BASIC CHARACTERISTICS OF RESISTANCE SPOT WELDING

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INTRODUCTION

Resistance spot welding is one of the resistance welding processes having a common characteristic, i.e. That welding is carried out with the application of heat and pressure. All of the resistance welding processes, i.e. butt, flash, projection, seam, and spot welding, have an important share in welding engineering as regards energy consumption as well as the number of job positions, and especially the number of welded joints /1, 2/. But among the afore - mentioned processes, it is resistance spot welding which is far in the foreground. This is specially true of electronic, automobile, and aircraft industries (in a car, there are e.g. 3 : 5.10^3 spots, in a modern aircraft, there are even more than 10^6 welded spots /3/.

The present article wishes to inform readers of physical and technological characteristics of the above-mentioned process as well as with standard methods of assessment of weld spot quality.

2. PHYSICAL FUNDAMENTALS

In the most general case of resistance spot welding, two workpieces placed between two axially symmetrical electrodes, making themselves part of the same circuit as a welding transformer, are welded together /4, 5/. During welding, pressure force Fv is applied to the workpieces by the electrodes Figure (1).

After joining the primary side of the transformer to the mains voltage Uo, voltage Uv(t) at the secondary side will operate on current Iv(t), which will depend on impedance of the welding circuit.

$$I_{v(t)} = \frac{U_{v(t)}}{\sqrt{X^2_{c(t)} + R^2_{c(t)}}} ; U_{v(t)} = U_o \sin(\omega t + \psi)$$

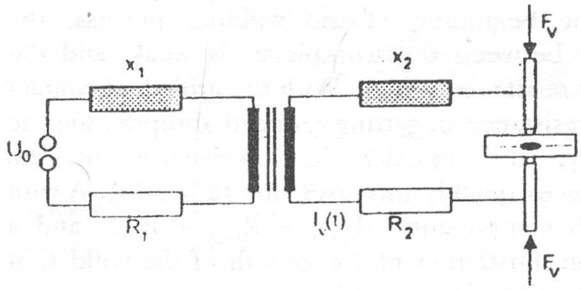

Figure 1. Essential scheme of resistance spot welding.

A weld spot is heated by heat energy released in accordance with Joule's law:

$$Q = \int_o^{t_v} U_{v(t)} I_{v(t)} dt$$

$$Q = \int_o^{t_v} I^2_{v(t)} R_{v(t)} dt$$

and respectively.

The total ohmic resistance between the electrodes varies in time and consists of several partial resistances:

$$R_E = R_{el} + R_{s1} + R_{v1} + R_s + R_{v2} + R_{s2} + R_{e2}$$

The electrodes being made of a well conductive material and cooled by water, the resistance of the electrodes $R_{e1} + R_{e2}$ as compared with the total resistance R_E is negligible:

$$R_{e1} + R_{e2} \leq R_E$$

Also contact resistances between the electrode and the workpiece Rs1 and Rs2 are low if compared with the total resistance RE:

$$R_{s1} + R_{s2} \leq R_E$$

A decisive role in generation of Joule's heat needed for melt of the weld spot is played by the contact resistance between the workpieces R_S and the resistance of the workpieces themselves $R_{v1} + R_{v2} = R_v$.

At the beginning of the welding process, the contact between the workpieces is weak, and the contact resistance is high. With the growth of contact spots, resistance in getting reduced abruptly. On the contrary, the initially low resistance of the workpieces quickly increases due to heating. A sum of both components, $R_{E(t)} = R_{s(t)} + R_{v(t)}$, and a skeleton illustration of the growth of the weld spot are shown in Figure (2) /6/.

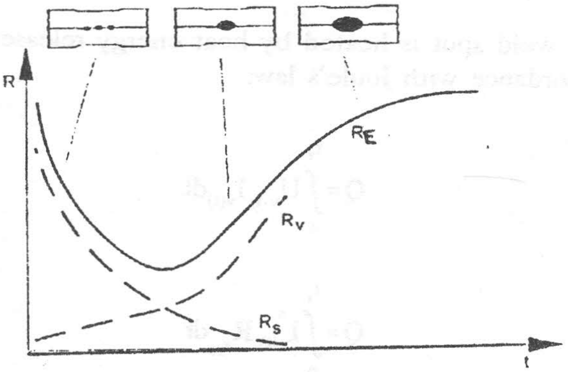

Figure 2. Time behaviour of the ohmic resistance and growth of the weld spot.

The optimum moment for the interruption of a current impulse is the moment when the total resistance RE starts to reduce.

For a proper formation of weld spots, it is necessary to apply pressure force F_v to the electrode. The force concerned has the following effects: it localises the welding current path, generates the pressure needed at the welding spot, prevents formation of pores in the weld due to shrinkage during cooling, and permits a good dissipation of heat from the workpieces to the electrodes.

3. THERMAL CONDITIONS

The total Joule's heat Q_c released during the welding process has to be much higher than the heat needed to partially fuse the weld spot Q_1. A very large quantity of heat namely dissipates into the neighborhood of the weld spot Q_2 and through the electrodes Q_3, while a negligible part is also lost by radiation Q_4. See Figure (3).

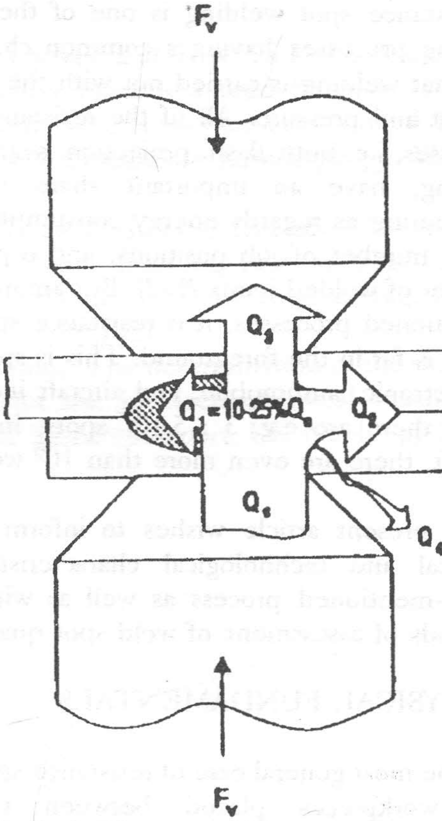

Figure 3. Sanky's diagram of heat currents.

The relation between individual shares of heat currents depends on the kind and thickness of the workpieces, the kind and shape of electrode tips, and to a very large extent on the welding parameters selected. It generally holds true that only 10. 25 % of the total heat energy Q_c is consumed for partial fusion of the weld spot /7, 8/.

Supposing that the volume of the weld spot is heated to the melting point of the workpiece, the portion of the "useful" heat energy Q_1 can easily be determined:

$$Q_1 = Q_{\Delta T} + Q_L = V \,.\, \rho .\, c_t .\, \Delta T + V \,.\, \rho .\, C_L$$

Where there are:

$Q_{\Delta T}$ thermal energy of heating;Q_L - latent heat
ρ specific density; c_t - specific heat;
V volume of spot; C_L - specific latent heat

The total quantity of heat energy required Q_c can be reached with various combinations of current intensities and weld times. The utilization factor of the energy supplied η_e which is determined by the relation between Q_1 and Q_c, however, is changing. See Figure (4).

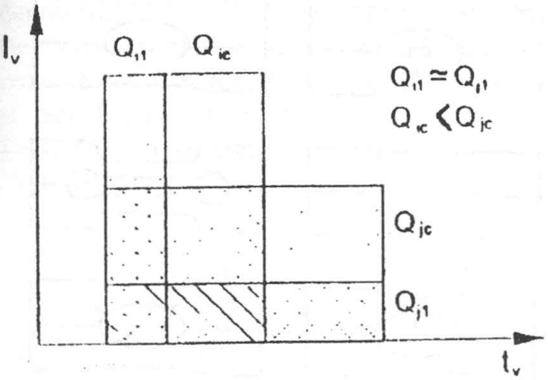

Figure 4. Influence of current intensity and weld time on the utilization factor of the energy supplied.

Within a multitude of combinations of current intensities and weld times, there is a certain lowest current intensity, which does not permit the formation of a weld spot irrespective of the weld time length /4/. Within feasible combinations, it is necessary to distinguish those which provide boundary areas small or brittle nuggets and expulsion level. See Figure (5). A high quality weld spot can be obtained with a combination of welding parameters which can be found between the boundary of bonding and that of spatter, and with constant remaining conditions, e.g. kind and thickness of the workpiece, diameter of the electrode tip, and pressure force F_v.

4. WELDING CYCLE

The resistance spot welding process can be illustrated by time behaviour of characteristic welding parameters. The welding force F_v being supposedly constant and the effective welding current intensity being approximately constant, the operations and temperature in the weld spot succeed as shown in Figure (6)/11/.

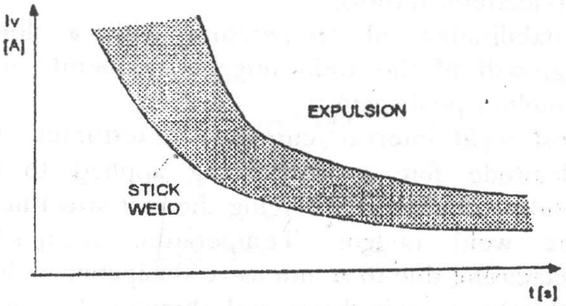

Figure 5. Zones of suitable combinations of current intensities and weld times.

and weld times

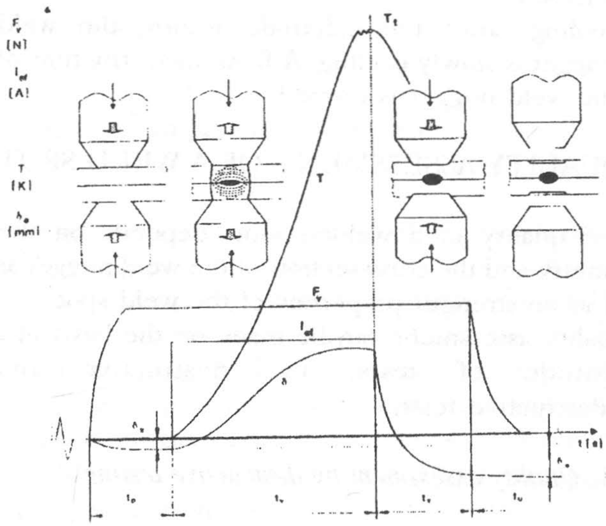

Figure 6. Welding cycle and operation within the cycle in resistance spot welding.

The welding cycle most often consists of four characteristic operations:

- prewled interval: the pressure between the electrodes leads to pulverisation of oxides and micro metal contacts between the workpieces occur;
- welding: switching-on of the welding current and simultaneous application of pressure force. This is an active phase of the welding process which

can be further divided into the following phases:
- decomposition of the oxide layer and restoration of metal bridges between the workpieces;
- growth of metal bridges and beginning of formation of a weld nugget:
- quick temperature growth with temperature expansion of the materials of the workpieces (electrode return);
- stabilisation of temperature with a slower growth of the weld nugget, frequently with molten pool spatter;

- post weld interval: current is interrupted, the electrode fore is still being applied to the workpieces and it is forging the cast structure of the weld nugget. Temperature is quickly decreasing due to an intensive dissipation of heat into the neighborhood and through the water-cooled electrodes. The value Tm which guarantees a minimum strength of the weld nugget being reached, the pressure force can be released.
- cooling: after the electrode return, the weld nugget is slowly cooling. A final microstructure of the weld nugget is formed.

5. QUALITY ASSESSMENT OF A WELD SPOT

The quality of a welded joint depends on the geometry and the cross-section of the weld nugget as well as on strength properties of the weld spot.

Quality assessment can be made on the basis of a multitude of tests, i.e. destructive and nondestructive tests.

5.1. *Quality assessment by destructive testing*

The most complete answer on the quality of a weld spot is obtained by means of metallographic examinations of the cross-section of the middle of such a spot. They can be carried out on a macro and/or micro level.

Macroscopic examinations englobe the assessment of geometric characteristics and a description of eventual defects. Figure (7) shows some frequent and characteristic defects occurring in resistance spot welds, with characteristic shapes:

a) Lack of fusion, i.e. too weak partial fusion of the weld spot
b) Spatter, inside and outside
c) Pores and inclusions in the weld spot
d) Burnt weld spot and too deep penetration of the electrodes
e) Surface and internal cracks (on the macro and/or micro levels)

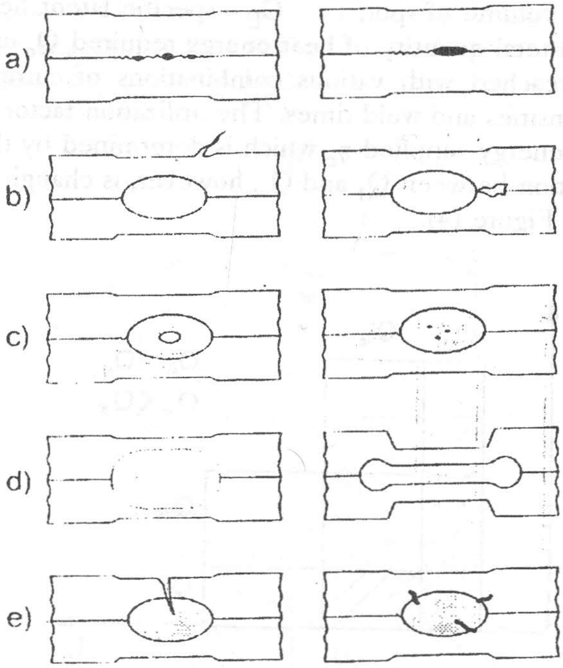

Figure 7. Characteristic defects occurring in resistance spot welding
a) Lack of fusion, i.e. too weak partial fusion of the weld spot
b) Spatter, inside and outside
c) Pores and inclusions in the weld spot
d) Burnt weld spot and too deep penetration of the electrodes
e) Surface and internal cracks (on the macro and/or micro levels)

Microscopic examinations englobe the assessment of crystal structures formed in the weld and the heat affected zone as well as microhardness distribution in the longitudinal and transversal cross-sections of the weld spot. See Figure (8).

A constituent part of quality assessment by destructive testing are also results of static and/or dynamic strength tests of weld spots.

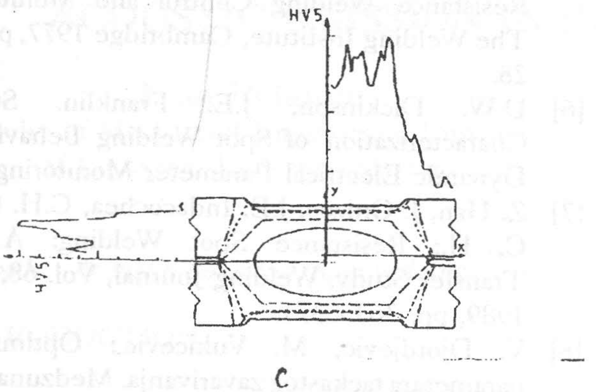

Figure 8. Elements of macroscopic and microscopes examinations of the weld spot.

According to DVS specifications, tests for determination of the static strength are as follows: tensile-shear test, tensile test, peel test, and torsion test. See Figure (9) /5, 9/.

Tests for determination of dynamic properties are as follows:

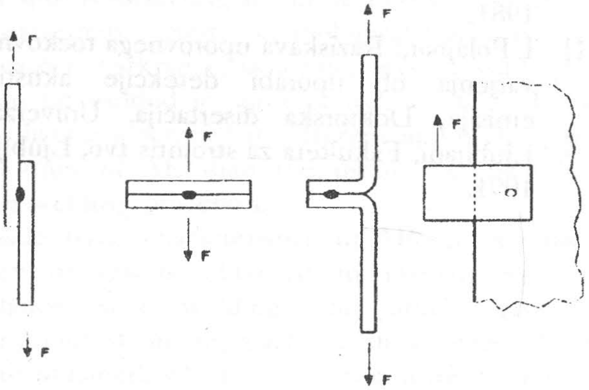

Figure 9. Static strength tests for weld spots.

A) tests of fatigue strength under pulsating stresses (from 20•80 Hz), where the influence of the arrangement of weld spots on the carrying capacity of the joints established for the kind of stress selected /9/.

B) impact toughness test where a quality criterion is energy required for welded-joint fracture. See Figure (10) /9/.

5.2. *Quality assessment by nondestructive testing*

The quality of weld spots can be tested after welding by all well-established methods of nondestructive testing, i.e. visual, penetrant, magnetic particle, ultrasonic, photometric examinations. These are all static testing methods due to the fact that testing is carried out after the welding process.

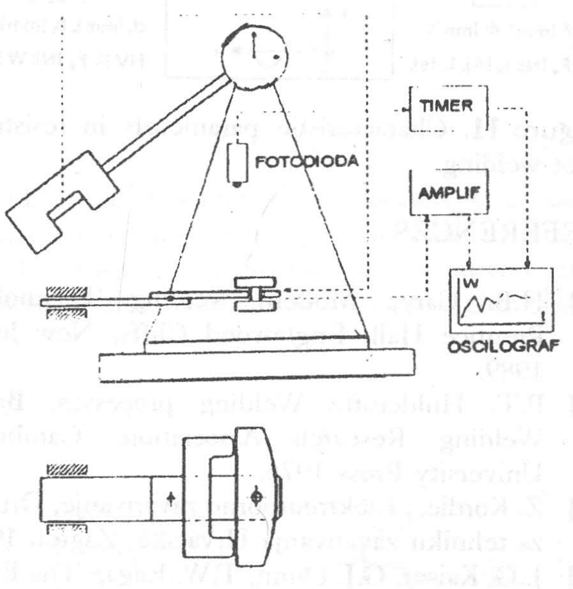

Figure 10. Impact toughness test.

Dynamic tests are those in which formation of a weld nugget is monitored by one or more characteristic parameters. The quality of a weld spot can be determined by measurable welding parameters, e.g. welding current, welding voltage, electrode displacement, temperature of workpieces, acoustic emission activity etc. Quality assessment of a weld spot also can be illustrated by a multitude of input and output parameters. See Figure (11).

6. CONCLUSIONS

The purpose of the article was to give o condensed description of basic characteristics of resistance spot welding, and show some general problems regarding quality assurance in the resistance spot welding process. At the same time, both issues create a basis for investigations of resistance spot welding by acoustic emission detection, which will be presented in our next article.

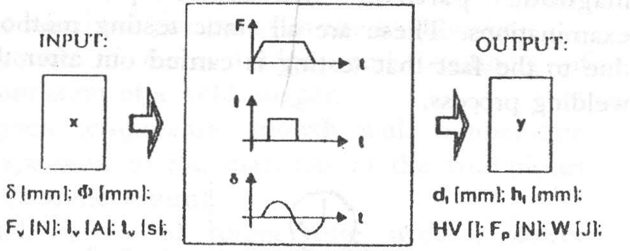

Figure 11. Characteristic parameters in resistance spot welding.

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