

The method of diagnosing glued joints subjected to static loads

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Abstract. The article presents a new type of sample developed for the purpose of assessing the strength of glued joints. The construction and the idea of testing glued joints were described in detail. In the article put a question: what geometric features of the sample significantly affect the change in the stress values at the measuring points S1, S2 and S3 under the influence of the acting bending moment? Analysis of the results of numerical calculations allowed to state that the width of the glued joint h , spacing of connectors $L3$ and the thickness of the upper beam g_1 significantly affect the value of stresses in points S1, S2 and S3.

1 Introduction

Designing of machine construction elements is based on criteria formulated by end users. Criteria enforce the search for cheaper and simple manufacturing technologies of elements. A commonly used method of joining structural elements is gluing. It is used in the production of vehicles (cars, buses, trains, trams etc.) as assembly connections, among others windshield with supporting structure. Such application requires from connections to maintain high strength properties over the assumed service life, to ensure a high level of safety for vehicle users. Conducting experimental tests of this type of connections, in terms of strength and durability, allows you to choose their geometric features that ensure compliance with normative and utility requirements.

At the initial stages of constructing the examination of structural elements of machines, they are carried out on samples. Their shape and dimensions are adopted on the basis of standards, examples of which are studies [1, 2, 3]. The results of tests carried out on standard samples are presented in the paper [4]. There are also many examples of tests carried out using non-standard samples [5, 6] from a wide range of scientific disciplines.

In the literature are presented the results of research on combining elements made of different materials. Standard samples or parts of structural elements are used in the tests. On their base, the strength and durability of connections is assessed. Presented at work [7, 8] the results of the glued joints tests were carried out on samples under the monotonic conditions of the increasing bending moment. The presented samples allow to assess the strength of glued joints in relation to the variable stiffness of the elements and the dimensions of the joints.

The purpose of the work is to determine, which of the geometrical features of a new type of sample significantly affects the value of stresses in points S1, S2 and S3 under constant load conditions, the value of the bending moment.

The scope of work includes the presentation of: construction of a new type of sample for testing glued joints, the idea of assessing the strength of joints in four-point bending

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conditions, results of numerical calculations for variable geometric features, analysis of results.

2 Innovative sample for testing glued joints

2.1 Sample structure

Strength testing of adhesive joints can be carried out using samples of shape shown on Figure 1. The construction of the sample was submitted as an invention to the Polish Patent Office, in which it was registered under number P.422884 [9].

The test sample is made of: an upper beam, a bottom beam, two glued joints and strain gauges. The geometric features of the sample elements are following (Fig.1a):

- top beam(M1): L1 – length, H1 width, g_1 – thickness,
- bottom beam(M2): L2 – length, H2 – width, g_2 – thickness,
- glued joint (AJ): L3 – length, h – width, g_3 – thickness,
- strain gauges (T): unified elements e.g.. TEN-TFS5/120-P [10].

Geometrical relations between the elements of the sample are shown in the figure 1a and 1b. Glued joints (AJ) they are symmetrical in relation to the length L1 upper beam (M1). Distance between connectors AJ defines the dimension L4. Bottom beam (M2) with a length L2 it is located symmetrically to the beam M1 and connectors AJ. Beam widths: M1 and M2 and the length of the connector AJ they have the same values: $H1 = H2 = L3$. On beam M1 and beam M2 measuring points were determined (S), in which the measurement of deformations is carried out at the moment of testing. Measurement points S they are symmetrically oriented with respect to the axis of the sample in the width range H1 and H2, as well as length L1. In the symmetry axis of the sample, measuring points are located: S2 on a beam M1 and S3 on a beam M2. The axis of the sample is distant from the edge of the beam M1 by value $0.5L1$. Position of the measuring point S1 in relation to the axis of symmetry determines the dimension F. Its value should be within the range $L4 < 2F < Y$. At each measuring point S1, S2 and S3 two strain gauges were mounted (T_0), located on both sides of the beam. The task of strain gauges T_0 is the measurement of deformations on the surface of the sample elements, i.e. the upper beam M1 and bottom beam M2.

This sample is designed to assess the strength of adhesive joints in conditions of controlled deformation of machine construction elements. The most advantageous form of loading the sample is a four-point bending with a monotonically increasing value of the bending moment. The structure of the sample also allows the implementation of tests in cyclic loading conditions with cycle asymmetry coefficient $R \geq 0$. The method of applying the load is shown on the Figure 1c.

During the tests, the sample rests on supports A remote from each other by value X. Forces loading the sample are applied in points B, remote from each other by value Y. Points of load application B they are symmetrical with respect to supports A. Position of the symmetry axis of the sample relative to the supports A defines the dimension X/2. The value of the bending moment loading the sample depends on the value of forces acting, as well as on the ratio of dimensions X/Y.

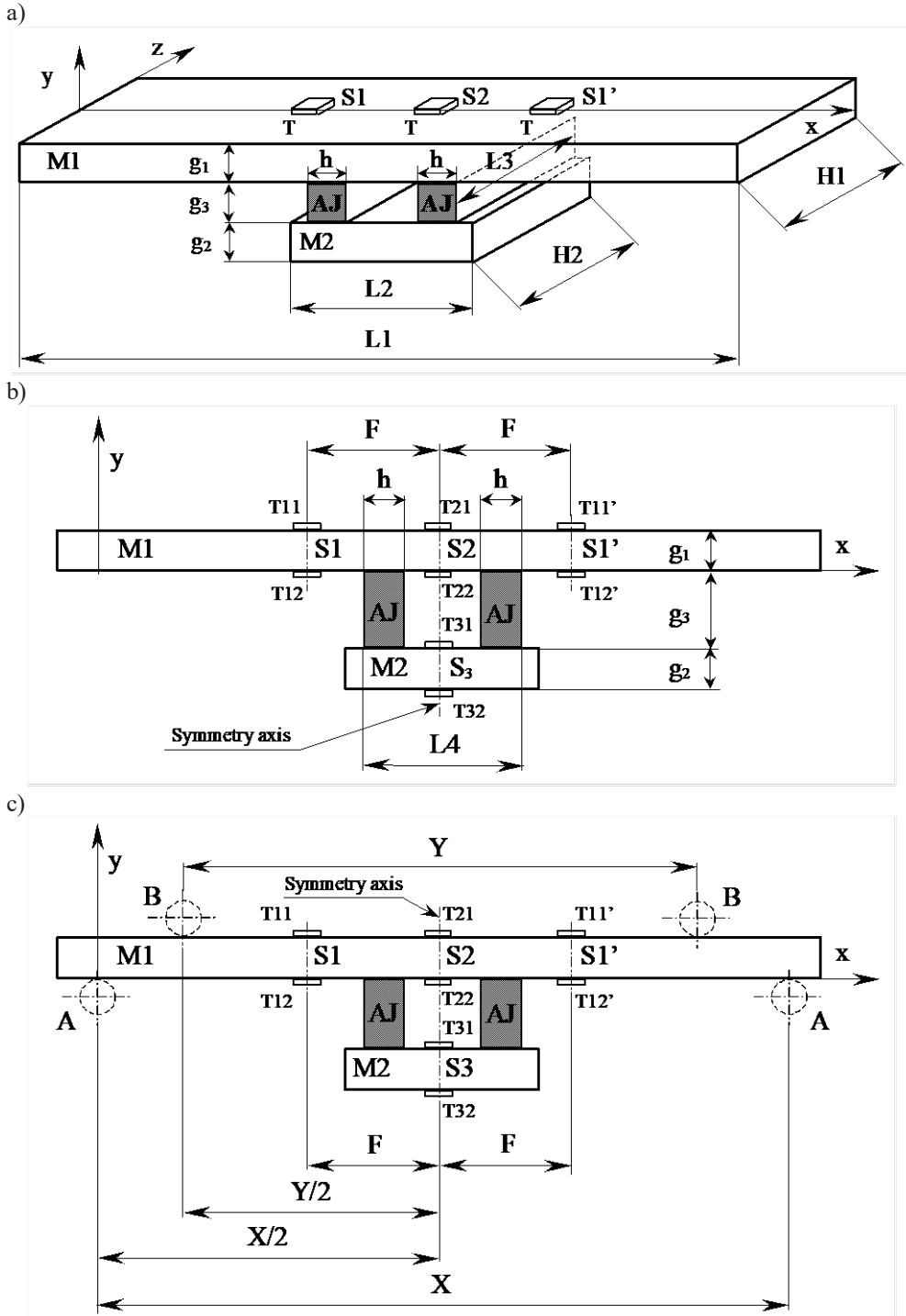


Fig. 1. Schematic of specimen for testing the strength of adhesive joint.

Strength and stiffness of the top beam M1, as well as the bottom beam M2 is shaped by the selection of: cross-section, geometric dimensions and material type. The cross-section of the beams is able to take the shape of simple figures (eg rectangle, square) or complex

figures (eg "C" section, "L" section and others). The shape of the cross-section and its dimensions affect the value of the static moment of inertia I_z . Presented on a Figure 1 the sample is made of a beam M1 and beam M2 having a rectangular cross-section. Dimensions of the cross-section of the beam M1 are $H1 \cdot g_1$, but beam M2 are $H2 \cdot g_2$. The value of the moment of inertia of each beam is determined by the thickness g_0 ($I_{z0} = (H() \cdot g_0^3)/12$), because values $H1 = H2$. Coefficient of stiffness of beams M1 and M2 is the product of the static moment of inertia I_z and modulus of longitudinal elasticity E (modulus Younga). Modulus Younga E is a characteristic parameter for the material.

2.2 The idea of testing glued joints

Examination of a sample of an innovative shape in four-point bending conditions with a monotonically increasing torque value consists in measuring the deformation values at the measuring points: S1 (S1'), S2 and S3. On the basis of strain measurements, the value of stresses is determined using prawa Hooke'a. Measurement points S1 and S2 they are in places where the value of bending moment has a constant value. Point S1 it is located outside the glued joints, and the point S2 between glued joints. The change in the stress value at S1 is proportional to the change in the bending moment value (Fig. 3).

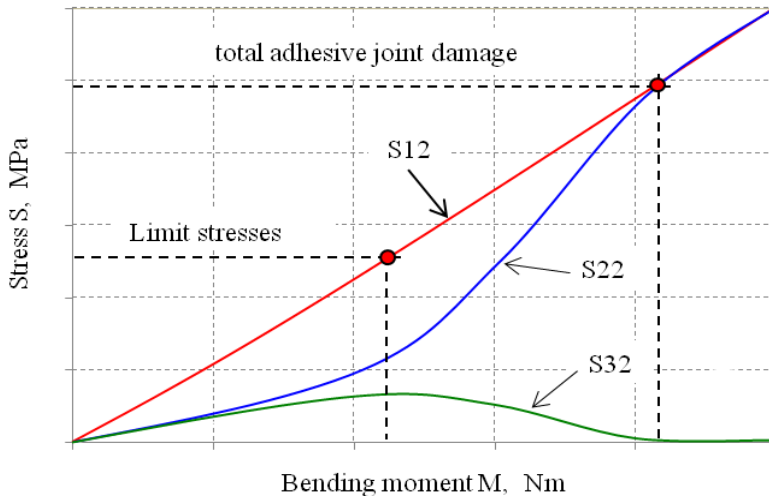


Fig. 3. The idea of assessing the strength of a glued joint on the basis of sample tests in four-point bending conditions.

Relationship between stresses in points S1 and S2 should be considered in three intervals (Fig. 3):

- section I – proportionally changing values of stresses S1 and S2 against the monotonically increasing value of the bending moment; this dependence indicates the lack of joint damage and work in the area of elastic stresses,
- section II - progressive increase of stresses S2 against stress values S1; This indicates the loss of load bearing capacity through the glued joint together with the increase of the bending moment, in the final stage the total failure of the joint,
- section III – equalization of stress values S1 and S2; applies to the situation of total damage to the glued joint.

The boundary between section I and section II should be considered as the value of allowable stresses, which do not damage the glued joint. Stress value $S1 = S2$ indicates that the joint is completely damaged. Stresses at S3 refer to load changes in the lower beam M2, which change in opposition to the value S2.

3 Numerical calculations

The purpose of calculations is to get the answer to the question: which geometrical features of the sample significantly affect the change in stress values at the measuring points S1, S2 and S3 under the influence of the acting bending moment?

3.1 Conditions for numerical calculations

Numerical calculations of stress values in elements of the test sample were carried out using the program Ansys. Dimensions of the model 3D adopted according to the signs presented on Figure 1. The following parameters were adopted for the purposes of calculations:

- constantly:
 - geometric:
 - spacing of supports $X = 340$ mm,
 - distance between the points of load application $Y = 260$ mm,
 - the width of the sample $H1 = H2 = L3 = 40$ mm,
 - length of the top beam $L1 = 400$ mm,
 - length of the bottom beam $L2 = 90$ mm,
 - distance of the measurement site S1 relative to the symmetry axis of the sample $F = 80$ mm,
 - material:
 - top bar M1 – structural steel $E = 2.1 \cdot 10^5$ MPa,
 - bottom bar M2 – structural steel $E = 2.1 \cdot 10^5$ MPa,
 - glued joint AJ – glue PLEXUS MA300 ($E = 1610$ MPa, $S_u = 23.7$ MPa) [11],
- variables:
 - geometric:
 - width of the glued joint $h = 3$ mm, 6 mm, 9 mm,
 - distance of glued joints $L3 = 20$ mm, 35 mm, 50 mm,
 - thickness of the top beam M1 $g1 = 2$ mm, 4 mm, 6 mm,
 - thickness of the bottom beam M2 $g2 = 2$ mm, 4 mm, 6 mm,
 - height (thickness) of the glued joint AJ $g3 = 2$ mm, 4 mm, 6 mm.

3.2 Calculation results

The results of numerical calculations allowed to determine the values of stresses in points S1, S2 and S3, which are presented in the tables 1-3.

Table 1. Stress value at point S1, S2 and S3 for the width of the glued joint $h = 3$ mm.

Lp.	Parametry zmienne					Wynik			Lp.	Parametry zmienne					Wynik		
	h	L3	g3	g1	g2	S1	S2	S3		h	L3	g3	g1	g2	S1	S2	S3
	mm	mm	mm	mm	mm	MPa	MPa	MPa		mm	mm	mm	mm	mm	MPa	MPa	MPa
1	3	20	2	2	2	61.4	44.4	2.4	42	3	35	4	4	6	22.8	21.2	0.5
2	3	20	2	2	4	61.6	42.5	2.2	43	3	35	4	6	2	17.5	17.4	0.5
3	3	20	2	2	6	61.6	42.1	1.4	44	3	35	4	6	4	17.5	17.3	0.4
4	3	20	2	4	2	22.7	21.3	0.8	45	3	35	4	6	6	17.5	17.3	0.2
5	3	20	2	4	4	22.8	21.0	1.0	46	3	35	6	2	2	62.0	46.7	3.9
6	3	20	2	4	6	22.8	20.7	0.7	47	3	35	6	2	4	62.1	45.5	2.3
7	3	20	2	6	2	15.5	14.8	0.4	48	3	35	6	2	6	62.2	45.2	1.5
8	3	20	2	6	4	15.5	14.7	0.5	49	3	35	6	4	2	22.7	21.7	1.0
9	3	20	2	6	6	15.5	14.7	0.5	50	3	35	6	4	4	22.8	21.6	0.6
10	3	20	4	2	2	61.1	48.3	3.5	51	3	35	6	4	6	22.8	21.5	0.4
11	3	20	4	2	4	61.2	47.1	2.2	52	3	35	6	6	2	17.5	17.4	0.5
12	3	20	4	2	6	61.2	46.8	13.0	53	3	35	6	6	4	17.5	17.4	0.3
13	3	20	4	4	2	22.7	21.8	1.0	54	3	35	6	6	6	17.5	17.4	0.2
14	3	20	4	4	4	22.7	21.6	0.7	55	3	50	2	2	2	65.2	36.6	4.6
15	3	20	4	4	6	22.7	21.5	0.4	56	3	50	2	2	4	65.4	34.8	1.7

16	3	20	4	6	2	15.5	14.9	0.5	57	3	50	2	2	6	65.4	34.4	0.7
17	3	20	4	6	4	15.5	14.8	0.4	58	3	50	2	4	2	23.1	20.3	0.8
18	3	20	4	6	6	15.5	14.8	0.3	59	3	50	2	4	4	23.1	20.1	0.8
19	3	20	6	2	2	60.9	50.0	3.7	60	3	50	2	4	6	23.1	20.0	0.7
20	3	20	6	2	4	61.0	49.0	1.9	61	3	50	2	6	2	48.0	47.0	1.0
21	3	20	6	2	6	61.0	48.8	1.1	62	3	50	2	6	4	48.0	47.0	1.0
22	3	20	6	4	2	22.7	21.9	1.0	63	3	50	2	6	6	48.0	47.0	1.0
23	3	20	6	4	4	22.7	21.1	0.5	64	3	50	4	2	2	64.0	41.8	3.4
24	3	20	6	4	6	22.7	21.8	0.3	65	3	50	4	2	4	64.1	40.9	2.7
25	3	20	6	6	2	15.5	14.9	0.4	66	3	50	4	2	6	64.1	40.7	2.1
26	3	20	6	6	4	15.5	14.9	0.3	67	3	50	4	4	2	22.9	21.2	1.2
27	3	20	6	6	6	15.5	14.9	0.2	68	3	50	4	4	4	22.9	21.0	0.9
28	3	35	2	2	2	63.1	39.4	1.8	69	3	50	4	4	6	22.9	21.0	0.7
29	3	35	2	2	4	63.3	37.4	1.6	70	3	50	4	6	2	48.0	47.0	1.0
30	3	35	2	2	6	63.3	36.9	1.3	71	3	50	4	6	4	48.0	47.0	1.0
31	3	35	2	4	2	22.9	20.8	0.8	72	3	50	4	6	6	48.0	47.0	1.0
32	3	35	2	4	4	22.9	20.4	0.8	73	3	50	6	2	2	63.4	44.6	2.5
33	3	35	2	4	6	22.9	20.2	0.6	74	3	50	6	2	4	63.6	43.6	2.9
34	3	35	2	6	2	17.5	17.2	0.4	75	3	50	6	2	6	63.6	43.2	2.0
35	3	35	2	6	4	17.5	17.1	0.4	76	3	50	6	4	2	22.8	21.5	1.2
36	3	35	2	6	6	17.5	17.1	0.3	77	3	50	6	4	4	22.9	21.4	0.8
37	3	35	4	2	2	62.4	44.2	3.3	78	3	50	6	4	6	22.9	21.3	0.6
38	3	35	4	2	4	62.5	43.1	2.3	79	3	50	6	6	2	48.0	48.0	1.0
39	3	35	4	2	6	62.5	42.8	1.6	80	3	50	6	6	4	48.0	48.0	1.0
40	3	35	4	4	2	22.8	21.4	1.0	81	3	50	6	6	6	48.0	48.0	1.0
41	3	35	4	4	4	22.8	21.2	0.7									

Table 2. Stress value at point S1, S2 and S3 for the width of the glued joint h = 6 mm.

Lp.	Parametry zmienne					Wynik			Lp.	Parametry zmienne					Wynik		
	h	L3	g3	g1	g2	S1	S2	S3		h	L3	g3	g1	g2	S1	S2	S3
	mm	mm	mm	mm	mm	MPa	MPa	MPa		mm	mm	mm	mm	mm	MPa	MPa	MPa
1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
1	6	20	2	2	2	63.4	27.8	2.3	42	6	35	4	4	6	23.3	18.0	0.4
2	6	20	2	2	4	64.1	20.5	3.1	43	6	35	4	6	2	17.6	16.6	0.2
3	6	20	2	2	6	64.3	18.0	1.8	44	6	35	4	6	4	17.6	16.5	0.2
4	6	20	2	4	2	23.0	19.0	0.4	45	6	35	4	6	6	17.6	16.5	0.2
5	6	20	2	4	4	23.1	17.6	1.1	46	6	35	6	2	2	65.6	26.3	1.3
6	6	20	2	4	6	23.2	16.9	0.9	47	6	35	6	2	4	65.7	25.4	1.1
7	6	20	2	6	2	13.2	12.8	0.1	48	6	35	6	2	6	65.7	25.2	1.1
8	6	20	2	6	4	13.2	12.5	0.5	49	6	35	6	4	2	23.2	19.1	0.7
9	6	20	2	6	6	13.3	12.6	0.5	50	6	35	6	4	4	23.2	18.9	0.6
10	6	20	4	2	2	63.2	29.6	1.3	51	6	35	6	4	6	23.2	18.9	0.5
11	6	20	4	2	4	63.4	27.1	1.4	52	6	35	6	6	2	17.5	16.8	0.4
12	6	20	4	2	6	63.5	26.5	0.8	53	6	35	6	6	4	17.5	16.7	0.3
13	6	20	4	4	2	22.9	19.6	0.4	54	6	35	6	6	6	17.5	16.7	0.3
14	6	20	4	4	4	23.0	19.2	0.7	55	6	50	2	2	2	69.0	22.7	0.3
15	6	20	4	4	6	23.0	19.0	0.5	56	6	50	2	2	4	70.3	16.2	2.2
16	6	20	4	6	2	13.2	12.9	0.2	57	6	50	2	2	6	70.8	13.6	1.6
17	6	20	4	6	4	13.2	12.9	0.3	58	6	50	2	4	2	23.8	17.3	0.5
18	6	20	4	6	6	13.2	12.8	0.3	59	6	50	2	4	4	24.1	15.6	0.7
19	6	20	6	2	2	63.0	31.3	1.5	60	6	50	2	4	6	24.3	14.7	0.6
20	6	20	6	2	4	63.1	30.4	1.4	61	6	50	2	6	2	14.2	12.8	0.4
21	6	20	6	2	6	63.1	30.2	1.0	62	6	50	2	6	4	14.3	12.3	0.3
22	6	20	6	4	2	22.9	20.0	0.6	63	6	50	2	6	6	14.3	12.1	0.3
23	6	20	6	4	4	22.9	19.8	0.6	64	6	50	4	2	2	68.9	22.6	0.7
24	6	20	6	4	6	22.9	19.8	0.5	65	6	50	4	2	4	69.3	20.3	0.6
25	6	20	6	6	2	13.2	13.0	0.3	66	6	50	4	2	6	69.4	19.6	0.3
26	6	20	6	6	4	13.2	13.0	0.3	67	6	50	4	4	2	23.7	17.9	0.6
27	6	20	6	6	6	13.2	13.0	0.2	68	6	50	4	4	4	23.7	17.4	0.3
28	6	35	2	2	2	66.1	24.4	1.1	69	6	50	4	4	6	23.8	17.3	0.4
29	6	35	2	2	4	67.0	17.5	2.6	70	6	50	4	6	2	14.1	13.0	0.4
30	6	35	2	2	6	67.4	14.9	1.7	71	6	50	4	6	4	14.1	12.9	0.3

31	6	35	2	4	2	23.4	18.0	0.1	72	6	50	4	6	6	14.1	12.9	0.3
32	6	35	2	4	4	23.6	16.4	0.9	73	6	50	6	2	2	68.6	23.6	1.4
33	6	35	2	4	6	23.7	15.5	0.7	74	6	50	6	2	4	68.7	22.8	1.1
34	6	35	2	6	2	17.6	16.3	0.1	75	6	50	6	2	6	68.7	22.7	1.2
35	6	35	2	6	4	17.6	15.9	0.5	76	6	50	6	4	2	23.5	18.4	0.8
36	6	35	2	6	6	17.7	15.6	0.4	77	6	50	6	4	4	23.6	18.3	0.7
37	6	35	4	2	2	65.9	25.0	0.7	78	6	50	6	4	6	23.6	18.2	0.7
38	6	35	4	2	4	66.2	22.5	1.0	79	6	50	6	6	2	14.1	13.2	0.5
39	6	35	4	2	6	66.2	21.8	0.5	80	6	50	6	6	4	14.1	13.2	0.4
40	6	35	4	4	2	23.3	18.6	0.4	81	6	50	6	6	6	14.1	13.2	0.4
41	6	35	4	4	4	23.3	18.2	0.4									

Table 3. Stress value at point S1, S2 and S3 for the width of the glued joint h = 9 mm.

Lp.	Parametry zmienne					Wynik			Lp.	Parametry zmienne					Wynik		
	h	L3	g3	g1	g2	S1	S2	S3		h	L3	g3	g1	g2	S1	S2	S3
	mm	mm	mm	mm	mm	MPa	MPa	MPa		mm	mm	mm	mm	mm	MPa	MPa	MPa
1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
1	9	20	2	2	2	64.8	21.4	1.2	42	9	35	4	4	6	24.0	14.0	0.7
2	9	20	2	2	4	65.7	12.6	3.5	43	9	35	4	6	2	17.7	15.8	0.2
3	9	20	2	2	6	66.1	8.3	2.8	44	9	35	4	6	4	17.7	15.3	0.5
4	9	20	2	4	2	23.3	17.2	0.2	45	9	35	4	6	6	17.8	15.1	0.4
5	9	20	2	4	4	23.5	14.5	1.7	46	9	35	6	2	2	68.0	16.2	0.4
6	9	20	2	4	6	23.7	12.6	1.7	47	9	35	6	2	4	68.3	14.0	1.1
7	9	20	2	6	2	17.5	16.1	0.1	48	9	35	6	2	6	68.4	13.1	0.7
8	9	20	2	6	4	17.6	15.3	1.0	49	9	35	6	4	2	23.7	16.2	0.4
9	9	20	2	6	6	17.7	14.6	1.1	50	9	35	6	4	4	23.8	15.6	0.3
10	9	20	4	2	2	64.9	19.6	1.2	51	9	35	6	4	6	23.8	15.3	0.2
11	9	20	4	2	4	65.3	14.8	2.5	52	9	35	6	6	2	17.7	15.8	0.3
12	9	20	4	2	6	65.5	12.7	1.7	53	9	35	6	6	4	17.7	15.7	0.2
13	9	20	4	4	2	23.3	17.3	0.2	54	9	35	6	6	6	17.7	15.6	0.1
14	9	20	4	4	4	23.3	16.0	1.1	55	9	50	2	2	2	70.8	18.5	0.9
15	9	20	4	4	6	23.4	15.7	0.8	56	9	50	2	2	4	72.3	11.6	2.2
16	9	20	4	6	2	17.5	16.2	0.1	57	9	50	2	2	6	73.1	8.2	2.2
17	9	20	4	6	4	17.5	15.9	0.6	58	9	50	2	4	2	24.3	15.7	0.9
18	9	20	4	6	6	17.5	15.7	0.5	59	9	50	2	4	4	24.9	12.9	1.0
19	9	20	6	2	2	64.9	19.1	0.6	60	9	50	2	4	6	25.3	10.9	1.3
20	9	20	6	2	4	65.1	16.7	1.4	61	9	50	2	6	2	17.8	15.3	0.7
21	9	20	6	2	6	62.2	15.8	0.8	62	9	50	2	6	4	18.1	14.1	0.6
22	9	20	6	4	2	23.2	17.5	0.2	63	9	50	2	6	6	18.3	13.1	0.9
23	9	20	6	4	4	23.2	16.9	0.5	64	9	50	4	2	2	71.3	15.7	0.6
24	9	20	6	4	6	23.3	16.7	0.4	65	9	50	4	2	4	72.1	12.0	1.6
25	9	20	6	6	2	17.5	16.3	0.1	66	9	50	4	2	6	72.5	10.2	1.4
26	9	20	6	6	4	17.5	16.2	0.3	67	9	50	4	4	2	24.3	15.3	0.7
27	9	20	6	6	6	17.5	16.1	0.2	68	9	50	4	4	4	24.6	13.9	0.6
28	9	35	2	2	2	67.6	19.5	0.1	69	9	50	4	4	6	24.8	13.1	0.6
29	9	35	2	2	4	68.9	11.9	2.7	70	9	50	4	6	2	17.8	15.2	0.5
30	9	35	2	2	6	69.4	8.2	2.4	71	9	50	4	6	4	17.9	14.7	0.3
31	9	35	2	4	2	23.7	16.2	0.5	72	9	50	4	6	6	18.0	14.4	0.4
32	9	35	2	4	4	24.2	13.5	1.3	73	9	50	6	2	2	71.5	14.7	0.8
33	9	35	2	4	6	24.4	11.5	1.5	74	9	50	6	2	4	71.9	12.8	0.7
34	9	35	2	6	2	17.7	15.7	0.4	75	9	50	6	2	6	72.0	11.9	0.6
35	9	35	2	6	4	17.9	14.7	0.8	76	9	50	6	4	2	24.3	15.3	0.7
36	9	35	2	6	6	18.0	13.8	1.0	77	9	50	6	4	4	24.4	14.6	0.2
37	9	35	4	2	2	67.9	17.0	0.2	78	9	50	6	4	6	24.5	14.3	0.1
38	9	35	4	2	4	68.5	12.9	2.0	79	9	50	6	6	2	17.8	15.3	0.5
39	9	35	4	2	6	68.8	10.9	1.6	80	9	50	6	6	4	17.8	15.1	0.1
40	9	35	4	4	2	23.7	16.1	0.3	81	9	50	6	6	6	17.9	15.0	0.1
41	9	35	4	4	4	23.9	14.7	0.8									

3.3 Selection of most important attributes

A set of attributes undergoes (in the form of parameter columns) initial data processing to enable their comparison and further analysis. Due to the type of processed data, standardization was used, in result of which, the variable mean expected value assumes zero and the mean variance is equal to one. The most commonly used standardization method can be expressed as:

$$z = \frac{x - \mu}{\sigma} \tag{1}$$

where: x – value of parameter, μ - mean value of parameter, σ – standard deviation of parameter.

There can be many parameters from one or more measurement but most of them are significantly interfered or independent of the monitored phenomenon. The proposed method involves choosing parameters with the use of rough set theory. This technique provides methods for determination of the most important attributes of a computer system without losing classification ability [12]. The rough set theory was developed by Zdzisław Pawlak [13, 14, 15] and is based on the concept of upper and lower approximation of the set, approximating space and models of sets. Measurement data is presented in the form of a table, whose columns correspond to the attributes and rows corresponds to particular objects or states. Such a record is called an information system [16]. Based on rough set theory is a reduct, which is the main part of the information system. As a result of this, it is possible to distinguish all the distinguishable objects from the original set of attributes, hence, reducts are minimal subsets of attributes maintaining characteristics of the whole set of attributes. Literature studies provides many algorithms for determination of sets of information system reducts. For the needs of our solution, the authors have taken into consideration the methods of: Johnson, global, local [17]. The algorithm of determining the set of reducts is as follows:

Input: Information system $A = (U, A)$

Output: Set $RED_A(A)$ of all reduction A

1. Determine the discrimination matrix $M(A) = (C_{ij})$
2. Reduce M using the extraction laws: d number of non-empty fields of the M
3. Build the family of sets R_0, R_1, \dots, R_d as follows:
4. **begin**
5. $R_0 = 0$
6. for $i = 1$ to d
7. $R_i = S_i \cup T_i$, where $S_i = \{R \in R_{i-1} : R \cap C_i \neq \emptyset\}$ and $T_i = (R \cup \{a\})$
8. **end**
9. Remove any unnecessary elements for each element of the R_d family
10. For each R_d family element, remove the repeating elements
11. **return** $RED_A(A) = R_d$

Significance of the attributes is described on the basis of the determined set of reducts, where the attributes are ordered according to the number of occurrence in the set. An exemplary set of reducts is presented in Table 4. Parameters ordered according to significance are presented in Table 5.

Table 4. The set of reducts for all attributes (S1,S2 and S3).

	Number	REDUCTS (no. of attributes)
1	5	{ h, L3, g3, g1, g2 }
2	5	{ L3, g3, g1, g2, S2 }
3	4	{ h, g3, g2, S1 }
4	4	{ g3, g2, S1, S2 }

Table 5. Parameters ordered according to significance.

Attribute	g3	g2	h	L3	g1
Number	4	4	2	2	2

The set of reducts for S1 is presented in Table 6. Parameters ordered according to significance are presented in Table 7.

Table 6. The set of reducts for S1.

	Number	REDUCTS (no. of attributes)
1	1	{ h }
2	4	{ h, L3, g3, g1 }
3	4	{ h, L3, g1, g2 }
4	5	{ h, L3, g3, g1, g2 }
5	4	{ h, L3, g1 }

Table 7. Parameters ordered according to significance.

Attribute	h	L3	g1	g3	g2
Number	5	4	4	2	2

The set of reducts for S2 is presented in Table 8. Parameters ordered according to significance are presented in Table 9.

Table 8. The set of reducts for S2.

	Number	REDUCTS (no. of attributes)
1	5	{ h, L3, g3, g1, g2 }
2	4	{ h, L3, g3, g1 }

Table 9. Parameters ordered according to significance.

Attribute	h	L3	g3	g1	g2
Number	2	2	2	2	1

The set of reducts for S3 is presented in Table 10. Parameters ordered according to significance are presented in Table 11.

Table 10. The set of reducts for S3.

	Number	REDUCTS (no. of attributes)
1	5	{ h, L3, g3, g1, g2 }
2	4	{ h, L3, g3, g1 }
3	4	{ h, g3, g1, g2 }
4	3	{ h, L3, g1 }
5	4	{ h, L3, g1, g2 }
6	4	{ L3, g3, g1, g2 }

Table 11. Parameters ordered according to significance.

Attribute	g1	h	L3	g3	g2
Number	6	5	5	4	4

Conclusions

Diagnostic possibilities of glued joints are related to the analysis of stress values at points S1, S2 and S3. The analysis of the results of numerical calculations shows that all indicated geometric parameters, i.e. h, L3, g1, g2 and g3 they affect the value of stresses in points S1, S2 and S3. Considering the set of results S1, S2 and S3 as a whole, the most important parameters are: g2 and g3. Analyzing the results of stresses at individual measurement points, it can be indicated that the most significant impact on the value:

- S1 have dimensions:h, L3, g1,
- S2 have dimensions:h, L3, g3, g1, g2,

- S3 have dimensions: g_1 , h , L_3 , g_3 , g_2 .

Further work will be related to the determination of the relationship between individual geometric parameters taking into account the variable material properties of individual sample elements.

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