FUNDAMENTALS OF RESISTANCE WELDING PROCESSES

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Contents

Summary

At the beginning, the significance of resistance spot welding processes for the welding technology is highlighted, giving some comparisons to other fusion welding processes in this context. These considerations are accompanied by the listing of most important milestones in the development of resistance welding processes.

The contribution continues with the physical foundations of resistance welding processes with pressure and with the classification, which has also been adopted by the International Institute of Welding.

The central part of this contribution includes a description of most important resistance welding processes. They are presented with principle schematics, characteristic welding cycles, description of important technological characteristics; including case studies from the industry. The welding equipment is presented separately and includes: welding machines, welding power sources, welding controls and electrodes.

The final part describes characteristic and most common faults and defects in butt and lap weld joints, as well as quality monitoring and assurance for these welding processes.

1. Introductory Explanations

1.1. Basic Characteristics

Resistance welding embraces that branch of the welding art in which the welding heat in the parts to be welded is generated by the resistance offered by these parts to the passage of an electrical current. It differs from other forms of welding in that no extraneous materials, such as fluxes, filler rods, etc. are used; therefore, the metallography of the weld is not complicated by the addition of these materials. Resistance welding further differs from the fusion welding processes, by utilizing the application of mechanical force to forge the heated parts together. The effect of the force is to refine the grain structure, thus producing a weld with physical properties, in most cases, equal to the parent metal, and sometimes even superior. The electric current which generates the heat may be introduced to the workpiece through electrodes with which the work makes contact, or it may be induced within the metal by a fluctuating magnetic field which surrounds the workpiece. One of very important principles of resistance welding is to generate the heat energy in the weld zone very rapidly so that the minimum amount of heat will be dissipated by conduction to the cooler adjacent material. This requires a high rate of heat generation and is accomplished by passing a large value of current through the weld zone resistance for a short time interval.

1.2. Classifications

The classification of welding methods, adopted by the International Institute of Welding, places the resistance welding processes into the first basic group: WELDING WITH PRESSURE having code number 1000; and with respect to the energy carried used into subgroup: USING ELECTRIC CURRENT having code number 1700.

All resistance welding processes using pressure therefore belong to this subgroup. The welding processes are classified with respect to the type of the joints and the method of creation to one of the six elementary groups, having code numbers as follows:

1710 – Resistance spot welding
1720 – Resistance seam welding
1730 – Resistance projection welding
1740 – Resistance butt welding
1750 – Resistance flash welding
1760 – High-frequency resistance welding

This chapter presents only the most commonly used processes that belong to one of the groups mentioned above. The key terms have been adopted from the multilingual terminological dictionary. The most important characteristics of individual processes were adopted to a large extent from the Welding Encyclopedia, Resistance Welding Manual and Welding handbook. The content does not include fusion welding processes, as the IIW classification places them into a different basic group: FUSION WELDING with code number 2000.

1.3. Comparisons and Significance

According to rough estimates, the resistance welding processes constitute approximately one third of all welding work. The value of welding machines and equipment, used to carry out these processes, is approximately in the same order of magnitude as the value of machinery and equipment used in the liquid-state welding processes. As far as the number of products welded by one of the resistance welding processes with pressure is concerned, these processes are absolutely leading when compared to all other welding processes.

However, a comparison of number and scope of published work on the topic of resistance welding shows a quite different picture. Regardless of the type of publication – books, manuals, textbooks, professional and/or scientific articles – it turns out these welding processes are in best case only represented with a one-fifth share. Such comparisons point to a large disproportion in the significance of these welding processes for the whole field of welding technology. Furthermore, they point out to a well know fact that the most useful things are always simple to use. Or, as a brilliant observer and one of the greatest artists of all times Pablo Picasso might have said upon some other occasion: “I do not search, I find”.

2. Historical Outline

Following a physical-metallurgical examination, the resistance welding processes are equivalent to forge welding. In both cases the welding involves introduction of heat and pressure. In forge welding, the workpieces are heated to the working temperature in the fire of a blacksmith's forge, whereas in the resistance welding processes the workpieces are heated by the conduction of electrical current. In forge welding, being practically as old as the use of metals i.e. more than 5,000 years, the parts to be joined are usually heated until they are plastic, and then they are hammered together, Fig. 1. A similar principle is also used in resistance welding, but with the constant presence of force during the heating. The conduction of electrical current and thereby heating are interrupted when a reliable weld is achieved. A technological examination therefore shows the two groups of processes are basically different, displaying big differences in the method and speed of realization, the utilization of spent energy and the achievable degree of repeatability.

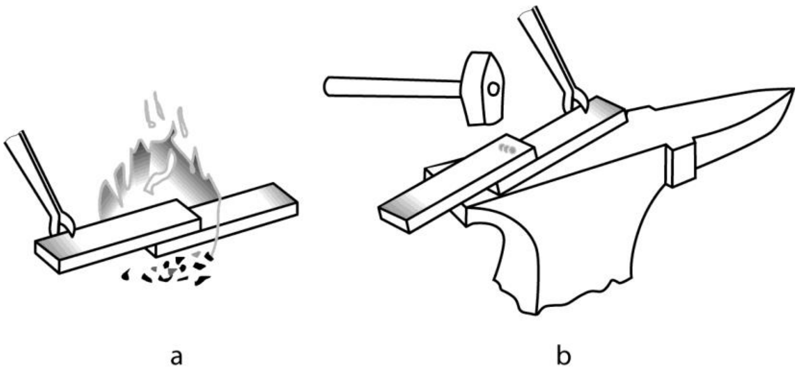

Figure 1. Example of Forge Welding

The realization that heat energy is released upon conduction of electric current in metals can be attributed to English physicist James Joule in 1856. Heat, generated in this way, was used for welding for the first time in 1887 in Russia.

Any consideration about resistance welding would be imperfect without mentioning inventor Prof. Elihu Thomson. As he was lecturing in 1877 at the Franklin Institute in USA, demonstrating the use of high-voltage capacitor to students, he was struck by an idea: what would happen if one should switch the primary and secondary windings of spark-coil transformer? Repeating a reversed procedure, he short-circuited the ends of the former primary winding and connected input voltage to the former secondary side (having a greater number of thinner turns of wire). Following a short current impulse, he noticed the short-circuited ends of the winding have overheated and welded together at the joint, Fig. 2. In this way, the idea of resistance welding was described and realized; its basic principle staying unchanged till this very day.

After having perfected the basic idea, realized as resistance butt welding, Prof. Thompson patented the resistance spot welding process in 1886. Both processes were adopted by the industry very quickly; especially spot welding that was able to produce results comparable to mechanical fastening with rivets or bolts. At the same time, welding enabled a significantly higher productivity and lower manufacturing costs. The quick and successful deployment of new joining technology was also facilitated by numerous technological improvements that enabled welding of light metals and simultaneous creation of a many spot welds. The subject of technological comparisons and change were mainly mass-produced items of metalworking industry, such as metal cookware and numerous joints in railroad cars. As the patent rights were held by the manufacturer of machines, charging for each weld that was carried out on a royalty basis, the use of the new welding method was not spreading as it could have. The standstill in the deployment of resistance welding continued until five different companies bought license rights for the manufacturing of resistance spot welding equipment. This was followed by a rapid development and increased production of machines and equipment for resistance welding. The demand for resistance welding equipment able to offer improved productivity was further stimulated by the needs of a new branch of mass production – the automotive industry. First all-steel automotive body joined by resistance spot welding was produced at Edward G. Budd Company as early as 1912.

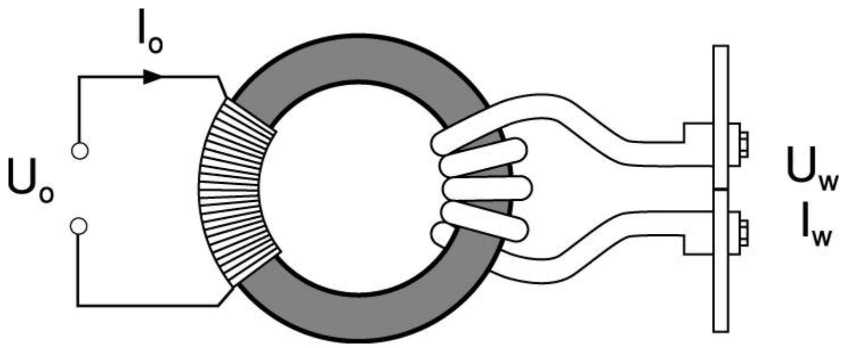

Figure 2. Thomson's Reversible Induction Discharge Protector

Interesting fact is that these welding processes have not been the subject of a noticeable development or extensive deployment during World War II. A rapid development ensued only after World War II with improved pneumatic and hydraulic systems for generating the pressure force and after the machines were equipped with better power sources and more capable controllers. Many new types of special machines were invented during this period, having design characteristics that are still used in machines of today.

Resistance welding processes flowered and achieved domination in mass-production welding in combination with auxiliary machinery and equipment, which enables a complete automation of welding in so-called computer-integrated manufacturing – CIM.

As the introduction of industrial robots into manufacturing processes began at the end of seventies, the resistance spot welding process was the very first to implement the use of robots in the welding technology. It is estimated today that the number of robots operating in the field of resistance spot welding is greater than the number of robots in all other fields of fusion welding together.

The most important achievements in the processes of resistance welding during the last period include new inverter-based sources, real-time monitoring of welding parameters and in-process control of welding process.

3. Physical Foundations

If we put together two metal parts and connect them to electric voltage U_w, electric current I_w will start running through contacting microsurfaces S_i. Applying additional pressure force F_w yields a coupled electro-thermo-mechanic system that starts to warm up according to Joule's law, Fig. 3.

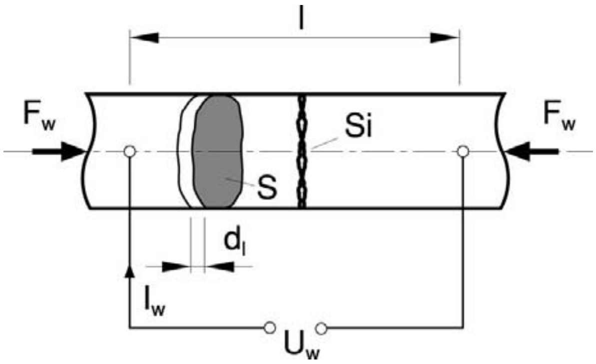

Figure 3. Two weld pieces forming a butt joint

Starting from the assumptions that both metal parts are made of the same material, that both parts have the same cross-section S [mm^2] and that the conductors supplying electrical current have insignificant electrical resistance, there are two variable electrical resistance in the closed circuit: the resistance of welded conductors R_w [Ω] and the resistance of contacts R_c [Ω]. Both resistances are time-dependant.

The resistance of conductors (weld pieces) depends on electrical resistivity of weld piece material ρ_w, weld piece cross section S_w and conductor length l.

$$R_w = \rho(T) \cdot \frac{l}{S} \tag{1}$$

$$\rho(T) = \rho_0 (1 + \alpha \cdot \Delta T) \tag{2}$$

where: $\rho(T)$ - electrical resistivity at temperature T

ρ_0 - electrical resistivity of weld piece material at starting temperature [Ω mm]

α - temperature coefficient of resistance [K^{-1}]

ΔT - temperature difference between measured and starting temperature [K]

The contact resistance R_c depends on specific contact resistance resistivity ρ_c and the total contacting surface S_i conducting the current I_w

$$R_c = \frac{\rho_c}{\sum S_i} \tag{3}$$

where: ρ_c - specific contact resistivity [Ω mm^2]
S_i - surface of an elementary metal contact [mm^2]

By conducting the electrical current the total contact surface S_o of weld pieces increases rapidly from the starting value S_i to a metal contact where the total contact surface equals the cross section of weld pieces $\left(\sum S_i \Rightarrow S_w\right)$, Fig. 4. As the total contact surface approaches S_w, the contact resistance R_c approaches zero.

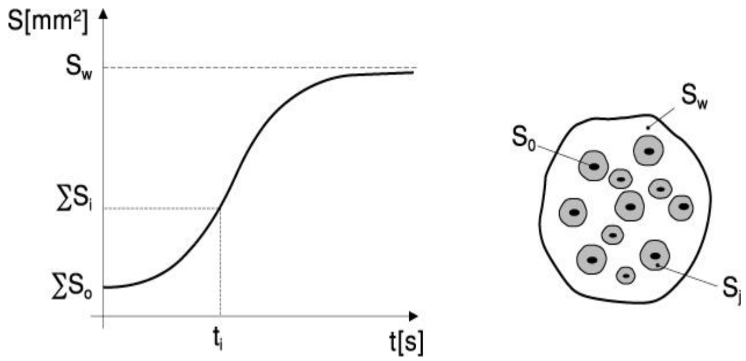

Figure 4. Time dependence of contact surfaces

Partial resistances R_w and R_c as well as total resistance $R_T = R_w + R_c$ are time-dependant quantities, so welding current I_w and heat released Q are time dependant, too. The quantity of heat released in two weld pieces in contact during a certain time period is determined using Joule's law:

$$Q = \int_0^{t_w} I_w(t) \cdot U_w(t)dt = \int_0^{t_w} I_w^2(t) \cdot R(t)dt \tag{4}$$

The total heat released (Joule's heat) is proportional to the product of effective current squared and the average values of total resistance and time of welding:

$$Q \cong \bar{I}_w^2 \cdot \bar{R} \cdot t_w \tag{5}$$

where: $I_w\left(t\right)$ – welding current in time t

$U_w(t)$ – welding voltage in time t
$R(t)$ – resistance in time t
I_w – average effective current [A]
$\bar{R}$ – average value of total resistance [Ω]
t_w – average time of welding [s]

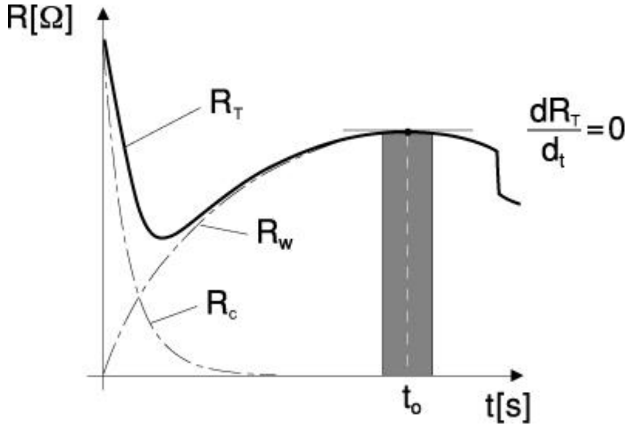

Figure 5. Time dependence of partial and total resistance

An approximate time course of both partial and total resistances in the welding of low-carbon structural steel is shown in Fig. 5. In the initial phase, the contact resistance R_c rapidly decreases due to a quick increase of contact surfaces $\sum S_i \Rightarrow S_w$ and $R_c \Rightarrow 0$. The initial increase in the weld piece resistance R_w is practically linear and can be attributed to the growing temperature of weld pieces. Once the contact surfaces are welded together $(R_c = 0)$, the total resistance R_T only constitutes of weld piece resistance $R_w \Rightarrow R_T$. Upon further heating, the total resistance stabilizes regardless of temperature increase due to plastic deformation of overheated material and shortening of length l. The results of research show the optimal time to interrupt the welding of structural steels is once total resistance approximately reaches equilibrium, i.e. near $dR_T/dt \approx 0$.

4. Division of Processes

The first step in any fundamental classification of resistance welding processes is division to pressure welding processes and fusion welding processes (without applying additional pressure). As the standpoints adopted by the International Institute of Welding treat the resistance welding processes equally, such standpoint was also taken in presenting of this chapter.

In the second step, the resistance welding processes are generally divided by the method of supplying electrical energy to the welding spot: conductive, i.e. by applying direct pressure on weld pieces with electrodes, or inductive, i.e. by induction heating and separately applying pressure to the weld pieces. The next step of division of resistance welding processes uses the position of weld pieces in the joint (butt and lap welding) and the method of creation of weld (spot, seam welding). Summarizing the given criteria yields a schematic overview of division of resistance welding processes into practically recognizable groups, Fig. 6. Each of the rounded groups also includes a series of autonomous processes, distinguished by the type and form of used current (e.g. capacitor discharge spot and butt welding, welding with direct current and high-frequency alternating current), as well as by technological characteristics (e.g. seam welding with a wire electrode and seam welding with filler material).

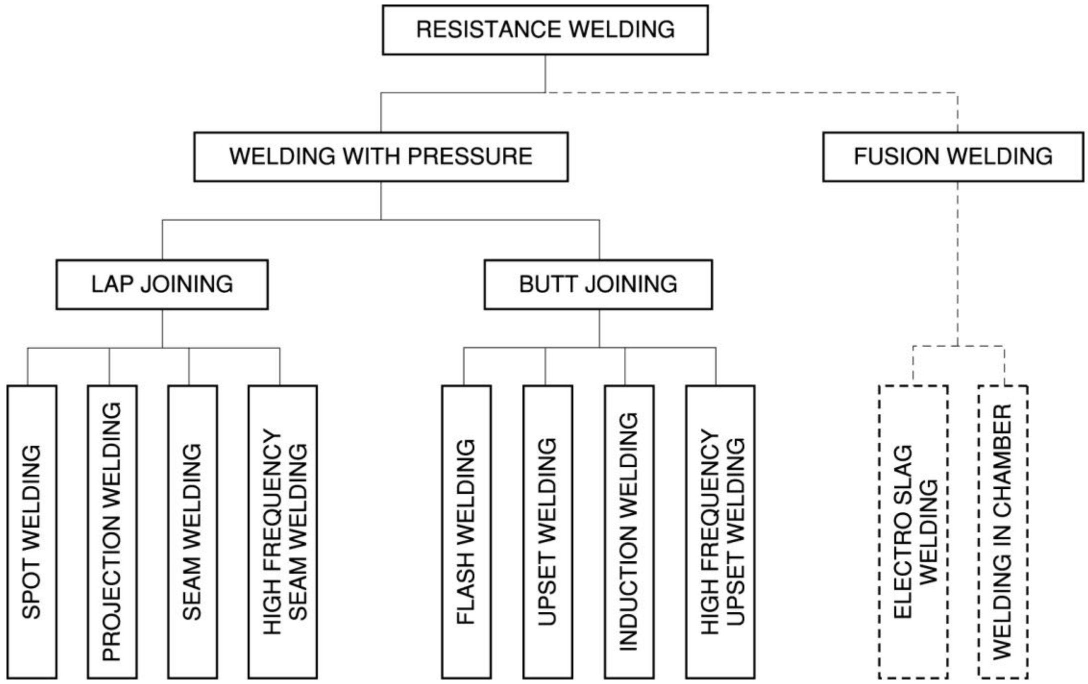

Figure 6. Division of resistance welding processes

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