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ESTIMATION OF DEFORMATION ENERGY DURING IMPACT DESTRUCTION OF ADHESIVE JOINT SAMPLES

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ABSTRACT

The analyses described in this article relate to the impact strength investigations of block bonded joints, dealing with one of its aspects. The authors attempted at estimating the actual deformation energy during the destruction of block samples in impact strength tests. The numerical calculations were completed with experimental testing of the examined cases. The experimental studies were conducted by means of the pendulum hammer, used to examine adhesive joints. During such testing, the energy used to tear off the upper part of the sample, that is the energy lost by the dropping device, is the measure of the impact load strength of a bonded connection. The sample elements were made with steel S235. In order to bond the samples, we used Epidian 57 epoxide resin with Z1 hardener. The results of numerical calculations indicate that the elastic energy of deforming the adhesive joint, the elements of the sample and of the impactor constitute merely a tiny part of the energy lost by the pendulum at the time of the destruction of the sample in experimental testing.

Keywords: adhesive joint, impact loading, pendulum hammer, numerical calculations.

INTRODUCTION

In numerous cases, adhesive bonds replace or complement traditional mechanical bonds. While the static investigations of adhesive bonds are quite common, having been conducted for a number of years, the issue of impact strength of adhesive joints seems to be a more difficult and less frequent issue undertaken by researchers (Adams, 1996). The investigation of impact strength in adhesive joints, although standardized, was largely conducted by means of original methodologies developed for the needs of their inventors (Belingardi, 2005).

Among the research methods described in the available literature (studies on low speeds), it is possible to distinguish three most commonly used methods:

- Block Shear Test (BST) (Asgharifar, 2014),
- Impact Wedge Peel Test IWPT) (ISO 11343, 2003),
- the method of impact shear of lap samples loaded in tension (Harris, 1995; Karachalios, 2013; Casas-Rodriguez, 2007; Casas-Rodriguez, 2008).

A major concern with regard to testing impact strength 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. This results from an insufficient assessment of test results as well as from the lack of strict mathematical dependencies which could enable an analytical determination of impact strength of adhesive joints, basing on experimental research.

One of the relevant problems is also the fact that impact strength of the adhesive joint, determined experimentally in the research, utilizing sample blocks, is too high since part of the energy is converted into elastic energy of the system, which is the examined sample and the impactor. The estimation of elastic energy of the adhesive joint itself is shown in article (Adams, 1996), assuming that on the basis of the elastic deformations of the adhesive, calculated by FEM, it is possible to calculate the work performed in connection with these deformations. It is equal to the elastic deformation energy which, assuming no other losses, is the energy lost on the destruction of the sample in the test. The authors calculated the value of deformation energy for the assumed load and then increased the load twenty times. The calculated increase in elastic energy accounted for only 10% of the total energy of the purely elastic case, despite exceeding the yield limit in the greater part of the adhesive joint. In the conclusions (Adams, 1996), it was found that the total absorbed energy is dependent on the elastic deformation of steel elements and is not the value of the energy absorbed by the adhesive, assuming that after the initiation of cracks, further energy is not required to damage the sample. The presented article estimates the elastic energy of the entire system: sample-impactor as well as the energy of joint rupture.

METHODOLOGY OF EXPERIMENTAL RESEARCH

In order to obtain comparative data for the numerical computations, the authors conducted experimental investigations, where a series of block samples of carbon steel S235 [Figure 1] was made. Each series included 10 samples.

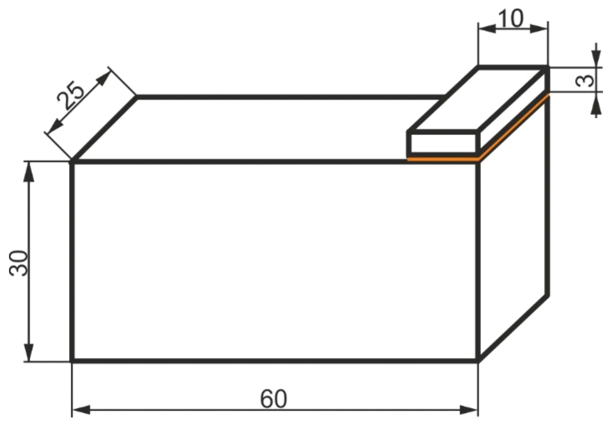

Fig. 1 - Sample used in the impact load test

In order to bond the samples, the authors used Epidian 57 epoxide resin with Z1 hardener, with mix ratio 10:1.

Prior to bonding, the metal parts were cleaned up; their surface was given proper structure and roughness through abrasive blasting, with copper slag as an abrasive medium. Next the surfaces of the samples were washed with petroleum ether. The prepared elements were bonded as soon as possible to avoid accidental soiling of the bonded surfaces or falling of dust, oxides or moisture. While fixing the items for bonding, particular attention was paid to proper positioning of the elements against each other, since even slight irregularities in the geometry of the samples lead to significant changes in the obtained findings (Komorek, 2017). The bonded samples were placed on a base plate and clamped down at a pressure of 40 kPa for the time of curing, which equalled 7 days at ambient temperature (21°C).

After curing the joints, the authors made an assessment of the quality of the obtained connections and removed the glue excess, which may result in increased joint strength (in practice they are not removed if this is not necessary).

The investigation was conducted on a special machine designed for testing block adhesive joints. The maximum energy of the pendulum used in the investigation equalled 15 J, whereas the speed in the lowest position was equal to 2.96 m/s. The investigation was conducted by applying impact load in accordance with the scheme shown in Figure 2.

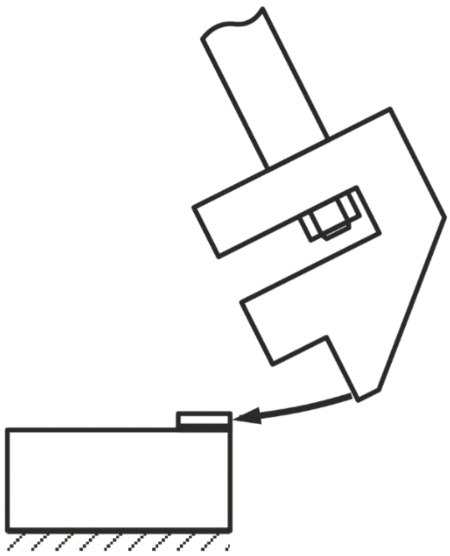

Fig. 2 - Scheme of applying load to the sample (Komorek, 2016)

During the investigation, the authors paid particular attention to maintaining a constant distance between the impactor and the adhesive joint, due to a significant impact of this parameter upon the obtained results (Komorek, 2017). In the tests the authors obtained average impact strength equal to 16.80±3.90 kJ/m^2. It should also be noted that despite the fact that the samples were made with low yield strength steel (S235), they did not show any visible plastic deformation.

NUMERICAL CALCULATIONS

The numerical calculations were conducted in order to estimate the deformation energy while examining the impact strength of block samples. The calculations were carried out in the programme Ansys, using the Static Structural and Explicit Dynamics modules. The authors built simple numerical models of the sample, which were divided into 8-node hexahedral finite elements, dedicated for dynamic computations (impact strength). In the modelling, the contact connection bonded-type - Solid to Solid was used. The adhesive was modelled as an elastic material with Young's modulus of E = 2 GPa or elasto plastic (bilinear) one with Young's modulus of 2 GPa, yield limit of 42 MPa and strengthening modulus of 965 MPa. In the Ansys software, the calculation of deformation energy was possible only in static computations. The authors modelled a sample block (Figure 1), 1 mm wide (Figure 3), by making a simplifying assumption that stresses along the sample width are constant.

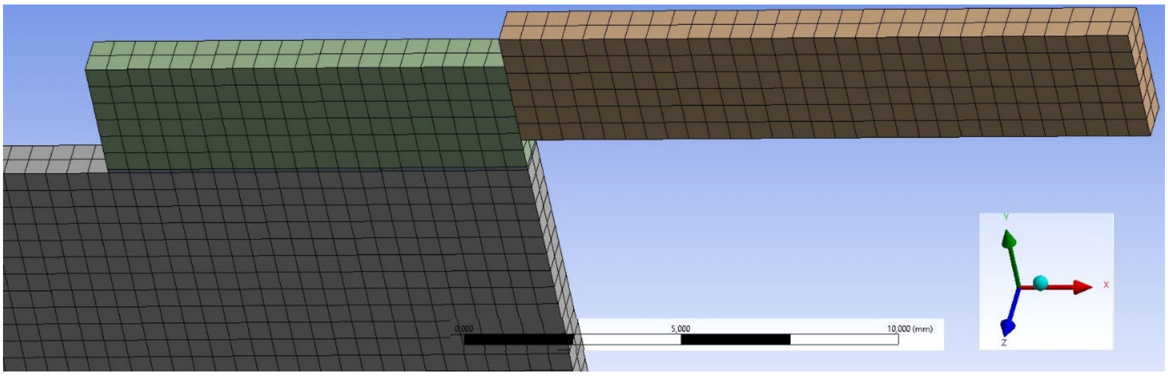

Fig. 3 - Model of a block sample used in the calculation of deformation energy

The model, which is a slice of the actual sample, was impact loaded with a force corresponding to 5,000 N of the real sample. Figure 4 shows the results of calculating of the distribution of deformation energy in the model of the adhesive joint.

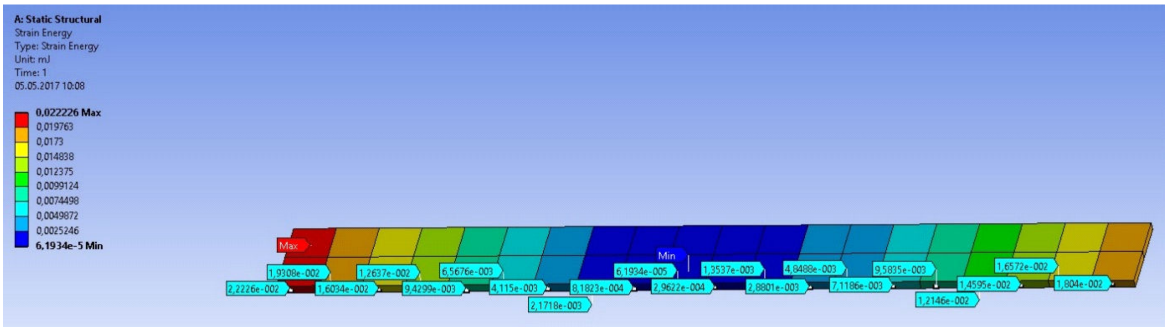

Fig. 4 - Map of deformation energy in the joint of a block sample under a load of 5,000 N

When adding up the deformation energies in particular joint elements and taking into consideration the actual dimensions, it was possible to estimate the total energy of the joint deformation as 10.13 mJ. Similarly, the authors estimated the energy of the cap as 5.06 mJ, of the impactor as 22 mJ and of the bottom element of the sample as 19.2 mJ. The deformation energy of the joint constituted approximately 18% of the deformation energy of the analyzed elements. For the adopted load, the value of maximum principal stresses in the joint was 62.5 MPa (Figure 5), which was considered too small a value to damage the joint made with the adhesive Epidian 57/Z1.

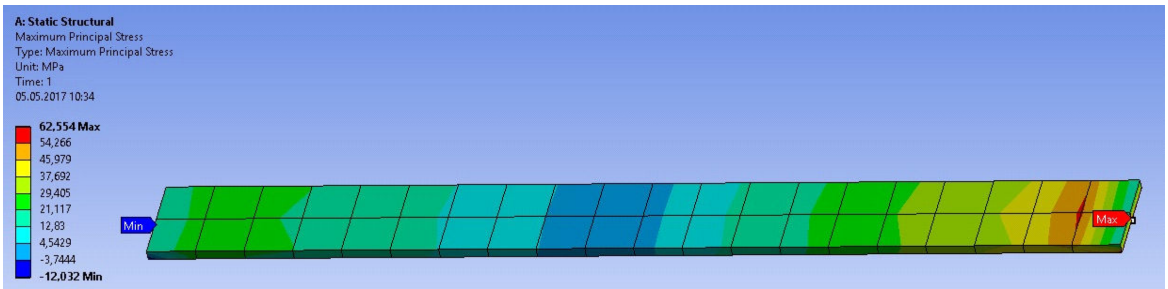

Fig. 5 - Stress distribution of maximum principal stresses in the joint of a block sample under a load 5,000 N

In order to estimate the load values, which should lead to exceeding the destructive stresses which damage the adhesive (approximately 81.5 MPa), a dynamic calculation was made. The authors built a model with the dimensions of the actual sample block, tested experimentally. The impactor was modelled as a rectangular prism consisting of two parts - one piece sized 6x25x3 mm, where the piece striking directly into the cap had the modulus of elasticity of steel (200 GPa), whereas the other one was higher by one order of magnitude (2,000 GPa), so as to reflect stiffness of the real impactor.

In the experimental studies, the authors determined the impact strength of block samples bonded with Epidian 57/Z1 adhesive, equal to 16.8 kJ/m^2, which after considering the joint dimensions of 10x25 mm, proves that the energy of destruction was 4.2 J. The authors also performed dynamic calculations by loading a sample with such energy (while maintaining the load speed of 2,960 m/s and appropriately adjusting the impactor's mass by dedicating appropriate density). For the computational time, at which the maximum principal stresses in the adhesive joint reached the value close to the strength of the adhesive (81.5 MPa), the authors determined the distribution of the normal stresses occurring on the loaded surface of the cap (Figure 6). This allowed calculating the force acting on the cap F = 9,581 N.

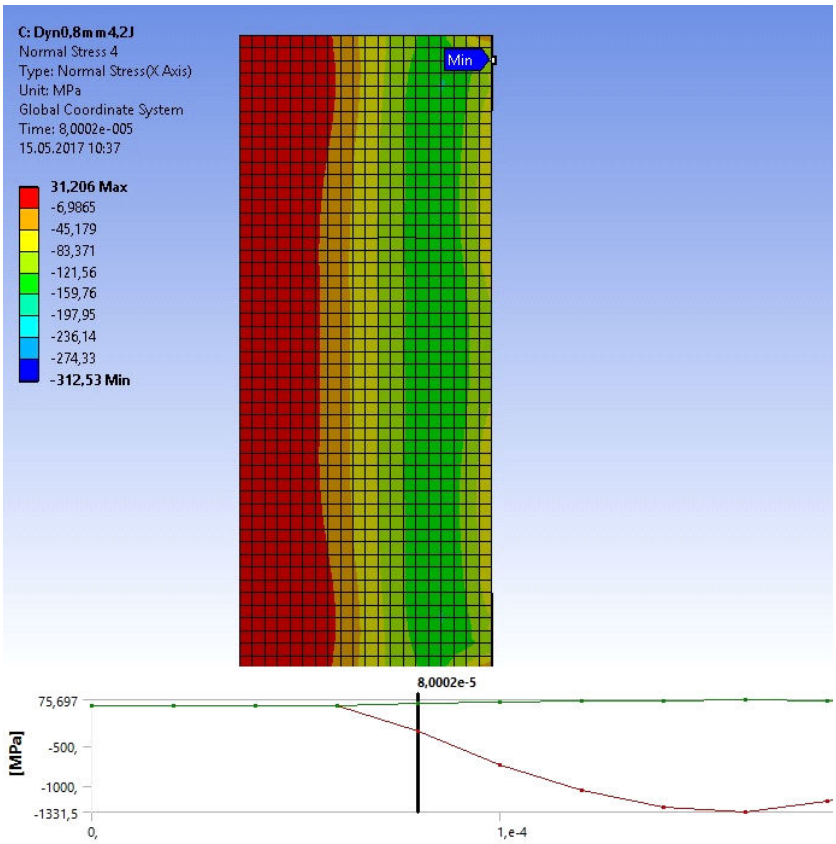

Fig. 6 - Distribution of normal stress in the impact loaded surface of the cap

For such an impact loading force, in the static calculations it was possible to determine the deformation energy of the adhesive with linear-elastic modelling: 33.7 mJ (Figure 7), the cap: 17.8 mJ (Figure 8), the impactor: 59 mJ (Figure 9) and the bottom element: 60 mJ (Figure 10) and also for the model of bilinear adhesive, respectively: 57.4 mJ, 17.5 mJ, 60.2 mJ and 54.6 mJ.

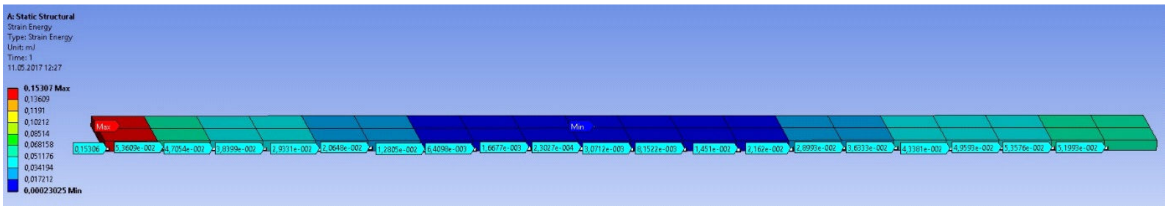

Fig. 7 - Map of deformation energy of the adhesive joint under the load of 9,581 N

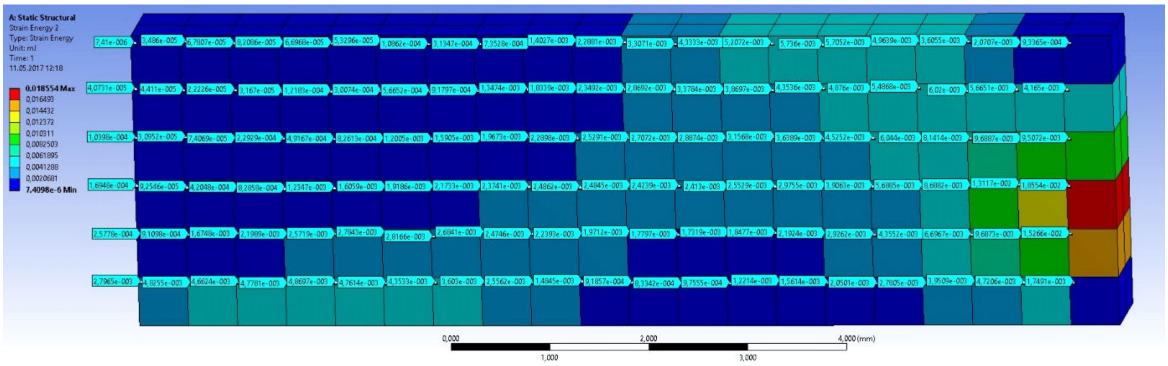

Fig. 8 - Map of deformation energy of the cap under the load of 9,581 N

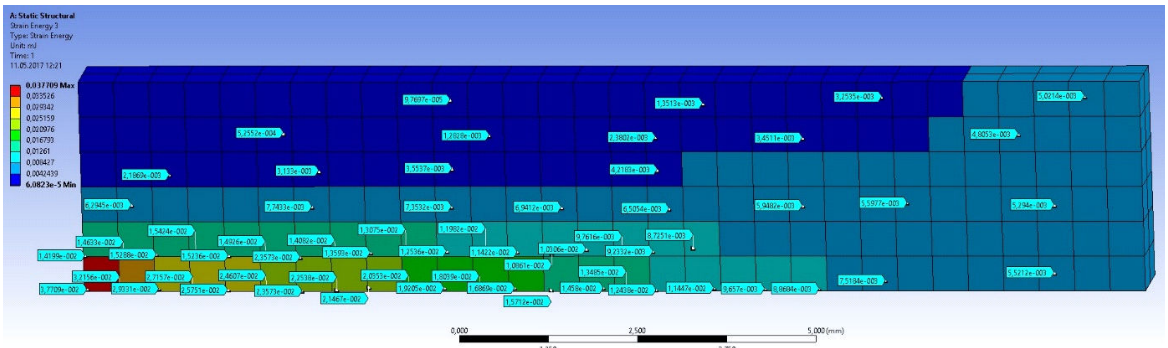

Fig. 9 - Map of deformation energy of the impactor under the load of 9,581 N

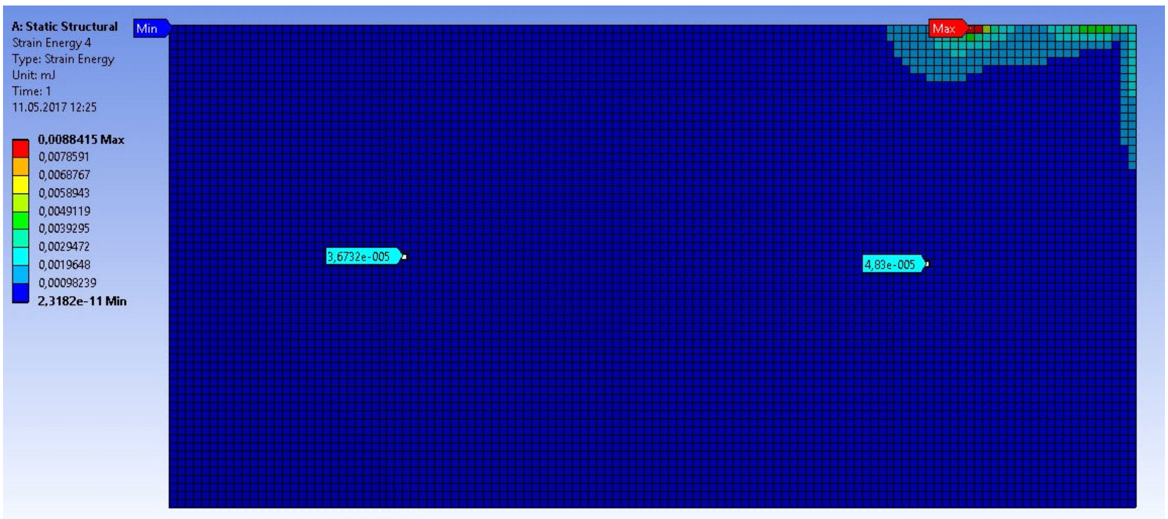

Fig. 10 - Map of deformation energy of the base under the load of 9,581 N

The total energy of deformation of the analyzed components of the test system equalled approximately 170 mJ for the linear model of the adhesive, which constitutes around 4%, and for the non-linear model, approximately 190 mJ, which constitutes approximately 4.5%.

If we assume that the speed of the torn cap is equal to the speed of the impactor at the moment of impact, then while estimating the overall mass together with the adhesive for 0.006 kg, the kinetic energy of the torn off piece does not exceed:

$$E = \frac{0{,}006 \times 2{,}96^2}{2} \cong 0{,}026J$$

The value of the critical rate of releasing the deformation energy of the Epidian 57/Z1 glue (toughness) experimentally in an attempt of tearing a tape with low elasticity off the rotating drum equals approximately $G_c = 2{,}50\ J/m^2$ (Figure 11).

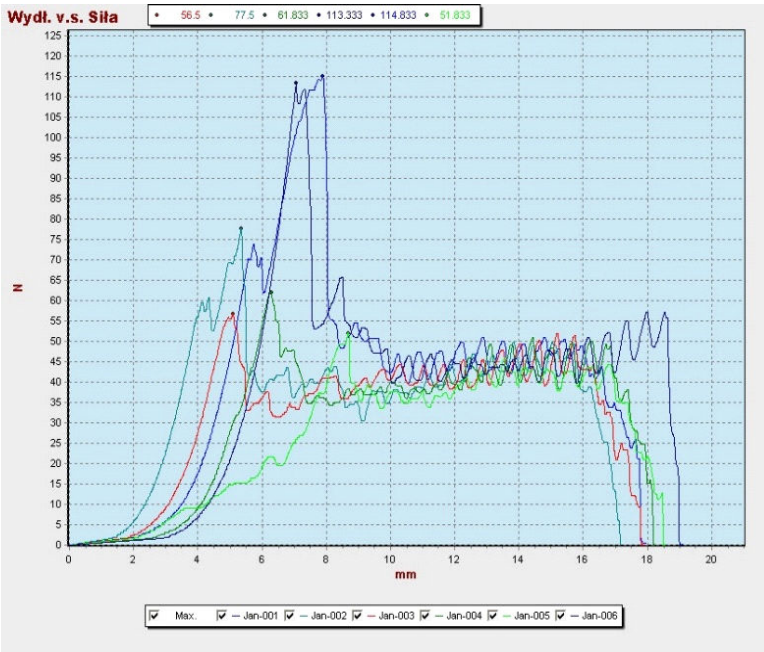

Fig. 11 - The results of the tests of tearing a low stiffness tape, 20 mm wide, off the rotating drum (Epidian 57/Z1 adhesive)

Therefore, the energy of destruction of the joint, sized 10x25 mm, has a value of:

$$E \cong 2250 \times 0{,}01 \times 0{,}025 = 0{,}5625J$$

The sum of the calculated deformation energy of the sample elements and the impactor, the kinetic energy of the torn cap and the destruction energy, in total equals:

$$E_c \cong 0{,}195 + 0{,}026 + 0{,}5625 = 0{,}7835J$$

which constitutes merely approximately 18.7%, recorded in the experimental studies.

CONCLUSIONS

- The results of the numerical analyses related to the experimental results indicate that only a small portion of the recorded energy of the destruction of block samples is related to their deformation energy.

- In order to estimate the actual energy of destroying the adhesive joint, it is necessary to conduct further calculations which take into account the elastic deformation energy of the remaining elements of the pendulum and the test device.
- In the course of conducting the research into adhesive bonds, where the bonded elements were made of steel, the authors did not observe any plastic deformations of the impacted element. If such damage occurs, it is essential to include it in the calculations.

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