Creating the strongest bond on Composites
L. Chouvet

February 2019
Why bonding?
Advantages of using adhesives

- Assembly of dissimilar substrates (different material / thickness)
- Light weight assemblies
- Stiffer structures
- No modification of the substrate
- Aesthetics
Why bonding?
Advantages of using adhesives

- Reduced stress concentrations
- Easy processing (manual/automatic)
- Complex assemblies
- Reduced corrosion
Bonding mechanism

3 Factors

- Wetting
- Adhesion
- Cohesion
- Final Strength

Contact  Mechanical Chemical  Polymer properties
Bonding mechanism
3 Factors

Wetting

Contact

Mechanical
Chemical

Adhesion

Polymer properties

Cohesion

Final Strength
Adhesives

Wetting

Wetting

Ability of the adhesive to spread on the substrate when the joint is initially formed

\[ \text{Good wetting} = \theta < 90^\circ \quad (\gamma_{\text{Substrate}} > \gamma_{\text{adhesive}}) \]

(Source: Wikipedia)
### Surface tension of common materials ($\gamma$ in mN/m)

#### Liquids
- n-hexane: 18 mN/m
- Silicone oil: 21 mN/m
- Lubricating oil: 29 mN/m
- Paraffin wax: 30 mN/m
- Acrylic monomers: 30 - 40 mN/m
- Epoxy resin: 43 - 48 mN/m
- Ethylene glycol: 48 mN/m
- Water: 73 mN/m

#### Solids
- PTFE: 18 mN/m
- Polypropylene: 29 mN/m
- Polyethylene: 31 mN/m
- Cured epoxy resin: 43 mN/m
- Polyamide: 46 mN/m
- Polycarbonate: 46 mN/m
- Acetal: 47 mN/m
- Glass: 290 mN/m
- Aluminium: 500 mN/m
- Copper: 1000 mN/m

(Source: Wikipedia)
Surface tension of common materials ($\gamma$ in mN/m)

<table>
<thead>
<tr>
<th>LIQUIDS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>n-hexane</td>
<td>18</td>
</tr>
<tr>
<td>Silicone oil</td>
<td>21</td>
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<tr>
<td>Lubricating oil</td>
<td>29</td>
</tr>
<tr>
<td>Parafin Wax</td>
<td>30</td>
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<tr>
<td>Acrylic Monomers</td>
<td>30 - 40</td>
</tr>
<tr>
<td>Epoxy resin</td>
<td>43 - 48</td>
</tr>
<tr>
<td>Ethylene glycol</td>
<td>48</td>
</tr>
<tr>
<td>Water</td>
<td>73</td>
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</table>
Surface tension of common materials ($\gamma$ in mN/m)

### SOLIDS

<table>
<thead>
<tr>
<th>Material</th>
<th>$\gamma$ (mN/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTFE</td>
<td>18</td>
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<tr>
<td>Polypropylene</td>
<td>29</td>
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<tr>
<td>Polyethylene</td>
<td>31</td>
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<tr>
<td>Cured epoxy resin</td>
<td>43</td>
</tr>
<tr>
<td>Cured Polyester</td>
<td>40</td>
</tr>
<tr>
<td>Polyamide</td>
<td>46</td>
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<tr>
<td>Polycarbonate</td>
<td>46</td>
</tr>
<tr>
<td>Acetal</td>
<td>47</td>
</tr>
<tr>
<td>Glass</td>
<td>290</td>
</tr>
<tr>
<td>Aluminium</td>
<td>500</td>
</tr>
<tr>
<td>Copper</td>
<td>1000</td>
</tr>
</tbody>
</table>

- **Low Wetting plastics**
- **Composites**
Adhesive
Wetting – Test inks

Source: plasmatreat https://www.plasmatreat.com/

➢ Test inks are a simple method to check the surface tension

➢ Surface tension measurement is not an adhesion measurement
Bonding mechanism
3 Factors

Wetting → Adhesion → Cohesion → Final Strength

Contact → Mechanical Chemical → Polymer properties
Adhesives
How does it bond?

Chemical theories:

**Adsorption**
Intimate intermolecular contact between two materials

**Chemisorption**
Primary chemical bonds across the interface. Chemical bonds are strong and make a significant contribution to the intrinsic adhesion in some cases.

Diffusion theory:
Inter-penetration of chains at the interface.
This may occur when the molecules of both materials are mobile and soluble in each other.
Adhesives
Failure modes

Cohesive failure

Adhesive failure

Advanced Materials
Creating the strongest bond
Surface preparation

Surface Pre-treatment.....why?

- To eliminate the weak surface boundary layer (release agent, pollution)
- To activate and increase the surface energy of substrates
- To increase the active bonding surface (inclusion of oxygen)

Different methods of pre-treatment used:

- **Mechanical pre-treatment** (file, abrasive paper, grit blasting, peel ply)
- **Chemical pre-treatment** (degreasing, etching, conversion, priming)
- **Energetic pre-treatment** (Flame, corona, plasma treatment)
Creating the strongest bond
Surface preparation

Performances of Araldite® adhesives on atmospheric plasma treated plastics

- Degreased substrates
- Plasma

Graph showing the performances of Araldite® adhesives on different plastics after atmospheric plasma treatment.
Creating the strongest bond
Surface preparation

Plasma Treatment on Glass reinforced Polyester

Plasma treatment

Surface Energy (mN/m)

Plasma treatment time (sec.)

Surface tension (mN/m) after 24 hours

30 sec. Treated  120 sec. Treated
Creating the strongest bond
Surface preparation - Evaluation

Aging Test is the best way to evaluate the surface preparation
- Temperature changes
- Humidity / Water
- Air

Standard Test to combine all aspects: Cataplasma ISO 9142 / E2
- Specimens wrapped in de-ionized water soaked cotton wool
- 7 Days at 70°C (1st chamber)
- 15 hours at -20°C (2nd Chamber)
- Test after 24 hours

Possible to extend to 14 days and 21 days
(after 14 days the specimens are wrapped in fresh cotton wool with fresh water)
Creating the strongest bond
Surface preparation

Bonding glass reinforced phenolic composite to stainless steel

<table>
<thead>
<tr>
<th></th>
<th>Lap Shear Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless steel /</td>
<td>20</td>
</tr>
<tr>
<td>Stainless steel -</td>
<td>10</td>
</tr>
<tr>
<td>abraded</td>
<td></td>
</tr>
<tr>
<td>Stainless steel /</td>
<td>15</td>
</tr>
<tr>
<td>composite / abraded</td>
<td></td>
</tr>
<tr>
<td>Stainless steel /</td>
<td>25</td>
</tr>
<tr>
<td>composite / sandblasted</td>
<td></td>
</tr>
</tbody>
</table>

- initial state
- 14 days cataplasma
- 21 days cataplasma
Creating the strongest bond
Surface preparation

Ageing performances of Araldite® 2015 on aluminium with different surface preparations

![Bar chart showing average lap shear strength (MPa) for different surface preparations.](chart.png)
Bonding mechanism

3 Factors

- Wetting
- Adhesion
- Cohesion
- Final Strength

Contact

Mechanical Chemical

Polymer properties
Creating the strongest bond
Joint Design

Joint loading conditions

- **Tension** stress component
- **Compression** stress component
- **Shear** stress component
- **Cleavage** stress component
- **Peel** stress component
Creating the strongest bond
Joint Design

A peel joint can be designed such that the forces acting on it become compression forces, making a stronger joint.

Weak cleavage joints can be strengthened through design, in this instance by adding a U-section to the previously bent sheet.

By adding reinforcing plates to this butt joint, the forces run along a much stronger shear joint.
Creating the strongest bond
Conditions in service

Bondline thickness vs measured shear strength on sandblasted aluminium

- Toughned epoxy
- Non toughned epoxy
- Basic PUR
- Toughned methacrylate
Creating the strongest bond
Conditions in service

Bondline thickness vs measured shear strength on sandblasted aluminium and abraded CFRP for Araldite® Epoxy adhesive

Aluminium : 1.6 mm Alloy L 165
CFRP : Bidirectional 2 mm / Epoxy Matrix
Creating the strongest bond
Conditions in service

Limit of low thicknesses: case of dissimilar substrates (GRP to Glass)

Source: clix industries www.clix-industries.com
Bonding mechanism
Summary

Wetting → Adhesion → Cohesion → Final Strength

- Contact
- Mechanical Chemical
- Polymer properties
Creating the strongest bond
Type of substrates - experience

<table>
<thead>
<tr>
<th>Composite Matrix</th>
<th>Adhesive</th>
<th>Degreasing</th>
<th>Pretreatment</th>
<th>Remark</th>
</tr>
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<tbody>
<tr>
<td>Polyester / Vinylester</td>
<td>MMA</td>
<td>Isopropanol</td>
<td>Abrasion</td>
<td>MMA diffusion</td>
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<tr>
<td></td>
<td>Epoxy</td>
<td>Acetone</td>
<td>Plasma</td>
<td>Styrene inhibition for Epoxies</td>
</tr>
<tr>
<td>Epoxy / Amine</td>
<td>Epoxy</td>
<td>Isopropanol</td>
<td>Abrasion</td>
<td>Toughness can improve strength</td>
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<tr>
<td></td>
<td>MMA</td>
<td>Acetone</td>
<td>Plasma Peel Ply</td>
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<tr>
<td>Epoxy / Anhydride</td>
<td>Epoxy (MMA)</td>
<td>Isopropanol</td>
<td>Abrasion (Plasma)</td>
<td>Toughness can improve strength</td>
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<td></td>
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<td>Acetone</td>
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</tr>
<tr>
<td>Phenolic</td>
<td>Epoxy (MMA)</td>
<td>Isopropanol</td>
<td>Abrasion (Plasma)</td>
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<tr>
<td></td>
<td></td>
<td>Acetone</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Low influence of the manufacturing process on the adhesion (RTM, Infusion, filament winding …) but high influence on the cohesion of the composite
- High influence of the release agents
Creating the strongest bond
Factors influencing quality

**Constant factors**
- Adhesive selection
- Component / bond design
- Tolerances / accuracy
- Component dimensions
- Production methods
- Training of workers

**Variable factors**
- Adhesive storage
- Substrate quality
- Pre-treatment quality
- Post-pre-treatment life
- Mixing and application
- Open or assembly time
- Assembly and curing

Advanced Materials
• Araldite® adhesives for Composites
• New product launches
• Adhesives in action
A strong reputation established as market leader in many commercial and industrial sectors, **50+% brand recognition** in Europe

Over **70 years’ experience**, a pioneer in high performance adhesive technology

A comprehensive range for high performance bonding applications, **5 technologies***, more than **500 sales items**

Serving worldwide manufacturing industry. **Thousands of companies around the world** use Araldite adhesives in markets such as aerospace, automotive, construction, electronics, marine, railway, sports equipment

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* Epoxy, Polyurethane, Methacrylate, Polyamide Hotmelt, Phenolic
Reliable and comprehensive bonding solutions

Our offer
- Products helping overcome key challenges,
- R&D capabilities for new solutions enabling reduced production process costs and lightweight designs (energy efficiency),
- Global manufacturing footprint,
- Local Technical Support & commercial teams.
• Araldite® adhesives for Composites
• New product launches
• Adhesives in action
Products Overview – composite bonders

Araldite® AW 4858 / HW 4858

Araldite® AW 4859 / HW 4859

Araldite® 2015-1

Araldite® 2031-1

Araldite® 2029-1

Araldite® 2048-1

Advanced Materials
Technical features

• Performance on composites

• Lap Shear Strength at 23°C (MPa) – ISO 4587
Technical features

• Performance on metals

• Lap Shear Strength at 23°C (MPa) – ISO 4587
Technical features

• Performance on aluminium at different temperatures

• Lap Shear Strength (MPa) – ISO 4587

*AW 4859 / HW 4859 : cure at 80°C
# Products Overview

<table>
<thead>
<tr>
<th>Product</th>
<th>Shear Strength</th>
<th>Peel Strength</th>
<th>Temperature</th>
<th>Chemicals</th>
<th>Flexibility</th>
<th>Fast cure</th>
<th>Cure at RT</th>
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<tbody>
<tr>
<td>Araldite® 2015-1</td>
<td></td>
<td></td>
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<tr>
<td>Araldite® 2031-1</td>
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<td></td>
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<tr>
<td>Araldite® AW / HW 4858</td>
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<tr>
<td>Araldite® 2029-1</td>
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<tr>
<td>Araldite® 2048-1</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
Special products

Very high temperatures (LSS > 5 MPa at 200°C\(^{(1)}\))

- Araldite® AW 4510 / Hardener HW 4511-1

Flame Retardant Adhesive (UL94 V-0 / EN 45545-2 HL3)

- Araldite® 2033

Universal toughened MMA adhesives (3 minutes and 10 minutes)

- Araldite® 2021-1, Araldite® 2022-1

\(^{(1)}\): LSS: Lap Shear Strength on sandblasted aluminum
• Araldite® adhesives for Composites
• New product launches
• Adhesives in action
### MMA-Adhesives

#### New product launches

<table>
<thead>
<tr>
<th>Highly flexible MMA`s</th>
<th></th>
</tr>
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<tbody>
<tr>
<td><strong>- Araldite® 2023-10</strong></td>
<td></td>
</tr>
<tr>
<td><strong>- Araldite® 2023-30</strong></td>
<td></td>
</tr>
<tr>
<td><strong>- Araldite® 2023-60</strong></td>
<td></td>
</tr>
<tr>
<td>- UV stable</td>
<td>- Gap filling</td>
</tr>
<tr>
<td>- Open Time: 10min, 30min, 60min</td>
<td></td>
</tr>
</tbody>
</table>

*Launch in June - September 2019*

<table>
<thead>
<tr>
<th>MMA`s for use in tough conditions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>- Araldite® 2050</strong></td>
<td>- Curing at minus temperatures (-20°C)</td>
</tr>
<tr>
<td><strong>- Araldite® 2051</strong></td>
<td>- High speed cure</td>
</tr>
<tr>
<td></td>
<td>- Application even under water &amp; saltwater</td>
</tr>
<tr>
<td></td>
<td>- Curing in humid areas</td>
</tr>
<tr>
<td></td>
<td>- Minimum pretreatment needed</td>
</tr>
</tbody>
</table>

*Launch in March 2019*
**Araldite® 2050**

Low temperature cure

<table>
<thead>
<tr>
<th>Temperature</th>
<th>-20°C</th>
<th>-10°C</th>
<th>0°C</th>
<th>10°C</th>
<th>23°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cure time to reach LSS &gt; 1MPa</td>
<td>4h</td>
<td>90 min</td>
<td>40 min</td>
<td>12 min</td>
<td>9 min</td>
</tr>
<tr>
<td>Cure time to reach LSS &gt; 10MPa</td>
<td>8h</td>
<td>3h</td>
<td>1h</td>
<td>20 min</td>
<td>13 min</td>
</tr>
</tbody>
</table>

**Lap Shear Strength (MPa)**

- Aluminium cure 24 hours at RT
- Aluminium cure 1 week at -20°C
- Aluminium cure 1 week at -10°C
- Aluminium cure 1 week at 0°C
Araldite® 2050
Bonding under water - Aluminium

Lap Shear Strength (MPa)

- Aluminium cure 24 hours RT: 30 MPa
- Aluminium bonding & cure 24 hours under water: 25 MPa
- Aluminium bonding & cure 24 hours under salt water: 25 MPa
Araldite® 2050
Bonding under water – UP-GRP

Lap Shear Strength (MPa)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Lap Shear Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UP-GRP cure 24 hours at RT</td>
<td>7</td>
</tr>
<tr>
<td>UP-GRP bonding &amp; cure 24 hours under water</td>
<td>6.5</td>
</tr>
<tr>
<td>UP-GRP bonding &amp; cure 24 hours under salt water</td>
<td>6.3</td>
</tr>
</tbody>
</table>

Note: substrates failures observed
Araldite® 2050 + 2051 Heavy Duty MMA
Main Features

- **Rapid curing**: 2-5 min pot life
- Outstanding **mechanical properties**
- Excellent bond to **metals**
- Superb **aging and weathering resistance**
- Curing even at **minus temperatures** (down to -20°C)
- Application under **water, saltwater and humid areas**
- **Minimum pretreatment needed**
- **Shelf-life**: 18 months at 2 – 8°C
  - 6 months at 8 - 25°C
  - 1 month at 25 – 30°C

<table>
<thead>
<tr>
<th></th>
<th>Araldite 2050</th>
<th>Araldite 2051</th>
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</thead>
<tbody>
<tr>
<td>Gel time</td>
<td>2 - 3min</td>
<td>4 – 5 min</td>
</tr>
<tr>
<td>Open Time</td>
<td>1min</td>
<td>4min</td>
</tr>
<tr>
<td>Time to 1MPa</td>
<td>9min</td>
<td>15min</td>
</tr>
<tr>
<td>Time to 10MPa</td>
<td>13min</td>
<td>25min</td>
</tr>
<tr>
<td>Tensile strength (MPa)</td>
<td>40</td>
<td>37</td>
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<tr>
<td>Modulus (MPa)</td>
<td>1700</td>
<td>1500</td>
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<tr>
<td>Elongation at break (%)</td>
<td>ca. 10</td>
<td>ca. 10</td>
</tr>
<tr>
<td>Tg (Peak) °C DMA</td>
<td>127</td>
<td>127</td>
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<tr>
<td>Aluminum L165</td>
<td>31</td>
<td>32</td>
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<td>Aluminium 5754</td>
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<tr>
<td>Steel</td>
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<tr>
<td>Stainless steel</td>
<td>30</td>
<td>29</td>
</tr>
<tr>
<td>EP-GRP</td>
<td>16</td>
<td>12</td>
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<tr>
<td>UP-GRP</td>
<td>7*</td>
<td>7*</td>
</tr>
<tr>
<td>CFRP</td>
<td>25</td>
<td>18</td>
</tr>
<tr>
<td>SMC</td>
<td>6</td>
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<tr>
<td>ABS</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>PVC</td>
<td>10*</td>
<td>8*</td>
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<tr>
<td>PMMA</td>
<td>5*</td>
<td>6*</td>
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<tr>
<td>PC</td>
<td>10*</td>
<td>9*</td>
</tr>
</tbody>
</table>

(*) : substrates failures
Long open time MMA
Application

- Araldite® 2023-10
- Araldite® 2023-30
- Araldite® 2023-60

- Easy pumping with a dosing unit
- High gap fill
- Ideal for big structures
Araldite® 2023 – High Flexible MMA

Main Features

- 10:1 mix ratio
- Light grey colour / UV stable
- Up to **30 mm** Gap filling
- Modulus 700 – 800 MPa
- **Elongation at break > 100%**
- High strength on **metals and composites**
- Open time: **10min, 30min, 60min**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
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<tbody>
<tr>
<td>Shelf-life: Resin</td>
<td>24 months at 2 - 8°C</td>
</tr>
<tr>
<td></td>
<td>12 months at 8 - 25°C</td>
</tr>
<tr>
<td></td>
<td>1 month at 25 - 30°C</td>
</tr>
<tr>
<td>Hardener</td>
<td>18 months at 2 - 8°C</td>
</tr>
<tr>
<td></td>
<td>6 months at 8 - 25°C</td>
</tr>
<tr>
<td></td>
<td>1 month at 25 - 30°C</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Araldite</th>
<th>2023-10 / 2023-30 / 2023-60</th>
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</thead>
<tbody>
<tr>
<td>Open Time</td>
<td>10 min. / 30 min. / 60 min.</td>
</tr>
<tr>
<td>Time to 1MPa</td>
<td>30 min. / 60 min. / 100 min.</td>
</tr>
<tr>
<td>Time to 10MPa</td>
<td>40 min. / 70 min. / 110 min.</td>
</tr>
<tr>
<td>Tensile strength (MPa)</td>
<td>19 MPa</td>
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<tr>
<td>Emodulus (MPa)</td>
<td>700 – 800 MPa</td>
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<tr>
<td>Elongation at break (%)</td>
<td>ca. 100%</td>
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<tr>
<td>Tg (Onset/Peak) °C DMA</td>
<td>45 / 75</td>
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<table>
<thead>
<tr>
<th>Material</th>
<th>Tabular Values</th>
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<tbody>
<tr>
<td>Aluminum</td>
<td>15</td>
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<tr>
<td>Steel</td>
<td>15</td>
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<tr>
<td>Stainless steel</td>
<td>16</td>
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<tr>
<td>EP-GRP</td>
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</tr>
<tr>
<td>UP-GRP</td>
<td>7*</td>
</tr>
<tr>
<td>CFRP</td>
<td>17</td>
</tr>
<tr>
<td>SMC</td>
<td>6*</td>
</tr>
<tr>
<td>ABS</td>
<td>6*</td>
</tr>
<tr>
<td>PVC</td>
<td>7*</td>
</tr>
<tr>
<td>PMMA</td>
<td>7*</td>
</tr>
</tbody>
</table>

(*): substrates failures
• Araldite® adhesives for Composites
• New product launches
• Adhesives in action
Epoxy Adhesive

Araldite® 2015-1 : toughened 2-component epoxy adhesive

Side blade Audi R8 CFRP to CFRP

Specification:
- Excellent adhesion to CFRP
- Good impact resistance
- Good fatigue resistance
- Gap filling
Epoxy & MMA Adhesives

Araldite® 2031-1: Toughened 2-component epoxy adhesive
Araldite® 2048-1: Flexible tough 2-component MMA adhesive

Sport car spoiler

CFRP to CFRP
&
CFRP to Aluminium
&
Aluminium to Aluminium

Specification:

- Excellent adhesion to CFRP and Aluminium
- Bonding on painted aluminium without any pretreatment
- Gap filling
Epoxy Adhesive

Araldite® 2031-1 : Toughened 2-component adhesive

Lamborghini Aventador
CFRP Roof to CFRP Chassis

Specification:
- Gap filling up to 4mm
- Excellent adhesion to CFRP
- Service temperature range: - 40 to + 100°C
MMA Adhesive

Araldite® 2022-1 : 2-component MMA adhesive

Hand dryer electrical engin

GRP to ABS / PC Blend

GRP Polyester

ABS / PC Blend
Epoxy Adhesive

Araldite 2022-1: toughened 2-component Methacrylate adhesive

Metal inserts into CFRP Hulls of racing boats

Specification:
- Fast cure
- Toughened with excellent impact and fatigue resistance
- Gap filling and sag resistant
Epoxy Adhesive

Araldite AW 4858 / Hardener HW 4858

Epoxy laminate to anodised aluminium brackets

Specification:

- Elevated temperature cure
- Toughened with excellent impact and fatigue resistance
- Gap filling and sag resistant
- Resistant to a range of chemicals including salt solutions
Epoxy Adhesive

Araldite AW 4859 / Hardener HW 4859: Composite Bonder

Carbon Bike
PA66 connecting parts to CFRP

**Specification:**
- High flexural strength
- High fatigue resistance
- Temperature resistance up to 70°C
Epoxy Adhesive

Araldite AW 4859 / Hardener HW 4859: Composite Bonder

Carbon Mast
CFRP to CFRP / Coaxial bonding

Specification:
- High flexural strength
- Service temperature up to 80°C
Araldite 2015-1 epoxy adhesive on the Aberfeldy and Dawlish bridges

Bonding components of first composite textile footbridge using high shear and peel epoxy
Paste bonding for very large structures

**Araldite AW 4856 / Hardener HW 4856**

- Non-slumping on vertical surfaces up to 40 mm
- Low exotherm and low shrinkage for thick bond lines
- Easy to pump
- Pot-life > 4 hours (500G)
Paste bonding for very large structures

Araldite AW 4856 / Hardener HW 4856
Paste bonding for very large structures

Araldite AW 4856 / Hardener HW 4856
Paste bonding for very large structures

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Paste bonding for very large structures

Araldite AW 4856 / Hardener HW 4856

1. MIXING AND APPLYING ADHESIVE ON UNDER PART IN THE MOULD
2. APPLYING ADHESIVE ONTO THE BONDED AREAS & ASSEMBLING ALL PARTS (SPAR, SHEAR WEB, …)
3. CLOSING MOULD, COMPRESSING & CURING
4. DEMOULDING & FINISHING
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