

# Aluminium solutions for heat exchangers

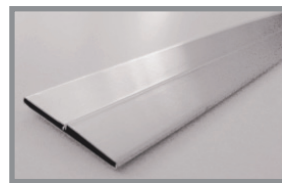
Aluminium alloys are increasingly used in the manufacture of automotive heat exchangers. The reason is simple: rolled aluminium products have many properties that make them ideal for thermal transfer applications, while being economic and efficient to produce.

Attentive to customer needs, we ensure our heat exchanger products and solutions are designed for optimal brazability.

## Advantageous properties for light-weight thermal transfer

From thick plate to thin tube, rolled products for heat exchangers, such as those offered by Constellium have a high thermal conductivity that optimizes the heat transfer process. Low in density, they have the requisite strength for automotive needs, notably at raised temperatures.

Aluminium rolled products also have good formability and excellent corrosion resistance properties, critical for the production of high-quality heat exchanger parts. What's more, by allowing highly automated and reliable heat exchanger manufacturing processes, aluminium rolled products drive greater efficiencies in production.



## End-uses for heat exchangers in automotive

Aluminium rolled products can be found in a variety of automotive heat exchangers.

- ▶ Unclad fin stock for radiators, charge air coolers, heaters, and more
- ▶ Clad fin stock for condensers
- ▶ Clad header plates and side plates for various types of heat exchangers
- ▶ Clad strips for welded or folded tubes for radiators
- ▶ Clad plates for evaporators and oil coolers.

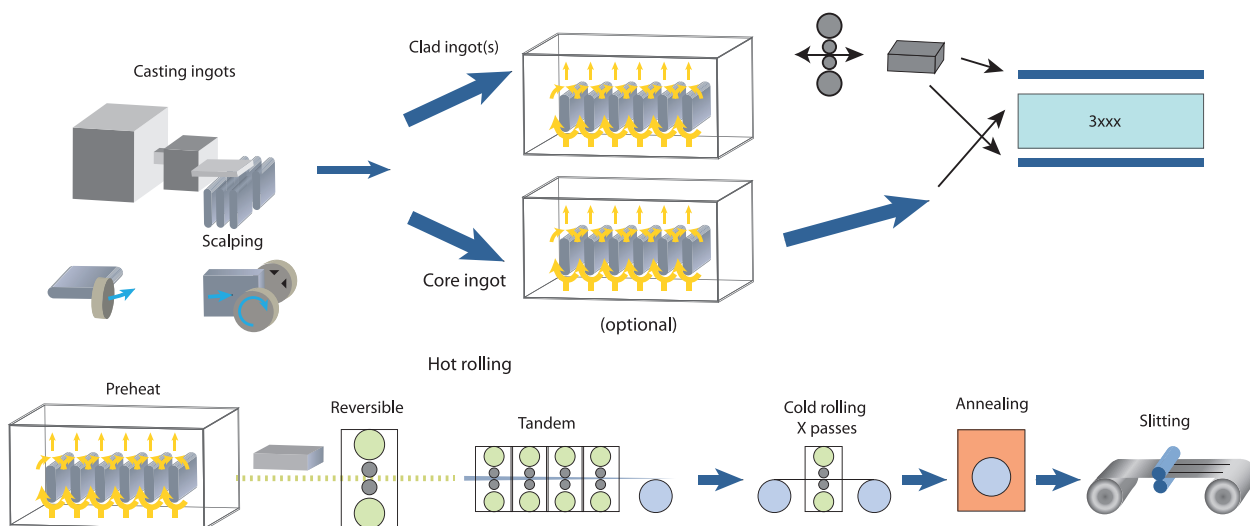


These are integrated into automotive end-products including:

- ▶ Engine cooling parts, such as radiators
- ▶ Condensers and evaporators for air-conditioning systems
- ▶ Oil cooling parts, for oil used in engine lubrication, transmission systems and power steering
- ▶ Heaters
- ▶ Charge air coolers (CAC), exhaust gas and fuel cooling, including water CACs.

## Clad brazing sheet for greater thermal conductivity and corrosion resistance

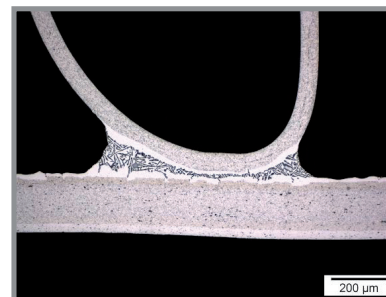
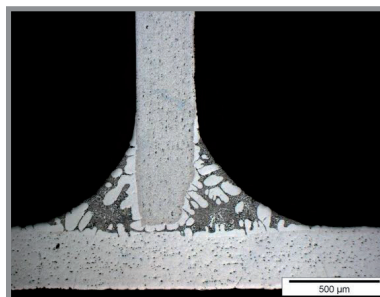
Constellium uses a cladding process to ensure best brazability and corrosion resistance. Under this process, separate slabs of core and clad material are hot and cold rolled together.



Brazability is a key feature of our heat exchanger products and solutions. Brazing, a customer process that creates a metallurgical bond between tube and fin, has a positive impact on several performance measures.

Most importantly, the process eliminates contact resistance between the tube and fin, significantly improving heat conduction.

The majority of aluminium heat exchangers for automotive applications are today produced by controlled atmosphere brazing.



*Fin/plate bonding after brazing*

# Constellium's heat exchangers offer

Constellium has a comprehensive portfolio of innovative heat exchanger products that meet the evolving needs of our automotive customers.

## Core and clad alloys

Robust, standardized and spanning a variety of thicknesses, our heat exchangers portfolio features a combination of core and clad alloys. These are purpose-designed for end uses in radiators, condensers and evaporators for air-conditioning, oil cooling systems and more.

At the same time, our new generation of multi-clad, KOOL X™, is pushing the boundaries of our product capabilities in terms of corrosion and fatigue resistance.

Constellium's broad offer allows for the combination of any core alloy with any clad alloy in a variety of thicknesses.

core		Si	Fe	Cu	Mn	Mg	Zn	Ti
	3003	≤0,6	≤0,7	0,05-0,2	1-1,5	≤0,02	≤0,2	≤0,2
	3916	≤0,3	≤0,3	0,5-1	1-1,5	≤0,02	≤0,2	≤0,2
	3915	≤0,3	≤0,3	0,6-1	1-1,5	0,1-0,25	≤0,2	≤0,2
clad	4343	6,8-8,2	≤0,6	≤0,25	≤0,1	≤0,05	≤0,1	≤0,1
	4045	9-11	≤0,6	≤0,25	≤0,1	≤0,05	≤0,1	≤0,1
	7072	≤0,7		≤0,1	≤0,1	≤0,1	0,8-1,3	≤0,1
	7972	≤0,7		≤0,1	≤0,1	≤0,1	2-5	≤0,1

# Excellent technical capabilities and mechanical properties

Aluminium makes an ideal material for heat exchanger components due to its enviable technical capabilities and mechanical properties. These include high thermal conductivity, low density, strength at raised temperatures, and corrosion resistance.

### Typical technical capabilities:

- ▶ H24 Temper (tubestock)
  - Thickness 0.2-0.6 mm
  - Width 28-200 mm
- ▶ O Temper (evaporator, header, end-plate...)
  - Thickness 0.25-3 mm
  - Width 100-800 mm

### Typical cladding:

- ▶ From 5% to 15%
- ▶ 1 side, 2 sides or 2 sides + interlayer(s)

## Typical mechanical properties

### ▶ O Temper

	UTS (MPa)	YS (MPa)	E%
3003	90-140	>30	>25
3916	110-170	>40	>20
3915	130-190	>50	>15

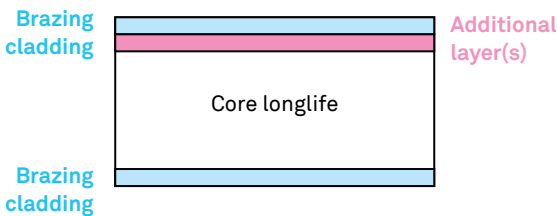
### ▶ H24 Temper

	UTS (MPa)	YS (MPa)	E%
3003	130-190	>110	>2
3916	160-240	>140	>1
3915	180-260	>150	>1

### ▶ Post brazing typical values (brazing simulation 10 mins at 600°C)

	UTS (MPa)	YS (MPa)	E%
3003	116	39	32
3916	153	56	21
3915	166	60	20

## Increased corrosion resistance



Constellium has developed a new range of multi-clad solutions. The KOOL X™ range features significant increase in key properties (greater corrosion, strength or fatigue resistance) when compared to standard monoclاد material.

# A commitment to relentless innovation

Constellium's portfolio of heat exchanger products and solutions reflects our tireless commitment to research, technology and innovation. But most importantly, it testifies to our understanding of automotive OEM needs and latest trends in heat exchanger technology.

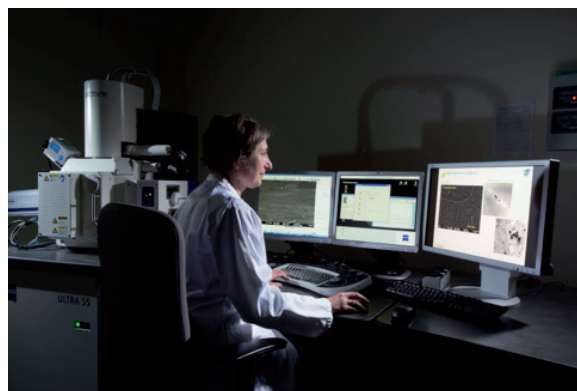
## Responding to trends in heat exchangers

The automotive sector is in constant evolution. Constellium develops heat exchanger products that meet automotive manufacturer needs, be it for customer, design, or environmental reasons.

### ► Light-weighting by down-gauging

As the number of heat exchangers used in modules increases, so too does the need to be smaller and lighter.

New cladded solutions resistance have allowed us to down-gauge heat exchanger parts with improved corrosion resistance and aluminium's other enviable properties.



### ► Improved fatigue and corrosion resistance

Heat exchangers that can better withstand fatigue and corrosion can improve the lifespan of a vehicle, as well as the number of years guaranteed to automotive manufacturers.

The advances achieved in thermal fatigue resistance respond to automotive trends for stop-start technologies, which have increased the frequency of thermal cycles in heat exchangers.



# Unique capacities for new product development

At Constellium's C-TEC technology center, Western Europe's largest research facility dedicated to aluminium and alloys, our 260 experts use latest equipment and knowledge to improve heat exchanger design. Such innovation has made it possible to develop our latest generation of multi-clad products, KOOLX™, a range that is today pushing the capabilities of heat exchangers in terms of corrosion and fatigue resistance.

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|--|--|
| <ul style="list-style-type: none"> <li>▶ Recycling and molten metal processing</li> <li>▶ Casting and solidification</li> <li>▶ Physical and mechanical metallurgy</li> <li>▶ Surface treatment, coatings and corrosion</li> <li>▶ Process modeling (rolling, finishing, extrusion)</li> <li>▶ Product modeling and design               <ul style="list-style-type: none"> <li>- Integrated metallurgical modeling of alloys</li> <li>- Structural application design, e.g. aerospace</li> </ul> </li> <li>▶ Joining &amp; forming</li> </ul> | <ul style="list-style-type: none"> <li>▶ Physical materials characterization &amp; testing, chemical analysis and microstructural characterization, e.g.:               <ul style="list-style-type: none"> <li>- Non-destructive, phased array ultrasonic testing</li> <li>- Large scale tensile and fatigue testing rig (2500kN)</li> </ul> </li> <li>▶ Prototype at industrial scale, e.g.:               <ul style="list-style-type: none"> <li>- Friction stir welding</li> <li>- Breakthrough AIRWARE® pilot casthouse</li> </ul> </li> </ul> |
|--|--|

## Our technical center capabilities with specific competencies in heat exchangers

### Prototyping on sheets

- ▶ Casting (small ingots)
- ▶ Clad rolling prototyping (hot and cold rolling)
- ▶ Heat treatments
- ▶ Brazing lab equipment, including a double wall Camlaw furnace, and double wall transparent furnace ▶

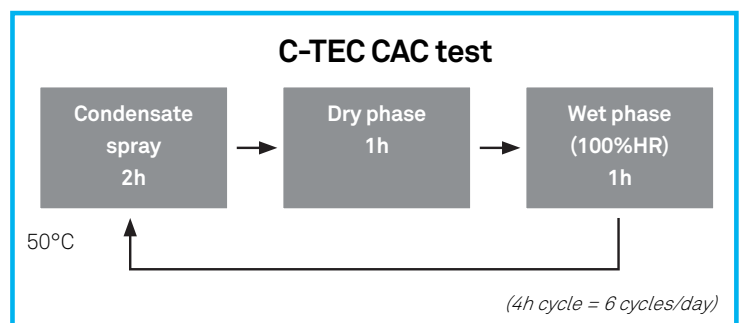
### Characterization

- ▶ Corrosion tests (SWAAT, OY, and internal tests to simulate charge air cooler conditions)
- ▶ Fatigue tests
- ▶ Mechanical tests (tensile and formability)
- ▶ Microstructure analysis (optical microscope, SEM, TEM, microprobe)

- ▶ **Numerical simulation** to improve the forming process at customer plants.

### ▶ Durability Test Reproduction & Conception

Constellium has strong competency in corrosion tests applied to heat exchangers. It has developed a specific Charge Air Cooler corrosion test performed in a climatic chamber with a synthetic condensate simulating the exhaust gas condensate formation and combining a wet and a dry cycle in order to be realistic compared to the in service situation.



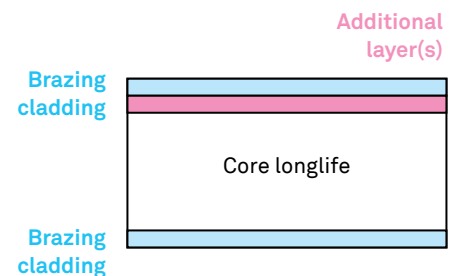
- ▶ Basic synthetic condensate:  $H_2SO_4 + HNO_3$  equi-molar
- ▶ Investigated condensates:
  - pH 2.5 → 1
  - Cl<sup>-</sup>: 100 → 1000ppm

# Introducing KOOL X™, developed for demanding applications

Constellium is committed to continuously developing the technology behind our heat exchangers offers and solutions.

## KOOL X™, a new generation of aluminium multi-clad for heat exchanger applications

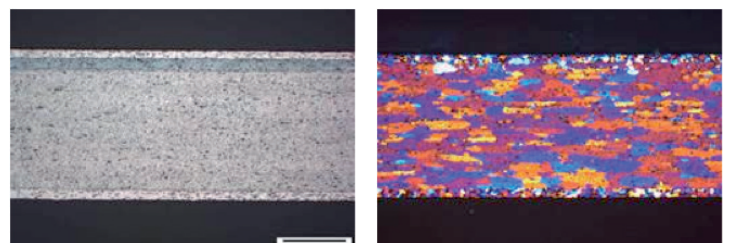
Designed with exceptional corrosion resistance, the KOOL X™ range is ideal for demanding applications such as water charge air coolers (CAC), air CACs, and evaporators. CACs work to cool down exhaust gas to be recycled inside the vehicle. Generally situated very close to the motor, they require higher corrosion resistance than other types of heat exchangers. Our new multi-clad KOOL X™ solutions have been developed to address these specific needs.



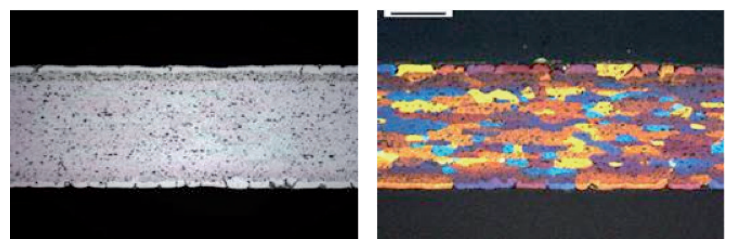
### Multiple layers for greater resistance

Multi-cladding consists of adding one or several additional layers to the traditional 3-layer cladding solution. This adds greater corrosion resistance while retaining the necessary brazability.

O-temper (before brazing)



After brazing



## Technical properties

Superior in its performance against traditional monoclاد, KOOL X™ has advantageous technical properties that include:

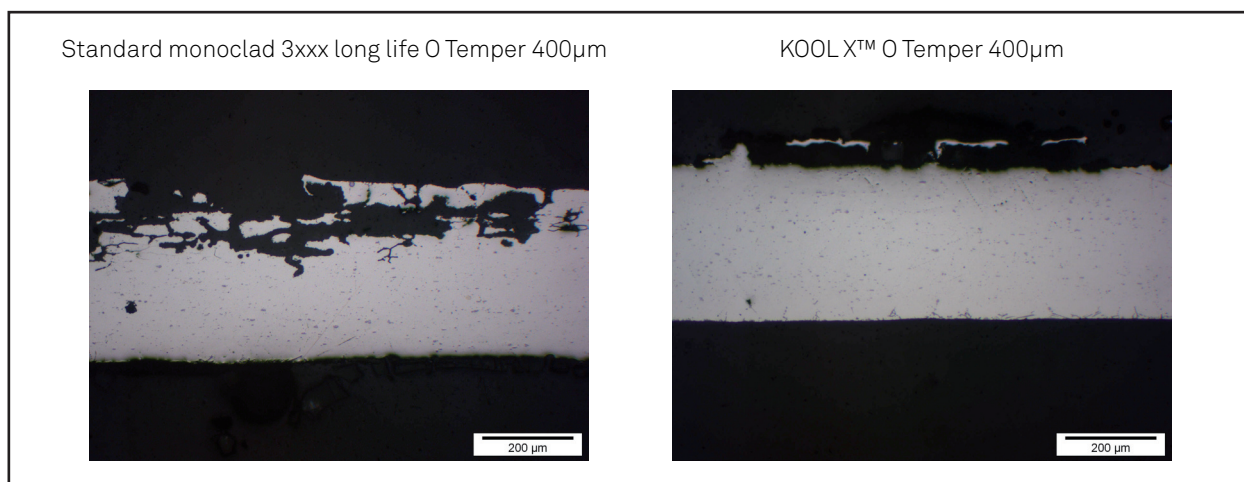
- ▶ Good brazability
- ▶ Improved fatigue resistance
- ▶ Superior corrosion resistance

## Proven performance

The advanced capabilities of KOOL X™ have been validated in standard industry tests along with Constellium's own analysis at our leading C-TEC technology center, Western Europe's largest research facility dedicated to aluminium and alloys.

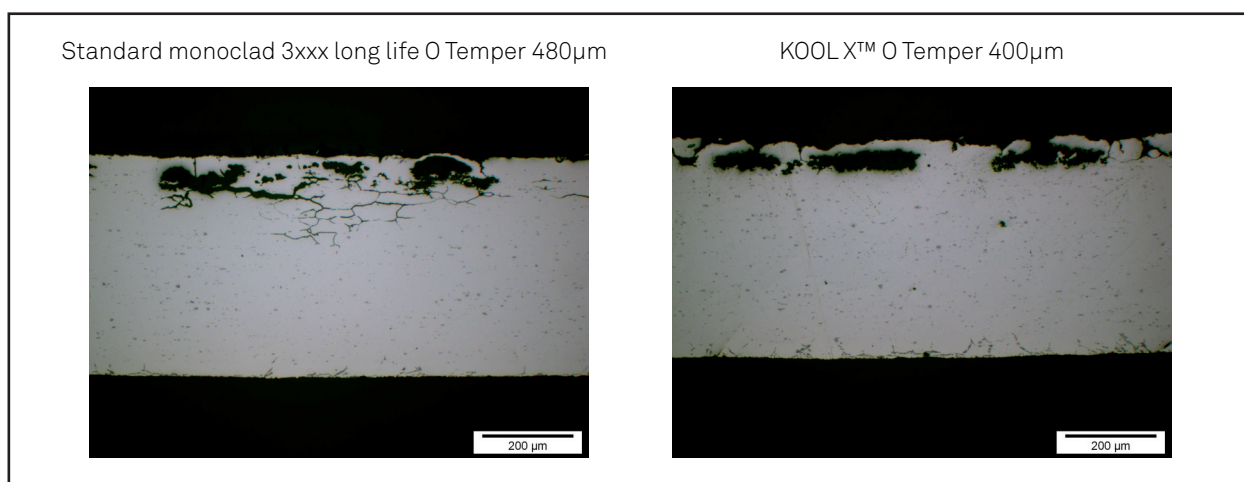
Constellium conducted trials with SWAAT test or simulating CAC conditions on different materials, and KOOL X™ significantly outperformed standard monoclاد materials.

- ▶ In separate seawater accelerated tests (SWAAT), KOOL X™ resistance is better than for 3-layer material. Photos below illustrate through thickness corrosion after 30 days of SWAAT (separate seawater accelerated tests) exposure with 3-layers or KOOL X™ material.



*Cross sections after a 30 days SWAAT exposure*

- ▶ For a CAC test (pH2, 100ppm Cl synthetic condensate and 4-weeks' exposure), KOOL X™ significantly outperformed standard 3-layer material.



*Cross sections after 4 weeks internal CAC corrosion testing (pH2, 100ppm Cl - synthetic condensate)*

## Next generations in development

Our KOOL X™ range is undergoing development as we explore how different compositions, processes and architectures can take its advanced properties even further in areas such as:

- ▶ Corrosion resistance (SWAAT or specific CAC conditions)
- ▶ Mechanical properties, by improving core material
- ▶ Thermal fatigue resistance