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THE SELECTED ASPECTS OF THE RESEARCH INTO IMPACT LOADING OF ADHESIVE JOINTS IN BLOCK SAMPLES – COMPARISON OF DIFFERENT WAYS OF APPLYING THE LOAD

Key word

Adhesive joint, impact loading, pendulum hammer.

Abstract

The research described in this article, relates to the survey methodology of block bonded joints, dealing with one of its aspects. The authors have decided to check experimentally what impact on the results of the tests has the manner (direction) of applying the load and whether it is possible to compare the results obtained on two different research devices. Experimental studies have been completed with numerical calculations of the test cases. The research was carried out with impact dropping tools - Gabaldini Impact 25 and with a special machine designed to test adhesive joints. The energy used to tear off the upper part of the specimen, that is the energy lost by the dropping device, is the measure of the strength of impact loading of an adhesive bond. The sample elements were made of steel S235. The samples were examined using two

different machines, however the applied hands allowed conducting an examination on both devices with samples of the same geometry. In order to bond the samples, the authors used Epidian 57 epoxide resin with Z1 hardener.

The results of experimental testing indicate that the impact strength of adhesive joints can be compared only if the research was carried out on the same test machine. Also, the direction of the load applied to the sample has a significant impact on the obtained results, as confirmed in the numerical calculations.

Introduction

In numerous cases, adhesive bonds replace or complement traditional mechanical bonds. While the subject of static endurance of adhesive bonds is quite well-known, the issue of impact loading in adhesive joints has been the subject of little research or theoretical deliberations. This results from insufficient assessment of test results as well as from the lack of strict mathematical dependencies which could enable to analytically determine impact loading of adhesive joints, basing on experimental research.

The investigation of impact loading in adhesive joints was largely conducted by means of original methodologies developed for the needs of their inventors [1, 2]. A major concern with regard to testing impact loading of adhesive joints is the inability to compare the results obtained with different research methods, which in turn results in using the findings exclusively for particular cases they are dedicated for.

However, among the research methods described in the available literature (studies on low speeds), it is possible to distinguish two most commonly used methods: Block Shear Test (BST) [1], Impact Wedge Peel Test (IWPT) [3].

The research described in this article, relates to the survey methodology of block bonded joints, dealing with one of its aspects. The authors checked experimentally what impact on the results of the tests is exercised by the manner (direction) of applying the load and (making use of the remarks [4]), whether it is possible to compare the results obtained on two different research devices. Experimental studies have been completed with numerical calculations of the test cases.

1. Research methodology

The test samples are composed of two parts. The lower element is a rectangle whose size allows to place it in the machine hand in such a way that it will not move during impact loading. The second component is a metal plate, whose width equals the width of the rectangle and is 3–5 mm in height; the third dimension is adjusted to the required surface of the bonding. The test is carried out with the a pendulum hammer, whose impactor, in accordance with the PN-ISO 9653 [5], should hit the upper element of the sample, as shown in Figure 1a. The energy used to tear off the upper part of the specimen, that is the energy lost by the swinging device, is calculated into impact loading of an adhesive bond [6]. Adjustment of the surface area of the joint is made by changing the length of the upper part of the sample, which results in the change of the geometry of the sample. Such an application of the load (Fig. 1a) and a solidly fixed sample grip prevent the impactor from striking a sample element when it is in its lowest position, and its kinetic energy is maximum. In order to resolve this issue, it was proposed that the impactor should hit from the front of the sample (Fig. 1b), which will separate the place of the load application from the length of the joint. This manner of impact loading has been compared in experimental and numerical studies with the normative methodology [5].

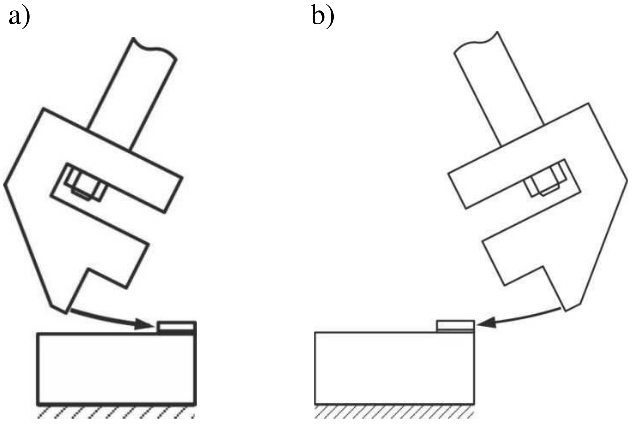

Fig. 1. The scheme of impact strength in the method of the Block Shear Test (BST): a) the method in compliance with the Polish Standard [5], b) a method of applying the load to the front of the sample

For the test results to be reliable, it is important to maintain the conditions described in the standard, which shows that part of the hammer that strikes the sample should be flat, wider than the element in which it strikes, and parallel to it. The lower edge of the hammer should drop on the upper part of the specimen, at the height of 0.80 mm (1/32 in) over the joint [5].

When choosing the material for the implementation of the samples, it is necessary to take into consideration the deformation of elements as a result of applying the load. Application of a stiff material such as steel minimizes this problem.

1.1. Conditions of conducting the research

In order to carry out the experimental studies, we performed a set of rectangular items, which are used to prepare the glued samples. Elements of the samples were made from steel S235. The block sample measurements used in the research have been presented in Fig. 2. On the basis of the results of the research [6], the length of the upper element was determined as 10 mm. The samples were examined using two different machines, however the applied hands allowed conducting the examination on both devices with samples of the same geometry.

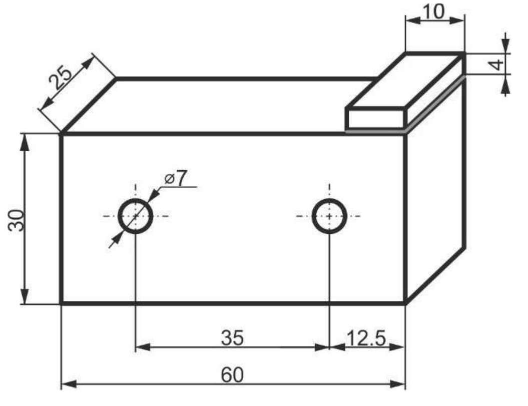

Fig. 2. Measurements of the block sample

The surfaces for gluing were prepared by means of abrasive blasting, and the abrasive agent was copper slag with particles measuring 0.4... 1.4 mm. Each of the samples were subjected to the operation of a stream of particles until a uniform surface has been obtained, and then the ready surface were inspected visually, using the metallographic microscope (magnification x 100) and evaluation using the Mitutoyo Surftest SJ-210 to determine the surface roughness. Due to abrasive blasting, we obtained surface roughness of mean arithmetic deviation of the profile from the mean line $Ra = 4.28$ µm.

After initial cleaning, the sample components were rinsed in mineral spirit in order to remove the remaining impurities and grease. Next, the elements were laid out on mats, and placed in the laboratory dryer chamber so as to allow the evaporation of the gasoline.

In order to bond the samples, the authors used Epidian 57 epoxide resin with Z1 hardener (triethylenetetramine), mixed with 10:1 ratio. The samples were bonded simultaneously in identical conditions, each series amounting to 10 or 5 items. The bonded surfaces were immediately covered with a layer of a bonding mixture and placed in a bonding hand, which was to protect it from dirt or covering by an oxide film. While putting together sample components for bonding, we paid particular attention to the proper placement of both parts of the sample to each other. After applying the bond, the samples were pressed by a device which enabled to achieve the pressure value of P = 40 kPa. The prepared samples were hardened under constant pressure for a period of 7 days at room temperature (21°C).

After hardening of the prepared bond joints, the authors performed general surface treatment by removing bond excess in between the bonded surfaces. The thickness of the joints in all samples was the same and equalled 0.10 mm.

1.2. Test instruments

The testing was conducted by means of the non-normative method (Fig. 1b), using a modified pendulum hammer Gabaldini Impact 25. The modification of the hammer consisted in making a hand for fixing block samples (Fig. 3a) and a dropping tool (Fig. 3b), which enabled to apply proper impact load to the sample.

a) b)

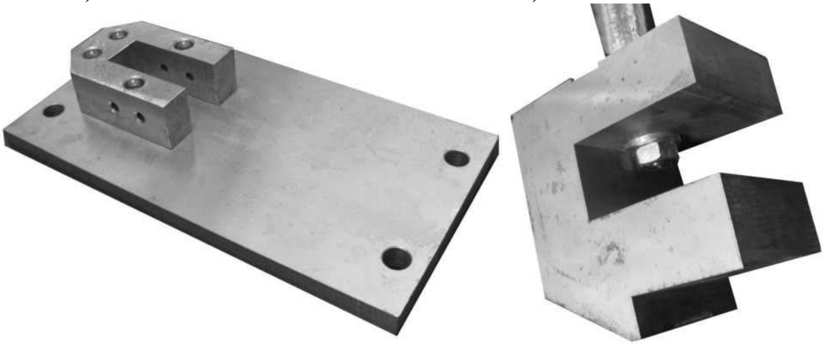

Fig. 3. Modified elements of the dropping impact load device: a) hand for fixing samples, b) dropping tool (impactor)

The applied pendulum allowed obtaining maximum energy of 15 J. In order to carry out the research by means of the normative method, the test device was constructed in which the impactor applies load to the specimen, as shown in Fig. 1a. The device allows conducting the examination in a semi-automatic cycle with a choice of maximum value of energy or speed of the impactor [7]. Due to the need of conducting the research by two methods with the same parameters, the value of the maximum energy is also specified as 15 J. In order to determine the influence of the direction of applying the load on the obtained results, we modified the sample hand, conducting the research according to the diagram shown in Figure 1b.

2. Experimental research

The study aimed at determining the possibility of comparing the results obtained from using a different method of application of the impact load and using different test equipment.

Methodology M1-1

The test is carried out by means of a pendulum hammer, whose impactor hits the upper element of the sample front (Fig. 1b). The energy used to tear off the upper part of the specimen, that is the energy lost by the dropping device, is calculated into impact loading of an adhesive joint [8].

The bonded sample was placed in the hand fixed to the base of the stand (Fig. 4) – a modified dropping device, Galdabini Impact 25. The sample was attached to the stand by means of two bolts.

Fig. 4. Fixing of a sample in the machine hand, Galdabini Impact 25

The fixing proved stable, which was confirmed by a recorded film made by an ultra high-speed video camera (Fig. 5).

The hand fixing the specimen was placed in such a way that the edge of the sample, where the impact load was applied, was in a position, where the hammer is characterized with maximum kinetic energy, i.e. it is in its lowest point.

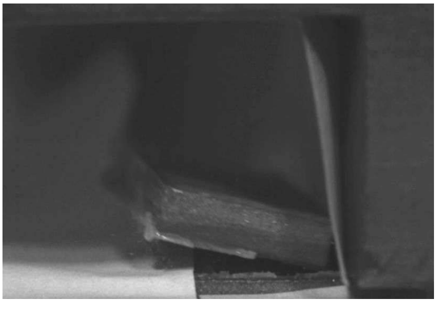

Fig 5. Damage of sample during an impact loading test

The impactor strikes the sample at a distance of 0.8 mm from the lower element of the sample (Fig. 6).

Fig 6. The position of the impactor with regard to the sample at the time of applying the load

Prior to the beginning of the tests for each set, there was specified a measurement error in an attempt of a loose swing of the hammer.

The samples of the first series have been tested, the results of which are shown in Table 1.

Table 1. The results of the impact tests of the first series of the samples

Energy of damage [J]	Average energy of damage [J]	Impact load of the joint [kJ/m^2]	Mean impact load of the joint [kJ/m^2]
0.67	0.80 ±0.13	2.69	3.18 ±0.52
0.91		3.63	
1.07		4.26	
0.68		2.73	
0.61		2.43	
0.55		2.18	
0.65		2.58	
0.96		3.83	
1.01		4.02	
0.86		3.45	

For each set of samples, the authors determined the mean value of impact loading (mean arithmetic value of impact loading of samples) as well as specifying a confidence interval by means of Student's *t* distribution for the confidence level of $1–\alpha = 0.95$.

The test may be considered successful if the sample becomes damaged in the first attempt. The results presented in the table indicate that all the samples have been destroyed.

Methodology M1-2

The test is carried out by means of a special pendulum hammer, whose impactor hits the upper element as in methodology M1-1 (Figure 1b).

The bonded sample was placed in the hand fixed to the base of the stand (Fig. 7). The sample was attached to the stand by means of a locking bolt.

The fixing proved stable, which was confirmed by a recorded film made by an ultra high-speed video camera. The hand was placed in such a way that the edge of the sample was in a position, where the hammer is characterized with maximum kinetic energy, i.e. it is in its lowest point.

The impactor strikes the sample at the same height as in the first method, i.e. 0.8 mm above the surface of the lower element.

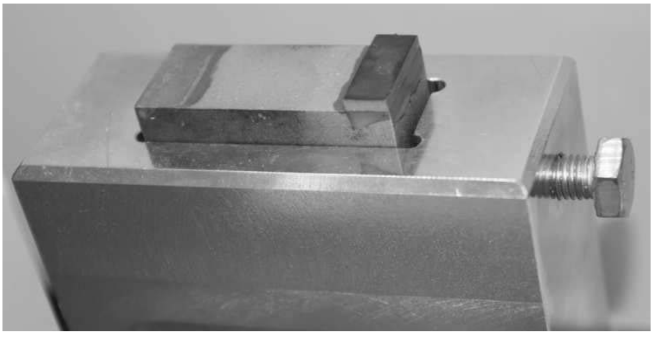

Fig 7. Fixing of sample in the machine hand

The results of the second series of tests have been shown in Table 2.

Table 2. The results of the impact tests of the second part of the testing

Energy of damage [J]	Everage energy of damage [J]	Impact load of the joint [kJ/m^2]	Mean impact load of the joint [kJ/m^2]
4.55	4.19 ±0.97	18.2	16.8 ±3.9
4.15		16.6	
5.36		21.4	
3.08		12.3	
3.83		15.3	

Methodology M2

In the third series we examined the samples in accordance with the methodology where the difference was a different direction of the load than in methodologies M1-1 and M1-2. The tests were carried out on the machine used for the methodology No M1-2 with a modified hand to mount the samples and allowing the load application as in Figure 1a. The test results are shown in Table 3.

Table 3. The results of the impact tests of the third part of the testing

Energy of damage [J]	Average energy of damage [J]	Impact load of the joint [kJ/m^2]	Mean impact load of the joint [kJ/m^2]
1.91	2.13 ±0.80	7.6	8.5 ±3.2
2.32		9.2	
3.25		13.0	
1.69		6.7	
1.51		6.0	

3. Discussion of experimental findings

While analysing the data, one may observe that there is a significant discrepancy among them, which might be caused by improper positioning of two components of the samples in relation to each other, and thus lead to a significant change in impact loading conditions [8], but also by other factors.

Although all the test samples were bonded under the same conditions clear differences of experimental results of each series is visible, depending both on the test device (methods M1-1 and M1-2) and the direction of the impact (methodology M1-2 and M2).

The highest impact strength (16.8±3,9 kJ/m^2) was shown on adhesive joints tested in accordance with the methodology M1-2, in which the loads were applied to the face of the sample. Likewise, applying the load in the tests carried out in accordance with the methodology M1-1 (Galdabini Impact 25 hammer), we obtained significantly lower impact strength (3.18±0.52 kJ/m^2), which confirms a crucial influence of the machine characteristics and the method of fixing the samples on the obtained results of impact loading in adhesive joints of block specimens. Also in the tests carried out in compliance with the methodology M2, we obtained average impact strength, which differed from the results of other tests (8.5±3.2 kJ/m^2). This result proves that the direction of impact loading the specimen should be specified in the examination clearly and it is unacceptable to change the direction during the tests. It seems that in order to compare the results, it is necessary to decide on specifying and using only one configuration of attempts.

The observation of joint cross-sections without magnification enabled to draw an initial request of cohesive nature as most of the damage with small areas of adhesive damage (up to 20% of the surface) (Fig. 8). A more detailed analysis of surface samples using the electron microscope reveals tiny traces of an adhesive also on the surfaces of the assumed adhesive damage. However, the presence in the photographs of areas completely devoid of adhesive confirms the cohesion and adhesive type of damage.

In the elements of the samples we did not observed plastic deformation.

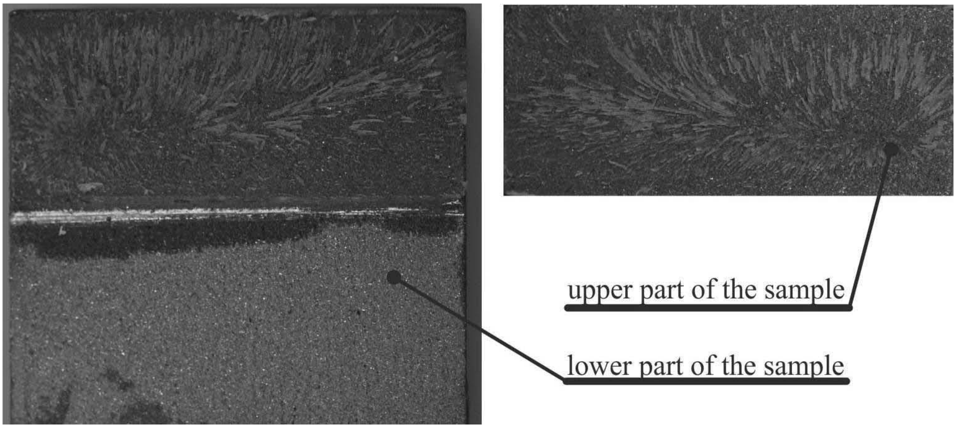

Fig. 8. Surfaces of the bonded sample after the destruction

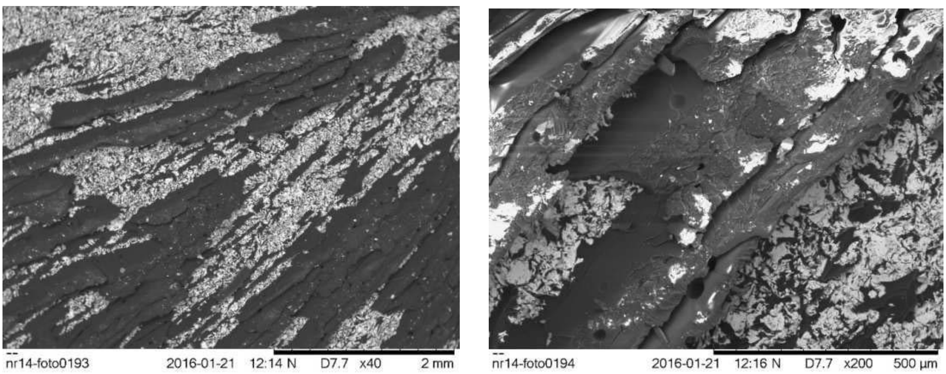

Fig. 9. The cross-section of an adhesive joint with visible, dark areas of the adhesive (electron microscope – a) × 40 magnification, b) larger magnification × 200

4. The analysis of FEM (Finite Element Method) stress in adhesive joints

In order to compare the stress distributions in sample joints impact loaded normatively and non-normatively we carried out calculations using the NASTRAN Windows software. The calculations were conducted linearly.

In accordance with the recommendations [9], the characteristics $\sigma = \sigma(\varepsilon)$ of the Epidian 57 glue hardened at ambient temperature during 7 days, in the compression test of cylindrical samples, we determined the samples cast from the adhesive sized 12.5 mm in diameter, 25 mm in length (Fig. 10). On its basis, we assumed the value of the elastic modulus of the adhesive E = 2,000 MPa.

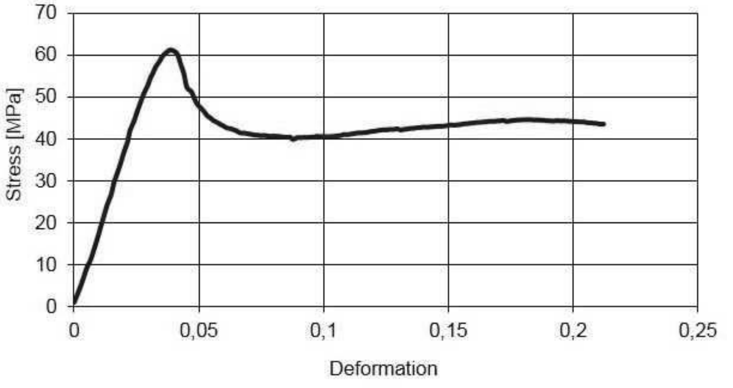

Fig. 10. The curve of compression of Epidian 57 cured at ambient temperature for 7 days

We built a model grid taking into account the real dimensions of the samples, also including the thickness of the joints. In accordance with [9], the adhesive joints were modelled with one layer of rectangular elements.

The ready numerical model was loaded statically with the force of 2,600 N, distributed on the grid nodes at a distance of 0.8 mm from the edge of the adhesive joint, applied alternatively to the sides of the glued plate. The way of applying the load reflected the actual conditions of the experimental research, presented in Figure 1.

We analyzed distributions of maximum main stresses in the joints, assuming that the hypothesis of maximum main stresses accurately describes strain of adhesively bonded joints. The maps of the maximum main stresses in joints of the examined statically loaded joints with equal force are shown in Figures 11–12.

The analysis of the stress distribution in the joint, in which the load was applied to the front (Fig. 11) allows observing that the stresses reach ultimate values at a distance of about 2.5 mm from the loaded joint edge and that they are tensile stresses. The highest value of the maximum major stresses equals approximately 17 MPa, and they are situated at the side edges. While approaching the edge situated opposite the loaded edge, the main stresses are reduced practically to zero values.

In the case of the load applied in a normative way (Fig. 12), the highest stress value occurs on the side of applying the load and equals approximately 27 MPa. Similarly to the first case, these are tensile stresses, whose value decreases along the overlap. The analysis of the perpendicular stress distributions to the joint surface shows that under non-normative load the loaded and opposite edge of the bonded plate are pressed into the lower part of the

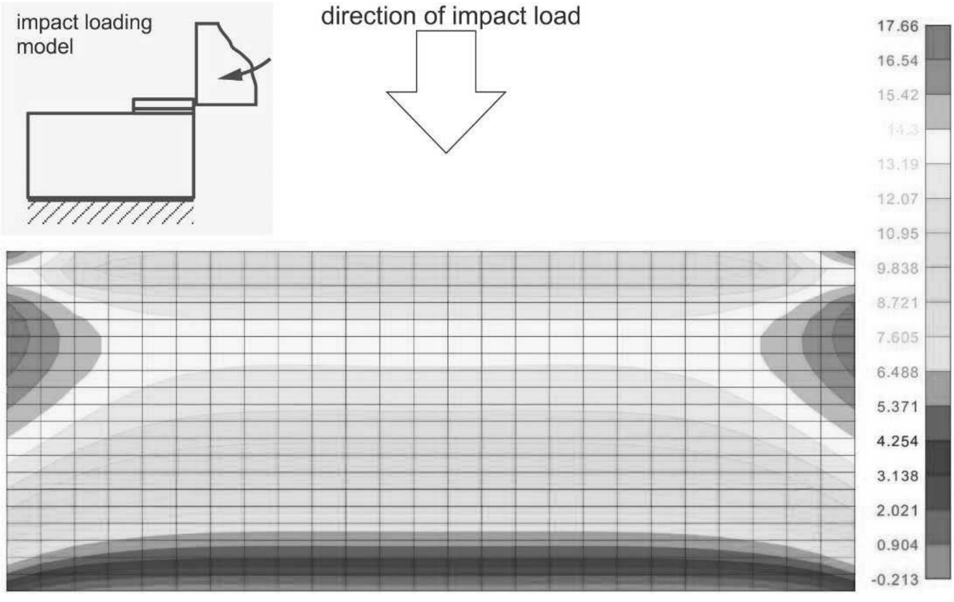

Fig. 11. The distribution of maximum main stresses in the joint loaded according to the methodology M2 at the front

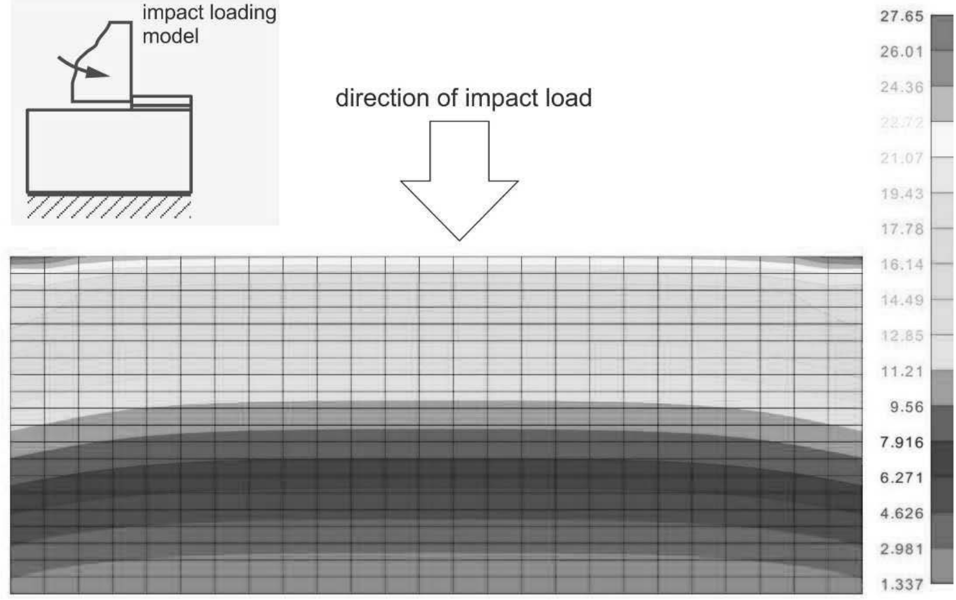

Fig. 12. The distribution of maximum main stresses in the joint normatively loaded (according to the methodology M1-2)

sample (the edge of the opposite side is pressed to a larger extent). Under the normative load, the impact loaded edge is torn off, whereas the opposite one is pressed even further.

Numerical calculations have shown a significant impact of the direction of applying the load on the distributions and stress values in the adhesive joint. Higher stress values under a normative load should result in lower measured impact loading.

5. Conclusions

On the basis of the conducted research, one may formulate the following conclusions:

1. The research findings depend upon the properties of the test machine used in the experiment. In order to obtain reliable comparative data, it is necessary to conduct the bulk of the research on the same test machine, with the same measuring instruments. Therefore, the results of testing the impact strength of the adhesive joints of block samples which were under shear load, at different test machines, cannot be compared.
2. Changing the direction of applying the load to the sample results in significant changes in the values of the obtained results of impact loading. The results of experimental testing have been confirmed in numerical studies, where it is apparent that lower maximum values of main stresses occur in adhesive joints, which are characterized with higher impact loading determined in experimental testing.
3. The results of impact load tests are characterized with a large spread that may be caused by deviations in the geometry of particular samples. In order to determine the impact of such parameters of research methodology on the quality of the obtained results, it is necessary to conduct further research.
4. With the applied energies of the examination, it was not possible to observe plastic deformations of the bonded elements.
5. Making an adhesive joint and conducting research requires an extensive preparation meritorically and with regard to the testing equipment.
6. A small number of the conducted tests does not allow drawing a conclusion as for the relation between the results obtained in studies carried out in accordance with different methodologies.

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Wybrane aspekty badań udarowych połączeń klejowych blokowych – porównanie metod przyłożenia obciążenia

Słowa kluczowe:

Połączenie klejowe, udarność, młot wahadłowy.

Streszczenie

Opisane w artykule badania odnoszą się do metodyki badań udarowych połączeń klejowych blokowych i rozpatrują jeden z jej aspektów. Autorzy postanowili sprawdzić eksperymentalnie, jaki wpływ na wyniki badań ma sposób (kierunek) przyłożenia obciążenia do próbki oraz czy można porównywać wyniki uzyskane na dwóch różnych urządzeniach badawczych. Badania eksperymentalne uzupełniono obliczeniami numerycznymi badanych przypadków. Badania przeprowadzano przy pomocy młotów wahadłowych – Galdabini Impact 25 oraz dedykowanego do badań połączeń klejowych. Energia zużyta do oderwania górnego elementu próbki, czyli energia wytracona przez wahadło, jest miarą wytrzymałości udarowej połączenia klejowego. Elementy próbek zostały wykonane ze stali S235. Próbki badano z wykorzystaniem dwóch różnych maszyn, jednak zastosowane uchwyty pozwoliły prowadzić badania na

obydwu urządzeniach z zastosowaniem próbek o takiej samej geometrii. Do klejenia próbek wykorzystano żywicę epoksydową Epidian 57 z utwardzaczem Z1.

Wyniki badań eksperymentalnych wskazują, że wytrzymałość udarową połączeń klejowych można porównywać, tylko jeżeli badania prowadzono na tej samej maszynie badawczej. Również kierunek przyłożenia obciążenia do próbki wywiera istotny wpływ na uzyskiwane wyniki, co potwierdzono także w obliczeniach numerycznych.