The Influence Surface Treatment on the Firmness of Spot Welds

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Abstract. Spot welding is a commonly used technology in practice to join metal material. It applies to all types of production, mass, series and piece production. Its biggest advantage is the high productivity, with which it is possible to weld. As with other welding methods, the cleanliness of the welded surfaces is important. The aim of the tests performed was to evaluate the influence surface treatment on the firmness of the test specimens of spot welds. The test specimens were made from steel. Welding was done while using manual clamp welders. Four sets of metal sheets were prepared before the welding, with different surface treatment - surface without treatment (original, not degreased), only degreased, grinded and degreased, blasted and degreased. The test specimens were made using different welding times, from 0.1 sec. to 2.0 sec. Then, they were loaded on a universal test instrument until destruction. All measured values were statistically evaluated. The evaluations show that although it is possible to weld sheets without surface treatment, it is not recommended. There is no statistically significant difference between the results of other types of pre-treatments.

Keywords: resistance welding, hand held spot welder, steel sheets, shear testing resistance spot welds, laboratory test

1 Introduction

In practice, this welding technology is used to make non-detachable joints, similar to soldering, gluing or riveting [1 – 6, 8, 11, 13, 15, 18]. Most welding methods (except for blacksmithing) were developed at the end of the 19th century and during the 20th century. The first mention of resistance welding dated back to 1877 [13]. In comparison to for example, the foundry industry, welding is a very new technology. A wide range of welding methods, smelting and pressure methods have been developed to date. An overview of the methods and their numerical labelling is stated in Czech Technical Norm (ČSN) EN ISO 4063 (05 0011) [19].

One of the methods, which is currently widely used, is pressure resistance welding. Its use is particularly advantageous in series and mass production, but it may also be applied in piece production. This is also the reason why it is the subject of specialized and scientific interest of many researchers. They examine resistance welding technology on different angles of view, for example, from the viewpoint of the types of welding material, from the viewpoint of the welding parameters used, from the viewpoint of the heat equilibrium when welding different sheet thicknesses, from the viewpoint of application in different industrial fields, etc. However, publications of systematically examining the influence surface treatment before welding were not found. Apart from the most frequently used steel, it is also possible to weld aluminium, nickel, copper and their alloys. Spot welding is for example essential in the automobile industry. Approximately 4 to 5 thousand spot welds are used to produce a regular passenger car. At least 20% more spot welds are used to produce race cars [7, 9, 10, 12, 14, 16, 17].

The heat necessary to form the joint is not supplied from the outside, as it is when welding using a flame or electric arc but occurs directly in the weld joint. The principle is relatively easy. The weld joint occurs from the melted basic material by heat developed during the passage of the electric current during the co-influence of the pressurized force. From the above mentioned, it is clear that added material or a protective atmosphere is not used for resistance. It is possible to weld in practically any position. This method is advantageous because of its high productivity.

The amount of heat incurred upon spot welding can be expressed based on the Joule-Lenz Law [1, 8, 13]

$$Q = \int_0^t R(t).I^2(t).dt \tag{1}$$

which is commonly written in form:

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

Where
Q … Total heat developed in the passing of a welding current [J],
R… Electrical resistance [Ω],
I … Welding current [A],
t…Welding time [sec].

Based on the size of the welding current and the welding time, there are two different welding regimes: short time welding and long time welding. In the short time welding, higher currents are used and the welding times are shorter. In the long time welding, lower currents are used and the welding times are longer [1, 3, 4].

For all methods used in engineering production, it is important to carefully follow all the prescribed technological procedures. The surface treatment is especially important, regardless of whether it is gluing, soldering or welding. Any possible impurities on the surface may cause problems during production and the consequent operation of the joint. In extreme cases, impurities may disable the creation of the joint. It is clear that it is necessary to spend a certain amount of finances for every step prescribed in the technological procedure. If the tests justifiably prove that it is possible to omit some of the steps in the technological procedure without reducing the quality of the joint, production is cheaper.

2 Materials and methods

Test specimens for spot welding were made of 11 321.21, low carbon steel grade, according to ČSN 41 1321 [22] (DC01 steel according to EN, St1203 steel according to DIN). The initial semi-finished material for its production was a 1000 x 2000 mm sheet, 1.5mm thick. The required sheet size was cut on NTC 2500/4 hydraulic guillotine shearing machine.

The objective of the experiments was to evaluate the influence of surface treatment on the load bearing capacity of the spot welded joints (according to the modified standard ČSN EN ISO 14273 [20]). In order to fulfil the tasks, four sets of test specimens were prepared with different surface treatments before welding. Sheets without treatment, in the state in which they were bought, were used as a standard. The second set of sheets were only degreased by acetone. Both ends of the sheets (top and bottom) in the third and fourth set that were subject to spot welding, were grinded, blasted and then degreased (at least 30 mm) using acetone and dried by hot air. Grinding of the whole sheet (in the direction of its shorter side) was done on a combined sander with abrasive belt Einhell BT-US 400. An A80 grain (corundum P80) corundum weave (cloth) was used. Blasting in a ITB 65 blasting cabin was done manually using MESH 80 garnet crushed fractions. Pressurized air with abrasive fell perpendicular to the treated surface.

The roughness of the sheet's surface before and after treatment was measured (according to ČSN EN ISO 4287 [21]) using a Surftest SJ-301 roughness measuring device, while monitoring two parameters: Ra - the arithmetical mean deviation of the assessed profile and Rz - the maximum height of profile. It was always measured twenty times, repeatedly for each of the four specimen series, in the direction of the longer specimen dimension. The results, stated in tab. 1, were statistically evaluated (F-test, t-test). It was discovered that both of the roughness parameters measured on the surface without treatment (not degreased) and the surface that is only degreased, are not statistically significant. There are statistically significant difference in the Ra roughness parameters between the original surfaces and surfaces that are only degreased on the one side and grinded and blasted surfaces on the other side. The Rz roughness parameters are statistically highly significant. It is also similar when comparing the grinded and blasted surfaces, where a highly significant statistical difference was discovered between the Ra and Rz roughness.

Tab. 1 *Surface Roughness of Tested Sheets*

Surface preparation - specification	Ra, µm	Rz, µm
Without treatment (not degreased)	1.25 ± 0.14	9.3 ± 1.4
Only degreased	1.31 ± 0.15	9.8 ± 1.4
Grinded and degreased	1.63 ± 0.22	13.1 ± 1.9
Blasted and degreased	1.91 ± 0.25	14.9 ± 1.9

The BV 2,5.21 hand held spot welder was used to finish the test specimens. It is a small welder, intended for operations with piece production. Its main components include the T 2,5.12 weld transformer, a lever mechanism for inferring pressurized force and the QX 12.1 electronic control (Fig. 1). The equipment works in the long time welding regime. The size of the welding current is constant at I_{max} = 6.4 kA. The electrodes are only cooled by the current of the surrounding air. The size of the recommended pressurized force in relation to the thickness of the welded sheets is set using the springs of the semi-turned set nut by a specified number of rotations. The operators must only change the welding time (time of passage of the welding current). The regulation level (control stage), not the welding time, is set on the control panel (Tab. 2). The parameters for welding two, 1.5 mm thick sheets, as recommended by the producer, are stated in tab. 3.

Fig. 1 *Hand held spot welder*

Tab. 2 *Welding time depending on the set regulation level (control stage)*

No.	1	2	3	4	5	6	7	8	9	10	11	12
t, s	0.10	0.15	0.20	0.25	0.3	0.4	0.6	0.8	1.0	1.3	1.6	2.0

Tab. 3 *Welding parameters recommended by the producer*

Sheet thickness s, mm	Welding time t, sec	Compressive force F, kN	Orientation welding speed, spot.h^{-1}
1.5 + 1.5	0.6	1.5	56

Considering the above stated facts by the producer in relation to the thickness of the welded sheets, we recommend a limited number of welds, which can be made per hour. From our own experience, acquired during the course of the experiment, it is clear that it is beneficial to follow these recommendations. When measuring using the Flir i7 thermal vision camera, it was discovered that there is a significant increase in the temperature of the electrodes and the surrounding parts of the equipment after a very short operating time. Fig. 2 illustrates a thermal vision image after doing one spot weld at the longest set welding time (2.0 sec.). It is logical that during shorter welding times, the heat is not so significant. Fig. 3 illustrates a zone of the spot weld affected by heat for all set regulation levels. In welding technology, the heat affected zone (HAZ) is the critical weld point. Enlarging the diameter, D, by the heat affected zone, can be well described using the (index determination $R^2 = 0.987$) logarithmic dependence in the form of $D = 2.992 . \ln(t) + 10.421$. In order to prevent any possible influence of the test results or damage to the electrodes or welders, the next spot weld was always done after the electrode was cooled to a temperature, where it is possible to hold it with your bare hands.

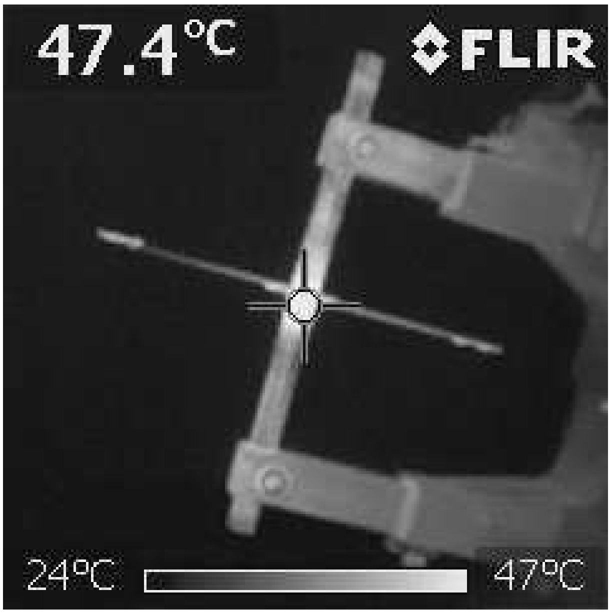


Fig. 2 *Increasing the temperature of the equipment, welding time 2.0 sec.*

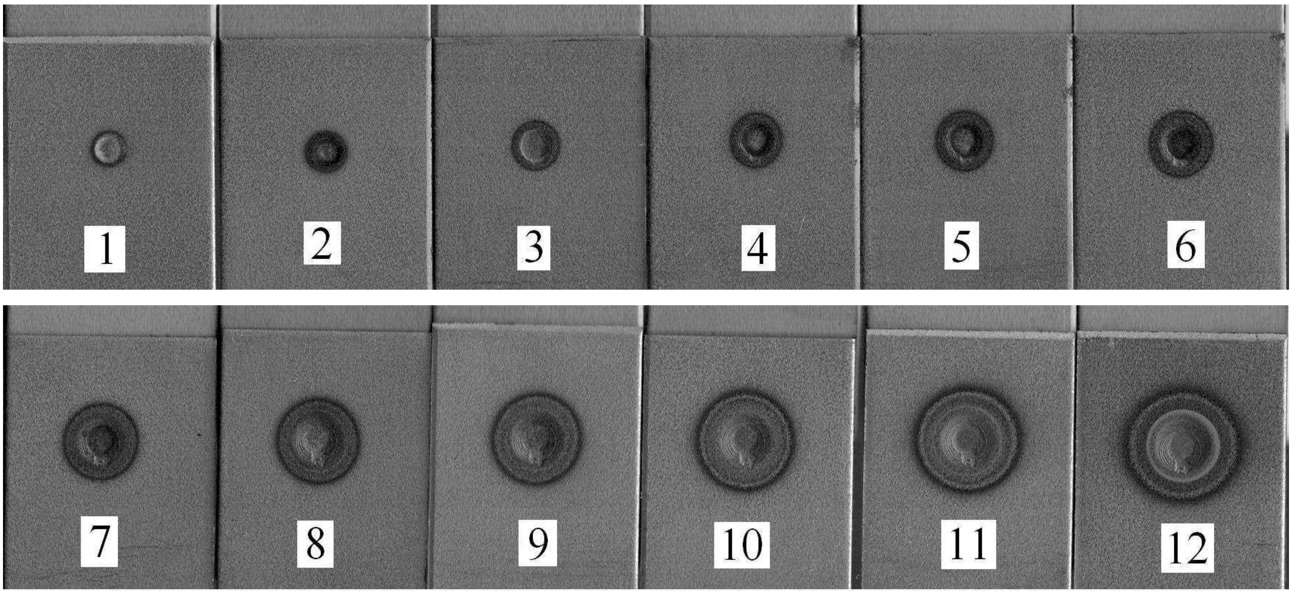


Fig. 3 *Size of the heat affected zone in relation to the regulation level used*

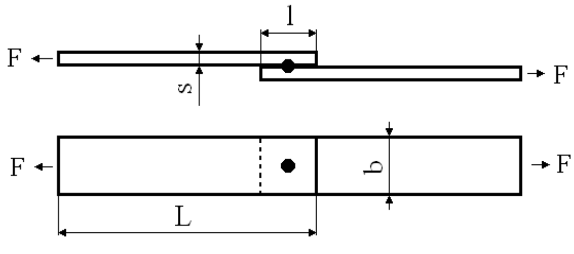


Fig. 4 *Shape and dimensions of the test specimen*

One hundred forty-four (144) test specimens were prepared from each of the four series (methods of surface preparation), 12 specimens from each of the 12 set welding times (Tab. 2). This amount is sufficient for the consequent statistical evaluation of the experiment. The dimensions and shape of the specimens and the location of the spot weld (lenses) are clear from Fig. 4 (L = 100mm, b = 25mm, l = 25mm, s = 1.5mm).

A random non-destructive and destructive quality check was performed before testing the test specimens. A non-destructive check using the ultrasound method was performed using the Resistance spot weld analyser RSWA F-1 (Frankie) device. Fig. 5 illustrates the satisfactory (left) spot weld and the unsatisfactory spot weld (right). Only 2 test specimens were scrapped due to suspicion of a faulty weld.

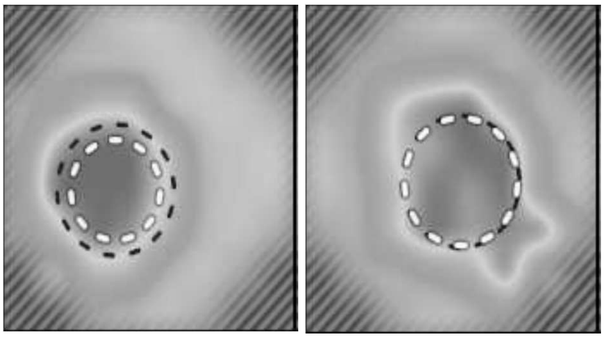
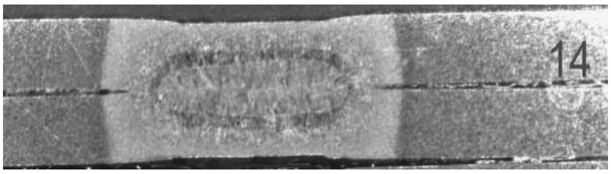
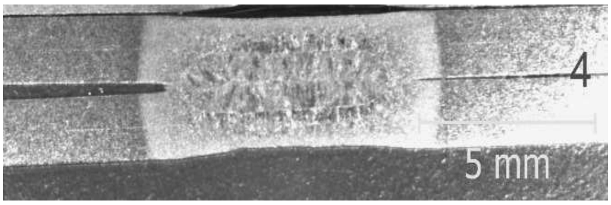


***Fig. 5** Ultrasound check of the spot welds*

The destructive test consisted in cutting the spot weld, grinding, polishing and etching it. Fig. 6 illustrates the macrostructure of two welds. Fig. 6a) illustrates the macrostructure of a spot weld of degreased sheets for a welding time of 2.0 sec. Fig. 6b) illustrates the macrostructure of spot welds of blasted and degreased sheets, also for a weld time of 2.0 sec. No defects were found on any of the test specimens that would indicate problems during their production.



a)

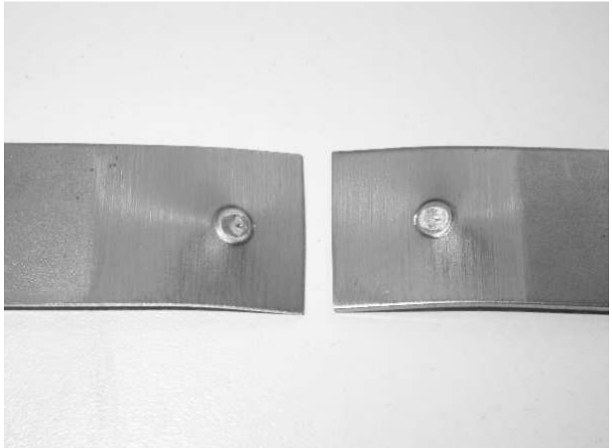


b)

***Fig. 6** Macrostructure of the spot weld: a) degreased surface, t = 2.0 sec.; b) blasted surface, degreased, t = 2.0 sec.*

3 Results and discussion

After welding, all test specimens were loaded on a universal LabTest 5.50 ST test device until they were damaged. The magnitude of the force was recorded. A damaged spot weld (Fig. 7) was either seen as a destruction of the spot weld (lens) or a destruction of the welding material. At the lowest welding time, the spot weld was always damaged in the lens. Once the welding time was prolonged, the number of welds damaged in the lens gradually decreased, regardless of the method of surface treatment used before welding. From a welding time of 0.6 sec. and higher all test specimens were damaged in the welding material.



a)

b)

***Fig. 7** a) Destruction in the spot weld (lens), t = 0.20 s, b) Destruction in the sheet, t = 0.6 s*

Fig. 8 graphically illustrates the results of the tests performed. The standard deviation is illustrated by small section by all the measured values.

Fig. 8 shows that until a welding time of 0.25 sec., there is a significant, practically linear increase of force necessary to damage the joint. The longer the welding time, the longer the force necessary to damage the joint, however, not that significant. Given a passage welding current of higher than approx. 0.8 sec., the force necessary to damage the test specimen does not increase. The longer the welding time, the character of damaging the test specimen changes. The percentage of samples damaged in the welding lens gradually decreases and the percentage of specimens damaged in the welding material increases. When using the producer's recommended device and a welding time of 0.6 sec. and more, there is always damage to the test specimens in the welding material.

Fig. 8 *Relation between rupture force and welding time (the standard deviation is illustrated by the line segments)*

Fig. 9 illustrates results of tests of the spot welds of sheets with different previous surface treatment for a welding time of 0.6 sec., which is the value recommended by the producer. The results of the firmness tests acquired when using half the welding time (0.3 sec.) and approximately double (1.3 sec.) the welding time in comparison with the recommended time, were also analyzed in more detail.

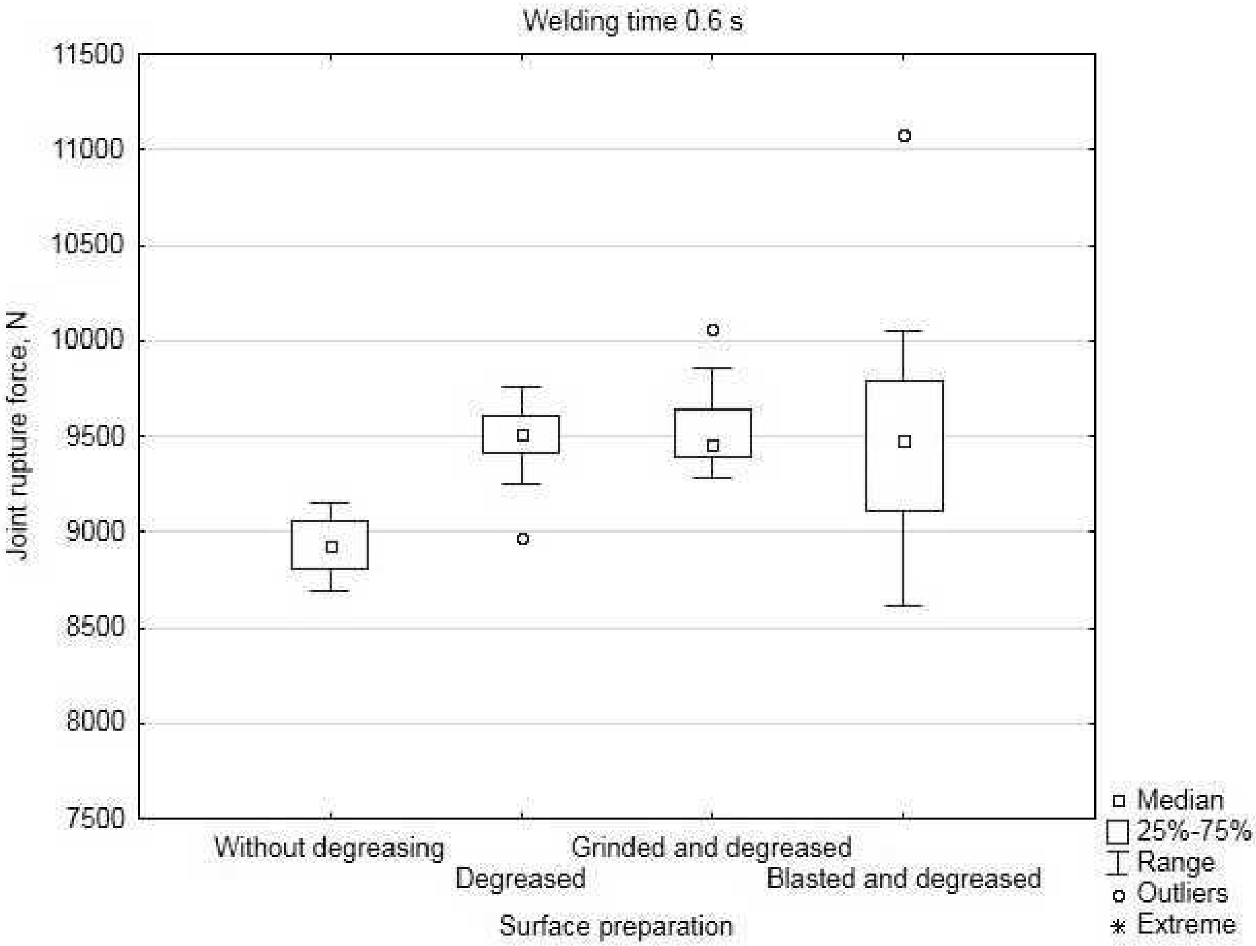


Fig. 9 *Test results for the producer's recommended welding time of 0.6 sec.*

All results were statistically evaluated (F-test, t-test). When evaluating the results for units welded from sheets in the original state (without treatment) and units welded from sheets that were degreased, grinded and degreased or blasted and degreased, there was a statistically highly significant or significant difference in the size of force necessary to damage the welded units. The results were practically identical for all three tested welding times (0.3 sec.; 0.6 sec.; 1.3 sec.). By simply pre-treating the surface (degreased), the force necessary to damage all joints for all monitored welding times increase (by 3.0 to 9.3%). It is clear that although welding sheets without any previous surface treatment is possible, it is not recommended.

If we compare the firmness of the welded units of differently surface treated sheets, we discover that the differences in the welding times of half (0.3 sec.) and the producer's recommended (0.6 sec.) are differences in the measured firmness that are statistically insignificant (0.3 – 0.8%). Only when using double the welding time (1.3 sec.), is the difference highly significant. For joints made when using grinded and degreased sheets, there was an increase in the load bearing of the spot welded units (by 2.3%), but joint made using blasted and degreased sheets decreased in firmness (by 3.3%).

Very similar results were obtained when comparing the results of joints made when using grinded and degreased and blasted and degreased sheets. Even though the differences in the firmness of the welded units for welding times of 0.3 sec. and 0.6 sec. were statistically insignificant (up to 0.4%) and statistically highly significant for a welding time of 1.3 sec., there was still a decrease in the force necessary to damage the joints (by 5.5%) for joints made using blasted and degreased sheets in comparison with joints made using grinded and degreased sheets. However, it is worth considering the increased costs when using approximately double the welding time compared to the time recommended by the producer.

4 Conclusions

This paper publishes results of spot welding firmness tests for a thickness of 1.5 + 1.5mm. The test specimens were prepared using a manual BV 2,5.21 spot welder. Test specimens with a dimension of 100 x 25mm were made of low carbon steel. The sheets were divided into four groups before welding. The sheets from the first group were welded without any previous surface treatment, in the state in which they were delivered. The sheets from the second group were degreased using acetone before welding. Both ends of the sheets (top and bottom) in the third and fourth groups that were subject to spot welding, were grinded, blasted and then degreased (at least 30mm) using acetone and dried by hot air. One hundred forty-four (144) assemblies were prepared from each of the four different test surfaces, therefore a total of 576 spot welds prepared under different parameters.

Based on statistical evaluation of the tests performed, it can be said that:

- a manual spot welder used for the production of test specimens is reliable,
- damage to the test specimens occurs by the destruction of spot welds (during short welding times) or the destruction of the welding material (during long welding times),
- when using the spot welding parameters recommended by the producer (tab. 3), we will get high quality, sufficiently firm and in practice, useful welds, regardless of the state of the surface of the sheet before welding, in which damage to the joint will always occur in the welded material,
- however, it is beneficial to at least degrease the sheets before welding, thereby increasing the force of damaging the joint by 3.0 to 9.3%,
- when using the welding parameters recommended by the producer, the surface treatment of the sheet before welding (degreased, grinded and degreased, blasted and degreased) practically does not have any influence on the firmness of the spot welds.

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