DEFECT DETECTION OF RESISTENCE SPOT WELDS USED IN AUTOMOTIVE INDUSTRY BY NON-DESTRUCTIVE TESTING

Lucie FOREJTOVÁ [1, 2], Tomáš ZAVADIL [2], Ladislav KOLAŘÍK [1], Marie KOLAŘÍKOVÁ [1]

[1]CTU - Czech Technical University of Prague, Faculty of Mechanical Engineering, Technická 4, Prague, Czech Republic, EU, Lucie.Forejtova@fs.cvut.cz

[2]ATG s.r.o., Toužimská 771, Prague, Czech Republic, EU, zavadilt@atg.cz

Abstract

Resistance spot welds (RSW) are one of the main joining technologies of thin plates in automotive industry. Key factors affecting the strength of the RSW joint are the nugget diameter, asymmetry, expulsions, intended surfaces, and presence of cracks. Despite its broad use, the weld quality verification is limited only to destructive testing and small number of NDT methods. Most of the testing is done destructively by sampling, which assesses only systematic defects. Ultrasonic Testing is the most used NDT method to detect nonsystematic defects in the RSW joints however the probability of defect detection (POD) of conventional testing technique is not fully satisfactory. Other approaches were invented to deal with this situation. The article compares the currently most used NDT approach with other options and discusses its usability and mutual interchangeability.

Keywords: Automotive, resistance spot welding, thermography, ultrasonic testing, probability of detection

1. INTRODUCTION

Resistance spot welding is a method of mechanical joining of materials by heat and pressure that allows high productivity. This method is used especially in automotive industry for production of car bodies.

There is a list of factors affecting the quality of resulting weld joint. The most important are stable electrode contact, malfunction of welding equipment, main welding parameters, quality of electrodes, and quality of the sheets surface. For this reason it is necessary to test the spot welds to assess the information about the weld quality and to have a feedback on the welding process [1-3].

Spot welds are often tested by a range of destructive testing methods that can assess systematic defects of the joint. The non-systematic defects are tested by nondestructive testing, mainly by visual (VT) and ultrasonic (UT) methods. This article discusses utilization of a new application of the thermography testing (IRT) for assessment of weld the quality and a feedback on welding process setup.

2. INDUCED HEAT AND TEMPERATURE

Resistance spot welding uses the so-called Joule's heat created by welding current flowing though the welded materials. The spot weld is created when current flows through the welded parts that are being simultaneously pressed together. Due to the electrical resistance on the place of connection of the welded materials the material is melted, simultaneously pressed together, and such a way the metallurgical joint is created. The heat is therefore created directly inside the welded material, and is not introduced from outside. The joint is created by flow of the electric current and the electrode force during a specific time interval.

The total induced heat Q is the higher the higher is the electric current $I\ [A]$, the higher is the electric resistance $R\ [\Omega]$ and the longer is the time interval of the flow $t\ [s]$. That's the known Joule-Lenz formula:

$$Q = U \cdot I \cdot t = R \cdot I^2 \cdot t \tag{1}$$

Induced heat is not constant in the whole area. It is concentrated in the area of the highest resistance. There are several partial electrical resistances affecting the total resistance R. The current flowing through the material in a column with a diameter equal to the approximate electrode diameter shall overcome the transition resistance R_d between the electrode and the material, the resistance of the material R_m affected by the thickness h and the specific resistance of the material. The highest value among the partial resistances has the transition resistance R_k between the joined materials. The resulting total resistance is therefore:

$$R = R_{m1} + R_{m2} + R_{d1} + R_{d2} + R_k \tag{2}$$

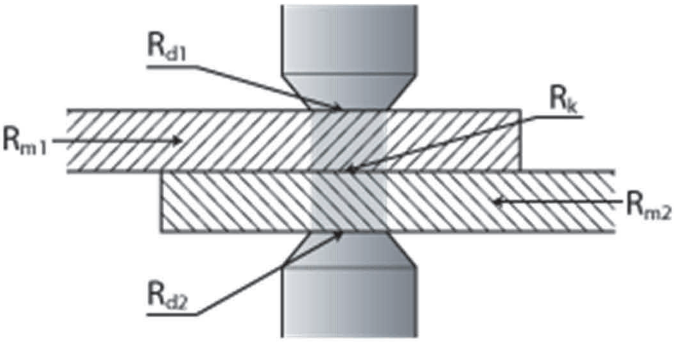

Figure 1 Items of total resistance RSV in welding joint [1]

The highest induced heat is created on resistance R_k where the weld joint is created. Undesirable resistance heat created by transition resistances R_d are partially affected by electrode force in the contact area and the conductivity of electrode tips. In order to avoid damage of the sheet surface by e.g. burning i tis necessary to ensure minimal transition resistance R_d. For this reason the surface of electrodes and the welded materials shall be perfectly clean. Material resistances R_m are provided by physical and mechanical properties of the welded materials, the thickness h, weld design, and the cross-section of the current flow. The welding process is therefore affected also by properties of welded materials, especially material type, thickness, anticorrosion coating and number of sheets in the in the weld [4].Total resistance items of welding joint can be seen in **Figure 1**.

3. RESISTANCE SPOT WELDING OF GALVANIZED SHEET METALS

The modern automotive industry, in order to ensure corrosion protection, utilizes galvanized sheet metals more and more every day. Galvanization however significantly affects the spot welding process of sheets. As explained by Matoušek [4], galvanization reduces the initial resistance and for this reason the temperature curve has smaller slope than it is necessary for good melting in the given time interval. That can be compensated by increase of the welding current. This area is limited from the top by creation of weld spatter (high current) and from the bottom by small weld nugget (low current). High current results to higher temperatures causing the softening of electrode (created from Cu alloys). That results in smaller diameter, in some cases even cold shuts. Except that softened Cu causes more frequent gluing of the newly used electrodes and their faster wear. Increase of contact area reduces the total resistance R and its partial parts. [4]

Perfect spot weld requires the current flow though the electrodes being as uniform as possible. Uniformity can be affected also by relatively low melting temperature of zinc coating that is melting at temperature of 420 °C. During the heating process to the meting temperature of the sheet material the zinc coating is melted first, alloying the CU electrodes. This alloying process is not uniform and it is generally more prominent in the center of the electrode. This changes the transition resistance R_d, that results in fluctuating current flow, irregular nuggets or small nugget diameters.

4. EXPERIMENT

The high-strength, deep-drawn steel DC06 (EN 10152), galvanized by Zn, with total thickness h = 0.7 mm and coating thickness of 4.5 μm was used. This steel is used e.g. by SKODA Auto for model Škoda Octavia.

Table 1 Chemical composition and mechanical properties of DC06 steel

C [%]	Mn [%]	P [%]	S [%]	Si [%]	Ti [%]	Re [MPa]	Rm [MPa]	A_{80} [%]
0.02	0.25	0.02	0.02	0.02	0.3	max 180	270 - 350	41

135 samples (27 batches by 5 samples) with dimensions 45 x 175 mm were welded by resistance spot welding on high-frequency welding device Dalex PMS 11-4. The diameter of the electrodes of 4mm is recommended for these joints by ČSN EN ISO 14373 [3]. The selected diameter of 5mm reflects the common practice in automotive industry. The welding current was adjusted to this change and its values were reduced (the effect of the electric current on required nugget size was discussed by Kolarikova et al. [2]). The samples were welded in batches, the settings verification and maintenance was in the time gap between batches. The welding parameters were selected from the range of values as follows: welding current I of 6, 7 or 8 kA (welding current of 8kA is considered as exceeding the common practice in automotive industry), welding time t of 160, 180 and 200 ms, and electrode force P of 1.9, 2.0, and 2.1 kN. Welding parameters were selected to create both satisfactory and unsatisfactory weld joints.

The welding process was monitored by the thermographic camera FLIR A615 from the distance of 600 mm, top view under the 45° angle. Collected thermograms were evaluated by SW Core Player from Workswell s.r.o. as a part of bachelor thesis of Mach [5]. Measured temperature values from the thermograms were transformed to histograms showing the frequency of occurrence for individual temperatures. Median $q(T)_{1/2}$ a 95-th percentile $q(T)_{95/100}$ was determined from the histogram as the maximal/minimal temperature value are subject to high error and thus being considered as outliers and discarded from the evaluation. It was expected that the unsatisfactory weld will show median and/or 95-th percentile shift due to altered amount of induced heat (e.g. caused by excessive transition resistance R_d). [4] VT of the weld joint was performed after the welding followed by UT of internal and structural defects. Olympus Epoch device with V2450 probe for spot welds, with water wedge and nominal frequency of 20 MHz and nominal diameter of 4 mm were used for UT. The results of the UT are taken from Holub [6].

5. RESULTS

For the purpose of this article 5 batches were selected from the total 27 batches. Batches V8, V9 and V14 satisfied the requirements for welding parameters setup and batches V19 a V20 didn‘t (I = 8 kA).

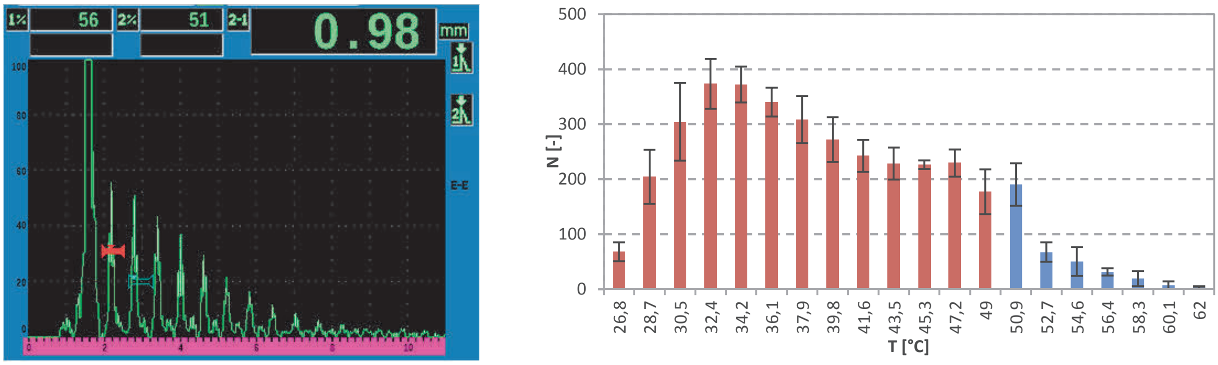

Figure 2 Batch V8 - Echogram of the sample V8-3 by ultrasonic testing (left) and histogram of measured temperatures from batch V8 by infrared thermography (right). Red bars indicate reach of 95-th percentile.

Batch V8 (**Figure 2**)was welded with I = 6 kA, t = 200 ms, and P = 2.0 kN. Echograms of the samples demonstrated linearily decreasing trend with satisfactory amount of backwall echoes. Histogram of the batch V8 had the median of temperature $q(T)^{V8}_{1/2} = (36{,}1 \pm 0)\ °\mathrm{C}$ and 95-th percentile $q(T)^{V8}_{95/100} = (49{,}38 \pm 0{,}76)\ °\mathrm{C}$ - see **Figure 2**.

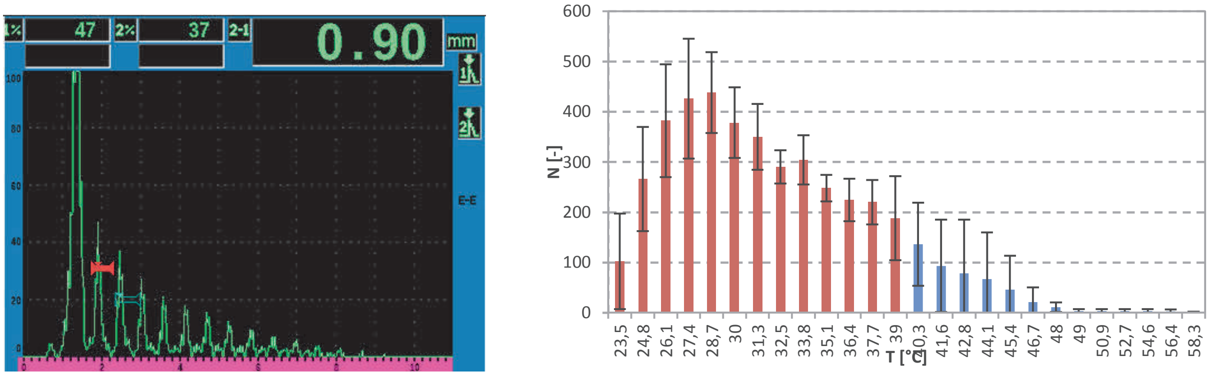

Figure 3 Batch V9 - Echogram of the sample V9-2 by ultrasonic testing (left) and histogram of measured temperatures from batch V9 by infrared thermography (right). Red bars indicate reach of 95-th percentile.

Batch V9 (**Figure 3**)was welded with I = 6 kA, t = 200 ms, and P = 2.1 kN. The echogram of sample V9-2 shown unsatisfactory amount of backwall echoes with values above 20 % FSH, other echograms were in norm. Subsequent tests reveiled Cu from the elctrode on the surface. Histogram of the batch V9 had the median of temperature$q(T)^{V9}_{1/2} = (29{,}74 \pm 0{,}97)\ °\mathrm{C}$ and 95-th percentile $q(T)^{V9}_{95/100} = (39{,}50 \pm 2{,}64)\ °\mathrm{C}$.

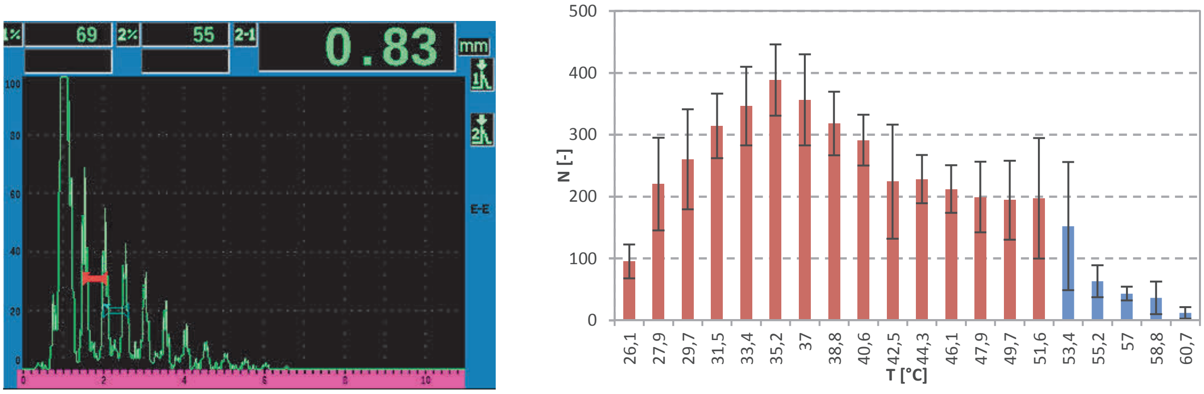

Figure 4 Batch V14 - Echogram of the sample V14-2 by ultrasonic testing (left) and histogram of measured temperatures from batch V14 by infrared thermography (right). Red bars indicate reach of 95-th percentile.

Batch V14 (see **Figure 4**) was welded with I=7kA, t=180ms, P=2.0kN. Echograms of the samples demonstrated linearily decreasing trend with satisfactory amount of backwall echoes. Histogram of the batch V14 had the median of temperature $q(T)^{V14}_{1/2} = (37{,}56 \pm 1{,}38)\ °\mathrm{C}$ and 95-th percentile $q(T)^{V14}_{95/100} = (51{,}98 \pm 1{,}89)°\mathrm{C}$.

Batch V19 (**Figure 5**) was welded with I = 8kA, t = 160ms, P = 1,9kN. Echograms of the samples demonstrated linearily decreasing trend with only 3 recognizeable backwall echoes. The weld was evaluated as burnt [4]. Histogram of the batch V19 had the median of temperature $q(T)^{V19}_{1/2} = (31{,}72 \pm 1{,}38)\ °$ and 95-th percentile $q(T)^{V19}_{95/100} = (42{,}86 \pm 1{,}40)\ °\mathrm{C}$.

Batch V20 (**Figure 6**) was welded with I = 8kA, t = 160 ms, P = 2.0kN. Echograms of the samples demonstrated linearily decreasing trend with only 3 recognizeable backwall echoes. The weld was evaluated as burnt [4].

Histogram of the batch V20 had the median of temperature $q(T)^{V20}_{1/2} = (30{,}93 \pm 0{,}95)\ ^\circ\mathrm{C}$ and 95-th percentile $q(T)^{V20}_{95/100} = (42{,}1 \pm 2{,}21)\ ^\circ\mathrm{C}$.

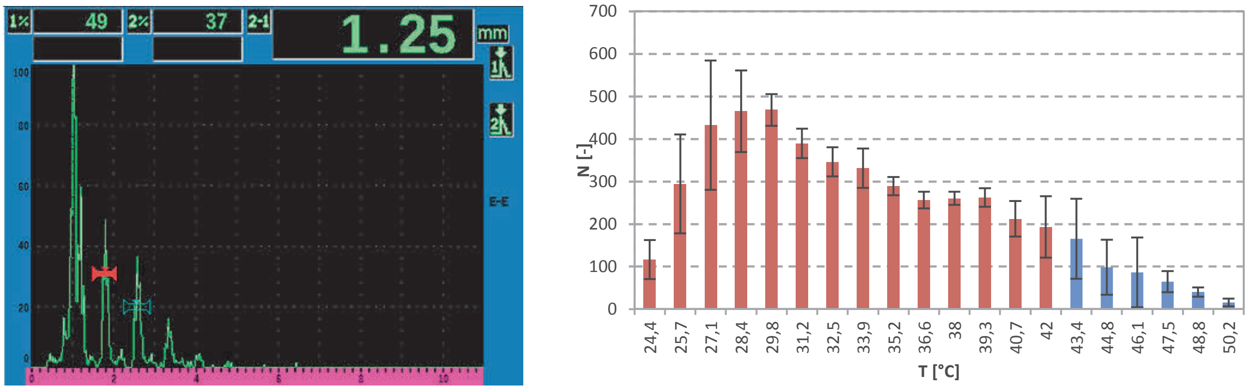

Figure 5 Batch V19 - Echogram of the sample V19-2 by ultrasonic testing (left) and histogram of measured temperatures from batch V19 by infrared thermography (right). Red bars indicate reach of 95-th percentile.

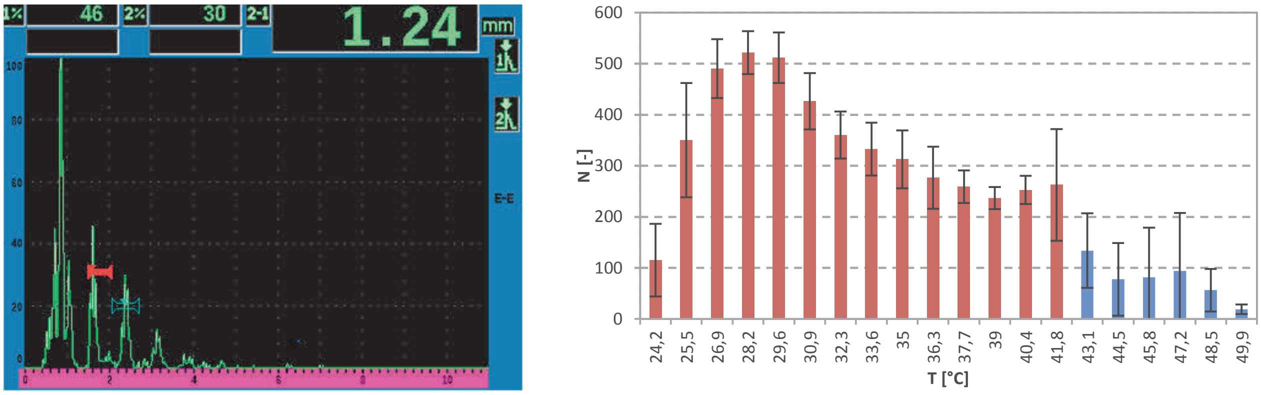

Figure 6 Sample V20 - Echogram of the sample V20-4 by ultrasonic testing (left) and histogram of measured temperatures from batch V20 by infrared thermography (right). Red bars indicate reach of 95-th percentile.

6. DISCUSSION

In the experiment the welds batches were selected to simulate both, satisfactory (V8, V9, V14) and unsatisfactory (V19, V20) requirements of ČSN EN ISO 14373 [3] and the common practice in automotive industry. It was assumed that if the welding process shall be obeyed and UT and VT shall not find any nonsystematic defects the results of batches V8, V9 and V14 shall satisfy the quality criteria and thus have also the same median and/or 95-th percentile of the temperature histogram measured by IRT.

It is visible from the results that the „unsatisfactory“ batches of V19 and V20 reached average median $\bar{q}(T)^{NA}_{\frac{1}{2}} \sim 31{,}32\ ^\circ\mathrm{C}$ and 95-th percentile $\bar{q}(T)^{NA}_{95/100} \sim 42{,}48\ ^\circ\mathrm{C}$, which is significantly less than for the „satisfactory“ batches V8 and V14 with average values of $\bar{q}(T)^{A}_{1/2} \sim 36{,}63\ ^\circ\mathrm{C}$, resp. $\bar{q}(T)^{A}_{95/100} \sim 50{,}68\ ^\circ\mathrm{C}$. These differences can´t be considered as the measurement error as the standard deviation σ measured for each of the batches never exceeded $\sigma^{max}_{q(T)1/2} = 1{,}38\ ^\circ\mathrm{C}$ for median values and $\sigma^{max}_{q(T)95/100} = 2{,}64\ ^\circ\mathrm{C}$ for 95-th percentile. The differences of the average values between „satisfactory“ and „unsatisfactory“ batches exceeded $3\sigma^{max}$ (i.e. $\bar{q}(T)^{A}_{1/2} - \bar{q}(T)^{NA}_{1/2} > 3\sigma^{max}_{q(T)1/2}$, resp. $\bar{q}(T)^{A}_{95/100} - \bar{q}(T)^{NA}_{95/100} > 3\sigma^{max}_{q(T)95/100}$).

Batch V9 satisfied the requirements of the ČSN EN ISO 14373 [3], nevertheless the IRT measurement found median of $q(T)^{V9}_{1/2} = (29{,}74 \pm 0{,}97)\ ^\circ\mathrm{C}$ and 95-th percentile of $q(T)^{V9}_{95/100} = (39{,}50 \pm 2{,}64)\ ^\circ\mathrm{C}$. The values were within range for "unsatisfactory" batches. Further testing by VT and UT revealed presence of Cu on the sheet surface of the sample V9-2, proving gluing of the electrode to the sheet. As these electrodes were maintained once the whole batch was welded, this affected the results of the rest 3 samples of the batch V9.

As noted by Matoušek [4], cleanliness, flatness, and diameter of the electrode tip play significant role in creation of quality welds. Wear electrodes have increased transition resistance R_d, that may cause creation of systematic defects by excessive heat on the electrodes and subsequent reduction of transition resistance $R_k$responsible for production of quality (satisfactory) weld, as proven by batch V9. It is necessary to mention that the UT and VT methods detected only one unsatisfactory result on the sample V9-2 from the whole batch V9. This concludes that the utilization of IRT method may theoretically help with detection of wear and/or damage of electrodes causing systematic errors that cannot be detected by other NDT methods. Confirmation of this statement is a subject of ongoing research activities and the dissertation thesis of the main author.

7. CONCLUSION

The goal of this article was to verify the ability of thermography NDT method to detect low quality welds of resistance spot welding. 27 batches per 5 samples were welded with welding parameters selected by ČSN EN ISO 14373:2015 and common practice in automotive industry. Part of the samples satisfied the requirements and some were designed to do not satisfy them. The samples were tested immediately after welding by thermographic camera and the results were compared with conventional NDT methods for spot welds as ultrasonic and visual testing

The results of the article proven that from the histogram of measured temperatures by thermographic camera it is possible to find characteristic temperature based on median and 95-th percentile. The quality welds demonstrated 18 % higher temperature values than those with low quality (evaluated as unsatisfactory).

This approach detected melting of electrodes tips and its effect on the whole one batch of samples. This result was observed despite the welding process was set to satisfy the requirements of the standard. Other NDT methods revealed this situation only on one of the samples and thus incorrectly interpreted the situation as nonsystematic defect. The proposed technique therefore may play its role in welding process control to prevent wrong welding process setup or its non-compliance or damage or wear of the welding equipment during the welding.

ACKNOWLEDGEMENTS

This research was been supported by the project TRIO č. FV10757 „Thermovision system for non-destructive testing of weld joints“, financed by MPO ČR and SGS16/217/OHK2/3T/12.

REFERENCES

[1] DVORAK, M., PILVOUSEK, T. Materials used for bodywork, *Company documents - ŠKODA Auto a.s.*, 2014.

[2] KOLAŘÍKOVÁ, M., KOLAŘÍK, L., FOREJTOVÁ, L., KRAMÁR, T., SOVA, J. The effect of parameters at resistence spot welding on quality of spot joint of steel DC06. In *METAL 2018: 27nd International Conference on metalurgy and Materials.* Ostrava: TANGER, 2018, in review.

[3] ISO14373:2015: Resistance welding - Procedure for spot welding of uncoated and coated low carbon steels. 2015.

[4] MATOUŠEK, J. *UT kontrola odporových bodových svarů*. Praha: ATG, 2008. 26 p.

[5] MACH, P.*Hodnocení jakosti odporových bodových svarových spojů pomocí termografie*. Bachelot´s thesis. Praha: ČVUT Praha, FS, 2017. 52 p.

[6] HOLUB, Š. *NDT kontrola odporových bodových svarů*. Bachelot´s thesis. Praha: ČVUT Praha, FS, 2017. 49 p.