesive 3 $0.11 \pm 0.01 \text{ mm}$, adhesive 4 $0.15 \pm 0.01 \text{ mm}$ and adhesive 5 $0.36 \pm 0.01 \text{ mm}$. Adhesives

1 and 5 were filled with metallic particles by the manufacturer. These are so called liquid metals.

The results of the mechanical properties of the adhesive bond are seen in Figs. 3 and 4. From the results obtained in experiments it is evident that the combination of the mechanical and chemical treatment provides the highest values of the force required for the destruction of the bond (variant A).

When the bond was created only with mechanical surface treatment (without chemical treatment, variant B), the decrease of the force required for the destruction of the bond ranged from 14.0 to 23.6% comparing to the standard variant A. An increase of the force required for the destruction of the bond by about 2% was measured only at the adhesive No. 3.

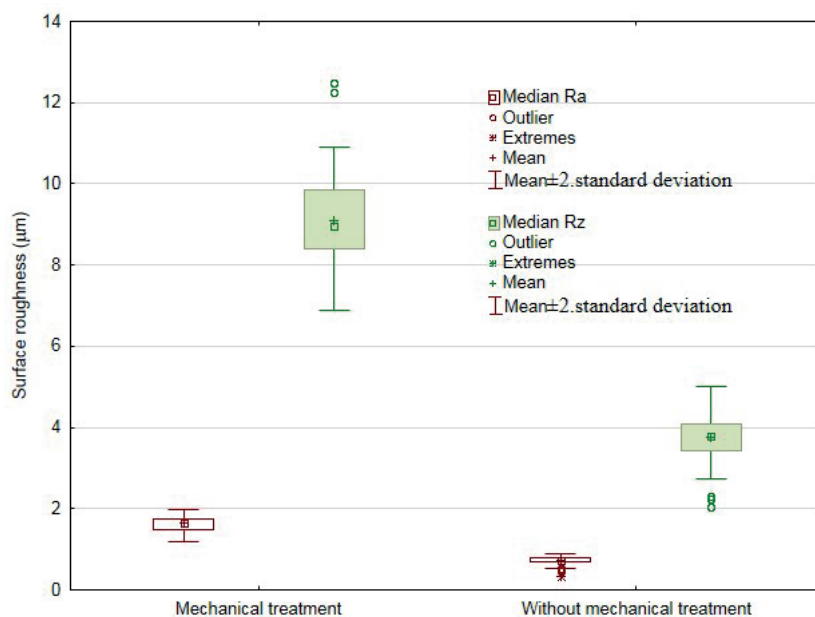
When the bond was created only with chemical surface treatment (without mechanical treatment, version C), the decrease of the force required for the destruction of the bond ranged in interval from 27.5 to 93.3% comparing to the standard variant A. A significant decrease occurred mainly at adhesives 1 and 3.

When the bond was created without mechanical and chemical treatments of adhesive bonded surface (variant D), the decrease of the force required for the destruction of the bond ranged in interval from 51.3 to 98.5% comparing to the standard variant A.

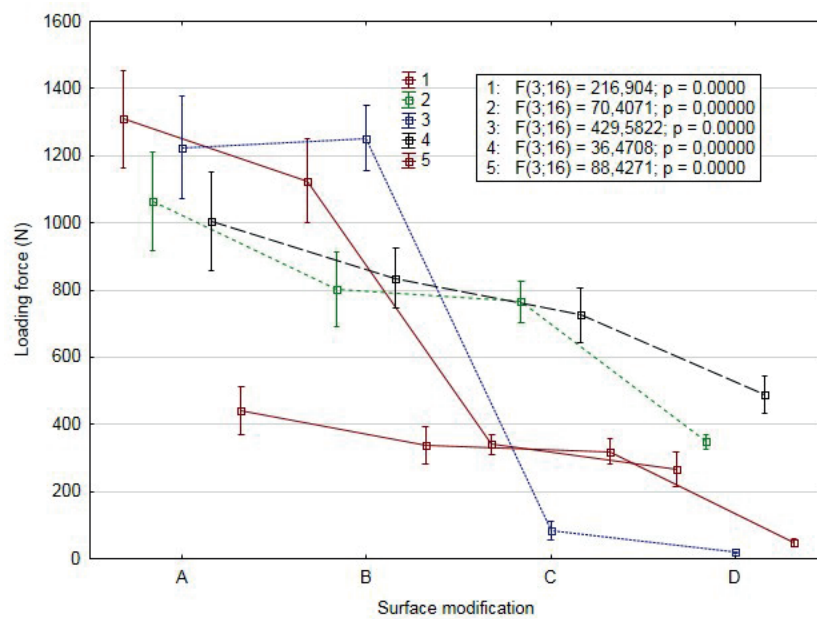
From the obtained results it is evident, that for the tested peel-loaded adhesives the mechanical treatment of the adhesive bonded surface is particularly significant.

A similar trend also showed the elongation of the adhesive bond (Fig. 4). Optimum properties were achieved at the specimens with mechanical surface treatment of adhesive bonds (variant A and B).

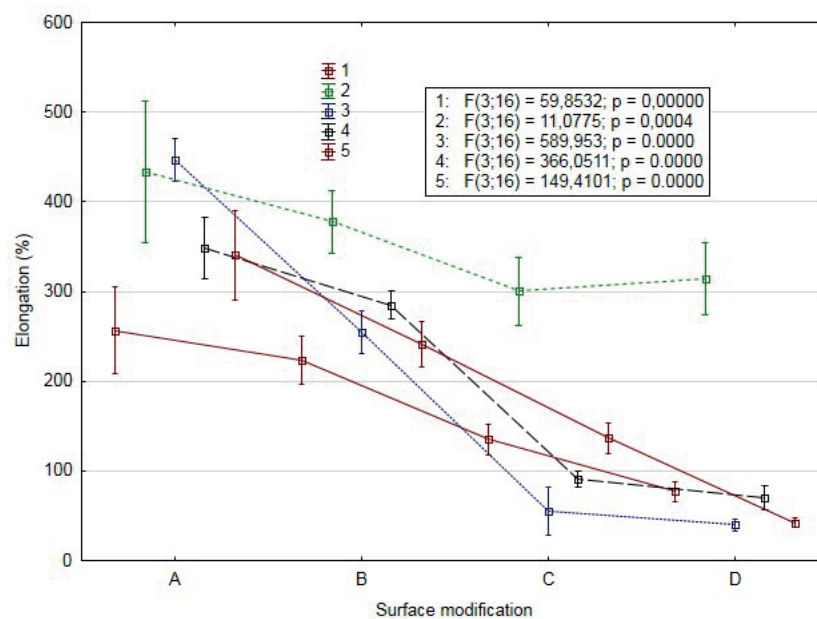
When the failure area was evaluated, the cohesive type of the failure was determined for bonds that



2: Effect of mechanical treatment of adhesively bonded material on roughness parameters R_a and R_z



3: Effect of surface treatment of adherent on force required to cause destruction of T-joints



4: Effect of surface treatment of adherent on elongation at T-joints

have been mechanically treated (A, B). For other variants of the surface treatment the adhesive-cohesive type or adhesive type of the failure of the bond were obtained. Fig. 5 shows the initiation of the adhesive failure area. The influence of the surface treatment on a change of the failure area was demonstrated.

When the adhesive bonds were stressed, the initiation of an increased rate of a curvature deformation of the adhesive bond occurred. A significant deformation occurred at the bond of type A (both mechanical and chemical treatment of adhesive bonded surface). This type of the failure

is apparent from Fig. 6 A. At adhesive bonds of type B and C smaller curvature (deformation) of adhesive bonds occurred-see Fig. 6 B. For adhesive bonds of type D (without surface treatment) there is no deformation – see Fig. 6 C. After exceeding the critical length of the overlap at bonds type A, B and C, there was a rapid destruction of the bond. The critical overlap length ranged in interval from 50 to 68 mm.

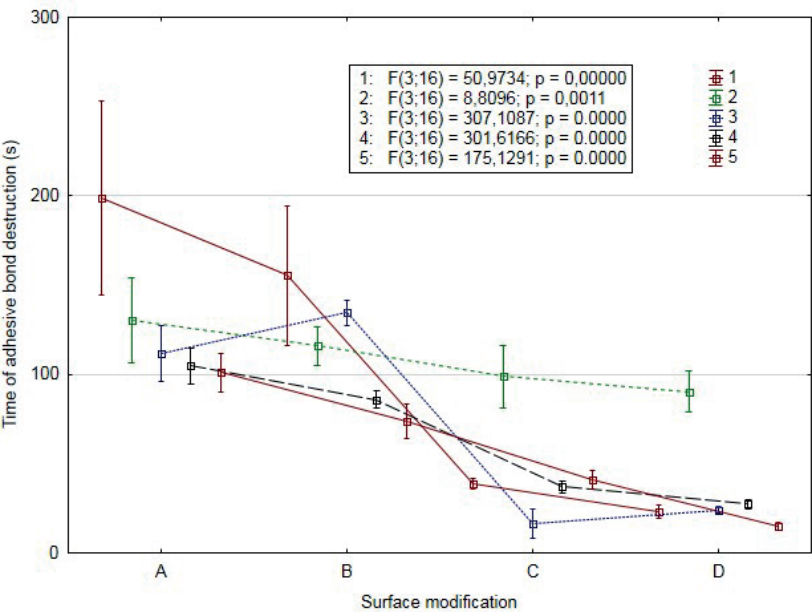
The results determining the time of the destruction of the adhesive bond depending on the surface treatment are shown in Fig. 7. From the results of these experiments it is clear, that



5: Initiation of failure area – adhesive type of failure of adhesive bond (treatment D)



6: Different deformations of test specimens depending on treatment of adhesive bonded surface



7: Effect of surface treatment on time of destruction of adhesive bonded T-joints

the combination of the mechanical and chemical treatment provides the longest time required for the destruction of the adhesive bond (variant A) except for the adhesive 3. The different trend was recorded at the treatment B – the increase of the time required for the destruction of the adhesive bond. This trend is also evident from Fig. 3, where the increase of the loading force required for the destruction of the adhesive bond occurred, when the surface treatment B was applied.

DISCUSSION

A significance of the surface treatment has been demonstrated in many studies (Müller and Valášek, 2013; Müller, 2013; Müller, 2014). A development of adhesives, however, aims to minimize the factors that affect the preparation of the bonded surface.

Conclusions, that there is the adhesive failure when the adherent is deformed and the critical length of the overlap is exceeded, were not confirmed (Akpınar *et al.*, 2013).

It was determined from the measurements that the critical overlap length, at which the rapid destruction of the adhesive bond occurs, depends on both, the type of the adhesive and the surface treatment (Castagnetti *et al.*, 2010).

Strength of T-joints did not exceed 0.4 MPa. In comparison with the tensile strength and the tensile lap-shear strength this strength is significantly smaller. The tensile lap-shear strength of tested adhesives ranges in interval from 7 to 18 MPa (Müller *et al.*, 2007).

From the experiments results a negative influence of forces causing a peeling of the adhesive layer from adhesive bonded materials determined by means of T-joints of the adhesive bonds is visible. It was negatively manifested itself on the load capacity (the adhesive bond strength). It follows from the above mentioned that the peeling forces in the construction of the adhesive bonds have to be eliminated at the practical application (Müller *et al.*, 2013; Müller *et al.*, 2014).

CONCLUSION

From the obtained results of the experiments it is possible to determine the following conclusions:

- Based on obtained results of the experiments, the hypothesis H_0 was not confirmed for all tested two-component epoxies. It follows that there is a difference in surface treatment of the adherents A, B, C and D in relation to the force required to cause the destruction of the adhesive bond and the elongation. This effect was statistically demonstrated at the significance level of 0.05.
- The presence of peeling forces was registered at almost all adhesive bonds. From the results of experiments tested on 5 two-component epoxies it was proved, that the negative effect of the peeling forces can be reduced by mechanical treatment of the adhesive bonded surface.
- A secondary aspect of testing the adhesive bonds is the time required for the destruction. The hypothesis H_0 was not confirmed for the tested two-component adhesives. It follows that there is a difference in the treatment of the adhesive bonded surfaces A, B, C and D in relation to the time required for the destruction of the adhesive bond. Longer time of the destruction is positive in relation to the safety of the structure. The treatment of the adhesive bonded surface A and B was evaluated as positive from this perspective.
- The treatment of the adhesive bonded surface also affects the size of the critical overlap length, at which the “immediate” destruction of the adhesive bond is initiated.

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