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Bibliography
1. Introduction

Aperam South America is the sole producer of non-oriented electrical grain (NGO), oriented and super-oriented grain (GoCore) steels in Latin America.

All of these steels offer excellent magnetic properties, the result of having silicon in their chemical composition and the use of strict process controls during all production stages. This magnetism is what makes electrical equipment made from these steels more energy efficient.
2. The different types of Aperam electrical steels
2.1. Non-oriented electrical grain steel (NGO)

Thanks to its versatility, NGO electrical steel can be found in a variety of applications, including: generator and electric motor cores, lighting system reactors, energy meters, and the motors for the hermetic compressors used in refrigerators, freezers and air conditioning units.

Aperam’s NGO electrical steel offers excellent permeability and low magnetic losses. It can also be supplied with insulating coating. All of our NGO electrical steel products are fully magnetic and cover the most varied classes as required by the market.

Supplied in coils, strips or sheets, our NGO electrical steels are available with the following coating options:

- **N0**: inorganic finishing of natural oxides (without coating) (ASTM C-0).
- **N5**: organic/inorganic insulation applied to the material’s surface, with an average thickness of 2.5 micrometers per side (ASTM C-5).
- **T5**: organic/inorganic insulation applied to the material’s surface, with an average thickness of 1.0 micrometer per side (ASTM C-5).
- **N6**: organic insulation varnish applied to the material’s surface (ASTM C-6).

2.2 GoCore steels (RGO and HGO)

GoCore Aperam South America’s brand of super-oriented grain steels produced using low temperature technology. Aperam’s Our GoCore steels include:

- Regular grain oriented electrical steel (RGO)
- Super-oriented electric grain steel (HGO).
Grain oriented electrical steel (RGO)

Whether being used for power transformer cores, energy distribution systems, power reactors, hydro-generators, or turbo-generators, Aperam RGO electrical steel helps reduce energy consumption and the release of greenhouse gases.

Designed to achieve low losses and high magnetic permeability, our RGO steel has excellent magnetic properties in the rolling direction.

Available in coils or strips with a C5 surface finish (ASTM standard).

Super-oriented electric grain steel (HGO)

GoCore HGO electrical steel is the material of choice for high efficiency transformers. That’s because only HGO offers the higher permeability and better energy efficiency these applications need to achieve lower electricity consumption. For the power generation and distribution sectors, this means smaller and more efficient transformers.

Available on the market since 2017, (HGO) has placed Aperam among a select group of producers worldwide. Its development is the result of one of the Company’s largest projects in recent years. HGO’s technological boldness represents a step change in the way steel is manufactured, having a net positive market impact.

How is it supplied and with which finishes?

All our grain oriented electrical steels are supplied in strips or coils and with an ASTM C-5 on ASTM C-2 coating. Although the coatings used for RGO and HGO steels have a different name (R5 press for RGO steels and H5 for HGO steels), they are in fact exactly the same.
2.3. Key differences between GNO and GoCore steels

Grain-oriented steels (GoCore), which offer optimized magnetic properties in the rolling direction, are mainly used in power and distribution transformers. Non-oriented grain steels (NGO), which have good magnetic properties in all directions of the sheet plane, and are typically used in electric motors, compressors, lighting system reactors, energy meters, and electric vehicles, amongst other uses.
3. Electrical Steel Coatings

GO and GNO silicon steels are coated with high dielectric strength surfaces that reduce magnetic losses caused by the eddy currents (Foucault currents) generated in the nuclei core of the electric machines. The coatings also improve stampability, as noted in the figure below.
Non-oriented grain steels

Aperam’s available coatings are outlined in the following table. The table also highlights each coating’s performance with respect to temperature resistance, electrical resistivity, stampability and weldability.

Table I — Performance of Aperam coatings for NGO electrical steels

<table>
<thead>
<tr>
<th>Type of coating</th>
<th>Composition</th>
<th>Resistance to temperature</th>
<th>Electrical resistivity</th>
<th>Stampability</th>
<th>Weldability</th>
</tr>
</thead>
<tbody>
<tr>
<td>N0</td>
<td>Natural oxide</td>
<td>Resists stress relief annealing</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>N5</td>
<td>Organic varnish with inorganic pigments</td>
<td>Resists burn-off annealing temperatures (450 to 480°C)</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>T5</td>
<td>Organic varnish with inorganic pigments</td>
<td>Resists stress relief annealing</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>N6</td>
<td>Phenolic-based organic varnish</td>
<td>Resists working temperatures of up to 250°C</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
</tbody>
</table>
Grain-oriented steels

Aperam’s grain oriented electrical steel coils are supplied with two coatings, C2 and C5. C2 coating is an inorganic substance consisting of a vitreous film formed during box annealing at high temperature in a hydrogen atmosphere. It is the result of how the magnesia applied on the strip reacts to the surface oxide of the steel. It resists stress relief annealing treatments and has sufficient electrical resistance for various applications. C5 coating is also an inorganic, ceramic substance, which gives it good resistivity. Aperam’s grain oriented electrical steels are supplied only with the C5 coating applied over the C2 coating.

These coatings are called R5 (for RGO steels) and H5 (for HGO steels). Both are intended for air-cooled or oil-cooled cores. The coating of GoCore and Aperam steels resists stress relief annealing treatments in neutral or slightly reduced atmosphere.
4. Care in handling, storage and cutting
4.1. Handling

Any deformation or damage to the product must be avoided when handling electrical steels. This is because deformations affect the material’s magnetic properties.

To avoid such deformations, one must use the appropriate equipment, such as “C” type handles, forklifts and others. If using C type handles, any area that could come into contact with the coil should be coated with rubber.

People who handle the material should always use appropriate Personal Protective Equipment (PPE), such as gloves with steel wire, sleeves with steel wire, appropriate boots, safety glasses, ear protectors, etc. Furthermore, to avoid oxidation of the material, one should never with wet gloves.

Figure 2 — ELECTRICAL steel handling equipment: (a) “C” type handle; (b) telescope coil grab; (c) forklift; (d) double “C” type handle; (e) forklift with fork; (f) spreader beam with chain.
4.2. Coil and package storage

Improper handling or storage of coils will cause bending stresses that negatively affect the material’s magnetic properties.

Coils should be stored in a covered place with a door that closes laterally and that is completely protected from rain. To prevent unwanted oxidation, the storage area should be clean and dry.

When no frames are available, coils with horizontal axis should be stacked to a maximum of three levels, superimposed in pyramidal form, with the outer diameters decreasing as the height of the battery increases (figure 3). The coils at the base should be placed with the wooden pallets. Coils with a vertical axis should be stacked no higher than two levels (figure 4).

Packages should be stored in piles of a maximum of six superimposed units. The lower transversal woods should be on top of the woods of the already stacked package. The length, width and weight of the packages should decrease in proportion to the height of the pile (figure 5).

Figure 3 — Horizontal axis coil storage

Figure 4 — Vertical axis coil storage

Figure 5 — Package storage

Figure 6 — Improper storage causing coils to become deformed
4.3. Cutting

To obtain a quality cut, start by checking the cleanliness of the axle and of the accessories being used.

For slitting lines, tungsten carbide knives are recommended. However, it is important to always check the condition of the knives and spacers and the parallelism between the axes.

It is also necessary to check the vertical clearance sp as to avoid open clearance and overlap. The corners of a flat table or even the radius of very small curvature can introduce stress into the material, damaging its magnetic properties (figure 8). Normally, the smallest radius that the material can be bent without causing plastic deformation, is 127 mm.

![Diagram](image)

Figure 7 — Types of clearances during the slitting process.

![Diagram](image)

Figure 8 — Incorrect handling of strips or plates can introduce stresses that impair the magnetic properties of the steel.
Stress relief annealing treatment of transformer coils

For GO silicon steels, the annealing temperature must be in the range of 780° to 840°C (soaking temperature). The furnace time should be sufficient to ensure that all load points reach at least one hour at the soaking temperature. Abrupt heating and cooling can introduce tensions into the material and must be avoided.

The furnace atmosphere should be neutral to slightly reducing and dry to prevent oxidation and carbonation of the material. This will also prevent degradation of the product’s coating and magnetic properties. A nitrogen atmosphere with 3 to 10% hydrogen and positive pressure is recommended during the entire annealing process.

The charge should not be exposed to air at temperatures higher than 400°C. Up to this temperature, the charge must be kept in a nitrogen atmosphere. At temperatures higher than 400°C and without a protective atmosphere, thermal shock can occur in the charge, damaging the coating and even introducing thermal stresses into the steel.

In addition, steel oxidation will occur, causing a reddish layer to form on the steel’s surface. This oxidized layer can even detach the coating, generating problems for the core and increasing the magnetic loss of the material. The reddish coloration of the core indicates that the material was in contact with oxygen from the air above 400°C.

In order to prevent the material from carbonisation, it is necessary to remove oils, greases and other organic compounds from the sheets before heat treatment. To prevent the material from regaining stress, it is recommended to handle the treated material with the utmost care.
Magnetic ageing on electric steels

Magnetic ageing is the decline, over time, of magnetic properties, as a result of reheating to approximately 300°C. This phenomenon reduces the efficiency and useful life of electrical equipment. This occurs through the precipitation of carbides and nitrides, and it is therefore necessary to avoid these elements in the chemical composition of steels. Aperam keeps these elements at low levels, ensuring a maximum magnetic ageing of 5% in an accelerated 225°C aging test for 24 hours (ABNT NBR 5161).
Magnetic Loss and Magnetic Permeability

Electric steels have the ability to amplify an externally applied magnetic field thousands of times. This property is called magnetic permeability. Magnetic permeability is the relationship between the value of magnetic induction and the intensity of the magnetic field that created it. The higher the magnetic permeability, the less magnetic field is needed to reach a certain induction value.

Magnetic loss is generally the most important control criterion of electric steels used in alternating current, for motors, generators, transformers, energy meters and others. When these equipment are excited by alternating electric currents, the magnetic fields are periodically inverted every 1/120 of a second (for 60 Hz frequency). Due to the existence of magnetic hysteresis* and the circulation of eddy current induced by the variation of magnetic flux inside the material, the process of magnetization inversion occurs with energy dissipation, that is, with magnetic losses.

*By exposing an electric steel to a magnetic field, an ordering occurs inside the material, with accumulation of energy, resulting in a magnetic induction. If this field is then removed, this ordering is not totally destroyed and the material becomes a magnetic induction remaining. This gap between the sorting and the applied field gives rise to the magnetic hysteresis curve.

Differences between semi-processed and fully processed GNO steels

The fully processed GNO steels have fully developed magnetic characteristics, already with low carbon content and with final annealing, i.e. ready for cutting / stamping and use. Aperam produces only medium and high efficiency fully processed grain steels.

Semi-processed GNO steels require final annealing at the customer to promote grain growth, elimination of residual stresses and decarburization. This heat treatment increases the responsibility of the customer as he must carefully control the annealing temperature and the atmosphere to produce the desired final magnetic quality.

In addition, the process involves different soaking times and atmospheres than those used in the case of stress relief. If the same heat treatment is used as for semi-processed steels for fully processed steels (with moisture), sub-surface oxidation may occur. This subsurface oxidation worsens the magnetic losses. Therefore, it is necessary that the furnace is as dry as possible for the annealing of fully processed steels.
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