EFFECT OF RESISTANCE SPOT WELDING PARAMETERS ON DC06 STEEL WELD SPOT QUALITY

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Abstract

The paper deals with the influence of the main welding parameters of resistance spot welding on the quality of the joint. The influence of the parameters was investigated within the range of welding area where satisfactory welding is expected (according to EN ISO 14373). DOE analysis was used as an analytical tool. The DC06 deep-drawing steel, 0.7 mm thick, used in the automotive industry was used as the base material. Quality was assessed by visual testing, ultrasonic testing, macroscopic and shear tests. The results shown that, in the area of optimized welding parameters, the welding current has a well-defined effect on the quality of the weld joint and the size of the welding nuggets. The results can be used to predict the size of the welding nugget depending on the set welding parameters.

Keywords: RSW, DOE, DC06, Welding Parameters, UT

1. INTRODUCTION

The quality of resistance spot welds has a decisive role in vehicle reliability. The classification of geometrical defects of metallic materials is according to ČSN EN ISO 6520-2: Welding and related processes - Classification of geometrical defects of metallic materials - Part 2: Pressure welding. There is a complication in assessing the permissible quality of weld spots. The permissible quality is not given by standards e.g. as with fusion arc welding methods. Quality assessment is usually based on company specifications, product codes or contractual relationships and agreements. Destructive tests can be only used for limited scope of control. They are time consuming and economically challenging (e.g. peel test, chisel test, hardness measurement, cross tension test). Non-destructive options used for RSW are tests such as visual and ultrasonic testing. These tests are however also time consuming and expensive. The possibility of using acoustic emission for quality control of weld joints was assessed by Polajnar at al. [1]. They concluded that because of too much interference signals, the quality of weld spot can not be detected from the acoustic emission alone. Non-conventional, newly proposed non-destructive testing method to assess the weld quality is thermographic measurement. For proper evaluation of thermograms, it is necessary to know the ranges of welding parameters when the weld is satisfactory. At the same time, it is necessary to know the influence of individual parameters on the quality of the joint. Kapsa [2] used DoE analysis to determine the influence of welding parameters and explicit expression of the nugget size. His results shown that the larger the diameter of the nugget, the greater the spot strength. He says the most important parameter is the welding time, which has 70 % influences on the quality of the joint. His results are confirmed by Wei Li et al. [3]. On the contrary, Aslanlar et al. [4] say that the most important parameter in spot resistance welding is the electrode force. Huin et al. [5] have concluded, that smaller metal splatter has a strong influence on the welding electric voltage but does not have a significant effect on the tensile strength. This is confirmed by Saha et al. [6], which argue that if the welding current is higher than 5 kA, cracks in the weld nuggets appear to have little effect on the strength of the joint.

2. MATERIALS

The 0.7 mm thick deep-drawing steel, one of the most commonly used materials in the automotive industry, was chosen as a parent material, (the material is also used by Škoda Auto a.s., for example for the roof structure of model Škoda Octavia). The used unalloyed deep-drawn steel has the designation DC06 (according to ČSN EN 10152). The chemical composition of the steel is in **Table 1** and mechanical properties in **Table 2**.

Table 1 Chemical composition of steel DC06

C [%]	P [%]	S [%]	Mn [%]	Ti [%]	Fe [%]
0.02	0.02	0.02	0.25	0.30	≈ 99.3

Table 2 Mechanical properties of steel DC06

Re [N / mm^2]	Rm [N / mm^2]	A_{80} [%]
max 180	270 - 350	41

The steel is galvanized from both sides. The thickness of the zinc layer was verified non-destructively by the electromagnetic method in accordance with EN ISO 2808. The average Zn coating thickness (on one side) is 4.5 µm. For welding the electrode caps type 39 D 1978-2 from material A2/2 - CuCr1Zr were used. Chemical composition of the cap is: Cu = 98.98 %, Cr = 0.9 %, Zr = 0.12 %.

3. EQUIPMENT

The device DeFelsko positector 6000 was used to determine the thickness of the coating. The Dalex PMS 11-4 medium-frequency welding resistor with control unit SER Mega 2 MF was used for welding. For the shear test, the Labtest 5.100 SP1 digital vertical hydraulic testing machine was used with a force measurement system according to ČSN EN 7500-1. For UT, the Olympus Epoch 650 ultrasonic defectoscope was used, with spot joints probe with watertight adapter and replaceable rubber membrane. The pulse-echo method was used for the testing.

4. EXPERIMENT

With the help of SW Design Expert, the experiment was designed to assess the effect of individual welding parameters on the quality of the spot resistance joint. Another aim of the experiment was explicit expression of weld nugget diameter as a function of welding parameters.

To evaluate the influence of individual welding parameters, the DoE (Design of Experiments) method was used, which is an experimental strategy that simultaneously examines the effects of several factors by testing them at different levels. The following parameters were chosen as evaluated factors: welding current I_s [kA], electrode force P [kN] and welding time t_s [ms].

Recommended welding parameters (factors) for joining of thin sheet steel with Zn coating is given by ČSN EN ISO 14373 (2015). For 0.7 mm thick sheets, the standard specifies the following ranges of parameters: welding current I_s = 7 - 9 kA, electrode force P = 1.9 - 2.2 kN and welding time t_s = 160 - 200 ms. The recommended diameter of the contact surface of the electrodes is 4 mm. In the automotive industry, however, in most of the cases, diameters of 5 mm are used. Therefore, electrode caps with a diameter of 5 mm of contact area were used for this experiment. For this reason, the recommended parameters have been slightly reduced to achieve satisfactory welds without defects. All factors were chosen at three levels (**Table 3**).

Table 3 Factors and their levels for DoE method

Factor / level	I_s [kA]	P [kN]	t_s [ms]
Level 1	6	1.9	160
Level 2	7	2.0	180
Level 3	8	2.1	200

The following quantities (responses) were selected as information about the quality of spot joint: shear force necessary for weld breaking F [N] - numerical value, the nugget diameter d [mm] - numerical value, the thickness of compressed sheets h [mm] - numerical value, the result of the ultrasonic test (1 - suitable, 0 - not suitable). The welded samples were therefore checked by ultrasonic test (UT). During UT the sheet thickness was measured at the the area of compression by the electrodes. Furthermore, a mechanized shear test according to EN ISO 14273 was used to determine the maximum force required for breaking the sample. The nugget diameter was measured on the broken samples. The method of response area was used to evaluate the measured values. Measured data in all cases (except UT result) best corresponded with linear model without transformation (see **Table 4**). To evaluate the UT result, the quadratic model without transformation is the most appropriate. The condition "Prob> F" is less than 0.05 in all cases, so models are significant. The influence of individual factors on the responses (in the examined range) can be seen from **Table 5** and **Table 6**.

Table 4 F values and Prob>F for models of responses

Response	Max shearing force F		Nugget diameter d		Sheet thickness in point of indentation h		Result of UT	
	F value	Prob > F	F value	Prob > F	F value	Prob > F	F value	Prob > F
model	7.81	0.0006	17.52	0.0001	12.83	0.0001	4.44	0.0021

Table 5 F values and Prob>F for responses in linear model

Response	Max shearing force F		Nugget diameter d		Sheet thickness in point of indentation h	
	F value	Prob > F	F value	Prob > F	F value	Prob > F
Welding current I_s	13.9	0.0009	46.31	0.0001	37.56	0.0001
Electrode force F	0.92	0.3458	0.57	0.4559	0.62	0.4386
Welding time t_s	8.60	0.0066	5.69	0.0241	0.31	0.5791

Table 6 F values and Prob>F for responses in quadratic model (A = I_s, B = P, C = t_s)

UT	A	B	C	A^2	B^2	C^2	AB	AC	BC
F value	0.46	1.84	4.13	18.12	0.17	0.75	2.75	11.01	0.00
Prob > F	0.5052	0.1892	0.0544	0.0003	0.6834	0.3948	0.1112	0.0031	1.000

The results show that welding current is the only parameter that has a significant impact from the selected range of parameters (given by welding areas according to ČSN EN ISO 14373). The fundamental influence of the electrode force on any of the responses has not been observed, it is lost in the noise. The welding time (compared to the welding current) has a smaller effect on the size of the nugget and is closely related to maximum shear force needed for broke the sample. The proportion of the welding current effect (F value) is more than 8 times. The welding time has the effect to UT result only in combination with the welding current setting.

Therefore, the next experiment was devoted to the influence of the welding current (6, 6.5, 7, 7.5, 8 and 8.5 kA) and the other welding parameters were kept constant (P = 2 kN, ts = 180 ms). The number of repetitions was

7. DoE analysis shows that in this range of parameters, the welding current has a fundamental influence only on the nugget size (**Table 7**). For other responses, the effect of factor was not proven. "Prob> F" values of less than 0.050 indicate that the models are significant, which occurred only on "Nugget diameter" (Prob> F = 0.0002). In this case, the factor "welding current" is a significant model condition.

Table 7 F values of welding current effect for responses

Responce	F	D	h	UT
F value	1.27	6.67	0.71	1.57
Prob > F	0.3005	0.0002	0.6182	0.1963

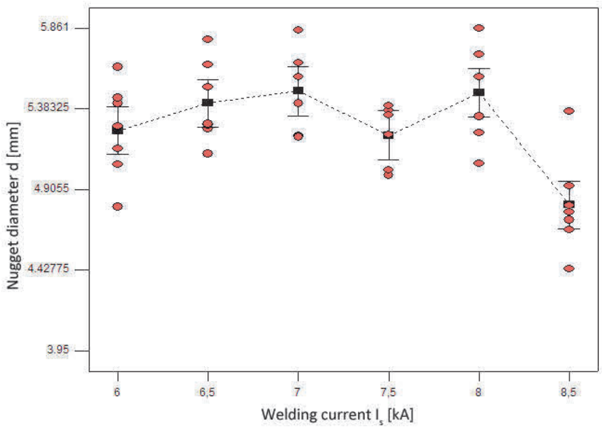
In all cases, the significance of the factor is relevant to the given range. In hypothesis testing, the response values were found to match the Student's distribution and the T-test. The results of the experiment are therefore relevant. According to the assumptions, the nugget diameter is the most significant response. Explanation of the nugget diameter was determined by the variance analysis (ANOVA), depending on the welding parameters set:

$$\text{Nugget diameter} = 1.878 + 0.455 \cdot I_s - 0.506 \cdot P + 0.008 \cdot t_s \quad (1)$$

where: I_s - the welding current, (kA)P - the electrode force (kN) and t_s - the welding time (ms).

5. DISCUSSION

The nugget diameter increases with increasing welding current (6 to 7 kA) (**Figure 1** - left). The scattering of values at the lowest currents is approximately the same (**Figure 1** - right). From 7 kA upwards, the instability of the welding process can be seen from the scattering of values. This manifests itself as a larger scattering of the nugget diameter. Fluctuations in average nugget diameter at higher currents are due to defects. Especially after the splash of metal, this material is missing in the nugget.



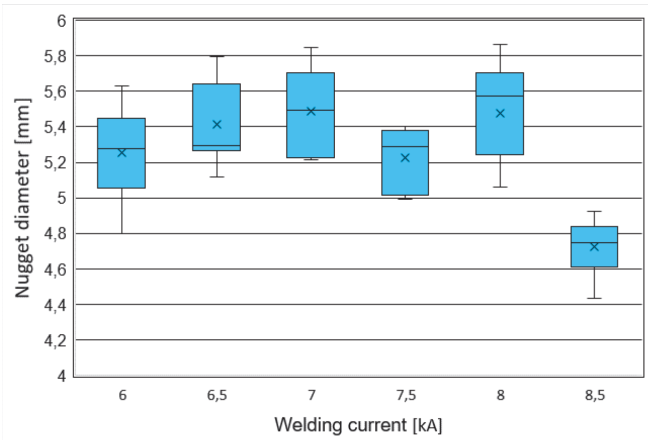


Figure 1 The dependence of the nugget diameter on the welding current (left) and the scattering of nugget diameter values (right) at different welding currents, P = 2 kN, t_s = 180 ms

From the shear force dependence on the welding current (**Figure 2** - left), it is clear that the highest bearing capacity have welds made with the lowest parameters (6 and 6.5 kA). From 7 kA up bearing capacity decreases and scattering of values increases considerably (**Figure 2** - right). With these high currents, most of the welded joints did not comply with the UT test, which corresponds to the results in **Figure 1**. The zinc adhering to the surface of the electrode averts the current transit through the welded sheets. With the increasing number of welds, the thickness of the zinc layer on the electrode increases. At the same time, the quality of the welds decreases.

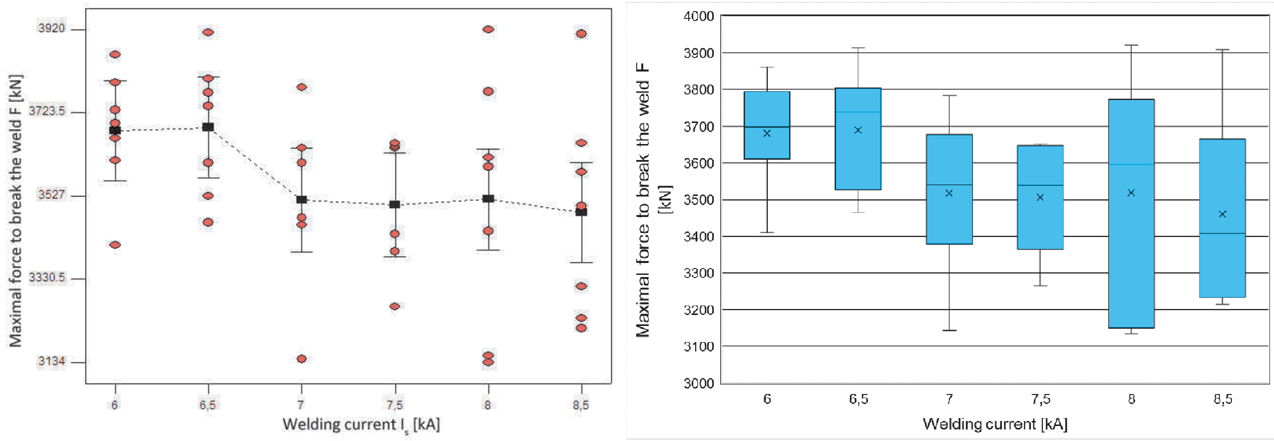


Figure 2 Dependence of the maximum force required for breaking the weld on the welding current (left) and scattering of the maximum force values (right) for different welding currents, P = 2 kN, t_s = 180 ms

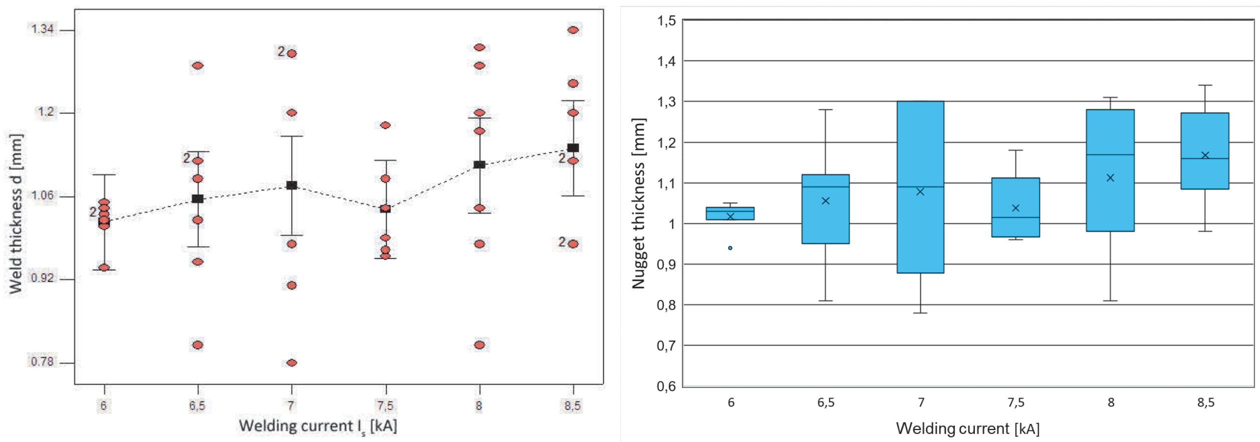


Figure 3 Dependence of spot thickness on welding current (left) and scattering of spot thickness values (right) at different welding currents, P = 2 kN, ts = 180 ms

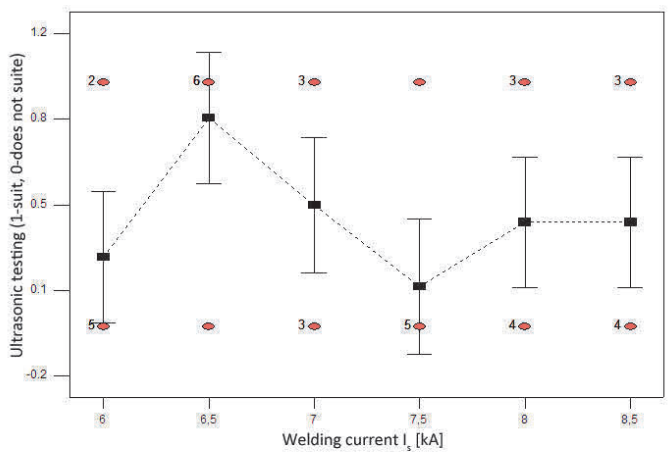


Figure 4 Dependence of UT result on welding current, P = 2 kN, t_s = 180 ms

The weld thickness increases with increasing current (**Figure 3** - left). The scattering of values increases equally (**Figure 3** - right). This may be due to the adhesion of Zn from the coating or Cu on the surface of the electrode, and this greatly affects the results of measuring the thickness of the compressed sheets. Zn coating significantly deteriorates both the fussion and resistance weldability of steel, as confirmed by Vontorová [7]. From ultrasonic test evaluation, it can be seen that most of the welds are suitable again at the lowest parameters. At the 6.5 kA current, even all joints was suitable (**Figure 4**). At the same current, almost the largest nugget diameter was also measured. This is also related to the highest value of the maximum shear force required for breaking weld. With a current greater than 7 kA, significant part of the welds examined do not suit. The results from UT correspond to the above information.

6. CONCLUSION

The properties of coated steel sheets used in the automotive industry are constantly evolving and improving. Therefore, it is necessary to modify the welding parameters. The goal is a high-quality weld joint especially in terms of strength requirements. The appearance of weld nuggets and their dimensions are dependent on the thickness of the sheets, the used materials (including surface treatments) and the used welding parameters. Based on the research, it was found that:

- The welding current has the greatest influence on the quality of the weld joint
- The most important factor determining the joint quality is the nugget diameter
- The nugget diameter can be explicitly expressed as a function of the welding parameters: Nugget diameter = $1.878 + 0.455 \cdot I_s - 0.506 \cdot P + 0.008 \cdot t_s$

The above conclusions are valid in the examined range of parameters, i.e. in the range of welding current 6 to 8.5 kA, electrode force 1.9 to 2.1 kN and welding time 180 to 200 ms.

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