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Andrzej KOMOREK *, Konrad OLESIEJUK, Paweł PRZYBYŁEK, Robert SZCZEPANIAK
Department of Aviation, Polish Air Force University, Dęblin, Poland
* Corresponding author: a.komorek@law.mil.pl

DEVICES FOR THE SAMPLES PREPARATION FOR DETERMINATION OF IMPACT STRENGTH OF ADHESIVE JOINTS TESTED TO CLEAVAGE

Key words: impact strength, adhesive joint, preparation device.

Abstract: The impact strength tests of adhesive joints loaded for cleavage using a wedge-shaped impactor are generally described in the Polish Standard PN-EN ISO 11343. In order to conduct the tests, it is necessary to prepare bonded samples consisting of two specially formed elements. To form sample elements, it is necessary to take advantage of a special device, which is not adequately described in the standard. In view of the fact that the test method is quite common, some information, however general, with regard to the moulding device is available in the literature. Therefore, the authors have developed a device which was later validated in research with sample elements made from steel and an aluminium alloy. After the formation of adherends, it is necessary to connect them by means of a glued joint; however, it also requires a special handle due to an unusual shape of the samples. The handle is to stabilize samples and generate an appropriate clam required in the process of bonding at the time of making the connection. Both newly designed devices were made as prototypes so as to be able to check the correct operation of the designed constructions. Various tests were made in which the sample elements were moulded until obtaining a proper shape. During the test, particular elements of the device were adjusted so that the shape of the obtained samples would be in compliance with the parameters specified in the standard. On completion of the adjustments, it was possible to obtain specific repeatable elements. The obtained samples were inspected visually, and, on this basis, modifications were made. Then successive series of samples were prepared. Finally, the samples were subjected to a quality assessment. The results of the work are presented in the paper.

Przyrządy do przygotowania próbek do badania udarności połączeń klejowych na rozczepienie

Słowa kluczowe: udarność, połączenie klejowe, przyrząd do przygotowania próbek.

Streszczenie: W artykule zaprezentowano metodykę badań wytrzymałości udarowej połączeń klejowych na rozczepienie z wykorzystaniem impaktora w kształcie klina. Jest to metodyka opisana ogólnie w Polskiej Normie PN-EN ISO 11343, według której prowadzi się badania udarności połączeń klejowych. W celu przeprowadzenia badań wymagane jest przygotowanie próbek klejonych, składających się z dwóch odpowiednio uformowanych elementów. Do formowania elementów próbek niezbędny jest specjalny przyrząd, o którym nie można uzyskać żadnych informacji na podstawie Normy. Ze względu na to, iż metoda badania jest rozpowszechniona w świecie, pewne informacje dotyczące przyrządu formującego dostępne są w literaturze, jednak są to informacje ogólne. Dlatego samodzielnie opracowano tego typu przyrząd i przeprowadzono badania walidacyjne z elementami próbek wykonanymi ze stali i stopu aluminium. Po uformowaniu elementów próbek należy je połączyć za pomocą spoiny klejowej, do czego również jest wymagany specjalizowany uchwyt ze względu na nietypowy kształt próbek. Zadaniem uchwytu jest stabilizacja złożonych próbek oraz wytworzenie odpowiedniego docisku wymaganego w procesie klejenia w czasie wiązania kleju. Obydwa zaprojektowane urządzenia wykonano w formie prototypowej w celu sprawdzenia poprawności działania zaprojektowanych konstrukcji. Przeprowadzono próby kształtowania elementów próbek do wymaganej formy, podczas których poddawano regulacji poszczególne elementy przyrządu, tak aby kształt otrzymanych próbek był zgodny z parametrami określonymi w Normie. Po przeprowadzonych regulacjach możliwe jest uzyskiwania właściwych, powtarzalnych elementów. Powierzchnie klejone uformowanych elementów próbek przygotowano przez obróbkę strumieniowo-ścierną z odtłuszczaniem, a następnie naniesiono klej, złożono i zamocowano w uchwycie do klejenia w celu weryfikacji jego przydatności. Otrzymane próbki poddano oględzinom wzrokowym i na tej podstawie wprowadzono modyfikacje, a następnie wykonywano kolejne serie próbek oraz przeprowadzono ocenę ich jakości. W efekcie powstały dwa specjalizowane, pomocnicze przyrządy do przygotowania próbek do badań udarności. Wyniki badań zaprezentowano w artykule.

Introduction

The impact strength of adhesive joints has been studied since 1980s, when it was observed that more frequently used adhesive connections may be exposed to impact loads. The problem is related to various types of means of transport in which adhesive joints replaced other types of connections. Currently, the transport industry uses a large number of adhesive connections [1] in which a significant percentage are construction joints. A continuously increasing use of adhesive joints led to various research projects aimed at determining the strength and durability in various operating conditions. Impact strength is one of such properties. Additionally, it is a feature that may be vitally important for the safety of structures. If it refers to means of transport, it can also contribute to human safety. Therefore, it is worthwhile and necessary to conduct impact strength research of adhesive joints [2].

Currently, there are numerous methods for the assessment of adhesive joints impact strength [1, 3, 4] and two of which are standard methods. The first one is a method in which a special block sample is subjected to impact load as a result of which an adhesive joint is destroyed by shear [5]. This method was discussed in several relevant studies indicating its defects as well as discussing research issues [6]. The other method uses a specially bonded adhesive sample consisting of two components. In the course of a trial, it is split by means of the impact wedge. In order to carry out impact testing, it is necessary to prepare samples. However, this can be achieved by possessing appropriate auxiliary tools, which are not described in the standard or any other scientific articles. The article refers to papers associated with the construction as well as research into auxiliary equipment for sample preparation, which are necessary to study the impact strength of adhesive joints in the aspect of cleavage.

1. Project assumptions

The main objective of the project was to create easy-to-use, long lasting, and effectively operating devices that facilitate the proper moulding of steel and duralumin samples and also the stabilization of the samples during adhesive curing which should ensure the repeatability of the characteristics of the manufactured samples. It was assumed that the final outcome of the on-going work was to devise two support tools for sample preparation: a tool for moulding metal sample elements and a tool for samples bonding.

It was assumed that the device for the preparation of sample elements should ensure the formation of one sample element in a single cycle; whereas, the device for bonding should allow gluing at least five samples simultaneously.

The moulding device is to transfer the moment resulting from tightening the screws onto the elements which are directly in contact with sample elements to ensure their proper bending. It was necessary to take into consideration the place of bending, its angle, and resilient properties, which vary in the case of steel and duralumin samples. For this reason, it is impossible to build one universal device for all types of materials used for the creation of samples. When bending, there are plastic and elastic strains, which disappear on completion of the bending process. The effect is secondary deformation, i.e. changes in the dimensions of the bonded element in relation to the dimensions imposed by the template at the time of bending. The value of the deformation depends upon the material type and its thickness, the angle of bending, and thermal treatment. Its value is usually determined experimentally. In order to facilitate conducting such an experiment, the project had to take into account the possibility of any changes in the angle value under which the material is bended, depending on the needs and the required corrections. Other parameters, such as particular dimensions (Fig. 1), which determine the usefulness of samples for testing, are specified in the Polish Standard PN-EN ISO 11343 [7].

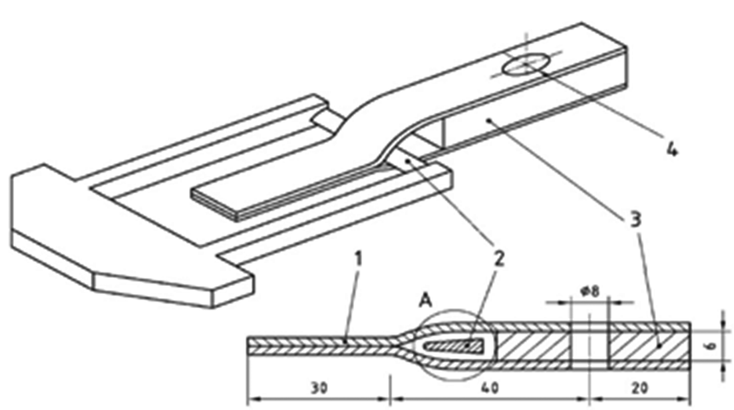

Fig. 1. Dimensions of a glued sample used in the examination of impact strength. 1. Sample, 2. Wedge, 3. Spacer, 4 Screw hole

The projects of the devices were prepared in SOLIDWORKS software.

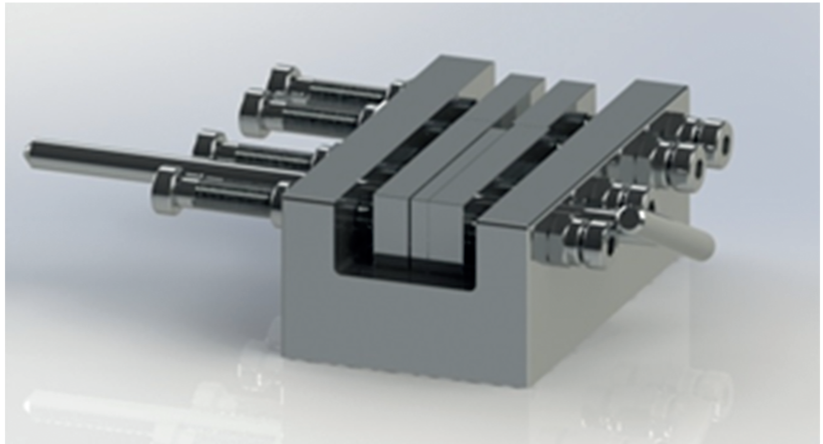

Fig. 2. Device for forming sample elements

The moulding device (Fig. 2), in accordance with the project, consists of the following components:

A steel frame of the device (Fig. 3) with eight holes, drilled through, with a grooved thread M8 x 1.25 mm, distributed axially against opposite holes, four on each side, separated into two holes per clamping element (cover plate). In each hole, a cylindrical-head screw with a hexagon socket M8 x 35 mm and a nut was screwed on. In the frame, two through holes, 8 mm in diameter, were made, on both sides, axially in relation to each other, intended to introduce the locking pin.

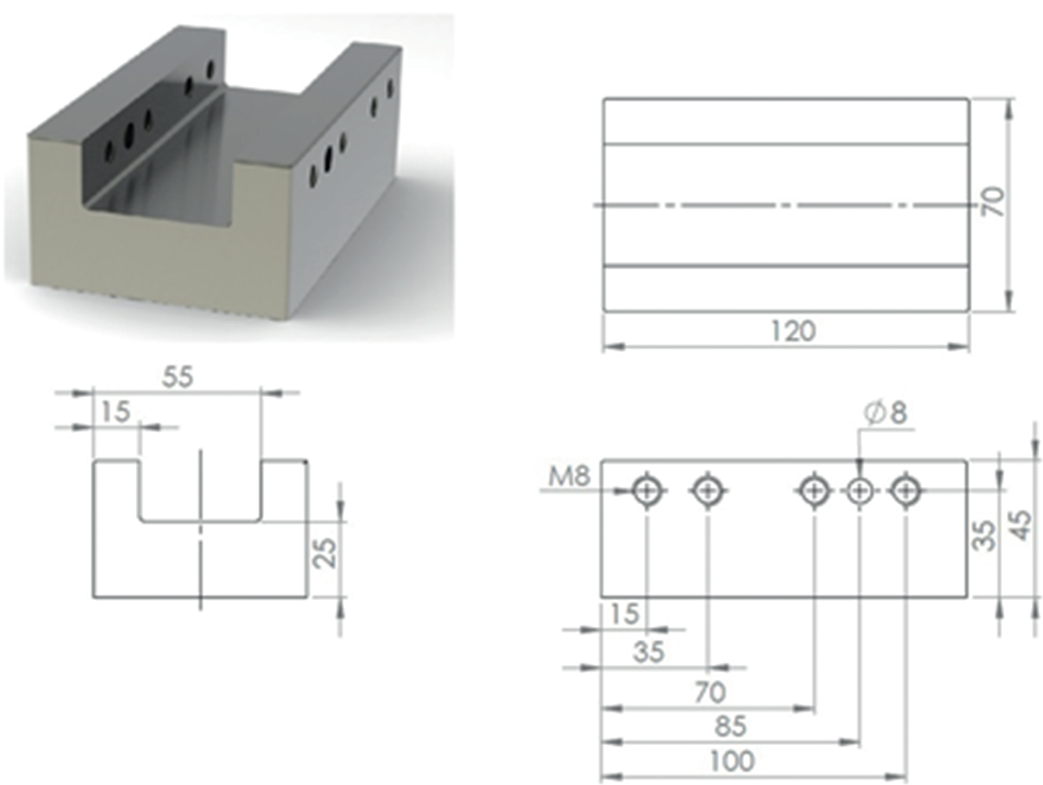

Fig. 3. The frame of device

- Locking pin made of a steel rod, 8 mm in diameter and 180 mm long, with a welded crossbar, 60 mm in length, is used to facilitate its introduction and removal.

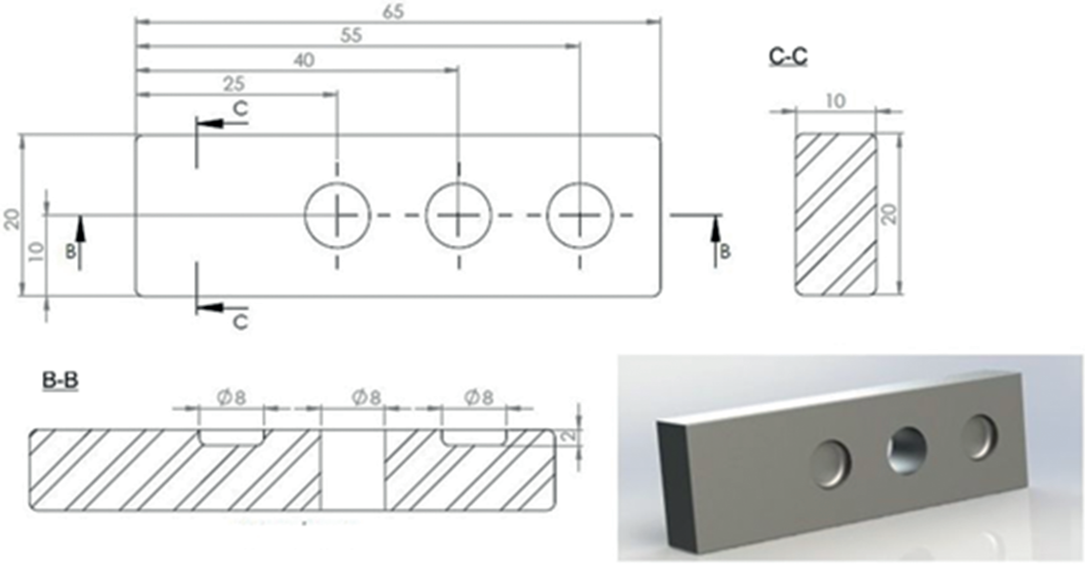

Fig. 4. Long cover plate

- Pressing the working elements (cover plates) distributed in pairs, in a parallel manner: two longer ones (Fig. 4) sized 65 x 20 x 10 mm, with two holes, 8 mm in diameter and 2 mm deep, intended to introduce the endings of the clamping screws in order to stabilize the cover plates at the time of its tightening, along with an extra through hole, 8 mm in diameter, intended for the introduction of the locking pin. Two shorter ones (Fig. 5), sized 37 x 20 x 10 mm, each with two holes, 8 mm in diameter and 2 mm deep, serving a similar purpose as in the case of long cover plates.

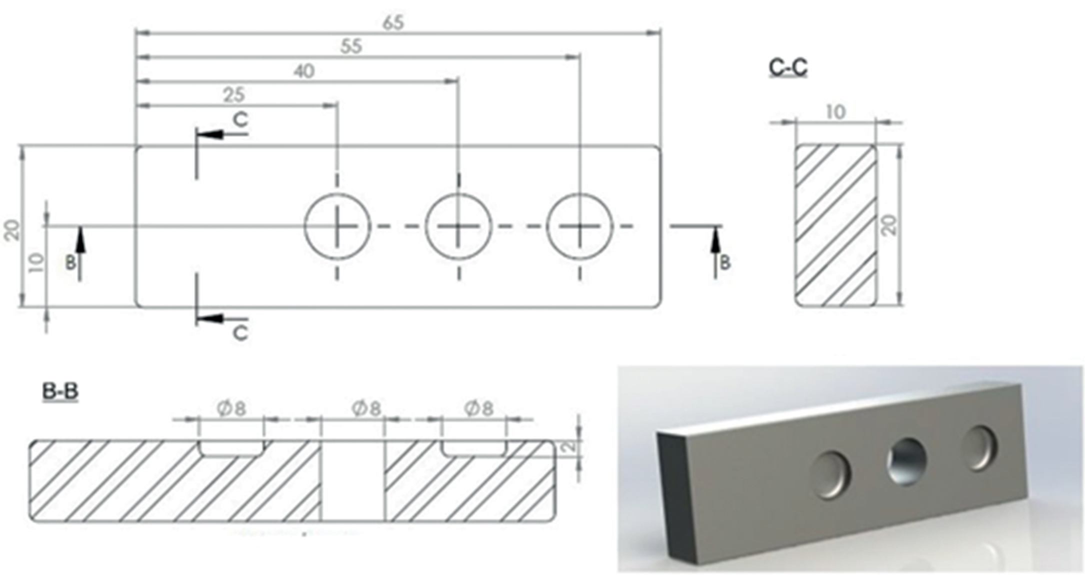

Fig. 5. Short steel cover plate

- A steel spacer sized 60 x 20 x 3 mm with a drilled through hole, 8 mm in diameter, is used to enter the locking pin and to determine the distance between the cover plates in order to obtain a desired angle of bending of the sample elements.

The bonding process will be conducted properly provided the bonded surfaces are in contact and remain stationary against one another during gluing. This is important to provide an appropriate joint and a sample shape. The second device (Fig. 6) is intended to stabilize and clamp the bonded samples during gluing at an appropriate force.

Fig. 6. Device for stabilizing glued samples

The device is composed of the following:

- A base (Fig. 7) made up of a steel flat, sized 200 x 60 x 8 mm: Inside the base, there are two M8 screws welded, 70 mm long, placed symmetrically along the long axis of the base, at a distance of 45 mm away from the edge. The screws have M8 wing-nuts put on. The screws are intended for the longitudinal stabilization of sample elements and also for blocking the crossbar, when clamping the samples. In the base, four steel rods, 6 mm in diameter, were also fixed symmetrically in pairs at a distance of 75 mm from the shorter edge of the base and 17 mm from the longer edge, intended for cross stabilization of sample elements.

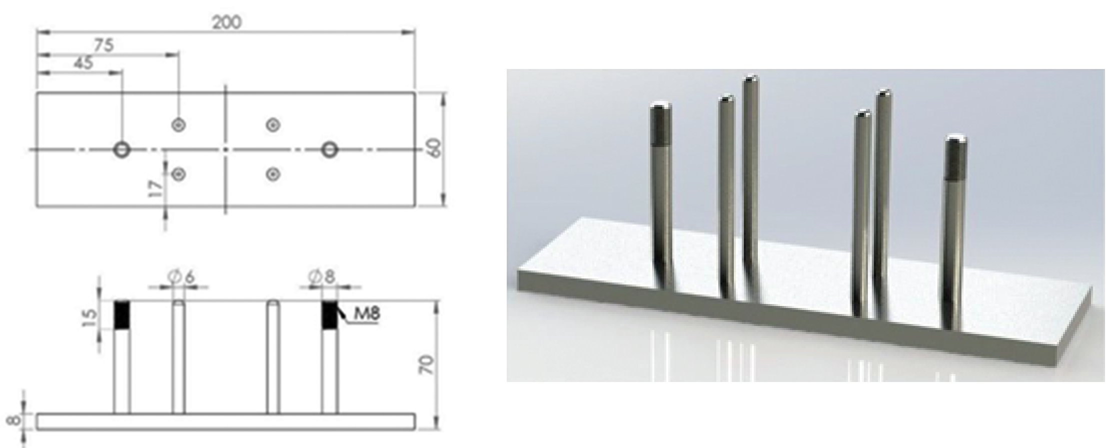

Fig. 7. Device base with screws and guides

- Steel spacers sized 27 x 20 x 4 mm placed between individual samples on the bonded section are used in order to provide an appropriate distance.

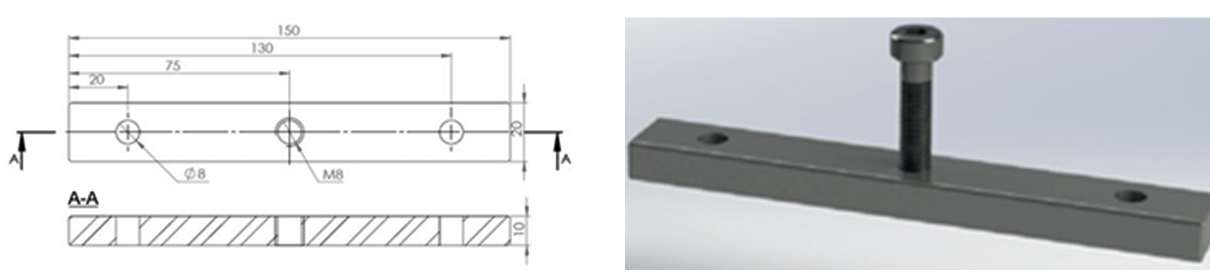

Fig. 8. Crossbar of the device with a clamping screw

- A steel crossbar (Fig. 8), sized 150 x 29 x 19 mm with two holes which are 8 mm in diameter, distributed symmetrically along the longitudinal axis, at a distance of 20 mm from the shorter edge, is intended to fix the cross bar on screws, and also with one grooved whole with M8 thread, which is to be found in the intersection point in the symmetry axis. In the hole, a cylindrical-head screw and a hexagon socket M8 x 35 mm was turned in, intended to exert pressure on the glued sample section.

2. Making devices

Based on the assumptions, taking into account the adopted principle of operation of the devices, prototype devices were made. Its main task was to confirm the correct design of the project.

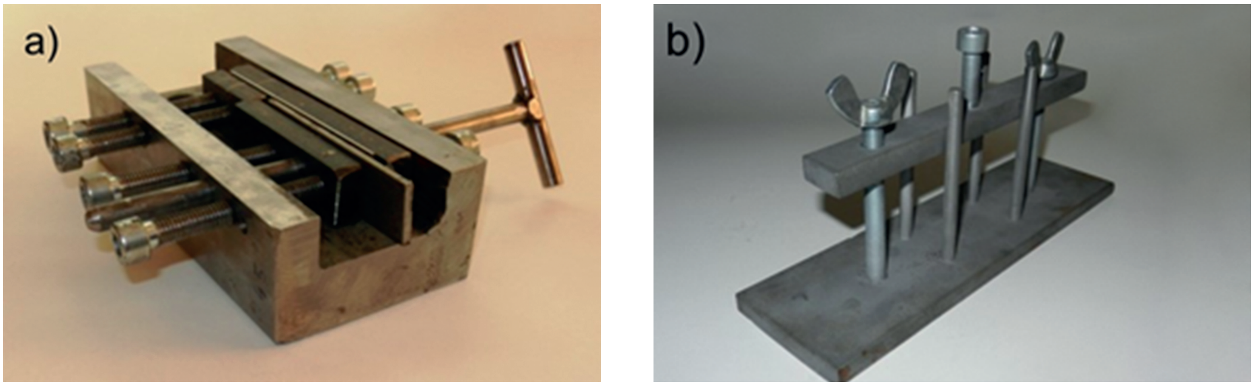

Fig. 9. Prototype devices: a) to form sample elements, b) for stabilizing glued samples

The frame of the prototype device (Fig. 9a) was made from two steel elements which were connected by welding. Next, the frame had all the designed holes drilled and grooved. Finally, the frame was subjected to grinding. The cover plates were made from S355 flat steel.

The second device (Fig. 9b) was made by fixing two rods, grooved with the M8 thread, and four steel bars, 6 mm in diameter, in previously drilled holes in the base of the flat steel.

3. Validation and usage of equipment

After making the prototype devices, the sample elements were moulded. Before fixing them in the device, first it was necessary to drill holes in them, 8 mm in diameter, in the element axis, 20 mm away from the shorter edge. The holes were used to introduce the locking pin, stabilizing the position of the sample elements in the frame. The sample elements, prepared in such a way, were individually fixed in the device. In order to facilitate the position of the cover plates, the distance between their external edge and the side frame edge were assumed as a reference point. In addition, one constant was assumed for the reference point, which was one edge of the longer cover plate in the zero position. Thus, it was constantly in contact with the side edge of the frame. The other cover plate edge and the other cover plate were subject to adjustment. The parallel cover plates were treated as the clamping element.

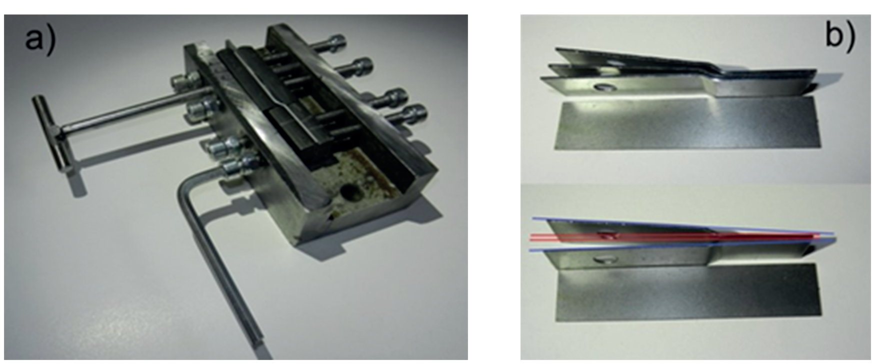

Fig. 10. Moulding sample elements (a), and improperly formed steel elements (b)

At first, steel components made from S235 steel, (Fig. 10a), were formed. The first attempts to set all the cover plates in a parallel configuration resulted in sample elements with a bending whose angle was too obtuse and whose bending angles had too gentle radii (Fig. 10b). The red lines indicate the parallel surfaces of shorter bends of the formed elements, whereas the blue lines represent an improper angle of longer bends.

It was necessary to regulate the cover plates as well as adjusting the pressing force so as to obtain correct bending angles. Therefore, at specified points (I, II, III, IV), the distance between the stones and the edge of the device frame were changed (Fig. 11).

Successive adjustment attempts are presented in Tab. 1.

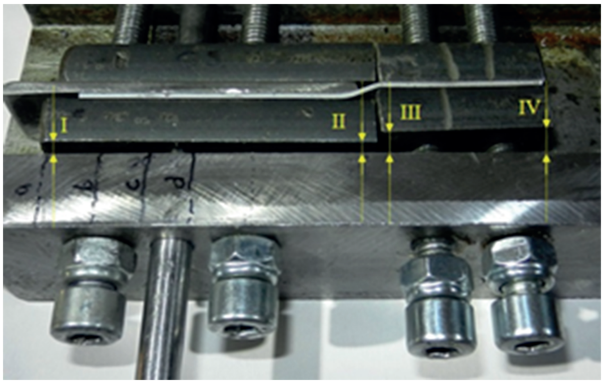

Fig. 11. Measurement points when adjusting the device

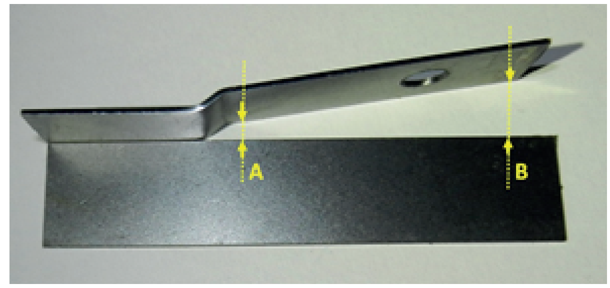

Fig. 12. Measurement points of effects of forming elements

Table 1. Values of adjusting cover plates and the results of forming sample steel elements

	Distance between the cover plate edge and the device frame [mm]				Deviation between sample elements [mm]	
No.	I	II	III	IV	A	B
1	1.2	0	3	3	3.1	2.8
2	0.7	0	3	3.6	3.2	4
3	0.7	0	3.1	2.9	3	4.3
4	0.7	0	2.8	3.7	2.3	0.5
5	1.5	0	3	3.2	2.8	2.6
6	1.5	0	3.2	3,5	3.1	2.9
7	1.2	0	3.1	3.6	3.2	2.9
8	1.2	0	3.2	3.6	3	3
9	1.2	0	3.2	3.6	3	3
10	1.2	0	3.2	3.6	3	3

Measuring the distance between the long cover plate (I and II) and the short cover plate (III and IV) from the device frame was made with a calliper. Smaller distances were measured with a feeler gauge. The measurement of the moulding results was made by measuring the distance between the long arms of the bent sample element, after applying its shorter arm to the flat surface (Fig. 12).

A satisfactory result was achieved already after eight attempts. The accuracy of the dimensions of the sample components was also on a high level, similarly to the repeatability of the results.

Next, the device was calibrated in order to be able to form duralumin samples. The measurements were taken on the same principle as steel samples (Table 2).

Table 2. The values of adjusting cover plates and the results of moulding steel elements

	Distance between the cover plate edge and the device frame [mm]				Deviation between sample elements [mm]	
No.	I	II	III	IV	A	B
1	1.2	0	4	1.9	4.5	10
2	1.2	0	4	2.7	4	7.8
3	1.2	0	3	3	2.7	4.2
4	1.4	0	3	3	2.8	4
5	1	0	3.3	3	3.1	3.6
6	1.4	0	2.7	3	2.3	3.6
7	1.8	0	3	3	3	4
8	1.8	0	3.2	3.2	2.8	4.5
9	1.2	0	3.9	2.4	3.6	9
10	1.4	0	3	3.6	3	4.3
11	1.2	0	3	3,5	3	4.2

12	1.2	0	3	4	3	3.7
13	1.2	0	2.8	4.6	2	1
14	1.2	0	3.1	4.5	2,5	0
15	1.2	0	3.3	3.7	3	3
16	1.2	0	3.3	3.7	3	3
17	1.2	0	3.3	3.7	3	3

In this case, the difficulty in making the adjustments was due to the fact that the examined aluminium alloy (2017A) is characterized by larger elastic deformations than previously moulded steel. As a result, it was necessary to increase the angles of bending of sample elements to such a degree that resilience does not exert a negative impact on their shape after moulding. However, this led to a situation (Fig. 13) in which the cover plates began to significantly affect the surface of the bent sample elements and, in extreme cases, causing their destruction by cutting.

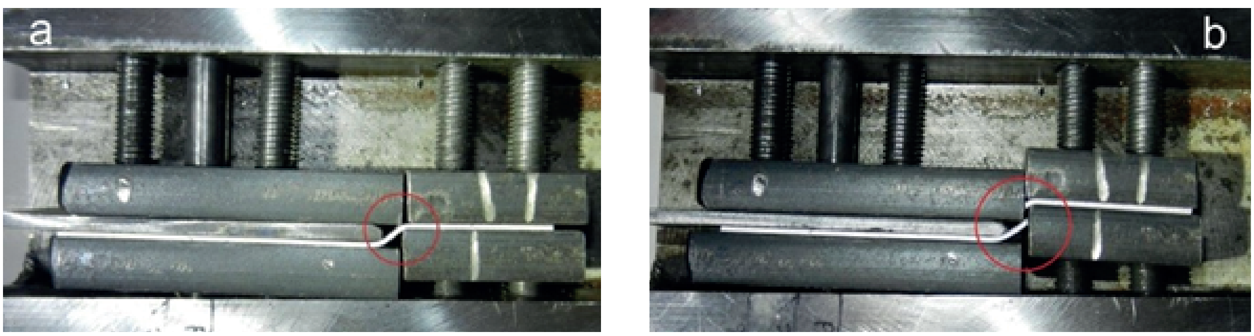

Fig. 13. Damage and destruction of an element by the edges of cover plates

To overcome this shortcoming, it was decided to change the 3 mm spacer for a 5 mm spacer, thus increasing the distance between the spacers by 2 mm.

The action had an intended consequence. Changing the thickness of the spacer sufficiently improved the capabilities of the device in the formation of sharper angles. It also facilitated manufacturing samples of required parameters (Fig. 14).

An intensive use combined with attempts of testing the strength of the device, by tightening successive screws with considerable force, close to destroying the thread, led to the emergence of cracks (Fig. 15) in places in which the frame elements were connected. In order to avoid such cases, the body of the device should be built by the method of a mechanical treatment from one piece of metal.

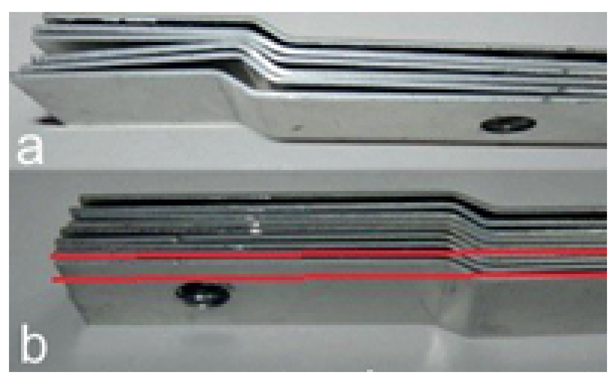

Fig. 14. Elements of the samples bent by means of the device during adjustment (a) and after setting the optimal parameters (b)

Fig. 15. Cracks in the device frame

Fig. 16. Samples fixed in the device during bonding

The designed tools were made from non-alloy tool steel. In order to protect the manufactured instruments from corrosion and to obtain appropriate aesthetic properties, the tools were oxidized.

When using the moulding device, the prepared sample steel elements were prepared for bonding, and next, using the second device, they underwent the process of gluing (Fig. 16).

Both during inserting and extracting the samples from the device, it was possible to observe minor difficulties in moving the complex sample components through the threaded lead screw. While for the already hardened samples, it does not constitute a major problem, in the case of placing samples in the device and moving them prior to gluing, this can be an impediment. In the final version of the device, the screws were replaced by steel rods of the same diameter; however, they were threaded only over a distance of 25 mm so as to be able to lock the crossbar with a clamping screw.

The obtained samples (Fig. 17) were checked for the parameters specified in the standard. After measuring them with a calliper, it was found that the samples met the dimensional requirements.

They were made using the specially manufactured tools. They were tested by means of a proper dropping hammer Instron Ceast 9340. The tests confirmed the correctness of the prepared samples.

Fig. 17. Glued samples

Conclusions

On the basis of the conducted experimental research, it was proved that the assumptions made in the design of the devices were suitable. The prepared devices are functional and the samples made by them have got the parameters required by the norm.

The device for forming the samples is adjustable, which makes its application versatile, as it allows moulding sample elements of different materials. In the examinations, the sample elements were made up of average quality steel and aluminium alloy; however, after an adjustment of the device, it is possible to form elements made up of any materials.

The bonding device allows simultaneous bonding of up to seven irregular shape samples. Clamping the bonding can be adjusted by tightening the clamping screw using a dynamometer.

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