PARAMETERS OF RESISTANCE SPOT WELDING OF DC06 STEEL AND THEIR HEAT INFLUENCE

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Abstract

Resistance spot welding of deep drawing steel DC06 is done and influence of welding parameters on spot weld quality is evaluated. Modern thermography methods are used to evaluate quality of the spot weld and its results are compared with standardly used methods. Thermographs taken directly after welding proved feasible to become NDT method as its results were in concordance with conventional quality control of spot welds (VT, UT, Fs, d).

Keywords: Spot welding; RSW; thermography; HAZ; UT; DC06; quality; NDT

1. INTRODUCTION

Welding technologies are widely used in almost any industry and it can be stated that it is necessary when many strong and load bearing joints are needed in the structure, e.g. transportation industry.

In welding of metals, there is permanent trial to automate and robotize the production. In Czech Republic, these trends are the best visible in automotive industry. For automation of car unitary body production the Resistance Spot Welding (RSW) proved the most efficient. The RSW method can compensate stamping imprecisions when welding several large stamped parts, producing lap welds. Modern welding jigs and welding power sources combined with long life RSW electrodes [1] are the factors that helped RSW to become the basic welding method of most car manufacturers [2].

For quality of the product, together with automation of production and productivity, new on-line methods of weld testing are looked for [3, 4, 5]. This research focuses on weld quality evaluation based on standard tests, modern thermography testing and their comparison. The aim is to demonstrate the applicability of thermography for quality evaluation (evaluation by using thermal fields).

Thermography is modern and productive way to evaluate quality that can in the future become great technique for weld quality evaluation. Using thermography and special software, spot weld and HAZ properties can be observed and evaluated.

2. BASE MATERIAL

There are many requirements placed on materials used for car body-in-white production. Outer parts must have excellent surface quality, high formability, corrosion resistance, while inner body parts must have high strength, stiffness etc. Some of requirements may be even contradictory.

Weldability of these materials also changes with surface treatments, coatings, and present processing oils. These may influence the welding process, create porosity and changes in welding process are needed. For the experiment widely used zinc coated deep drawing steel was used - DC06 (EN 10152) of thickness 0.7 mm. The material is in Škoda Auto a.s. used for roof and side panel stamping. Chemical composition is in **Table 1**, mechanical properties in **Table 2** [2]. Spectral analyser Brucker Q4 Tasman was used to verify chemical composition. Sheets have electrolytic Zn coating and are phosphated, average Zn layer thickness is 4.3 μm, verified by DeFelsko Positector 6000 in accordance with EN ISO 2808. Also metallography has shown same Zn layer thickness.

Table 1 Chemical composition of DC06 steel

Element	C	P	S	Mn	Ti	Fe
wt. %	0.02	0.02	0.02	0.25	0.3	rest

Table 2 Base metal mechanical properties - DC06

Yield strength R_e [MPa]	Tensile strength R_m [MPa]	Ductility A_{80} [%]
max. 180	270-350	41

3. EXPERIMENT

Sheet metal samples of size 45 x 175 mm were welded by welding machine Dalex PMS 11-4. Welding parameters were selected in accordance with EN ISO 14373 [6], welding current in range from 6 to 8 kA, welding time 160 - 200 ms and force 1.9 - 2.1 kN. Parameters were selected in wide range so that the good and bad welds were created to enable evaluation use of thermography for weld quality testing. Thermographic (thermal image) camera FLIR A615 was used to observe the weld from distance 60 mm at an angle 45°. Sheet emissivity was set using thermocouple measurement, thermocouple K was connected to device Ahlborn Almemo 5690.

Table 3 Welded samples and their welding parameters

Sample set	Current [kA]	Time [ms]	Electrode force [kN]	Sample set	Current [kA]	Time [ms]	Electrode force [kN]
1	6	160	1.9	15	7	180	2.1
2	6	160	2	16	7	200	1.9
3	6	160	2.1	17	7	200	2
4	6	180	1.9	18	7	200	2.1
5	6	180	2	19	8	160	1.9
6	6	180	2.1	20	8	160	2
7	6	200	1.9	21	8	160	2.1
8	6	200	2	22	8	180	1.9
9	6	200	2.1	23	8	180	2
10	7	160	1.9	24	8	180	2.1
11	7	160	2	25	8	200	1.9
12	7	160	2.1	26	8	200	2
13	7	180	1.9	27	8	200	2.1
14	7	180	2				

Results from thermography evaluation were compared with standard methods of spot evaluation, destructive and non-destructive. NDT methods included visual testing (VT) and ultrasonic testing (UT). UT was done using Olympus Epoch with special equipment for RSW spot welds, used frequency 20 MHz, probe diameter 4 mm. Destructive analysis was done using metallography and tensile shear test (according to ISO 14273).

4. RESULTS

Altogether 27 sample tests were welded (each set with 5 pieces) with welding parameters as in **Table 3.** Spot weld quality was first evaluated by visual test VT in accordance with EN ISO 14373. This norm demands to check the following: Weld diameter should be symmetrical with size between $3.5\sqrt{t}$ - $5\sqrt{t}$ (t - sheet metal thickness). Weld diameter is normally 1.15x larger than nugget diameter. Electrode penetration, indentation must be shallow, without sharp corners, depth must not exceed 20 % of sheet thickness. Weld joints height should reach 20 - 80 % of both sheet metal thickness. Weld dimensions were evaluated by metallography and tensile shear test EN ISO 14329 - see **Table 4**.

Table 4 Evaluation of weld quality by VT, UT (sample sets)

Sample	1	2	3	4	5	6	7	8	9
VT, UT	N^a,A^b,A^c	N, A, A	N, A, A	N, A, N	N, A, A	N, A, A	N, A, N	A, A, A	A, A, A
Sample	10	11	12	13	14	15	16	17	18
VT, UT	A, AC, A	A, N, A	N, N, A	N, N, A	A, A, A	A, N, A	A,NC,A	A, N, A	N, N, A
Sample	19	20	21	22	23	24	25	26	27
VT, UT	N, N, A	N, N, N	N, N, N	N, N, A	A, N, A	A, N, A	A, N, A	A, N, A	A, N, A

Explanation: VT = visual test, UT = ultrasonic test

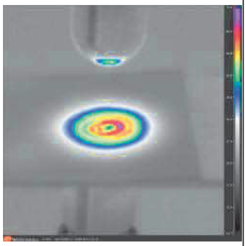
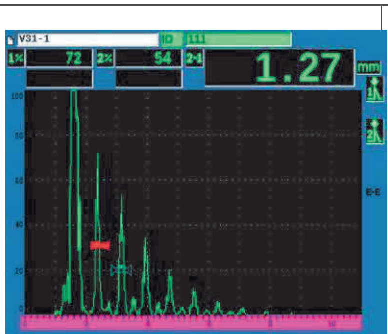
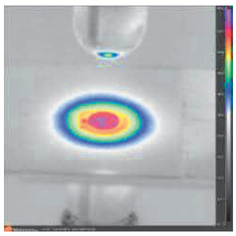
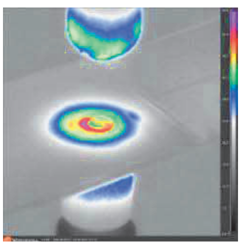
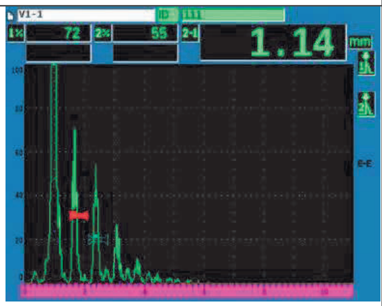
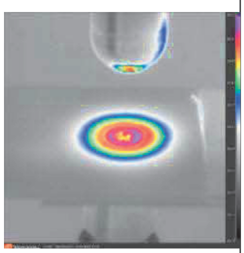
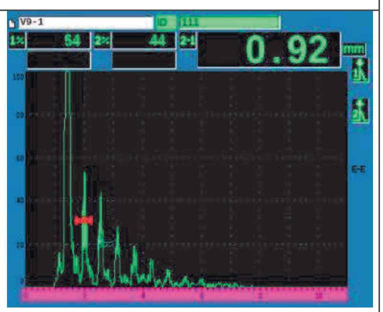
a) Weld diameter: (A - acceptable, N - non acceptable),

b) Electrode indentation: (A - acceptable, N - non acceptable, C - Cu presence on surface)

c) Inner defects: (A - acceptable, without defects, N - non acceptable, defects present)

Next, UT was done. Ultrasonic testing is very sensitive NDT method for evaluation of inner defects, also usable for thickness measurement of final weld thickness.

Table 5 Selected thermographs and UT echograms for typical welds as in **Figure 1**

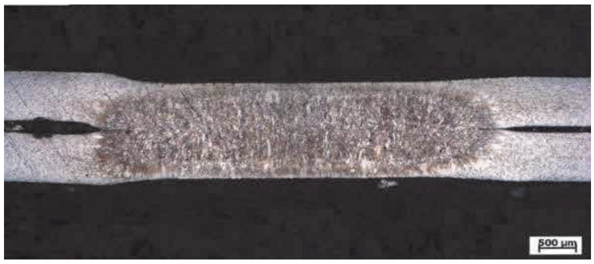
			
A		B	
			
C		D	

In **Table 5A** is shown echogram of unacceptable weld. It can be recognized by presence of small echoes that represent inner defects. The weld thickness as measured is 1.27 mm and is acceptable. In **Table 5B** we can see acceptable weld, with continually decreasing echo intensity. The high number of echoes can possibly signalize insufficient spot creation (absence of fusion at the boundary of sheet metals) but metallography proved high weld quality. Thickness is 1.33 mm, penetration is low but sufficient. **Table 5C** shows acceptable weld, small number of echoes was caused by presence of copper on the surface, copper absorbs the acoustic energy. Thickness is 1.24 mm, acceptable. **Table 5D** shows unacceptable weld, the penetration is too high and thickness after welding is only 0.92 mm.

It **Figure 1** typical weld macrographs are shown. Example shown at **Figure 1A** is showing low weld parameters, without enough heat input. The weld is too small and with inner defects present. Sample sets 1 to 7 belong to this group.

Increasing weld time or (and) current, spot weld creation is acceptable, as at **Figure 1B**. Quality of weld is acceptable, (for example sample 8). Further increase of heat input leads to proper spot size creation, yet copper electrode traces are present at the sheet metal surface, shown at 1C, (for example sample 10). Copper electrode partial melting leads to high electrode wear and possibility of inner defects. Too high parameters, as at **Figure 1D**, lead to too large spot, too high indentation, failure of EN ISO 14373 requirement. Too high heat input was found for samples 18 - 22. In accordance with macrographs were the data of tensile shear test and weld spot diameter measurement as in **Table 6**.

A - Unacceptable weld - small size, inner defect



B - Acceptable weld

C - Size of weld acceptable, traces of Cu

D - Unacceptable electrode indetation

Figure 1 Typical spot weld macrographs, defects

Table 6 Tensile shear force Fs and weld nugget diameter

Sample	A	B	C	D
Tensile shear force Fs [N]	3236	3373	3206	3763
Weld nugget diameter d [mm]	4.9	5.5	5.1	6.2

In **Figure 2** microstructure of one selected weld is shown. Weld metal (WM) (**Figure 2-1**) has grains oriented in direction of temperature gradient during solidification. In HAZ grain coarsening occurred (size up to 200 um) (**Figure 2-2**). Base material (BM) is shown in **Figure 2-3**. For all welds microstructure has similar features, though size depends on welding parameters.

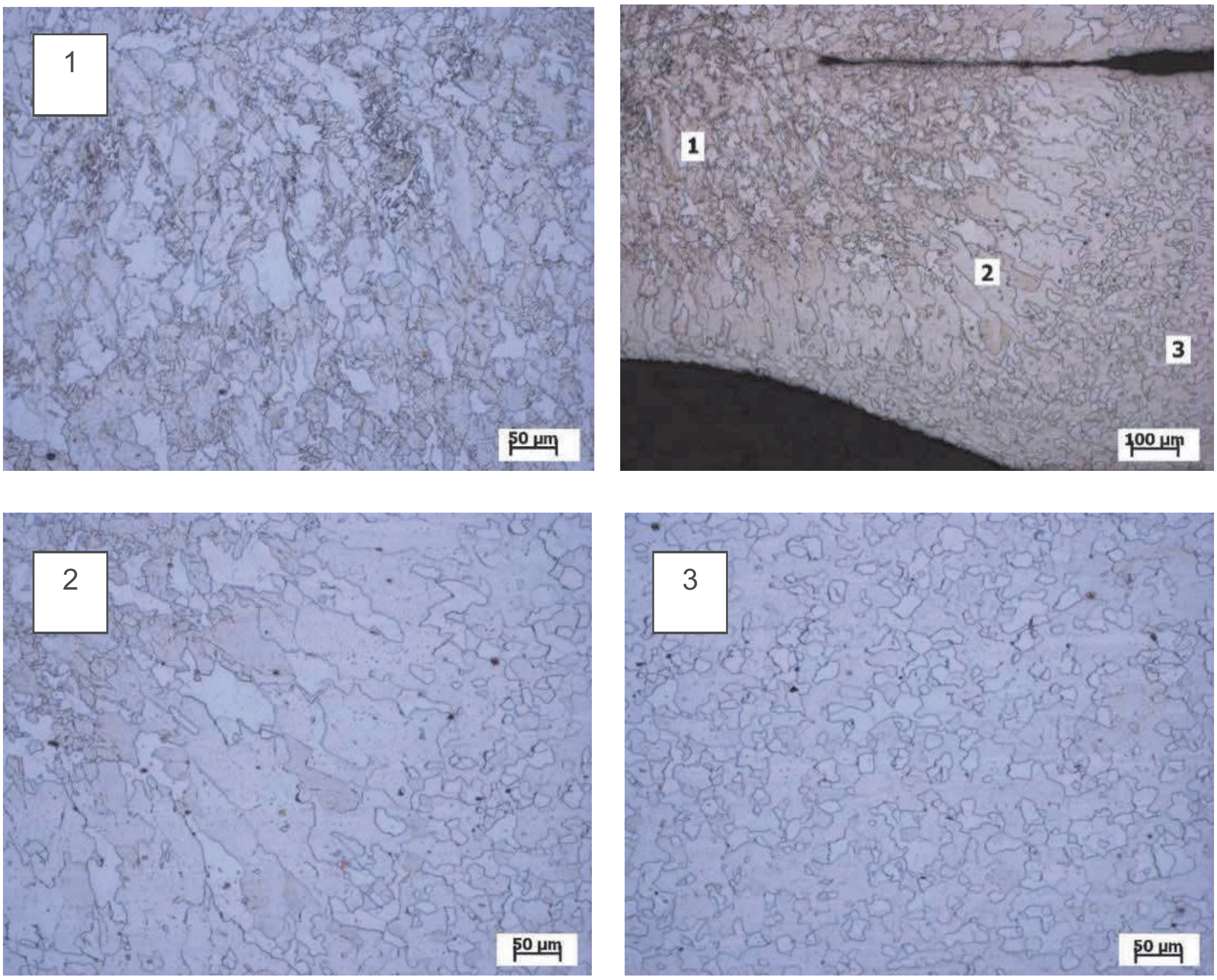


Figure 2 Typical weld microstructure (1 = WM, 2 = HAZ - grain coarsening, 3 = base material)

5. DISCUSSION

All weld thermograms were captured 1 s after electrodes retraction from weld spot, already during weld cooling time. In **Table 5** we can see thermographs and UT echograms for welds as in **Figure 1**. Thermograms were further data processed as in **Figure 3.**

Acceptable welds were created with parameters: 6 - 7 kA, 160 - 200 ms, 1.9 - 2.1 kN. For other sheet metal thicknesses, machine type, electrode size and impedance the parameters would differ.

Thermography did prove as promising non-destructive testing method, because it can measure and diagnose heat input and based on that estimate the weld quality. Maximum temperature after retraction of electrodes from sheet metal was 75 °C. Z For creation of acceptable welds on sheet metal DC06 of thickness 0.7 mm the measured temperature should be 40 - 50 °C for 50 % area and over 60 °C there should not be over 25 - 30 %. For such thermograms, the weld quality as controlled by standard evaluation methods would be acceptable.

6. CONCLUSION

Resistance spot welding is often used in serial production in fully automated lines. With this in mind, it is important to find out 100 % online non-destructive quality control. The article data proved that thermography data as measured directly after the weld creation can be used for such quality control. Thermography can provide quality test results in concordance with conventional quality control of spot welds (VT, UT, Fs, d).

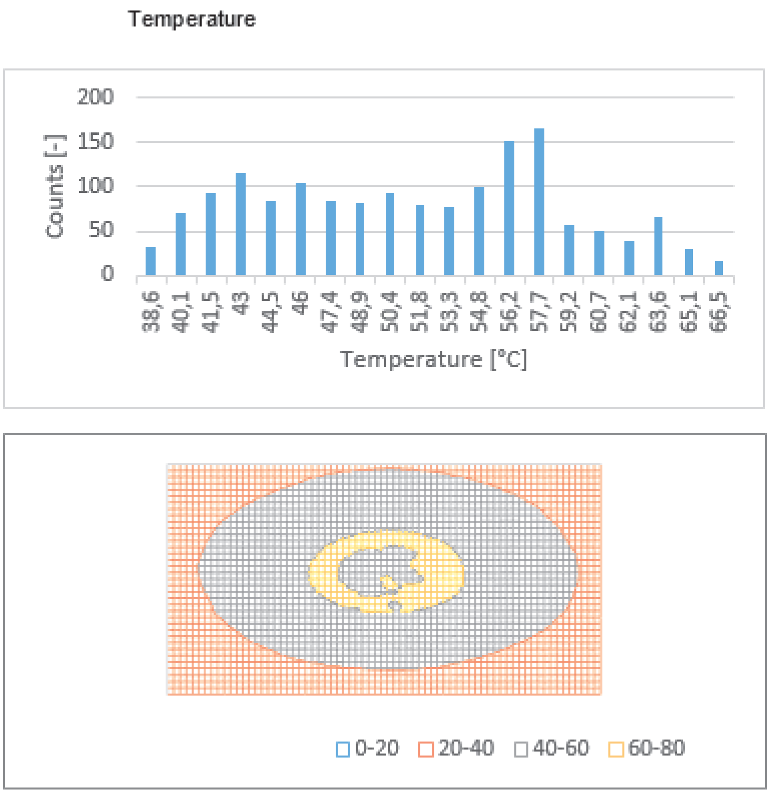


Figure 3 Temperature field as 2D map and temperature histogram for the Figure 1D case

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