# RESISTANCE SPOT WELDING OF STEEL SHEETS OF DIFFERENT THICKNESS

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**Abstract.** Resistance welding ranks among progressive and in practice often used manufacturing techniques of rigid joints. It is applied in single-part production, short-run production as well as in mass production. The basis of this method is in the utilization of the Joulean heat, which arises at the passage of current through connected sheets at collective influence of compressive force. The aim of the carried out tests was the determination of the dependence between rupture force of spot welds made using sheets of different thickness and rupture force of spot welds made using different welding conditions. The test specimens of dimensions 100 x 25 mm and thickness of 1 mm, 2 mm, 3 mm and 4.5 mm were made from low carbon steel. In the place determined for welding the test specimens were corundum blasted and then degreased. The welding of two specimens of different thickness 1 + 2 mm, 1 + 3 mm and 1 + 4.5 mm was carried out using the spot welding machine type BV 2,5.21. For welding the electrodes delivered by the producer of the same working end diameter and electrodes of our production were used, which were made so that the heat balance according to the calculation was ensured. At this spot welder type the welding current value is constant. The welding time (the time of the passage of current) was changed in the whole entirety. The compressive force was chosen according to the thickness of the connected sheets. From the results of the carried out tests it follows that the quality spot welds of sheets of smaller different thickness (1 + 2 mm and 1 + 3 mm) can be made using electrodes delivered by the producer. The force needed for rupture of these spot welds made at the use of electrodes of the same and of different working end diameter differs only by several per cent (depending on the welding time), namely no more than by 4.2 % at sheets 1 + 2 mm and no more than by 6.2 % at sheets 1 + 3 mm. A considerably different situation is at welding of sheets of thickness 1 + 4.5 mm. Here it is suitable to use electrodes of different working end diameter for ensuring the heat balance. Using electrodes of different working end diameter the joint rupture force was higher in the whole range of the tested welding times, namely up to 33.1 % compared to the use of electrodes of the same working end diameter, delivered by the producer of the spot welder.

**Keywords:** resistance welding; steel sheet; laboratory test; shear testing resistance spot welds.

## Introduction

Joints of two or more parts used in practice are usually divided into removable and rigid ones. Removable joints, made, e.g., using screws, washers and nuts, we can repeatedly dismantle and assemble without damage of the above mentioned parts. On the contrary, rigid joints are permanent. They can be “dismantled” (affect of strength or heat), but at the cost of their irreversible damage (destruction). It is a case of joints made by riveting [1], adhesive bonding [2-5], soldering [6-8] or welding [9-11]. A row of welding methods exists today – they are classified according to CSN EN ISO 4063. One of them is resistance welding (resistance welding, method 2). In the world resistance welding is known already since eighteen eighties. But in our country it began to be used since nineteen thirties. Since then the technology has been very advanced. Today spot welding is used not only for welding of ferrous steels including stainless steels [12-14], but also of nonferrous metals [15]. It is possible to weld sheets with previous surface finish, e.g., zinc-coated sheets [16-18]. Without problems it is today possible to weld two different materials, too. The most typical application of resistance welding technology today is in car industry [16]. Modern technologies make possible the on-line quality monitoring and controlling of resistance spot welding [19]. Attention is paid to the spot welds behavior under conditions of fatigue [20]. According to CSN EN ISO 4063 the resistance welding falls into spot welding (resistance spot welding, method 21) and seam welding (resistance seam welding, method 22). At spot welding, which is studied in this contribution, the weld is created in the contact of welded materials (sheets) between surfaces of two electrodes. The area of the weld (so called metallic lens) is approximately the same as the area of the working ends of the electrodes.

At resistance welding the collective influence of Joulean heat (1), arising by passage of current through the welded materials, and compressive force, is used.

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

where $Q$ – heat, J;
$R$ – resistance, Ω;

$I$ – welding current, A;
$t$ – welding time, s.

The quality spot weld formation is determined by the thermal symmetry in the place of the future weld formation. In practice the heat balance breach occurs relatively often, e.g., at welding of two different materials (carbon steel – austenitic steel, brass – aluminium) or at welding of sheets from the same material, but of different thickness. In these cases the welded sheets get warm unequally and asymmetrically. But this problem can be solved relatively easily – by the use of electrodes of different working end diameter. On the side of the thicker material the electrode of the bigger working end diameter, on the side of the thinner material the electrode of the smaller working end diameter are used. The concrete electrode working end diameters can be determined graphically (Fig. 1) or by the calculation using the equation (2).

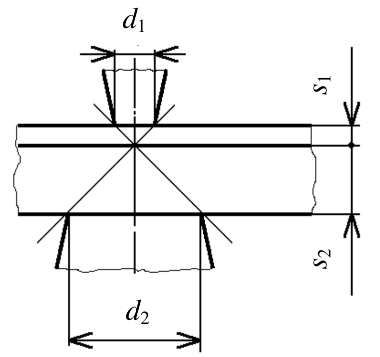


Fig. 1. **Graphic calculus of the heat balance**

$$d_1 = \frac{d_2 \cdot s_1}{s_2} \tag{2}$$

where $d_1$ – electrode working end diameter at thinner sheet, mm;
$d_2$ – electrode working end diameter at thicker sheet, mm;
$s_1$ – thickness of thinner sheet, mm;
$s_2$ – thickness of thicker sheet, mm.

The heat $Q$, which is needed to melting-down of the required metal volume, can be achieved by two ways. Depending on this, we distinguish the short time welding conditions (high $I$, short $t$) and the long time welding conditions (low $I$, long $t$). The final quality of spot welds depends on the optimum setting of the working variables by the operator, primarily on the welding current intensity, on the time of the current passage and on the compressive force. The surface cleanness is taken for granted.

## Materials and methods

Size, dimensions and shear testing procedure of spot welds for sheets of thickness from 0.5 mm to 10.0 mm are stated in the standard CSN EN ISO 14273. The size of the test specimens is different depending on the thickness of the welded sheets. The width ranges from 45 mm to 100 mm, exceptionally from 30 mm to 100 mm. The length ranges from 175 mm to 320 mm. The lapping length ranges from 35 to 100 mm. This diversity of test specimen dimensions does not enable the comparison of the results gained by the planned experiment. Therefore, the dimensions of the specimens were unified. They were the dimensions of test specimens used in our department already over a long period for tests of adhesive bonded joints according to the standard CSN EN 1465, soldered joints and riveted joints.

The test specimens for spot welding were made from the low-carbon steel 11 343 according to ČSN 41 1343. Sheets of size 1000 x 2000 mm and thickness $s_1$ ($s_2$) 1 mm, 2 mm, 3 mm and 4.5 mm were semi-products for their production. The parting of semi-products to test specimens was carried out by shearing. The dimensions and shape of the test specimens and the location of the spot weld (lens) is evident from Fig. 2 ($L$ = 100 mm, $b$ = 25 mm, $l$ = 25 mm).

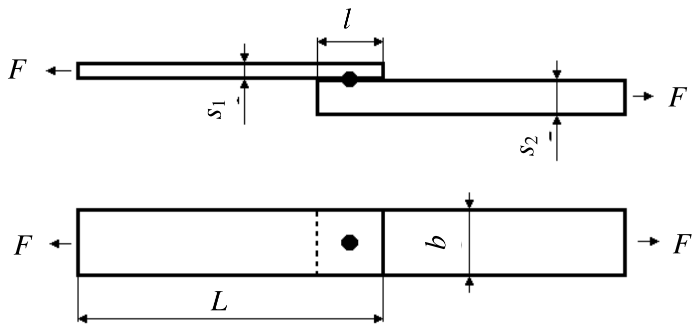


Fig. 2. **Dimensions and shape of test assemblies**

The surface preparation of the test specimens before spot welding is very important. All potential dirt on the material surface decreases the joint strength, or makes impossible the spot weld formation. Therefore, the surface of all specimens was blasted using artificial corundum fraction F 80 on one end (determined for welding) on both sides in the length of about 30 mm. After blasting all specimens were degreased using perchlorethylene and dried using warm air. Immediately the spot welding ensued.

The electrodes of this spot welder are made from the alloy CuCrZn of 0.3 – 1.2 Cr and 0.03 – 0.3 Zr. For this experiment rods of 12 mm diameter were bought, from which the electrodes are made by turning. Their working end was turned to the diameter calculated using the equation (2). The electrodes delivered by the spot welder producer have the working end diameter 7 mm. Then the calculated electrode working end diameter at the thinner sheet is 3.5 mm for sheets 1 + 3 mm and 1.56 mm for sheets 1 + 4.5 mm.

For welding of the assembly consisting of two specimens of different thickness the spot welder type BV 2,5.21 was used. The welder uses the long time welding conditions. It is determined only for shops with piece production and so for the lower work intensity, e.g., for school and remedial workshops and fitting shops. The reason is the highest permissible current and heat load of electrodes, which are cooled only by air. The producer recommends the welder for welding of steel sheets from low-carbon steel till to $C_{max}$ = 0.3 % and 2.5 + 2.5 mm thickness. Owing to study reasons the spot welds of sheets 1.0 + 4.5 mm were carried out, too. The main parts of the spot welder are the welding transformer type T 2,5.12, the lever weighting and the electronic device type QX 12.1 [21]. The electronics ensures the reproducible setting of the chosen working variables and the compensation of possible changes of the supply voltage. The required compressive force is set by means of the spring by turn of the setting nut. The welding time (time of the current passage) is possible to set in 12 steps from 0.1 to 2.0 s. According to the producer instruction it is possible to make only limited number joints within an hour, which depends on the welded sheet thickness (Table 1). At this welder the welding time *t* and the compressive force *F* (Table 1) are the basic parameters, which are possible to set. The welding current cannot be changed ($I_{max}$ = 6.4 kA).

Table 1

**Welding variables**

| **Sheet thickness $s$, mm** | **Welding time $t$, s** | **Compressive force $F$, kN** | **Orientation welding speed, spots per hour** |
|---|---|---|---|
| 1.0 + 2.0 | 0.6 | 1.5 | 56 |
| 1.0 + 3.0 | 0.8 | 1.7 | 35 |
| 1.0 + 4.5 | 1.6 | 2.2 | 27 |

For the purpose of the experiment always the couples of specimens (assembly) of different thickness were spot welded, so 1 + 2 mm, 1 + 3 mm and 1 + 4.5 mm. For their welding the electrodes of the same working end diameter (delivered with the spot welder) and of different working end diameter (made for the purpose of this experiment) were used. For each sheet thickness the making of 6 assemblies was proposed always at the use of 11 welding times (0.15 s, 0.20 s., 0.25 s, 0.3 s, 0.4 s, 0.6 s, 0.8 s, 1.0 s, 1.3 s, 1.6 s, and 2.0 s). So, for tests 792 specimens were prepared and in total 396 assemblies were made.

After welding all assemblies were loaded using the universal test machine LabTest 5.50 ST till to their rupture. The rupture force was written down. The spot weld rupture was always characterized by the destruction in the thinner sheet of 1 mm thickness.

**Results and discussion**

The results of the carried out tests are shown in Fig. 3 (steel sheets thickness 1 + 2 mm), in Fig. 4 (steel sheets thickness 1 + 3 mm) and in Fig. 5 (steel sheets thickness 1 + 4.5 mm). The full uninterrupted line shows the dependence for the electrode working ends of the same diameter; the interrupted line shows the dependence for the electrode working ends of different diameter. At all measured values the standard deviation is demonstrated by the line segments.

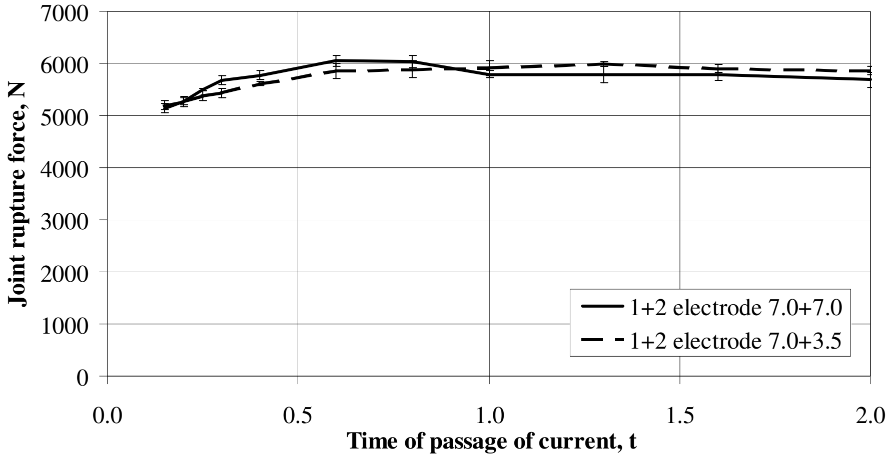


Fig. 3. **Relation between rupture force and time of passage of current for sheets thickness 1 + 2 mm**

From Fig. 3 it follows that the difference between the spot welds rupture force of sheets of 1 + 2 mm thickness made using electrodes of the same working end diameter and electrodes of the different working end diameter (for heat balance securing) is very small, practically negligible. In the range of all tested welding times the difference does not exceed the value of 4.2 %.

Similar results were determined also at the spot welds of sheets of 1 + 3 mm thickness (Fig. 4), where the determined difference did not exceed 6.2 %.

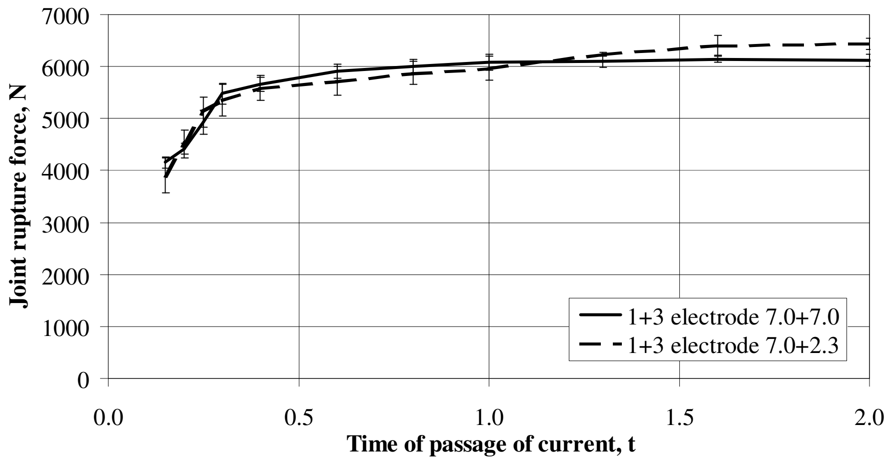


Fig. 4. **Relation between rupture force and time of passage of current for sheets thickness 1 + 3 mm**

But significant rupture force differences were determined at the sheets of 1 + 4.5 mm thickness. As it is evident from Fig. 5, the higher rupture force values were determined at spot welds made using electrodes of different working end diameter, which means at the heat balance securing. More considerable differences (up to 33.1 %) were determined at spot welds made using shorter welding times. With the increasing welding times over 0.6 s the difference is practically negligible, below

3.2 %. From the above mentioned it follows that the use of electrodes of different working end diameter, securing the heat balance, is meaningful only at welding of sheets of considerably different thickness.

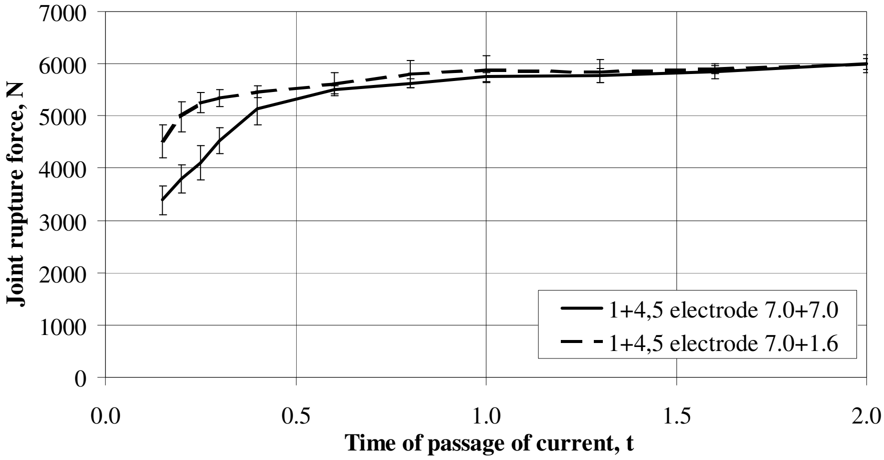


Fig. 5. **Relation between rupture force and time of passage of current for sheets thickness 1 + 4.5 mm**

## Conclusions

In the contribution the rupture force results of the spot welds tests of the assemblies from two sheets of different thickness are published. The spot welds were made using the spot welder BV 2,5.21. The test specimens (steel sheets) of size 100 x 25 mm were made from low-carbon steel. In the place of the future weld the sheets were before welding on both sides corundum blasted and degreased. In total 396 assemblies were spot welded using different working variables.

The following variables were changed: welded sheets thickness (1 + 2 mm, 1 + 3 mm and 1 + 4.5 mm) and time of current passage (0.15 s, 0.20 s, 0.25 s, 0.3 s, 0.4 s, 0.6 s, 0.8 s, 1.0 s, 1.3 s, 1.6 s and 2.0 s); welding current intensity was constant ($I_{max}$ = 6.4 kA). The compressive force was chosen according to the welded sheets thickness from 1.5 to 2.2 kN.

On the basis of the carried out tests it is possible to state:

- At spot welding of sheets of thickness 1 + 2 mm (Fig. 3) the differences between rupture forces of welds made using electrodes of the same working end diameter and using electrodes of the different working end diameter are practically negligible – below 4.2 % at all used welding times.
- Similar results were determined also at welding of sheets of 1 + 3 mm thickness (Fig. 4), where the differences between rupture forces were below 6.2 %.
- But significant differences were determined at welding of sheets of 1 + 4.5 mm thickness (Fig. 5), where the rupture force differences were up to 33.1 % (at the shortest welding time); at the same time it was proved that at increasing the welding time the differences of the rupture force of spot welds made using electrodes of the same and electrodes of different working end diameter gradually decrease; at the welding time of 0.6 s and longer they are practically negligible (max. 3.2 %).
- From the carried out tests it definitely follows that for welding of sheets of smaller thickness difference it is possible to use by the producer delivered electrodes of the same working end diameter without risk of spot weld strength reduction; at welding of sheets of considerable thickness difference, when the influence of heat balance becomes evident, it is necessary to use electrodes of different working end diameter.

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## References


1. Brožek M., Nováková A. Porovnání jednostranných nýtů s trnem různých výrobců (Comparison of blind rivets of different producers). Proceedings of XXXVI. konference kateder částí a mechanismů strojů (díl 1). June 13-14, 1995, Brno, VUT, Czech Republic, pp. 37-40. In Czech.
2. Brockmann W. et al. Adhesive bonding: materials, applications and technology. Weinheim: Wiley-VCH, 2009. 414 p.
3. Brožek M. Technical-economical evaluation of beech plywood bonding. Proceedings of 13th International Scientific Conference "Engineering for Rural Development". May 29-30, 2014, Jelgava, Latvia University of Agriculture, Latvia, pp. 168-173.
4. Brožek M. Technical-economical evaluation of plywood bonding. Proceedings of 5th International Conference "Trends in Agricultural Engineering". September 3-6, 2013, Prague, Czech University of Life Sciences Prague, Czech Republic, pp. 100-105.
5. Brožek M. Optimization of adhesive layer thickness at metal bonding using quick-setting adhesives. Manufacturing Technology, vol. 13, 2013, pp. 419-423.
6. Nippes E. F. Metals Handbook. Vol. 6., Welding, Brazing, and Soldering. Metal Park: ASM International, 1983. 1152 p.
7. Brožek M. Soldering steel sheets using soft solder. Research in Agriculture Engineering, vol. 59, 2013, pp. 141-146.
8. Brožek M. Soldering sheets using soft solders. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, vol. 61, 2013, pp. 1597-1604.
9. Blaščík F. et al. Technológia tvárnenia, zlievárenstva a zvárania. (Technology of Forming, Founding and Welding) Bratislava: ALFA, 1987. 832 p. In Czech and Slovak.
10. Brožek M. Wear resistance of multi-layer overlays. Proceedings of 11th International Scientific Conference "Engineering for Rural Development". May 24-25, 2012, Jelgava, Latvia University of Agriculture, Latvia, pp. 210-215.
11. Brožek M. Layer number influence on weld deposit chemical composition. Proceedings of 10th International Scientific Conference "Engineering for Rural Development" May 26-27, 2011, Jelgava, Latvia University of Agriculture, Latvia, pp. 393-397.
12. Liu H., Wang H., Zhang X., Li, C. Optimization of parameters and research on joint microstructure of resistance spot welding of 201stainless steel. Advanced Materials Research, vol. 418-420, 2012, pp. 1359-1363.
13. Peasura P. The influence of welding parameters on effected the complete for resistance spot welding on mild steel. Advanced Materials Research, vol. 214, 2011, pp. 113-117.
14. Pouranvari M. Effect of resistance spot welding parameters on the HAZ softening of DP980 ferrite-martensite dual phase steel welds. World Applied Sciences Journal, vol. 15, 2011, pp. 1454-1458.
15. Tentative Standards and Recommended Practices and Procedures for Spot Welding of Aluminium Alloys. New York: American Welding Society, 1942. 48 p.
16. Hayat F., Sevim I. The effect of welding parameters on fracture toughness of resistance spot-welded galvanized DP600 automotive steel sheets. International Journal of Advanced Manufacturing Technology, vol. 58, 2012, pp. 1043-1050.
17. Svítil A. Odporové bodové svařování tenkých pozinkovaných ocelových plechů. (Resistance spot welding of thin galvanized steel sheets). Praha: b. t., 1980. 210 p. In Czech.
18. Wang Z., Wang Y., Zhang D., 2013: Optimization on parameters of resistance spot welding process for galvanized steel plate. Advanced Materials Research, vol. 658, 2013, pp. 178-181.
19. Li R. X. Quality monitoring of resistance spot welding based on process parameters. Energy Procedia, vol. 14, 2012, pp. 925-930.
20. Younger A., Gourd L. M., Jubb, J. E. M. An Investigation into the Fatigue Properties of a Single Spot Weld Lap Joint. Cranfield: College of Aeronautics, 1966. 18 p.
21. Brožek M. Working variables optimization of resistance spot welding. Manufacturing Technology, vol. 14. 2014, pp. 522-527.