Girish P. Kelkar, Ph.D.
(562) 743-7576
girish@welding-consultant.com
www.welding-consultant.com

Projection Welding

Conventional resistance welding is typically utilized for welding sheet metal parts, where two or more sheets are sandwiched between electrode tips and welded with heat generated from flow of welding current. In Figure 1, schematic section on the left shows a typical resistance welding sandwich where the two electrodes pinch the parts to be welded. While such a setup requires limited part preparation (keep 'em clean!) it does take a toll on the welding electrodes which are exposed to high pressure and high current density flowing through the tips, and require cooling and frequent maintenance. Conventional welding can also face challenges in welding dissimilar materials or parts with considerable difference in size. As an alternative, projection welding (Figure 1.) offers many benefits (and challenges too!) by utilizing a projection that ensures that the welding current and heat is focused at the projection. During the welding process, the projection collapses and the weld contact area grows in size. Use of a projection provides many benefits as listed and discussed below:

1. Extended electrode life

   With projection welding, weld size is no longer tied to electrode size; consequently, the electrode size (contact area) can be much bigger than the projection size, resulting in considerably reduced contact pressure and current density at the electrode/part interface. Due to the reduced pressure and current density, electrodes will have longer life.

2. Improved heat balance

   One of the challenges in welding parts that are dissimilar in size or material property is the issue of heat balance – ability to produce equivalent softening/heating on both sides of the weld interface. If the parts being welded are considerably different in size (thermal mass) or material properties (melting point, conductivity), it becomes difficult to weld them with conventional resistance welding. In such situations, a projection on the larger or more conductive part helps regain heat balance.

3. Removal of plating

   A key attribute of projection welding is the ability to get rid of plating on the surface and expose parent metal on both sides. Parts are often plated for various reasons but often the plating material interferes with welding. For example, zinc plating on the surface of galvanized steel is not conducive for welding as it has poor bond strength and can actually form cracks in the weld by weakening the grain boundaries. When welded with projection welding, most of the zinc gets flashed out during early part of the weld. Similar effect is seen when welding tin-plated copper parts. Tin plating is squeezed out and allows base copper on both sides to come in contact and form a strong bond. Both tin and zinc, have lower melting point compared to the typical base metals of steel and copper, respectively, and hence work well with projection welding without having to be removed prior to welding. The technique of removal of plating during projection welding does not work when the plating has a higher melting point compared to base metal, as is the case with Ni plating on copper.

4. Multiple weld spots with single electrode

   When multiple spot welds have to be made in reasonable close proximity at predetermined locations, use of projections makes the process fairly straightforward and robust. Additionally, all the welds can be made in one shot with a single electrode. Such welds are quite common when welding brackets to sheet metal frames.

Of all the benefits of projection welding, removal of plating during welding is the least appreciated. Figure 2 shows a section of a weld between two tin-plated copper pieces where one of them had a projection. The tin plating can be seen squeezed out from the weld interface leading to a strong copper-copper solid state bond.

Projection Designs

Projections are typically made by stamping, machining, or coining. Stamping of sheet metal to form a projection is quite common for metal brackets and electrical terminals. Projections can be made in relatively thin sheets as long as the projection is strong enough not to collapse under action of welding force even before the welding takes place. Typical sheet thickness used for projections in steel sheets ranges from 0.02" (0.5 mm) to 0.250" (6 mm). Stamped projections are often in the shape of a dome (also known as dimple projections) or can be elongated to look like speed bumps on the road. As for the size of the dimple, there is a lot of literature out there with tables but you can keep it simple by using the following ratios (see Figure 3 for a schematic):

1. Dimple diameter = 2 to 4 times sheet thickness (larger diameter for thinner sheets)
2. Dimple height = 0.5 to 1 times sheet thickness (lower height for thicker sheets)
3. Electrode diameter = 3 times dimple diameter

Keep in mind that these are recommended ratios and you can deviate from those to suit your needs. As for location, try to keep the edge of the projection at least one dimple diameter away from the sheet edge or any bends.

Coined or machined projections do not have the same concerns as a stamped projection as there is no risk of the premature projection collapse during welding. Shape and size of coined/machined projections is only limited by your imagination; typical dome shape with diameter/height ratio of 3:1 will work well as a starting point. Shapes can be triangular, trapezoidal, or asymmetric (to push the softened/molten metal to a particular side). Coined projections are common on welding nuts while machined projections are often used to make circumferential projections to form a hermetic seal. Another projection design used is the corner projection which is commonly used to plug a hole in a reservoir. All four projection designs are shown schematically in Figure 4. Weld sections of typical projection welds are shown in Figure 5.

Strength of a projection weld can be calculated to a simple approximation by area of the dimple and assuming base metal properties for shear/tensile strength, based on type of loading during testing. Actual weld strength depends on multiple factors including failure mode, changes in material properties during welding, and size of the weld produced which can be greater or lesser than dimple diameter based on process parameters.

Projection Welding Process

As mentioned earlier, projection is a feature that focuses current and force to a single point/line at the beginning of the weld. During the welding cycle, the weld contact area grows till it reaches a desired size which usually coincides with the mating surfaces coming in contact, at which point the weld is terminated. One of the main differences between conventional sheet-to-sheet resistance welding and projection welding is that projection welding is a dynamic process where there is considerable movement of the upper (moving) electrode. In conventional resistance welding the key parameters are energy, welding force, and time; displacement is often limited to less than 10% of the total stack height. On the contrary, projection welding is defined by extensive electrode displacement as the projection collapses during welding. It is this displacement that makes projection welding far more challenging for process control. The key to process control in projection welding is the ability of the weld head to continue to apply welding force even as the weld collapses, referred to as **follow-up**. Process control then becomes a tug-of-war between ability of the power supply to provide energy and the ability of the weld head to move quickly and maintain the welding force as the parts soften throughout the cycle. If the rate of energy supplied is greater than the rate at which the weld head can follow-up, it leads to a series of unfortunate events listed below in sequence of occurrence:

1. Energy applied leads to rapid softening at the projection contact area.
2. Inability of the weld head to follow-up and keep applying the welding force leads to a drop in instantaneous applied force at the weld (if the weld head had enough follow-up, it would have deformed the softened projection, thus leading to more contact area and a consequent drop in energy density, thus reducing the rapid temperature rise).
3. Drop in instantaneous force leads to a rapid increase in resistance at the weld interface.
4. Increase in resistance leads to further increase in heating rate and consequent softening at the interface.

5. The chain reaction continues till there is uncontrolled melting at the weld interface; the molten metal is violently expelled from the weld resulting in weld splash and arcing, which can be seen and heard if you are standing near the welding machine. If you have hooked up a weld monitor with good resolution, weld splash will appear as wild fluctuations in weld voltage.

Note that there will be some minor expulsion from zinc and tin-plated parts as the plating material is ejected, but should not include any expulsion of the base metal.

<u>Process Control</u>

Once the part is ready for welding at the machine, the three main factors that can be tweaked are the force, power, and time. Force should be set such that it is just enough to make a small indent at the tip of the projection prior to firing the weld. Force is typically held constant throughout the weld but can be increased in latter part of the weld to provide a forging action. Depending on the type of power supply being used, power delivered to the weld can be programmed in terms of current/voltage/power (in DC and HF power supplies), or AC cycles and %heat (AC controllers), or W-sec (Capacitor Discharge). Depending on the size and type of materials being welded, time can range from a few milli-seconds up to a second (50/60 cycles).

The power and time space can be thought of a process map with a smaller area being the actual process window where acceptable welds can be made, and is shown in Figure 6. The graph, with power on y-axis and time on x-axis, can be divided into four quadrants surrounding the process window in the center. At low power and short time (quadrant III), welds will be weak while combination of high power and long time (quadrant I) will deliver excessive heating and subsequent meltdown.

Most of the active welding and process tweaking will be done in quadrants II and IV. In quadrant II, delivery of high power in short time can lead to arcs, sparks, and electrode sticking. Such arcing can be attributed to poor follow-up of the weld head and/or constrained movement of parts being welded. Keep in mind that the part in contact with the moving electrode should be completely free to move along with the electrode during weld collapse. In automated manufacturing operations, it is quite common to have the other end of the part anchored in either a housing, fixture, or due to a prior weld. Constrained movement will shrink the size of the process window.

In quadrant IV, the situation is the opposite; the weld head has good follow-up, but the power supply may not be able to deliver power at a fast enough rate leading to a slow collapse of the projection. Longer weld time will allow the weld heat to dissipate and prevent the weld interface from reaching the desired peak temperature leading to weak welds. Keep in mind that the total energy (energy = power x time) may be the same for a welding process point in quadrant II and IV, but it is the rate of energy delivery which is critical for projection welding.

Size of the process window can be increased by proper selection of materials (electrodes and parts), part design, welding equipment, and process parameters. A wider process window will allow for a robust process that is not sensitive to normal variations in incoming parts.

(Figures on following pages)

For additional questions or concerns, please contact
Girish P. Kelkar, Ph.D. at 562-743-7576 (USA)
girish@welding-consultant.com

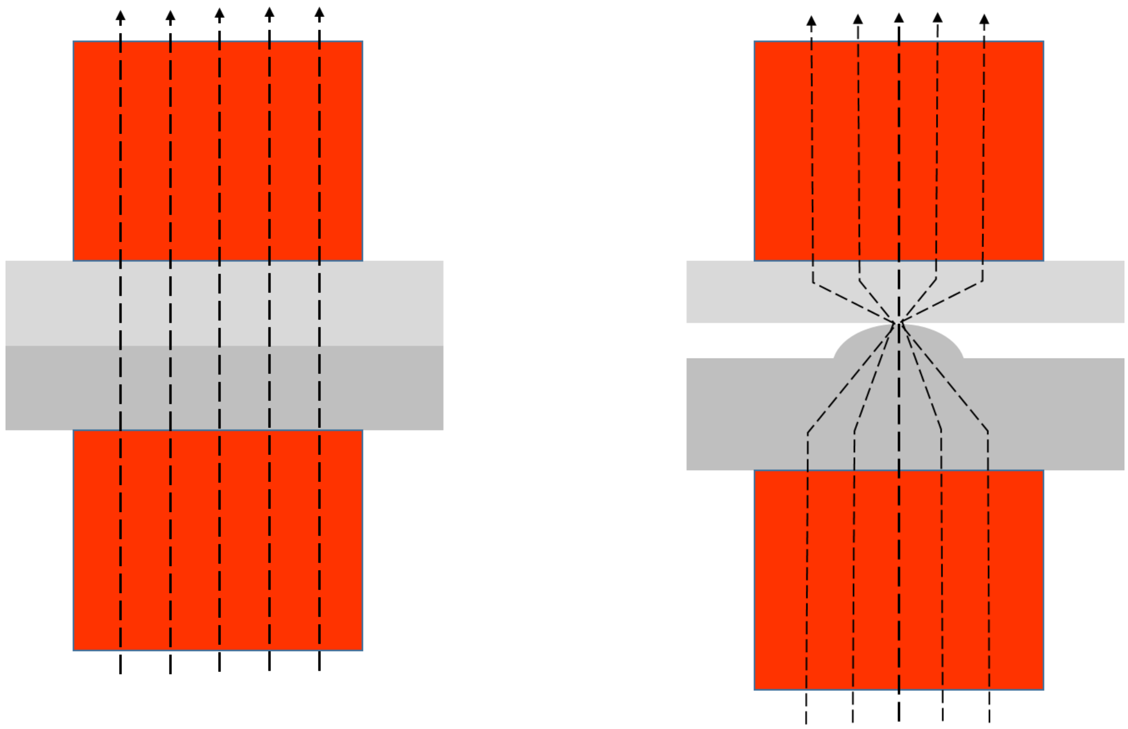

Figure 1. Schematic showing a typical resistance weld between two flat sheets (left) and a projection weld (right). Dashed lines show flow of welding current.

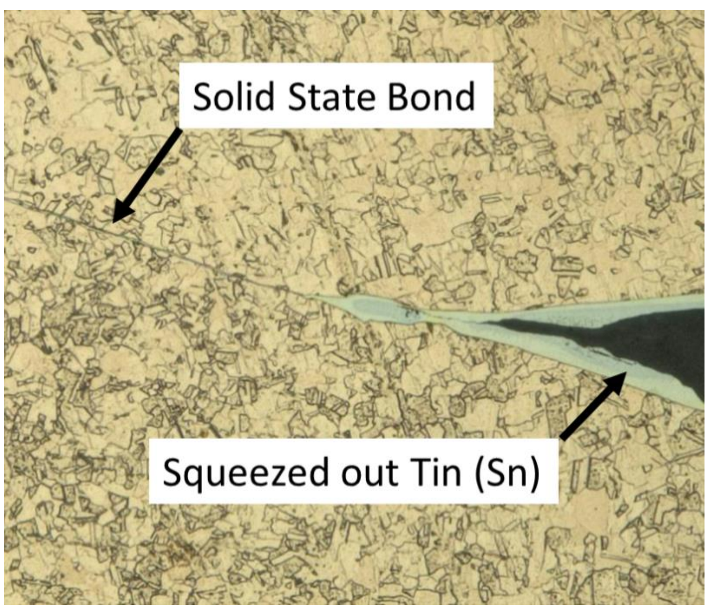

Figure 2. Weld section showing tin plating squeezed out from the welding interface leading to a strong copper-copper solid state bond.

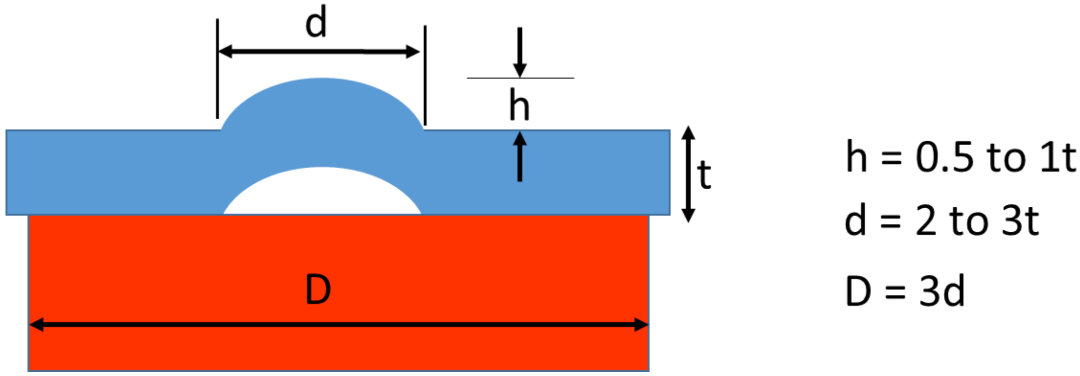

Figure 3. Schematic shows guidelines for ratios and dimensions of a dimple projection with reference to the sheet thickness (t). Also shown is the welding electrode with diameter D.

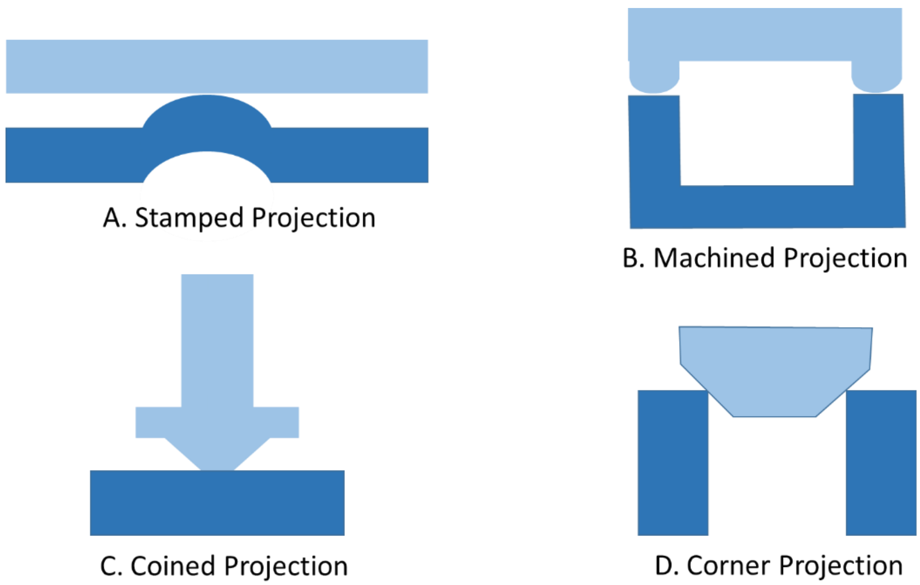

Figure 4. Schematic sections of four types of projection welds. Machined and corner projections are common in applications for circumferential welds leading to a hermetic joint.

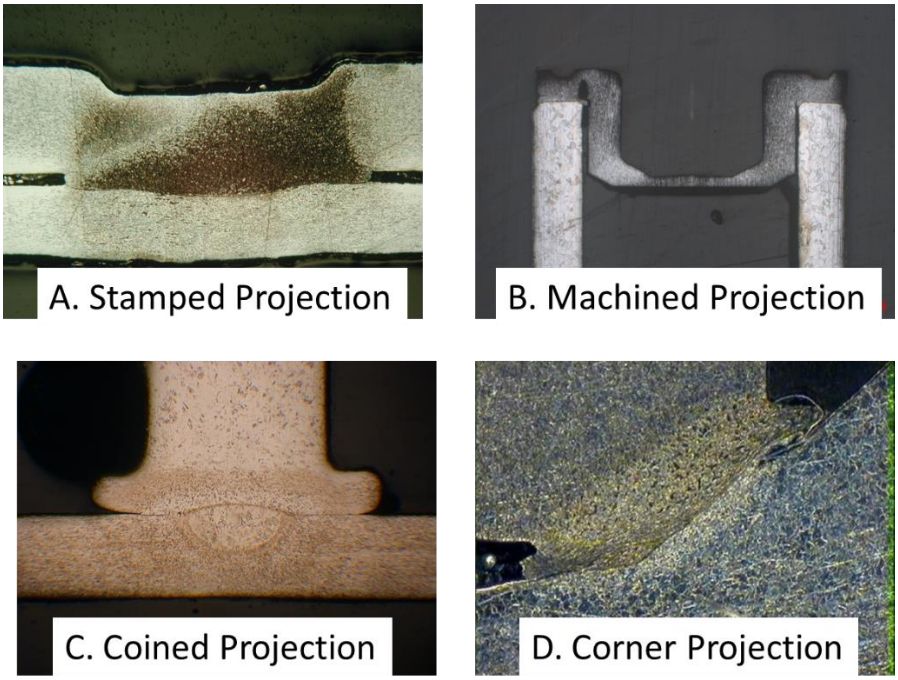

Figure 5. Weld sections of four types of projection weld designs shown in Figure 4. The welds can be fusion or solid-state depending on materials and process parameters.

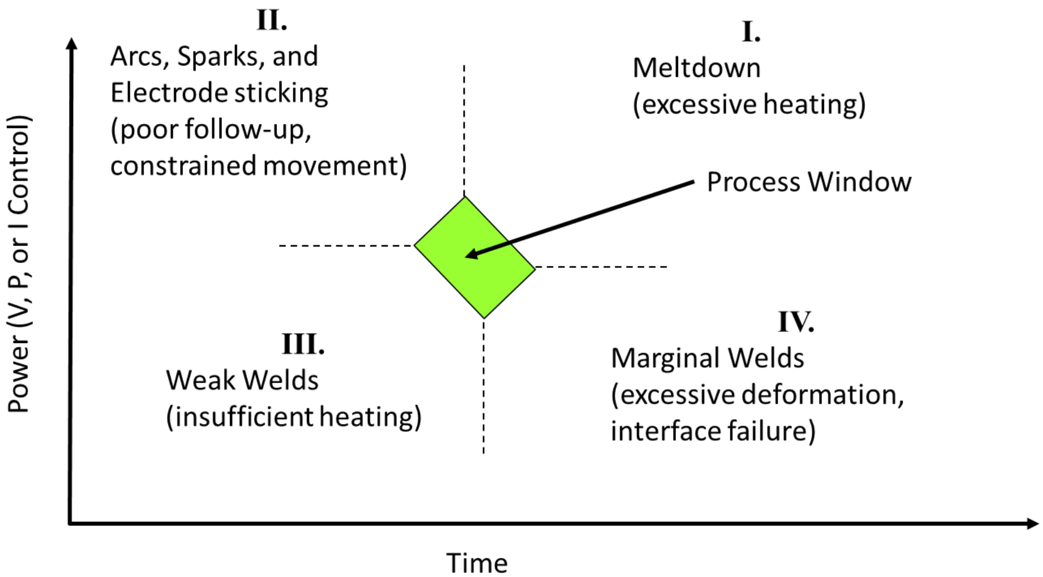

Figure 6. Schematic graph showing a typical process window and neighboring regions. Size of process window can be increased by proper selection of materials, design, equipment, and process parameters.