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STC F Keynote 2013

Joining by plastic deformation

Cold welding, friction stir welding, self-pierce riveting, mechanical clinching, joining by forming, etc.

by

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Joining by plastic deformation

Parts in vehicles

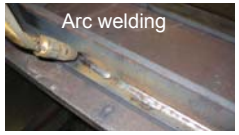
Scale and complexity for vehicles

10,000 - 30,000 parts

Several million parts

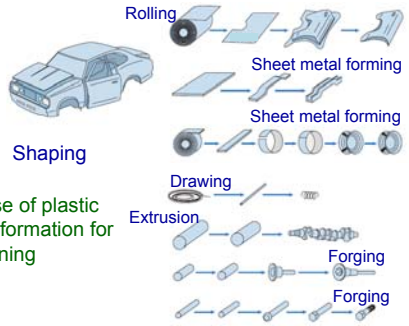
Joining of parts

Typical joining processes



Welding: thermal effects
Adhesive bonding, mechanical fastening: low strength
High performance, high productivity, low cost, dissimilar materials

Forming processes using plastic deformation



Use of plastic deformation for joining

Joining processes by plastic deformation

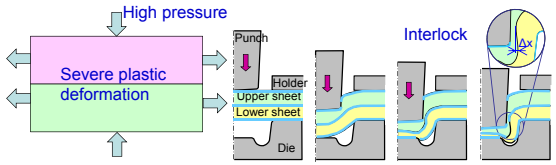
Metallurgical joining (bonding):
- Cold welding by rolling, extrusion, forging, etc.
- Friction welding, Friction stir welding
- Resistance welding, etc.

Mechanical joining:
- Self-pierce riveting
- Mechanical clinching
- Joining by forming such as hydroforming, electromagnetic forming, incremental forming, etc.
- Fastening such as hemming, seaming, staking, etc.

Joining mechanism

Metallurgical joining: large plastic deformation

Mechanical joining: control of plastic deformation



The oxide films and contaminant layers at the interface between workpieces are broken up by severe plastic deformation, and the resulting clean surfaces are bonded by high pressure.

The workpieces are mechanically interlocked by plastic deformation.

Advantages and disadvantages of joining by plastic deformation

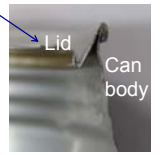
Advantages	Disadvantages
• Wide range of joining materials, including dissimilar ones (metallic/non-metallic) • No distortion, embrittlement or residual stresses due to missing microstructural transformation • High process reliability and simple quality control • Environmental safety	• Mainly overlap joint • Geometrical unevenness of joining zone due to nature of processes • More difficult correction and repair • Lack of standardisation and calculation methods

Conventional joining processes by plastic deformation

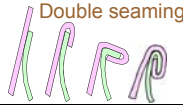
Riveting

Friction welding

Seaming for beverage cans



Double seaming



Recent developments and progress of joining processes by plastic deformation

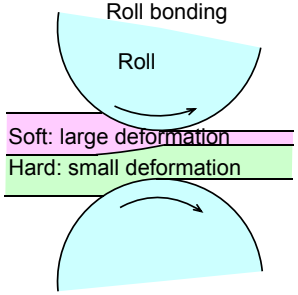
Joining by plastic deformation

1. Motivation
2. Cold welding
3. Friction stir welding
4. Self-pierce riveting and mechanical clinching of sheets
5. Joining by forming
6. Future trends

Cold welding process

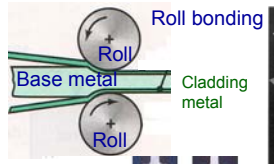
solid-state welding process

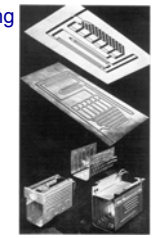
Roll bonding



- Surface preparation: scratch brushing (within 10 minutes), electrochemical treatment and chemical plating
- Plastic deformation: to create clean interface
- Pressure: to establish welds

Cold welding processes

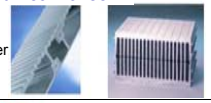


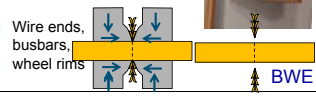


Butt welding

Shear welding

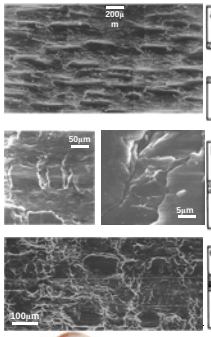
Martinrea Honsel





BWE Ltd.

Joining mechanism of cold welding



(a) Brittle cover layers created by scratch brushing (20 μm), and contaminant films of oxides and water vapour (10-100 nm)

(b) Fracture of cover layers and contaminant films by larger surface expansion

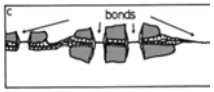
(c) Extrusion of virgin metal and bonding

Bay

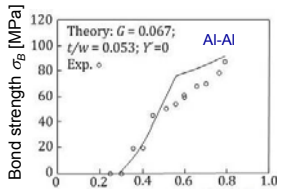
Calculation of bond strength

$$\frac{\sigma_B}{\sigma_0} = (1-\beta)\frac{p-p_E}{\sigma_0} + \beta\frac{Y-Y'}{1-Y'}\frac{p}{\sigma_0}$$

Extruded virgin metal — Film layer

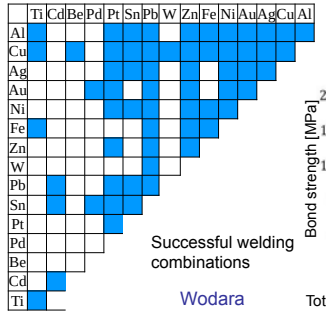


σ_B: bond strength
σ_0: flow stress of material after deformation
p: normal pressure on base metal surfaces
p_E: pressure required to extrude through cracks of cover layer
Y': threshold surface exposure for film layer
$\beta = \psi_f^2$
ψ_f: fraction of film layer on scratch brushed surface



Bay

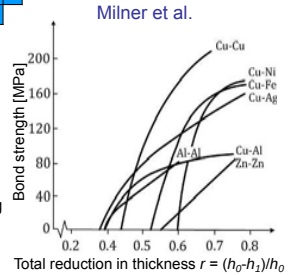
Cold welding of dissimilar metals



Successful welding combinations

Wodara

Milner et al.



Joining by plastic deformation

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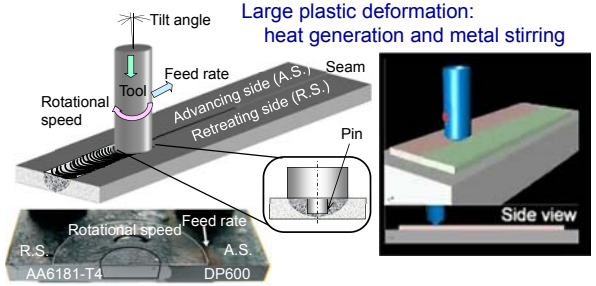
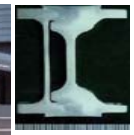
Friction stir welding

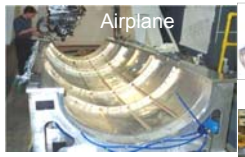
Large plastic deformation: heat generation and metal stirring



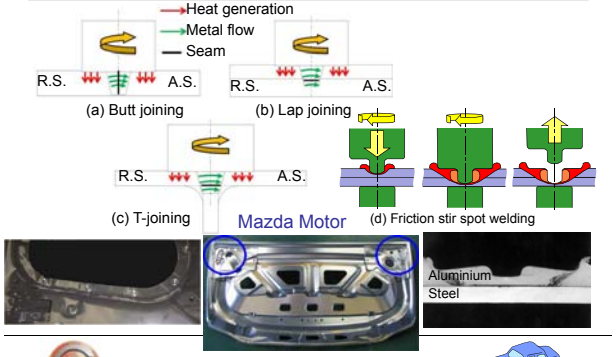
Material: aluminium alloy, magnesium, copper, steel, stainless steel, dissimilar materials

Application of friction stir welding

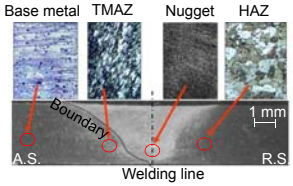




Friction stir welding processes

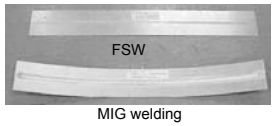


Properties of joined workpieces



(a) Microstructure in cross section of AA7075-T6 butt joint

Fratini

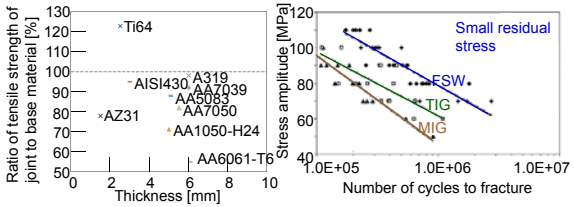


MIG welding

(b) Joined aluminium alloy sheets

Hitachi, Ltd

Strength of joint

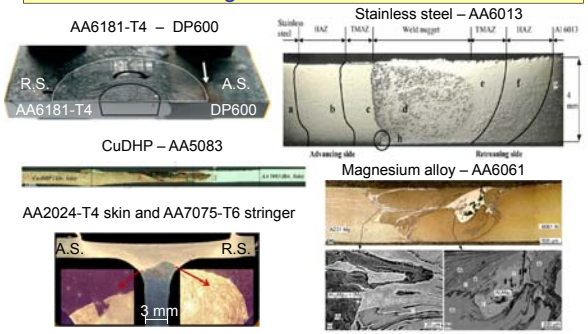


(a) Static strength

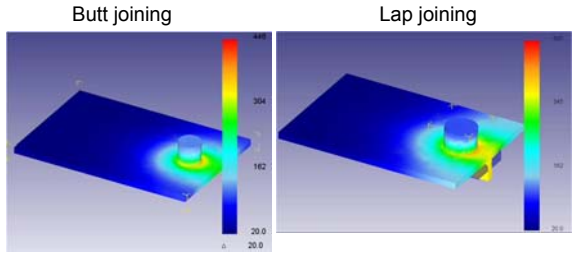
(b) Fatigue strength

Ericsson

Joining of dissimilar metals



Finite element simulation of temperature distribution in friction stir welding

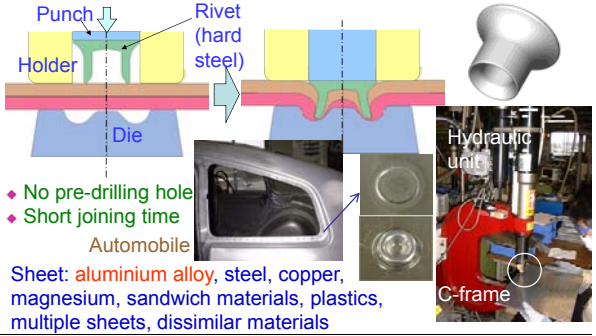


Fratini

Material constants: temperature dependent

Joining by plastic deformation

Self-pierce riveting for joining sheets

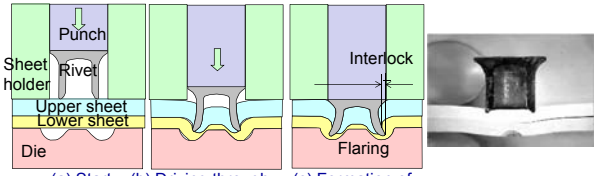


- No pre-drilling hole
- Short joining time

Automobile

Sheet: aluminium alloy, steel, copper, magnesium, sandwich materials, plastics, multiple sheets, dissimilar materials

Self-pierce riveting for joining sheets



(a) Start (b) Driving through upper sheet (c) Formation of interlock

Requirements for successful self-pierce riveting

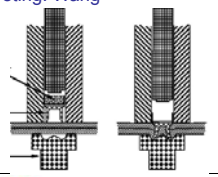
- Driving of rivet skirt through upper sheet
- Flaring of rivet skirt in lower sheet
- Avoiding of fracture in lower sheet

New self-pierce riveting processes

Aluminium alloy rivet: Abe

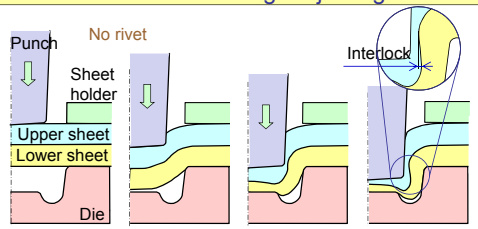
Hydro-self-pierce riveting: Neugebauer

High speed self-pierce riveting: Wang



Joining of multiple sheets: Abe

Mechanical clinching for joining sheets

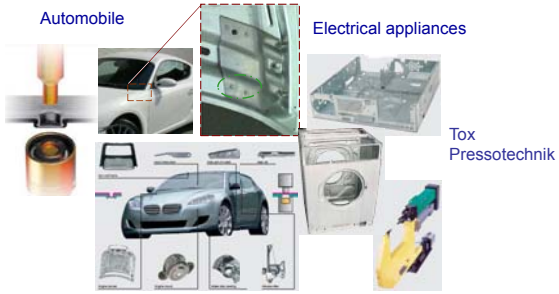


(a) Start (b) Bulging (c) Compression (d) Formation of interlock

Requirements for successful mechanical clinching

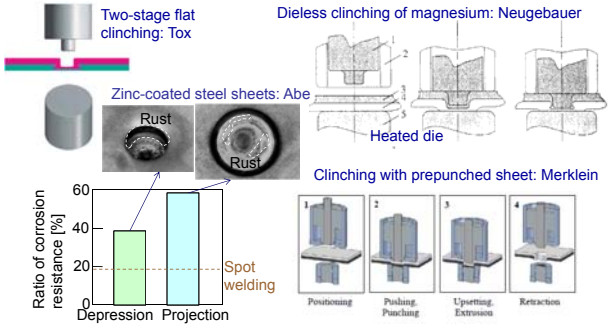
- Forming of interlock
- Avoidance of excessive thinning of upper sheet at neck of joint
- Avoidance of fracture of sheets

Application of mechanical clinching

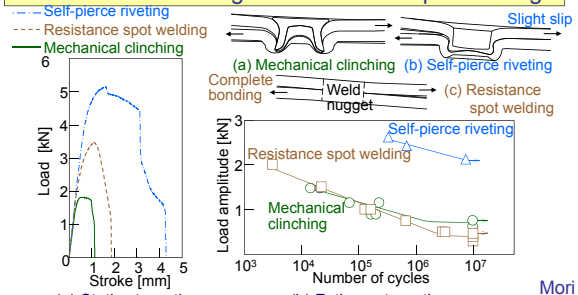


Sheet: steel, aluminium alloy, coated, copper, magnesium, dissimilar materials

New mechanical clinching processes

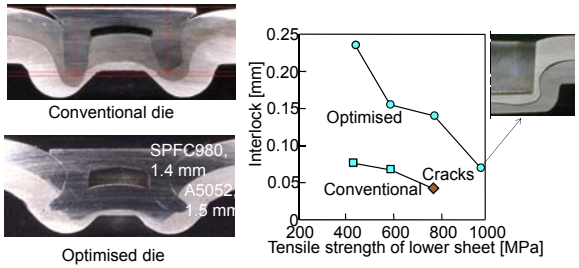


Static and fatigue strengths in tension-shearing test of aluminium sheets joined by self-pierce riveting, mechanical clinching and resistance spot welding



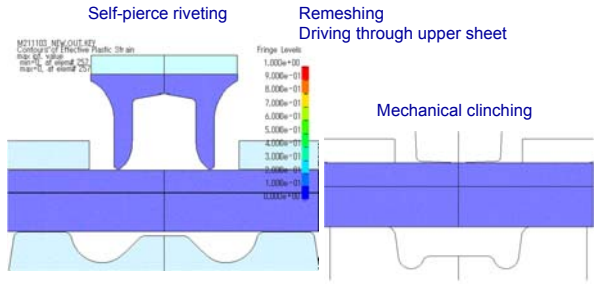
Mori

Joining of high strength steel and aluminium alloy sheets



Mori

Finite element simulation of self-pierce riveting and mechanical clinching processes



Mori

Joining by plastic deformation

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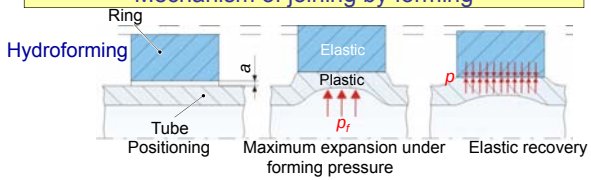
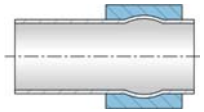
Mechanism of joining by forming



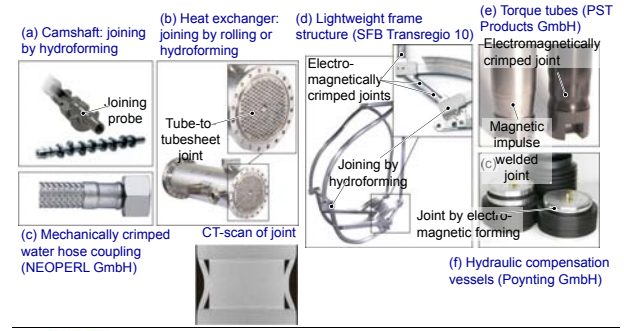
(a) Interference-fit joint



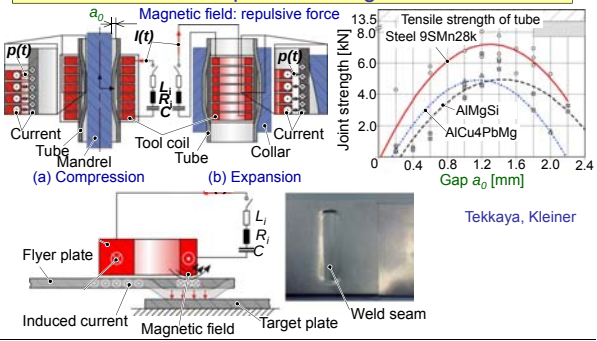
(b) Form-fit joint

Joining processes by electromagnetic forming, crimping, shear spinning and rolling are similar mechanism.

Application of joining by forming

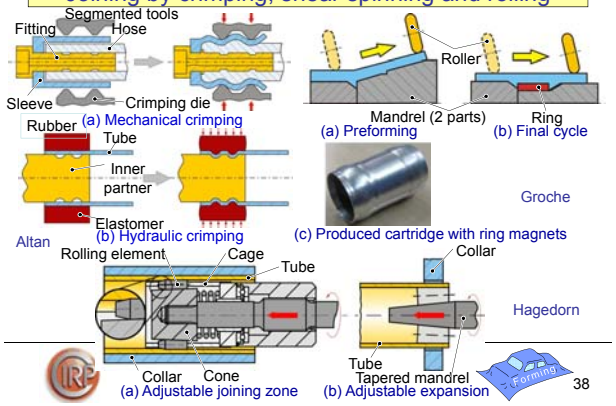


Joining by electromagnetic forming and magnetic impulse welding

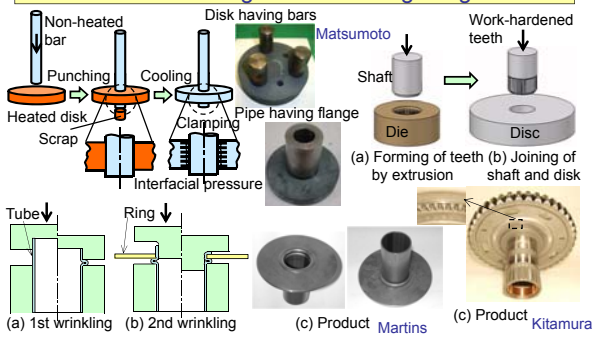


Tekkaya, Kleiner

Joining by crimping, shear spinning and rolling



Manufacturing of shaft having flange



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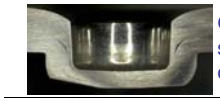
Joining of materials having low ductility and high strength

Sufficient ductility

Ultra-high strength steel sheet: mechanical clinching

Magnesium alloy sheets: laser assisted self-pierce riveting

Durandet

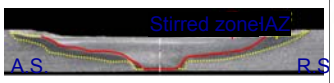


Optimisation of tool shapes in mechanical clinching

Abe

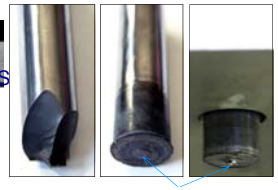
Friction stir welding of of titanium alloy workpieces

Ti–6Al–4V titanium alloy sheets



Polycrystalline cubic boron nitride (PCBN), iridium-based tool

Fratini

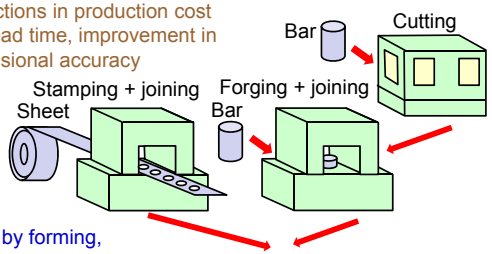


Broken pin

(a), (b) Tool steels (c) Tungsten carbides

Integration of joining into other manufacturing processes

Reductions in production cost and lead time, improvement in dimensional accuracy

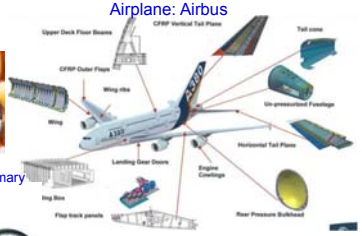


Joining by forming, hemming, staking, mechanical clinching, self-pierce riveting

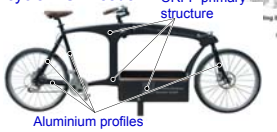
Application of CFRP

Automobile: BMW

Airplane: Airbus

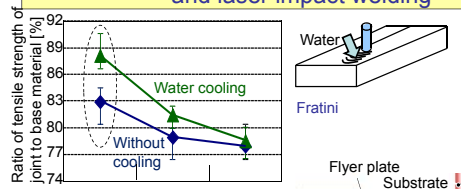


Bicycle: TU Dresden



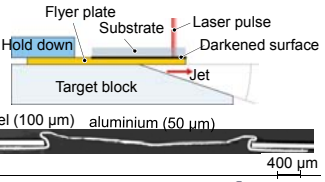
GFRP ring and aluminium tube: Joining by hydroforming

In-process heat treatment using friction stir welding and laser impact welding



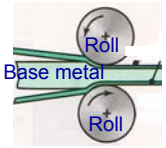
Fratini

Vollertsen

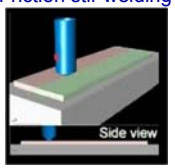


Joining processes by plastic deformation

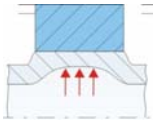
Cold welding



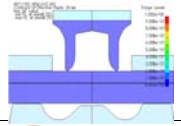
Friction stir welding



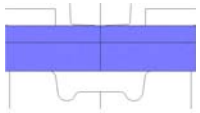
Joining by forming



Self-pierce riveting



Mechanical clinching



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