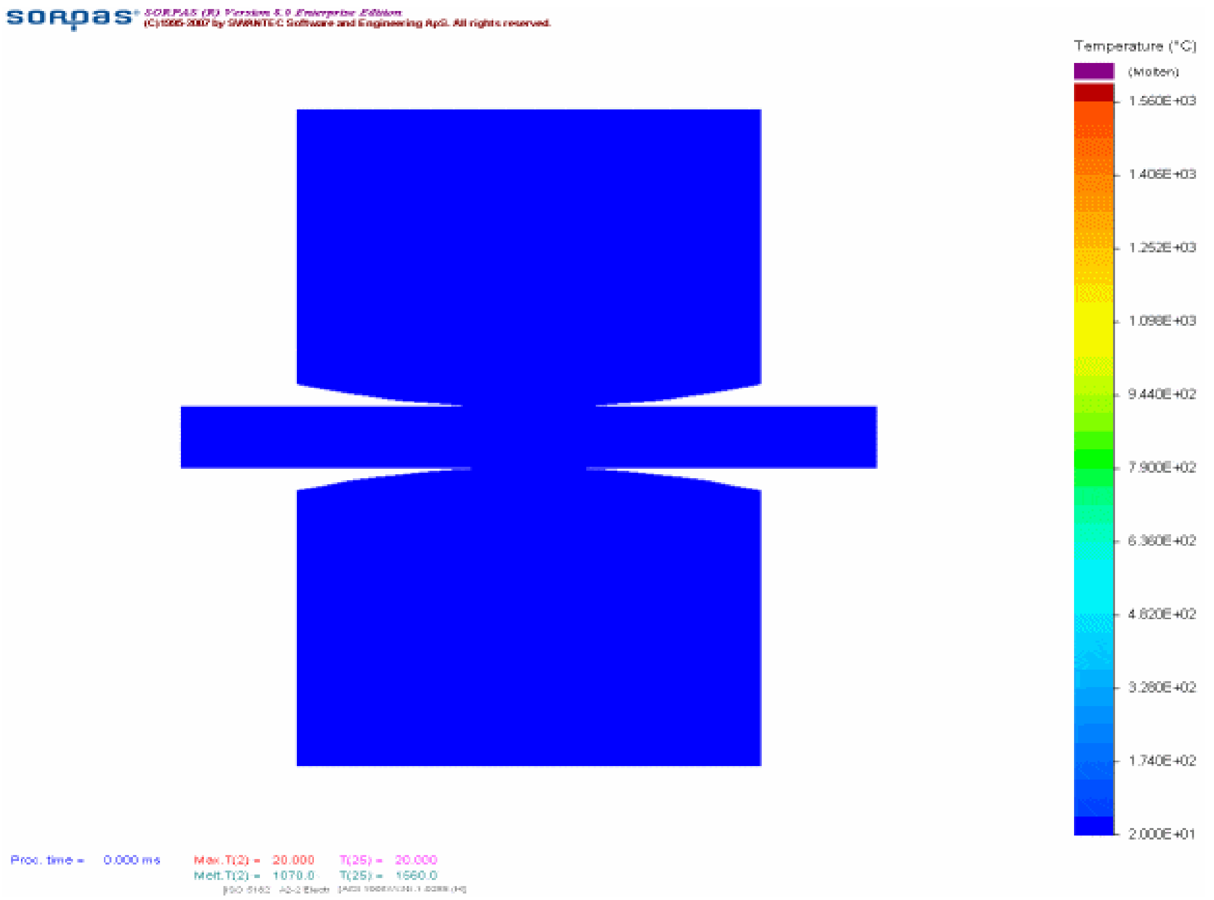
Resistance Spot Welding

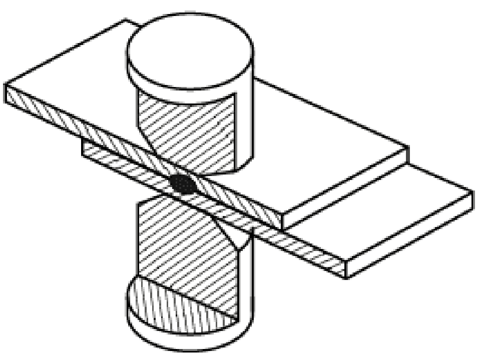
Resistance welding is a welding technology widely used in the manufacturing industry for joining metal sheets and components. The weld is made by conducting a strong current through the metal combination to heat up and finally melt the metals at localized point(s) predetermined by the design of the electrodes and/or the workpieces to be welded. A force is always applied before, during and after the application of current to confine the contact area at the weld interfaces and, in some applications, to forge the workpieces.

More details are described in the following sections:



Resistance welding processes

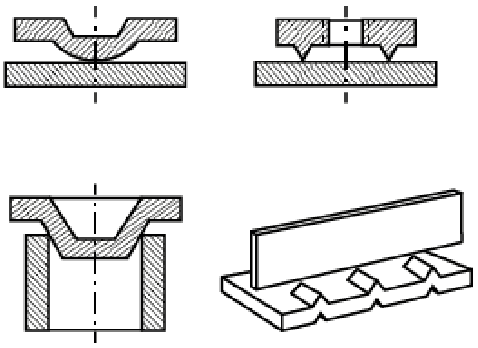
Depending on the shape of the workpieces and the form of the electrodes, resistance welding processes can be classified into several variants among which the most commonly used are spot welding, projection welding, seam welding and butt welding. More details are described below:



Resistance Spot Welding

Spot welding is a resistance welding process for joining metal sheets by directly applying opposing forces with electrodes with pointed tips. The current and the heat generation are localized by the form of the electrodes. The weld nugget size is usually defined by the electrode tip contact area.

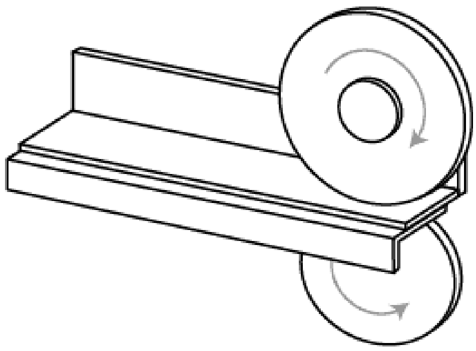
Spot welding is the predominant joining process in automotive industry for assembling the automobile bodies and large components. It is also widely used for manufacturing of furniture and domestic equipment etc.



Resistance Projection Welding

Projection welding is a resistance welding process for joining metal components or sheets with embossments by directly applying opposing forces with electrodes specially designed to fit the shapes of the workpieces. The current and the heat generation are localized by the shape of the workpieces either with their natural shape or with specially designed projection. Large deformation or collapse will occur in the projection part of the workpieces implying high process/machine dynamics.

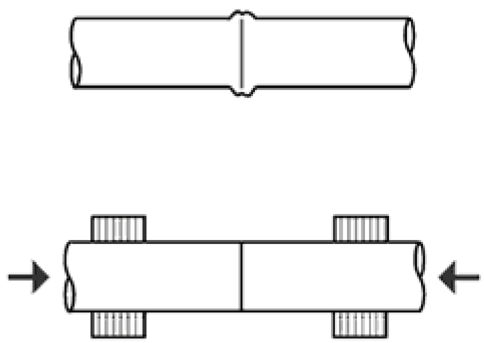
Projection welding is widely used in electrical, electronics, automotive and construction industries, and manufacturing of sensors, valves and pumps etc.



Resistance Seam Welding

Seam welding is a resistance welding process for joining metal sheets in continuous, often leak tight, seam joints by directly applying opposing forces with electrodes consisting of rotary wheels. The current and the heat generation are localized by the peripheral shapes of the electrode wheels.

Seam welding is mostly applied in manufacturing of containers, radiators and heat exchangers etc.



Resistance Butt Welding

Butt welding is a resistance welding process for joining thick metal plates or bars at the ends by directly applying opposing forces with electrodes clamping the workpieces. A forging operation is applied after the workpieces are heated up. Often no melt occurs, thus a solid state weld can be obtained.

Butt welding is applied in manufacturing of wheel rims, wire joints and railway track joints etc.

Single-Sided (One-Sided) Resistance Welding

Is a special resistance welding process where a spot weld is made with only one electrode accessing from one side to the weld zone with or without a backing plate from the other side. Low weld force is usually used, which limits the single-sided (one-sided) spot welding to joining of relatively thin sheets. It may be useful for welding components with limitation of electrode access from both sides.

Resistance Weld Bonding

Is a combined joining process with adhesive bonding and resistance welding. The adhesive is applied to the faying surfaces of sheets to be welded, and subsequently resistance spot weld is made through the sheets before curing of the adhesive. The joint can have good strength from the spot welding and good stiffness from the adhesive bonding.

Cross Wire Welding

Is a resistance welding process for joining bars or wires in cross joints by directly applying opposing forces with usually flat electrodes. The current and the heat generation are localized at the contact points of the crossed bars or wires. Cross wire welding is widely used in construction and electrical industry as well as for manufacturing of metal wire nets and shopping trolleys etc.

Indirect Spot Welding

Is a special resistance welding process where a single spot weld is made with one electrode directly connecting to the weld zone, while the other electrode is offset at a distance, but still conducts the current along the workpiece.

Series Spot Welding

Is a special resistance welding process where two spot welds are made at the same time with two electrodes offset at a distance but still conducting the current along the workpieces between the two welds.

Micro Resistance Welding

Refers to the resistance welding processes for joining micro or miniaturized components, which in principle can be any of the above mentioned process variants but in a micro scale.

Parameters in resistance welding

The principle of resistance welding is the Joule heating law where the heat Q is generated depending on three basic factors as expressed in the following formula:

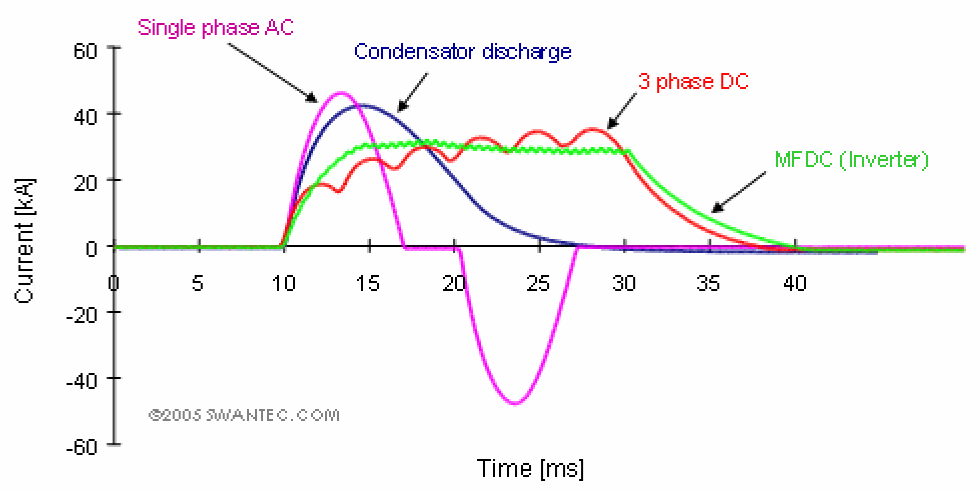
$$Q = I^2 R t$$

where I is the current passing through the metal combination, R is the resistance of the base metals and the contact interfaces, and t is the duration/time of the current flow.

The principle seems simple. However, when it runs in an actual welding process, there are numerous parameters, some researchers had identified more than 100, to influence the results of a resistance welding. In order to have a systematic understanding of the resistance welding technology, we have carried out a lot of experimental tests and summarized the most influential parameters into the following eight types:

1) Welding current

The welding current is the most important parameter in resistance welding which determines the heat generation by a power of square as shown in the formula. The size of the weld nugget increases rapidly with increasing welding current, but too high current will result in expulsions and electrode deteriorations. The figure below shows the typical types of the welding current applied in resistance welding including the single phase alternating current (AC) that is still the most used in production, the three phase direct current (DC), the condensator discharge (CD), and the newly developed middle frequency inverter DC. Usually the root mean square (RMS) values of the welding current are used in the machine parameter settings and the process controls. It is often the tedious job of the welding engineers to find the optimized welding current and time for each individual welding application.



2) Welding time

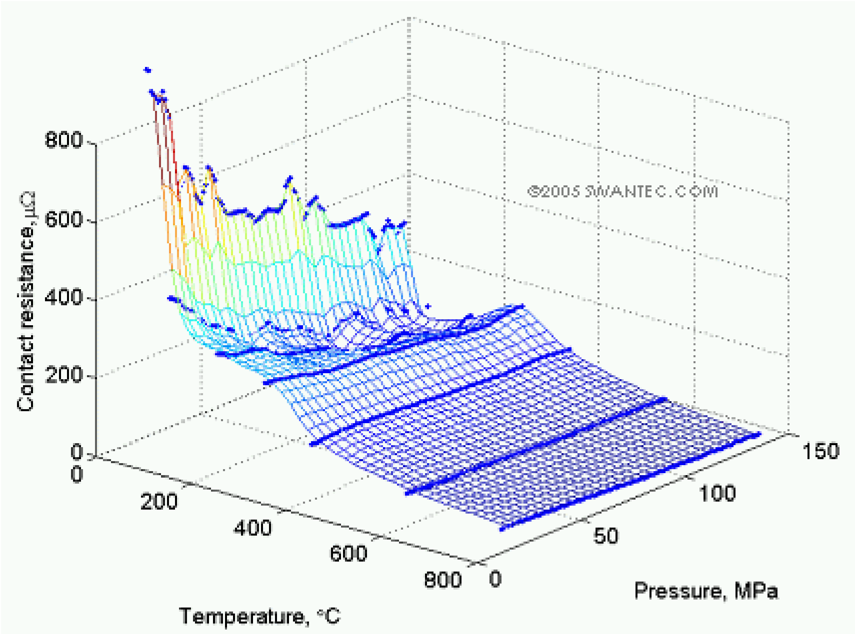
The heat generation is directly proportional to the welding time. Due to the heat transfer from the weld zone to the base metals and to the electrodes, as well as the heat loss from the free surfaces to the surroundings, a minimum welding current as well as a minimum welding time will be needed to make a weld. If the welding current is too low, simply increasing the welding time alone will not produce a weld. When the welding current is high enough, the size of the weld nugget increases with increasing welding time until it reaches a size similar to the electrode tip contact area. If the welding time is prolonged, expulsion will occur or in the worst cases the electrode may stick to the workpiece.

3) Welding force

The welding force influences the resistance welding process by its effect on the contact resistance at the interfaces and on the contact area due to deformation of materials. The workpieces must be compressed with a certain force at the weld zone to enable the passage of the current. If the welding force is too low, expulsion may occur immediately after starting the welding current due to fact that the contact resistance is too high, resulting in rapid heat generation. If the welding force is high, the contact area will be large resulting in low current density and low contact resistance that will reduce heat generation and the size of weld nugget. In projection welding, the welding force causes the collapse of the projection in the workpiece, which changes the contact area and thereby the contact resistance and the current density. It further influences the heat development and the welding results.

4) Contact resistance

The contact resistance at the weld interface is the most influential parameter related to materials. It however has highly dynamic interaction with the process parameters. The figure below shows the measured contact resistance of mild steel at different temperatures and different pressures. It is noticed that the contact resistance generally decreases with increasing temperature but has a local ridge around 300°C, and it decreases almost proportionally with increasing pressure. All metals have rough surfaces in micro scale. When the welding force increases, the contact pressure increases thereby the real contact area at the interface increases due to deformation of the rough surface asperities. Therefore the contact resistance at the interface decreases which reduces the heat generation and the size of weld nugget. On the metal surfaces, there are also oxides, water vapour, oil, dirt and other contaminants. When the temperature increases, some of the surface contaminants (mainly water and oil based ones) will be burned off in the first couple of cycles, and the metals will also be softened at high temperatures. Thus the contact resistance generally decreases with increasing temperature. Even though the contact resistance has most significant influence only in the first couple of cycles, it has a decisive influence on the heat distribution due to the initial heat generation and distribution.



5) Materials properties

Nearly all material properties change with temperature which add to the dynamics of the resistance welding process. The resistivity of material influences the heat generation. The thermal conductivity and the heat capacity influence the heat transfer. In metals such as silver and copper with low resistivity and high thermal conductivity, little heat is generated even with high welding current and also quickly transferred away. They are rather difficult to weld with resistance welding. On the other hand, they can be good materials for electrodes. When dissimilar metals are welded, more heat will be generated in the metal with higher resistivity. This should be considered when designing the weld parts in projection welding and selecting the forms of the electrodes in spot welding. Hardness of material also influences the contact resistance. Harder metals (with higher yield stress) will result in higher contact resistance at the same welding force due to the rough surface asperities being more difficult to deform, resulting in a smaller real contact area. Electrode materials have also been used to influence the heat balance in resistance welding, especially for joining light and non-ferrous metals.

6) Surface coatings

Most surface coatings are applied for protection of corrosion or as a substrate for further surface treatment. These surface coatings often complicate the welding process. Special process parameter adjustments have to be made according to individual types of the surface coatings. Some surface coatings are introduced for facilitating the welding of difficult material combinations. These surface coatings are strategically selected to bring the heat balance to the weld interface. Most of the surface coatings will be squeezed out during welding, some will remain at the weld interface as a braze metal.

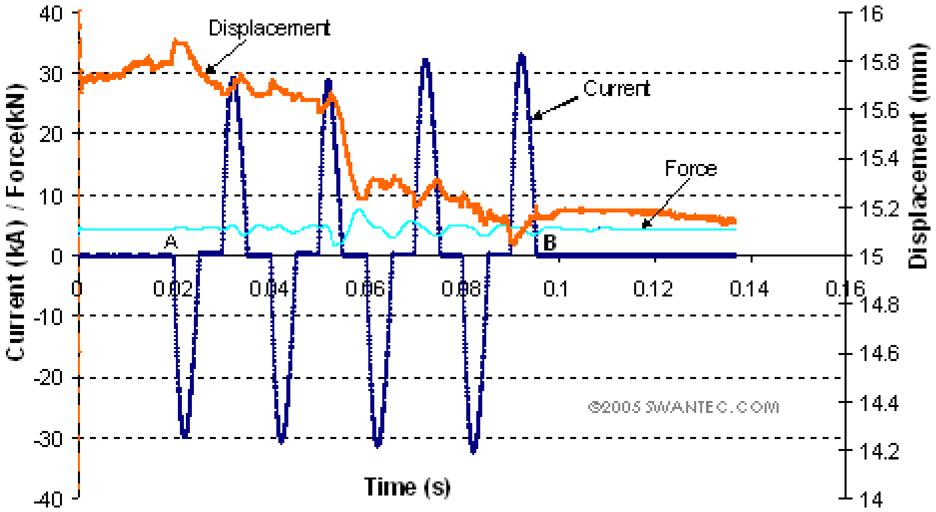
7) Geometry and dimensions

The geometry and dimensions of the electrodes and workpieces are very important, since they influence the current density distribution and thus the results of resistance welding. The geometry of electrodes in spot welding controls the current density and the resulting size of the weld nugget. Different thicknesses of metal sheets need different welding currents and other process parameter settings. The design of the local projection geometry of the workpieces is critical in projection welding, which should be considered together with the material properties especially when joining dissimilar metals. In principle, the embossment or projection should be placed on the material with the lower resistivity in order to get a better heat balance at the weld interface.

Find out more about weld designing >

8) Welding machine characteristics

The electrical and mechanical characteristics of the welding machine have a significant influence on resistance welding processes. The electrical characteristics include the dynamic reaction time of welding current and the magnetic / inductive losses due to the size of the welding window and the amount of magnetic materials in the throat. The up-slope time of a welding machine can be very critical in micro resistance welding as the total welding time is often extremely short. The magnetic loss in spot welding is one of the important factors to consider in process controls. The mechanical characteristics include the speed and acceleration of the electrode follow-up as well as the stiffness of the loading frame/arms. If the follow-up of the electrode is too slow, expulsion may easily occur in projection welding. The figure below shows measured process parameters in a projection welding process, which include the dynamic curves of the welding current, the welding force and the displacement of the electrode, where the sharp movement corresponds to the collapse of the projection in the workpiece.



Electrode degradation and tip dressing

The resistance welding process is characterized with a high current passing through the materials to be welded between the electrodes under pressure for generating concentrated heat to form a weld. This highly concentrated heat also causes problems to the electrode tips with increasing number of welds.

1. Mechanisms of electrode degradation

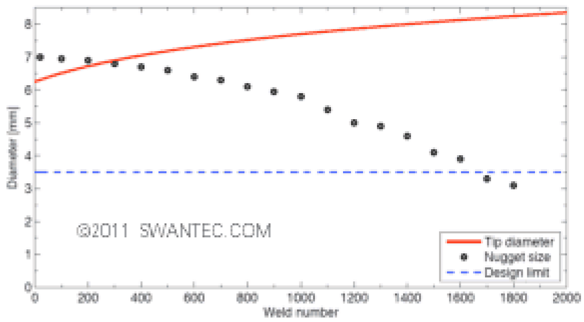
The severe conditions of high current and pressure during resistance welding expose the electrode tips at a high risk of degradation. The photo to the right shows a comparison of the new and used electrode tips in spot welding of galvanized steel sheets. With increasing number of welds, there will be two major changes in the electrode tips:

- **Geometric changes:** The electrode tip diameter will increase due to deformation and wear, such as mushrooming, pitting or local material removal by picking up.
- **Metallurgical changes:** The material properties near the tip surface will also change during resistance welding such as alloying with sheet and coating materials, and recrystallization and softening by overheating.

New tip Used tip

2. Effects of electrode degradation

The increasing tip diameter will result in larger contact area between electrode and sheet thereby reducing the current density passing through the weld interface. At the same time, alloying of the electrode material with sheet and coating materials at the tip surface will reduce the conductivity of the electrode tip thereby also drag heat concentration away from the weld interface. Both effects lead to progressively reducing weld nugget sizes. After a certain number of welds, the resulted weld nugget will drop to below the minimum nugget size required for the weld quality as shown in the graph to the right. The number of welds achievable until the resulted weld nugget sizes dropping to the limit of weld quality is called the “electrode life”. This is dependent on the form and material of electrodes, the materials to be welded, surface coatings, and the interactions of dynamic welding process parameters.

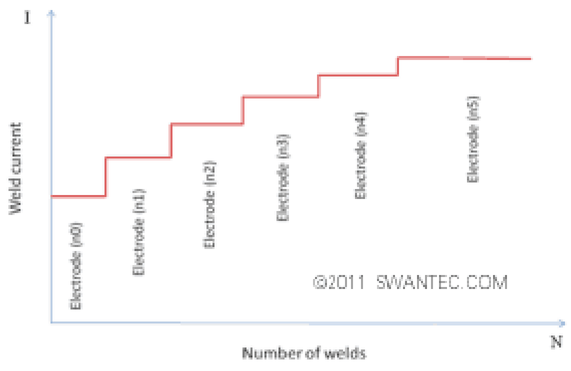


3. Step current and tip-dressing

Apart from adopting new materials and new designs of electrodes, two methods are generally used in production for compensating the electrode degradation in order to maintain the weld quality and increase the electrode life:

- **Step current**
- **Electrode tip-dressing**

Step current is a method to plan the spot welding process with a stepwise increasing weld current at each certain number of welds to compensate the loss of current density due to increasing tip diameter as shown in the graph to the right. The higher current needed with the larger tip diameter may be optimized through welding tests or by support of numerical simulations. In this way, more welds can be achieved without replacing electrodes hence a prolonged electrode life.



Electrode tip-dressing is a method to mechanically re-shape or abrasively clean the electrode tip after a certain number of welds to preserve nearly the same initial tip diameter and surface conditions. In this way, the welding process can be controlled at the same process parameters or slightly regulated by an adaptive control system to maintain consistent weld quality.