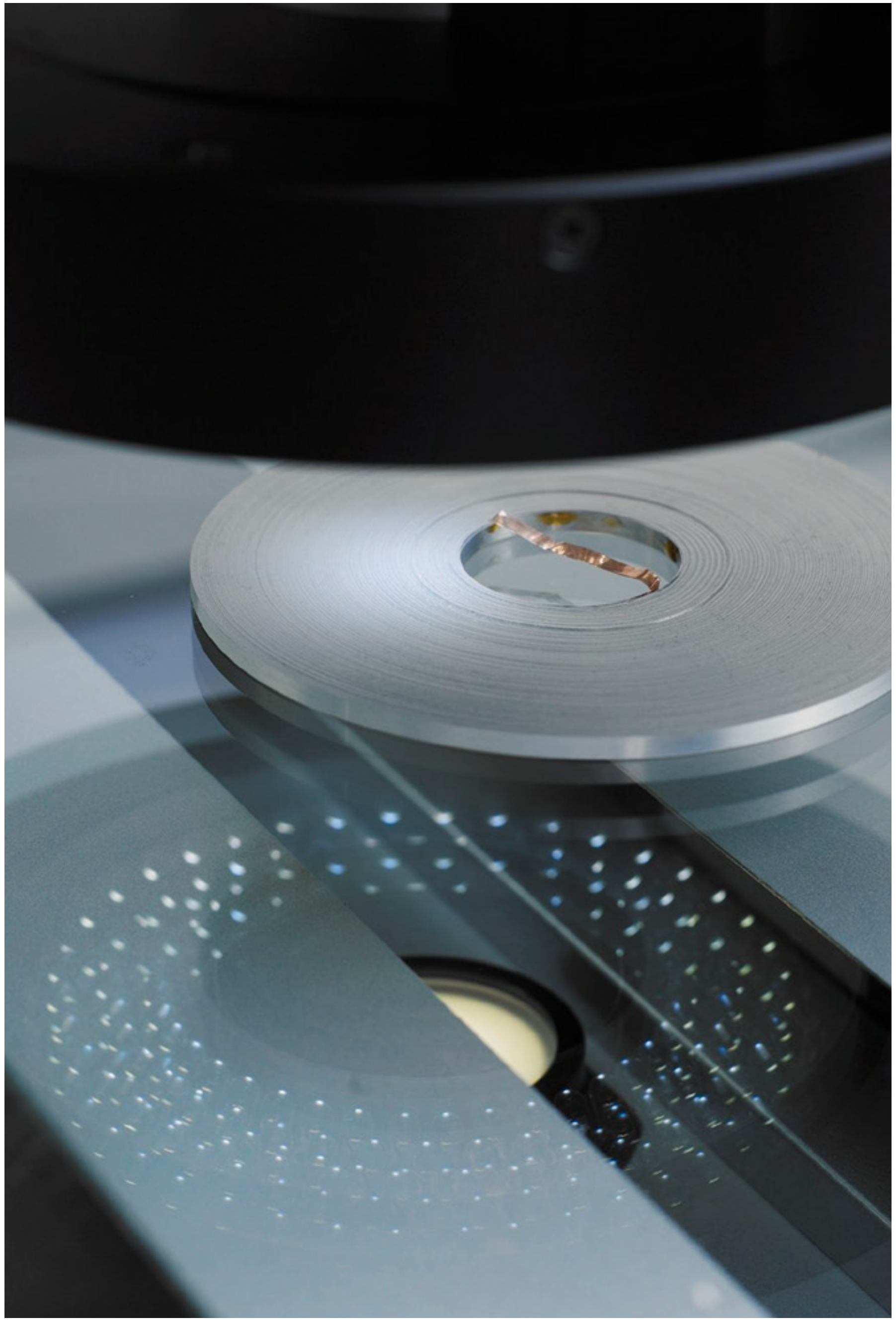
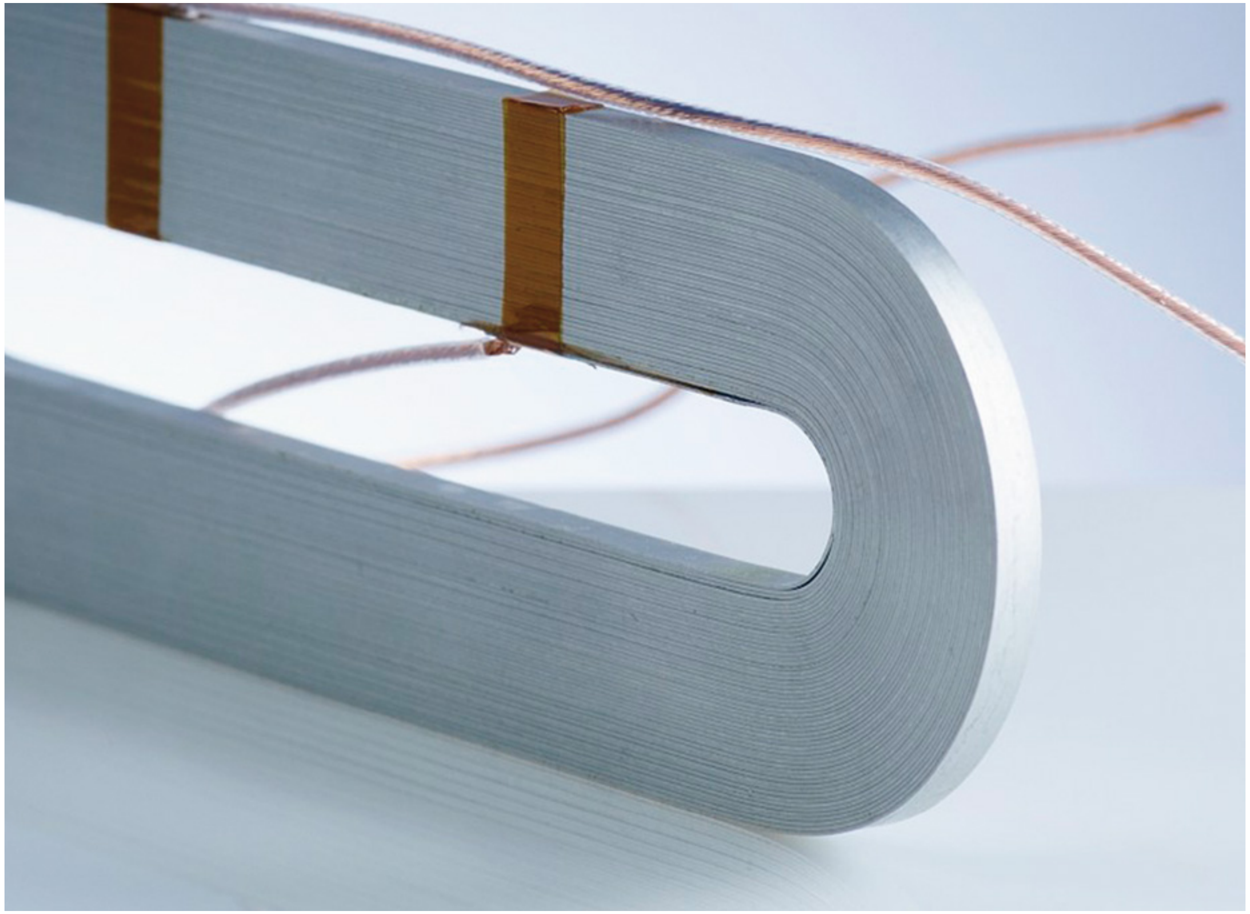




ANOFOL in Detail

Slitting, Anodizing & Winding Aluminum

Technical Advantages of ANOFOL Strip Coils

The characteristics of aluminum and its oxide permit the production of coils which possess a number of significant advantages over their copper wire counterparts.

Suitability for high temperature service

Since the oxide layer will not melt below 2000°C and aluminum has a melting point of 658°C, anodized aluminum coils can be used in continuous service at temperatures of 500°C. By contrast, copper wire requires special pre-treatment at temperatures over 180°C to protect the conductor from oxidation and, ultimately, disintegration. At operating temperatures exceeding 180°C, for instance, only silver or nickel-plated wire can be used, and the use of this plating does not yet resolve the insulation issue. Apart from the fact that few insulating materials are available for this temperature range at all, insulation volume will always remain a problem.

Superior heat dissipation

In a coil made of lacquered copper wire, the dissipation of heat from the center of the coil is significantly obstructed. The poor thermal conductivity of the insulation in conjunction with air inclusions may result in heat build-up that may ultimately destroy the coil. Coils made of anodized aluminum strip can dissipate heat from the center of the winding much faster, since every turn is itself part of the heat-emitting exterior surface.

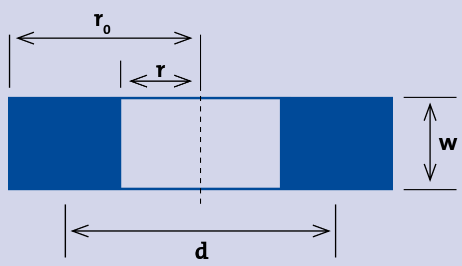
Lower operating temperature

An aluminum strip coil has a 27% greater surface area than a copper wire coil of identical conductivity. This characteristic, in addition to aluminum's greater heat capacity, is responsible for the fact that aluminum strip coils build up less heat under load. The thermal conductivity and heat emission capability of the oxide insulating layer are highly superior to conventional insulating material and even a coil made of lacquered copper strip will not conduct heat so efficiently.

No need for interlayer insulation

Since the individual turns of an anodized aluminum strip winding are firmly in contact with each other, there exist virtually no air-filled interspaces. Since the interlayer voltage is equal to the interturn voltage, there is no need for an interlayer insulation used in wire coils. With lacquered wire, the insulation layer is significantly thicker. As a result, the space factor of anodized aluminum strip coils varies between 0.85 and 0.995, whereas that of lacquered copper wire coils lies in the range between 0.25 and 0.65.

Mathematically can be demonstrated that for an anodized aluminum strip coil with a space factor of 0.85 that an equivalent copper wire coil would have a space factor of 0.52. For a copper coil with a lower space factor, a smaller coil could be produced using anodized aluminum strip.



Conductor length: $l = \pi\, d\, N$
Number of turns: N
Conductor cross-section: $A = [w\, \pi\, (r_0^2 - r^2)\, k] / l$
Space factor: k
Typical values of k: Cu = 0.25-0.65, Al = 0.85-0.995
Resistance: $R = (\rho \times l) / A$

$R_{Al} = [\, 2.8264 \times 10^{-6}\, \pi\, (d\, N)^2\,] / [\, w\, (r_0^2 - r^2)\, k_{Al}\,]$
$R_{Cu} = [\, 1.7241 \times 10^{-6}\, \pi\, (d\, N)^2\,] / [\, w\, (r_0^2 - r^2)\, k_{Cu}\,]$

For $R_{Al} = R_{Cu}$ all coil dimensions are identical, if $k_{Al} = 0.85$, $k_{Cu} = 0.52$.
For $k_{Cu} < 0.52$ the aluminum coil will be smaller.

The specific gravity of aluminum is only about one-third the specific gravity of copper. The electrical resistance of an aluminum conductor of identical cross section is higher by a factor of 1.61. An aluminum strip coil of identical conductivity, having the same number of turns and the same resistance as its copper counterpart, will weigh only half as much as the latter.

Conductor volume: $V = A \times l = w\, \pi\, (r_0^2 - r^2)\, k$
Weight: $w = \rho \times V$
The copper coil will have the same size as an aluminum coil if $k_{Cu} = 0.52$, $k_{Al} = 0.85$.

Weight – copper coil: $8.89\, w\, (r_0^2 - r^2)\, 0.52$
Weight – aluminum strip coil: $2.7\, w\, (r_0^2 - r^2)\, 0.85$

In this case the weight of the aluminum coil will be:
$w_{Al}\, (2.7 \times 0.85) / (8.89 \times 0.25) \times w_{Cu} = 0.496 \times w_{Cu}$.

ANOFOL – Quality is no Coincidence

Anodized aluminum

The insulating properties of aluminum oxide have been known for a long time. The first proposals for producing insulating coatings on aluminum wire date back to the year 1898. However, another 12 years went by before the first load lifting magnet with an aluminum oxide insulation was put into service.

Anodizing

Anodic oxidation, better known as the "Eloxal" process in Germany, is a method permitting the time and intensity-controlled creation of an oxide layer on aluminum surfaces. Given the unique properties of aluminum, this process is specifically attractive in almost all fields of electrical engineering. STEINERT has harnessed the particular characteristics of aluminum for its ANOFOL products and can thus provide its customers with a finest-grade conductor material.

The oxidising process

In simplified terms, the oxidizing process can be described as follows: When aluminum is anodically polarized in an electrolyte, e.g. sulphuric acid, oxygen is released near the anode and reacts with the aluminum. The result is converted aluminum oxide. The surface of the aluminum anode is converted into an oxide layer which firmly adheres to the metal surface. Indeed, its bond with the substrate is so strong it cannot be removed from the base material even in fragments, not even by mechanical means.

The aluminum oxide forms a hexagonal cell structure with a pore in its center. During the electro galvanic process several diffusion processes take place, which transport the oxygen inside the base material and aluminum outside. These diffusion processes form a homogenously grown oxide layer on the aluminum surface.

To close the pores and further improve the oxide layer's resistance to all forms of moisture, the freshly anodized strip is then subjected to additional processing steps. The coatings obtained by this process are stronger and more resistant than naturally formed oxide layers.

Technical specification

- High temperature resistance (500°C under constant operation)
- Insulating class C (> 180°C)
- Base metal: Al 99.5 and E-Al 99.7 pure aluminum
- Hardness per customer specification – O (soft), H14 (medium hard) or H18 (hard)

Physical properties of aluminum

Melting point of Al:	658°C
Mean coefficient of thermal expansion:	23.5×10^{-6} K^{-1}
Temperature coefficient of electrical resistance between 1 and 100°C:	0.004 K^{-1}
Density:	2.7 kg/dm^3
Tensile strength:	70-180 N/mm^2
Thermal conductivity:	2.3 W/cm x K
Electrical conductivity at 20°C:	34-36.5 m/Ohm x mm^2 depending on hardness
Electrical resistivity at 20°C:	$2.92\text{-}2.73 \times 10^{-6}$ Ohm x mm depending on hardness
Mean specific thermal capacity between 1 and 100°C:	0.92 J/g x K

Modulus of elasticity (average value):	7×10^{-4} N/mm^2

Physical properties of the oxide layer – Al_2O_3

Melting point approx.:	2000°C
Hardness:	similar to corundum (HV 250-350)
High wear and abrasive resistance	
Dielectric constant:	7-8
Insulation properties:	typically up to 20V/µm
Thickness:	2µm - 6µm

Standard delivery range films and strip

Colour:	natural
Material gauge range:	0.03-1.5 mm
Material width:	3-260 mm, but max. cross section 150 mm^2
Standard film thicknesses:	50, 60, 70, 80, 90, 100, 115, 125, 135, 150, 175, 200, 220, 250, 270 µm
Standard strip thicknesses:	0.30, 0.35, 0.40, 0.45, 0.50, 0.55, 0.60, 0.65, 0.70, 0.80, 0.90, 1.00, 1.10, 1.20, 1.25, 1.40, 1.50 mm

- Additional dimensions available upon request

STEINERT – Special Quality

Dedicated cutting and edge preparation methods

A major challenge in the production of anodized aluminum slit strip lies in the inferior edge condition of conventionally cutted aluminum strip material. These sharp strip edges have numerous disadvantages. Thus the anodized coating may get damaged on coils wound from such strip or very high field intensities may be produced resulting in voltage flashover and short circuiting.

Together with leading rolling mill operators, STEINERT has developed a special edge processing method specifically for ANOFOL products. In this process any remaining burr is removed after the slitting cycle and the edges are rounded to an appropriate radius.

Slitting

Our slitting line for the production of ANOFOL strip has been optimized specifically for cutting aluminum strip to width. Designed for maximum efficiency and precision, STEINERT's dedicated slitting equipment delivers an optimum slitting result conforming to the most exacting standards.

Cold pressure welding

Cold pressure welded joints constitute the cheapest and most straightforward method of connecting anodized strip electrically. The surfaces are joined by producing a metallic bond through the application of high pressure at room temperature.

Only by forcing metals to "flow" under high pressure can the molecules of the separate parts be brought into close enough contact to combine. The two parts are united at the surface, producing a complete and genuine weld joint.

Joints of this type have been found to give excellent results, both electrically and mechanically. Load testing with a 30 x 1 mm strip comprising 17 pressure weld points revealed a voltage drop of less than 2 mV between the first and last pressure weld at 100 A/ 50 Hz. No appreciable heat generation was observed.

Ultrasonic welding

Metallurgically spoken, ultrasonic welding is a cold welding process. The heat generated by ultrasonic energy contributes only insignificantly, or not at all, to the formation of the joint. Compared with cold pressure welding, ultrasonic welding uses a significantly lower contact pressure between the parts to be united. Generally described as a friction welding process, ultrasonic welding can be used to join aluminum film and thin aluminum strip to most metals employed in electrical engineering.

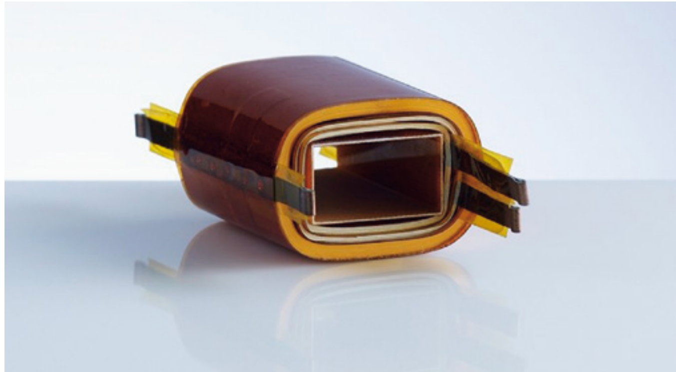
Winding

The benefits of optimum winding characteristics:

Strip winding has evolved into the preferred method of improving the productivity of high-performance transformers and inductors. This raises the question of bottom power limit for this winding technique.

To remain within the technically and economically viable strip conductor thickness range, a minimum conductor cross-section must be used for a given strip width. The characteristics of aluminum and its oxide permit the production of coils which possess a number of significant advantages over their copper wire counterparts:

- Higher space factor
- Superior heat dissipation
- Reduced sensitivity to thermal loads
- Lower cost of production
- Shorter manufacturing cycles



Substantial cost benefits
For aluminum strip to have the same conductivity and hence, the same power loss as copper wire, its cross-section must be 60% larger. However, thanks to the material's superior cooling behaviour, the losses may be 25% greater (or the conductor cross-section can be 25% smaller) at an identical heat load. In other terms, the cross-section factor instead of 1.6 needs to be 0.75 x 1.6 = 1.2 only. By using the full range of ANOFOL product benefits, it is possible to realize cost advantages of up to 50% and more over a technically equivalent coil made of conventional copper sectional wire.

Storage/Raw material
Based on an extensive stock of 800-mm-wide parent coils in our advanced high-back rack storage facility, we can supply even larger quantities at short notice in standard gauges.

Minimum quantities
Regardless how small, your order will be filled promptly and reliably. Depending on strip dimensions, minimum quantities start at 100 kg for the aluminum strip, and 50 kg for the anodized aluminum strip.

Packaging
Our downstream packaging line ensures that your product will be uniformly packaged to high standards with reliable protection in transit.

Contract slitting
At your request we will slit **customer-supplied aluminum strip to your specifications.** This offer is valid for all aluminum alloys in the stated thicknesses and width range.

Delivery time
Mill finish slit strip and ANOFOL products in ex-stock lengths and quantities up to 5 tons per gauge can usually be delivered within 3 weeks at the latest.

Tolerances
The specified thickness or width tolerance can be minimized to half the tolerance levels required by EN 485-4 or EN 546-3, respectively.

Quality
All slit strip supplied is subject to continuous quality inspections.

ANOFOL ex-stock delivery range
- Base material: Al 99.5 and E-Al 99.7 pure aluminum
- Hardness per customer specification: O, H14 or H18
- Surface: mill finish

Foil and strip
- Gauge range: 0.05-3.5 mm according to DIN 1784 EN
- Strip width: 3.0-800 mm
- Standard film thicknesses: 50, 60, 70, 80, 90, 100, 115, 125, 135, 150, 175, 200, 220, 250, 270 µm
- Standard strip thicknesses: 0.30, 0.35, 0.40, 0.45, 0.50, 0.55, 0.60, 0.65, 0.70, 0.80, 0.90, 1.00, 1.10, 1.20, 1.25, 1.40, 1.50 mm

Mill finished aluminum strip slitting and supply service

- **Anodized aluminum slit strip**
- **Individual coils, coil batch and series production**
- **Aluminum slit strip made of Al 99.5 and E-Al 99.7**

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