

## METALLOGRAPHIC PREPARATION

# ALUMINUM

### INTRODUCTION

Aluminum is a fairly recent metal compared to iron or copper, given that it appeared in the second half of the 19th century. Aluminum does not exist pure in nature. It exists in the form of ores, the best known being bauxite. Today it is one of the most widely-used metals in industry in the world after steel. This element is one of the most abundant in the earth's crust.

#### ALUMINUM

Symbol: **Al**

Atomique n°: **13**

Density: **2,7**

Molar mass: **27 g.mol<sup>-1</sup>**

Melting point: **660°C**

**Aluminum is manufactured in several stages:**

- First of all there is the extraction of the Bauxite ore (contains 60% aluminum oxide  $Al_2O_3$ , 20-30% iron oxide  $Fe_2O_3$  and silicon oxide  $SiO_2$  and titanium oxide  $TiO_2$  in smaller quantities).

- The bauxite is then transformed into alumina using caustic soda, at high temperature and under high pressure.

- The previously-alumina obtained is dissolved in a cryolite bath, and an electric current is passed through the tank. This operation, known as electrolysis, allows aluminum to be collected at the cathode.

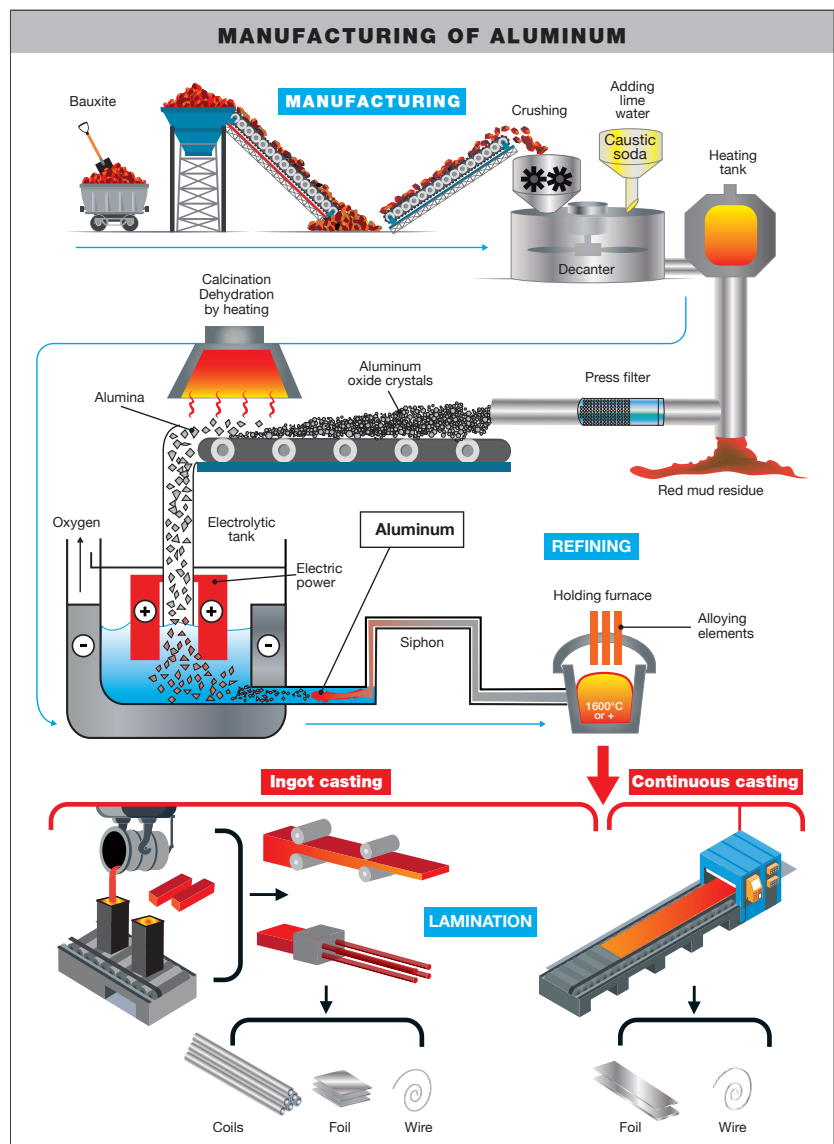


Fig. 1: Aluminum processing

Aluminum is a metal that can be recycled infinitely without losing its physical and chemical properties. Aluminum recycling is a less energy-intensive process than producing primary aluminum (extracted from bauxite).

**Alloying elements are used to improve aluminum’s properties:**

- Magnesium improves corrosion resistance.
- Silicon increases the malleability of the alloy in the foundry.
- Copper hardens aluminum
- Zinc and manganese are also key additional elements in the production of aluminum alloys

**There are two main families of aluminum:**

**WROUGHT ALUMINUM**

Wrought aluminum (which undergoes hot deformation) is cast into slabs or billets and is then transformed via a hot process by rolling, forging, extrusion, etc.

The most commonly-used name for wrought aluminum is a 4-digit reference (NF EN 573-1), preceded by EN AW.

**The first digit** determines the alloy group to which the aluminum belongs.

**The 2<sup>nd</sup> digit for group 1** corresponds to any impurities contained in the aluminum.

**The 2<sup>nd</sup> digit for the other groups** corresponds to changes in the alloy’s chemical composition.

**The 3<sup>rd</sup> and 4<sup>th</sup> digits** for group 1 alloys depict the percentage above 99% and for the other groups, to identify an alloy in its group.

Example: EN AW - 2024 is an aluminum alloy with 4% copper and 1.5% magnesium. (The W (wrought) refers to a wrought alloy).

Group	Aluminum or Alloy
1	Aluminum (content ≥ 99.00%)
2	Aluminum - copper
3	Aluminum - manganese
4	Aluminum - silicon
5	Aluminum - magnesium
6	Aluminum - magnesium-silicon
7	Aluminum - zinc
8	Other aluminum alloys

Table 1: Aluminum alloy groups

**FOUNDRY ALUMINUM**

Casting aluminum is cast in moulds from which the finished product is recovered after cooling. Few reworkings are carried out on the castings. These parts are intended for the automotive and aeronautics industries, handling equipment manufacturing, etc.

The foundry aluminum name refers to the NF EN 1780-1, -2 and -3 standards.

The numerical identification is a series of 5 digits, the first of which refers to table 1 of wrought alloys. The last 3 digits depict the chemical

Example: EN AC - 42000 is an aluminum alloy with 7% silicon with traces of magnesium.

The symbolic identification includes chemical symbols of the alloy additions and their respective mass contents after the letters EN AC (C corresponding to «cast» for cast alloy).

In the previous example this gives: EN AC - AlSi7Mg

Finally, standard NF EN 1706 indicates the chemical composition limit of each alloy as well as the mechanical characteristics of these cast alloys.

## SURFACE TREATMENTS OF ALUMINUM

Aluminum can undergo two surface treatments:

### ANODIZING

This is a surface treatment that creates a layer by conversion of  $\text{Al}_2\text{O}_3$  to protect and/or decorate an aluminum part. Sulphuric anodizing is the most commonly used. The part is placed in a sulphuric acid bath as an anode. The alumina layer forms according to the following reaction:



This layer is porous. A sealing step in boiling water closes the alumina layer's pores. An intermediate colouring stage can be performed before sealing.

Some aluminum alloys have been specially developed for this treatment and anodization thickness can range from 5-50 $\mu\text{m}$ .

This surface treatment improves corrosion resistance and is also used for aesthetic purposes.

### POWDER COATING

Also known as electrostatic powder coating, powder coating is a process that allows powder paint to be spray-applied. The powder is positively charged by an electric field while the part is connected to the negative charge. Final kiln curing polymerises the paint and permanently fixes it to the part. This process gives the part good anti-corrosion properties, good durability and a good final appearance.

## BENEFITS AND APPLICATIONS OF ALUMINUM AND ITS ALLOYS

Aluminum and its alloys have many qualities:

- Mechanical resistance: this is improved by the addition of alloy additions to the aluminum.
- Corrosion resistance: a layer of oxides forms naturally on aluminum and protects it from corrosion. The anodizing surface treatment can further improve corrosion resistance.
- Very good thermal and electrical conductivity: this is why aluminum is often used for heat dissipation applications. The electrical conductivity of aluminum is 65% of that of copper.
- Lightness: particularly appreciated in aerospace and aeronautics, this characteristic is very important in these fields.
- Impermeability: aluminum does not allow light, odours or micro-organisms to pass through. This is why it is used for food and pharmaceutical packaging.

Aluminum is used in aerospace construction and the automotive industry.



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Aluminum is also widely used in the food and pharmaceutical industries.



In the building sector, aluminum is widely used for the manufacture of windows, bay windows, profiles on external facades, etc.

## METALLOGRAPHIC PREPARATION

Obtaining an inspection surface requires a succession of operations, each one as important as the next and this regardless of the material. These operations come in this order:

- Removal of the product to be examined (if necessary), called «CUTTING».
- Standardisation of the geometry of the sample taken (if necessary), called «MOUNTING».
- Improvement of the surface condition of this sample, called «POLISHING».
- Sample characterisation: to reveal the microstructure of the sample by an etching reagent (if necessary) called «METALLOGRAPHIC ETCHING» and microscopic observation (optical or electronic).

=> Each of these steps must be carried out rigorously, otherwise the following steps will not be possible.

## CUTTING

The purpose of cutting is to remove a precise section of a product, in order to obtain a suitable surface for inspection, without altering the physico-chemical properties of the aluminum. In other words, it is essential to avoid heating or any deformation of the metal that could lead to degradation of the material. Cutting is a fundamental step which conditions the further preparation and inspection of parts.

PRESI's wide range of medium and large capacity cutting and micro-cutting machines can be adapted to any need with regard to cutting precision, sizing or quantity of products to be cut:



Fig 2: MECATOME T202



Fig 3: MECATOME T330

Each of the cutting machines in the range has its own customised consumables and accessories. The clamping system and choice of consumables are key factors in a successful metallographic cut.

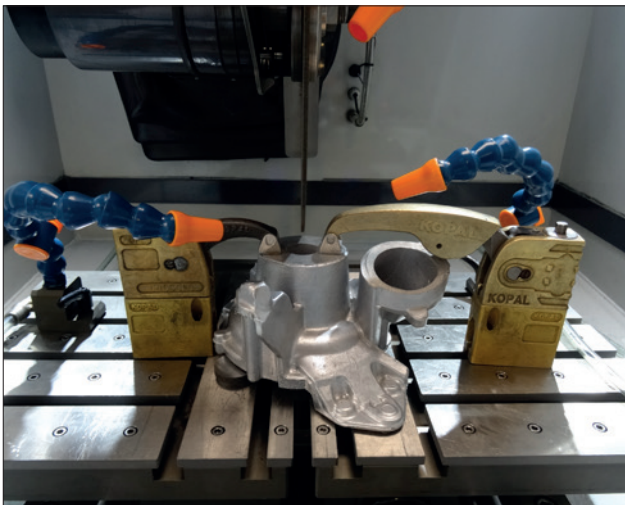


Fig. 4: Turbo clamping - EVO 400

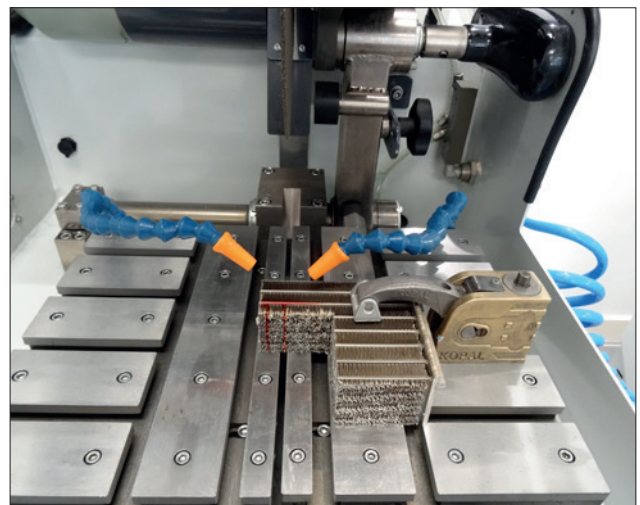


Fig. 5: Intercoler clamping - ST310

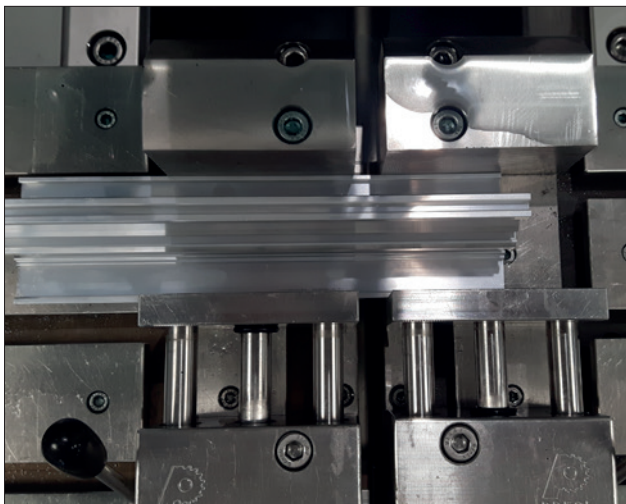


Fig. 6: Profile clamping - T330

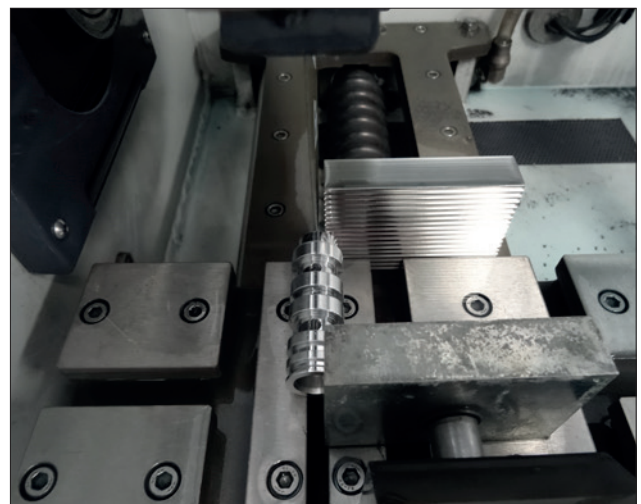



Fig. 7: Turning part clamping - T210

=> Clamping, i.e. holding the workpiece, is essential. If the workpiece is not held properly, the cut can be detrimental to the cut-off wheel, the workpiece and the machine.

In the previous figures, different clamps are used depending on the geometry of the parts to be cut. In the present cases, Kopal clamps and quick-action vices were used. All of these clamping means can be adapted to the various cutting machines (in the examples above: Mecatome ST310, EVO 400 and Mecatome T330 or Mecatome T210).

## CONSUMABLES

All cutting machines are used with a lubricating/cooling liquid composed of a mixture of water and anti-rust additive in order to obtain a clean cut without overheating. The additive also protects the sample and the machine from corrosion.



	ALUMINUM AND ITS ALLOYS
Micro-cutting	MNF UTW S (Ø 180mm) C
Medium-capacity cutting	MNF
High-capacity cutting	MNF

Table 2: Choosing the right cut-off wheel type

=> The choice of the cut-off wheel type has to be adequate, in order to avoid cutting failure, or excessive cut-off wheel wear or even breakage. The hardness of the workpiece determines the wheel selection.

## MOUNTING

Samples can be difficult to handle due to their complex shape, fragility or small size. Mounting makes them easier to handle by standardising their geometry and dimensions.

Achieving good-quality mounting is essential to protect fragile materials and also to achieve good preparation results for polishing and future analysis.

Before mounting, the specimen should be deburred with coarse abrasive paper, for example, to remove any cutting burrs. Cleaning with ethanol (in an ultrasonic tank for even greater efficiency) is also possible. This allows the resin to adhere as well as possible to the sample and thus limits shrinkage (space between the resin and the sample).

If shrinkage persists, it can lead to problems during polishing. Abrasive grains may become lodged in this space and then be released at a later stage, thus creating a risk of pollution for the sample and the polishing surface. In this case, cleaning with an ultrasonic cleaner between each step is recommended.

There are two mounting options:

• **HOT MOUNTING** is to be preferred for edge inspection purposes or if the metallographic preparation is carried out in preparation for hardness testing. **This option requires a hot-mounting machine.**



Fig 8: MECAPRESS 3

The machine required for hot-mounting is the Mecapress 3:

- Fully automatic hot-mounting press.
- Easy to use: memorisation, adjustment of processes and speed of execution make it a high-precision machine,
- The hot-mounting machine has 6 different mould diameters from 25.4-50mm.

### + POINT

One of the main advantages of this process is that it provides perfectly parallel faces.

- **COLD MOUNTING** is to be preferred:
- If the parts to be examined are fragile/sensitive to pressure
- If they have a complex geometry such as a honeycomb structure.
- If a large number of parts are to be mounted in series.

The cold process can be used with:



Fig 5: Pressurized mounting device

### + POINT

Substantially improves quality, in particular by reducing shrinkage, optimising transparency and facilitating resin impregnation.



Fig 6: Vacuum mounting device:  
POLY'VAC

### + POINT


Machine allowing vacuum impregnation of porous mounted materials using an epoxy resin.

Cold resins do not always provide a flat mounting “back” because of the meniscus of the liquid resin. Before any polishing operation, a brief step using abrasive paper will remove this meniscus. The important thing is to ensure that this operation renders the two sides of the mounting parallel.

## CONSUMABLES

To meet user needs, PRESI offers a full range of cold mounting moulds.

The cold process has different mounting moulds with diameters from 20-50mm. These are divided into several types: optimised moulds called «KM2.0», rubber, Teflon or polyethylene moulds. Cold mounting is also more flexible, hence the existence of rectangular moulds for more specific needs.



	ALUMINUM AND ITS ALLOYS
Hot process	Phenolic Allylic
Cold process	KM-U 2S IP

Table 3: Choosing the right mounting resin type

When mounting a «honeycomb» intercooler, it is advisable to combine the use of Poly'vac, which will help the resin to infiltrate into the sample, and subsequently a pressurized unit to maximize air bubble elimination.

When the hard anodizing layer is to be observed, the sample should be mounted using a low-shrinkage resin so as to be able to observe the anodizing layer as well as possible.

## POLISHING

The last and crucial phase in the sample preparation process is polishing. The principle is simple, each step uses a finer abrasive than the previous one. The aim is to obtain a flat surface and to eliminate scratches and residual defects that would hinder the performance of metallographic control examinations such as microscopic analysis, hardness tests, microstructure or dimensional inspections.

PRESI offers a wide range of manual and automatic polishing machines, with a wide choice of accessories, to cover all needs, from pre-polishing to super-finishing and polishing of single or series samples.

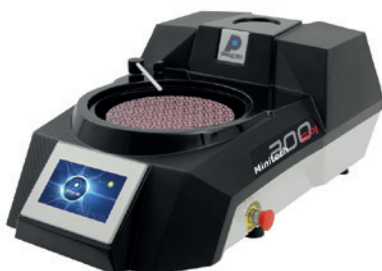


Fig 11: MINITECH 300 SP1



Fig 12: MECATECH 300 SPC

The **MINITECH range of manual polishers** incorporates the most advanced technologies. User-friendly, reliable and robust, they provide a simple answer to all needs.

The **MECATECH range of automatic polishers** allows both manual and automatic polishing. With its advanced technologies, motor power from 750-1500W, all the PRESI experience is concentrated in this very complete range. Whatever the sample number or size, MECATECH guarantees optimal polishing.

### CONSUMABLES AND POLISHING RANGES

All the polishing ranges below are given for automatic sample preparation (for manual polishing: do not take into account the parameters at the top). They are the most commonly used and are given for information and advice.

All the first steps of each range are called «levelling» and consist of removing material quickly to level the surface of the sample (and resin). Those given below are standard and can therefore be modified as required.

Applied pressures vary according to sample size, but in general the following applies: 1daN per 10mm mounting diameter for the pre-polishing steps (ex: Ø40mm = 4 daN) then reduce force by 0.5daN at each polishing step with an abrasive suspension.

The following is a general polishing range for **aluminum and its alloys**:

#### RANGE N°1

N°	Support	Suspension / Lubricant	Platen Speed (RPM)	Head Speed (RPM)	Rotation direction platen / head	Time
1	P320	Water / Ø	300	150	→ →	1'
2	TOP	9µm LDM / Reflex Lub	150	135	→ →	4'
3	RAM	3µm LDM / Reflex Lub	150	135	→ →	3'
4	NT	1µm LDM / Reflex Lub	150	135	→ →	1'
5	SUPRA	SPM / Water	150	100	← →	1'

**NB:** Levelling with P320 abrasive paper is enough for a sample from a metallographic cut. If more material removal is required, a larger grit-size should be used.

For pre-polishing, the head and plate rotation direction should not be reversed, as this can detrimentally affect flatness. However, reversing rotation direction can help if a large amount of material has to be removed.

Diamond polishing can be performed using a monocrystalline diamond suspension. But generally, a polycrystalline diamond solution also works (be careful of possible abrasive grains that can get stuck in the aluminum). This can be useful in the case of consumable rationalisation if aluminum is not the only material to be polished.

If abrasive grains become embedded in the material, it should be polished with the monocrystalline diamond suspension.

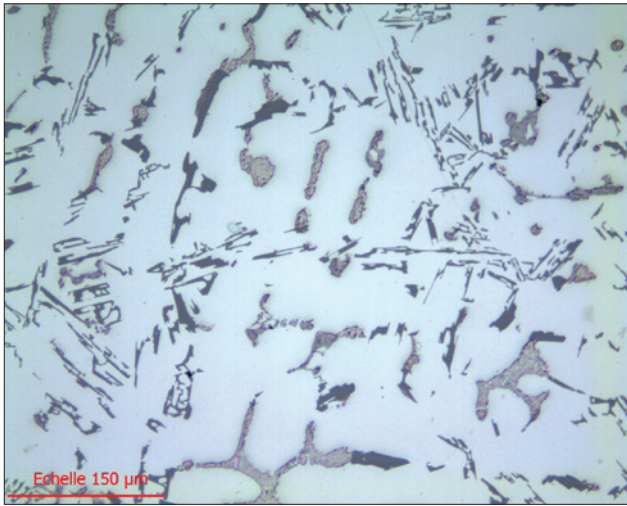


Fig. 13: SPM lensx20 finish

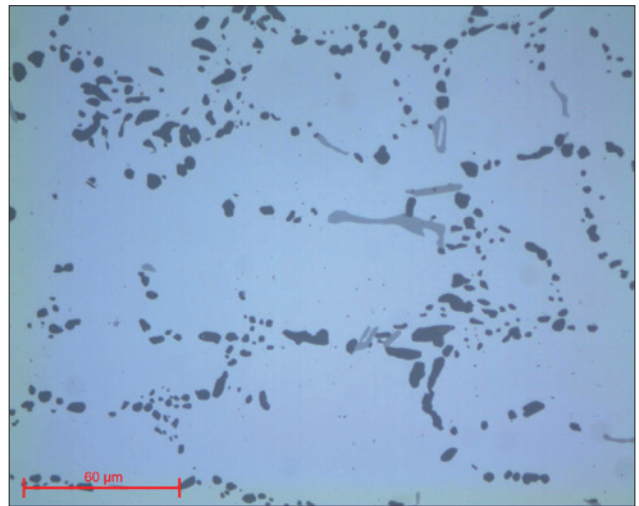


Fig. 14: SPM lensx50 finish

The most important part of polishing aluminum is superfinishing using a colloidal silica suspension (SPM). This SPM suspension can be diluted up to 7 times in water.

During this step, the rotation of the head is reversed in relation to the platen in order to keep the suspension on the polishing cloth as much as possible.

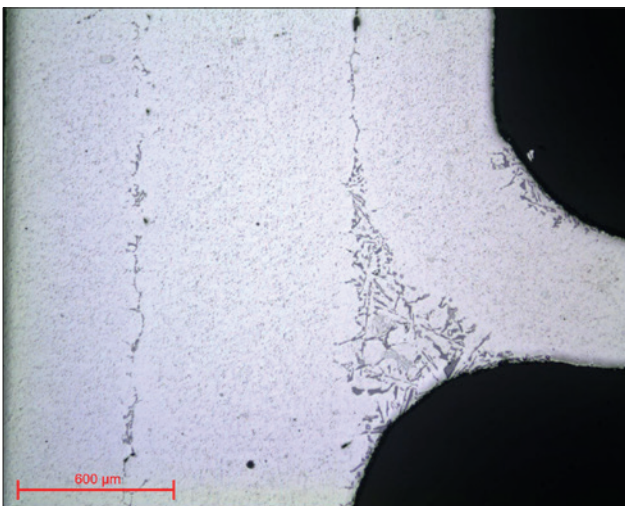


Fig. 15: Alu braze lensx5

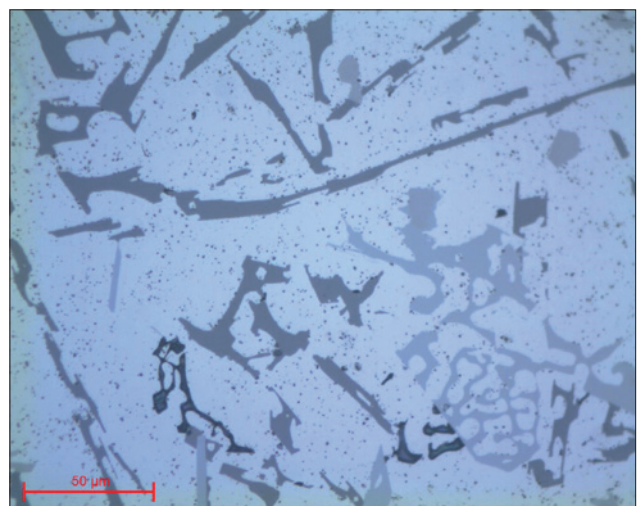


Fig. 16: Alu braze lensx50

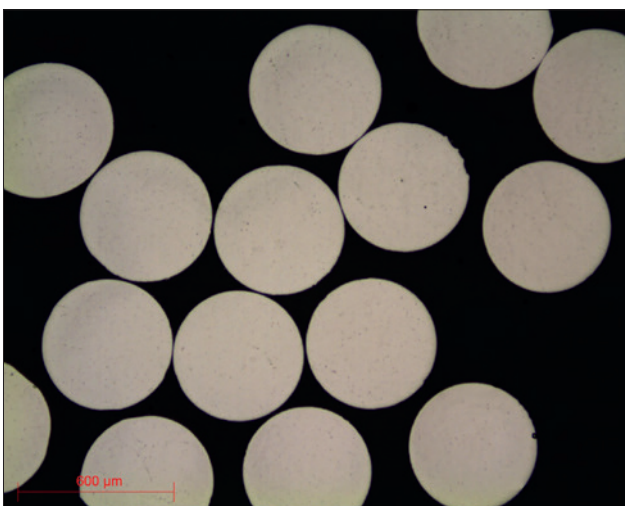


Fig. 17: Aluminum wire lensx5

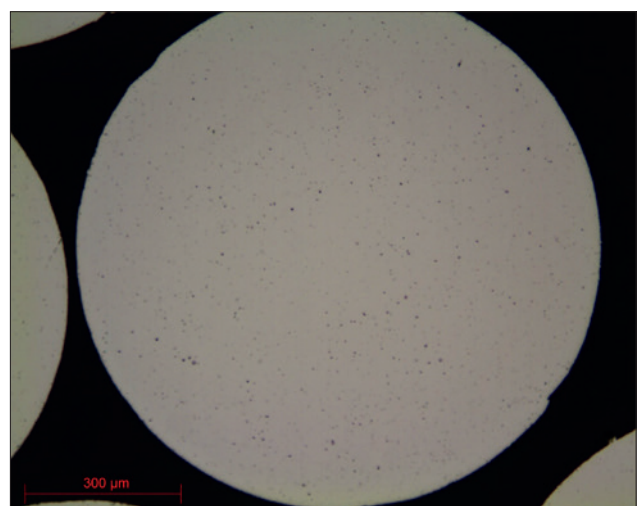


Fig. 18: Aluminum wire lensx10

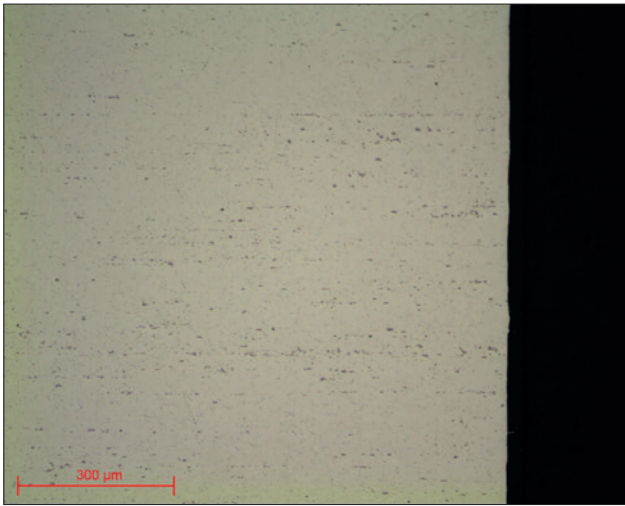


Fig. 19: Anodised aluminum lensx10

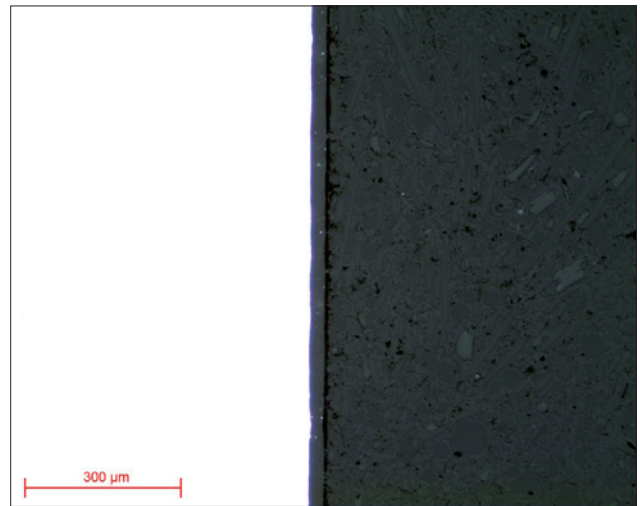


Fig. 20: Anodization lensx10

Figures 13-20, show the polishing result after using Range No. 1 on different aluminum samples.

A second polishing range can be used for polishing **aluminum and its alloys**:

#### RANGE N°2

N°	Support	Suspension / Lubricant	Platen Speed (RPM)	Head Speed (RPM)	Rotation direction platen / head	Time
1	P320	Water / Ø	300	150	→ →	1'
2	MED-R	9µm Diamond MED R / Ø	150	135	→ →	4'
3	RAM	3µm LDP / Reflex Lub	150	135	→ →	3'
4	NT	1µm LDP / Reflex Lub	150	135	→ →	1'
5	SUPRA	SPM / Water	150	100	→ ←	1'

This is an MED-R support which is used during the second stage of this range n°2. This polishing disc is composed of resin pads which maintain good flatness and replaces several polishing cloths.

A diamond suspension specially designed for MED-R is used on this support. This suspension combines diamond and lubricant.

For weld inspections, a third Range corresponds specifically to this type of inspection.

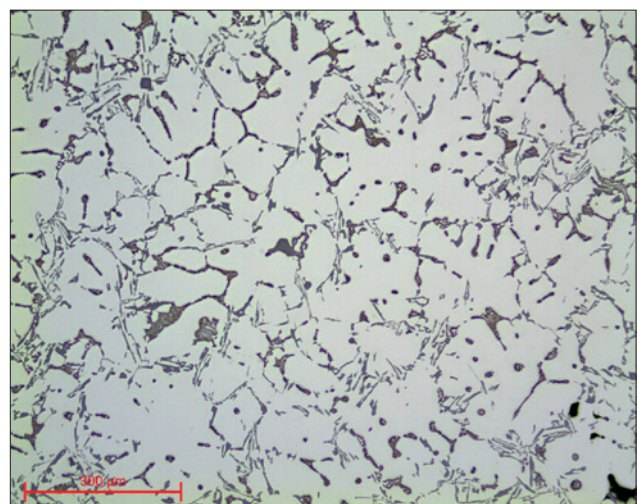


Fig. 21: SPM finish - Range MED-R lensx10

## RANGE N°3

N°	Support	Suspension / Lubricant	Platen Speed (RPM)	Head Speed (RPM)	Rotation direction platen / head	Time
1	P320	Water / Ø	300	150	→ →	1'
2	TOP	9µm Gel 2+ poly / Ø	150	135	→ →	4'
3	ADR II	3µm Gel 2+ poly / Ø	150	135	→ →	3'

This range consists of 3 steps, which is enough for observing the welds under a trinocular magnifying glass after etching with a reagent.

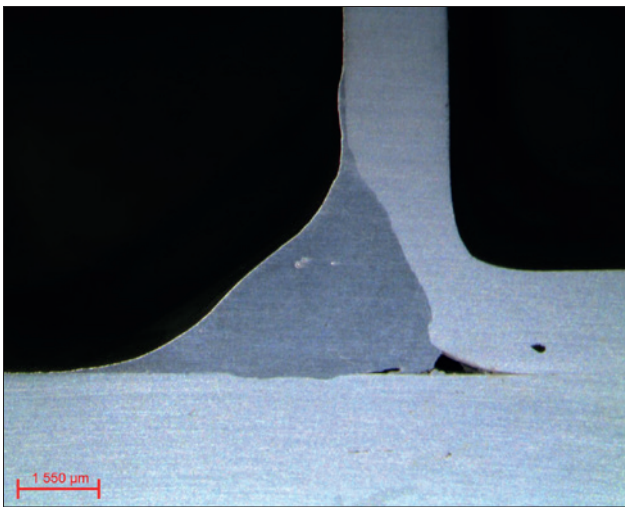


Fig. 22: Aluminum weld

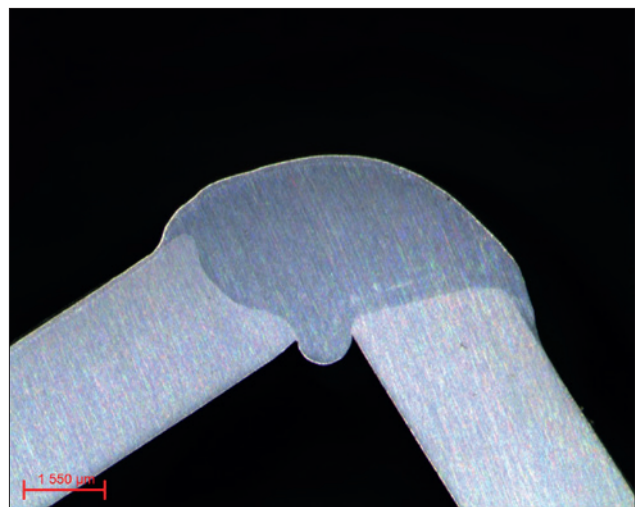


Fig. 23: Aluminum weld

The diamond suspensions used are Gel 2+ suspensions, i.e. the lubricant is already present in the suspension with the diamond. Polishing on uncoated workpieces is usually performed manually, so these 2-in-1 suspensions facilitate preparation for subsequent weld inspection.

## MICROSTRUCTURE

The structures of aluminum and its alloys can be revealed using various reagents such as Keller's reagent, Barker's reagent, soda solution or a hydrofluoric acid solution. All micrographs presented were created using the **PRESI VIEW** software:

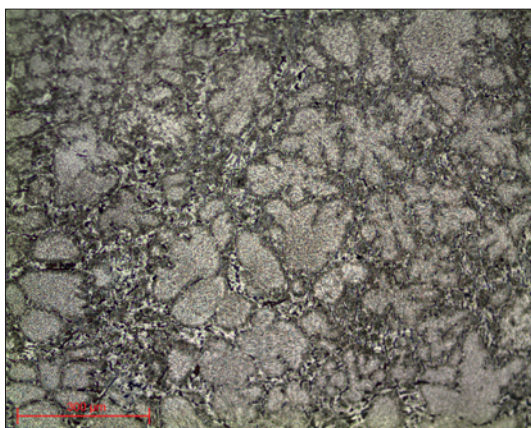


Fig. 24: Structure lensx10

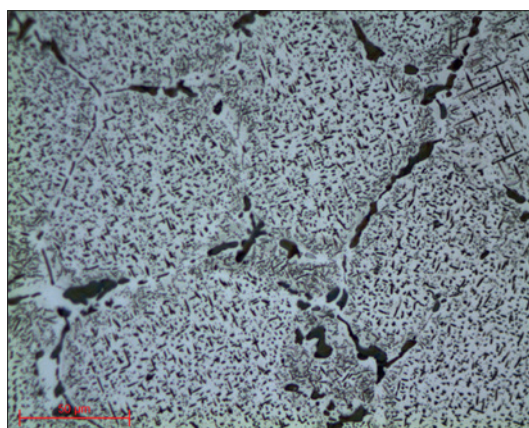


Fig. 25: Structure lensx50

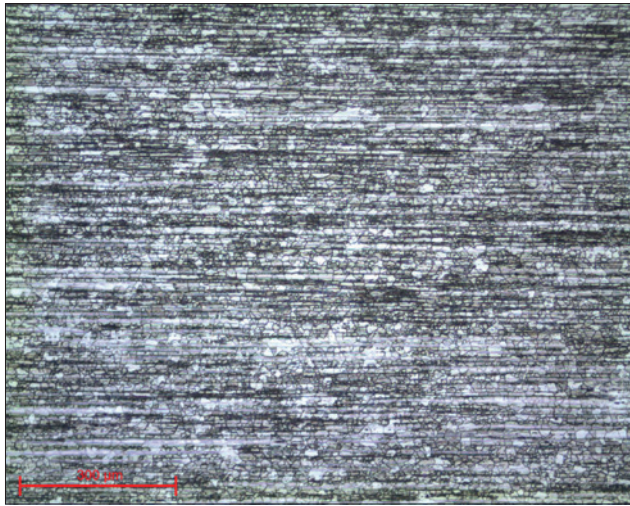


Fig. 26: Aluminum 2024 CS lensx10

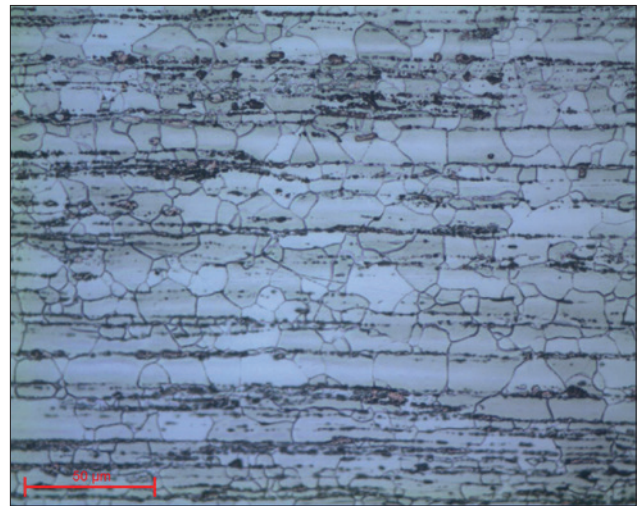


Fig. 27: Aluminum 2024 CS lensx50

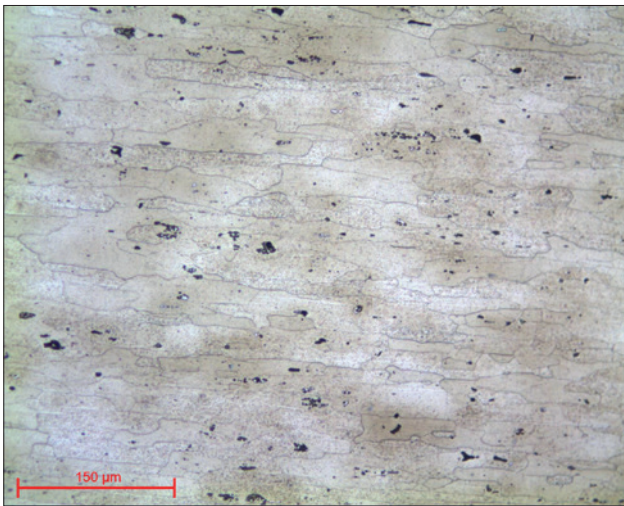


Fig. 28: Structure Aluminum lensx20



Fig. 29: Structure Aluminum lensx20

Figures 24 to 29 show different aluminum alloys whose structures were revealed using Keller's reagent.