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The analysis of spot welding joints of steel sheets with closed profile by ultrasonic method

Dariusz Ulbrich *, Jakub Kowalczyk, Marian Jósko, Jarosław Selech

Poznań University of Technology, Institute of Machines and Motor Vehicles, Poznań M. Skłodowskiej-Curie 5, 60-965 Poznań, Poland

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ABSTRACT

Resistance spot welding is widely used in the fabrication of vehicle bodies and parts of their equipment. The article presents the methodology and the results of non-destructive ultrasonic testing of resistance spot welded joints of thin steel sheet with closed profile. Non-destructive test results were verified on the basis of welded joint area after destructive testing. The obtained results were used to develop an assessment technique for spot welded joints of closed profile with steel sheet, which could be used in factories employing such joints. In addition, the article makes comparison between the costs of the developed assessment technique and currently used destructive method.

1. Introduction

Resistance spot welding is an efficient joining process widely used in the fabrication of the auto-body assemblies. These connections [9] made on a steel scaffolding maintain adequate stiffness of the structure during fatigue loads (during the operation of the vehicle) or in critical conditions during a collision or a traffic accident [5]. Typically, the joined elements are steel sheets of the same or similar thickness (from 0.7 to 2 mm). In addition to steel sheets, aluminium body panels are also subjected to resistance spot welding, which requires the application of suitable equipment (electrodes with specified geometry) and maintenance of required welding parameters [4,16]. Resistance spot welding is so widely used in the automotive industry, because it has excellent techno-economic benefits including, among others, the high suitability for automation, which shortens the process duration [1] and relatively low cost of production, especially high volume.

Gedeon and Eagar [8] described the mechanism of developing a nugget of a single weld, whose proper shape and strength significantly affects the quality of the entire vehicle body. Raoelison et al. [17] found that the quality of the spot weld is a function of the weld nugget size formed as a result of current flow and pressure of the welder's electrode. In addition, Kang et al. [11], Wang and Barkey [23] focused on the fatigue life of spot welds subjected to different loads. For many years, research is being carried out on the causes and methods of detecting and ways of preventing defects that may occur in the spot-welded joints [20].

Lee et al. [13] described a system based on neural networks and fuzzy logic, which is intended to monitor the manufacturing stage of spot-welded joint. In addition, in the 60's of the last century ultrasonic method was used to examine the spot-welded joints in various industries and it is used up to date [3,6,12]. Apart from the statistical evaluation, it allows for a thorough verification of developed joints carried out on the basis of destructive testing and measuring the diameter of the

* Corresponding author at: Poznań University of Technology, Faculty of Machines and Transport, M. Skłodowskiej-Curie 5, 60-965 Poznań, Poland. Tel.: +48 512862197.
E-mail address: dariusz.ulbrich@put.poznan.pl (D. Ulbrich).

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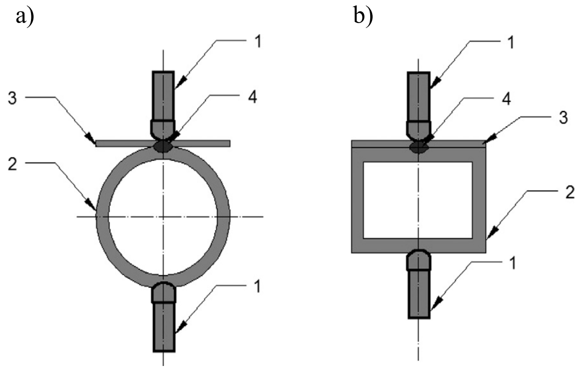

Fig. 1. Scheme of welded joints of steel sheets with closed profile: a) sheet – circular cross profile, b) sheet – rectangular cross profile; 1 – welder's electrode, 2 – closed profile, 3 – steel sheet, 4 – weld nugget.

weld nugget of randomly selected joints from the entire series. Attempt to estimate the diameter of the weld nugget with the use of ultrasonic wave was made by Rokhlin and Adler [18]. Now, in factories producing automobiles ultrasonic method is widely used to control the steel sheet welds. Spinella et al. [21] found that the ultrasonic method provides a reduction in costs associated with the control of welded joints. However, the same work confirmed the conclusions contained in the Mozurkewich publication [15], concerning the relevant qualifications and skills of ultrasonic controllers, especially those who test the welds with the A-scan technique.

Ultrasonic testing of aluminium spot welded joints is also conducted in the C-scan technique, and the resulting images allow controlling both the diameter of the weld nugget and its shape [22]. Modern factories also use systems of measuring welds during its realization, and sometimes the welding process is controlled on the basis of signals from the ultrasonic transducers placed in the welder's electrodes [7,10,14]. In addition, Schubert et al. [19] presented possibility of use the modern ultrasonic equipment for resistant spot welding (e.g. US matrix array system).

This article attempts to apply the ultrasonic method (A-scan) and develops evaluation procedure of a specific type of joints, sheet steel spot-welded with closed profile, which is used in the fabrication of modern car seats. Such connections carry the loads of the human weight and the forces that occur during acceleration, braking and turning. Seat frame should also transfer the loads and keep required properties during accident.

2. Experimental study

The first stage of the experiment included the number of spot-welded joints of steel sheet with closed profile, which has been prepared on the production line of automotive vehicle interior components. The study used two different types of joints that connected steel sheet (1 mm thick) with a closed profile. In the first case, it was a tube with a diameter of 40 mm and a wall thickness of 3 mm. In the second case, the metal sheet was connected with a closed profile having a rectangular shape and dimensions of 10×25 mm and a wall thickness of 2 mm. Welded material was steel, which was carefully selected by the manufacturer of tested components of vehicle interior equipment. Fabrication of spot-welds in the case of connecting the above mentioned elements requires the use of appropriate welder's electrodes, which include electrodes of varying size and shape, for example, spherical, cylindrical or conical. Welding process parameters have been chosen in such manner that the diameter of the weld nugget meets the requirements and standards of the manufacturer (after destructive testing it equaled at least 4 mm) and the joint is of high quality.

In the case of presented welded joints, applying electrodes is essential, especially for closed profile, which is not directly the place of weld nugget formation (Fig. 1). This is an important difference that distinguishes the tested welds from classic joints (sheet–sheet).

Cross-sectional view of the tested joint after it has been cut is shown in Figs. 2 and 3.

The second stage of the experiment used ultrasonic method to evaluate performance and quality of previously manufactured welded joints. Ultrasonic flaw detector USLT 2000 was used with a set of standard ultrasonic probes of high-frequency (20 MHz) with water delay dedicated for spot welds control. The shape of the delay line is cylindrical and the tank with water was closed. At the end of transducer was membrane fixed for better stick to the surface during the test. The diameters of the ultrasonic transducers were chosen for the minimum diameter of the weld nugget, which should be 4 mm.

3. Results

Selected results of ultrasonic and mechanical (destructive) tests carried out on a series of welded joints of steel sheet and closed profile (circular and a rectangular sections) are summarized in Table 1. The most important ultrasonic control parameter is the number of echoes and the so-called intermediate echoes, which may indicate an incorrectly performed joint. When testing standard procedure of welded joints (sheet–sheet) is carried out, joint thickness denoted as RWS is also

Fig. 2. General view of welded joint cross-section.

Fig. 3. Macrographic view of welded joint cross-section.

Table 1
Ultrasonic test results for selected joints sheet–closed profile.

Item No.	Number of echoes	Number of intermediate echoes	Weld thickness	Diameter 1	Diameter 2	Evaluation of the joint
1	3	0	2.56	7.47	5.87	Proper
2	4	5	2.25	0	0	Stick weld
3	5	5	2.26	0	0	Stick weld
4	3	0	2.39	6.78	4.23	Proper
5	3	1	2.71	6.25	6.65	Proper
6	2	0	3.13	7.34	6.56	Proper
7	5	4	1.98	4.6	3.19	Small nugget
8	4	0	2.1	5.97	5.1	Proper
9	5	0	2.04	7.3	5.3	Proper
10	4	0	2.03	6.97	4.2	Proper

controlled. The thickness measurement is difficult for presented welds and virtually impossible to realize in the conditions of industrial control. This is due to joints' characteristic shape and structure, since one of the welder electrodes does not touch directly the location where the weld nugget is formed. Therefore, it is difficult to determine the appropriate deformation of tested items, which is formed upon pressing the electrode to the sheet and closed profile, and thus the thickness of the tested weld.

For mechanical testing, the controlled parameter is the diameter of the weld nugget measured in two perpendicular directions after destructive testing of the joint. In addition, Table 1 shows determined joint quality based on the ultrasonic parameters, which was confirmed by mechanical tests.

Examples of impulses obtained during welded joints testing are shown in Fig. 4 (impulses for a correctly performed joint) and Fig. 5 (incorrectly performed joint–sticking).

For a properly performed weld joint the ultrasonic flaw detector screen showed four echoes (from the bottom of the joint) and the corresponding destructive tests confirmed the appropriate diameter of the weld nugget (Fig. 6). For other properly performed welded joints the number of echoes ranged from 2 to 5.

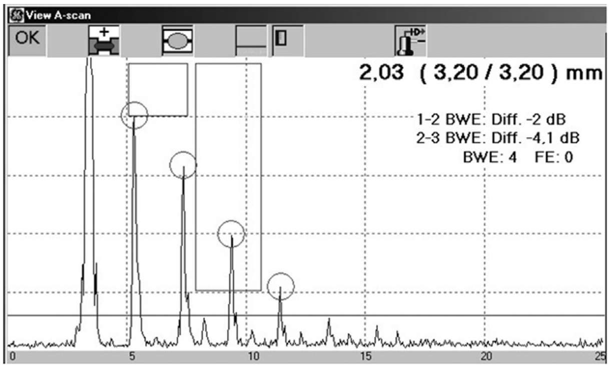

Fig. 4. The configuration of ultrasonic impulses obtained during the implementation of tests for a properly performed weld joint.

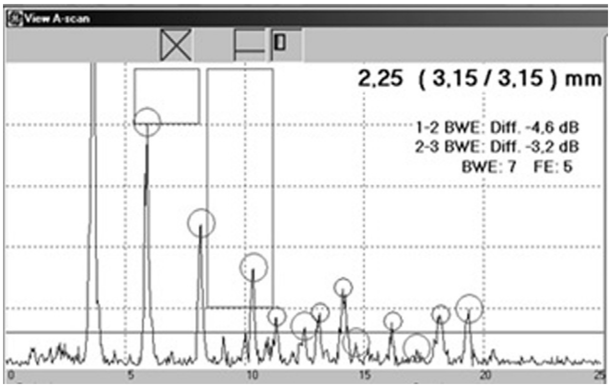

Fig. 5. The configuration of ultrasonic impulses obtained during the implementation of tests for an improperly performed weld joint–sticking.

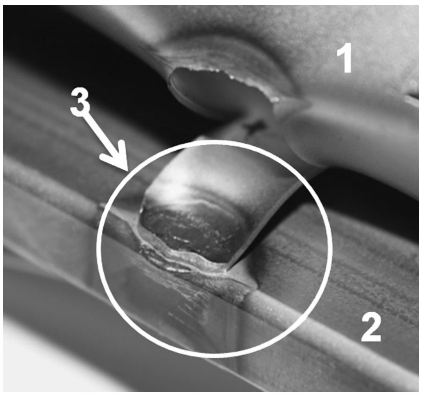

Fig. 6. View of the weld nugget after destructive testing of welded joint–properly performed joint; 1) steel sheet, 2) closed profile, 3) surface fracture.

Detected improperly performed welded joint (Fig. 7), in which adhesion occurred, is characterized by the presence echoes from the bottom of the joint but also the so-called intermediate echoes. In the welded items (sheet and closed profile) there was no remelting in the electrodes pressure zone, therefore after destructive testing the lack of weld nugget was found.

Summing up the research results it should be noted that the above-mentioned defects in spot welded joints of steel sheet and closed profile (sticking, too small nugget diameter) may be due to misalignment of the electrodes performing them. Lack of alignment of electrodes' changes the pressure force, whose proper value is necessary to perform a correct joint. This situation is related to the location of welded joints on car seat elements and the need of applying lengthy and often complicated shapes of the special arms to which welder's electrodes are attached.

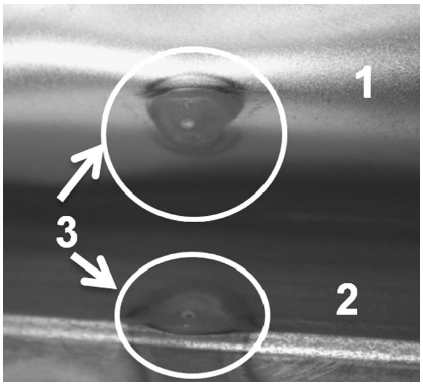

Fig. 7. The view of the weld nugget after destructive testing of welded joint–improper joint (sticking); 1) steel sheet, 2) closed profile, 3) place of contact point.

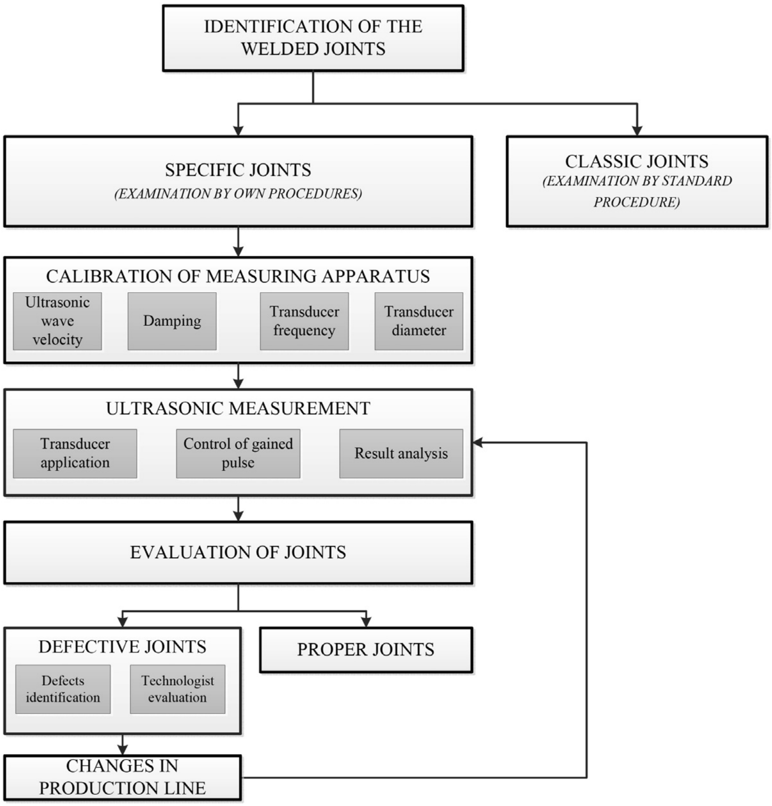

Fig. 8. Ultrasonic testing procedure for spot welded joints of sheet with closed profile.

4. Testing procedure

The ultrasonic tests enabled the development of quality control procedures of sheet steel and closed profile welded joints (Fig. 8), which can be used in factories manufacturing automotive vehicle equipment components. The main elements of this procedure is calibration of the ultrasonic flaw detector, by which is meant the choice of properly developed program and the proper execution of the measurement, which is often a practical problem and can have a negative influence on the result of ultrasonic tests.

5. Case study – analysis

As it was already mentioned, non-destructive control using ultrasonic method may in many cases replace traditional destructive methods used for testing welded car seats elements, (welds between closed profile and sheet). The purpose of the analysis of the product, in this case the frame of an automotive vehicle's seat, is to determine whether destructive or non-destructive investigation of steel sheet and closed profile spot welded joints is more favourable from the point of view of the company. The period of analysis was defined for five years, according to the approved period in which the purchased equipment will operate efficiently. Generally accepted cost model by Fabrycky and Blanchard [2] assumes that the final moment of the analysis is the liquidation or sale of the product.

In the analysed case, the vast majority of costs are production losses, which will exceeded the costs of acquisition and operation, which in turn determines the present value of the investment. Application of non-destructive methods to verify welding parameters brings about many benefits including: rapid identification of defective welds, a large number of verified items in a short time and reduction of production losses. For comparison, in the case of traditional destructive methods, the acquisition of equipment necessary to conduct control of weld quality is not very high; however, the time needed to verify the defective weld components is quite long. A thorough check of one frame, which has approximately 50 welds requires approximately 8 hours. In case of a positive identification of defective sample, the entire batch of products from a given shift is withdrawn, which in this case involves the withdrawal of 480 manufactured frames. Such a large amount of waste products generates high costs resulting from delays, which translates into fees in the supply, great losses of materials used in the manufacture of frames and non-effective work time for staff members.

For non-destructive methods using ultrasonic waves, with similar effort of two employees, each of them is able to verify approximately 10 frames per hour, which gives approximately 160 frames a day. In addition, feedback on irregularities in production is almost immediate allowing for quick response and immediate identification of defect causes in the production process. This gives the company very large savings at the stage of production phase. Higher costs need to be incurred in the initial phase including the purchase of control equipment and any specialized training of workers. However, these costs will be recovered very quickly, the method will bring large savings to the company. Details of the case study costs were reserved by the manufacturer and have not been included in the article.

6. Conclusion

Based on the research it can be stated that:

- Resistance spot welding can be used to produce an acceptable quality of welded joints of steel sheet and closed profile.
- Ultrasonic method allows for non-destructive quality evaluation of welded joints of steel sheet of low thickness with closed profile.
- Studied joints of steel sheet with closed profile presented defects in the form of sticking (no remelting), despite the fact that connected elements did not have coating that protects them from corrosion.
- Cost analysis showed that the high costs of acquisition and possession of ultrasonic equipment are balanced by its applicability, which in turn leads to cost savings in the production stage.

The study demonstrated the possibility of using an ultrasonic method for the evaluation of the specific type of joints of spot welded steel sheet of low thickness and closed profile. During the research unclear results of ultrasonic testing were obtained occasionally. In that case, the tested connection were destroyed and analysis of the causes of failure was performed. The testing method presented in this article can be used in factories producing contemporary automotive vehicle equipment.

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