Aluminum Foams - An overview of processing technologies

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Technologies to produce a part!

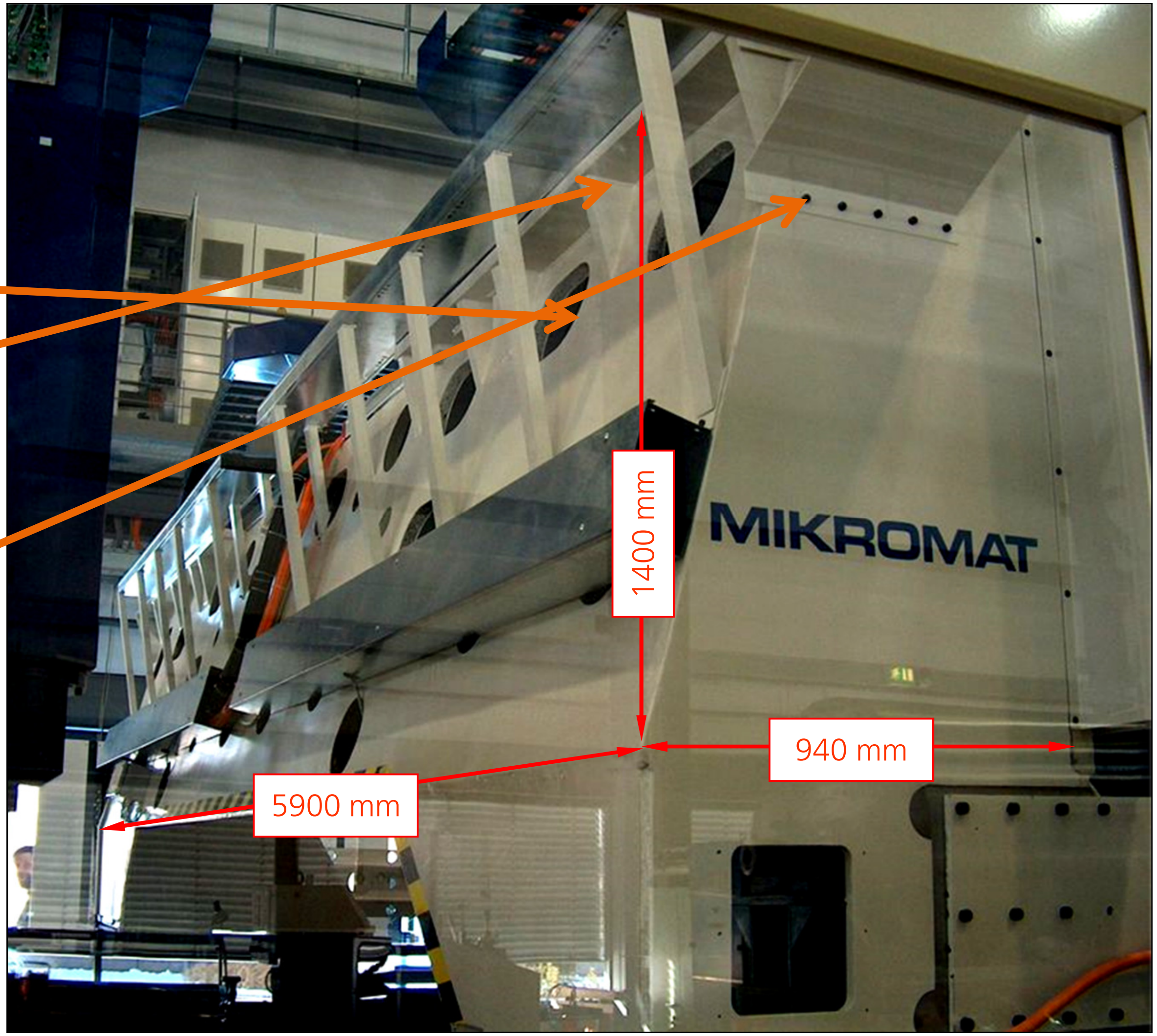
Cutting

Welding

Drilling/Joining

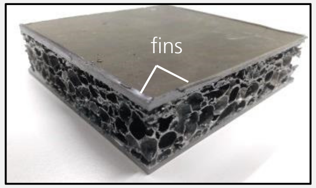
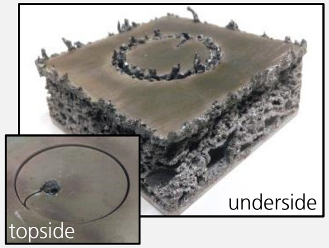
(Gluing)

(Forming)



CUTTING

Cutting of Al-Foam and Al-Foam Pre-products

	Separation Method			
Parameter	**Sawing**	**Abrasive Waterjet Cutting**	**Laser Cutting**	**Plasma Cutting**
Process	Abrasion	Erosion process (Abrasive material in H_2O)	Melting process through concentrated laser beam	Flame-/Gas welding process with ionized gas
Materials	All materials	All materials	Steel, stainless steel, Al	Steel, stainless steel, Al
Tolerance(*) • Sandwich-topside • Sandwich-underside	• 1/10-Millimeter • 1/10-Millimeter	• ≤ 10 mm ±0,1 - 0,2 mm ≤ 40 mm ±0,2 - 0,5 mm > 40 mm ±0,5 - 1,5 mm • Millimeter range	• 1/10-Millimeter • Millimeter range	• 3/10 • Millimeter range
Cutting rate(*)	Cutting rate varies in dependence to the machine for SAS, AFS an Al-Foam	Company-specific	0,2 cm/min (SAS: 3 / 29 / 3)	80 cm/min (cutting test)
Characteristics	• Rectangular cut with appropriate clamping and blade guidance possible • finning	• Widening of cutting gap with increasing cutting depth • No finning • Puncture necessary • Following CAD design	• Limited cutting depth (laser beam is diffusely reflected at cell wall, cutting efficiency decreases to ca. 10 mm) • Molten material at the underside • Following CAD design	• Clear cut at top cover sheet • Separation of plasma beam below upper cover sheet • Bubble formation in Al-Foam
Picture (*) … estimated				

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Folie 4

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hf1 Stand auf Probe mit 3 / 29 / 3, Stahl
hf; 18.11.2014

hf2 http://www.watercut-nw.de/Leistungen/Wasserstrahlschneiden/?gclid=CIiGve-6hMICFTLMtAodkw8Amw
hf; 18.11.2014

hf3 http://www.aquacontour.com/?gclid=CJGy2ZC8hMICFanItAod6EMA7g
hf; 18.11.2014

hf4 http://www.flowwaterjet.com/de-DE/waterjet-technology/comparative-cutting.aspx
hf; 25.11.2014

Cutting of Al-Foam and Al-Foam Pre-products

Universal regulations for processing Aluminum Foam

- ***Dry processing*** should be preferred since cooling lubricant penetrates the pores of the cut
- Processing forces should be chosen appropriately
- ***Processing speed*** (e.g. sawing) can be ***higher*** in comparison to massive Aluminum
- Processing parameter of compounds (z. B. AFS, SAS) should be fitted to the material's strength/hardness of the cover sheet

SAWING

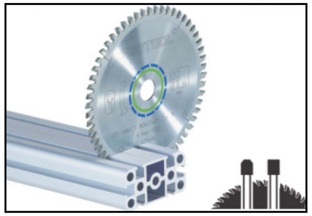
Sawing

- Circular or band saw with rough saw blade, to avoid built-up effects at cutting geometry
- The harder the material, chose a less fast cutting speed (heat generation)
- When processing sandwiches, chose the cutting parameters appropriate to the cover sheet
- When sawing Al-Foam, cooling is mandatory to reduce the daubing of the pores

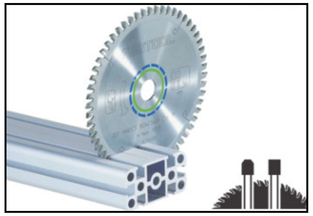
Parameter	Circular Saw (*)	Band Saw(*)
Cutting fluids • Al-Foam • AFS • SAS • Steel	Saw blade: • Blade for Al / TF-tooth, 72 Teeth • Blade for Al / TF-tooth, 72 Teeth • Blade for Steel / Flat tooth, 36 Teeth • Blade for Steel / Flat tooth, 36 Teeth	Saw band: • rough band (Al) • Rough band (Al) • fine band (Steel, HSS) • fine Band (Steel, HSS)
Rotation speed/Band speed • Al-Foam • AFS • SAS • Steel	decreasing V_{cut} e.g. hand-held circular saw (Dm. 210) • 3500 min^{-1} • 3500 min^{-1} • 1500 min^{-1} • 1500 min^{-1}	decreasing V_{cut}

(*) … general information, device specific

Saw blade



Carbide Circular Saw Blade TF-tooth for Al/plastics



Carbide Circular Saw Blade Flat-tooth for Steel/Sandwich plates

Saw band

rough band

fine band

ABRASIVE WATERJET CUTTING

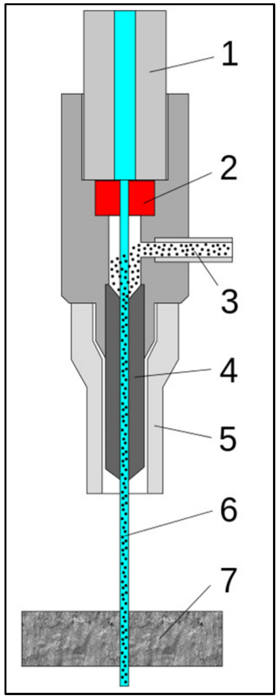
Abrasive Waterjet Cutting

Cutting parameters are oriented on optimum figures for massive aluminum processing. Example:

Pressure:	3000 bar
Nozzle Diameter:	12 mm
Focus Diameter:	0,9 mm
Focus Length:	60 mm
Feed Rate:	30 till 400 mm/min (depends on material thickness)
Working distance:	2 mm
Abrasive:	Garnet sand HP 120

These materials can be processed with these parameters:

- Material thickness: 8 till 50 mm
- Alloy: AlSi12 und AlMgSi0,5
- Density: 0,4 till 1,0 g/cm³
- Surface: Sandwich structure with Aluminum and Steel cover sheets



1 Water under high pressure
2 Pure Water Nozzle
3 Abrasive
4 Focusing Abrasive Nozzle
5 Guideway
6 Cutting Waterjet
7 Material

Quelle: http://waterjets.org/

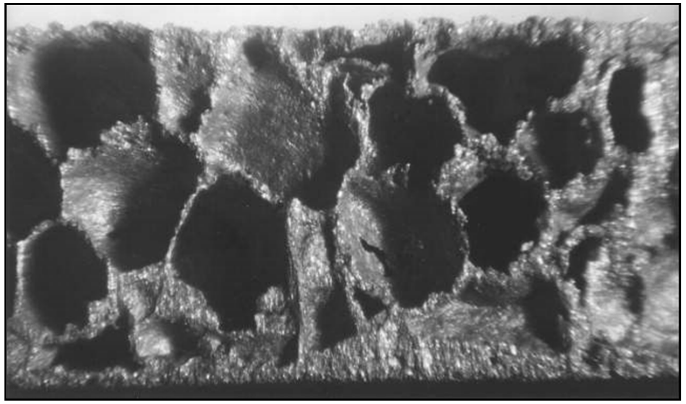
Abrasive Waterjet Cutting

- Suitable for foam plates sandwiches with straight or curved 2D cut outlines
- Cutting agent:
  - Water with Abrasive (e.g. Garnet, Corundum…)
  - The cutting quality can be influenced with the granulation of the blasting material and subjectively evaluated (e.g. fine = Rz10, middle = Rz40, rough = Rz80).

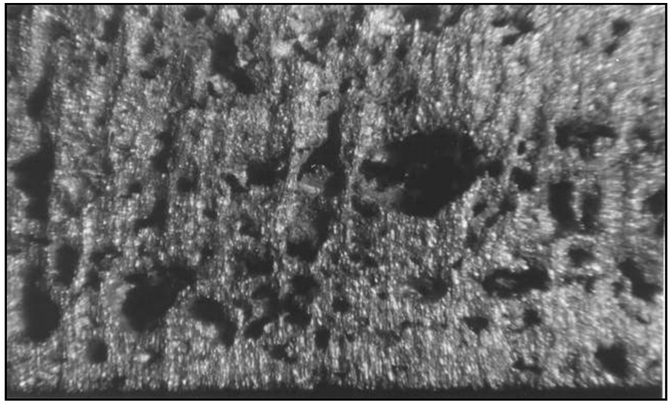
Attention

- Water causes oxidation on steel without alloy
- Water, abrasive and material rests deposit in pores
  It is to be recommended to blow out the material with compressed air followed by drying with approx. 110 °C
- The cutting jet widens with increasing thickness (critical from ca. 20 mm thickness).
- Jet widening results in the loss of accuracy on the leakage side

Abrasive Waterjet Cutting



Density of ca. 0,4 g/cm3



Density of ca. 1,0 g/cm3

Distraction of the cutting jet of a AlMgSi foam sample against the <u>infeed direction</u>

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PLASMA CUTTING

Plasma Cutting
Cutting test of SAS-Sandwich with h = 40 mm

Cutting parameter

- 440 A
- Plasma gas: argon + hydrogen
- Cutting speed: 800 mm/min

Result

- Cover sheet is cut very neatly
- Plasma arc divides
- Alu is partially rinsed into the saw kerf of the surface layer

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Plasma Cutting

Conclusion

- Considerably faster than abrasive waterjet cutting
- Probably more cost-efficient than abrasive waterjet cutting

Aluminum Foam with fine but also coarse bubbles, therefore changing results

But:
Since there is no considerable improvement in the quality of the cut, it is momentarily no alternative to abrasive waterjet cutting.

LASER CUTTING

Laser Cutting

- Optical/heat separation process with limited useability only (SAS and AFS with maximum 10 - 12 mm)
- Requirements: Laser direction is **vertically** oriented to the surface of the workpiece
- Outer skin of Al-Foam meets these requirements
- Laser beam hits lower positioned pore walls with randomly oriented surfaces under the casting skin, thereby it cannot provide the energy to the processing location entirely
- Laser beam is **scattered and looses his energy** and separating effect the faster the thicker the component. The laser beam cannot cut the lower cover sheet.

JOINING

- Non-Detachable Joining
  - Adhesive Bonding
  - Welding (AFS, SAS)
    - MIG/WIG-Welding
    - Laser Welding
    - Friction Stir Welding

- Detachable Joining
  - Fasteners (bolts, screws, nuts)

NON-DETACHABLE JOINING

Adhesive Bonding

Adhesive Bonding

Method	firmly bonded joining of materials with adhesive (organic material).
Advantages	• unchanged surface and microstructure, no damage • in comparison to a welded, screwed or riveted joint, a glued joint features better vibration damping • joining of different materials (glass-metal, wood-metal, aluminum-steel) possible • no heating of workpieces necessary (no thermal distortion, no tension)
Dis-advantages	• Demanding implementation, i.e. adhesive and surface pretreatment need to be assimilated to the needs of the materials that are to be combined • **Limited creep strength** of many adhesives • **Aging** • Glue is **limited to temperature**

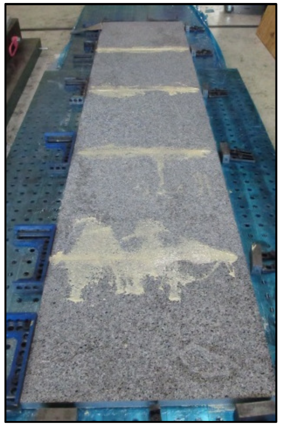
Adhesive Bonding

Steps for Processing a Sandwich


1 + 2


3


4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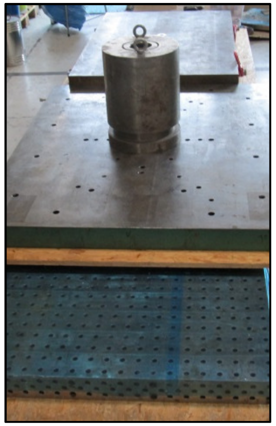
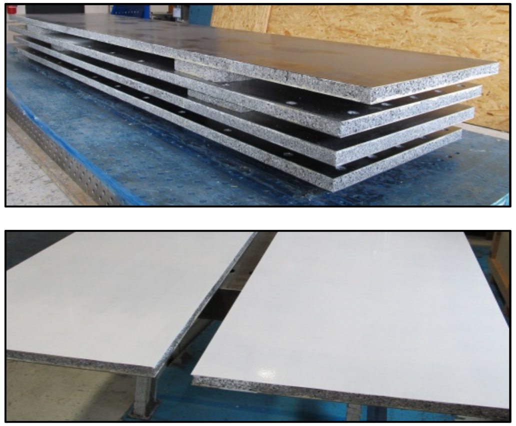
5 + 6


8 + 9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1. Sheets are cleaned and activated
2. First sheet is placed and fastened on gluing table
3. Sheet is coated with adhesive
4. Foam plates are placed on adhesive; edges between the plates are coated with adhesive as well
5. Placed foam plates are coated with adhesive (edges especially)
6. Cover sheet is coated with adhesive
7. Cover sheet is placed and clamp fastened
8. Weights are positioned
9. Adhesive hardening
10. Finishing (cleaning, coating)

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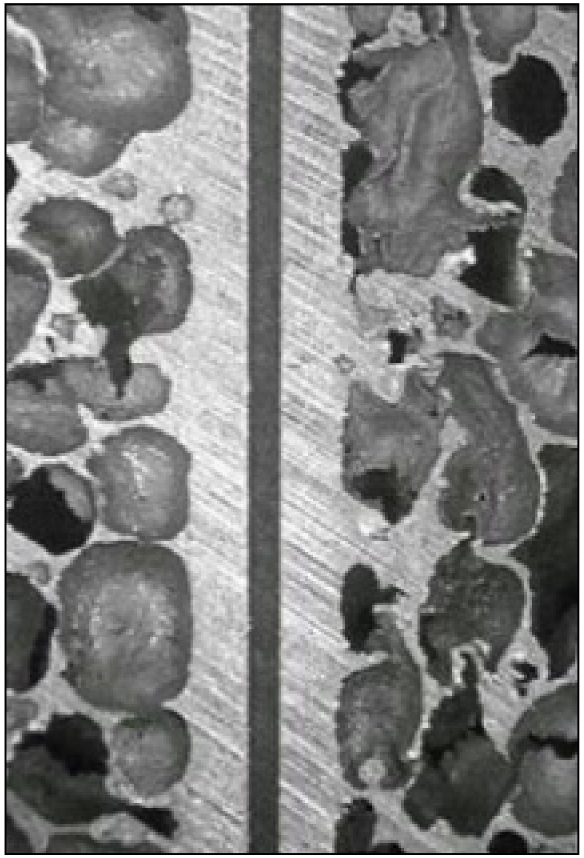
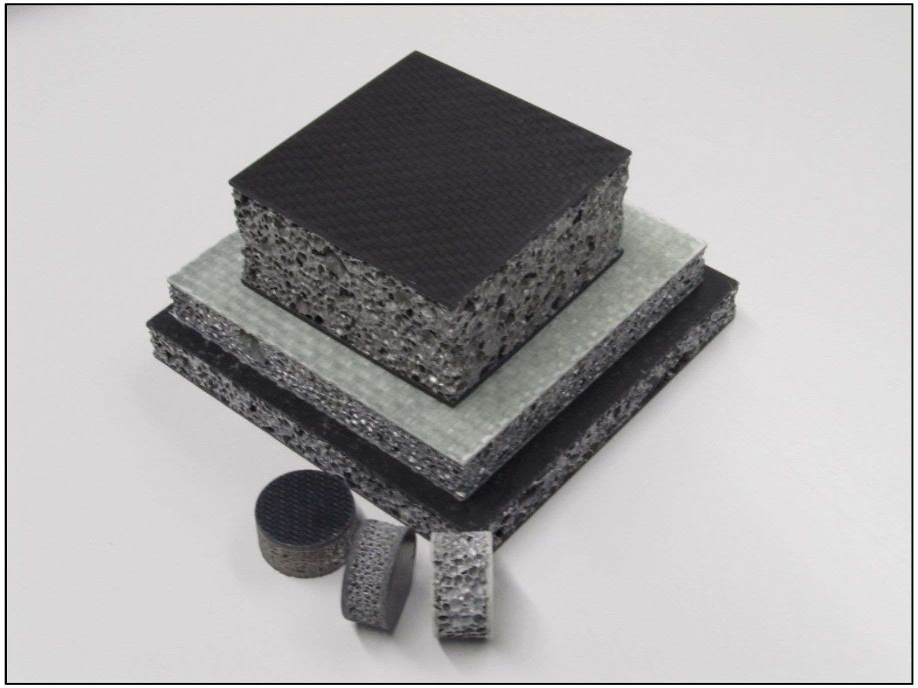
Adhesive Bonding
Examples



Adhesive bond: AFS with AFS
[Karmann]



Adhesive bond: diverse top layers (CRP, GRP) with foam [IWU]
(shown in Poster from Drebenstedt et.al.)

NON-DETACHABLE JOINING
WELDING

MIG/WIG-WELDING OF AFS

MIG/WIG-Welding of AFS

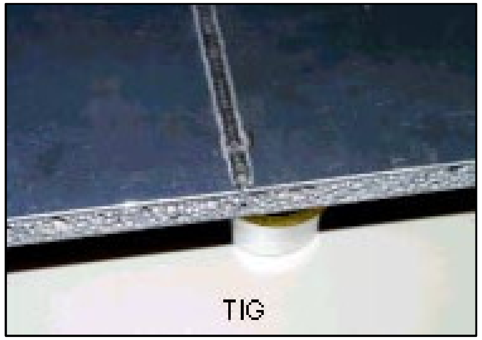
Process Characteristics

- Gap bridging ability in all welding positions
- Sturdy process
- High productivity
- High penetration depth
- Only few splashes and slag formation
- Neat and clean surface (weld surface)
- Welding speed up to 1 m/min
- Welding by hand or automatic possible

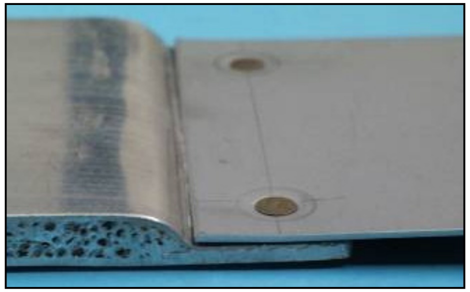
Quality Optimization

- Process parameter
- Pressing of AFS – to connect massive Aluminum pieces with AFS

MIG-weld seam AFS – AFS [Karmann]



WIG-weld seam AFS – AFS [Karmann]



Rivet compound of massive Al with pressed AFS

MIG/MAG-WELDING OF SAS

MIG/MAG-Welding of SAS

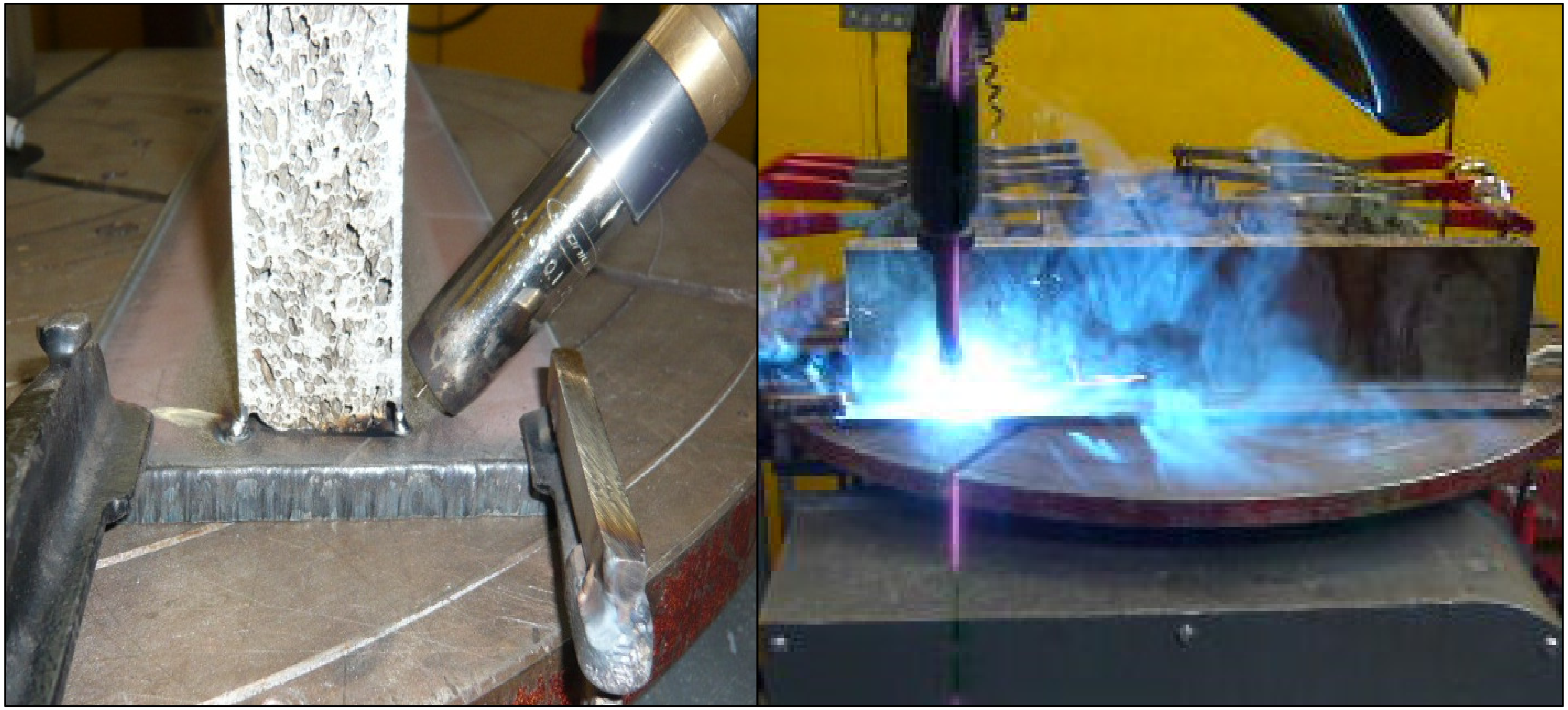
1. CMT Welding – Fa. Fronius
2. EWM-coldArc® – Fa. EWM
3. Cold Process – Fa. Cloos

MIG/MAG-Welding of SAS

Cold process – Fa. Cloos

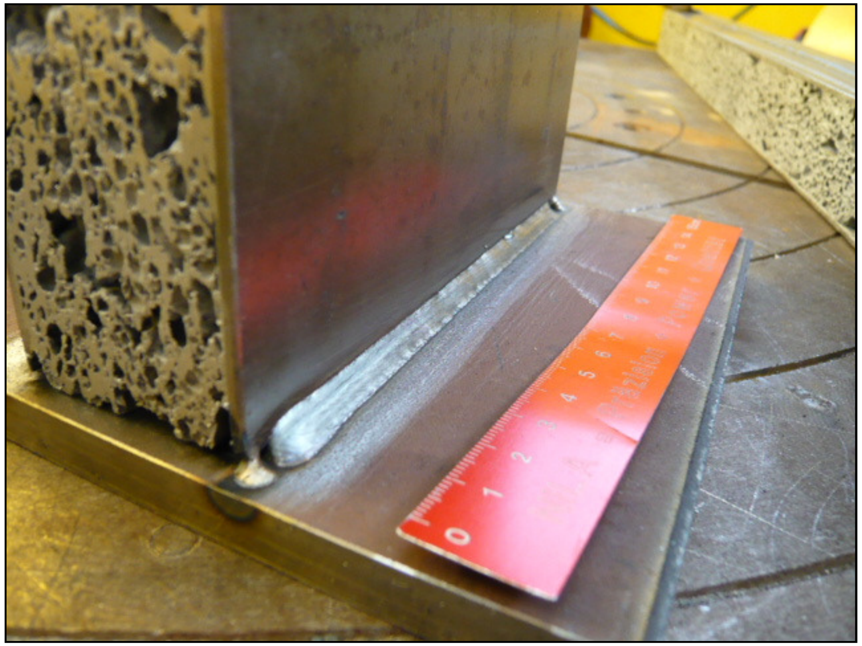
- by hand or supported by a robot
- minimal component distortion
- good gap bridging ability
- very good for thin-walled sheets
- minimum heat effort up to 3,5 mm component thickness
- for steels of high strength, Aluminum, Stainless steel
- splash-free

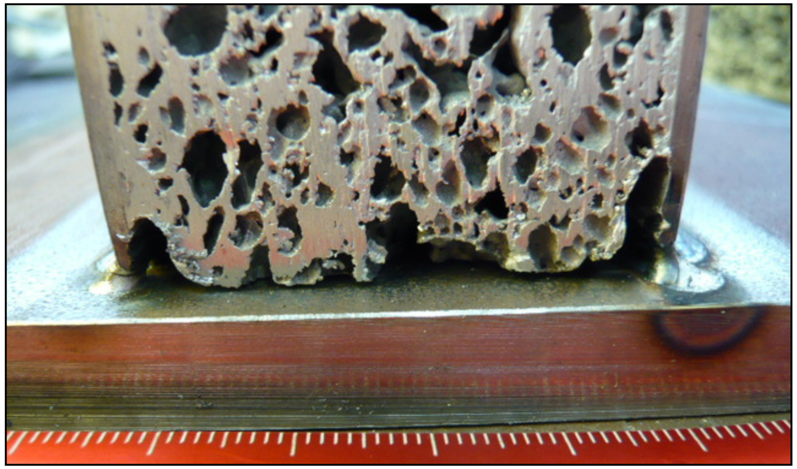
MIG/MAG-Welding of SAS
Robot Welding

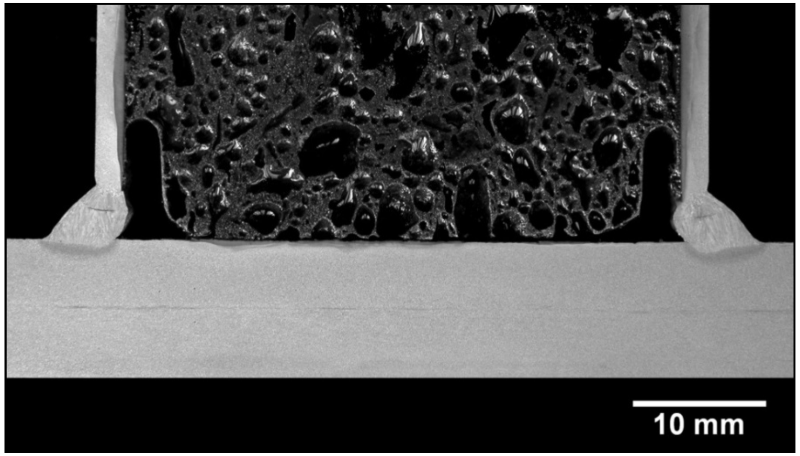


Robot welding of a T-Joint (SAS on 10 mm-Steel sheet)
Welding Robot Fronius; shielding gas: mixed gas 82 % Argon, 18 % CO_2 weld material: G3Si1

MIG/MAG-Welding of SAS
Robot Welding





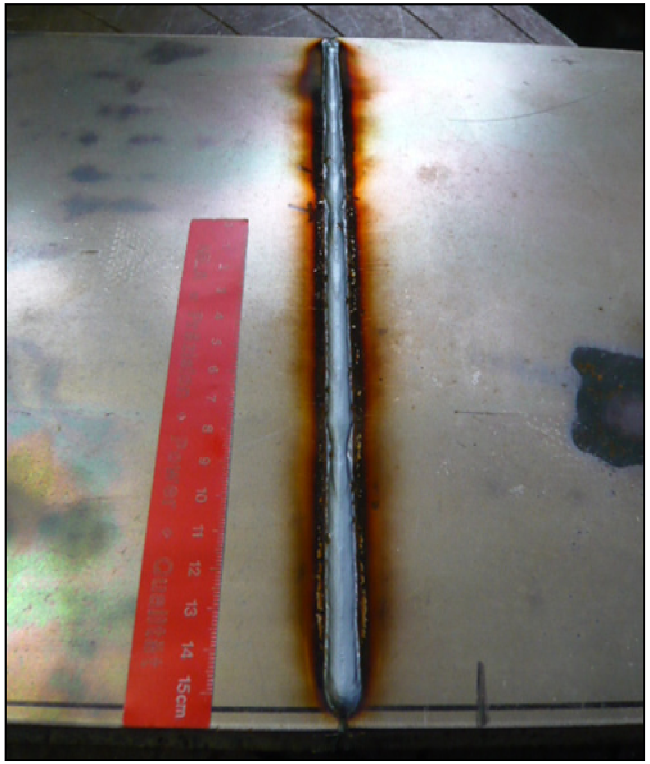


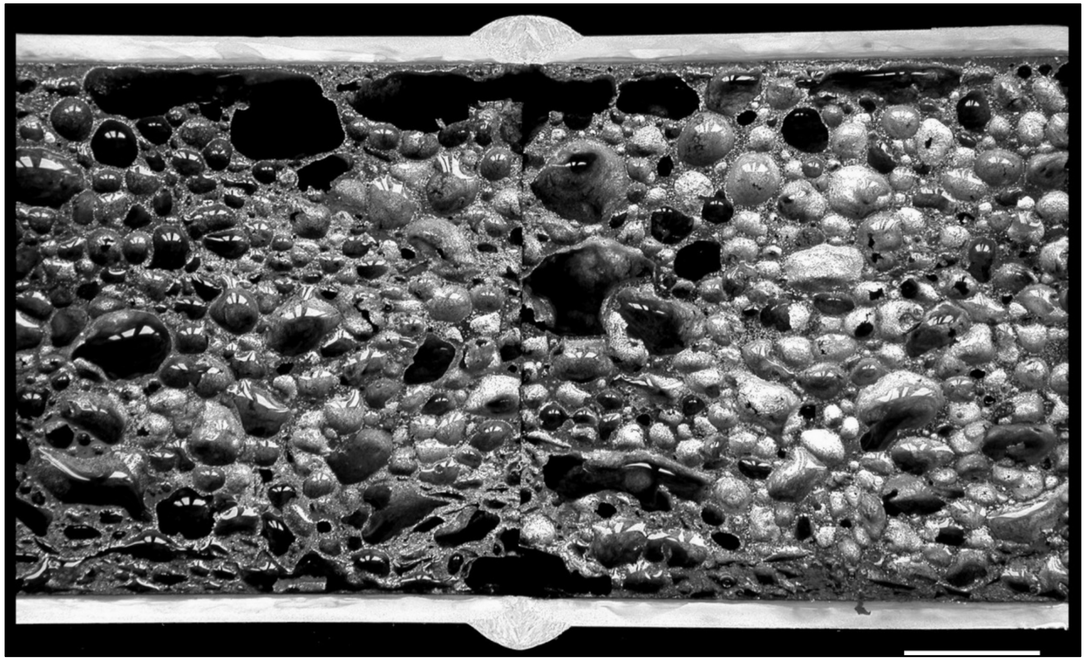
Filled weld of a T-Joint with microsection

MIG/MAG-Welding of SAS
Robot Welding

Robot welding of a butt joint of compound SAS/SAS
Welding Robot Fronius; shielding gas: mixed gas 82 % Argon, 18 % CO_2 weld material: G3Si1

MIG/MAG-Welding of SAS
Robot Welding





Butt joint with microsection

MIG/MAG-Welding of SAS
Robot Welding

- Weldability of SAS-Sandwich for MIG/MAG-Welding with Fronius Cold-Metal-Transfer-Technic (CMT) attested
- From 0,3 mm sheet thickness on, hand and robot welding possible
- Very good weld seam quality and geometry attested
- Determined welding parameter
- Energy efficient
- damaging strength investigations show no weld seam malfunction until plastic deformation

LASER WELDING

Laser Welding
For Joining Aluminum Foam and SAS

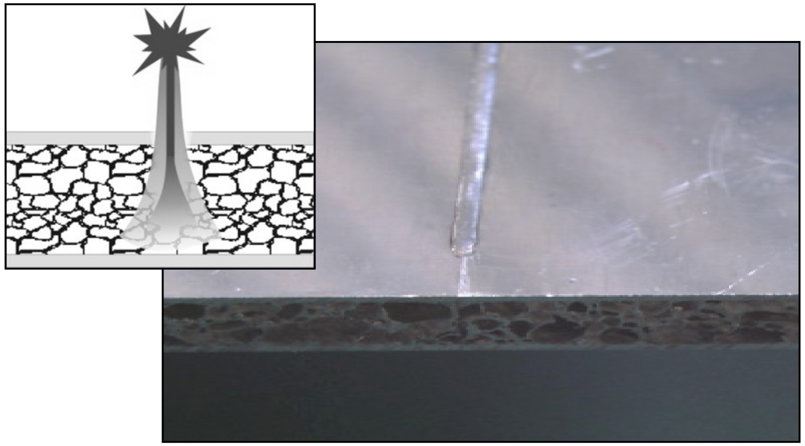
Advantages

- Punctual heat input
- Flexible and fast process
- Connections are of excellent weld seam quality
- Especially enabled with cover sheets (weld seam preparation is needed)
- Welding and cutting on a device possible
- Welding speed up to 10 m/min

Disadvantages/Difficulties:

- Defocus in lower cover sheet area
- Exact positioning of welded plates

Laser Welding
For Joining AFS and SAS



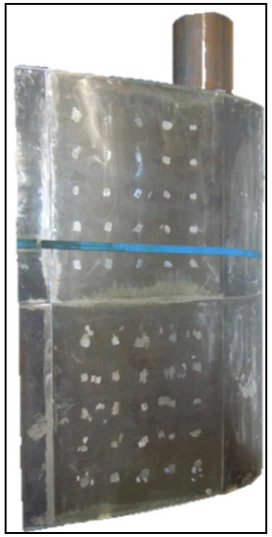
Laser weld joint between two AFS

Laser weld joint AFS - AFS [Karmann]

Otto, A.: Fügen von Schaum. DGM-Fortbildungsseminar Zellulare Metalle 19./20.4. 2007. Erlangen

Laser Welding – Example SAS

- **Gear box foundation-demonstrator**
  - ca. 40 m (32 %) weld joint of 125 m manufactured
  - ca. 85 m (68 %) weld joint through gas shielded metal arc welding manufactured (SIAG)

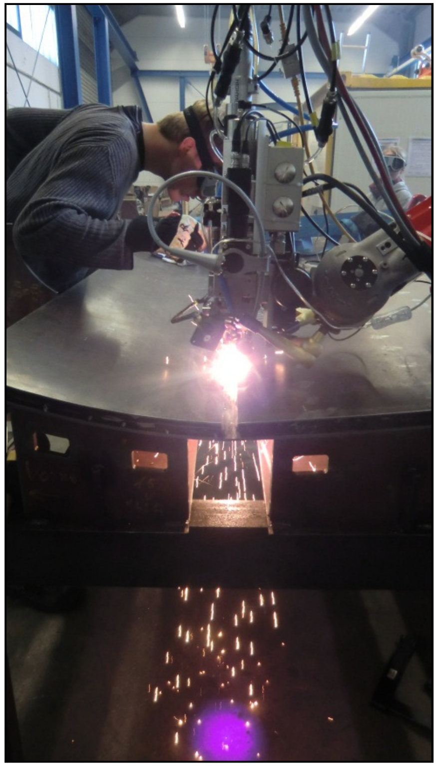


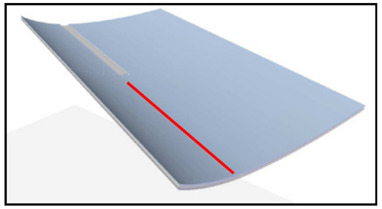
- **Ship rudder-demonstrator**
  - ca. 17 m (28 %) weld joint of 60 m manufactured
  - ca. 43 m (72 %) weld joint through gas shielded metal arc welding manufactured (LZH)

FAZIT: 185 m weld joint of which are 57 m (30 %) manufactured through laser welding

Laser Welding – Rudder-Demonstrator

Welding of outer skin and weld seam result

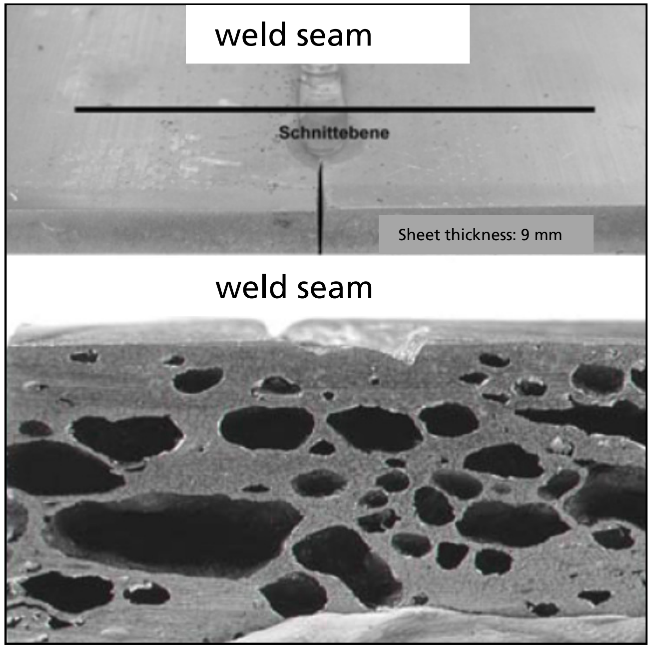




- Process parameter:
  - Laser power (P_L): 5 kW
  - Feed speed (v_f): 1 m/min
  - Shielding gas -
  - Focus diameter: 600 µm
- Penetration welding of 5 mm thick Steel sheets
- Without shielding gas → deposition of welding fumes
- Joint surface with slight exaltation

FRICTION STIR WELDING

Friction Stir Welding



Friction Stir Welding on 9 mm thick, foamable precursor material, weld seam is clearly visible (on top) and (below) connection after foaming

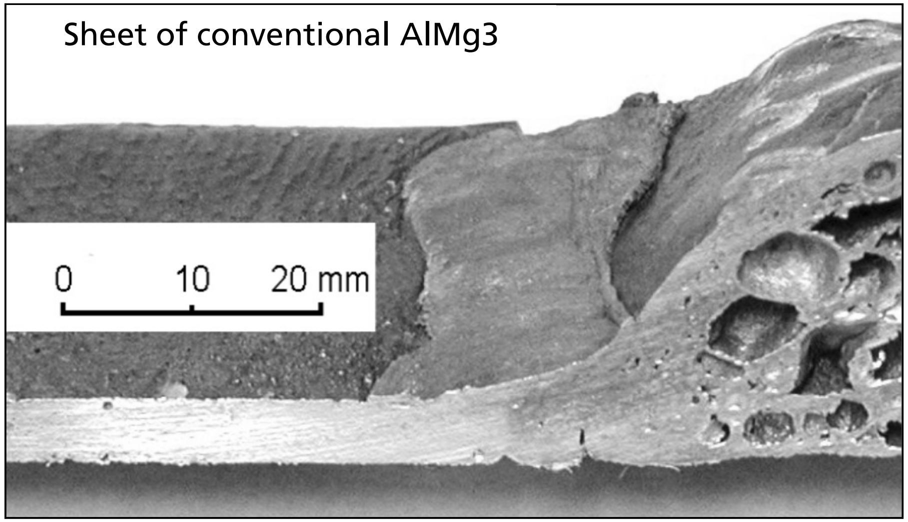
Horn, H.: Neue Entwicklungen bei Reibschweißverfahren; DVS Jahrbuch 2002

Friction Stir Welding

- Weld joint between conventional sheet (connected plate) and foamable pre-product possible
- Connection not separated by foaming process
- No interference during foaming process of the pre -product
- Tension tests show high strength – fracture occurs in base material
- Foaming material with connected plate (conventional material) can be combined with other compounds (through an appropriate welding method, a conjunction of a magnesium sheet with Al-Foam (a foamable alloy with a low melting point is assumed) is also possible)

Horn, H.: Neue Entwicklungen bei Reibschweißverfahren; DVS Jahrbuch 2002

Friction Stir Welding



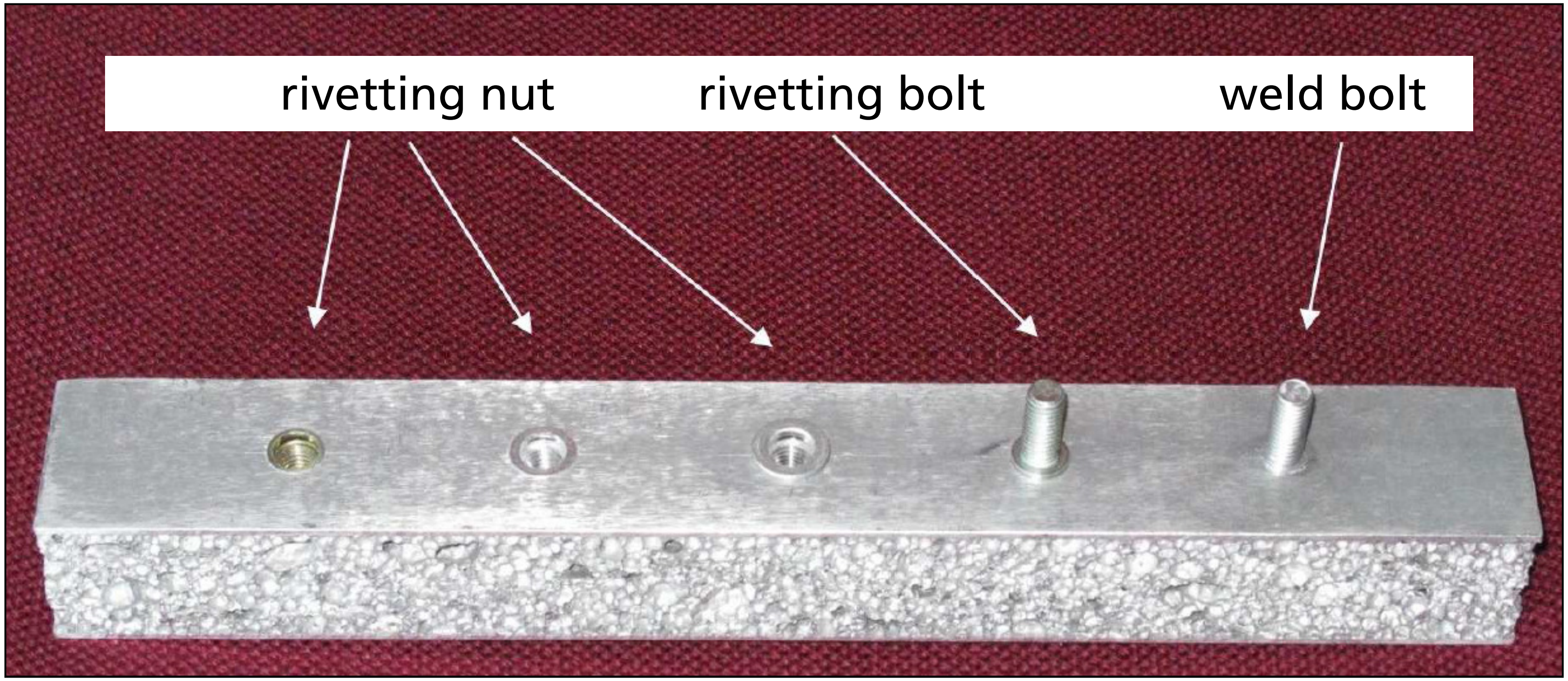
Compound of a foamable pre-product and a solid AlMg3 sheet after the foaming process

Horn, H.: Neue Entwicklungen bei Reibschweißverfahren; DVS Jahrbuch 2002

DETACHABLE JOINING

Screws and Inserts

Mechanical Joining of AFS



Sviridov, A.: Leichtbau mit Aluminiumschaumsandwich - Prozessketten zur Herstellung von Bauteilen; Dissertation, TU Cottbus, Oktober 2011

Mechanical Joining – Rivetting Nuts and Rivetting Bolts

Rivetting bolts

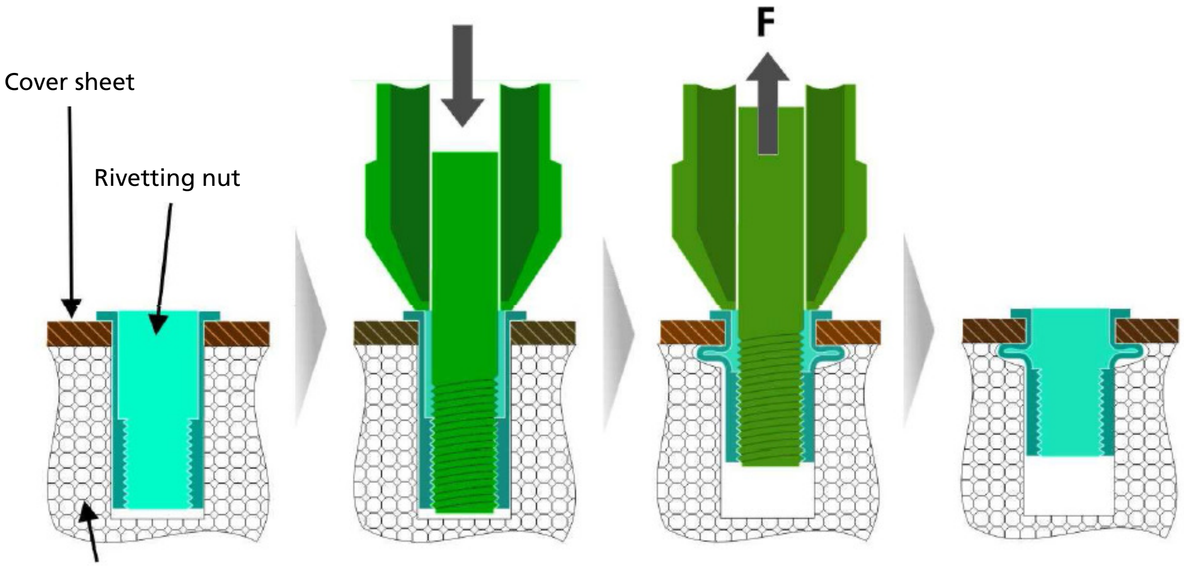
- Drilling of cover sheet and core material equivalent to outer diameter of the rivet
- Inserting of bolt and clamping with rivetting pliers in drilled hole
- Rivetting pliers supports itself on upper cover sheet, tightens on the lower part of the rivetting bolt (it creates a clamp beading and seizes the cover sheet between the upper and lower part of the rivetting bolt).
- Here: galvanized steel-rivetting bolt, type: M8 x 3020

Rivetting nuts

- Manufacturing – same as rivetting bolt
- Here: galvanized steel-rivetting nut; type M8 x 3020 with countersunk head
- Here: rivetting nut of Aluminum; type 336771 M 8 with flathead

Sviridov, A.: Leichtbau mit Aluminiumschaumsandwich - Prozessketten zur Herstellung von Bauteilen; Dissertation, TU Cottbus, Oktober 2011

Mechanical Joining – Rivetting Nuts and Rivetting Bolts

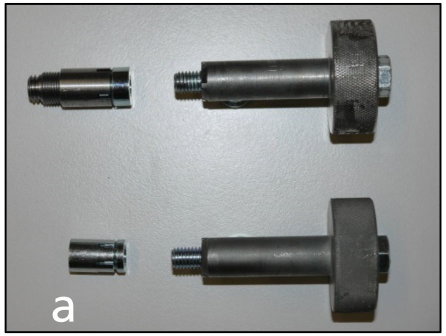


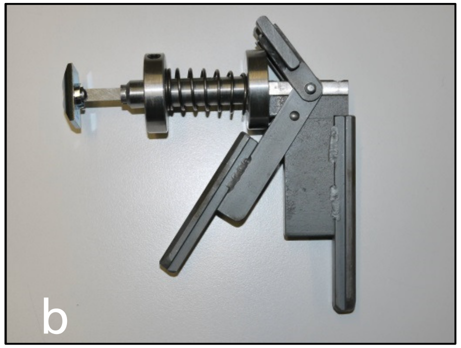
Fundamental procedure for inserting rivetting nuts in AFS

Sviridov, A.: Leichtbau mit Aluminiumschaumsandwich - Prozessketten zur Herstellung von Bauteilen; Dissertation, TU Cottbus, Oktober 2011

Suitable Fasteners
„FH FoamConnector“

- Universally applicable
- Easy installation and tools
- In all metric sizes and for any pre-product thickness available
- Strength category 8.8 for M8 thread → dependent on used cover sheet material
- economically manufacturable due to cold extrusion





Connection installation with positioning guide (a) or press-in tool (b)

„FH FoamConnector“

Fasteners for AFS

Maximum extraction forces and tightening torques of chosen inserts (M8)

	Expansion sleeve with thread and tolerance compensation	Expansion sleeve with thread	Through nut	One sided expansion sleeve
				
Extraction force	10 kN		19 kN	10 kN

- Type of failure: coversheet and foam core failure
- Tightening torques > 26 Nm possible

„FH FoamConnector“

Fasteners for SAS

Maximum extraction forces and tightening torques of chosen inserts (M8)

	Expansion sleeve with thread and tolerance compensation	Expansion sleeve with thread	Through nut	One sided expansion sleeve
				
Extraction Force	15 kN	21 kN	24 kN	15 kN

- Type of failure: coversheet and foam core failure
- Tightening torques > 44 Nm possible

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MILLING, FORMING

Milling, Turning

Applicable cutting angle geometries

Cutting Angle Parameter	Al-chipping massive	Al-chipping foam
Angle of inclination λ	> 0° 1) , 20° 2)	15°
Cutting angle γ	0° - 15°	15°
Clearance angle α	12° - 18°	15 - 27°
Comments	1) Cast alloys 2) Wrought alloys	

Cutting forces were only gathered during wet processing and an ideal cutting process.
As expected of solid Aluminum materials, the emerging cutting forces are low.

Milling, Turning

Cutting Forces

- AlSi12: **F_c = 25 until 95 N** (Cast alloy)
- AlMgSi: **F_c = 20 until 80 N** (hardenable wrought alloy)
- Densities: 0,5; 0,7; 1,0 g/cm^3

Figures are valid under the following conditions:

Cutting Tool Material: uncoated hard metal

Cutting Parameter:
Cutting speed depends on:

- Possible RPM: v_c = 500 bis 2000 m/min
- feed: f_z = 0,06 bis 1,0 mm
- Cutting depth: a_p = 1,0 bis 2,0 mm
- Width of contact: a_e = 50 mm

Cooling Agent: Dry and wet processing

Forming

Depth 10 mm, Thickness 8 mm, T_{Room}

Pressing of Aluminum Foam [IWU]

thickness10 mm, Dm. 300 mm, T_{Room}, 3-Roll-Rollframe

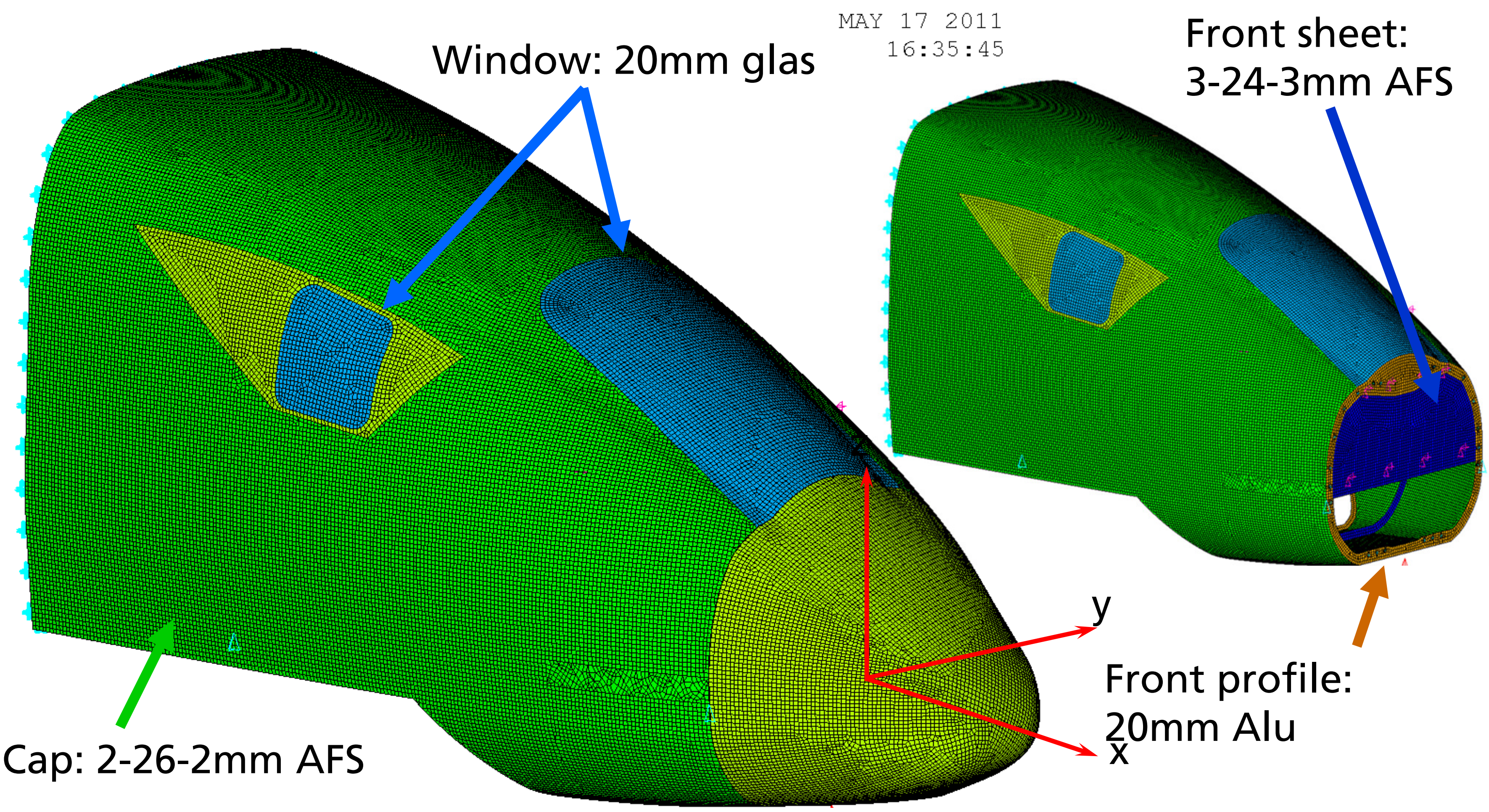
Rolling of Al-Foam [IWU]

Forging AFS [Pohltec]

APPLICATIONS

ICE 3

Quelle: www.siemens.com/press


MAY 17 2011
16:35:45
Window: 20mm glas
Front sheet:
3-24-3mm AFS
Front profile:
20mm Alu
Cap: 2-26-2mm AFS
y
x

demonstrator

* welding process TIG

Comparison

ICE 3 D - Siemens

- bodywork: frame + outer shells
- Aluminum sheet 10 mm
- time-consuming positioning
- high tool expenses

Demonstrator - BlueS

- bodywork: sandwich, self-supporting
- Aluminum-Foam-Sandwich 30/2 mm
- reduced installation effort
- low tool expenses
- 20 % weight saving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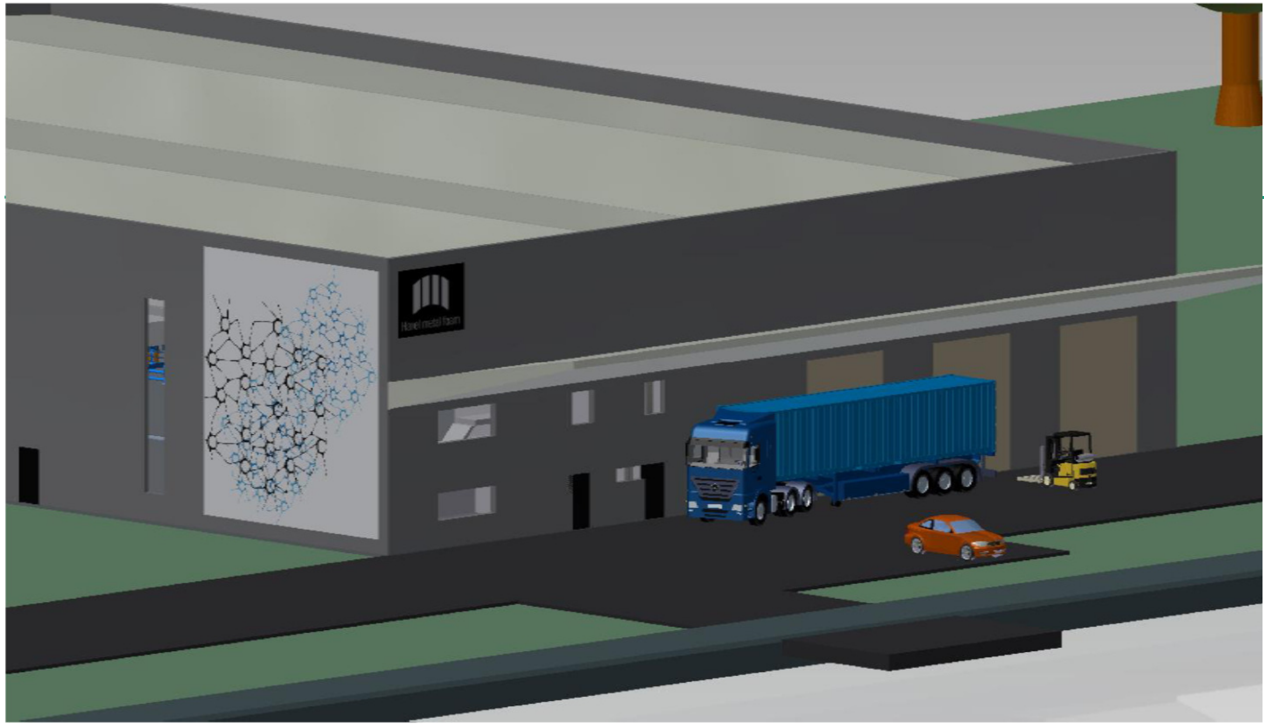

Zukünftig:

Produktion von

- AFS
- SAS
- 3D-Schaumteilen

in Serie

Thank you for your attention!