Experimental studies of adhesive joints in four-point static bending

A Jasińska¹, B Ligaj¹ and A Mazurkiewicz¹

¹UTP University of Science and Technology in Bydgoszcz, Faculty of Mechanical Engineering, al. Prof. S. Kaliskiego 7, 85-796 Bydgoszcz, Poland

E-mail: bogdan.ligaj@utp.edu.pl

Abstract. A new type of specimens, being the subject of the patent application in Poland, was used in the studies. The sample consists of two beams: top one (longer) made of structural material such as steel, aluminium alloy and bottom one (shorter), which is part of the glass, which is tempered, layered or traditional glass. The top beam may have any cross-section, e.g. rectangular, square, c-shaped, etc., which is characterized by different values of the moment of inertia. The bottom beam, meanwhile, is made of rectangular glass. The tests were performed under four-point bending conditions at monotonic incremental bending moment values on the Instron 5965 durability machine. The sample allows bending tests to be performed at bending loads while maintaining a constant bending moment in the glued joint area. The new type of specimen has been developed to allow for the testing of glued joints of different structural rigidity, with special emphasis on the steel-glass, aluminum-glass, steel-aluminum and similar connections. The experimental study of the durability of adhesive joints under four-point bending conditions with the monotonic incremental bending moment allows to determine the values of stresses, whose value is related to initiation of damage of the tested joint.

1. Introduction

The use of adhesive joints in machine building is widely used, which is confirmed by examples of aircraft, trains, buses, etc. The advantages of this type of connections are [1-4]:

- the possibility of combining materials with different physical properties,
- joining construction elements without creating additional geometric notches,
- the possibility of obtaining tight connections,
- high durability achieved through the use of modern structural adhesives,
- the possibility of correction the shape errors of the combined elements,
- corrosion resistance,
- the ability to damp vibrations.

At the initial stages of building the construction of the machine components are carried out on samples. Their shape and dimensions are based on norms, which examples are developped [5-7]. The results of tests carried out on standard specimens are presented in [8]. There are also many examples of research conducted using non-standard samples [4], [9] from a wide range of scientific disciplines.

The paper [10] describes the study of glue joints in which nanoparticle glue was used. The use of nanoparticles has been associated with the ability to diagnose damaged joints. In the study, overlapping samples were used. In the work [11] the defectability and static strength of adhesive joints, produced using five different types of dispersion methods, were carried out on the basis of
examinations of overlapping samples. In the article [12], adhesion tests in glass supporting structures are presented in relation to the effect of different substrates (glass, structural steel and stainless steel, aluminum alloy) and surface preparation (sanding of the glass surface). The original test samples consisted of a glass rectangle adhered to a cuboid with glass, steel and aluminum alloy.

This paper is to present a method of assessing the damage of the adhesive joints under conditions of a monotonically increasing bending moment.

2. Experimental research

2.1. Research object
In researches were used new type of specimen, being the subject of a patent application in Poland (Figure 1) [13]. The sample consist of two beams: top one with coarseness $g_1$ and bottom one with coarseness $g_2$, which were made of construction material. The beams are able to have any cross-section, e.g. rectangular, square, c-shaped etc. The top beam with the bottom beam are connected by adhesive joints with width $h$ and thickness $g_3$. In certain points of the top beam and bottom beam installed strain gauges allowing to denotation deformation: $S_1$ – deformation in the top beam besides the place of making adhesive joints, $S_2$ – deformation in the top beam between adhesive joints, $S_3$ – deformation in the bottom beam between adhesive joints.

![Figure 1. Schematic of specimen for testing the strength of adhesive joint.](image1)

![Figure 2. Test conditions of adhesive joint: a – beam load model, b – bending moment diagram, c – specimen loading method.](image2)
The specimen is able to be used in glued joint tests in four-point bending conditions. The tested glued joint must be in the area of constant bending moment (Figure 2). The specimen is able to be used under load conditions: tensile force or torque. The specimen load is able to be a combination of a tensile force load, a bending moment and a torsional moment.

Specimens for testing were made of flat bars 4 mm thick and 40 mm wide. The detailed dimensions of the specimen are shown in Table 5 in accordance with Figure 1. Were used the following materials: S235JR steel (Table 1), D16CzATW aluminum alloy (Table 2), thermally reinforced soda-lime glass (Table 3). The elements were joined using glue PLEXUS MA300 (Table 4). Strength properties of materials are presented in Tables 1-4. The shape of the test object is shown on Figure 3.

**Table 1. Mechanical properties of the S235JR steel [14].**

| Data according to the standard | S_y | S_u | E   | A   |
|-------------------------------|-----|-----|------|------|
| min.                          | 235 | 360 | 510  | 210000 |
| min.                          | 26  |     |      |      |

**Table 2. Mechanical properties of the D16CzATW aluminium alloy [15].**

| Mean value | S_y,0.2 | S_u | E   | A_5 | Z   |
|------------|---------|-----|------|-----|-----|
| MPa        | MPa     | MPa | %    | %   | %   |
| 335.7      | 460.1   | 68402 | 25.2 | 28.7 |

**Table 3. Mechanical properties of thermally reinforced soda-lime glass [16].**

| Data by manufacturer | R_c | R_g | E     | G      | ν    |
|----------------------|-----|-----|-------|--------|------|
| MPa                  | MPa | MPa | MPa   | Mpa    | -    |
| 39                   | 83  | 72000 | 30000 | 0.23   |

**Table 4. Mechanical properties of PLEXUS MA300 glue [17].**

| Mean value | S_u | E   | A   | ν   |
|------------|-----|------|-----|-----|
| MPa        | MPa | %    | %   | -   |
| 23.7       | 1610| 16.4 | 0.49|

**Table 5. Dimensions of the specimen (according to Figure 1).**

| Symbol | Value mm | Symbol | Value mm | Symbol | Value mm |
|--------|----------|--------|----------|--------|----------|
| a      | 63       | k      | 47       | L      | 59       |
| e      | 100.5    | g_1    | 4        | X      | 386      |
| f      | 83       | g_2    | 4        | Y      | 260      |
| h      | 9        | g_3    | 4        | Width  | 40       |

**Figure 3.** Specimen for testing: a – construction, b – physical object; M1 – S235JR steel, M2 – material: S235JR steel or D16CzATW aluminium alloy or thermally reinforced soda-lime glass, AJ – PLEXUS MA300 glue.
2.2. Research stand

The tests were carried out in four-point bending conditions with bending moments increasing monotonically. The main element of the test stand is the strength machine Instron 5965. Measurement of the deformations of elements were carried out by a tensometric method. Were used resistance strain gauges TF-5/120.

![Research stand](image1)

**Figure 4.** Research stand: a – general view, b – specimen loading method.

2.3. Test results

The test results are presented in the form of the dependence \( S = f(M) \) on Figures 5-7. Determination of extensometers S12, S22 and S32 is compatible with Figure 1. Achieved results for the tested samples point, that the highest stress values were obtained for the strain gauge S12. Stress values S22

![Stress values](image2)

**Figure 5.** Change in stress values in specimen elements of S235JR steel – S235JR steel.
and S32 depends on the material from which the element was made M2. For the specimens S235JR steel (M1) – S235JR steel (M2) change in the value of stresses S22 and S32 follows in a similar way. For the specimens S235JR steel (M1) – D16CzATW aluminium alloy (M2) and S235JR steel (M1) – soda-lime glass value of stresses S22 is higher than the stress value S32. This location of the curves of stress changes indicates, that the glued joints (AJ) devolve load from element M1 to element M2.

Figure 6. Change in stress values in specimen elements of S235JR steel – D16CzATW aluminium alloy.

Figure 7. Change in stress values in specimen elements of S235JR steel – thermally reinforced soda-lime glass.

3. Analysis of research results and conclusions
Obtained results of tests indicate, that made glued joints weren’t damaged under the influence of the acting bending moment. The glued joint should be considered damaged, if the stress values S22 are equal to the stresses S12. Then the stress value S32 will go to 0. An exemplary graph of stress changes for a damaged sample is shown in Figure 8.
Figure 8. The idea of assessing the strength of a glued joint on the basis of sample tests in four-point bending conditions.

Further work will concern the development of the dimensions of the samples allowing to determine the value of the limit stresses for the glued joint, which will take into account the properties of the combined materials.

Flaw of innovative samples is the need to measure stresses in individual areas of the sample. The easiest method to measure stresses is a strain gauge method that requires attaching the strain gauges. It is caused, that the research sample has a complex structure. It should also be noted that the implementation of tests requires the use of a durability machine and a strain gauge amplifier.

Further research will concern the mathematical model of a new sample type for the assessment of stress values in an adhesive joint.

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