Foreword

Resistance welding manual was compiled in order to provide assistance to Ruukki’s customers and partners (like research institutes and education departments) who are resistance welding in their production process or planning to invest in resistance welding. The manual includes background and advice in choosing welding parameters and recommended welding parameters for both cold-rolled un-coated sheets and metal coated sheets of Ruukki.
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1. **Introduction to resistance welding**

Resistance welding is the most commonly used method for joining steel sheets. No filler metal is needed and the heat required for the weld pool is created by means of resistance when a high welding current is directed through the welded workpieces. An electro-conductive contact surface is created between the workpieces by pressing them together. Contact is made using the shape of either the welded surfaces of the workpieces or the shape of the electrodes.

Water-cooled electrodes made of alloyed copper are used in resistance welding. Electrodes convey a pressing force to the joint and direct the welding current to the joint in the appropriate manner. After welding, the electrodes rapidly cool down the welded joint.

Work stages in resistance welding are very fast. The surfaces to be welded do not usually need to be cleaned before welding, in addition to which the weld does not usually require grinding or postheating. The resistance welding process can be easily automated.

Resistance welding is a highly efficient production method that is particularly well-suited for automated production lines and mass production. Resistance welding is also suitable for small batch production, because the method is flexible, equipment simple and the welding process is easy to control. In addition, an important advantage of the method is that it can be used for joining a great number of metallic materials. Resistance welding is also suitable for the welding of the most common metal coated steel sheets.

The most commonly used welding method is resistance spot welding, where workpieces are joined by means of a lap joint. The maximum thickness of workpieces when producing lap joints by means of resistance welding is approximately 6 mm for uncoated steels and 4 mm for coated steels. Lap joints can also be made using projection welding and seam welding.

Sheets can also be joint using butt joints by means of flash welding or resistance butt welding. These welding methods are often used for the making of butt joints between tubes, profiles or thicker sheets. Profiles and, for example, fixing bolts can also be welded to level surfaces by means of stud welding. Resistance welding can also be used for welding nuts and other fixing tools on the workpiece surface.

This publication describes the processes of resistance spot, seam and projection welding of steel sheets (Figure 1.).

2. **Resistance welding in steel sheet lap joints**

Resistance welding methods are inexpensive and efficient, which has made them highly popular in the making of sheet joints. The major appliers of the method are the automotive industry and household...
appliance manufacturers. Resistance welding methods can best be exploited in automated production with high production quantities.

The greatest total thickness of workpieces in spot, roller seam and projection welding is 6 mm. When joining workpieces of different thicknesses, the welding current is chosen according to the thinnest sheet. Lap joints can also be made by joining several sheets at the same time. In this case, the welding current is also selected on the basis of the thinnest component. When joining workpieces with different thicknesses by means of roller seam or spot resistance welding, the proportionate thickness of the components must not exceed 3:1. Such limitation is not applicable in projection welding.

Resistance welding is a very useful way of joining galvanised steel sheets. When making lap joints, the zinc layer melts before the parent metal in the joint and is directed away from the weld. Therefore, the actual weld consists of the parent metal and the zinc coating remains intact in the electrode contact point and at the edges of the weld between the contact surfaces.

Thanks to its low costs and high efficiency, resistance welding is superior to other welding methods when making metal sheet lap joints. The equipment and its use are inexpensive. The lap joining methods that can, to some extent, compete with resistance welding are mechanical joining and gluing. Compared to resistance welding, an advantage of some mechanical jointing methods is that they can be reopened without breaking the actual product.

The use of lap joints must be taken into account when designing the end product. The making of lap joints requires sufficient overlapping of workpieces. The degree of overlapping depends on the welding method used and thickness of the workpiece. Also, the space needed for welding electrodes and electrode adaptors must be taken into consideration in case of box sections and complex workpieces.

3. **Adjustable resistance welding parameters**

The most important adjustable resistance welding parameters are welding current, weld time, electrode pressing force and electrode geometry, and the choice of electrode materials. The other adjustable parameters include the duration of squeeze and hold time, possible heat treatments before or after welding, adjustment of the up- and downslope of the welding current (slope function), changes in electrode force and timing on the basis of work stage, and pulsation of welding current. Not all these options are available in the most common welding equipment.

![Figure 2. Work stages of resistance welding. The welding current-up and downslopes have been adjusted using the slope function, and heat treatment has been applied after the current pulse. In addition, electrode force has been increased at the end of welding process.](image)

**Welding current and weld time**

The amount of heat generated in the weld mainly depends on welding current. A slight increase in welding current rapidly increases the diameter of the weld, root penetration and therefore also the strength of the weld. In most resistance welding machines, welding current is adjusted as a percentage of the nominal power of the machine, although in some equipment adjustment is made by changing the transformer ratio.

The size of the weld increases more slowly when adjusting the weld time (current time) than when adjusting the actual welding current. Weld time is adjusted in cycles. The duration of one cycle is 0.02 seconds in the 50 Hz power frequency (in the USA 60 Hz).

The amount of energy input in the weld depends on the welding current used and weld time. Short cycle times are usually preferred in resistance welding, which means higher welding current and as short a
weld time as possible. In this case, less heat is conducted to the areas immediately surrounding the weld and therefore thermal expansion remains at a lower level, in addition to which the weld also solidifies and cools down faster.

When using too low a welding current, the workpiece and electrodes conduct all heat away from the connecting surface and no weld pool is created. Due to the high conductivity of aluminium and copper, they have significantly higher minimum welding current values than steel.

Increase in weld time increases the wear of the electrodes and indentation on the workpiece. In addition, heat will have more time to conduct to a wider area around the weld. This results in a longer cooling time, which may be useful when welding materials with a tendency to be brittle or harden. Longer cooling time must, however, be taken into consideration in terms of a sufficiently long hold time.

Electrodes and electrode force
Electrodes convey the force and welding current to the desired location. Electrodes also cool down the weld during the entire welding process.

Electrode force affects the contact between electrode tips and the workpiece. Too little force does not create the required contact between workpieces and between the electrodes and the workpiece. In this case, sparking, splashing and rapid wear of electrodes may occur.

Sufficient electrode force keeps the weld pool inside the joint so that it cannot protrude or splash outside the area supported by contact surfaces. When welding using the correct electrode force, contact resistance in the interfaces remains at such a low level that no melting occurs in the interface and the electrodes can cool down the weld properly. In this case, the weld has good heat balance: most of the heat generated by welding energy is created at the faying surfaces of the workpieces where the weld is intended to be.

Too high electrode force presses the electrodes too much on the workpiece surface, which causes indentation. Large indentation lowers the strength of the weld. Some welding machine models allow the adjustment of electrode force during the welding process, which allows to better control the problems caused by high contact resistance or good conductivity.

The geometry and diameter of welding electrodes have a great impact on the welding process and weld properties in spot and seam welding. The proportion between the diameter of the electrodes and the workpiece thickness must be correct. In spot and seam welding, the electrode tip diameter is usually \(5\sqrt{t}\), where \(t\) is workpiece thickness. The geometry and diameter of electrodes affect the focalisation of the force and current density in the weld interface and therefore, to an extent, also the location of the weldability area. Problems in the positioning of the workpiece or aiming of the electrodes can be compensated by using convex electrodes. The material of the electrodes has, up to a point, impact on the cooling ability and heat balance of the weld interface.

Squeeze and hold time
The pre-welding squeeze time does not affect the technical properties of the weld. However, it must be long enough to allow the electrode pressing force to reach the adjusted level before welding current

Figure 3. Different electrode types: cross-section of a straight standard electrode and a bevelled cooling tube in the uppermost picture. Other electrodes: raised flat tip, convex and wide flat tip electrode.
is switched on. Too short a squeeze period may lead to molten metal expulsions from the weld or expulsions between the electrode and workpiece surface.

The post-welding hold time must be long enough for the molten metal to solidify and achieve sufficient strength to bear loads directed at the weld. Therefore, increased thickness of the workpiece and longer weld time require longer hold time. Common value for hold time in can spot welding is 10–50 cycles. A very short hold time be used for materials susceptible to becoming brittle in order to quickly eliminate the cooling effect of electrodes from the weld (10–20 cycles). The hold time of galvanised sheets is adjusted to be as short as possible to minimize wear of the electrodes.

**Other adjustable parameters**

Pulsation of welding current or heat treatment may have to be used when welding thicker sheets or for materials that are more difficult to weld.

In this case, heat treatment refers to lower current pulses that are applied to the workpiece either before or after the actual welding current. The pulsation of welding current allows to focus energy input to the weld better, which means that a relatively higher welding current can be used. This is beneficial when welding great material thicknesses, or materials of different thicknesses or those with good heat conduction properties. Heat treatment is advantageous for hardenable materials.

The welding current rate of rise and fall (up- and downslope) can be adjusted using the slope function. When welding galvanised sheet, the adjustment of the upslope allows more time for the zinc coating to withdraw from the weld. In addition, when welding aluminium, the slope function can also be used for preventing the harmful effect of high contact resistance at the beginning of the welding process. The thickness of the welded material affects the length of the slope sequence. Typical slope adjustment length varies from 1 to 4 cycles.

4. **Heat input**

The amount of heat generated in an electrically conductive workpiece depends on three factors: amount of electric current, resistance of the workpiece and the period of time of the current passing through the workpiece. The amount of heat can be calculated using the three factors on the basis of the following equation:

\[ Q = I^2 R t \]

- \( Q \) = heat generated, joules
- \( I \) = current, amperes
- \( R \) = total resistance of the workpiece, ohms
- \( t \) = total duration of heat input (weld time), seconds

The squared current, and the duration of heat input and resistance directly proportionally. A part of the heat generated is used for melting the metal i.e. the creation of the weld, and a part is conducted to the surrounding workpiece and electrodes.

Heat input in resistance welding is controlled by adjusting welding current and weld time. The workpiece has its own specific resistance and thermal conductivity coefficients which depend on the material and cannot thus be adjusted. However, the electrode force used and the surface properties of the workpieces – such as the thickness of the oxide layer, cleanliness and possible coatings – have an impact on the total resistance of a workpiece.

**Heat balance**

The heat balance of a weld is good when the nugget penetration is equally deep in both workpieces and when most of the heat is generated between the workpieces.

Usually, workpieces joined by means of resistance welded lap joints are of the same material and have the same thickness and surface properties. Heat balance in the weld may become a problem when joining materials of different thicknesses and resistances. When heat balance changes, more heat is created in one workpiece, which means that the penetration of the weld moves away from the centre line of the joint. In this case, the load bearing properties of the weld differ from the load bearing properties of the weld located at the centre of the joint.

Heat balance can be changed by changing the thickness of workpieces, or using different electrode diameters or alloys.
Electric resistance of workpiece

The total resistance of workpieces and contact surfaces have an impact on the amount of heat created in resistance welding. The total resistance changes during welding, which is why it is also called dynamic resistance.

Dynamic resistance is the sum of the specific resistance of the material and contact resistances between electrodes. The specific resistance of the workpiece forms the main part of total resistance. The specific resistance of steel increases as the temperature rises or when the alloy content increases. For example, HSLA steels can be welded using lower current levels than when welding non-alloyed steels.

Transfer resistance depends greatly on the surface quality of the workpiece. Oxides and impurities increase transfer resistance. Too high a transfer resistance makes welding more difficult and disturbs the heat balance of the weld. The level of transfer resistance does not cause problems when welding cold-rolled steels but in case of aluminium, for example, the rapidly forming oxide film often causes difficulties in resistance welding. The transfer resistance of an oxide layer is high and local variations in transfer resistance, in particular, make welding more difficult.

The highest transfer resistance can be found between workpieces, because soft copper electrode tips create a better contact with the workpiece surface. High transfer resistance between workpieces creates the weld between workpieces, see Figure 4.

The contact surface area affects the degree of transfer resistance. Transfer resistance between a workpiece and an electrode decreases when the electrode tip surface is increased or electrode force is increased, which increases the actual contact surface as the irregularities of the surface are pressed against each other. In projection welding, the contact surface between workpieces is significantly smaller than between the workpiece and electrodes. Thus, transfer resistance creates heat in the joint at the exact location of the weld. In addition, the contact surface of electrodes is not heated, which significantly decreases dirt and wear in electrodes.

Transfer resistance increases when electrodes get dirty or alloyed with the welded material. Increased transfer resistance between electrodes and workpiece (R1, Figure 4) increases heat generation at their interface, which leads to more rapid wear and deposit build-up on the electrodes, decreased heat balance at the joint and smaller weld diameter.

Weldability of cold-rolled uncoated and coated steel sheets

Sheet metal weldability

It is often considered that low-carbon cold-rolled steels have the best weldability. Therefore, the weldability of other materials is often compared to the weldability of low-carbon cold-rolled steels. The most commonly resistance welded materials are cold-rolled steel sheets. Hot-rolled and pickled sheets are also resistance welded but in smaller amounts.

Sheets are usually made of low-carbon (C ≤ 0.15 %) steels with good weldability. The weldability range is extensive and parameters can be flexibly adjusted. The best result in spot welding is obtained by using high welding current and short weld time, in addition to high electrode force.

Carbon content significantly affects the mechanical properties and weldability of different steel grades. Increasing carbon content decreases weldability. As the carbon content increases, weld time must be increased and welding current decreased. This means that the time of heat input is prolonged and therefore cooling down of the weld takes longer, due to the higher temperature of the surrounding work-
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piece. Slow cooling decreases the possible hardening of the weld. Hardening causes brittleness in the weld, in addition to which it may cause cracks.

Resistance welding can also be used for welding medium and high carbon steels, but heat treatment is often required. Heat treatment can be done either in conjunction with the welding process by using separate current pulses or by means of a post-welding heat treatment of the entire workpiece.

In addition to carbon, other alloying elements also affect the properties of the weld. Adding alloying elements significantly affects microstructures created by heat input. The alloying of the steel, together with rapid cooling of the weld that is typical to resistance welding, may lead to hard and brittle microstructures or cracks and hot cracks in the weld.

Phosphorus and sulphur impair the resistance welding properties of steels. The impact of these alloying elements depends on their joint effect in the steel grade in question. If the carbon, phosphorus and sulphur contents of steel are high enough, resistance welds have brittle fractures. There are good experiences in improving resistance welding properties by decreasing the carbon content of steel and strengthening the steel with phosphorus alloying.

The impacts of sulphur can be decreased by manganese alloying in which case most sulphur is combined as manganese sulphide. The sulphur content should be less than 0.035%. Sulphur content of over 0.050% causes hot cracking.

The joint impact of carbon content and other alloying elements on the hardenability of a weld is expressed using the carbon equivalent value CEV. There are a number of different ways to calculate carbon equivalent values; two possible equations are presented below.

\[
\text{CEV 1} = C + \frac{Mn}{6} + (\frac{Ni + Cu}{15}) + (\frac{Cr + Mo + V}{5})/5
\]

\[
\text{CEV 2} = C + \frac{Si}{30} + (\frac{Mn + Cu + Cr}{20}) + (\frac{Ni}{60}) + (\frac{Mo}{15}) + (\frac{V}{10}) + 5B
\]

Steels are well suited for resistance welding if the carbon equivalent values are within the following limits: \(\text{CEV 1} < 0.13\) and \(\text{CEV 2} < 0.15\). Resistance welding may be possible without any special measures above the limits; however, the possible brittling of the weld must be taken into account. It is often enough to prolong weld time if the aforementioned limits are exceeded.

In addition to hardenability, alloy contents have an impact on the fracturing of the weld. The impacts of sulphur, phosphorus and silicon on the type of fracture occurring in two different destructive testing methods are calculated using the following equations:

No partially brittle fracture occurs in the cross tensile test when: \(C + 1.91S + 0.64P < 0.153\).

No brittle fracture areas occur in the peel test when: \(C + 3.23S + 0.179P - 0.043Si < 0.095\).

The equations above are only guidelines. It is recommended to verify the carbon equivalents and ratios of the materials and if there is any reason to suspect that the alloy may affect the mechanical properties of the weld, test welds must be carried out using different parameters and the welds must be fractured for inspection.

Typical alloying elements in high-strength low-alloy structural steels (HSLA) include titanium, niobium and vanadium. The weldability of HSLA steels is good. In addition to hardenability, the alloying of a metal sheet also affects the specific resistance of the material. Alloying elements increase the electric resistance of the material, which can be seen e.g. in the weldability range with lower welding currents. The weldability range of high-strength steels may be greater than that of ordinary non-alloyed steels. The surface roughness of the contact surface must be flattened at the beginning of the welding process in order to achieve sufficient electric contact. This means that higher electrode forces must be used when welding high-strength steels.

The same principles concerning the weldability of materials that were given for spot welding also apply in seam welding, although seam welding sets a higher standard for surface cleanliness. Therefore, seam welding is primarily only used for the welding of cold rolled steel grades.
The resistance welding properties of low-carbon steel sheets in projection welding are comparable to those of spot welding. Variation in the hardness of the parent metal may cause deviation in the shape and size of projections, which makes projection welding more difficult.

Resistance welding of galvanised steel sheets
The specific resistance and transfer resistance of zinc coating are lower than those of steel. Zinc coating increases the impact of stray currents in resistance welding. Longer weld times (20–50%), higher force (10–25%) and higher welding current (30–40%) is used when welding galvanised sheets, compared to the welding of uncoated steel.

Compared to the welding of uncoated sheets, the welding of galvanised sheets requires more accurate control of welding parameters, and the weldability range is narrower than in case of uncoated sheets. Weldability decreases as the thickness of the coating increases.

The aim in the resistance welding of coated materials is that the coating gives way to the weld, thus allowing the parent metals to join and, at the same time, keeping the coating intact between the electrodes and workpiece.

The zinc coating must fully melt between the joined sheets in order to avoid zinc inclusions in the molten metal. Excessive heat input may melt the zinc coating also in the electrode contact surface. In this case, zinc coating of the readymade product is impaired and molten zinc remains in the electrode tips, thus shortening their service life.

Galvanised sheets can be welded using either flat or convex tip electrodes. Less zinc sticks to convex electrodes, and the tip geometry also facilitates the retreat of zinc from the contact surfaces. Flat tip electrodes, on the other hand, are easier to clean and service.

Due to the adhesion of zinc in electrode tips, short total weld times are used. The amount of zinc adhering to the electrode tips is directly proportional to the duration of the contact between electrode tips and hot zinc.

The production method of the zinc coating and the alloying elements in it affect the weldability of the sheet. Zinc electroplated coatings are usually purer and thinner than hot-dip galvanised coatings. The weldability of thin coatings is better and they cause less wear in the electrodes. The use of zinc nickel coatings has increased in particular in the automotive industry, thanks to its good properties in resistance welding. The weldability range of zinc-nickel coated sheets is large and they cause relatively little wear to the electrodes. Galvannealed coating has better welding properties than pure zinc coating, whereas the weldability of aluminium zinc coatings is poorer than that of pure zinc coating. Weldability decreases as the aluminium content increases. Then too, electrodes also wear out rapidly.

When resistance welding galvanised steel sheets, particular attention must be paid to the cooling of the electrodes. The welding currents and weld times used are greater, which means that the temperature of the electrodes is higher than when welding cold-rolled steel sheet of the same thickness. Heating of the electrode tip causes two problems: zinc adheres to and mixes with the copper electrode faster and the zinc coating may melt under the electrode contact surface.
The principles given for the resistance welding of galvanised surfaces also apply to sheets coated with other metallic coatings. The coating must recede from the weld in such a way that the joint is created from the parent metal of the welded workpieces. A common characteristic of metallic coatings is that their melting point must be lower than that of the parent metal.

When welding metal coated sheets, the properties of both the coating and the parent metal must be taken into account. Coated workpieces may require a different kind of cleaning than the parent metal.

**Welding of glued and paint-coated sheets**

Glue and spot welding are simultaneously used in certain applications. The advantages of this kind of a joint compared to an ordinary spot welded structure are enhanced fatigue resistance and vibration damping. In order to enhance the corrosion resistance of closed box-type structures, primers have been developed that can be used for coating sheets that are further processed by means of resistance welding.

Two resistance welding methods are used in the welding of glued and paint coated sheets: either the paint or the glue is conductive so that resistance welding is possible as such or welding current circulates through separate conductors and melts the glue in the connection point, in which case the conductive contact is created between parent metals. Adhesive joints can also be made by carrying out welding before the glue is dry. In this case, jigs are not required. Electrode force and welding current must usually be increased when welding with adhesives.

**The impact of dirt, oxides and protective oils on resistance welding**

Cold rolled steel sheets are covered with protective oil to prevent corrosion during transport and storage. Ordinary oil and grease content is almost insignificant in terms of resistance welding properties of the sheet. Large amounts of oil and grease must be wiped off. Dirt sticking to oil is significantly more harmful than oil itself. Oil and grease burn and evaporate before the weld is melted, but dirt contained in oil remains in welds as inclusions or adheres to electrodes.

Rolling scale, rust and thick layers of oxides make resistance welding more difficult and impair the mechanical properties of welds. They remain in the weld as harmful inclusions that decrease the load-bearing cross-section of the weld and may connect separate fractures. Defects caused by inclusions are very difficult to find. Surfaces must be cleaned from the aforementioned layers before welding in order to produce high-quality welds.

The amount of dirt, rolling scale and oxides on the surface greatly depends on the delivery condition of the sheet. Hot-rolled unpickled steel grades are not recommended for welding as such, because they usually have a thick oxide layer and rolling scale on the surface. The surface of pickled hot rolled and cold rolled sheets is usually sufficiently clean for resistance welding. In addition, cleansing hydrogen-based protective gas is used in annealing after cold-rolling. This creates a surface that is excellently suited for resistance welding, as the surface is cleansed from impurities and the surface oxide layer is thin and uniform.

**7. Resistance welding equipment**

The most common resistance welding machines use AC that has not been transformed from the supply frequency. DC machines have become slightly more common than before. Their welding current can be slightly lower than in AC machines. Some welding machines transform the supply frequency of the welding current to be higher, which has several advantages e.g. smaller transformers. High-frequency welding current is better focussed on the connection point, which allows using significantly lower welding currents.

The frame solutions for resistance welding machines can vary greatly. In larger welding units and automated production, welding force is created by means of pneumatic and hydraulic cylinders.

Resistance welding machines load the power supply network heavily during welding. Problems may occur in the use of large-scale series spot welding machines in particular, if the mains conductors of the power supply network are not sufficiently large. It is therefore recommended to check the network capacity and possible over-loading problems before
purchasing resistance welding machinery. The purchase and use of resistance welding equipment is discussed e.g. the MET publication “Piste-, käsnä- ja kiekkohitsauslaitteet” (Spot, projection and roller seam welding equipment).

The properties of resistance welding machine affect the selected welding parameters. Most resistance welding machines are powered by AC, in which case the welding current used depends on the size of the ferritic workpiece and gap surface of the welding machine. Different kinds of transformers and their location also have an impact on the selected welding current. These factors are difficult to assess without data collected from welding procedure tests. When selecting welding parameters, it must be noted that standard values given in tables may be somewhat different from the optimal welding parameters of the welding machine.

Resistance welding machines are equipped with a cooling system, which is most commonly based on the circulation of cooling water. Components that are cooled down are electrodes, electrode holders, transformers and contactors. The cooling of transformers and contactors is usually separate from the other cooling circuit. Equipment manufacturers usually state the minimum cooling water circulation rate that must be adhered to. Inadequate cooling impairs the heat balance of the joint and wears the electrodes quickly. The insufficient cooling of the transformer or contactor may damage the welding machine.

8. Electrodes

Electrodes press the welded surfaces together, conduct welding current to the workpiece and cool the weld and its environment. These tasks set the following requirements for electrodes: the electrode material must have good electrical and heat conduction properties, which must significantly differ from those of the welded materials. The electrode material must not form alloys with the parent material. This is a problem in particular when welding galvanised sheets in which case zinc tends to create bonds with copper electrodes. Electrodes must endure compressive force during welding, which means that the electrode material must be hard enough even when hot. In addition, it must have sufficient strength properties and have a high softening temperature. For these reasons, unalloyed copper is not a suitable electrode material.

Due to the aforementioned requirements, copper in different alloys is almost always used as electrode material. A common electrode material includes, in addition to copper, a couple of percent of chrome and zirconium. The electrode material must be selected on the basis of the welded material. When welding galvanised sheets in particular, an electrode material that has minimal reaction with zinc must be used. Sufficient cooling of electrodes must be ensured when welding galvanised metal sheets.

9. Resistance spot welding

Resistance spot welding is the most commonly used resistance welding method. Spot welding is used to join sheets together by means of lap joints. Spot welding produces single spot-like welds, which are also called nuggets. Welding current is directed to the workpieces through electrodes, which also generate pressing force. Electrodes are usually located
on both sides of the workpiece and either one or both move and transmit force to the workpiece.

The welding current of 4–20 kA is used for making a single weld. The welding current depends on the material to be welded and workpiece thickness. A number of spot welds can be welded simultaneously, which is called serial spot welding. A number of transformer solutions can be used in spot welding, see Figure 8.

The advantages of spot welding include cost-efficiency, efficacy, good dimensional accuracy and reliable production. Spot welding can be used for joining several metallic materials and sheets of different thicknesses together without large deformations. Spot welding allows large-scale production with a small number of employees and it can be easily automated.

**Stages of resistance spot welding**

The stages of resistance spot welding resistance welding are as follows: electrodes press the welded workpieces together; electrode force decreases the transfer resistance of workpieces between the electrodes, which allows directing welding current through the workpieces through the desired route. Welding current is connected after the termination of the squeeze time. Welding current produces heat at the faying surfaces and thus creates a weld pool between the workpieces. Welding current is switched off as the weld time ends. Electrode force still presses the workpieces together and electrodes cool the weld down. The weld pool must solidify and the weld must achieve sufficient strength properties during the post-weld hold time. After the end of the hold time, electrodes are retracted from the workpiece and the total weld time required for the production of one spot weld ends, Figure 7.

![Figure 7. The principle of spot welding.](image)

![Figure 8. Different kinds of transformer solutions used in resistance welding.](image)

![Figure 9. Spot weld, nugget size (d), indentation (h), nugget penetration (t), gap between sheets (x), diffusion joint area (Dc) and heat affected zone (HAZ) diameter (Dhaz).](image)
Stages suitable for the welding of ordinary cold rolled steel are described above. Pulsed welding current, changing of electrode force during the welding process or up- and downslope adjustment (slope function) can be used when welding more challenging materials such as aluminium or coated or thick steel sheets. The most basic spot welding machines may not have these options available.

**Growth of weld nugget**

The formation, size and growth rate of weld depend on the welding parameters used. The increase in the weld nugget diameter as a function of welding current is presented in Figure 10. The figure shows how the weld nugget diameter increases rapidly at the beginning of the process, after which the growth slows down. At the end of the curve, the nugget is too large for the electrodes to hold the weld pool between the welded sheets, which causes a burst of molten metal - expulsion - from between the sheets.

A good spot weld has sufficient diameter and nugget penetration. The minimum acceptable diameter of weld nugget is considered to be $3.5\sqrt{t}$, where $t$ is workpiece thickness. Welds with smaller diameter do not have sufficient penetration and the size of the weld is not enough to bear the calculated loads. In addition, too small welds are created in the welding current range where the nugget size increases rapidly. In this case, small variations in the workpiece surface quality, welding parameters or the wear of electrodes greatly affect the variation of the weld size.

A recommended weld diameter is $5\sqrt{t}$. This value is usually achieved slightly under the splash limit, where the weld nugget growth is stabilised and small variation in the welding current or workpiece surface quality do not significantly change the size of the weld.

Splash limit is exceeded when welding with excessive heat input. Large cavities remain in the weld as molten metal splashes out from the joint, which decreases the load-bearing surface of the weld. Expulsions of molten metal also make the electrodes indent further on the workpiece surface. Such an indentation decreases material thickness at the edges of the weld, which further impairs the technical properties of the weld. The area between the minimum acceptable weld diameter and splash limit is called the weldability range. Welds produced in this range meet the common requirements set for spot welds.

The four stages of weld nugget formation and growth:

1. **Heat increase**, when the weld pool has not yet been created. Electrode force and the elevated temperature smooth the surface roughness of the workpiece and transfer resistance decreases. In case of galvanised material, zinc melts and recedes from between the sheets at this stage, before the parent metal melts.

---

**Figure 10. Weld nugget growth curve and weldability range.**
2. Rapid growth of weld nugget diameter. The weld pool is created and the molten metal diameter and nugget penetration increase rapidly. The resistance of molten metal is higher than that of solid metal, which increases total resistance.

3. The growth of the weld nugget slows down. The weld size growth slows down significantly. The growth of the weld pool is restricted by cooling electrodes and the increasing surface area of the weld pool.

4. Splash. The weld pool size increases so much that electrode tips can no longer contain the molten metal between the sheets, and therefore expulsions occur. A significant amount of molten metal splashes from the weld.

**Weldability range**

Weldability range (lobe) is the area where acceptable welds can be produced using a specific combination of welding current and weld time. Welding range is limited by the minimum acceptable weld size and splash limit.

In spot welding, weldability range is usually defined using coordinate axes where weld time is located on one axis and welding current on the other. The electrode force used, electrode geometry and cleanliness, and the consistency and thickness of the welded material affect the shape and size of the weldability range. Materials with good welding properties have a large weldability range, which means that welding parameters can be selected from a great number of different combinations.

Cold rolled metal sheets usually have a large weldability range. Welding current can vary from 1.0–2.0 kA in common weld times. The alloying of the steel and thick zinc coating, in particular, may decrease the weldability range. In this case, the correct use of appropriate welding parameters is very important in terms of producing good spot welds.

Recommended welding parameters for Ruukki coated and uncoated sheets are presented in Appendix I.

The following Figure 11 shows the impact of electrode force on the weldability range of steel grade DC03.

**Mechanical properties of spot welds**

The tensile strength of spot weld depends on the nugget diameter, nugget penetration, thickness and strength of the workpiece, electrode indentation and possible defects and brittleness of the weld. The weld diameter and root penetration meet the strength requirements set for a weld when welding within the weldability range and with good heat balance. The nugget penetration must be 20–80 % of the workpiece thickness.
The shear strength of a single spot weld can be calculated as follows:

\[ \tau = 2.6 \cdot t \cdot d \cdot R_{m} \]

where:

- \( \tau \) = shear strength, N
- \( t \) = sheet thickness, mm
- \( d \) = weld diameter, mm
- \( R_{m} \) = tensile strength of the material, MPa

Electrodes indent at least slightly on the workpiece surface. A moderate indentation ensures that the weld is tight, but too much indentation decreases the thickness of the workpiece on the edge weld in such a way that the strength of the weld is impaired. Indentation must be less than 20 % of workpiece thickness, preferably less than 10 %. Too great an indentation is caused by excessive electrode force, long weld time and inadequate heat balance where heat is created, in particular, in the contact surface of the electrodes and workpiece.

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### Welding parameters for cold rolled and coated sheets

<table>
<thead>
<tr>
<th>Sheet thickness, ( t, \text{mm} )</th>
<th>Weld diameter ( D, \text{mm} )</th>
<th>Electrode tip ( d, \text{mm} )</th>
<th>Force ( F, \text{kN} )</th>
<th>Weld time, cycles</th>
<th>Effective welding current ( I, \text{kA} )</th>
<th>Minimum distance between welds, mm</th>
<th>Minimum acceptable overlapping, mm</th>
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</thead>
<tbody>
<tr>
<td>0.6</td>
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<td>5</td>
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### Welding parameters for cold rolled sheets

<table>
<thead>
<tr>
<th>Sheet thickness ( t, \text{mm} )</th>
<th>Electrode tip ( d, \text{mm} )</th>
<th>Hot-dip galvanised sheet, Z275 Force ( F, \text{kN} )</th>
<th>Weld time cycles</th>
<th>Welding current ( I, \text{kA} )</th>
<th>Minimum distance between welds, mm</th>
<th>Minimum acceptable overlapping, mm</th>
</tr>
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<td>26 - 30</td>
<td>6.6 - 8.0</td>
<td>17 - 21</td>
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</tbody>
</table>

Welding parameters for hot-dip galvanised sheets using two coatings: Z275 and Z100. The recommended welding current slope adjustment is 2–4 cycles.
Loading focuses on the outer edge of the spot weld, which means that any failures, fragile phases and indentations impair the mechanical properties of the weld. Cavities due to inadequate force or expulsions are created in the middle of the weld and they decrease its strength properties, however, less than defaults at the edge of the weld. Thick oxide layers, layers of protective oil and dirt cause inclusions in the weld.

When welding with high energy input and long weld time, some sheets have the tendency to detach from each other which may leave a gap of several millimetres between the sheets. Too large a gap impairs the mechanical properties of the weld. The gap must not be more than 10% of the thickness of the workpiece. Detachment occurs almost always with excessive electrode indentation, which makes the impact of indentation on the strength of the joint more significant.

Weld cools down very fast in spot welding, which may lead to the hardening of the weld in case of high-strength steels. Hardened microstructures are brittle, and often micro fractures occur in the weld when martensite is created. The small thickness of the workpiece further accelerates cooling. The welding tests carried out with Ruukki high-strength steel sheets showed slight brittleness in welds in short weld times. These problems were eliminated by extending the weld time and shortening post-weld hold time.

Fully brittle welds crack parallel to the sheet surface when exposed to loads, whereas welds with ductile failure mode mainly sheared off from the other sheet. The most common fracture type for high-strength steels is a combination of these two types: the weld is partly sheared off from one sheet and a brittle fracture can be seen at the edges. When the thickness of workpieces is increased, the tendency of ductile welds to break parallel to the sheet surface also increases, due to joint geometry. Welds in sheets less than 1.5 mm of thickness should shear off.

**Testing and quality management of spot welds**

It is difficult to visually inspect the size and mechanical properties of spot welds. The easiest way to inspect size is to break the joint and measure the diameter of the weld. A simple and much used destructive testing method is the peel test, Figure 13, where consecutive welds are made to two metal sheet slit strips, after which the sheets are torn apart. The weld diameter is measured as described above. The peel test can be used to define the weldability range and ideal welding parameters of a material. The peel test is easy to carry out in a production environment and no specific machinery is needed. The test must, however, be complemented with destructive tests of the end products in order to take the workpiece geometry and size into account in the welding process. Britteness and mechanical properties of the weld can also be deduced from the fracture surface of the opened welds. Simple destructive tests can also be complemented with tensile tests to assess the tensile strength of the welds. Specific specimens made of sheets are used in tensile testing. Tensile test require specific machinery. Figure 14 presents different kinds of specimens.

Weld diameters can also be measured using non-destructive testing. Such tests are usually carried out by means of ultrasound equipment. In addition to the weld diameter, ultrasound can also be used to assess some defects in the weld, but it does not fully replace destructive testing. The use of ultrasound...
sound in weld testing requires specific machinery and an experienced machine operator.

Welds can also be inspected using a microscope if a microsection of the weld is made. A metallurgical microscope with a magnifying capacity of 10–100 is sufficient for testing, but specific equipment is needed for the making of the microsection. A microscope can be used to inspect the weld for gas pores, cavities, larger fractures and inclusions.

It is recommended to carry out routine testing in production in order to control the quality of products. In this case, visual testing and the peel test are sufficient. Inspections must be carried out daily during each shift, whenever electrodes are maintained or welding parameters adjusted and immediately after changing the welded material or maintaining the welding equipment. Testing and inspection should be made on end products whenever possible. The welding of galvanised sheets requires better control of welding parameters than the welding of cold-rolled steel. Therefore, the products and equipment must also be inspected more often.

It is recommended to register weld testing in conjunction with the welding parameters used and other remarks concerning production. This facilitates the finding of the most suitable welding parameters in order to minimise the number of defects in products. Electrode wear and deposit pick-up can be decreased using suitable welding parameters, but finding the correct parameters requires long-term monitoring of production and products.

The minimum and maximum values of the most important welding parameters must be defined in welding instructions. These values must be controlled during production.

**Spot welding of galvanised sheets**

Higher welding current and longer weld time are used in the spot welding of galvanised sheets than in the spot welding of uncoated sheets. In order to minimise electrode wear, it is recommended to use short weld time and post-weld upset time to minimise the contact between hot zinc and electrodes. Special attention must be paid to the efficient cooling of electrodes and maintenance of electrode tips.

The spot welding of galvanised products requires an accurate current control unit and slope function for increasing the service life of electrodes and improve weldability. The weldability range of coated sheets is smaller than that of uncoated sheets. The thickness and consistency of zinc coating have significant impact on the weldability of the product. The weldability range is greater and less current is needed in the welding of products with thinner coating. Electrodes wear and get dirty significantly faster when welding coated sheets. A small amount of nickel or iron alloyed in zinc decreases electrode wear.
Zinc coating increases the proportion of stray current of the welding current. Therefore, the distance between spot welds must be increased; in addition higher welding current must also be used, partly for this reason.

**Other factors to consider in spot welding**

Failures in the alignment of the electrodes significantly affect the welding range and the mechanical properties of the weld. In the case of flat tip electrodes, the flatness of the tip and angle affect the concentration of force, current density and splash limit. An incorrect angle between the electrodes and the workpiece creates asymmetric welds and may significantly lower the splash limit. This decreases the weldability range, in addition to which incorrect weld diameter, root penetration and excessive electrode indentation impair the mechanical properties of the weld. Alignment failures are often caused by uneven wear of electrode tips and incorrect installation or alignment of electrode holders.

Shunt currents are problematic in particular in spot welding, and it must always be taken into account when designing the product or welding process. In spot welding, current tends to find the easiest way from one electrode to the other, which means that it usually passes through the nearest completed spot weld, leaving only a part of the welding current available in the weld that is being made. Shunt currents often amount to up to tens of percents of the welding current. The impacts of diffusion currents can be avoided by leaving enough space between spots. Minimum distances between two spots are given in welding parameter table of page 16. Shunt currents can also pass through other electrical contacts, for example, through burrs remaining in the sheet after cutting. The shunt current level depends on the thickness, conductivity and transfer resistance of the workpiece. Increase in any of these factors will also increase the proportion of shunt currents of the total welding current.

**10. Projection welding**

**Advantages of projection welding**

Welding current is strongly localised before the weld pool is created in the top of the projection, which allows welding in an extremely large parameter range. The concentration of welding current makes projection welding more efficient than other resistance welding methods in terms of energy use. Workpieces of very different thicknesses can be mated by projection welding (proportion 6:1 or even greater).

Projection welding can be used for making several welds simultaneously. In addition, welds can be located relatively close to each other without the harmful impact of stray currents. The contact sur-

---

**Figure 15. Shunt currents in spot welding.**

**Figure 16. The principle of projection welding.** In resistance projection welding, the pressing force and welding current are localised to the workpiece weld through projections made prior to mating the workpieces together. Projections are usually made in conjunction with other forming of the sheet and they can be of different shapes (embossed, elongated, annular projections etc.). Projection welding is well suited for the welding of coated metal sheets.
face between projection weld electrodes and the workpiece is large and current density small, which creates a number of advantages: the contact surface is not heated as in other resistance welding methods, electrodes do not leave marks in the workpiece, and they do not get dirty, blunt or react with coatings.

The aforementioned properties make projection welding particularly well suited for the welding of galvanised sheets. Electrodes have longer service life, stray currents do not cause problems and, thanks to the wider parameter range, welding is easier to control.

Due to the varying number of projections and shape of the workpiece, electrodes must often be made separately for each application. The welding equipment used in projection welding and welding stages are the same as in resistance spot welding.

Projection welding is particularly recommended for workpieces in which projections can be made in conjunction with other forming. Making projections separately is only profitable in certain special applications.

The weld joint is created as follows: the contact surface is created between workpieces and the high points of the projections. When welding current is turned on, the projection and contact surface are heated and the projection collapses, which increases the contact surface and heat is created in a larger area. When the weld pool forms, the projection is already fully melted and collapsed. Post-weld hold time commences after flow of welding current through the projection is stopped. The post-weld hold time has the same function as in resistance spot welding.

Special attention must be paid to the selection of correct pressing force at the beginning of the welding process. Use of excessive force causes the projection to collapse before the weld pool is created, which increases the contact surface and reduces current density. Variation in tensile strength of the workpiece may make welding more difficult, because it may result in projections of different sizes, in addition to which they flatten in different ways during welding.

When welding several projections at the same time, problems may occur in the heat balance of the joint or in the flattening of the projections. Problems can often be avoided by increasing the distance between projections. The recommended distance is four times the diameter of the projection.

**Projection welding of galvanised steel sheets**

Projection welding is the best welding method for joining galvanised sheets. Since current density at the electrode contact surface is small and the surface does not heat as much as in other resistance welding methods, very little zinc adheres to the elec-
trodies. Nevertheless, attention must be paid to the cleanness of the electrodes when joining galvanised sheets by projection welding.

Zinc coating affects the welding parameters used. Changes are smaller than in other resistance welding methods. Welding current and force must be higher and weld time longer than when welding uncoated sheets of the same thickness.

**Other aspects of projection welding**

The cycle times in projection welding are slightly shorter than in spot welding and pressing force in particular must be controlled more precisely. As a consequence, the control unit of a projection welding machine must be sufficiently accurate. More advanced equipment has the same kind of sequencing and adjustment possibilities for welding current and force as in spot welding machinery.

Welding soft materials may be difficult if the workpiece thickness is less than 0.50 mm, because projections may collapse before welding current is applied.

Slightly shorter weld times and greater electrode cooling power are typical of projection welding compared to spot welding. Projection welding may cause more brittle joints in materials that are prone to embrittlement than spot welding.

### 11. Seam welding

Seam welding is similar to spot welding. Equipment is very similar both in terms of welding current production, control and pressing force. Seam welding, however, differs from spot welding mainly because of the rolling welding wheel. In most applications, wheels on both sides of the workpiece produce the weld. The method allows producing continuous tight weld or separate spot welds at defined intervals. A tight weld is also made of overlapping spot welds. The roller seam weld width is usually about 80% of the electrode face diameter.

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**Projection welding parameters**

**Projection welding parameters for cold rolled sheets**

<table>
<thead>
<tr>
<th>Sheet thickness mm</th>
<th>One projection Pressing force, kN</th>
<th>Welding current, kA</th>
<th>Weld time cycles</th>
<th>Two projections Pressing force total, kN</th>
<th>Welding current total, kA</th>
<th>Weld time cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.6</td>
<td>5</td>
<td>3</td>
<td>0.9</td>
<td>8.5</td>
<td>3</td>
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<td>1.2</td>
<td>10.5</td>
<td>3</td>
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<td>5</td>
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<td>36</td>
<td>2.5</td>
<td>35</td>
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</tbody>
</table>
The contact surface of the electrode wheel may be convex or flat. Similar to spot welding, the face width of a flat electrode is chosen according to the workpiece thickness, \( d = \sqrt{t} \), where \( t \) is workpiece thickness. The angle between the wheels and workpiece can be changed in some applications if the form of joint or accessibility so requires. When welding sheets of different thicknesses or conductivity, the electrode face width must be selected in such a way that the heat balance of the joint is as good as possible: a narrower electrode is selected for a thinner and more conductive surface.

The same overlapping degree, distance from the edge and electrode contact surface are used in roller seam welding as in spot welding. However, significantly higher welding current must be used in roller seam welding due to stray currents circulating though consecutive weld nuggets.

Apart from the smallest sheet thicknesses, pulsed welding current is used for controlling heat input in seam welding. Each current pulse is followed by a force-off time. Welding currents in seam welding are higher and weld times shorter than when spot welding the same sheet thicknesses. Welding current ranges from 10 to 30 kA. Welding speed for A/C equipment operating in the supply frequency ranges from 1.0 to 5.0 m/min. Welding speed decreases as the sheet thickness increases.

The weldability range in seam welding is usually defined in proportion to welding current and welding speed. The maximum weldability range limit is the splash limit or the limit above which fracture occurs in the weld. Splash may occur between the sheets or on the sheet surface. Fractures in the upper limit are parallel to the weld and they may occur in the heat affected zone next to the weld or in the middle of the weld.

The distance between separate spot welds must be taken into account when welding a tight joint. As the workpiece thickness decreases, the diameter and penetration of the weld also decrease, which means that distances between welds must be shorter.

Figure 19 is a system drawing of a weld made by means of seam welding. The drawing shows the minimum and maximum penetration and the overlapping of spot welds. Figure 19 shows the measurement of minimum width of a broken weld.

**Advantages of seam welding**

Seam welding can be used for manufacturing tight and pressure resistant welds in an efficient way. Welding is fast and both coated and uncoated sheets can be welded. Seam welding can be used for joining sheets of different thicknesses, similar to other resistance welding methods. Seam welding is more difficult than other resistance welding methods when the total combined sheet thickness is over 3.5 mm.

The cooling rate of the weld is slower in seam welding than when using other resistance welding methods. Therefore embrittlement, which occurs in the welding of high-strength steels, is less common in seam welding.

**Seam welding of galvanised sheets**

The sensitivity of the method to dirty electrodes is emphasised in the seam welding of coated sheets. The high welding current used results in zinc adhering to the electrodes. Wheels can be protected.
using a copper string or wire running on the electrode contact surface (Figure 18, the first drawing). In addition, the wheel can also be cleansed by grinding or machining during the welding process. The adhesion of zinc to electrodes can be decreased by the efficient cooling of the electrodes.

Higher welding current and electrode force are used in the seam welding of galvanised sheets compared to the welding of uncoated materials. Good control of welding parameters is emphasised in the welding of coated sheets. Short current pulses and force-off times require an accurate control system and experience in choosing welding parameters. Similar to spot welding, the thickness and alloying of zinc coating also affect seam welding parameters.

Other factors to consider in seam welding

The cooling of the seam welding electrodes is of utmost importance. When welding a continuous weld, weld nuggets are produced rapidly, and therefore electrodes heat up fast if not properly cooled. In addition to common cooling practices, electrodes can also be cooled by spraying or by submerging them in cooling water.

Seam welding is also sensitive to the surface cleanliness of workpieces. Even the smallest amounts of dirt adhere to electrodes increasing transfer resistance, which in turn increases the heating and dirtying of the wheel. Seam welding is therefore mainly used for the welding of cold rolled sheets with good surface cleanliness. Welding speed must be decreased when the oxide layer on the workpiece surface increases.

Figure 19. Evaluation of seam welds, minimum and maximum acceptable weld penetration, weld overlapping (O) and weld width (W).

<table>
<thead>
<tr>
<th>Sheet thickness mm</th>
<th>Pressing force, kN</th>
<th>Electrode face Width mm</th>
<th>Welding current kA</th>
<th>Welding time cycles</th>
<th>Press-off time cycles</th>
<th>Welding distribution spots /cm</th>
<th>Welding speed m/min</th>
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<td>5.5</td>
<td>14</td>
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<td>2</td>
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<td>1.2 – 1.5</td>
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<td>2.0 – 2.5</td>
<td>7.5</td>
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<td>22</td>
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</table>
12. Literature and standards


ISO/FDIS 17677-1 Resistance welding -- Vocabulary -- Part I: Spot, projection and seam welding


EN ISO 14329 Resistance welding. Destructive test of welds. Failure types and geometrical measurements for resistance spot, seam and projection welds


ISO 5182:2008 Resistance welding -- Materials for electrodes and ancillary equipment

EN 25184, Straight resistance spot welding electrodes, 1994
Appendix: Recommended welding parameters

Cold-rolled uncoated sheets

The recommended weld diameter $5\sqrt{t}$, see page 10, is achieved using the following welding parameters. The throat surface of the welding machine, distance between spots and distance from the edge as well as electrode geometry affect the welding parameters chosen. The impact of these factors must be taken into account when applying the parameters presented in the tables in production.

The welding parameters and weldability range of steel grade DC03 are presented in Figure 11.

<table>
<thead>
<tr>
<th>DC01</th>
<th>DC04</th>
<th>S215</th>
<th>HC380LA &amp; HC420LA</th>
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<tbody>
<tr>
<td>Symbol</td>
<td>Thickness, mm</td>
<td>Electrode diameter, mm</td>
<td>Pressing force, kN</td>
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<tr>
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### Recommended welding parameters

#### Hot-dip galvanised sheets

<table>
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<th>Symbol</th>
<th>Thickness, mm</th>
<th>Electrode diameter, mm</th>
<th>Pressing force, kN</th>
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</thead>
<tbody>
<tr>
<td>DX51D+Z100</td>
<td>0,5 0,75 1,0 1,5</td>
<td>4 6 6 6</td>
<td>2,0 2,2 3,0 4,3</td>
</tr>
<tr>
<td>DX51D+Z200, Z275 and Z350</td>
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<td>2,0 2,2 3,0 4,3</td>
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<tr>
<td>DX52D/DX53D/DX54D+Z100</td>
<td>0,5 0,75 1,0</td>
<td>4 6 6</td>
<td>2,0 2,2 3,0</td>
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<tr>
<td>DX52D/DX53D/DX54D+Z275</td>
<td>0,5 0,75 1,0 1,5</td>
<td>4 6 6 6</td>
<td>2,0 2,2 3,0 4,3</td>
</tr>
<tr>
<td>S350GD+Z275</td>
<td>1,0 1,5</td>
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<td>3,0 4,3</td>
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<td>HX420LAD+Z275</td>
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LITEC 600DP+Z100

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<tr>
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</tr>
<tr>
<td>Electrode diameter, mm</td>
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<tr>
<td>Pressing force, kN</td>
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LITEC 800DP+Z100/Z275

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LITEC 1000DP+Z100

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<tbody>
<tr>
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<tr>
<td>Electrode diameter, mm</td>
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<tr>
<td>Pressing force, kN</td>
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LITEC 700TRIP+Z100

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<tr>
<td>Electrode diameter, mm</td>
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<tr>
<td>Pressing force, kN</td>
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Galvannealed-coated sheets

**HX340LAD+ZF100**

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**LITEC 600DP+ZF100**

<table>
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<th>Electrode diameter, mm</th>
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<tbody>
<tr>
<td></td>
<td>1.2 1.2 2.0</td>
<td>6 6 6</td>
<td>3.0 3.6 4.0</td>
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</table>

**LITEC 800DP+ZF100**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Thickness, mm</th>
<th>Electrode diameter, mm</th>
<th>Pressing force, kN</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>1.2 1.2</td>
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<td>3.0 3.6</td>
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Galfan-coated sheets
DX51D+ZA95/ZA255

<table>
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<tr>
<td>Electrode diameter, mm</td>
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<td>6</td>
<td>6</td>
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<tr>
<td>Pressing force, kN</td>
<td>2,2</td>
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LITEC 600DP+ZA185

<table>
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<td>Electrode diameter, mm</td>
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![Graph showing welding current vs welding current for DX51D+ZA95/ZA255 and LITEC 600DP+ZA185](image)