HIGH LEVEL OF MAGNETIC PERFORMANCE

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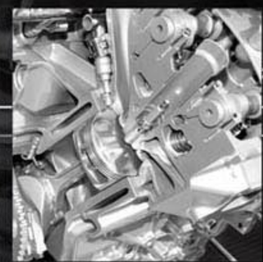
HIGH LEVEL OF MAGNETIC PERFORMANCE

SOFT MAGNETIC STEELS

Stainless Steels & Iron Silicon Alloys



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STAINLESS AND SPECIALTY STEELS

SOFT MAGNETIC STEELS

Stainless Steels & Iron Silicon Alloys

Vicenza plant, Italy

Bolzano plant, Italy

Fort Wayne plant, IN-USA

Valbruna, founded in 1925 and leader in the production of Stainless Steels, Nickel Alloys and Titanium long products, is underpinned by long experience and a highly qualified customer service.

Mills — ITALY: Vicenza, Bolzano — USA: Fort Wayne

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VALBRUNA... SUCH A GREAT REALITY!

Our extensive and strategic distribution network is our corner stone in a global market, granting not only a worldwide commercial presence but also a continuous feedback with our customers.

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SOFT MAGNETIC STAINLESS STEELS

Ferritic Steels are so named because their body-centered-cubic structure is the same of that of Iron at room temperature and have a ferromagnetic behavior.
Ferritic Stainless Steels are widely known for their good magnetic properties combined with a very interesting corrosion resistance. They do not reach the high level of magnetic performance of Iron-Silicon alloys but are irreplaceable if the corrosion were a problem.
A design of any magnetic device requires a knowledge of steel characteristics in terms of its metallurgical and magnetic properties evaluating both the corrosion resistance and magnetic behavior.

A general rule suggests knowing of a specific steel grade:

A) the degree of corrosion resistance in service corrosive environment
B) the most important magnetic properties
C) cycle of production and its cost

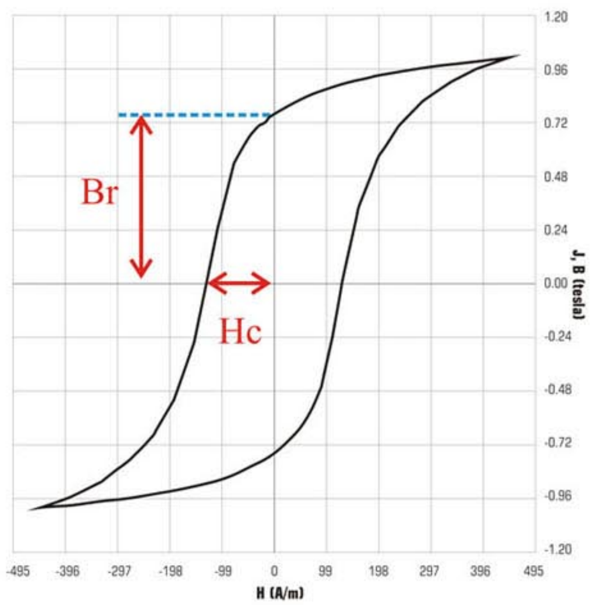
Corrosion resistance criteria

Corrosion resistance depends on the chemical composition of the Ferritic Stainless Steels, especially on their Cr and Mo contents in addition to a low level of interstitial elements such as C and N and on their heat treatment. Sticking to general considerations, the more Cr and Mo with lowest C+N contents, the more resistance to pitting and crevice corrosion. In Free Machining grades, Sulfur is added to improve machinability and its influence on corrosion should be well evaluated because the MnS - inclusions could prime points of pitting when exposed to some corrosive environments. On the contrary, Free Machining grades alloyed with Ti do not suffer from this local attack and have also a good resistance to intergranular corrosion. All Ferritic grades have an excellent and better stress corrosion cracking resistance than Austenitic ones. Nevertheless, for a maximum corrosion resistance, the surface of finished blanks have to be free of tint, contaminants as cutting fluid, iron particles, dirty and scale. A final passivation should be considered.

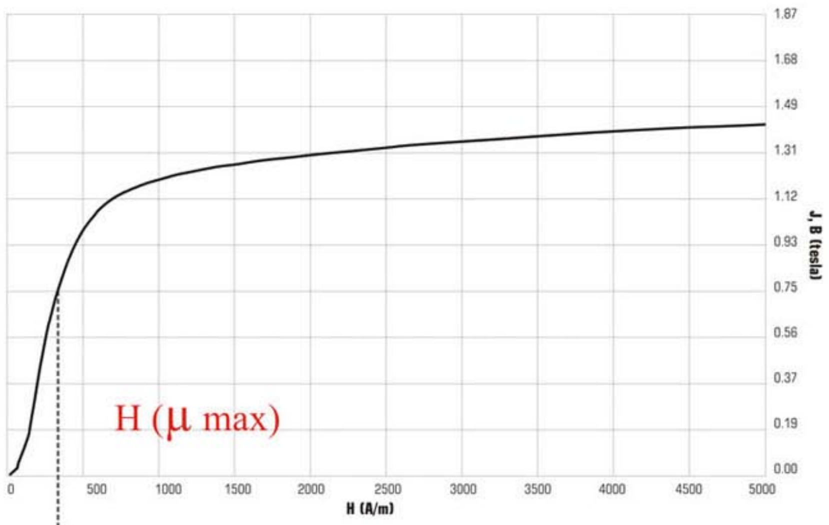
Magnetic properties criteria

The most important magnetic characteristics to consider for a right selection of all the magnetic grades should primarily be the **Saturation Induction Bs (J)**, the **Magnetic Permeability μ max** and the **Coercive Field Strength Hc** and, secondarily, the **Electrical Resistivity ρ** and the **Residual Induction Br.** Particularly, a low Coercitivity influences the capacity of a piece to have a fast magnetization - demagnetization avoiding adhesion effects; a higher Permeability allows the ability to obtain higher magnetic induction without resorting to large amount of electrical current. This results in dimensionally small magnetic devices and an important energy savings. The evaluation of magnetization curve allows one to know the value of Induction B at every value of H. This knowledge helps ensure the proper application of the correct material for the typical and useful zone of the magnetic appliance (that is from zero to *knee* of magnetization curve). Saturation Induction should be as high as possible in order to allow the magnetic devices to operate with low energy but it's important to point out that its value doesn't depend on magnetic annealing or fabrication process but basically on the chemical composition of steel. The more alloyed grades, the lower Saturation Induction. In the same way, Resistivity is strongly influenced by the alloy content. All Ferritic Stainless Steels have higher Resistivity than Electrical Iron and Fe-Si steel grades due to the content of main alloying elements Cr and Mo. A further increase of its values could be obtained by a Si addition. Resistivity has an important concern with a considerable reduction of eddy currents in AC circuits typical of solenoid valves.

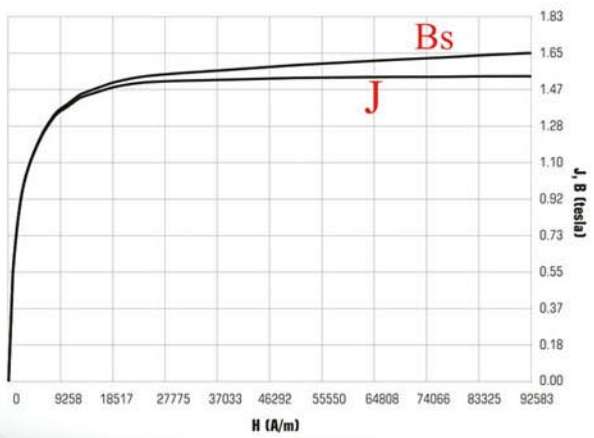
Hysteresis Loop



First Magnetization curve



First Magnetization Curve

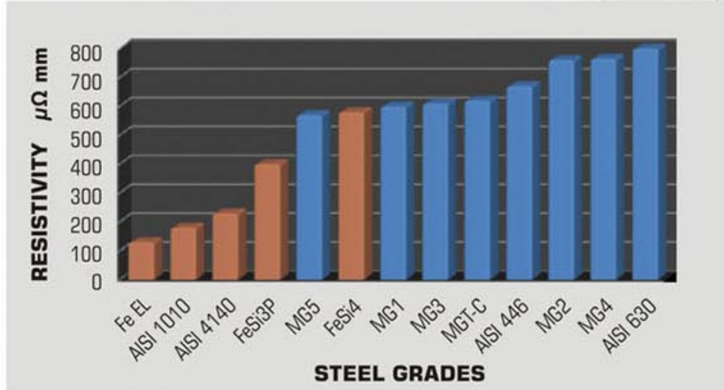


Magnetic Relative Permeability Curve

Magnetic Testing

All magnetic testing of bars or finished components are performed according to International Norms in force.
Magnetic properties are verified by a **Permeameter** and/or **Coercimeter.** It should be of knowledge that only the **Permeameter** provides a complete hysteresis loop B-H at various values of B, the magnetization curve, the magnetic permeability μ max and Coercive field strength Hc from values of low B up to higher as Bsat. (e.g.: Hc measured at B=1T).
Coercimeter provides only the value of Hc from Saturation Induction.

ALLOYS RESISTIVITY



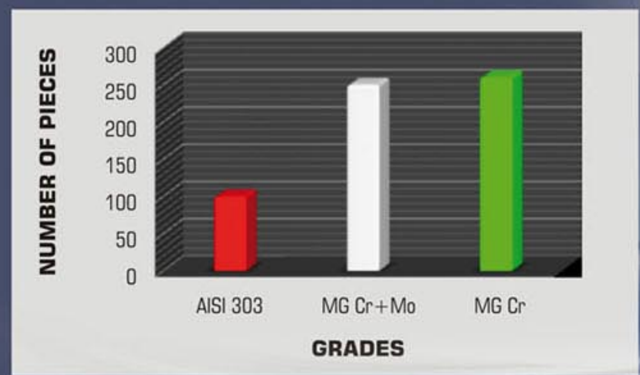
Alloys Machining

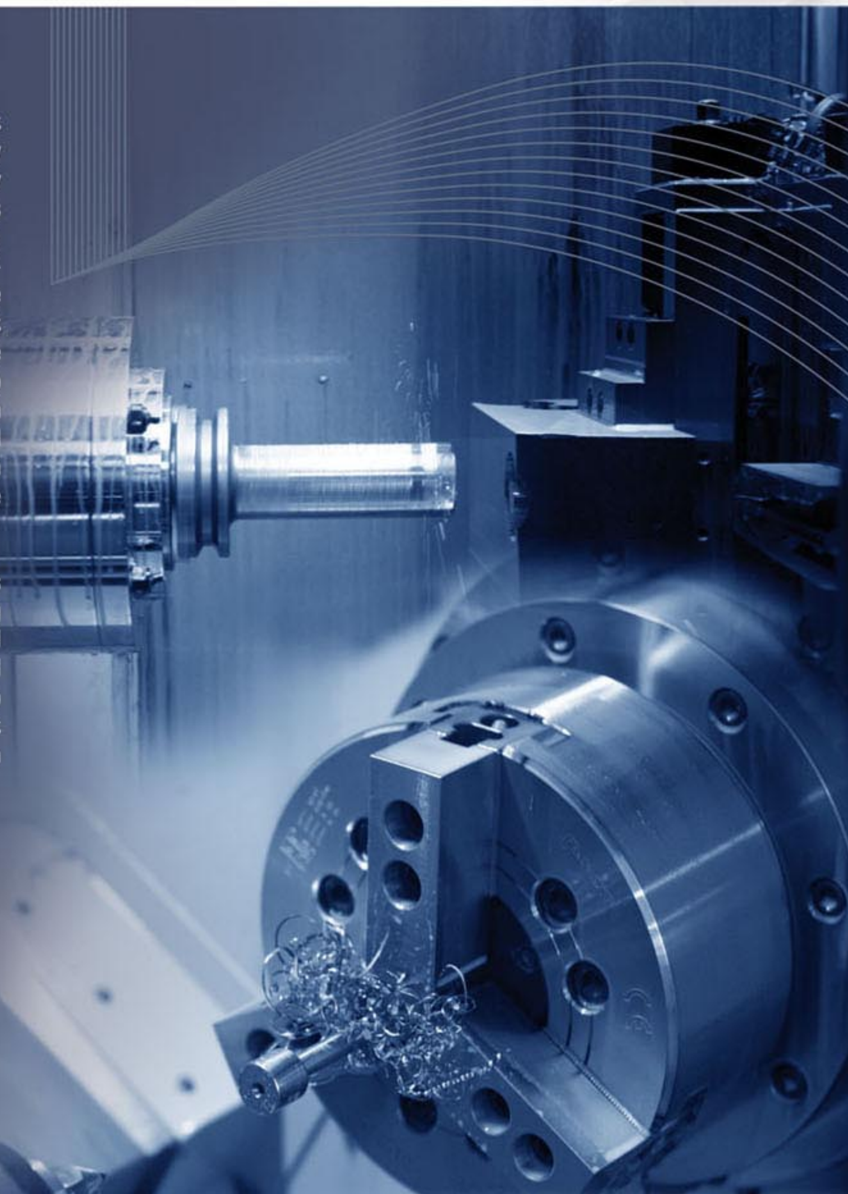
These alloys are the easiest of stainless steel to machine but some slight differences in machinability may exist between each MG grade. Productivity gain basically varies with cutting speed but it points out that machinability depends on many variables as type of machines, tools material, tools geometry, cutting fluids and kind of machine operations on the parts produced. As a rule, the lower Cr-alloy MG5 exhibits best machinability than higher Cr-alloy MG1 and MG2. The more corrosion resistant grades MG3 and MG4 have a machinability a little lower due to the higher Mo content necessary to inhibit the Sulfur effect. Grades MGC and MGT offer the higher corrosion resistance and a machinability nearly to the MG3. Nevertheless, it's important to consider that, in magnetic annealed condition, all grades have a large grain structure and very low hardness. This situation influences surface finish and chip morphology. Within certain limits, a little bit harder structure typical of a mill annealed and cold drawn bars, offers some advantages in some machine operation and better surface roughness.

Iron - Silicon alloys are more difficult to machine because their stringy chips and BUE tendency. This situation is typical of Fe-Si 4. A moderate cold working has a beneficial effect on chip-ability and reduction of BUE for either Fe-Si4 and Fe-Si3P. This last alloy shows the best machinability due to its micro resulfured structure in conjunction with a Phosphorous addition. Together, these two additions help the chip become embrittled allowing it to break in short segments. Cutting fluids and tool geometry are also important factors when working to overcome machining difficulty.

MACHINABILITY TEST

HSS tool, Cutting speed 50 mt/min, single-spindle lathe





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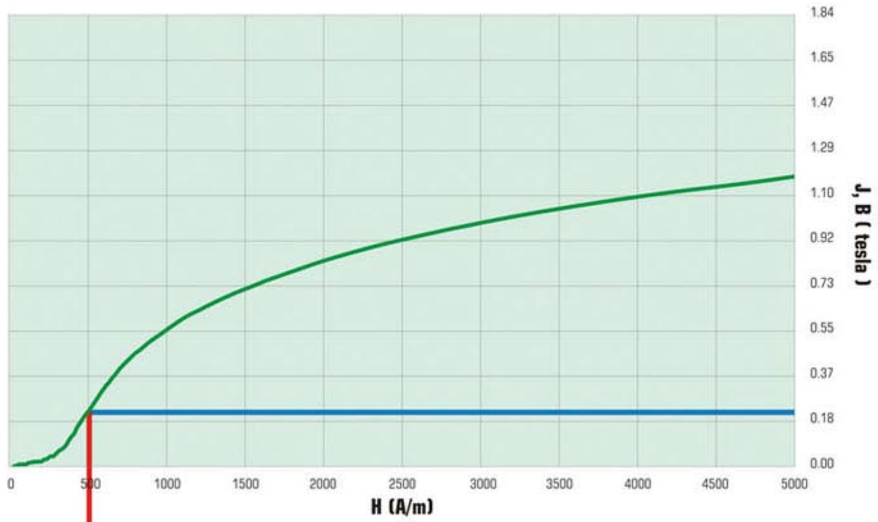
Processes and costs

The choice between several fabricating processes of electromechanical components should consider that any kind of strain hardening or cold deformation has a deleterious influence on magnetic properties. Consequently, a magnetic annealing of finished components or of bars must be carried out to obtain the required characteristics. The first one imposes a Hydrogen or vacuum or inert atmosphere annealing and shrewd evaluation of the stability of dimensional tolerances and surface condition of finished components; the second one provides fully magnetic annealed bars ready to be machined. Therefore, finished components don't need to be heat treated hence no loss of dimensional tolerances or resulting surface tint. Both executions should give the same results if components were annealed at the same temperature and same cooling parameters. This allows one to make the best choice examining the time and cost of each step of fabricating process of component.

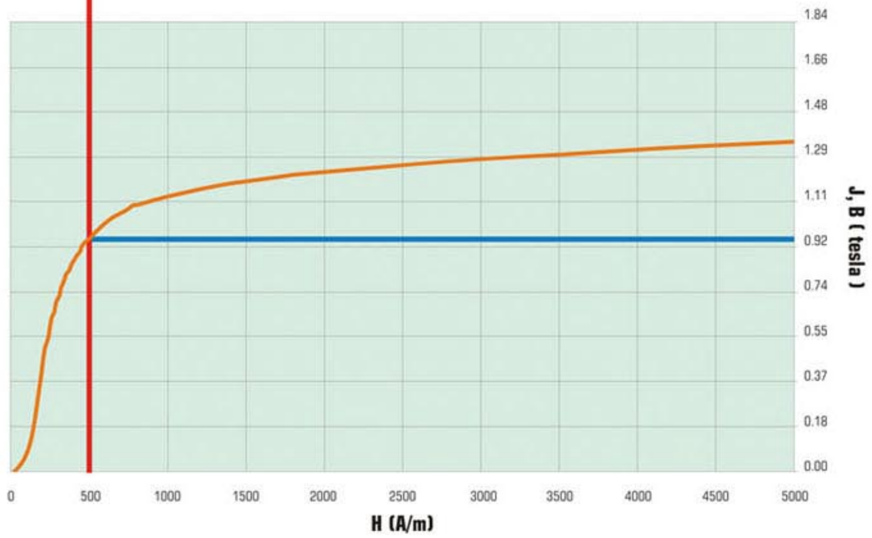
MG2 ANNEALED
COLD DRAWN
GROUND

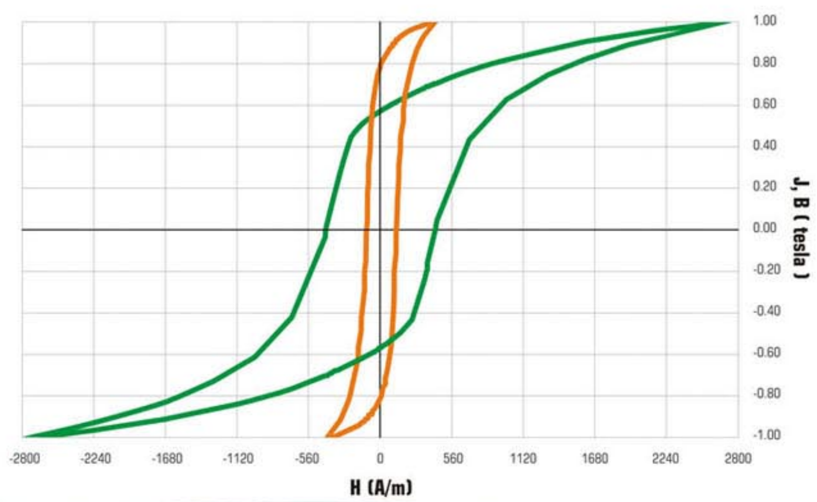
Hc = 424 A/M
H (μ max) = 813 A/M
μ max = 455
J = 1,54
Br = 0,57 T



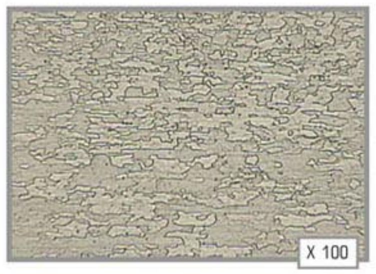
MG2 ANNEALED
COLD DRAWN
MAGNETIC ANNEALED
GROUND

Hc = 117 A/M
H (μ max) = 252 A/M
μ max = 1972
J = 1,54
Br = 0,80 T





MG2
COLD DRAWN
Grain size: 5



MG2 SOFT
MAGNETIC
ANNEALED
Grain size: 2

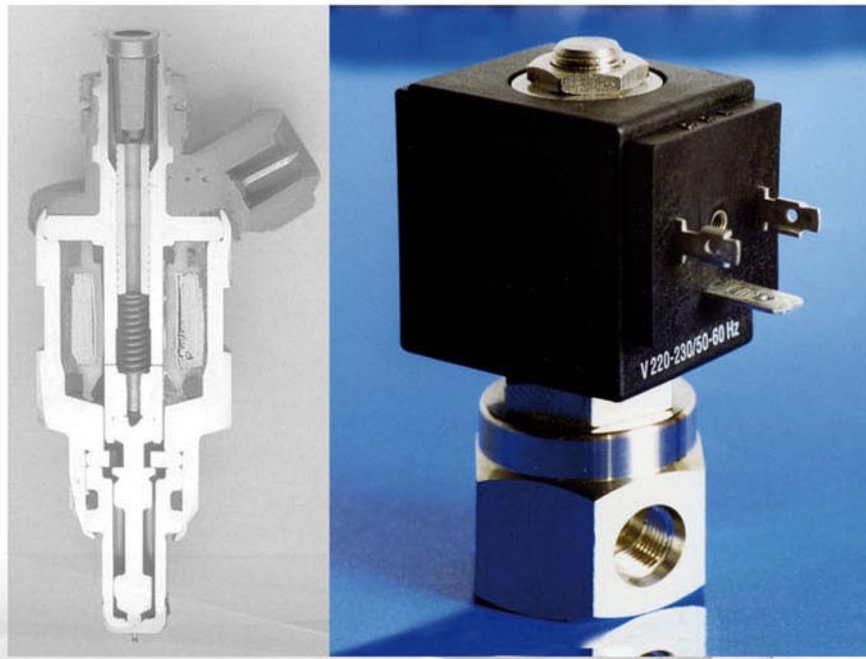
MAGIVAL®

Magival® is a group of free machining ferritic stainless steel designed for magnetic application requiring high magnetic permeabilty and low coercitivity. A carefully chemical analysis and special metallurgical processes have been developed to provide ferritic structures very sensitive to magnetic field after the magnetic annealing of bars avoiding an expensive heat treatment of components after machining.

Typical applications of these grades are:

- Solenoids valves, pole piece and magnetic core
- Electromagnetic pumps
- Electromagnetic devices
- Fuel injection components
- Electromagnetic switches and relays
- Antilock brake system
- Automotive application as sensors, actuators and fuel pumps

The free machining grades here described are normally preferred because of their machinability but other Standard Ferritic Stainless Steels are available (AISI 430L, AISI 434...) if the primary requirement is corrosion resistance.
The machinability of these Standard Ferritic Stainless Steels is poor if compared to Free Machining grades. Their micro-resulfuring can reduce the gap between the different machinability providing an improved corrosion resistance and weldability while the magnetic properties are similar or a little bit better.



MG GRADES WELDABILITY

MG is a group of Free Machining grades whose chemical balance was designed to obtain good magnetic properties along with a high productivity in machining processes. The most important element to improve machining performance is Sulfur whose capacity to prime and cause hot cracks and porosity in fuse zone is well-known to welding process: that is the reason why the whole Free Machining grades are not recommended for welding. Even if MG series have a very low content of C and N and/or right balance of Ti and Nb in order to decrease or avoid the formation of Austenite at highest temperature generated by high energy and rapid cooling of LW or GTAW so to that hardening due to Martensite formation is reduced, a carefully evaluation of grain size of HAZ and FZ boundaries in addition with typical large grain size of magnetic annealed parts or bars should be consider in terms of low ductility and toughness of weld zone whose restoring can only partly be done by PWHT.
In case of autogenous welds, low heat imputs are required while if a filler were used, a Ferritic grade filler should be chosen.
Austenitic filler to increase ductility of weld doesn't solve the problem in HAZ while a lowest magnetic permeability of Austenitic structure dramatically modified the magnetic flux behavior of weld zone in terms of flux leakage caused by highest difference between magnetic permeability.

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MG1 SOLENOID QUALITY

The best - known Free Machining grade with high machinability and corrosion resistance similar to 430F extensively used in automotive industries and soft magnetic components application.

C% max	Mn% max	Si%	Cr%	Ni% max	Mo%	P% max	S% max	N% max
0,030	0,30-0,60	0,30-0,60	17,25-18,25	0,30	0,20-0,35	0,030	0,25-0,35	0,030

Typical Physical Properties

Density (kg/dm^3)	7,62
Resistivity ($\mu\Omega$·mm)	600
Mean Coefficient of thermal expansion (20°- 500°C) ($10^{-6} \cdot K^{-1}$)	11,9
Curie Temperature (°C)	670
Modulus of Elasticity (KN/mm^2)	220

Mechanical Properties in the soft magnetic annealed condition*

Rm (N/mm^2)	484
Rp0,2 (N/mm^2)	323
A5%	36
RA%	72
Hardness Hrb	77-79

* measured on a specimen ø 9,00 mm

Magnetic Properties*

Saturation Flux Density Bs (Tesla)	1,69
Magnetic Permeability μ_{max}	1610
Coercive Field Strength Hc A/m ●	159
Residual Induction Br (Tesla) ●	0,80

* Measured on a specimen ø 9,00 mm
● Measured at 1T

Reference Norms

ASTM A 838 ALLOY 1
ASTM A 582 430 F
EN 10088-3; 1.4105

MG2 SOLENOID QUALITY

Free Machining grade with high machinability and corrosion resistance similar to 430F showing higher Permeability and lower Coercitivity than MG1 due to higher Silicon content. Its higher resistivity allows to reduce the eddy currents in those components using AC.

C% max	Mn% max	Si%	Cr%	Ni% max	Mo%	P% max	S% max	N% max
0,030	0,60	1,20-1,50	17,25-18,25	0,30	0,20-0,35	0,030	0,25-0,35	0,020

Typical Physical Properties

Density (kg/dm^3)	7,59
Resistivity ($\mu\Omega$·mm)	760
Mean Coefficient of thermal expansion (20°- 500°C) ($10^{-6} \cdot K^{-1}$)	11,9
Curie Temperature (°C)	660
Modulus of Elasticity (KN/mm^2)	220

Mechanical Properties in the soft magnetic annealed condition*

Rm (N/mm^2)	504
Rp0,2 (N/mm^2)	337
A5%	35
RA%	67
Hardness Hrb	81-83

* measured on a specimen ø 9,00 mm

Magnetic Properties*

Saturation Flux Density Bs (Tesla)	1,65
Magnetic Permeability μ_{max}	1840
Coercive Field Strength Hc A/m ●	125
Residual Induction Br (Tesla) ●	0,81

* Measured on a specimen ø 9,00 mm
● Measured at 1T

Reference Norms

ASTM A 838 ALLOY 2

MG3 SOLENOID QUALITY

Free Machining grade with similar magnetic properties than MG1 but with better pitting corrosion resistance due to its Mo content allowing applications in mild corrosive environments.

C% max	Mn% max	Si%	Cr%	Ni% max	Mo% max	P% max	S% max	N% max
0,025	0,50	0,60-1,00	17,50-18,25	0,30	1,50-2,00	0,030	0,25-0,35	0,030

Typical Physical Properties

Density (kg/dm^3)	7,80
Resistivity ($\mu\Omega$·mm)	610
Mean Coefficient of thermal expansion (20°- 500°C) ($10^{-6} \cdot K^{-1}$)	11,1
Curie Temperature (°C)	670
Modulus of Elasticity (KN/mm^2)	220

Mechanical Properties in the soft magnetic annealed condition*

Rm (N/mm^2)	510
Rp0,2 (N/mm^2)	345
A5%	34
RA%	65
Hardness Hrb	81-83

* measured on a specimen ø 9,00 mm

Magnetic Properties*

Saturation Flux Density Bs (Tesla)	1,67
Magnetic Permeability μ_{max}	1600
Coercive Field Strength Hc A/m ●	165
Residual Induction Br (Tesla) ●	0,78

* Measured on a specimen ø 9,00 mm
● Measured at 1T

Reference Norms

ASTM A 582 XM34
W.Nr. 1.4114

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MG4 SOLENOID QUALITY

Free Machining grade with similar magnetic properties than MG2 but with better pitting corrosion resistance due to its Mo content allowing applications in mild corrosive environments. Its higher Resistivity allows to reduce the eddy currents in AC applications.

C% max	Mn% max	Si%	Cr%	Ni% max	Mo% max	P% max	S% max	N% max
0,020	0,30-0,60	1,25-1,50	18,00-18,50	0,250	1,50-2,00	0,030	0,25-0,35	0,020

Typical Physical Properties

Density (kg/dm³)	7,78
Resistivity ($\mu\Omega$·mm)	765
Mean Coefficient of thermal expansion (20°- 500°C) ($10^{-6} \cdot K^{-1}$)	12
Curie Temperature (°C)	680
Modulus of Elasticity (KN/mm²)	220

Mechanical Properties in the soft magnetic annealed condition*

Rm (N/mm²)	542
Rp0,2 (N/mm²)	380
A5%	35
RA%	67
Hardness Hrb	81-83

* Measured on a specimen ø 9,00 mm

Magnetic Properties*

Saturation Flux Density Bs (Tesla)	1,61
Magnetic Permeability μ_{max}	1410
Coercive Field Strength Hc A/m ●	134
Residual Induction Br (Tesla) ●	0,75

* Measured on a specimen ø 9,00 mm
● Measured at 1T

Reference Norms

≈ ASTM A 838 ALLOY 2 + Mo
W.Nr. 1.4106

MG5 SOLENOID QUALITY

Free Machining grade with high magnetic properties and machinability but with lower corrosion resistance than 17%Cr MG series.
Widely used in the automotive injection system.

C% max	Mn% max	Si% max	Cr%	Ni% max	Mo% max	P% max	S% max	N% max
0,025	0,75-1,50	0,50-1,00	12-13	0,30	0,30-0,60	0,045	0,25-0,35	0,025

Typical Physical Properties

Density (kg/dm³)	7,70
Resistivity ($\mu\Omega$·mm)	570
Mean Coefficient of thermal expansion (20°- 500°C) ($10^{-6} \cdot K^{-1}$)	12
Curie Temperature (°C)	720
Modulus of Elasticity (KN/mm²)	220

Mechanical Properties in the soft magnetic annealed condition*

Rm (N/mm²)	420
Rp0,2 (N/mm²)	250
A5%	37
RA%	60
Hardness Hrb	76-77

* Measured on a specimen ø 9,00 mm

Magnetic Properties*

Saturation Flux Density Bs (Tesla)	1,85
Magnetic Permeability μ_{max}	1739
Coercive Field Strength Hc A/m ●	129
Residual Induction Br (Tesla) ●	0,72

* Measured on a specimen ø 9,00 mm
● Measured at 1T

Reference Norms

≈ EN 10088-3; 1.4005

MGC SOLENOID QUALITY

Free Machining grade with similar corrosion resistance and magnetic properties than MGT but with better machinability.

C% max	Mn% max	Si% max	Cr%	Ni% max	Mo% max	P% max	S% max	N% max	Nb%
0,020	0,50	0,85-1,00	17,50-18,00	0,30	1,70-1,80	0,025	0,30-0,35	0,020	0,25-0,30

Typical Physical Properties

Density (kg/dm³)	7,70
Resistivity ($\mu\Omega$·mm)	620
Mean Coefficient of thermal expansion (20°- 500°C) ($10^{-6} \cdot K^{-1}$)	12
Curie Temperature (°C)	720
Modulus of Elasticity (KN/mm²)	220

Mechanical Properties in the soft magnetic annealed condition*

Rm (N/mm²)	520
Rp0,2 (N/mm²)	345
A5%	35
RA%	61
Hardness Hrb	82-83

* Measured on a specimen ø 9,00 mm

Magnetic Properties*

Saturation Flux Density Bs (Tesla)	1,67
Magnetic Permeability μ_{max}	1577
Coercive Field Strength Hc A/m ●	167
Residual Induction Br (Tesla) ●	0,81

* Measured on a specimen ø 9,00 mm
● Measured at 1T

Reference Norms

≈ W.Nr. 1.4114 + Nb

MGT SOLENOID QUALITY

Free Machining grade with magnetic properties as MG4 but with better pitting and crevice corrosion resistance due to its Mo and Ti contents allowing applications in more severe corrosive environments. Similar machinability than MG4.

C% max	Mn% max	Si% max	Cr%	Ni% max	Mo% max	P% max	S% max	N% max	Ti%
0,025	0,50	1,00	17,50-19,00	0,30	2,00-2,50	0,040	0,25-0,35	0,025	0,30-0,70

Typical Physical Properties

Density (kg/dm^3)	7,7
Resistivity ($\mu\Omega$·mm)	620
Mean Coefficient of thermal expansion (20°- 500°C) ($10^{-6}\cdot K^{-1}$)	11,9
Curie Temperature (°C)	680
Modulus of Elasticity (KN/mm^2)	220

Mechanical Properties in the soft magnetic annealed condition*

Rm (N/mm^2)	540
Rp0,2 (N/mm^2)	350
A5%	34
RA%	58
Hardness Hrb	82-84

* Measured on a specimen ø 9,00 mm

Magnetic Properties*

Saturation Flux Density Bs (Tesla)	1,66
Magnetic Permeability μ_{max}	1849
Coercive Field Strength Hc A/m ●	112
Residual Induction Br (Tesla) ●	0,71

* Measured on a specimen ø 9,00 mm
● Measured at 1T

Reference Norms

EN 10088-3; 1.4523

Ferritic and other grades available on request

IRON SILICON ALLOYS

These Fe-Si grades are used in fabrication of electro mechanical devices requiring better magnetic properties than provided by soft magnetic LC Iron and Free Machining Stainless Steels as Magival®. Where corrosion isn't a concern and the highest permeability is a primary target, the choice of these alloys yields the best results in making of fuel injectors, solenoids switches and relays. Main steel types are identified by Silicon content in order to make an easy comparison of the Valbruna trade-mark to their chemical analysis. Some grades are micro-resulfured in addition to higher contents of Phosphorus in order to improve machinability because the typical and soft ferritic structure is difficult to machine due to a built-up-edge and poor chip-ability. Since the Fe-Si alloys are normally supplied in mill annealed and cold worked condition, the machined parts or components must be magnetic annealed in vacuum or protective atmosphere to obtain the best magnetic properties and a protective coating must immediately be applied on their surface due to their rusting rate.

VALBRUNA GRADE	ASTM
FeSi1P	ASTM A 867 - TYPE 1F
FeSi3	ASTM A 867 - TYPE 2
FeSi3P	ASTM A 867 - TYPE 2F
FeSi4	ASTM A 867 - TYPE 3

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FeSi3P Iron - Silicon Steel

Fe-Si alloy with enhanced machinability due to sulfur additions and P content allowing an important reduction of typical difficulties in this process. No significant influence on magnetic properties compared to standard alloys. High Resistivity with highest value of magnetic permeability and lowest coercitivity have brought this alloy to become the best choice in making relays, pole piece, solenoids switches and fuel injectors. Normally supplied in mill annealed and cold worked condition. Soft magnetic annealing in a protective atmosphere should be carried out to obtain the best magnetic properties .
One should note that Fe-Si alloys are not stainless grades and rust quickly if not immediately protected by coating after magnetic annealing of finished parts.

C% max	Mn% max	Si%	Cr% max	Ni% max	Mo% max	P%	S% max
0,030	0,50	2,50-3,00	0,10	0,050	0,050	0,10-0,15	0,020-0,035

Typical Physical Properties

Density (kg/dm^3)	7,65
Resistivity ($\mu\Omega$·mm)	400
Mean Coefficient of thermal expansion (20°- 400°C) ($10^{-6} \cdot K^{-1}$)	13,2
Curie Temperature (°C)	750

Mechanical Properties in the annealed and cold drawn condition*

Rm (N/mm^2)	719
Rp0,2 (N/mm^2)	668
A4%	26
RA%	72
Hardness HB	216

* Measured on a specimen ø 11,00 mm

Magnetic Properties*

Saturation Flux Density Bs (Tesla)	2,05
Magnetic Permeability μ max (straight length specimen)	5027
Coercive Field Strength Hc A/m ●	56
Residual Induction Br (Tesla) ●	0,73

* Measured on a specimen ø 18,00 mm soft magnetic annealed according to ASTM A 867
● Measured at 1T

Reference Norms

ASTM A 867 - TYPE 2F

FeSi4 Iron - Silicon Steel

Fe-Si grade with the highest resistivity between the alloys included in ASTM A 867. This characteristic together with low values of coercitivity strongly reduces the eddy currents effects in AC circuits. Pole piece and relays are the main magnetic devices where this alloy has found applications.
Machinability is poor compared to FeSi3P but this gap could be partly filled with an accurate choice of tools and cutting fluids. Normally supplied in mill annealed and cold worked condition. Soft magnetic annealing in a protective atmosphere should be carried out to obtain the best magnetic properties.
Naturally, all Fe-Si alloys are not stainless grades and rust quickly if not immediately protected by coating after magnetic annealing of finished parts.

C% max	Mn% max	Si%	Cr% max	Ni% max	Mo% max	P%	S% max
0,030	0,20-0,30	3,80-4,20	0,10	0,050	0,050	0,030	0,020-0,030

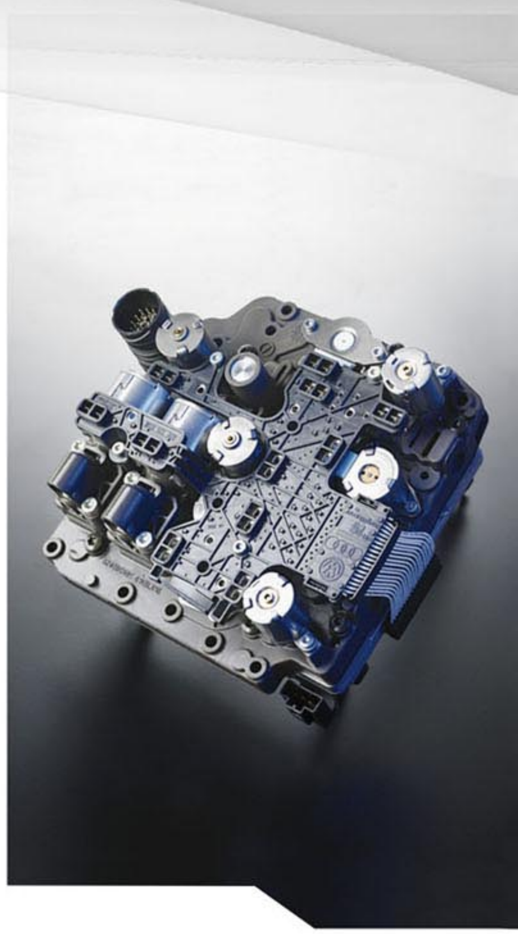
Typical Physical Properties

Density (kg/dm^3)	7,60
Resistivity ($\mu\Omega$·mm)	580
Mean Coefficient of thermal expansion (20°- 400°C) ($10^{-6} \cdot K^{-1}$)	13,5
Curie Temperature (°C)	730

Mechanical Properties in the annealed and cold drawn condition*

Rm (N/mm^2)	628
Rp0,2 (N/mm^2)	448
A4%	23
RA%	66
Hardness HB	190

* Measured on a specimen ø 14,00 mm



Magnetic Properties*

Saturation Flux Density Bs (Tesla)	2,02
Magnetic Permeability μ max (straight length specimen)	4054
Coercive Field Strength Hc A/m ●	54
Residual Induction Br (Tesla) ●	0,71

* Measured on a specimen ø 18,00 mm soft magnetic annealed according to ASTM A 867
● Measured at 1T

Reference Norms

ASTM A 867 - TYPE 3

ACCIAIERIE VALBRUNA
High quality is our standard