Joining Processes for Low-Carbon Automotive Applications

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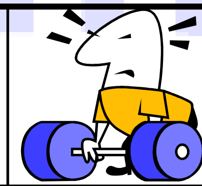
The mass conflict

Drivers	Who?	
Safety improvements	Legal	↑
More equipment & gadgets	User	↑
Preference for larger vehicles (e.g. SUVs)	User	↑
Fuel economy	Both	↓
Reduce emissions	Legal	↓

Solutions lie in…

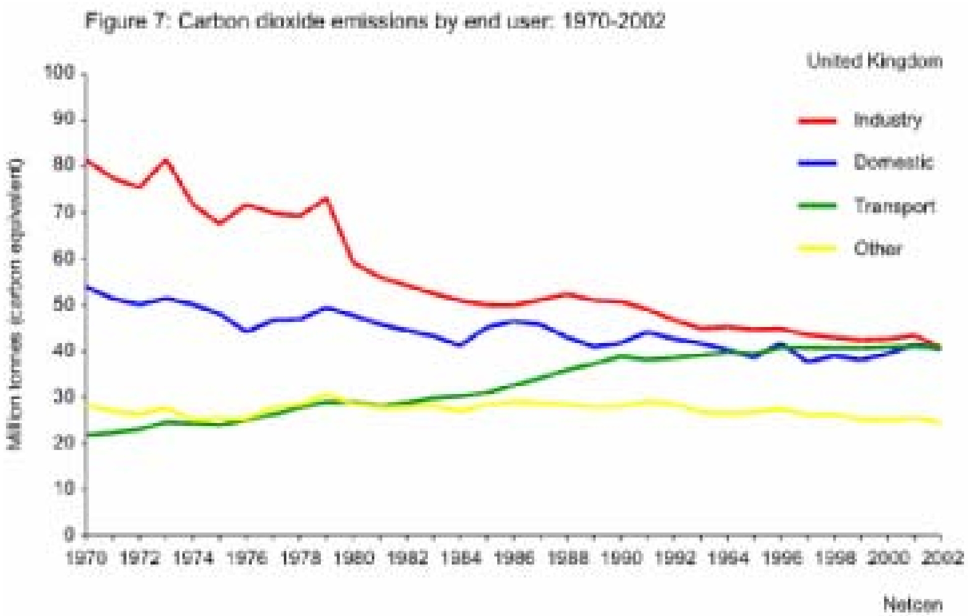
- Powertrain (incremental, step-change)
- Lightweight materials (F=ma)
- Managing losses (drag, friction, etc.)

Environmental effect of transport

- Automotive usage contributes significantly to greenhouse gas emissions
- This trend is set to increase as the number of vehicles and the distances driven continue to escalate
- Limiting the environmental impact from vehicles will only be addressed on a global scale by producing significant quantities of low-carbon emitting vehicles (soon!)

Barriers to mass-produced low-carbon vehicles:

- Inertia (manufacturers)
- Cost penalty
- Technology development



Source: Defra 2005

Bringing it to the masses

- Typically, advanced technologies appear first in low-volume, high-priced, niche vehicles
  - Less risk (manufacturers)
  - Costs can be more easily passed on
  - Performance benefits
  - No effect on global emissions

Honda NSX

- As the technologies become more established, they can be moved into the **mass-production** market
  - Production friendly
  - Low cost
  - Efficiency benefits
  - Significant effect on global emissions

Audi A2

Joining technology for lightweight vehicles

- For **mass-produced** sheet structures point-joining processes are the most important:
  - Mechanical fasteners
  - Resistance spot welding
  - Spot friction joining
  - Laser stitch welding
  - Ultrasonic welding
- For optimum vehicle performance and mass reduction, some of these "discontinuous" processes can also be combined with structural adhesives

High-volume low-cost joining has to be:

- Fast (robotic)
- Cheap
- Available now!

Need to consider:

- Design aspects
- Performance requirements
- Assembly constraints
- Economics
- Health & safety
- Quality assurance
- In-service durability
- Repairability
- Recyclability
- Others…

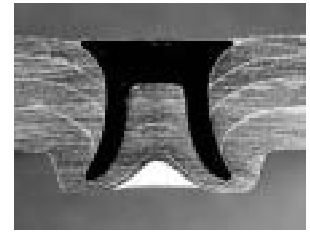
Some production-proven point-joining methods

Self Pierce Riveting (SPR)

+ Best mechanical properties
+ Mixed material joints
+ Cold process
+ Join through adhesive
- Gun cost and ongoing rivet cost
- Gun flexibility for different joints
- Thick base sheet needed for interlock

Button

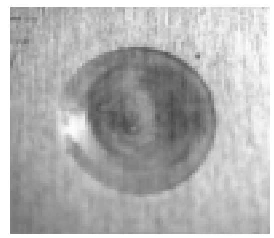
5 mm



Cross-Section

Resistance Spot Welding (RSW)

+ Low cost of equipment
+ Gun flexibility for different joints
+ Join through adhesive
- Consistency remains to be proven
- Tip maintenance needed
- High force gun needed to minimise spatter



Indent

7 mm

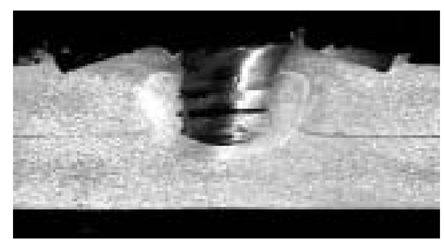
Cross-Section

Spot Friction Joining (SFJ)

+ Joining thin materials
+ Low running costs
- Joining through adhesive
- Long process time for thick sheet
- Gun flexibility for different joints

Indent

10 mm



Cross-Section

Why use resistance spot welding?

- Suitable for high-volume manufacturing (robotic manipulation)
- Low running costs (no per-joint consumables)
- Available now (compatible with existing vehicle designs and manufacturing methods)
- No added parts: optimises weight saving, and facilitates recycling

But RSW has some perceived "problems":

- Short electrode-life
- Consistency of process
- Tired unglamorous image!

Aluminium spot welded liftgate on General Motors Yukon / Tahoe

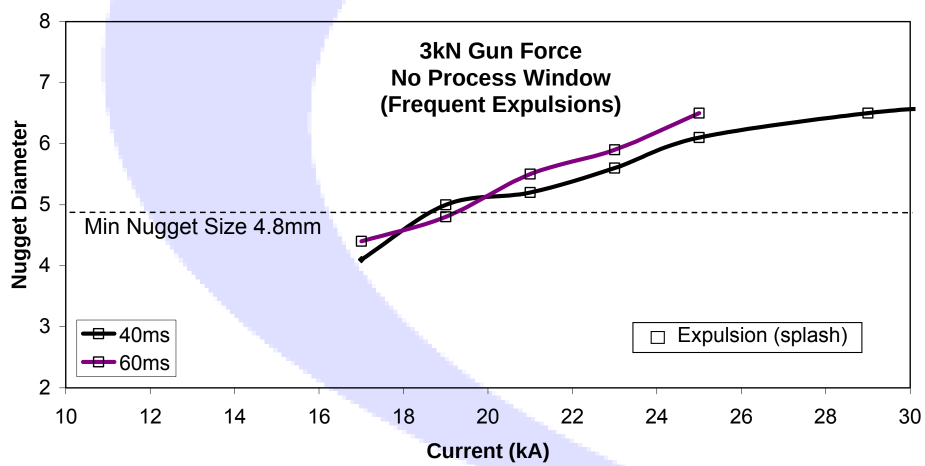
Aluminium resistance spot welding equipment

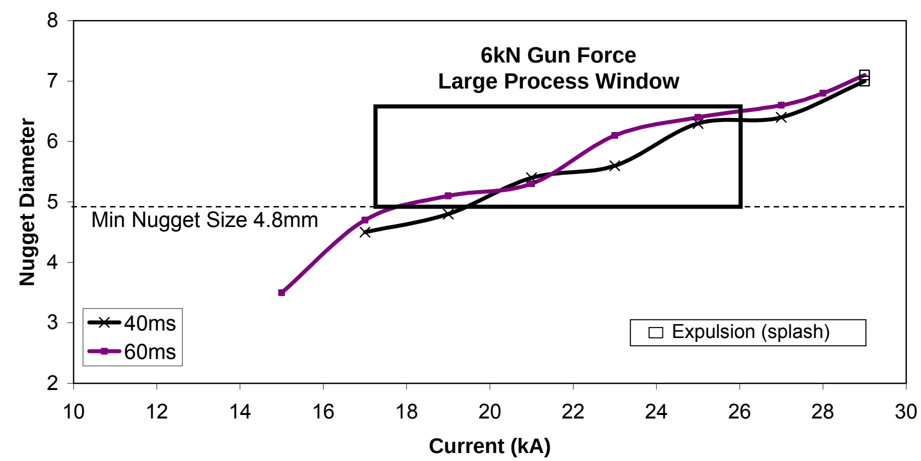
- **Medium Frequency Direct Current (MFDC)**
  - The reduced size and mass of MFDC welding transformers compared to those for AC enables robot manipulation of high-current guns
  - Typical weld current requirement: Steel up to 15 kA, Aluminium up to 40 kA
- **Servo-guns**
  - Operate accurately at low and high forces
  - Velocity control gives potential for faster cycle times and “soft touch” (quieter)
  - Opportunities to adjust the force during gap closing and welding

Robotic MFDC servo gun at Warwick University

The need for higher gun force

- RSW of aluminium requires higher gun forces than steel
  - Steel RSW typically uses up to 4 kN
  - Aluminium RSW typically uses up to 8 kN
  - Low force (0.5 kN) is useful for electrode dressing (steel & aluminium)
- Higher gun force inhibits detrimental expulsion
  - The result is a much larger process window and high quality welds

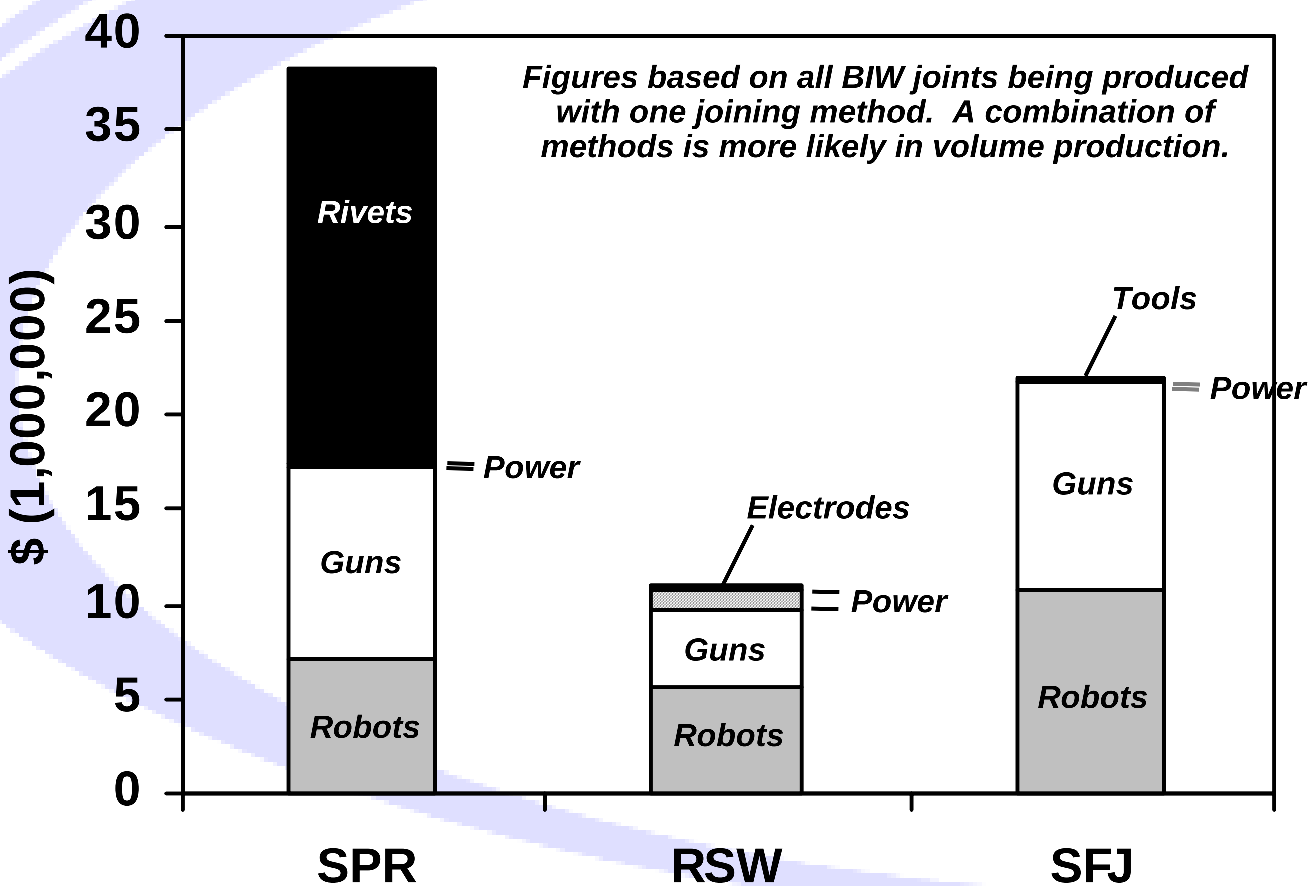




Gun force charts for 1.5 + 1.5 mm AA5754

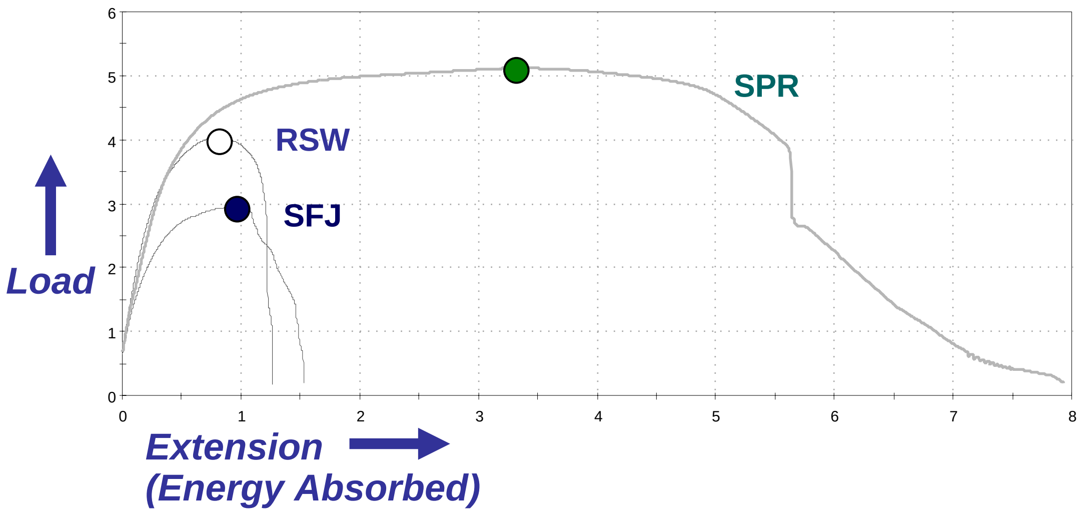
Overall cost comparison: 5 year

Graph comparing the cost differences for SPR, RSW and SFJ based on installing a line for producing 35,000 units per annum and running the line for five years.

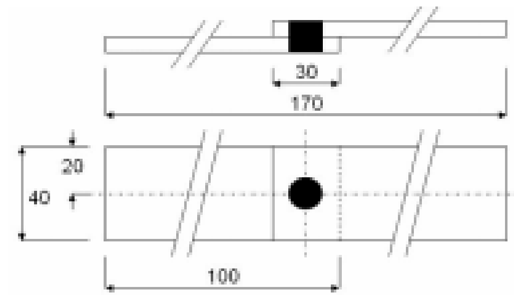


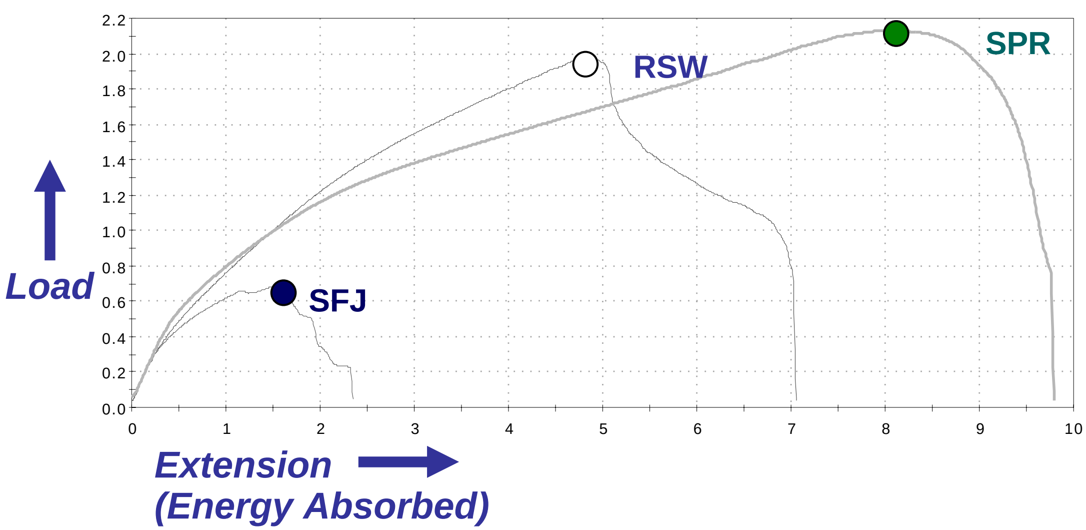
Comparison of mechanical performance

Tensile Test Curves For 2.0 + 2.0 mm AA5754

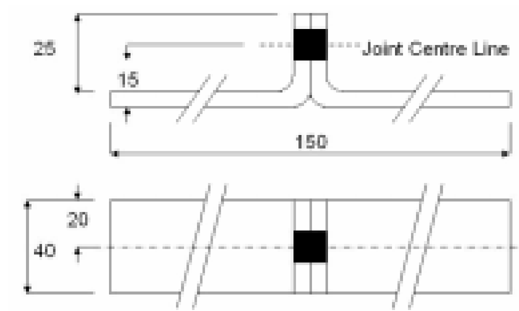


Lap-Shear Joint





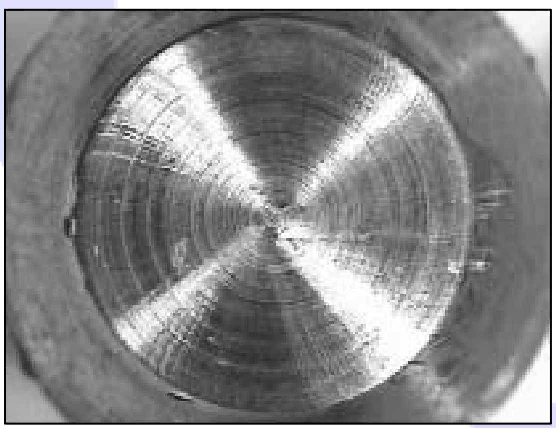
T-Peel Joint



○●● **= Max Load**

When the weld current is too high…

- Aluminium on the outside melts and sticks to the electrode
- A build-up of aluminium on the electrode face is undesirable
  - It increases the electrical resistance causing further melting, leading to more aluminium build-up on the electrode
  - The molten aluminium alloys with the copper electrode creating pits in the electrode face when this intermetallic is removed
- Without electrode maintenance to break this cycle, the electrode rapidly becomes badly pitted and completely coated in aluminium



10 mm

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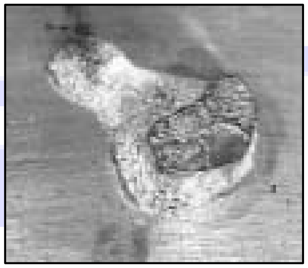
Within a few hundred welds

The benefit of regular electrode maintenance

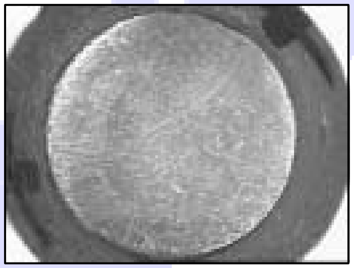
Electrode

Component surface

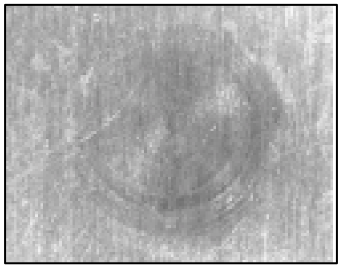


Weld button

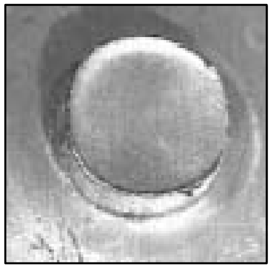
After 700 welds
(no buffing)



Electrode



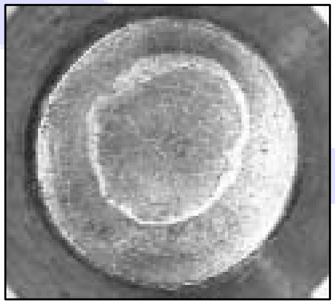
Component surface



Weld button

After 10,000 welds
(regular buffing)

Electrode buffing to remove aluminium pick up
before it causes more severe electrode damage



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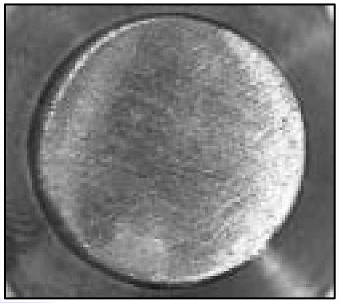
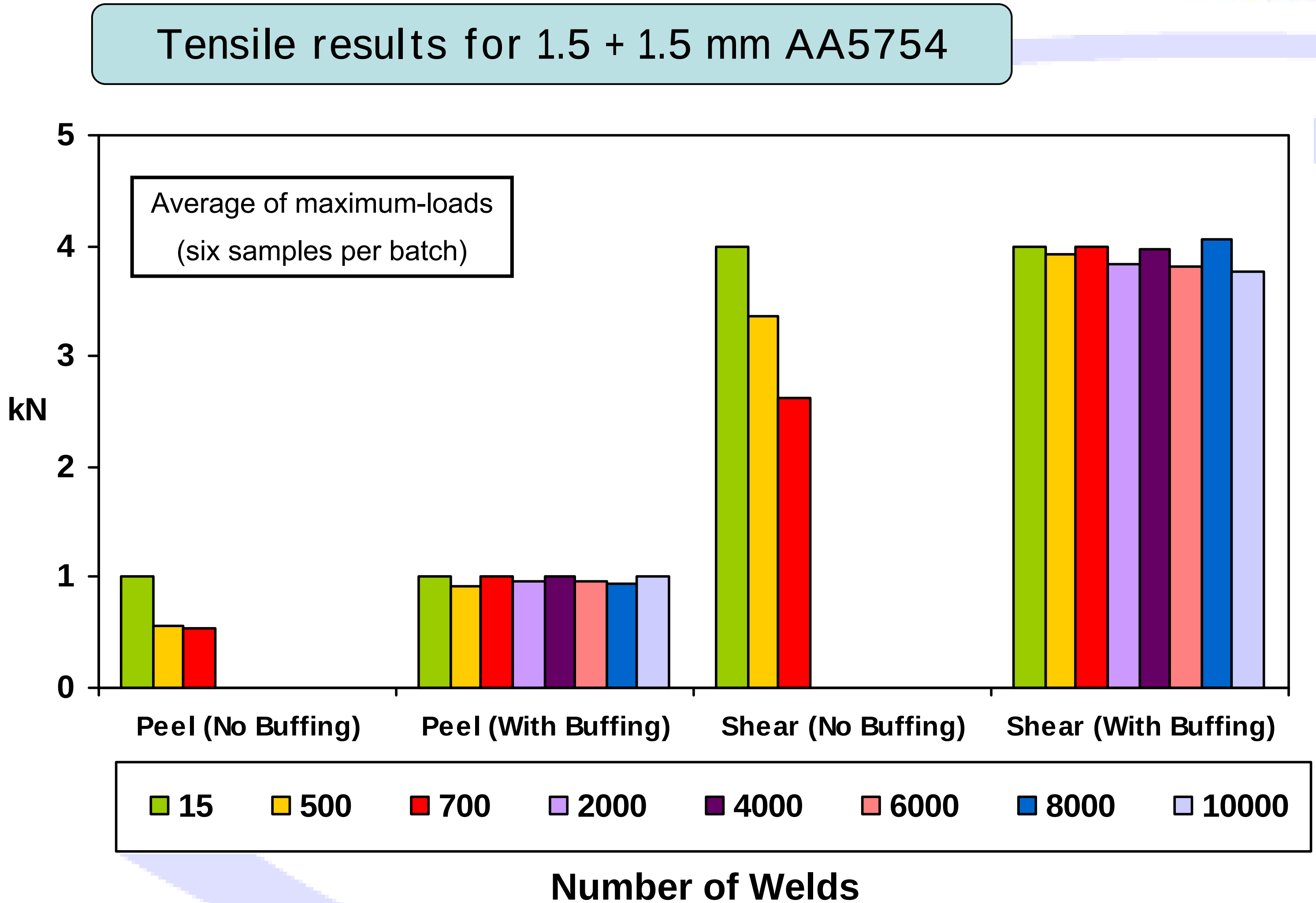


Effect of electrode damage on mechanical properties



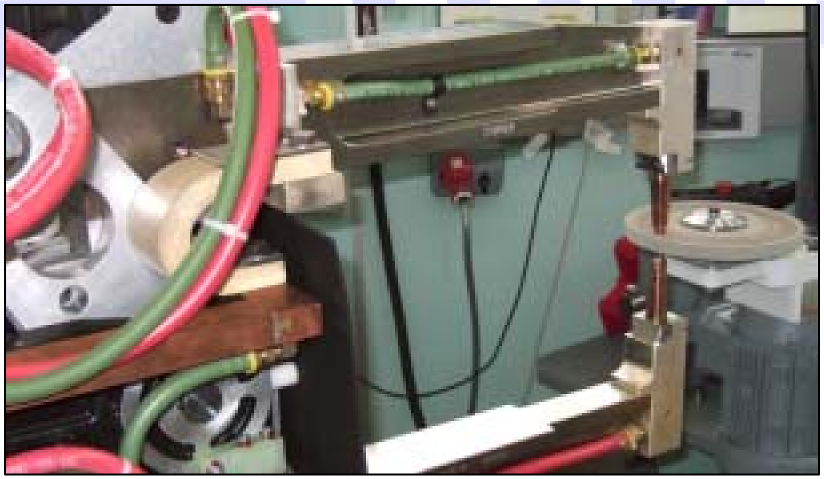
Note: The test without electrode maintenance was stopped at 700 welds when the nugget diameter dropped below 4√t (4.8 mm diameter).

Robotic electrode maintenance

Robotic DRESSING

AMDP

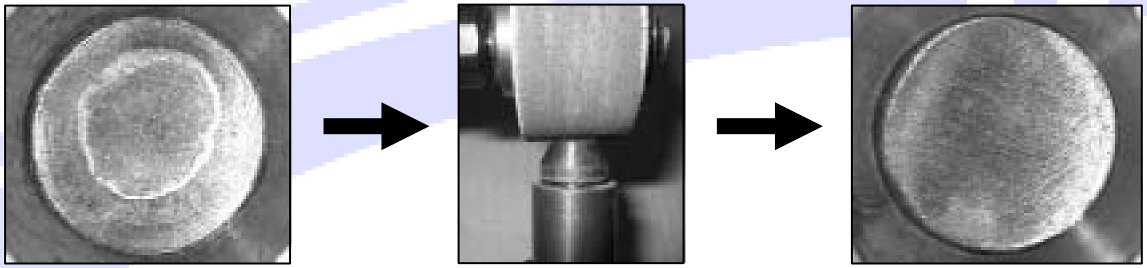
Robotic BUFFING



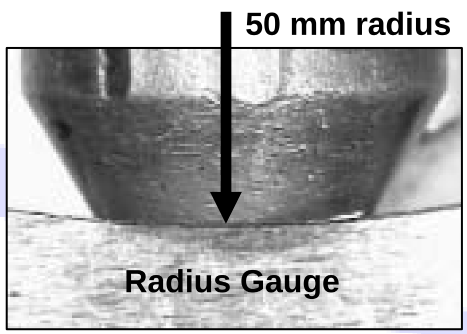
THE UNIVERSITY OF WARWICK

Electrode buffing research

- A particular abrasive wheel was found to be extremely effective at quickly removing aluminium from the electrode face



- This wheel gave a long service life achieving more than four thousand buffing operations
- The wheel can also be profiled with a radius for domed electrodes
- A 50 mm dome radius was accurately maintained for 10,000 welds with buffing carried between every component (more than 600 buffs)

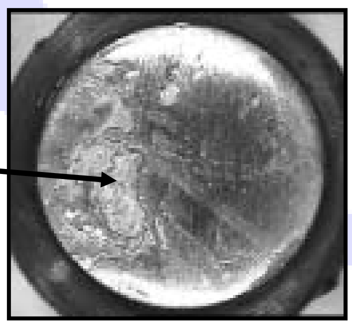


Side view of electrode

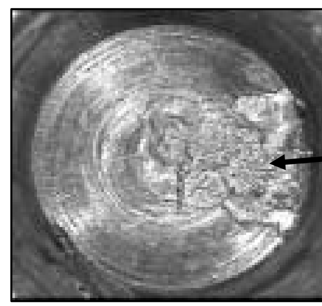
Buffing frequency

- Buffing in the “dead-time” between each component is effective
- But it is only necessary to buff when aluminium sticks to the tip
- 10,000 high quality welds were achieved by two approaches
  - Buffing between every component: required > 600 buffs
  - Buffing when aluminium was visually detected: required < 20 buffs
- Deep pits or heavy aluminium sticking cannot be removed by buffing
  - Therefore it is useful to be able to detect more serious damage and initiate a tip dress with a cutter to create a fresh electrode face when required
  - Serious electrode damage can usually be detected by monitoring changes in the electrical signals recorded by the weld controller

Pitting



Severe pitting and/or aluminium sticking can only be fixed by dressing with a cutter



Aluminium sticking

Status of RSW electrode buffing

- Frequent electrode maintenance makes a huge improvement in the number of **consistent** high-quality welds from **one set of electrodes**
- There is a lack of commercially-available automated electrode buffing equipment designed specifically for aluminium RSW
- Existing dressing cutters are too aggressive to be used frequently enough to exploit the real benefits from the “little & often” approach to keeping the electrode face clean (although they are better than nothing!)
- A robust robotic solution will ideally combine buffing and dressing
- Further work is underway on methods to detect and measure electrode damage to trigger the buffing or dressing operations:
  - Electrical measurements
  - Vision systems
  - Ultrasonic sensors

Summary

- A route to low-carbon vehicles is to reduce their weight
- Significant reduction in the weight of vehicles has already been commercially demonstrated by substituting aluminum for steel in conventional automotive designs
- Resistance spot welding (RSW) is highly suited to automotive mass-production techniques and is cost-effective
- The perceived barriers for using RSW in aluminum can be overcome by employing “little & often” maintenance to extend electrode-life and significantly improve weld consistency

Any Questions…?

End

Audi A2 Aluminium Intensive Vehicle

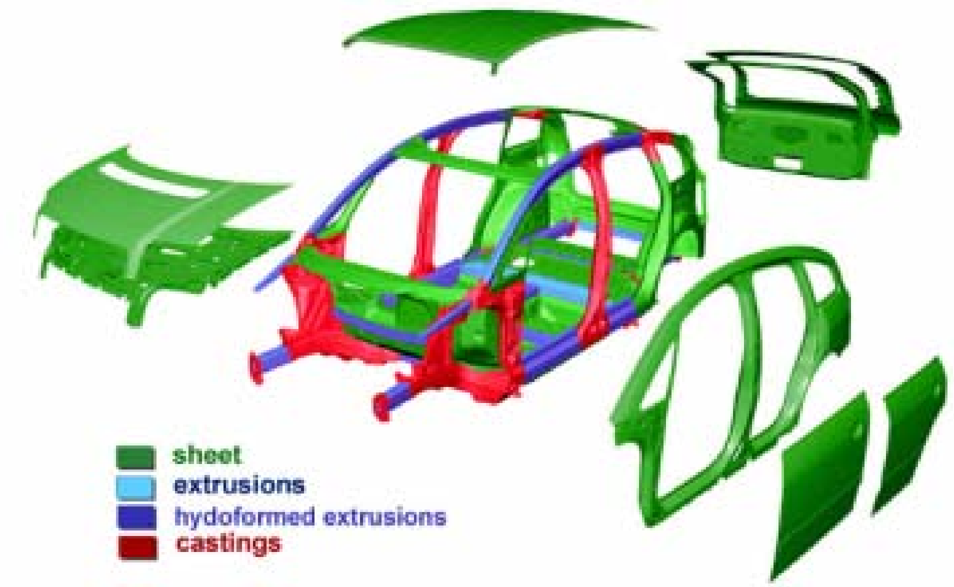
Description: Space frame:
SOP 1999
Weight: BIW (121 kg) + closures 153 kg
Number of parts: 225
Volume (cars/year)**:** scheduled 70,000
Joining:
Self piercing rivets: 1800
MIG weld: 20 m
Laser weld: 30 m

Materials/parts:
Stampings: 183 (81%)
Extrusions: 22 (10%)
Castings: 20 (9%)

Weight saving 231 kg

119 to 144 g/km (1.2 TDI 80 g/km)

165,000 vehicles built



General Motors Yukon/Tahoe

- Spot welded aluminium liftgate (AA6111 and AA5182)
- High-volume: 500,000 vehicles per year (from 2 lines)
- Novelis (formerly Alcan) supplied 20 million pounds per year
- Invertor (MFDC) power supplies
- Frequent, automated electrode maintenance (every 50-100 spots)

Electrode buffing

- Dressing with an aggressive cutter can only be carried out a limited number of times before the electrode geometry is affected (typically around 20 times)
- For a longer electrode life it is useful to be able to clean the electrode face to remove aluminium frequently without affecting the geometry
- This can be achieved using an abrasive wheel

- A range of abrasive wheels were tested for electrode buffing