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Testing of beveled crimp connections made on a prototype stand

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ABSTRACT

The purpose of this study is to form and test inseparable tight joints, commonly used in the construction of heat exchangers, by crimping operation on designed prototype stand. Crimped joints are made by tools in form of cones with two types of shapes, each of the designed tools have got identical forming angle. This study uses two types of connecting blocks and plates, differing in diameters of hole and flange. Elaboration contains a case study of joints being made by the stand, which in addition to the crimping operations for some cases were glued or brazed. The article presents the features of the formed joints, by examining them by destructive testing: Micrography, tensile strength test, and non-destructive testing: Leakage test. The examined elements have been made of aluminum 6060, which is well suited to indirect or direct operations of forming joints for all kinds of coolers or condensers. Elaborated tests and studies in this study allowed to state, that joining the connection block to plate with the small diameter, was more energy-consuming than in sample sets with bigger diameter, use of glue increasing the strength of the joints by 20%, significant strength increase can be obtained after mechanical clinching with brazing operation or modification of geometrical shape of the jaws.

1. INTRODUCTION

Inseparable crimped joints, formed by mechanical deformation of joined materials, are commonly found and used in mass production of components for the automotive or aerospace industry. Joining elements with and without additional processes significantly different from each other, has to meet specific and assumed for them requirements [1]. Fulfilling the demand raised for the joints are strictly dependent on the size of external factors that will affect on the component. Construction elements of industrial applications can be subjected to aggressive influence of the cooperating medium, high pressure or high temperature gradients. Those factors lead to shorter operating time of particular applications and possible failures.

Budget factor is as well important in designing process of making the joint. Economical approach of different devices is up to many things like kind of process connections, parameters, material, needed energy. [2, 3]. Despite of different method of welding, aluminum alloy is still a challange to weld. [4-6]. Currently the CMT (Cold Metal Transfer) method of welding or laser welding is known but it is still developing. Other method like friction stir welding can be also alternative [7], adhesive joining or mechanical crimping, clinching [8-10]. Using mechanical clinching or crimping has such advantages like no heat impact of the joint, no spark and smoke durning the process of joining, no damage of elements surface out of the connection area [4, 11].

Therefore, the division of making methods of joints should be made in which the operation of clinching, crimping or rounding is treated as a final operation or it will be treated as an indirect operation. The second joint forming method will be used as a preparation for subsequent processes e.g. brazering or welding.

However, the most frequent difficulty in the process of forming the joint is limited space for mechanism providing relatively high force used to make the connection between

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two materials, which can cause troublesome issues many times.

2. MATERIALS AND METHODS

The application of the designed prototype stand is to make repeatable inseparable joints in industrial conditions. Case studies of made connections, consisting of two elements of a flat plate, which can be part of the tank in air conditioning systems and connecting block are presented in this elaboration. The Fig. 1 presents the examined case.

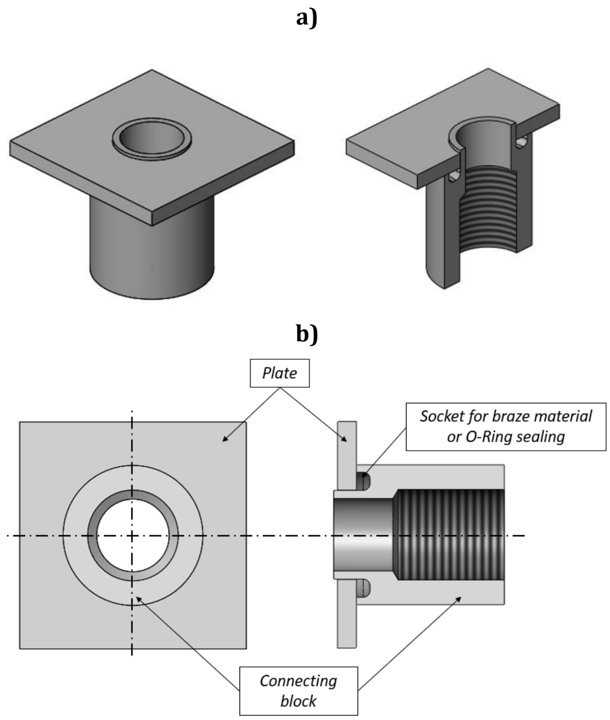


Fig. 1. Studied elements: a) 3D view; b) elements with descriptions

Tight joints used by the automotive and aircraft branch of industry in manufacturing heat exchangers are based particularly on NOCOLOK Brazing technology where using the flux details contacting each other. Providing of the leaktight it is also possible to use various kinds of seals and also using the glue should be taken in to account [10,12].

In presented inseparable joint (Fig. 1), connecting block has a place for static sealing like an O-ring, glue or braze ring. The material which was used for both parts of the block and the plate was aluminum alloy 6006.

In the examined case of inseparable joint, the mechanism providing required force to form connection haven't got restrictions in limited space as a result of that the forming jaws may have the shape of cones (two kinds) and can affect the inner part of the hole of the connecting block, which allows to plastically deform and permanently connect two elements. During the process of forming the joint both details must be pressed against each other. The steps of forming the joint can be divided to three stages presented in (Fig. 2).

Formed joints were performed with the use of tools in the shape of cones manufactured of hardened steel in delivery - M261 with the hardness described 42HRC.

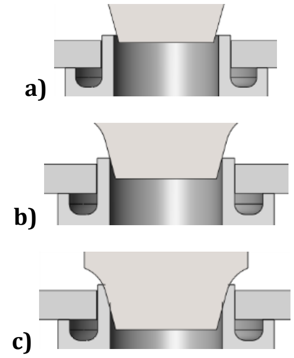


Fig. 2. Theoretical schematic description of joint making process: 1st phase – prior to jaws (a); 2nd phase – contact (b), 3rd phase - interaction of jaws into material (c).

3. STAND CONCEPT

Designing of the prototype stands or machines working in the production areas forces, in addition to the repeated fulfillment of its technological and quality functions, is to fulfill specific standards in the field of ergonomics and safety. One should not forget about the economic balance of the issue and conscious discussion on the choice of the best concept from the several considered. During the design process it is important to constantly take into account the values of physical quantities that are required for the correct modeling of the technological process [13].

As a result of the preliminary considerations of the process, the values of forces that will be applied to the system were selected. A concept based on an actor in the form of a pneumatic actuator with a piston size Ø200 together with a Keyence GT2 sensor was selected for the implementation of forming the connection. The disadvantage of chosen solution is the lack of control of the relationship between the road, time or force applied. However, performed tests in production conditions confirmed that for analyzed case, this was not a problem and the joint was made correctly.

On the prototype stand, where forming process has been performed, the control of the course of force as a function of the road, has been made by the control of the envelope constituting the field of tolerance of the resulting reactions.

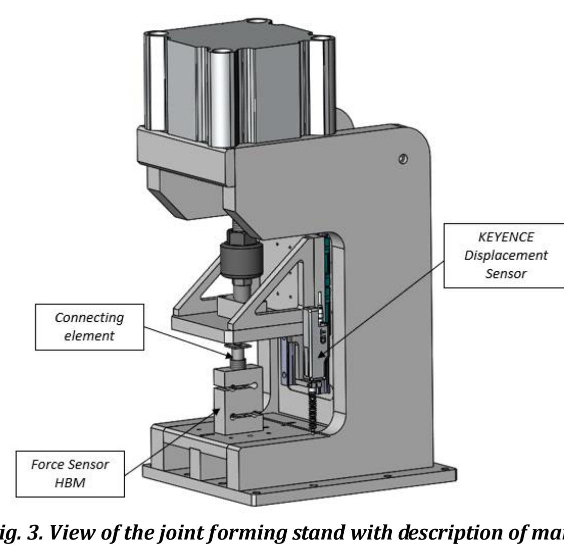


Fig. 3. View of the joint forming stand with description of main components.

Stand actuators were based on a pneumatic cylinder, which at a pressure of 6 bar can achieve a force of 3kN (Fig. 3). Sensors and measurement systems are based on the following elements:

- Force sensor HBM RSCC3/2T with an RM4220 transducer, the range of 2 tons and accuracy of ± 0.25%;
- Displacement sensor Keyence GT2-H32 Sn32 with accuracy of 5μm;
- SMC pressure sensor supervising its magnitude during the tests.

In order to collect current (4-20mA displacement sensor) and voltage (0-10V force sensor) signals a PC with my PCLab transducer was used.

4. METHODOLOGY OF THE EXPERIMENT

The study was prepared basing on 20 sample sets, each of them contains an aluminum bushing with thread inside and a flat plate. As a main criterion for dividing the experiment cases were inner diameters of plates hole and outer diameters of connecting block flange. Among manufactured sample sets 10 samples were made with a larger diameter and 8 ones were made with a smaller diameter. Another classification type of samples was stage of connection technology, the intermediate or final. The group of samples classified as intermediate was prepared for brazering or gluing, during or after crimping. The sample sets in which crimping was final technological process was equipped with an O-ring or glued with Epoxy 7706 glue. The view of cross section of the sample is shown in Fig. 4, values of important dimensions of the samples are shown in Table 1.

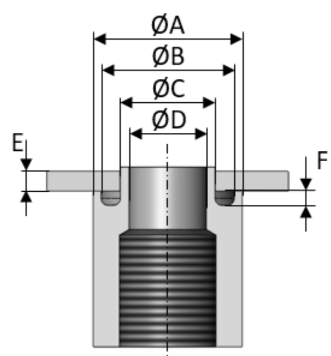


Fig. 4. Joint view with shown key dimensions.

Table 1. Joints dimensions divided by the experiment case.

No	Case	ØA	ØB	ØC	D	E	F
1	A	Ø18.5	Ø17 H7	Ø12 H7/h11	Ø10	2.5	1.8
2	B	Ø18.5	Ø15 H7	Ø10 H7/h11	Ø8	2.5	1.8

Critical dimensions of designed sample elements were manufactured with high precision (diameters ØC) in order to provide good quality joints, it should be noted that obtaining the required accuracy may not be available in mass production or it can be economically unjustified [14].

In order to make the joint, 4 kinds of matched jaws to 2 groups of inner diameter of the tube each (larger and smaller) have been used (Table 2 and Table 3). The jaws can be designed in various concepts, the main difference between them will be in shape of the tools and the size of the clinching surface. In general, in every single concept jaws perform plastic deformation in both of joint elements [15]. However, the obtained mechanical clinched joints, will have different strength in relationship to the geometry of clinching [16].

Table 2. Detailed division of samples

No	Case	Tool	Stage of connection technology	Test 1 Leak test	Test 2 Tensile strength	Micrography	Sealing
1	A	S1	Final	X	X		O-ring
2	A	S2	Final	X	X		O-ring
3	A	S1	Final	X	X		O-ring
4	A	S2	Final	X	X		O-ring
5	A	S1	Intermediate	X	X		Braze
6	A	S2	Intermediate	X	X		Braze
7	A	S1	Final	X	X		Glue
8	A	S2	Final	X	X		Glue
9	A	S1	Final	X		X	Braze
10	A	S2	Final	X		X	Glue
11	B	S3	Final	X	X		O-ring
12	B	S4	Final	X	X		O-ring
13	B	S3	Final	X	X		O-ring
14	B	S4	Final	X	X		O-ring
15	B	S3	Intermediate	X	X		Braze
16	B	S4	Intermediate	X	X		Braze
17	B	S3	Final	X	X		Glue
18	B	S4	Final	X	X		Glue
19	B	S3	Final	X		X	Braze
20	B	S4	Final	X		X	Glue

The joints were performed under the supervision of the Data acquisition (DAQ) systems. In the control loop of system force sensor and displacement sensor were connected. DAQ system, along with the sensors, consists of myPCLab software and hardware connected to PC.

The obtained forces reaction allowed for an empirical knowledge of their values. These results will allow to compare force supplied in order to form the joint relative to its strength. The proper quality of the performed joints can be inspected through a variety of verification tests, both destructive testing as Micrography or Tensile strength test and non-destructive testing. The second group includes air and helium leak tests, x-ray machines and industrial tomography.

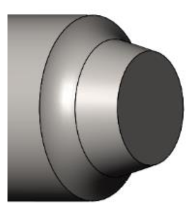
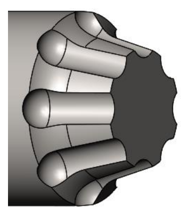
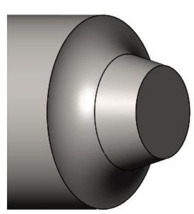
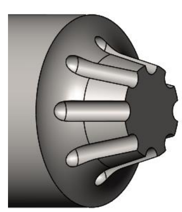
The sample sets were subjected to the following tests: air tightness test and tensile strength test. Formed joints were considered after crimping process without further technological operations, after brazering and after crimping connected with gluing.

On several sample sets destructive tests were carried out, in form of micrography taken along the axis of the hole, with consideration of points in which the interference in material was maximal. The purpose of this study was to compare the angles on forming tools with formed material after plastic working and to analyze the depth of interference in material in relation to the obtained strength.

Air tightness tests were carried out with the ATEQ F520. Each of the samples sets were attached to the device using the internal thread in connecting block, while the opposite side was covered by tight chamber, sealed with O-ring.

The tensile strength test was made on the prototype stand, where the force is provided by a ball screw and HBM force sensor with Keyence displacement sensor are used for data acquisition. The ball screw was driven manually using a crank. The internal threads in the connecting block were used as a connecting element for HBM sensor, and the flat plate was connected using special connecting adapter.

Table 3. The clinching jaws used in the case study.

	S1	S2
Case „A”		
	S3	S4
Case „B”		

5. RESULTS AND DISCUSSION

The first performed tests were air leak tests, which belong to non-destructive tests. Tested sample sets were loaded with pressure of 0.6 MPa. A leak that eliminates the joint as faulty was established on the level of 4[Pa*l/s], which is the standard maximum level of leakage for oil or water coolers in the automotive industry. Analyzing the obtained results, the influence of temperature on the results can be seen. This effect can be presented as relation resulting from the number of tests carried out for the same sample set. With the increase of the number of carried out test for the sample set, the temperature of detail rose, which followed with the increase of the volume of the element. This trend is visible in particular for the sample sets with smaller diameter, due to the low thermal capacity.

The results of the tests matched established leakage area for each type of used sealing, O-ring seal, glue or braze. The results are presented in Table 4.

To verify the level of interference in the material of the sample sets and similarity of the shapes of forming cones in the material of connecting block after forming process, the micrography has been made. The most important geometrical parameter affecting on the strength of the joint was an alpha angle, of which in studied cases the average value was 14.7 degrees. The obtained value of the alpha angle in formed joints was similar to the angle on the forming tools and the ratio between them was 99,5%. The study of micrography shows that, during the formation of joint, top material of flange has been compressed, the significant impact on compression was reaction force F2 (Fig. 5). The deformation of the hole in the plate followed the direction of force F1. The angular relationship between the forming tool and formed joint has a significant impact on the strength of the joint, by multiplication of applied force. In the studied case, the angle on the forming tools was not self-locking, therefore there was no risk of stuck of the tools. The significant influence on the quality of formed joints have also, connecting block flange thickness, connecting block supported flange height, height of material protruding beyond the plate and sharpness of hole edge in the plate on the side of inflection.

Table 4. Results of the leak test.

Test no	Pressure (MPa)	Leakage ((Pa x l)/s)
1	0,6	2
2	0,6	2
3	0,6	3
4	0,6	3
5	0,6	2
6	0,6	3
7	0,6	2
8	0,6	3
9	0,6	3
10	0,6	2
11	0,6	2
12	0,6	3
13	0,6	3
14	0,6	3
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16	0,6	2
17	0,6	3
18	0,6	3
19	0,6	3
20	0,6	3

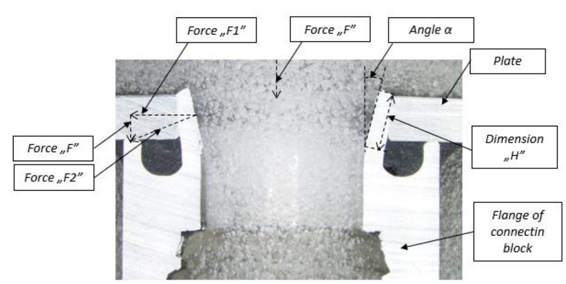

Fig. 5. Micrography section of connection joint with marked key dimensions and reaction forces.

Regardless the classification of cold formed joints, as final or intermediate, its strength and resistance to external factors in the form of forces pressures and vibrations are important. Those factors are smaller for sets from the group of non-final operations. However, they must counteract the force created during the process of handling details.

During the forming process all samples sets were supervised in the scope of traveled distance of forming tools and generated reaction forces. The analysis of the obtained parameters of the process, can be made dividing to dimensions of diameters of connecting block flange/plates hole and four types of punch.

As the first study case, sample sets with larger diameter formed by the tools with two different shapes, although with the same cone angle, were taken under the consideration.

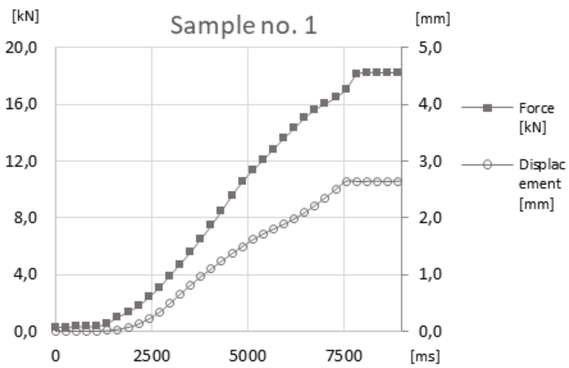

Fig. 6. Diagram of the force-at-time and displacement-at-time for sample no. 1.

Where the cones with the regular shape as shown in Fig. 6, it can be noticed that both the course of the reaction force depending on time and distance travel depending on time during formation process of joint is quite regular and with a steady slope. At the top of the graph before reaching the maximum points gentle decrease of force without reflect in distance travel can be seen, which can be described as the last phase in which the upper part of the flange is bent at the edge of the hole. Therefore, for this case, the maximum reached force was 17.1 kN.

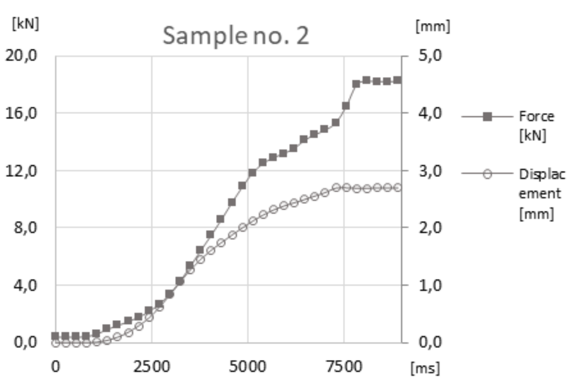

Fig. 7. Diagram of the force-at-time and displacement-at-time for sample no. 2.

Analyzing the Fig. 7, the shape of the graph demonstrates that in the second part of the joint formation (period of time between 5s and 7.5s) reaction force was increasing slower than in the previous stage (period of time between 1.25s and 5s), this was related to the geometry of forming tool and the strong impact of connecting block flange on the wall of the plates hole. Reached magnitude of the forces when the last stage of forming joints ended was equal to 15.3kN. Comparative analysis of the results obtained in Fig. 6 and Fig. 7 gave the following conclusions:

- There is a relationship between the force needed to form the joint and the shape of the forming tool;
- Different types of shape of forming tool, while maintaining the same angle of S1 and S2 cones, cause different reaction force for forming joint;
- Force needed to form the joint for the tool S2 is smaller than for the tool S1.

The following study cases taken under consideration were sample sets with smaller diameter. To form joints, tools with two different shapes, although with the same cone angle, have been used.

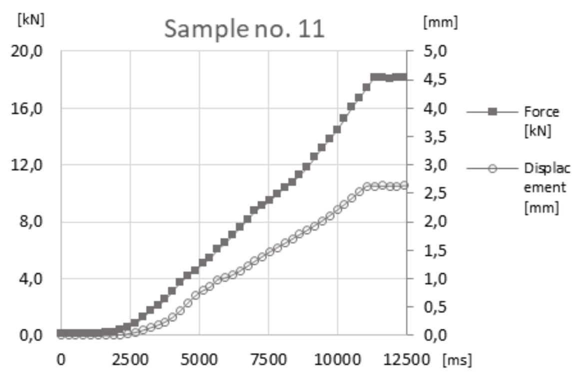

Fig. 8. Diagram of the force-at-time and displacement-at-time for sample no. 11.

Analyzing Fig. 8, it can be noted that achieved force increasing trends for regular shape tools are similar to Fig. 6. The maximum force was 17.9kN.

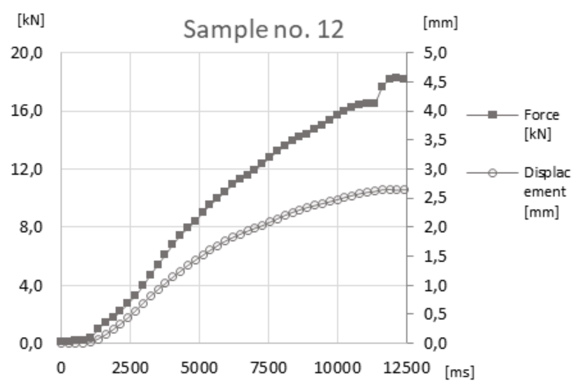

Fig. 9. Diagram of the force-at-time and displacement-at-time for sample no. 12.

The Fig. 9 represents forming the joint with tool S4, the course of reaction force depending on time and distance travel depending on time during formation process of joint is increasing steadily, however, from the middle of the process, the rate of increase in time begins to slow down. Similar phenomenon can be observed on the Fig. 7, which comes from the shape of forming tool used to produce the joint. The strength that was achieved was 16.4 kN. Using a comparative analysis between the Fig. 8 and Fig. 9 may provide a similar conclusion as for the Fig. 6 and Fig. 7.

The obtained results of force and distance for each sample sets and made micrography allow to analyse the stages of joint formation. The first stage, which is the elimination of space between connecting block and plate, is almost unnoticeable and it is difficult to refer to it clearly on the figures. The second stage of forming the joint for most cases can be identified as a straight line with a constant angle of inclination on graphs. The value of received reaction forces, for this stage, for tool type S1 and the diameter group A was 17.1kN, for tool type S3 and the smaller diameter was 17.5kN. Whereas, for tools S2 and S4 the straight line was up to circa 16kN, then the increase of the value in time was decreasing, in result for case A with used tool S2 the value reached 15.3kN and for smaller diameter of sample sets with used tool S4 the value reached 16.4kN. What follows, that forming the joint for the smaller diameter was more energy-consuming than for the larger diameter, which was caused acting on relatively close distances of the formed sections by cone tool with non-regular shape.

The next study was a destructive tests in the form of a tensile strength test, the article presents the results for the samples which were presented on previous figures.

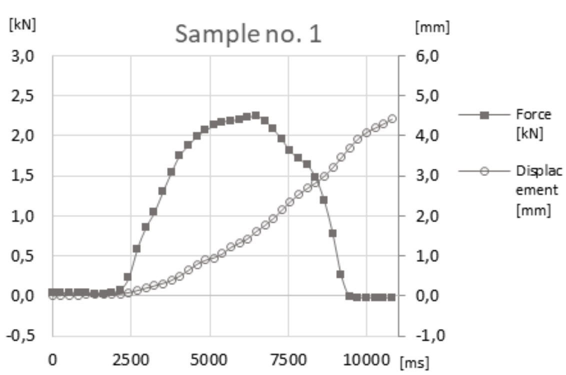

Fig. 10. Diagram of the force-at-time and displacement-at-time for sample no. 1.

In reference to Fig. 10 and Fig. 11, relating to the group joints "A", it can be noted that the strength of the joint is higher for joints formed by S1 tool with regular shape. The destruction of the joint took place at a force of 2.2 kN, while for the joint formed by the second tool at force of 1.9 kN. Similar results were observed for the group joints "B". The joint made with the S3 forming tool allowed to obtain the maximum force of less than 2.3 kN, while in the case of joint made with the S4 tools, the force was 2.0kN.

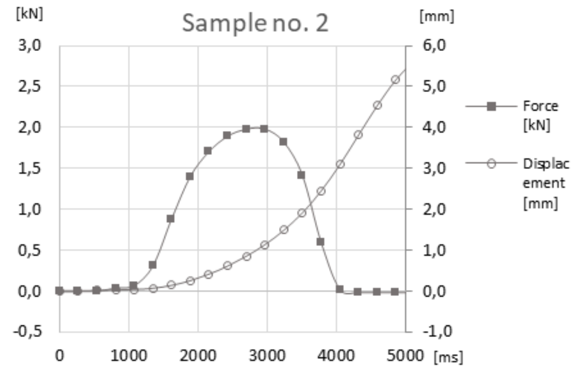

Fig. 11. Diagram of the force-at-time and displacement-at-time for sample no. 2.

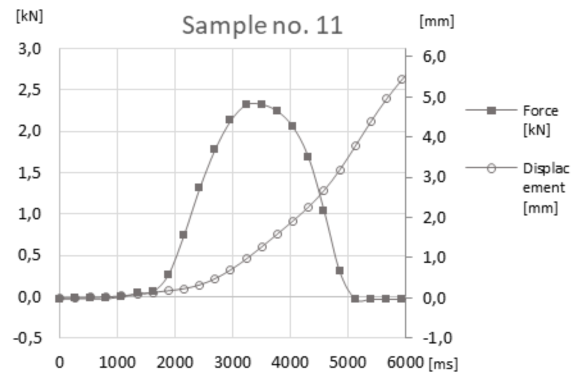

Fig. 12. Diagram of the force-at-time and displacement-at-time for sample no. 11.

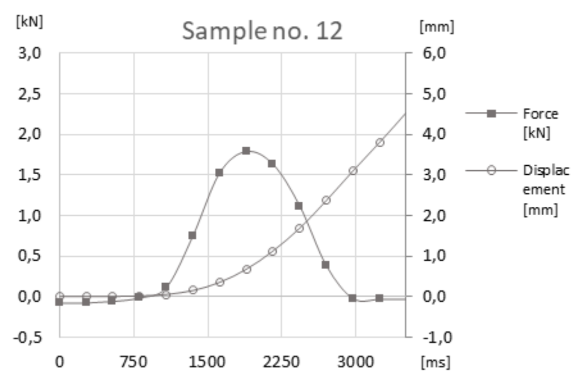

Fig. 13. Diagram of the force-at-time and displacement-at-time for sample no. 12.

Strength tests were also carried out for a joint that was crimped and glued. The presented results are for the sample sets with a larger diameter produced by the tool S1. On Fig. 14 obtained strength is shown, according to the diagram use of glue, for a dry surface, however not degreased, allowed to achieve a strength force of 2.4kN. Which was an increase of less than 20% compared to the previous sample. Brazed samples were also subjected of destructive testis. The result for the sample set 6 is shown on Fig. 15. The brazed joint strength was 22.7kN.

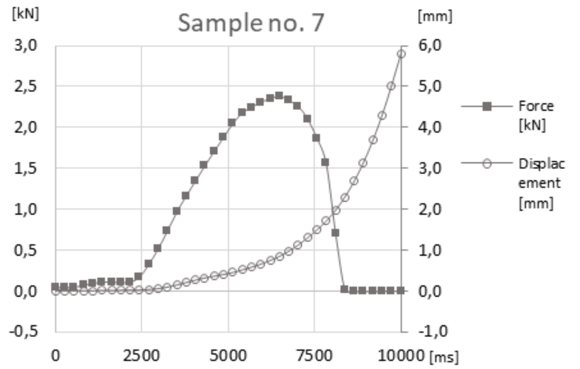

Fig. 14. Diagram of the force-at-time and displacement-at-time for sample no. 7.

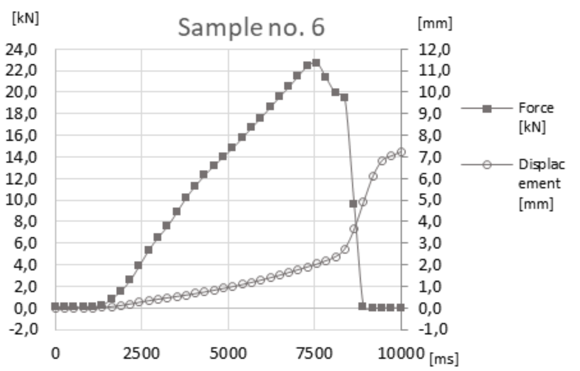

Fig. 15. Diagram of the force-at-time and displacement-at-time for sample no. 6.

6. CONCLUSIONS

Thanks to the tests and studies it is possible to formulate the following conclusions:

- Geometrical difference between 2 main groups "A" and "B" was 2mm, it means that the ratio of the smaller diameter to the larger one was 0.83%;
- Forming the joint for cases of groups "A" and "B" was less energy-consuming when using the tools S2 and S4. The percentage ratio between tool S1 and S2 was 10% less in favor of S2, while for S3 and S4 it was equal to 6%;
- Joining the connection block to plate for the small diameter, from group "B", required higher force - was more energy-consuming - than for group "A". The difference in force for the use of regular shaped tools S1 and S3 was 0.3 kN, which is equal to the ratio of 0,97% larger diameter to smaller. Considering formed joints by tools S2 and S4, the difference was 1.1kN, which means the ratio was at 0.93%;
- The joint made with cones from the S1 and S3 groups proved to be more durable than the joints created with the S2 and S4 tools. In cases "A" the difference between S1 and S2 was 0.3kN, so the regular shape of the tooling made the joint carry 13% more load. With the reference to the second type of cases, "B", the difference was 0.32kN, which was 13.9%;
- The connections of the larger "A" diameters turned out to be weaker than the "B" groups. The maximum difference was 0.4kN, which gives about 20% better result for the group "B" ;
- The use of glue allowed to increase the strength of the joint produced by 20%, in relation to the crimp connection;
- The greatest strength was obtained by a joint that was mechanically clinched and brazed, obtaining a value of 22.7kN for a destructive test;
- Geometrical shape of the jaws gives the possibility to increase the strength of the joint;
- Each of the joints and sealing gives a similar result of the leakage but don't exceed more than 4 [(Pa * l) / s]. It shows possibility to use glue instead of braze or seals;
- In order to use the mechanical joining with O-ring or glue like a final operation the applied force to produce the joint should be about 20% - 30% increased;
- Full control and checking of the making joint process like dynamic, speed, acceleration and force would be possible with a servo drive instead of a pneumatic piston.

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