Joining – Resistance welding

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2 Resistance welding

2.1 Resistance Spot Welding (RSW) – Process

See also:
- AAM – Design – 1 Design philosophy > Assembly and tolerance

History
The RSW process was invented in 1884 and patented one year later by Elihu Thomson the American co-founder of General Electric (the other was Thomas Edison). Thomson discovered spot welding during a practical demonstration while he was giving a lecture about the exciting new field of electricity. Initially spot welding was used predominantly for manufacture of fencing for livestock.

Description
Workpieces are overlapped & clamped locally under pressure between two high-conductivity copper electrodes. A large current is passed through the electrodes and workpiece for a very short time. Governed by Joule's Laws, heating is caused due to the resistance of the workpiece and its surfaces. The material is thus forged & fused in a localised area (typically a circular nugget of diameter between 4 & 7 mm is produced). There is no protruding weld-bead, on either side of the joint.
Schematic of RSW process

I is welding current, R is total resistance and t is duration of current

*Electrical Current, mechanical Force & Time are the essential elements for RSW*
2.2 Joint configurations for RSW

Description
Two (or more) components are overlapped in the region to be joined. Typically this is along a weld flange specifically incorporated on the components for the purpose of accommodating the spot welds. RSW is most often configured in a way that requires access to both sides of the joint, so welding to closed sections is not generally possible. There are some single-sided variants of the RSW process, but these are largely unproven for aluminium.

A selection of joint configurations suitable for RSW

*Joint Configurations for Aluminium are essentially the Same as for Steel.*
2.3 Flanges for RSW of aluminium

Rationale

In order to minimise the possibility of edge-welds and uncontrolled weld expulsion, weld flanges must be of adequate width to provide a flat portion that is wider than the anticipated weld nugget diameter.

Also, for reasons of accessibility, gun alignment, and avoidance of current shunting, no part of the electrode, or its holder, should be allowed to contact the corner radii, or the up-flanged part of the component.

Notes

A: there must be no interference between electrode and the work piece.

D: is the weld nugget diameter.

F: is the weld flat dimension, and must be several mm greater than D, plus usual tolerances for spot positioning and flange mismatches.

W: is the dimension of the overall flange width. It includes the allowance for the forming radius.
2.4 RSW in the Automotive Industry

RSW is widely used in high-volume manufacture of sheet metal products.

The automotive industry has relied on RSW as a principal joining method for many decades. A typical car contains between 2000 and 3000 spot welds.

Advantages of RSW in high-volume automotive manufacturing

- Inexpensive (per-weld cost ~€0.05)
- Rapid process (<1 second per weld)
- Ease of automation (flexible process)
- No per-weld consumables (i.e. no issues of piece-cost, inventory, additional weight, or recycling difficulties)
- Low training costs (in manual operations).

General Motors Yukon (SUV), with light-weight spot welded all-aluminium rear door (liftgate)

Manufactured at 500,000 units per year

Source: GM
2.5 Role of material surfaces in RSW

See also:
- AAM – Products – 1 Rolled products > Microstructure and surface
- AAM – Manufacturing – 4 Surface finishing > Pre-conditioning of Al-forms > Sheet / strip

Heat = I²Rt
Modern equipment can accurately control the current and time. Any uncertainty in the process comes from variability in the resistance term. Furthermore, with aluminium metal being such a good electrical conductor (~three times more than steel), heat generated during welding is primarily obtained from the contact resistances at the faying surfaces, and not from the bulk material resistance. Resistance spot welding of aluminium is therefore a surface-critical process.

There are many different materials-related factors that combine to determine the value of contact resistance at the sheet surfaces:
- Surface texture (e.g. EDT or none)
- Composition of oxide film (function of alloy type and processing route)
- Degree of any surface cleaning
- Type & amount of any chemical pre-treatments
- Type & amount of any residual lubricants, weld-through sealers or adhesives.

Reproducible and stable sheet surfaces are essential for successful RSW of aluminium.
2.6 Process-related resistance factors

Effect of poor part fit-up

Closing force is the force required to move the parts back into intimate contact.

Contact resistance is directly related to the force applied at the surfaces. Poorly fitting parts reduce the effective force to contain the growing weld nugget.

Process factors that affect resistance
- Applied electrode force
- Electrode geometry (i.e. force density)
- Nearby welds offer lower resistance path
- Part fit-up (reduces net force)
- Workpiece and/or electrode misalignment (see micro-movement)
- Electrode surface roughness (initial)
- Electrode wear and pickup
- Temperature of electrodes & workpiece
- Micro-movement at any of the surfaces (e.g. gun skidding, electrode rotation, or shear forces caused by asymmetric stack-ups or electrode geometries).

Misalignments cause changes in effective force, and promote sliding at surfaces.

Poorly maintained equipment and improper positioning of weldgun can alter the resistances.

Changes in net force or electrode profile can affect weld quality.
2.7 Typical parameters for RSW of aluminium

Literature:

Deutscher Verband für Schweißtechnik: Widerstandsschweißen; Messen des Übergangswiderstandes an Aluminiumwerkstoffen, DVS 2929, 1985 (revised 1988). Describes a method for Static resistance measurements. It is NOT a good indicator of spot weldability for materials that have surfaces with pre-treatment, lubricants, or that have not been chemically cleaned.

Dynamic Resistance
Chart above shows how aluminium's electrical resistance falls rapidly at commencement of welding.

Because aluminium has such a low electrical resistance & is a good conductor of heat, high welding currents, delivered for very short times, are necessary (see table).

The table (for a relatively thin closure-sheet gauge) illustrates the need for more powerful equipment when spot welding aluminium. Thicker gauges (e.g. for structural

<table>
<thead>
<tr>
<th>0.9 mm Gauge</th>
<th>Bare Aluminium*</th>
<th>Bare Steel</th>
<th>Zn Coated Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weld Time (50 Hz cycles)</td>
<td>3</td>
<td>7-10</td>
<td>9-12</td>
</tr>
<tr>
<td>Current Range (kA)</td>
<td>18.0-23.0</td>
<td>7.0-10.0</td>
<td>8.5-11.0</td>
</tr>
<tr>
<td>Force (kN)</td>
<td>4.1-5.0</td>
<td>1.9-2.6</td>
<td>2.2-2.9</td>
</tr>
</tbody>
</table>

* AA6111 mill finish + lubricant

Typical spot welding parameters for aluminium and some steels

Aluminium needs higher currents, higher electrode-forces and shorter weld times when compared to steels.
2.8 RSW weld lobe diagrams

Literature:

For a given combination of materials, electrodes, process conditions, and at a particular electrode-force, the weld lobe describes a region of acceptable welding parameters. The parameter axes are generally weld time (duration) & weld current. The "lower" boundary is the parameter combination that produces a weld button of minimum acceptable dimensions. There are many available standards to define this value, but most approximate to $4\sqrt{g}$ (gauge of thinnest sheet). The "upper" boundary is defined by expulsion conditions. Expulsion is a probabilistic event, so one way to define the limit is to find the conditions that lead to (say) 50% of welds expelling. The area inside the lobe represents the "safe" welding window for new electrodes. Generally the wider the better.

![Schematic of a typical weld lobe](image)

Weld lobes can give an idea of the parameter robustness, but do NOT consider the electrode life.
2.9 Equipment for RSW of aluminium

Literature:

Invertor (medium frequency DC) C-gun mounted on robotic weld station
Source: GM

High-capacity equipment is required for RSW of aluminium.

Aluminium can be spot welded by all conventional RSW systems and power-supplies, if they meet the following...

Equipment requirements
- High electrode force (4-8 kN)
- High welding current (20-45 kA)
- Minimal deflection in gun arms (<1 mm)
- Efficient water cooling of electrodes, gun arms, & all current-carrying components
- Low-friction force actuator, to maintain weld force as electrodes move during weld formation (i.e. good follow-up).
Schematic showing (exaggerated) effect of high loads on inadequately designed gun components

High electrode forces can make inadequately designed gun arms deflect, causing misalignment and skidding (micro-movement).
2.10 RSW microstructure and discontinuities

Ideal weld
Cross-section showing good shape, acceptable penetration, no cracks, and minimal porosity

Expulsion
A failed tensile test-piece showing a weld with significant (undesirable) molten metal expulsion.
Unacceptable weld
Cross-section showing large and small porosity, over-penetration, and cracking. Defects at periphery are very

![Image of an unacceptable weld]

Poor weld
Source: Alcan

Spot weld performance is NOT significantly affected by discontinuities located in the centre of the nugget.
2.11 Electrodes and their maintenance

![Schematic of an electrode for aluminium RSW](source)

**Reasons for electrode maintenance**

- Improved consistency of RSW process (quality assurance)
- Increased productivity (less down-time for electrode changes)

Electrode maintenance equipment for aluminium RSW should be designed primarily to remove accumulated oxide deposits from the electrode contact surface. Retention / restoration of the original electrode geometry is less necessary than for steels because there is little mechanical deformation during wear. Frequent "light" operations (e.g. buffing / polishing after every ~20 welds) are preferable to the "heavy" in-situ re-machining (dressing) approach. By adopting the "little & often" approach, the electrodes remain "as-new", and there is no practical limit to the number of times an individual electrode can be re-buffed.
Electrode buffing can dramatically extend electrode-life
This test was terminated due to lack of material
Source: Alcan

Frequent electrode maintenance is essential for consistent RSW of aluminium.
2.12 Good Practice in RSW of aluminium

Literature:

Do
- Use appropriate high-capacity equipment that has been specified and designed for spot welding aluminium
- Use materials that have consistent and stable surfaces
- Select appropriate weld parameters, particularly beneficial is a high electrode force
- Employ regular electrode cleaning (buffing) to keep the electrodes in "as-new" condition. Ideally this should be an automated process
- Make compensation for adjacent welds (shunts), and remember to reduce the current for un-shunted "first-welds"
- Have an efficient and stable water cooling system
- Keep all process parameters stable (air pressure, line voltage)

Don't
- Make welds that consistently expel. They will always be of inferior quality to those without expulsion, due to increased porosity / discontinuities, and undersize weld nuggets
- File the electrodes by hand. It is impossible to maintain the correct geometry / profile and surface finish
- Tamper with the sheet surfaces (unless it is part of a pre-determined procedure) e.g. no abrading, wire brushing, etc.
- Make welds in the wrong place e.g. edge welds, or too close to corner radii (see flange design considerations)
- Try to re-weld on top of an existing weld (resistance will be too low).

Aluminium can be successfully spot welded, provided that the correct "Rules" are followed.
2.13 Safety considerations for RSW

Specific precautions for resistance spot welding
- In common with steel, **fume extraction** is essential when RSW parts that have been pre-lubricated, or combined with any sealers or adhesives
- Physical **guarding** from possible molten metal expulsion is necessary (note that molten aluminium does not glow red like steel, and is therefore difficult to detect)
- Do not attempt to spot weld through **non-conducting** surfaces (e.g. paper labels / stickers, primers or paints).

Normal precautions in an industrial environment
- Electrical safety (e.g. high voltage cables on transguns)
- Machine mechanical safety (e.g. pinch points)
- General robot safety procedures
- Personal protective equipment (e.g. standard safety glasses, gloves, foot protection).

**Safety considerations for aluminium RSW are NOT significantly different to those required for steel RSW.**
2.14 Other resistance welding processes

Literature:

Resistance seam welding (RSEW)
A process where a series of overlapping weld nuggets are produced forming a continuous (and leak-tight) joint. In RSEW the spot welding electrode tips are replaced by a pair of driven copper wheels (typically ~200 mm in diameter), or one wheel acting against a stationary backing piece. A pulsed welding current is generally used to form the individual spots. The process is most often used to produce leak-proof tanks from pressed sheet metal components.

Projection welding
Pre-formed “dimples” or embossments on one of the workpieces are used to “focus” and increase both current & force density. As the weld develops the projections melt and collapse. This technique is not much used in aluminium since the very rapid collapse of the projections make it difficult to maintain weld force using conventional equipment.

Cross-wire welding is a variant where intersecting wires provide the individual projections when making a wire mesh.

Conductive heat resistance seam welding (CHRSW)
A recent variation on the traditional seam welding process. Steel covering strips are interposed between the copper welding wheels and the outer surfaces of the workpieces (which can be butted together rather than overlapped). The consumable steel strips provide both a heat source, and a mechanical constraint, for the weld. The strips do not fuse, and are discarded from the joint. The process has particular promise for aluminium TWB manufacture and coil joining.

In addition to spot welding there are several other variants of the resistance welding process.