Testing of Tight Crimped Joint Made on a Prototype Stand

Nikodem Wrobel, Michal Rejek, Grzegorz Krolczyk and Sergej Hloch

Abstract The paper presents a project of a prototype solution of a device for making inseparable crimped joints consisting in forming the material of two elements to be joined to each other with the use of punches. The work contains the assessment and analysis of the joints made in the stand with the use of various forming tools. Furthermore, the paper presents the analysis of the characteristic features of the new joints, as well as dependences in strength tests. The elements joined on the machine had been made of 5754 aluminium. This material and the presented joint are used in the construction of heat exchangers, such as water, oil coolers or condensers in the automotive or aircraft branch.

Keywords Prototype stand · Inseparable tight joints · Crimped joints · Bent joints

1 Introduction

Reliable and economical operation of various devices strongly depends on many factors, such as the type and condition of the material [1–3], components geometry [4, 5] or type of work conditions [6, 7]. Industry expects more accurate methods for manufacturing quality products [8–10] to face the challenges related to technological progress. 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 applica-

N. Wrobel · M. Rejek
PRO-ZAP Grupa Introl, 47a Grabowska Street, 63-400 Ostrów, Wlkp, Poland

G. Krolczyk (✉)
Department of Manufacturing Engineering and Production Automation,
Opole University of Technology, 76 Proszkowska Street, 45-758 Opole, Poland
e-mail: g.krolczyk@po.opole.pl

S. Hloch
Faculty of Manufacturing Technologies, Technical University of Kosice,
080 01 Presov, Slovakia

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tions and possible failures [11]. The automotive and aircraft industry, with the assumed rate of development of new projects and principles related to the sequence of manufacturing the construction of the individual vehicle or aircraft parts, determine the possibilities of creating smaller sub-assemblies, as well as the mode of manufacturing them and possible mounting [12]. The difficulties resulting from the above aspects determine physical values, such as forces or torques to be set to the given product via the machine in order to obtain satisfactory results in the form of properly tight joint with adequate tightness. The design actions in the above-mentioned area, however, are constrained by the limited mounting possibilities which can be used in order to supply the demanded energy to the system.

2 Materials and Method

The prepared device is intended for simultaneous forming two identical joints, at a distance of 45 mm from each other, for the same tube diameters and sizes of sockets in which they are seated. Figure 1 shows the tested case of joint before the execution of it.

Tight joints used by the automotive and aircraft industry in manufacturing heat exchangers are based particularly on soldering details contacting each other or on the use of various kinds of seals out in or cast on the material. In the manufactured and described joint (Fig. 2), static sealing in the form of an o-ring has been applied. It allows the connection block to be added to the already soldered exchanger. The material selected for the execution of the joints was aluminium alloy 5754.

In order to make an inseparable joint between the pipe and the block, it has been assumed that the block flange with the wall thickness of 1.2 mm will be bent towards the pipe flange so that, in the first phase, the inner part of the block flange contacts the outer rounding and, in the second phase, the upper part of the flange contacts the upper part of the pipe. It is assumed in the connection that, when the joint is being formed, the pipe should be pressed to the socket for initial

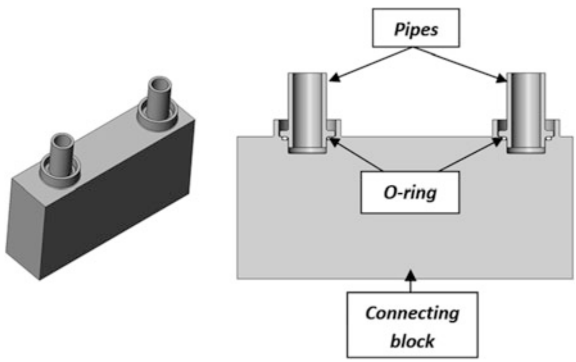


Fig. 1 A view of connection block with the pipe and o-ring

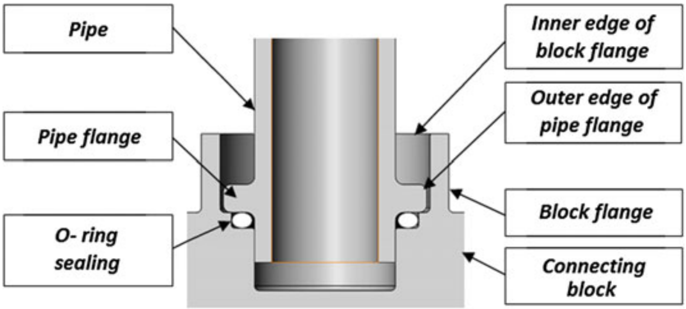


Fig. 2 A 3D view of the connection block cross section with the explanation of the individual element parts

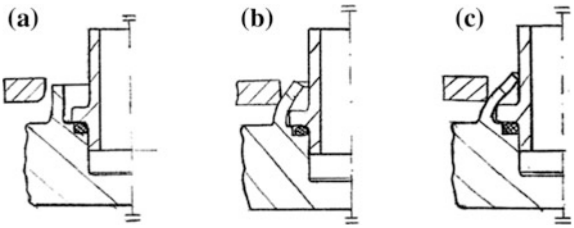


Fig. 3 Joint formation: the system before the punch coming in (**a**); first phase—contact of the flanges (**b**); second phase—the block flange contact with the pipe (**c**)

compression of the o-ring. This eliminates the risk of "catching" and as result execution of a defective joint has been avoided. A diagram of manufacturing the connection has been shown in three steps (Fig. 3).

Plastic deformations of the described joint result in the material consolidation in the forming area, which positively influences its strength. In the construction of prototype tools for manufacturing various types of joints, in the case of aluminium, materials whose main destination is injection moulds are often used. In this case, material 1.2311 with the hardness of 32 HRC has been used.

3 The Stand Concept

Each device or machine must meet the predetermined assumptions. Therefore, it is important to design according to strictly defined principle and standards of creating a construction and to keep in mind the financial balance of the project. In prototyping, the critical issue, prior to the proper work, is to select the best concept and to learn the values of the physical magnitudes required for correct modelling of the technological process. The concept of the stand has been based on the assessment of

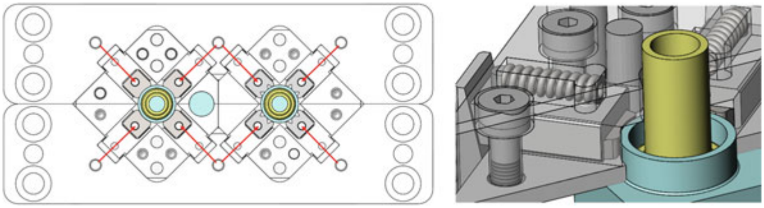


Fig. 4 A view of the method of applying forces to the joint

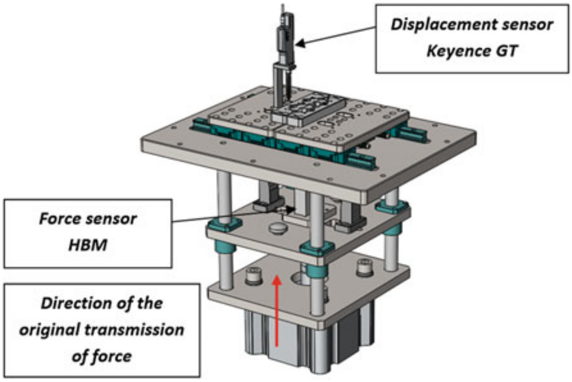


Fig. 5 A view of the main unit of the force generating machine

the forces to be applied to the system to execute the joint, possibilities of mounting, time of execution and quality of the joint, as well as the work ergonomy. The role of the stand is reliable execution of joints formed by the punch perpendicular entering the pipe flange and bending it on the pipe planes. Due to that two details will be joined to each other without an additional bond, just with the use of the native material. A diagram of force application to the joint via the device can be seen in Fig. 4.

Limited access has necessitated basing the machine design on mechanical transmissions in the form of two wedges for each of the punches. The conversion is effected from the vertical motion generated by the servomotor to the horizontal motion of the punch socket. Figure 5 shows a 3D view of the stand with the indication of the elements of acting and sensing.

The measurement system for data collection has been based on a PC provided with a PC LAB transducer which allows for collecting signals during the test, in the form of current values (4–20 mA—displacement sensor) and voltage values (0–10 V—force sensor).

4 Methodology of the Experiment

Six connection blocks have been prepared for the tests; there are two sockets in each of them for 12 pipes. The test has been performed for two pipe diameters, and each of them had also two values of the flange diameter. Ten samples have been provided with sealings in the form of o-rings, and two had no sealing rings. A view of the joint with the dimensions has been shown in Fig. 6 and Table 1; the experiment design in Table 2.

In order to make the joint, four kinds of punches have been used with two kinds of shapes matched to various diameters (Table 3). The execution of each joint has been recorded by the system of data collection and presented in two dependences: force as a function of time and force as a function of the path. The test results are to serve for learning the forces necessary to obtain proper quality of the joint. The joint is supposed to have proper tightness and strength. The executed joints have been subjected to destructive and non-destructive tests. A test verifying a joint in industrial conditions is measurement of tightness in which air helium is used. In the case under discussion, air device, ASTEQ F520 has been used. The sealings have been based on elastic hoses clamped on the outer diameter of the pipe. The samples have been subjected to tensile tests with the use of the testing machine.

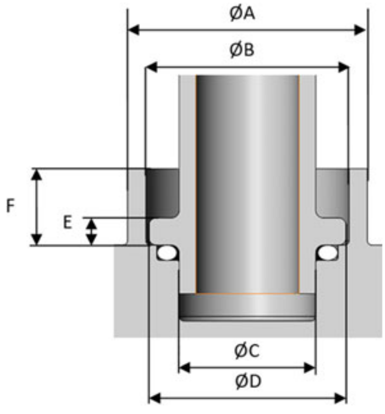


Fig. 6 A view of the joint with dimensions

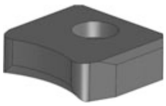
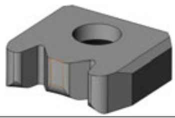
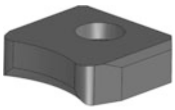
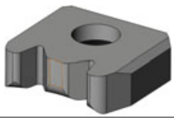
Table 1 Dimension description of the joint

No	Case	ØA	ØB	C	ØD	E	F	O-ring
1	A	15.8h7	13.4H7	9h7/H6	13h13	1.7h13	5	Ø8 × 1.5
2	B	14.8h7	12.4H7	8h7/H6	12h13	1.7h13	5	Ø7 × 1.5

Table 2 Design of the experiment

No	Case	Tool	Test 1 tightness	Test 2 tensile strength	Micrography	Notes
1	A	S2	X		X	
2	A	S1	X		X	
3	A	S2	X	X		
4	A	S1	X	X		
5	A	S2	X		X	No O-ring
6	A	S1	X		X	No O-ring
7	B	S4	X		X	
8	B	S3	X		X	
9	B	S4	X	X		
10	B	S3	X	X		
11	B	S4	X		X	No O-ring
12	B	S3	X		X	No O-ring

Table 3 The punches used in the tests

	S1	S2
Case "A"		
	S3	S4
Case "B"		

The force has been applied by means of a precision ball screw. For the tensile test, internal threads have been made in the connection blocks; the pipes had internal threads for case "A" and external ones for case "B" (Table 2).

5 Results and Discussion

Each of the 12 samples has been subjected to an analysis of tightness. Expectations concerning the joints were as follows: with the pressure of 0.6 MPa, the admissible leakage has been determined at the level of 4 [(Pa l)/s]. The magnitude meets the requirements of the present automotive branch for heat exchangers in the form of oil and water coolers. In order to adapt to the tested object such test parameters as the time of filling, stabilisation or test have been selected in trials. The results indicate that each of the joints has the desired test parameters. The results have been shown in Table 4.

The obtained results show small differences between the leakage magnitudes. The reason of the described fluctuations is the relatively small volume of compressed air in the test system. The consequence of the fact is the influence of temperature on the result related, among others, to the thermal expansion of the detail and its variable volume resulting in the pressure drop. It has also been found that the result deteriorates with the number of tests performed on one sample. The changes can also be caused by delivering compressed air to the joint, which is likened to labour which changes into heat in accordance with the first principle of thermodynamics. During the selection of the test parameters consisting, among others, in increasing the pressure from 0.1 to 0.6 MPa, the set pressure of 0.175 MPa has been found to maintain for the test case no. 5. The sample had no sealing. This means that it is possible to obtain tightness with a lower range of requirements even with the absence of o-ring. This phenomenon implies that, in series production, if lower requirements are adopted, an incomplete joint can be qualified as a good one. Micrography of that sample can be seen in Fig. 7; very good adherence of the joined elements is noticeable which can occur within the three characteristic points. On the other hand, the acquisition of the described tightness was influenced by point 2. The first one is the upper part of the pipe flange, this means that local embossing of the flange on the pipe flange radius has occurred at that place. Due to that, on the described circumference, surface roughness has been smoothed. The sample has been made by means of S3 tool which makes joint by even shape in the whole pressure surface.

Table 4 Description of joint dependence and the tests performed on the joint

Test no	1	2	3	4	5	6	7	8	9	10	11	12
Pressure (MPa)	0.6	0.6	0.6	0.12	X	X	0.6	0.6	0.6	0.6	X	X
Leak (Pa l)/s	3	4	3	X	X	X	2	3	3	4	X	X

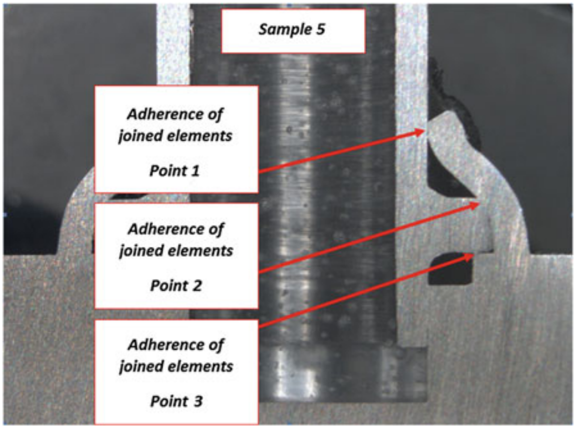


Fig. 7 Microsection of joint number 5

Constructional joints made by forming a socket flange on the pipe flange are loaded mainly with tensile forces. However, they must be resistant, too, to the operator's actions during transport of the exchanger. The tested samples have been analysed while applying the forces.

Analysis of the test results shown in Fig. 8 has allowed us to formulate the following dependences:

- Dependence of the arisen reaction force on the tool shape. The results were characteristic and analogous between samples 1 and 2, as well as between samples 7 and 8.
- Dependence of the arisen reaction force on the diameter of the connection block flange.

Description of those dependences has been executed basing on the diagrams made for cases 1 and 2 as well as 7 and 8. The first samples 1 and 7 have been formed by means of a punch with the same shape type, and the situation with samples 2 and 8 was similar. It has been observed that the force necessary to form a joint by means of punches S2 and S4 is smaller than that for punches S1 and S3. Its total value for the first case was 60.5 kN, for the second case 65.0 kN, for the

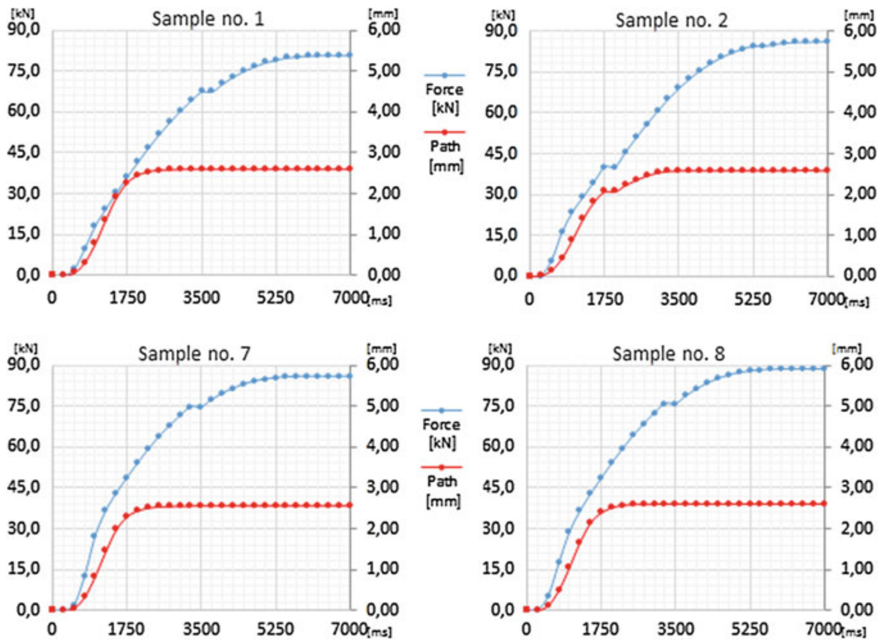


Fig. 8 Diagram of the dependence of the force on time and force on the path for sample 1,2,7,8

seventh one 67.8 kN and for the eighth one 68.6 kN. The differences are less perceptible for smaller diameter or for cases “A”. This is due to matching the punches to the smaller flange diameters and, consequently, for punch S3 the distance between the teeth is less, which influences the closeness of the contact surfaces. During plastic forming, local hardening of the material occurs, reduction of the distance of the contact points causes increase of the force.

Samples 3, 4, 9 and 10 have been subjected to a tensile test. The purpose was to check the joint with the minimum force of 1.56 kN. This magnitude corresponds to the application of a pressure of 10 MPa to the flange.

The tests whose results have been shown in Fig. 9 have proved that, with the force applied, the joint has not been destroyed. Only the connection pipe has been broken. For cases “A”, the values have oscillated around 5 kN; for cases “B”, they amounted about 3 kN. The differences were due to the execution of thread in the pipe (Fig. 10).

Joints are significantly influenced by the parameter of the bending angle of the support flange, as well as its thickness and girding on the pipe radius. Samples 2 and 8 have been made by the same kind of jaws, and the angle values are close to each other (Fig. 11).

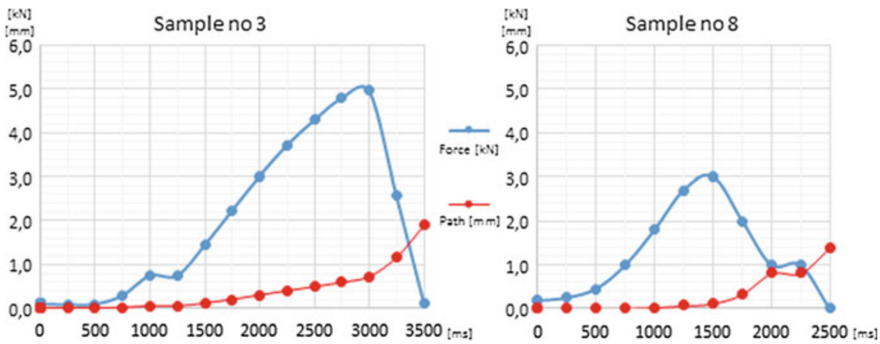


Fig. 9 Diagram of the joint stretching in the dependence of force on time and path on time for sample 3 and 8

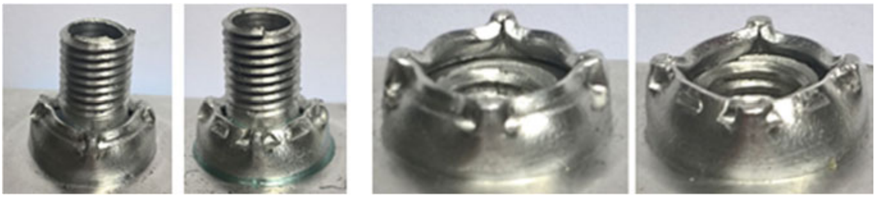


Fig. 10 Photographs of the samples after the execution of the joint and after the strength test

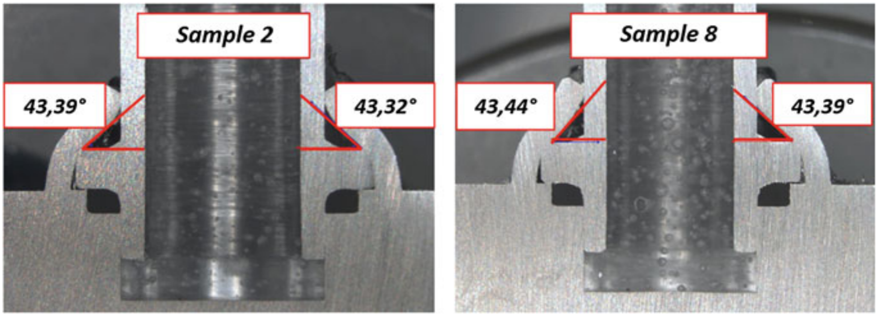


Fig. 11 A photograph of the microsection made for joint no. 2 and 8

6 Conclusions

The performed tests of inseparable constructional joint have allowed us to formulate the following conclusions:

I. Application of punch kinds S2 and S4 has reduced the forces necessary for forming the joint,
II. Smaller flange diameter with the applied S3 and S4 punches has resulted in an increase of the forces used to make the joint,
III. Non-destructive examination in the form of the test of air tightness has shown that adequate selection of parameters and the temperature influence are very important,
IV. As regards the aspect of strength, each of the tested joints can work in any kind of heat exchangers, water or oil, coolers or condensers,
V. In the prototype machine, the best solution for force application is electric servo drive; it allows for full control of the process of the joint execution.

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