CLIFFS

DI-MAX® NON-ORIENTED
ELECTRICAL STEELS

- **Motors**
- **Generators**
- **Ignition Coils**
- **Transformers**

DI-MAX® NON-ORIENTED ELECTRICAL STEELS are silicon steels in which magnetic properties are practically the same in any direction of magnetism in the plane of the material. Standard grades from M-15 to M-47 are available with the advantages of special DI-MAX® processing that enhance the magnetic properties.

Product Description

M-15 THROUGH M-47

DI-MAX grades have superior permeability at high inductions, low average core loss and good gauge uniformity. In addition, cold finishing plus strip annealing produce a smooth surface and reduce buckles and waves, resulting in excellent flatness and a high stacking factor.

Cleveland-Cliffs Non-Oriented Electrical Steels are available both Fully Processed and Semi-Processed, depending on grade. Properties of Fully Processed material are developed completely by Cleveland-Cliffs. These materials are ready for use without any additional processing required. However, a low-temperature heat treatment may be employed by the user to eliminate stresses introduced by fabrication of the material into cores. Cleveland-Cliffs Fully Processed Non-Oriented Electrical Steels meet all the requirements of ASTM Specification A677.

Semi-Processed steels are finished to final thickness and physical form by Cleveland-Cliffs, but are not fully annealed to develop final magnetic quality. With these materials, achievement of magnetic properties becomes the responsibility of the user. Cleveland-Cliffs Semi-Processed Non-Oriented Electrical Steels meet all requirements of ASTM A683.

TABLE 1 – CLEVELAND-CLIFFS NON-ORIENTED ELECTRICAL STEELS

Grade	Processing
DI-MAX M-15	Fully Processed
DI-MAX M-19	Fully Processed
DI-MAX M-22	Fully Processed
DI-MAX M-27	Fully Processed
DI-MAX M-36	Fully Processed
DI-MAX M-43	Fully Processed, Semi-Processed
DI-MAX M-45	Fully Processed
DI-MAX M-47	Fully Processed, Semi-Processed

Specifications

AVAILABLE FORMS

Gauges

Electrical steels are ordered by gauge number or decimal thickness only. The use of gauge-weight equivalents is impractical because densities of the steels vary with silicon and aluminum contents. In addition, these steels are manufactured to provide specific electromagnetic properties for certain established thicknesses. The standard gauge table on this page is the only one that applies to Cleveland-Cliffs Non-Oriented Electrical Steels.

TABLE 2 – STANDARD GAUGES

Electrical Steel Gauge Number	Thickness in. (mm)
24	0.0250 (0.635)
26	0.0185 (0.470)
29	0.0140 (0.356

Widths

Coils are supplied in 0.75 – 48.0 in. (19 mm – 1220 mm) widths. Maximum width depends upon grade and thickness. As a result, some materials are not available in this full range.

TABLE 3 – APPLICATIONS

Application	Grades		
	M-15 M-19 M-22	M-27 M-36 M-43	M-45 M-47
Large Motors and Generators (>100 hp)	X	–	–
Small Motors and Generators (<100 hp)	–	X	X
Ignition Coils	–	X	X
Large Transformers (>10 kVa)	X	X	–
Small Transformers (<10 kVa)	–	X	X

Surface Insulations

Cleveland-Cliffs offers a variety of surface insulations on DI-MAX Fully Processed Non-Oriented Electrical Steels. This allows manufacturers of electrical equipment to meet design requirements and the limitations imposed by fabrication most effectively.

Semi-Processed material is supplied with a special ANTI-STICK™ coating (equivalent to ASTM Type C-5-A Coating) to reduce sticking during annealing of stamped laminations. This thin inorganic coating provides a low level of surface insulation resistance, which is adequate for many applications.

The following surface insulations are supplied on Fully Processed material only.

STANDARD SURFACE FINISH (C-0)

Unless otherwise specified by the customer, all Cleveland-Cliffs Non-Oriented Electrical Steel grades are supplied with a very thin surface film (equivalent to ASTM Type C-0 coating) resulting from the DI-MAX processing for best die life. This smooth, tightly-adherent film provides sufficient surface insulation resistance for many applications in small apparatus. The insulation resistance of this surface is usually enhanced by a stress-relief anneal and is not adversely affected by oils. However, this type of insulation provides less protection against rust than other available insulations. For rust protection and additional insulation resistance for larger apparatus, it is suggested that a suitable coating be applied.

C-3 INSULATION

This organic varnish coating (equivalent to ASTM Type C-3 coating) is applied over the natural oxide surface. It provides very high levels of surface insulation resistance, as well as protection against rusting. C-3 insulation also has a beneficial effect on die life. While it is suitable at normal operating temperatures of electrical apparatus, it will not withstand the heat of stress-relief annealing. It withstands oil and is suitable for oil-immersed and air-cooled cores.

C-5 INSULATION

This chromium-free inorganic-based surface insulation (equivalent to ASTM Type C-5 coating) is suggested for use where superior insulation is required. It provides a uniform, high-resistance insulation for the more severe requirements of large electrical apparatus. C-5 insulation has a minimum effect on lamination factor. It can be exposed to ordinary stress-relief annealing temperatures without impairment of its superior insulation resistance when specified protective annealing atmospheres are used. In addition, C-5 insulation is not affected by oils, and provides some rust resistance. A small amount of organic material is contained in C-5 insulation to enhance die life relative to the standard surface finish and C-5-A insulation. C-5 insulation is especially useful in large transformers made with stacked, flat laminations and in large motors and generators.

C-5-A INSULATION

This thin inorganic coating (equivalent to ASTM Type C-5-A coating) is best for punched laminations where only a moderate degree of surface insulation is required, but good die life and minimum effect on lamination factor are important. It provides thorough surface coverage with a very thin film that affords a moderate amount of surface insulation. It is not harmed by ordinary stress-relief annealing temperatures, retaining adequate surface insulation characteristics for many applications when annealed in recommended protective atmospheres. C-5-A insulation is unaffected by oils, making it useful for either oil-immersed or air-cooled apparatus. This special Cleveland-Cliffs insulation provides some protection against rusting.

Surface Insulations

TABLE 4 – TYPE OF SURFACE INSULATION AND TYPICAL APPLICATIONS*

Coating Type	Description	Typical Applications
C-0	An insulation consisting of the natural oxide film formed in processing annealing. The insulation resistance is low, but usually is adequate for small cores. It will withstand stress-relief anneals in neutral or slightly reducing atmospheres.	Ignition coils, small motors and transformers.
C-3	An organic varnish coating intended for air-cooled or oil-immersed cores. It provides excellent interlaminar resistance and also serves to promote better punchability. This type will not withstand stress-relief annealing.	Large motors, generators and transformers.
C-5	This is a high-resistance inorganic-based coating with the addition of inorganic fillers to enhance its electrical resistance and a small amount of organic material to enhance punchability. It withstands stress-relief annealing if temperature does not exceed about 1550 °F (845 °C) and a neutral or slightly reducing atmosphere is used. High resistance makes this insulation advisable for cores of large size with a volts per turn ratio in the highest range. It has little effect on lamination factor and is unaffected by oil immersion.	Large motors, generators and transformers
C-5-A	A thin inorganic coating that is suitable for air-cooled or oil-immersed cores. It withstands stress-relief annealing at temperatures below about 1550 °F (845 °C) in neutral or lightly reducing atmospheres. Moderate insulative resistance makes it adequate for most 60 Hz cores weighing up to a few hundred pounds.	Medium motors, generators and transformers.

**Based on the classification of surface insulations in ASTM A976. Cleveland-Cliffs' standard surface finish (C-0) is produced by normal processing used to develop magnetic quality and is an integral part of the steel surface. Other surface insulations are coatings applied over the standard surface finish to boost insulative capability in severe applications.*

Surface Insulation Resistance

Measurement of how effectively insulation can limit extraneous interlaminar eddy currents to negligibly low values is important where power ratings are quite high.

DETERMINATION OF INSULATION RESISTANCE

The surface insulation resistance method of ASTM A717 is the standard for quality control for insulative coatings. The method is easy to use, and measures the resistivity of each surface independently. Surface insulation resistivity values obtained by the Franklin Test normally are lower than those obtained in stack-resistance tests, and, in reality, are not interlaminar resistivity values. For this reason, it is preferred that insulation effectiveness evaluated by the Franklin Test be expressed by the test reading in amperes rather than the derived resistivity value.

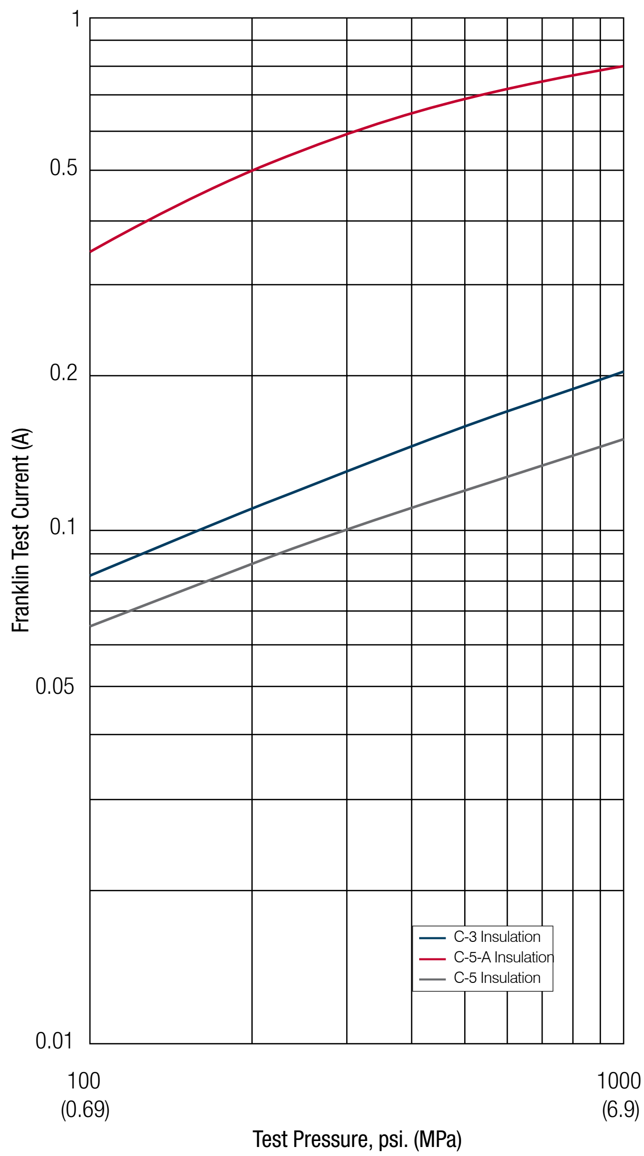
EFFECT ON DESIGN

The effectiveness of insulative coatings in resisting interlaminar current flow depends on the pressure on the core lamination surfaces and on the surface characteristics. Therefore, for best performance, unduly high assembly pressures should be avoided. Likewise, designers should avoid making excessively high estimates of needed insulation resistance. This penalizes the design because of the reduced lamination factor resulting from heavier-than-needed surface coatings.

TYPICAL INSULATION RESISTANCES

The graphs of insulation characteristics provide a guide to the relative insulating abilities of available surface insulations and show their response to pressure. Values in the graphs are typical of those obtained at the mill by the Franklin Test method. The range of the Franklin Test method is not suitable for the evaluation of the surface resistance of the standard mill finish, which is usually in the fractional ohm range, with Franklin amperes typically over 0.90 amperes. Of course, normal variations in both the mill surface and the applied coatings will necessitate allowing for resistance both higher and lower than those stated.

FIGURE 1 – TYPICAL SURFACE INSULATION CHARACTERISTICS AT VARIOUS PRESSURES



**Values determined by the Franklin Test.*

Maximum Core Loss Limits

The core limits presented in Tables 5 and 6 are appropriate for Fully Processed as-sheared (AS) and Semi-Processed quality annealed (QA) Epstein specimens prepared in accordance with procedures specified in ASTM Method A343. For most grades, the typical core loss is appreciably lower than the maximum core loss.

TABLE 5 – CORE LOSS LIMITS FOR FULLY PROCESSED MATERIAL AT 60 HZ* (ASTM A677) (W/LB.)

Grade	15 kG		
	0.014 in. (29 gauge)	0.0185 in. (26 gauge)	0.025 in. (24 gauge)
DI-MAX M-15	1.45	1.60	–
DI-MAX M-19	1.55	1.65	2.00
DI-MAX M-22	1.65	1.80	2.10
DI-MAX M-27	1.75	1.90	2.25
DI-MAX M-36	1.85	2.00	2.35
DI-MAX M-43	1.95	2.10	2.50
DI-MAX M-45	2.05	2.40	2.75
DI-MAX M-47	–	2.80	3.20

**As-Sheared, 50/50.*

TABLE 6 – CORE LOSS LIMITS FOR SEMI-PROCESSED MATERIAL AT 60 HZ* (ASTM A683) (W/LB.)

Grade	15 kG	
	0.0185 in. (26 gauge)	0.025 in. (24 gauge)
DI-MAX M-43	1.55	2.00
DI-MAX M-47	1.65	2.10

**ANTI-STICK™ Coating, QA, 50/50.*

Mechanical and Magnetic Properties

TABLE 7 – TYPICAL MECHANICAL AND PHYSICAL PROPERTIES

Grade	Density gm/cm³	Yield Strength ksi. (MPa)	Tensile Strength ksi. (MPa)	Elongation % in 2 in. (50 mm)	Rockwell Hardness
DI-MAX M-15 FP	7.65	52 (358)	71 (490)	23	72
DI-MAX M-36 FP	7.75	42 (290)	63 (434)	30	64
DI-MAX M-47 FP	7.75	39 (269)	62 (428)	34	61
DI-MAX M-43 SP **	7.75	50 (345)	70 (483)	32	64
DI-MAX M-47 SP **	7.75	48 (331)	67 (462)	33	62

**Values are typical of data obtained on as-sheared specimens.*
***Semi-Processed grades have not been quality annealed.*

TABLE 8 – TYPICAL D-C MAGNETIC AND ELECTRICAL PROPERTIES

Grade	Electrical Resistivity μΩ•cm	Hysteresis Loss B_{max}= 10 kG J/lb./cycle	Coercive Force B_{max}= 10 kG Oe	Maximum Permeability	Saturation Induction kG
DI-MAX M-15 FP*	50	0.0068	0.41	8000	20.1
DI-MAX M-27 FP*	43	0.0077	0.46	7400	20.5
DI-MAX M-36 FP*	43	0.0085	0.52	6900	20.5
DI-MAX M-43 FP*	43	0.0092	0.57	6500	20.5
DI-MAX M-45 FP*	37	0.0083	0.50	7200	20.8
DI-MAX M-47 FP*	37	0.0094	0.57	6800	20.8
DI-MAX M-43 SP**	43	0.0054	0.30	15000	20.5
DI-MAX M-47 SP**	37	0.0050	0.28	16300	20.8

**Values are typical of data obtained on as-sheared specimens.*
***Semi-Processed grades have not been quality annealed.*

Specimen Preparation for Testing

All magnetic tests are made on Epstein specimens sheared with sharp shears to avoid burr and excessive strain to dimensions specified by ASTM Method A343. Core losses determined on Fully Processed as-sheared (AS) specimens represent the magnetic quality of mill annealed material, except for the effect of strains introduced in shearing the strips.

When core loss tests for grading purposes are made on Semi-Processed quality annealed (QA) specimens, strips are given a laboratory anneal to develop the inherent magnetic properties of the material. This annealing, performed in a standardized method, is similar to annealing that must be performed by the customer on Semi-Processed grades.

ANNEALING PROCEDURE

In accordance with industry practice for grading purposes only, specimens of semi-processed material are annealed for one hour at 1550 °F (843 °C) in a decarburizing atmosphere. All test specimens are annealed on flat plates to ensure a suitable degree of flatness for core loss measurement.

Testing Methods

INDUCTION DETERMINATIONS

Induction is calculated from the net cross-sectional area of the specimen. Net area is determined from the actual weight of the specimen and the assumed specific gravity values (as specified by ASTM). Designers may approximate net area by multiplying gross area of the compacted core by its lamination factor, expressed as a decimal. A-C induction is calculated from voltage measurements made on an unloaded secondary winding using an average-responsive (rectifier-type) A-C voltmeter.

TEST CIRCUIT

Magnetic data are obtained on a magnetic circuit having negligible joint effects with an exciting winding uniformly distributed along the circuit. In all tests for A-C magnetic properties, the flux wave form is sinusoidal. If a design calls for a substantial departure from these test conditions, suitable allowances must be made in applying the test data.

CORE LOSS AND EXCITING CURRENT MEASUREMENT

Core loss values are determined using wattmeter methods that eliminate the factor of copper loss and voltage drop in the test windings. Exciting current values are measured using a true rms reading ammeter, so exciting power (exciting volt-amperes) is the rms value.

Annealing by the User

Two types of annealing may be performed by users of non-oriented electrical steels. If Fully Processed grades are used, annealing will consist of a stress-relief anneal. This treatment is required only to eliminate the impairment of magnetic properties caused by stresses induced during punching or assembly. If Semi-Processed material is used, a different type of anneal is required to develop the magnetic properties fully.

STRESS-RELIEF ANNEALING

Stresses are introduced into the electrical steels whenever they are punched, sheared or wound into cores. These stresses have an adverse effect on magnetic characteristics such as core loss, permeability and exciting current.

A stress-relieving anneal restores magnetic properties of highly-stressed regions in laminations to their original values. Annealing also reduces the effect of the sharp edges of burrs and improves the stacking factor.

Stress-relief annealing is not always necessary. Whether or not it is required depends upon thickness, size and type of lamination or core, and the required magnetic properties. Stress-relief annealing always incurs the possibility of impairing lamination flatness unless special precautions are taken to preserve or improve flatness during annealing. However, if the full magnetic properties of a grade are required, stress-relief annealing is necessary, particularly when the lamination width is less than one inch. The user must decide, based upon whatever specific requirements are needed.

ANNEALING SEMI-PROCESSED GRADES

Because Semi-Processed electrical steels are not processed at the mill to develop their magnetic properties fully, the user must always complete the processing of these materials by proper annealing. This treatment by the user might be called a final processing anneal. This necessary annealing not only decarburizes the material, but also produces grain growth. Both of these are essential to the development of the optimum magnetic properties of semi-processed grades.

Because decarburization and grain growth are involved, proper decarburizing atmospheres must be used, and both temperature and time of annealing carefully controlled. Temperatures generally are higher and annealing times somewhat longer than for stress-relief annealing.

GENERAL PROCEDURES

Both stress-relief and final process annealing can be accomplished by the batch method or by continuous annealing. However, with either process, adequate precaution must be taken to assure proper atmosphere control. The time and temperature necessary for the grade being processed should be compatible with the process used.

BATCH ANNEALING

This type of annealing is especially adapted to intermittent or relatively low-volume annealing operations. However, it is more easily controlled and more flexible in operation than continuous methods.

Stacked flat laminations or stampings can be annealed in batches, either in a covered annealing box or on open trays with an adequate furnace atmosphere.

Annealing trays or plates should be flat. Plates and charge covers, if used, should be made of low-carbon material to prevent possible harmful carbon contamination. For the same reason, punching lubricants should be removed before annealing.

Load the charge compactly on the plate, preferably in such a manner that radiant heat can strike a portion of the edges of laminations or cores. This facilitates heat transfer and reduces heating time.

Use of a box or annealing cover is preferred for either stress-relief or final process annealing. This makes it much easier to control the atmosphere properly and requires much less gas. When an inner cover is not used, a sufficient quantity of protective gas must be used to flush the furnace adequately and diminish the effect of leaks. Oxidation of electrical steels must be avoided because it impairs magnetic properties, particularly at high inductions. Annealing box covers should fit closely and original air should be flushed completely before heating.

To avoid distortion from cooling large batches of wide laminations too rapidly, cool the material slowly under protective atmosphere to a temperature of 600 – 800 °F (316 – 427 °C). For charges weighing only a few thousand pounds, the cooling rate should not be more than 50 °F (28 °C) per hour. Even slower cooling is advisable for heavier furnace charges.

Annealing by the User

CONTINUOUS ANNEALING

Continuous annealing methods are especially adapted to high volume production. They can be used effectively to either stress relieve or process anneal electrical steels.

As in batch annealing, adequate precautions must be taken to assure proper atmosphere control. Because continuous annealing furnaces are apt to have leaks, they must be adequately flushed with protective atmosphere to prevent oxidation. Usually, oil can be removed from stampings and cores by burn-off in the pre-anneal chamber. Although individual charges are not as large as those used in batch processes, care should be taken in loading and stacking to prevent the possibility of distortion. This is especially important if stampings are stacked on edge.

Because of the continuous nature of this process, laminations and cores are brought to temperature quickly. This precludes stacking cores or laminations in heavy charges. Metal volume in any given mass must be small enough to permit it to reach the annealing temperature quite rapidly.

Special attention must be paid to stacking procedures and furnace capacity if process annealing is done in a continuous unit. This is necessary because the final process anneal of Semi-Processed material requires longer time at temperature and good circulation of the decarburizing atmosphere to all parts of the charge.

TEMPERATURES AND ATMOSPHERES

A controlled atmosphere, suited to the type of material being annealed, is necessary to prevent contamination and consequent impairment of magnetic properties. Temperatures for commercial annealing should be closely controlled and no higher than required to obtain the necessary magnetic performance of the final product.

In certain critical applications, somewhat higher temperatures or modified atmospheres may yield slightly better magnetic properties. However, such practice is not generally recommended, because the temperature, time and atmosphere must be controlled more carefully. This is necessary not only to obtain consistent results, but also to avoid deterioration of surface insulations and an increased tendency for adhesion, or sticking, of laminations.

Procedures for Specific Grades

FULLY PROCESSED DI-MAX GRADES

Grades M-15 to M-47 have exceptionally low carbon content and have been processed at the mill to develop their magnetic properties. They are annealed by the customer only to relieve fabricating stresses. Annealing should be done at 1450 °F (788 °C) in an atmosphere of nitrogen, which may contain 2% – 10% hydrogen. Such atmospheres will not support a flame. However, atmospheres containing more than 4% hydrogen may be explosive in the presence of oxygen. Time at maximum temperature need be no longer than that required to heat the charge uniformly. Contamination of the steel must be avoided during annealing. The recommended atmosphere is the least expensive one that does not contain the most common contaminants – carbon and oxygen. The addition of hydrogen to the nitrogen atmosphere provides protection against oxidation, but a minimum amount is recommended when annealing materials which have C-5-A or C-5 coatings.

SEMI-PROCESSED GRADES

Grades M-43 and M-47 have not been processed at the mill to develop magnetic properties fully. The customer must complete this processing by proper annealing. This necessary annealing involves decarburization and grain growth, both of which are essential to development of optimum magnetic properties.

Decarburizing atmospheres of nitrogen/hydrogen mixtures containing water vapor are preferred. Although not recommended, atmospheres formed by partial combustion of a fuel gas are also used. Annealing temperatures range from 1550 – 1600 °F (843 – 871 °C). The higher temperatures produce somewhat improved magnetic properties, but increase the problem of adhesion or sticking of laminations. Higher temperatures can also produce excessive oxidation, resulting in deterioration of magnetic properties. A practical temperature, based on service experience, seems to be about 1550 °F (843 °C).

Because decarburization is involved, annealing time depends not only on the temperature and atmosphere used, but also on the width of the laminations or core and time. Sufficient annealing time permits adequate circulation of the atmosphere, which removes the carbon from the steel surface. This means that the required annealing time must be specifically determined for any given set of conditions. It also means that wide laminations may require lengthy annealing times. Consequently, there is a practical limit to lamination width for which the semi-processed grades are economical.

EFFECTS OF FABRICATION

Detrimental effects of stresses introduced into laminations by shearing or other fabricating operations can be eliminated by a suitable stress-relieving anneal of the core material after fabrication. When stress-relieving is impractical, design allowances must often compensate for magnetically harmful fabricating stresses.

Procedures for Specific Grades

CONVERSION OF MAGNETIC UNITS

The following conversion factors may be useful in the application of data on Cleveland-Cliffs Non-Oriented Electrical Steels:

Core loss at 50 Hz = 0.79 x Core loss at 60 Hz*.

$$\text{kiloGauss} = \frac{\text{Flux lines per square in.}}{6450}$$

$$\text{Oersted} = \frac{\text{Ampere-turns per in.}}{2.02}$$

$$\text{Weber} = \frac{\text{Flux lines}}{108}$$

$$\text{Teslas} = \frac{\text{kiloGausses}}{10}$$

$$\text{Teslas} = \frac{\text{Flux lines per square in.}}{64{,}500}$$

$$\text{Ampere/meter} = \frac{\text{Oersteds}}{0.01257}$$

*VALID AT 1.5 KG ONLY

ADDITIONAL CLEVELAND-CLIFFS ELECTRICAL STEELS

Cleveland-Cliffs also produces a complete range of Grain Oriented Electrical Steels (GOES) and Non-Oriented Electrical Steels (NOES). Complete magnetic, mechanical, and physical properties can be found under Electrical Steels on www.clevelandcliffs.com/products.

DI-MAX NON-ORIENTED ELECTRICAL STEELS

About Cleveland-Cliffs Inc.

Cleveland-Cliffs is the largest flat-rolled steel producer in North America. Founded in 1847 as a mine operator, Cliffs also is the largest manufacturer of iron ore pellets in North America. The Company is vertically integrated from mined raw materials, direct reduced iron, and ferrous scrap to primary steelmaking and downstream finishing, stamping, tooling, and tubing. The Company serves a diverse range of markets due to its comprehensive offering of flat-rolled steel products and is the largest supplier of steel to the automotive industry in North America. The Company is headquartered in Cleveland, Ohio with mining, steel and downstream manufacturing operations located across the United States and in Canada. For more information, visit www.clevelandcliffs.com.

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