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Determination of reasons for crack generation in hinge welded elements

Abstract: The purpose of the study was to determine reasons for damaging welded pins in hinge elements and to recommend activities which can limit the incidence of pins breaking out of hinges. In order to develop a welding technology ensuring a good and repeatable quality of joints it was necessary to analyse the previously used joining technology and a weld design as well as to carry out macroscopic metallographic tests, hardness measurements and observations of the fractures of damaged elements. On the basis of the tests conducted it was possible to develop a welding technology ensuring the required quality of joints.

Keywords: Spot welding, Cracking, Hinges

Introduction

Designing welded structures requires a design engineer to be knowledgeable about joining processes. Recent years have seen a discussion among welding engineers about the necessity of training civil and design engineers in the fundamentals of joining technologies. The technological problem described in this study confirms this necessity. The design of a hinge put to a test was damaged not only due to an improperly selected welding technology but, first of all, the result of a wrongly designed joint. Within the scope of this research it was necessary to determine reasons for damage to pins welded to steel structural shapes as part of hinge elements on which a gate is mounted. During gate mounting, hinges often become damaged as a result of broken pins.

Manufacture of the element

The technological hinge manufacturing process consists in placing a pin (Ø 7.9 mm) made of steel grade S235JR in an opening (Ø 10.0 mm) prepared in a shape made of 3.00 mm thick steel grade DC01 sheet (Fig.1, 2). By means of a special tool, a pin is placed 1.5 mm deep in the shape opening; next it is welded manually using the MAG method (plug weld). After making the joint, the face of the weld is subjected to grinding, the purpose of which is to obtain the required weld reinforcement height. Afterwards, the element undergoes electrogalvanising.

A quality criterion is a positive result from a workshop mechanical strength test consist-

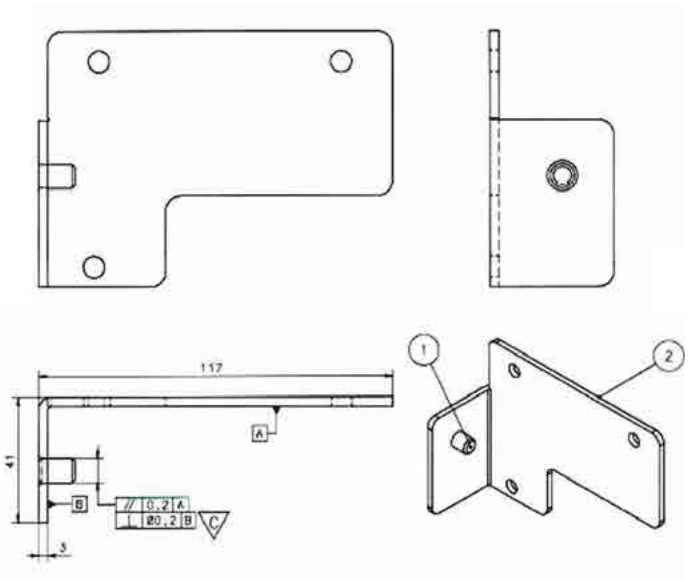

Fig. 1. Hinge element design: 1 - pin, 2 - shape

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Fig. 2. Element of hinge directly after welding: A – view from plug weld face, B – view from pin (visible notch)

ing in hitting the pin with a hammer three times. The impact test should not result in damage to the welded joint – a broken pin or a pin torn off the steel shape is unallowed.

A solid wire MAG welding process is carried out on a station provided with a semi-automatic TPS 3200 welding machine manufactured by the FRONIUS company. The pin is positioned in the opening (1.5 mm below the upper surface of the shape) by means of a special fixing tool (Fig. 3).

Welding is conducted in accordance with a Welding Procedure Specification (WPS). The process is carried out manually; the movement is helical starting from the circumference and finishing in the central part of the pin. Such a welding manner creates problems with maintaining process repeatability. As it is necessary to guide a welding arc very precisely during manual welding, making a plug weld characterised by required quality and strength requires a great deal of experience. It is difficult for a welder to repeat the same weld geometry and penetration depth consistently. As a consequence of failing to achieve these requiements, a joint failing to meet requirements may be produced.

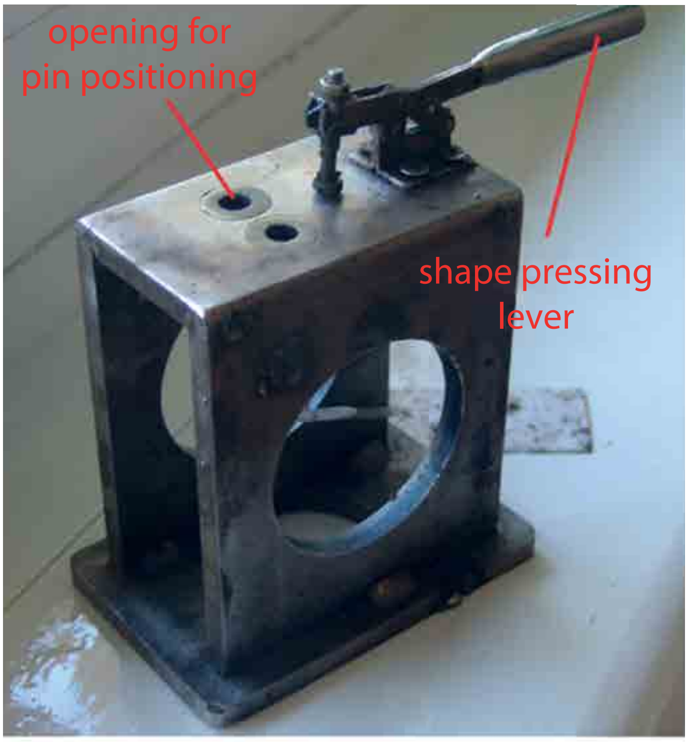

Fig. 3. Tool for fixing shape and pin before welding

Determining reasons for damage to welded pins and shape

In order to determine the reasons for damage to hinges caused by a load it was necessary to carry out macroscopic tests of the joints, hardness measurements and an observation of the fractures. The following elements were subjected to tests:

- hinges after welding,
- elements which were not broken or cracked during joint strength tests (Fig. 4),
- hinges damaged during workshop joint strength tests.

Fig. 4. Hinge element after workshop mechanical strength test; test result was positive

Macroscopic tests

The hinge elements made in accordance with a technology specified in a related Welding Procedure Specification were cut along the pin axis. Next, in order to reveal their macrostructure, the elements underwent grinding, polishing and etching in the Adler's reagent. The samples selected for the tests were the following:

- hinge element damaged during gate mounting (sample no. 2, Fig. 5);
- element damaged during the workshop strength test (sample no. 3, Fig. 6);
- hinge meeting the requirements (sample no. 4, Fig. 7);
- hinge element which underwent allowed damage during the workshop strength test (sample no. 5, Fig. 8);
- element meeting the requirements, (sample no. 6, Fig. 9).

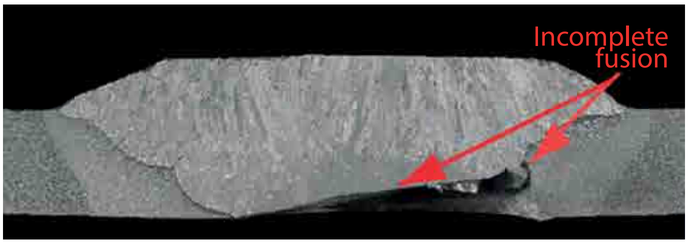

Fig. 5. Macrostructure of sample no. 2. Mag. 6.5x

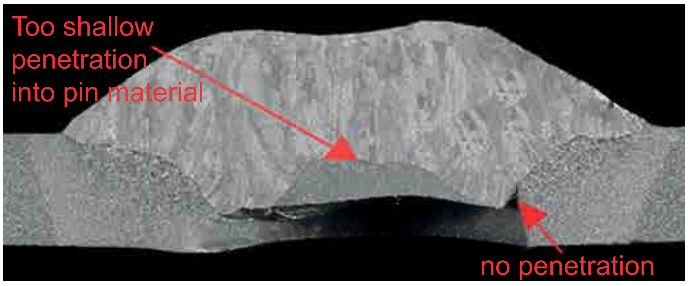

Fig. 6. Macrostructure of sample no. 3. Mag. 6.5x

The metallographic specimens of the damaged samples revealed an inadequate joint penetration and incomplete fusions (Fig. 5 and 6). The excessive diameter of the opening in which the pin was placed is the reason for the generation of gaps in the welded joint root (Fig. 8 and 9). The gaps, incomplete fusions and the inadequate joint penetration constituted a geometrical notch leading, under load, to cracking and resultant destruction of the hinge welded joint during the mounting of a gate or in the strength test.

The macroscopic metallographic tests of the elements revealed the lack of welding process repeatability (Fig. 7, 8, 9), mainly due to the manual guiding of the MAG welding torch. During manual welding it is more difficult to eliminate the welding imperfections determined in the tests and obtaining a penetration ensuring the required strength of welded joints (on the pin circumference).

Afterwards, the fractures were observed by means of a stereoscopic microscope. It was revealed that the character of the fractures was brittle. An example of the fracture of sample no. 2 is presented in Figures 10 and 11.

On the fractures it is possible to observe the area of the pin material and the weld fragment. The fracture area underwent cracking due to an insufficient penetration depth, which might be attributed to improper welding technique and the excessive diameter of the opening in which the pin was positioned.

Hardness measurements

Hardness measurements were carried out using the Vickers method and a Brickers 220 hardness tester in accordance with standard

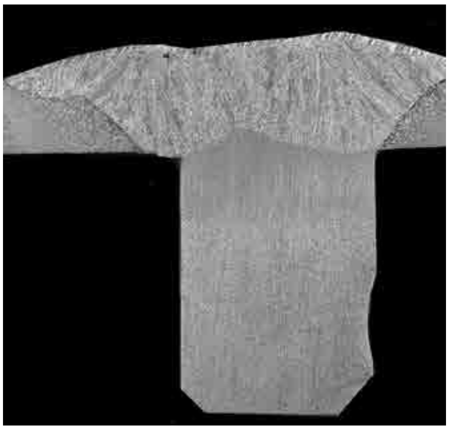

Fig. 7. Macrostructure of sample no. 4. Mag. 5x

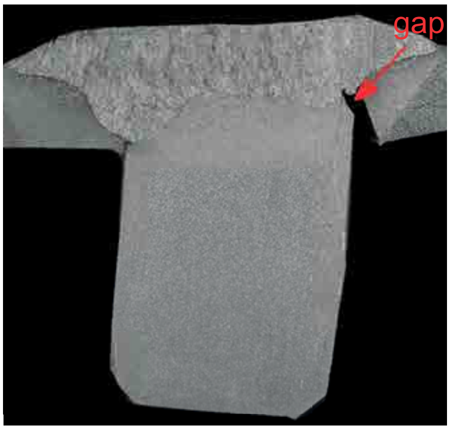

Fig. 8. Macrostructure of sample no. 5. Mag. 5x

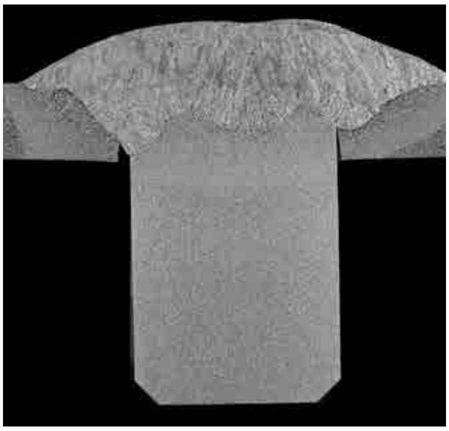

Fig. 9. Macrostructure of sample no. 6. Mag. 5x

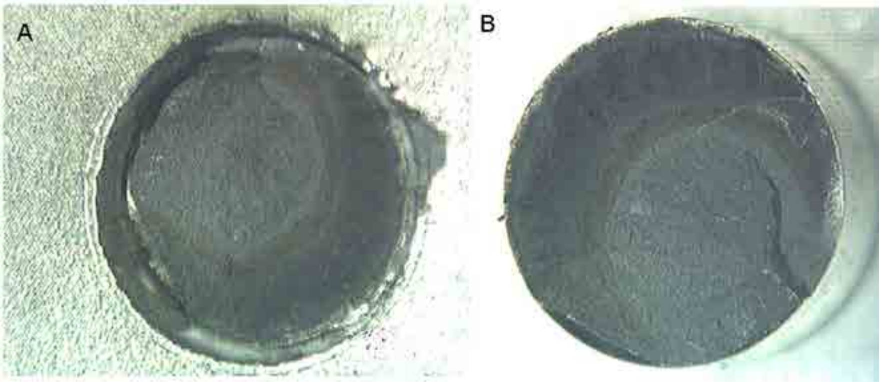

Fig. 10. Structure of fracture of sample no. 2:
A: shape, B: pin, magnification 9.0x

Fig. 11. Structure of fracture of pin,
sample no. 2, magnification 12x

PN-EN ISO 9015-1:2011 [1]. The applied load amounted to 98.1 N. The tests involved the use of the previously prepared metallographic specimens. The test was conducted along a measurement line including the base metal of the elements joined, Heat Affected Zone (HAZ) and the weld as presented in Figures 12 and 13. The hardness measurement results are provided in Tables 1 and 2 below.

The measurements revealed that the welding process did not trigger disadvantageous changes in joint hardness; the hardness did not exceed the allowed value of 380 HV according to standard PN-EN ISO 15614-1 [2]. Therefore it is possible to draw the conclusion that the welded joints are free from disadvantageous structural changes which might favour the generation of damage to the tested hinge elements.

Table 1. Hardness measurement results of samples no's 2 and 3

	Hardness (HV) in measurement points according to Fig. 12														
	Base metal, shape			HAZ			Weld			HAZ			Base metal, shape		
Sample no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2	93.5	93.7	94.0	111	117	128	226	238	284	133	126	119	95.2	98.1	96.1
3	98.1	101	96.1	113	116	134	232	235	240	134	121	117	97.5	96.8	99.2

Table 2. Hardness measurement results of samples no's 4, 5 and 6

	Hardness (HV) in measurement points according to Fig. 13																		
	Base metal, shape			HAZ			Weld			HAZ			Base metal, shape			HAZ	Base metal, shape		
Samp. no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
4	117	108	110	118	118	129	187	191	185	141	126	130	97.1	98.5	92.5	200	196	210	212
5	112	113	109	123	122	137	198	199	211	139	125	117	97.1	99.1	101	117	182	179	189
6	100	95.7	96.0	120	132	149	205	208	208	134	117	114	108	121	120	157	165	188	184

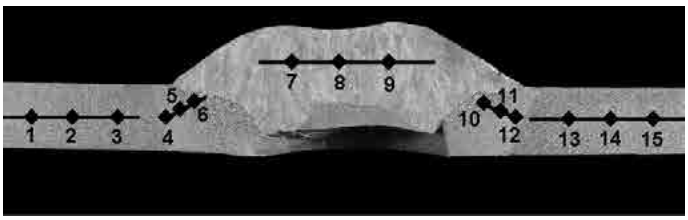

Fig. 12. Arrangement of measurement points
in hardness tests of samples no's 2 and 3

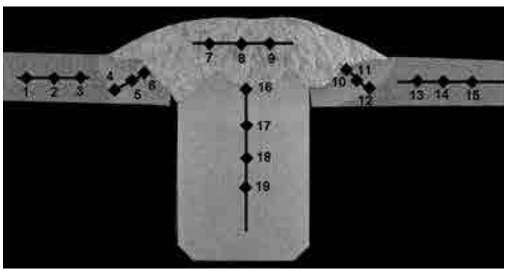

Fig. 13. Arrangement of measurement points
in hardness tests of samples no's 4, 5 and 6

Development of improved welding technology

Another stage of the research was to determine welding technological conditions ensuring fusion on the whole cross-section of the opening and pin as well as process repeatability. After carrying out comparative tests of manual welding around the opening circumference by means of electrode wires with diameters of 0.8 mm, 1.0 mm and 1.2 mm and using spot welding it was ascertained that the welding technique used before should be replaced with spot welding.

When a spot weld is being made a T-shape is pressed (by means of a welding torch gas nozzle) to the pad on which the pin is placed. Another task of the gas nozzle is to maintain a constant exposed length of wire and ensure the outflow of the shielding gas, e.g. through cut-outs in the lower part of the nozzle. Pressing the gas nozzle is followed by the ignition of the welding arc and the fusion in the pin as well as in the shape material over the pin. The molten electrode material fills up the space of the pin creating reinforcement. The time of spot welding is relatively short (several seconds). It is set on the time relay of the MIG/MAG welding machine. The quality of spot welded joints depends mainly on process parameters and the dimensions of elements in a spot where a joint is made.

Spot welding technological tests were carried out on a station provided with a semi-automatic welding machine equipped with a system for adjusting welding time between 0.1 and 5 s. The station was provided with new instrumentation for the maximum limitation of a human factor during a spot welding process (Fig. 14 and 15). The gas nozzle was provided with a ring ensuring a constant exposed length of wire as well as the centric position of a contact tube precisely in the pin axis. During the welding tests a copper pad was used. The purpose of this was to increase welding parameters and, consequently, obtain the proper shape of a plug weld root.

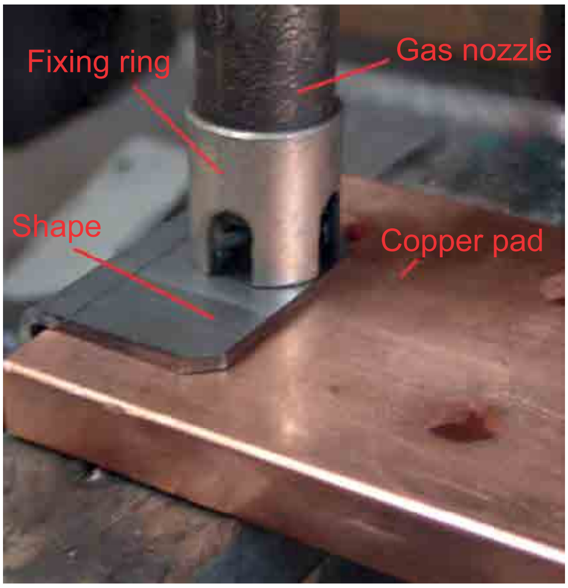

Fig. 14. Instrumentation for spot welding tests

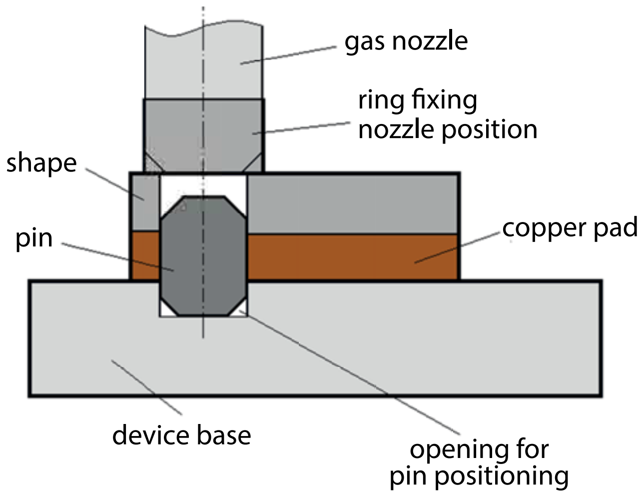

Fig. 15. Scheme of instrumentation for spot welding of hinge elements

The welding tests involved the use of welding consumables (electrode wire and shielding gas) in accordance with a related Welding Procedure Specification. The tests conducted using the electrode wires with diameters of Ø 0.8 mm, Ø 1.0 mm and Ø 1.2 mm revealed that a proper welding process (repeatable arc ignition precisely in the central part of the pin and a deep penetration) can be obtained by using a wire having a diameter of Ø 1.2 mm. The tests involved making joints of pins with a diameter of 7.9 mm placed at different depths in the shape opening with a diameter of 10 mm and 8 mm. During the tests various current and welding times were used. The figures below

(Fig. 16, 17) present the macrostructures of the joints made by means of the modified welding technology and altered process parameters.

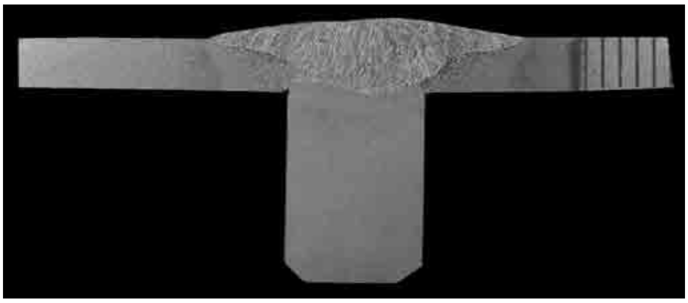

Fig. 16. Macrostructure of spot welded sample no. 18

Fig. 17. Macrostructure of spot welded sample no. 19

Afterwards, a workshop mechanical strength test of welded elements (30 pieces) was carried out. The samples were significantly deformed as a result of being hit with a hammer, yet the welded joints of the pin to the shape were not destroyed (Fig. 18). The workshop strength test revealed that the joints were characterised by a satisfactory quality.

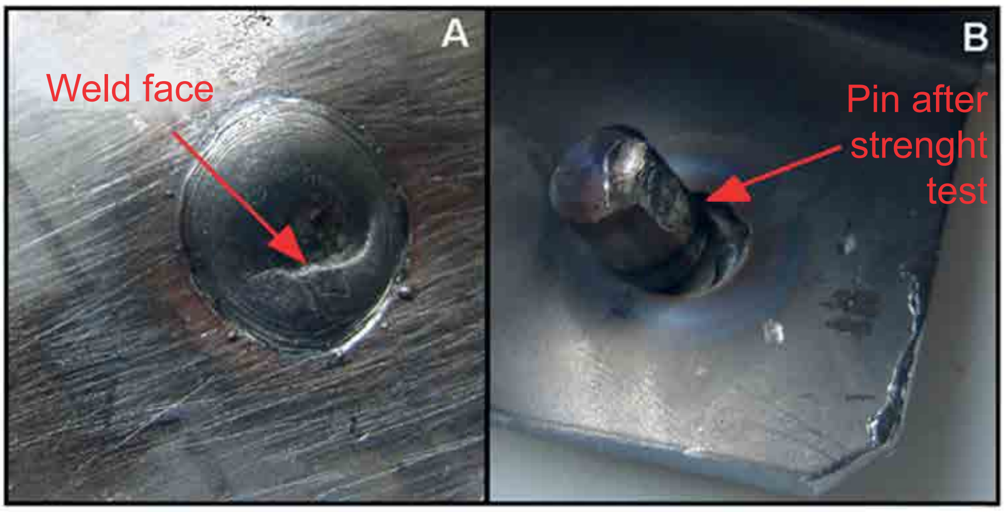

Fig. 18. View of spot welded hinge element after workshop strength tests. Sample was made using parameters identical to those used for sample no. 19

Concluding remarks

The tests of the hinges welded manually by means of the MAG method in accordance with a related Welding Procedure Specification revealed that the reason for a damage to elements under load during mounting or in the workshop mechanical strength test was a notch formed as a result of the improper root penetration of the joint connecting the pin with the shape. The generation of this welding imperfection was favoured by the diameter of the opening in the shape, greater by 2 mm than the diameter of the pin. In turn, no unallowed hardness increase in the welded joint area was observed. The quality of manually made joints was predominantly influenced by the welder skill. As the tests carried out in relation to this study revealed, the technique of manual girth welding failed to ensure the repeatable quality of welded joints. The continuation of welding hinges according to the previously used technology required improvement of the welding technique by welders.

The comparative tests of manual welding along the opening circumference as well as the tests involving spot welding revealed that the previously used welding technique could be replaced with spot welding. This process is partly mechanised and thus limits the influence of the welder's skill on the quality of joints as the welding torch remains fixed while a weld is being made. The spot welding tests conducted with related instrumentation for fixing the position of the pin in the opening as well as the macroscopic tests enabled the determination of technological conditions which ensure the obtainment of quality joints. During the tests it was also determined that the diameter of the opening in the shape should be reduced to 8 mm. The workshop mechanical strength test of the spot welded elements revealed the repeatable quality of the joints tested.

An advantage of the modified welding technology, in addition to the limitation of the welder's manual skill in achieving joint quality, is the obtainment of a more convenient joint geometry – the reinforcement is lower than in the case of the manual welding technology. As a result, post-weld mechanical treatment can be reduced.

On the basis of the analysis of the results of the macroscopic metallographic tests, hardness measurements, technological tests and the workshop mechanical strength tests of the joints, it is possible to formulate the following conclusions and recommendations:

1. The reason for damaging hinge elements during mounting was the improper technique of manual welding leading to the production of joints characterised by inadequate and asymmetric penetration into the pin material. This insufficient penetration was also responsible for the generation of an inconvenient notch in the fusion zone, caused by a 1 mm distance between the pin surface and the wall of the opening in the shape. As a result, the quality of welded joints was predominantly dependent on the welder's skill.

2. The proper penetration of a plug weld, satisfactory quality of the joint connecting a pin with a shape and the repeatability of a process can be obtained by means of spot welding based on the technology developed. Application of the technology entails the modification of the instrumentation fixing elements before welding and the reduction of the opening in the shape as well as the use of an electrode wire with a diameter of 1.2 mm.

References

1. PN-EN ISO 9015-1:2011 *Destructive tests on welds in metallic materials. Hardness testing. Part 1: Hardness test on arc welded joints*
2. PN-EN ISO 15614-1 *Specification and qualification of welding procedures for metallic materials. Welding procedure test. Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys*