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Application of Active Thermography in the Quality Control of Laser–Welded Overlap Joints

Abstract: The article presents possibilities of using active thermography as a non–destructive method verifying the quality of laser-welded joints made of steel sheets. The article presents the testing methodology and the preparation of test joints as well as describes a new test rig currently implemented in the company. Thermographic images obtained in the tests were subjected to image analysis processing performed to identify the maximum “temperature” gradient distribution in the test joints. The thermographic image analysis results were verified by cross-sectional macroscopic tests performed in accordance with currently valid standards. The results obtained in the tests confirmed that the method developed and implemented in the company can be successfully applied when assessing the quality of laser-welded lap joints. The article also includes a brief description of SITECH Ltd.

Keywords: laser welding, active thermography, quality control

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Introduction

The necessity of achieving increasingly high productivity when making welded structures entails the implementation of increasingly many automated or robotic welding stations as well as the use of highly efficient joining methods (laser welding, hybrid welding etc.). Laser welding technologies are also becoming increasingly more popular in the automotive industry where they are used in the production of car bodies, seats and other components assembled using joining methods.

Highly efficient joining methods usually replace traditional ones, e.g. spot resistance welding. The advantages of the new methods include high power density, high welding rate and the ease of process automation and robotisation. Laser technologies also enable the use of smaller sized overlaps than those required in resistance welding, where the size of an overlap is limited by the size of electrodes and protection against undesirable spatter. Laser welding makes it possible to design joints accessible only from one side of sheets/plates being joined without compromising the process of joining or the rigidity of the structure requiring joints along the entire length of overlaps [1]. In addition, laser welding is used when repairing elements where an improperly selected spot resistance welding technology led to the formation of improper spot welds [9]. The comparison of overlap joints made using laser and spot resistance welding (with easily visible advantages of the laser weld) are presented in Figure 1. However,

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laser beam welding not only brings advantages but also creates numerous challenges, e.g. the necessity of making more precise elements to minimise the gap between sheets, the use of significantly more expensive welding fixtures for the positioning and pressing elements during assembly and welding or, last but not least, the use of significantly more expensive complex equipment required in laser welding.

Fig.1. Comparison of the design of the overlap in laser weld and spot-weld

The quality of welded joints is highly affected by the process of welding. Therefore, to ensure the obtainment of good mechanical and aesthetic properties of joints, it is necessary to properly adjust welding conditions and parameters and, more importantly, to maintain their stability during the entire process [3]. One of the methods ensuring process stability consists in the continuous monitoring (measuring) of welding parameters. For instance, in MAG welding, parameters requiring special attention include welding current, arc voltage, shielding gas flow rate, whereas during laser welding attention should also be paid to source power measurements. In addition to the supervision over the above-named parameters, the use of conventional quality control methods, e.g. ultrasonic or radiographic tests, is presently absolutely necessary in any facility making welded structures [8]. Improperly selected technological processes could lead to the formation of imperfections which, if undetected, might result in structural failures posing hazard to human life [4] [10]. The stability of welding processes is often disrupted by incidental factors such as impurities, inaccurately prepared edges or thermal expansion-induced strains of elements being joined. Such factors may lead to the formation of various welding imperfections including excessive undercuts, lacks of penetration, cracks, burn-throughs, excess weld face penetration, incompletely filled groove, gas pores and many others [3]. Sometimes, even properly adjusted laser welding parameters and conditions do not prevent situations where two sheets are not joined (locally or completely), compromising the strength of finished products or, in extreme cases, putting human life at risk [1]. In terms of car seats, in addition to reduced structural strength, the lack of properly made laser welded joints could increase operational noise and, eventually, result in customer complaints. The above-presented issues are behind the development of new non-destructive testing methods enabling the control of joints made using laser-based and other welding technologies.

Presently, automated welding stations often enable the use of adaptive (constituting part of the production process) methods of welding process control [2,4]. Industrial applications include numerous methods allowing welding process supervision and joint quality control during welding. One of such methods is the visual control of welding processes involving the recording of welded joint images both in the range of visible radiation as well as in the range of near and far infrared, followed by their analysis. The most important advantage of visual methods is the possibility of the fast detection of welding process disruptions, mistaken positioning of elements being welded and the elimination of welding imperfections in entire lots of welded products. In addition, the above-named control increases production efficiency and reduces or even eliminates the necessity of performing cyclical destructive tests aimed to assess the internal structure and mechanical properties of obtained joints [2÷4]. Scientific publications rate methods based on the analysis and interpretation of infrared images among the most promising methods enabling the assessment of welding processes and welded joints, among other things, since they do not require the contact of a measurement system with an element being tested [3,7]. The possibilities resulting from thermography have frequently been used in various industries, e.g. during the non-destructive tests when identifying cracks in small concrete and stone bridges or bridges over motorways [5,6] as well as when supervising arc welding processes or assessing the quality of adhesive joints [4,8]. The intensive development of thermographic applications in industry and increasingly high emphasis given to the quality of elements were the major arguments for the implementation of the innovative active thermography-based method developed by Sitech Ltd. and enabling the quality control of laser-welded joints.

Company

Sitech Ltd. is a renowned company belonging to the Volkswagen concern; the company specialises in the design and production of car seat metal frames for selected models of car makes including Volkswagen, Audi, Skoda or Porsche. The use of advanced technologies in production and quality control enables the Company not only to satisfy the highest production and quality-related standards but also contributes to environmental protection. Presently, in Poland the Company has three production facilities, i.e. in Polkowice, Głogów and Września (Poland).

Objective of Tests

In order to demonstrate the possible use of active thermography for the qualitative assessment of laser welded overlap joints it was necessary to develop a schedule of tests including the preparation of (proper and improper) specimens, programme the movements of the robot making it possible to reach required areas, and select the most appropriate method of thermographic measurements (transmission or reflection) as well as the method enabling the verification of obtained results.

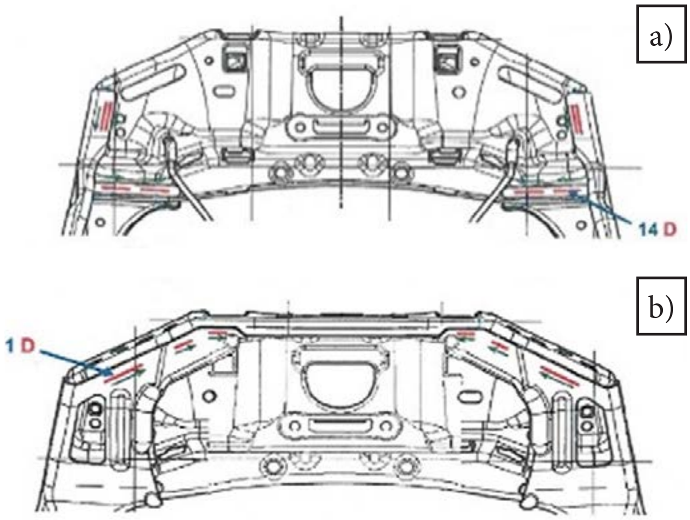

Fig. 2. Location of test welds: a) front view, b) rear view

Preparation of Test Specimens

The tests involved the use of two opposite types of specimens (in terms of quality): proper joints with full penetration along the entire length and improper joints without penetration (i.e. incomplete fusion – imperfection no. 401 according to DIN-EN ISO 13919-1:1996–09) in the lower sheet along the entire length. The proper welds/laser-welded joints were selected from those made in the process of serial production, using a welding booth and standard parameters (Table 1). The welding station was composed of a welding robot (Fanuc) and a TruDisk disc laser (Trumpf) having a maximum power 4 kW. The location of the test

Table 1. Welding parameters used when making proper welds

Weld no.	Beam power [kW]	De-focus [mm]	Welding rate [mm/s]	Start of programme – power [%]
1	3.8	+ 5.0	75	100
14	3.8	+ 4.0	88	100

Table 2. Welding parameters used when making improper welds

Weld no.	Beam power [kW]	De-focus [mm]	Welding rate [mm/s]	Start of programme – power [%]
1	3.8	+ 5.0	170	100
14	3.8	+ 4.0	190	100

Fig. 3. Test parts with proper welds:
a) front view, b) rear view

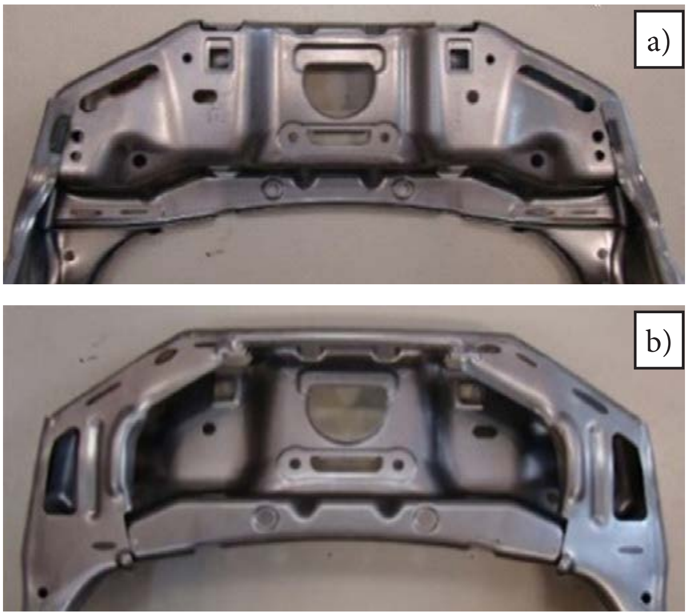

Fig. 4. Test parts with improper welds:
a) front view, b) rear view

Fig. 5. Proper welds on the face and root side

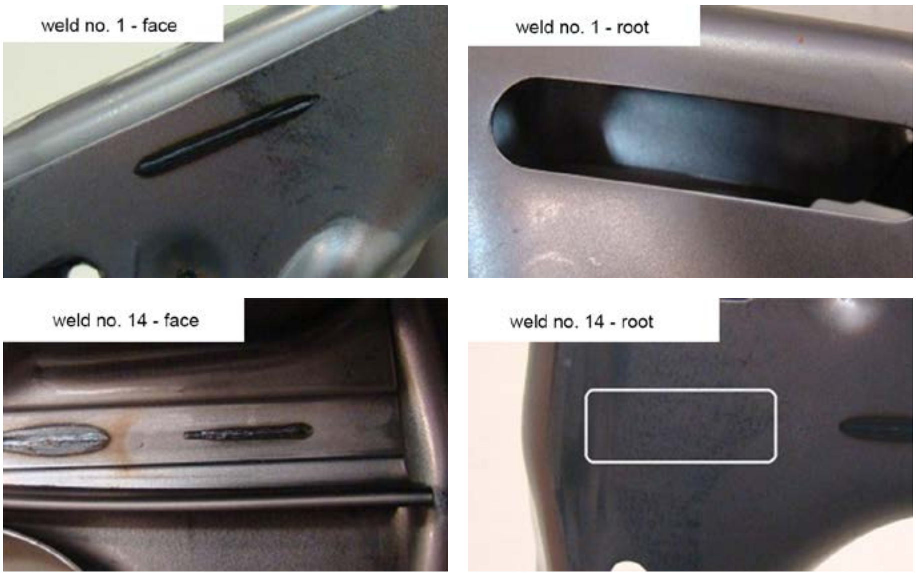

Fig. 6. Improper welds on the face and root side

joints on a welded element is presented in Figure 2. The improper joints were made using the same welding booth after changing parameters (see Table 2). The parameter subjected to a change was the welding rate (approximately 2.2 times).

The overlap joints were composed of two steels grades, i.e. steel HC420LA according to DIN EN 10268:2013-12 and dual phase steel DOCOL 800DP (produced by SSAB) having thicknesses of 0.8 and 0.9 mm respectively, placed in a manner enabling the formation of an overlap joint. Figure 3 and 4 present a fragment of a car seat backrest frame containing test welds; Figure 5 and 6 present the test welds on the face and root side.

Because of the lack of visible root penetration in the welds prepared as improper, the visual tests would not make it possible to ascertain whether the required joint was present in the lower sheet. In such a situation, in order to identify the level of joints, a standard procedure would require the use of a classical destructive method involving macroscopic tests. It should be noted that the visible penetration present in the root of a laser weld is not tantamount to the joint between the sheets.

Test Rig

The experimental tests involved the use of a test rig implemented at SITECH Sp. z o. o. (Ltd.) in Polkowice.

Fig. 7. Test rig

The primary components of the test rig included a robot made by Fanuc M-20iA, a Flir SC5500-M thermographic camera (Fig. 7), two compressed air vessels and nozzles. The operation of the device consisted in the cooling of the test area using compressed air (approximately 8 bar) flowing through the nozzle. The air was supplied by the 10 bar company system and stored in two vessels. When the robot with the thermographic camera and the nozzle directing the cooling air stream reached a specified position (Fig. 8), the air was released onto the surface of the weld. The test area was cooled by approximately 2-3°C, which led to the flow of heat from the hotter area to the cooler one (in accordance with the second law of thermodynamics). The entire process was recorded using the thermographic camera. The film containing the recording of the cooling process followed by the reheating of the test area was uploaded to the measurement software programme and subjected to appropriate processing enabling the presentation of results in the form of thermograms.

Fig. 8. View of the measurement position for weld no. 14

The cooling process was recorded using a Flir SC5500-M thermographic camera with the cooled matrix of InSb detectors (indium antymonide) having a resolution of 320 × 256 px and making it possible to observe infrared radiation in the band of the average length of 3.7-5.0 µm. The operation of the camera was fully synchronised with a measurement software programme enabling the automated operation of the entire system. During measurements, the camera was inclined by an angle of approximately 5° in relation to the examined surface. The use of the above-named angle aimed to minimise the unfavourable effects of the reflections of other heat sources which could occur because of the very low emissivity of steel materials subjected to welding (approx. 0.5). Before the commencement of the automatic measurement cycle, all the laser welds subjected to tests were cleaned of any impurities, oil etc. The analysis and assessment of thermographic images was performed using the original software programme developed by the equipment producer in the LabView system.

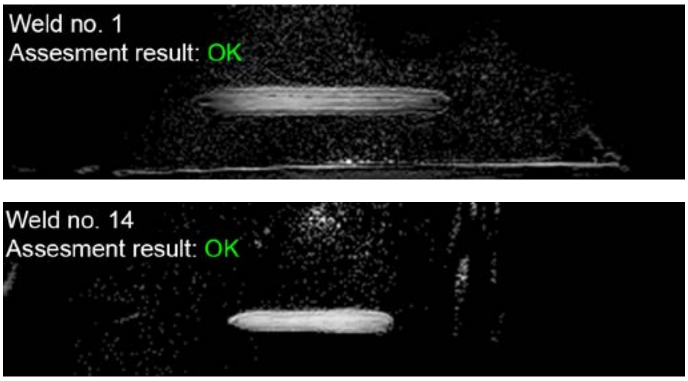

Fig. 9. Thermograms of proper welds (no. 1 and 14)

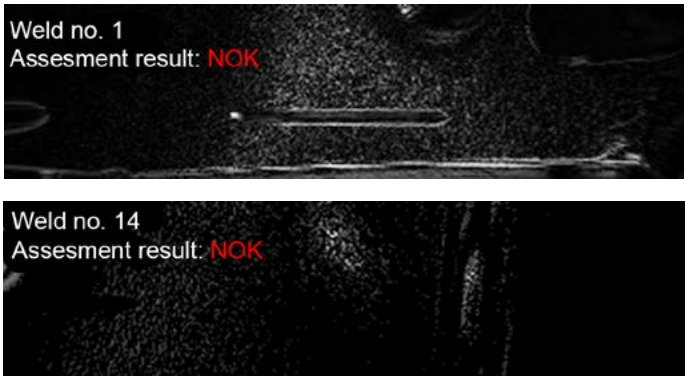

Fig. 10. Thermograms of improper welds (no. 1 and 14)

Analysis of Results

The tests led to the obtainment of thermographic images (Difference Image Transmission) presenting the quality each of the selected joints (Fig. 9 and 10). Both thermograms were developed using a method of thermographic image analysis enabling the obtainment of the most precise and reliable experimental results.

The thermograms presenting properly made welded joints are characterised by the presence of the bright area indicating the physical connection of the sheets. The bright area recorded by the thermographic camera informs about the flow of heat from the surface on the weld face side (joint no. 1) or weld root side (joint no. 14) causing the reduction of temperature to that of the cooled area on the other side of the joint. The thermograms of the improper welds did not reveal the presence of the characteristic gradient temperature area, which indicates the lack of a joint.

Macroscopic Tests

Figures 11 and 12 present the macroscopic images of the welded joints (to correlate the images with the results of the thermographic tests). All the properly made welds were characterised by full penetration (Fig. 11), whereas improper joints contained incomplete fusions in the lower sheet, entirely disqualifying given welds (Fig. 12). The metallographic specimens of both types of joints were made at the half of their length. The assessment was based on the guidelines of the VW 01141:2016-04 concern standard and of the DIN-EN ISO 13919-1:1996-09 international standard.

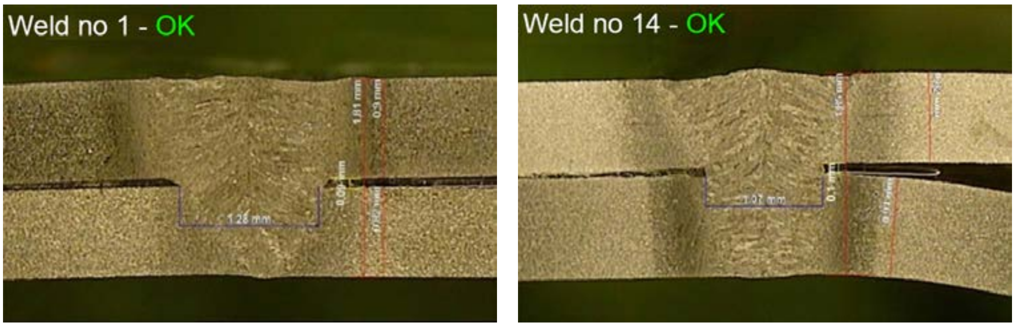

Fig. 11. Macroscopic pictures of proper joints

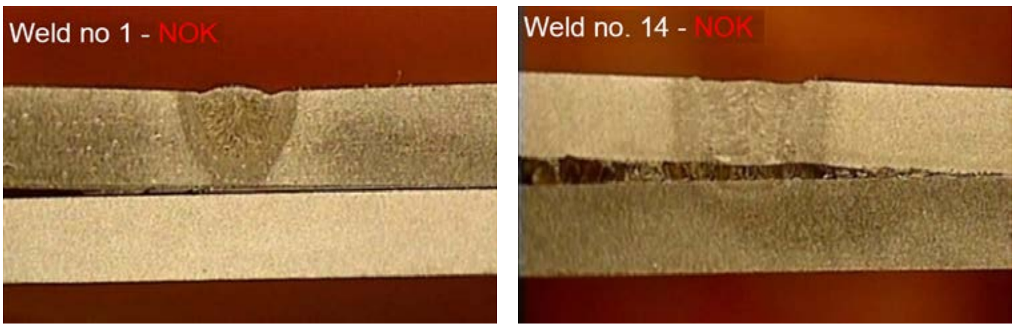

Fig. 12. Macroscopic images of improper joints

Summary

The results of the experiment justify the use of active thermography as a non-destructive method for controlling the quality of laser welded overlap joints. The experimental tests involved the simulation of a laser-made weld imperfection, i.e. incomplete fusion over the entire length of the joint. Afterwards, using the excitation of temperature gradient and the flow of heat in the test joint, the imperfection was identified in thermographic images. The test results were confirmed by the cross-sectional macroscopic examination of the welds. The experiment was performed using a thermographic test rig in the material laboratory at the quality assurance department. The above-named test rig will ultimately be used for the serial quality control of laser welded products. The implementation of the innovative technology will allow the limitation of laborious destructive tests (macroscopic and peeling tests). In addition to an increase in quality control, the major advantage of the above-presented solution includes the possibility of returning (if necessary) an inspected element directly to the production department immediately after the completion of measurements and obtainment of results. Consequently, the company will not incur additional costs by generating scrap. The method will continue to be developed regarding the possibility of detecting surface and internal imperfections including gas pores and, primarily, in order to able to precisely determine penetration depth.

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Standards

- VW 01141-1:2016-04 – *Laser Beam welding – Sheet Steel Joints*
- DIN-EN ISO 13919-1:1996-09 – *Schweißen – Elektronen- und Laserstrahl- Schweißverbindungen Leitfaden für Bewertungsgruppen für Unregelmäßigkeiten – Teil 1: Stahl*
- DIN EN 10268:2013-12 – *Kaltgewalzte Flacherzeugnisse aus Stählen mit hoher Streckgrenze zum Kaltumformen – Technische Lieferbedingungen*