Revised 2022/07

ACCIAIERIE VALBRUNA
High quality is our standard

ACCIAIERIE VALBRUNA
Viale della Scienza, 25 36100 Vicenza - ITALY
Tel. +39 0444 968211 Fax +39 0444 963836
www.valbruna-stainless-steel.com

ACCIAIERIE VALBRUNA
Via Volta, 4 39100 Bolzano - ITALY
Tel. +39 0471 924111 Fax +39 0471 924497

VALBRUNA SLATER STAINLESS INC.
2400 Taylor Street West 46801 Fort Wayne, IN - USA
Tel. +1 (260) 434 2800 Fax +1 (260) 434 2801
www.valbrunastainless.com
e-mail: info@valbruna.us

VALBRUNA ASW INC.
42 Centre Street L3B 0E5 Welland, ON - CANADA
Tel. +1 (905) 735 5500 Fax. +1 (905) 735 4603
www.asw-steel.com
e-mail: InfoValbrunaASW@ValbrunaASW.ca

MAGIVAL
HIGH LEVEL OF MAGNETIC PERFORMANCE

www.valbruna-stainless-steel.com

HIGH LEVEL OF MAGNETIC PERFORMANCE

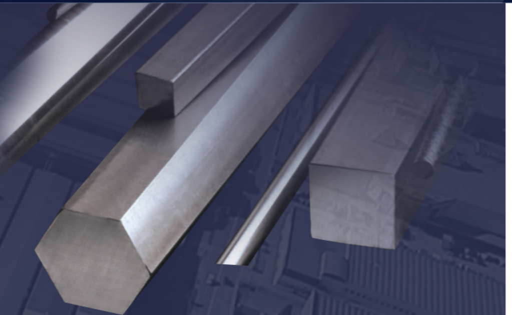
SOFT MAGNETIC STEELS

Stainless Steels & Silicon Iron Alloys

MAGIVAL®
HIGH LEVEL OF MAGNETIC PERFORMANCE

ACCIAIERIE VALBRUNA
High quality is our standard

STAINLESS AND SPECIALTY STEELS



SOFT MAGNETIC STEELS

Stainless Steels & Silicon Iron Alloys

Valbruna, founded in 1925 and leader in the production of Stainless Steels, Nickel Alloys and Titanium long products is underpinned by long experience, as well as highly qualified Customer Service team. Our extensive distribution network ensures a strategic presence within the market, while receiving constant feedback from Our Customers worldwide.

Mills

ITALY: Vicenza, Bolzano

USA: Fort Wayne

CANADA: Welland

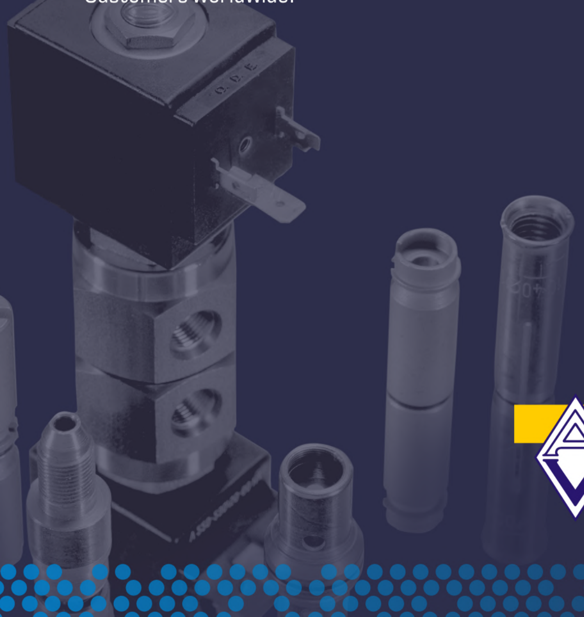
ITALY	**EUROPE**	**AMERICA**
Ancona	Czech Republic	Canada
Bologna	Denmark	Mexico
Brescia	Finland	United States
Milano	France	**ASIA - OCEANIA**
Parma	Germany	Australia
Torino	Ireland	Hong Kong
Treviso	Nederland	India
	Norway	Malaysia
	Poland	Turkey
	Spain	UAE
	Sweden	**AFRICA**
	Switzerland	South Africa
	United Kingdom	

Vicenza plant, ITALY
(Total surface: 294.608 m²)

Bolzano plant, ITALY
(Total surface: 197.049 m²)

Fort Wayne plant, IN-USA
(Total surface: 248.356 m²)

Welland plant, ON-CANADA
(Total surface: 339.288 m²)



ACCIAIERIE VALBRUNA
High quality is our standard

SOFT MAGNETIC STAINLESS STEELS

Ferritic Steels (FS) are so named because their body-central-cubic structure is the same as Iron at room temperature and they have a ferromagnetic behavior.

Ferritic Stainless Steels (FSS) are widely known for their good magnetic properties combined with considerable corrosion resistance. They are not comparable to the Silicon-Iron alloys, that reach a high level of magnetic performance, but FSS are definitely the best choice when corrosion resistance is an important requirement.

The design of any magnetic device requires knowledge of utilized steel properties in terms of their metallurgical and magnetic behavior with a specific focus on corrosion resistance.

Therefore, it is mandatory to properly evaluate:

A) The best achievable magnetic properties and evaluation of the most important parameters in relation to requested performance and application

B) The machinability performances

C) The degree of corrosion resistance in service in a corrosive environment

D) The production cycle and relevant costs

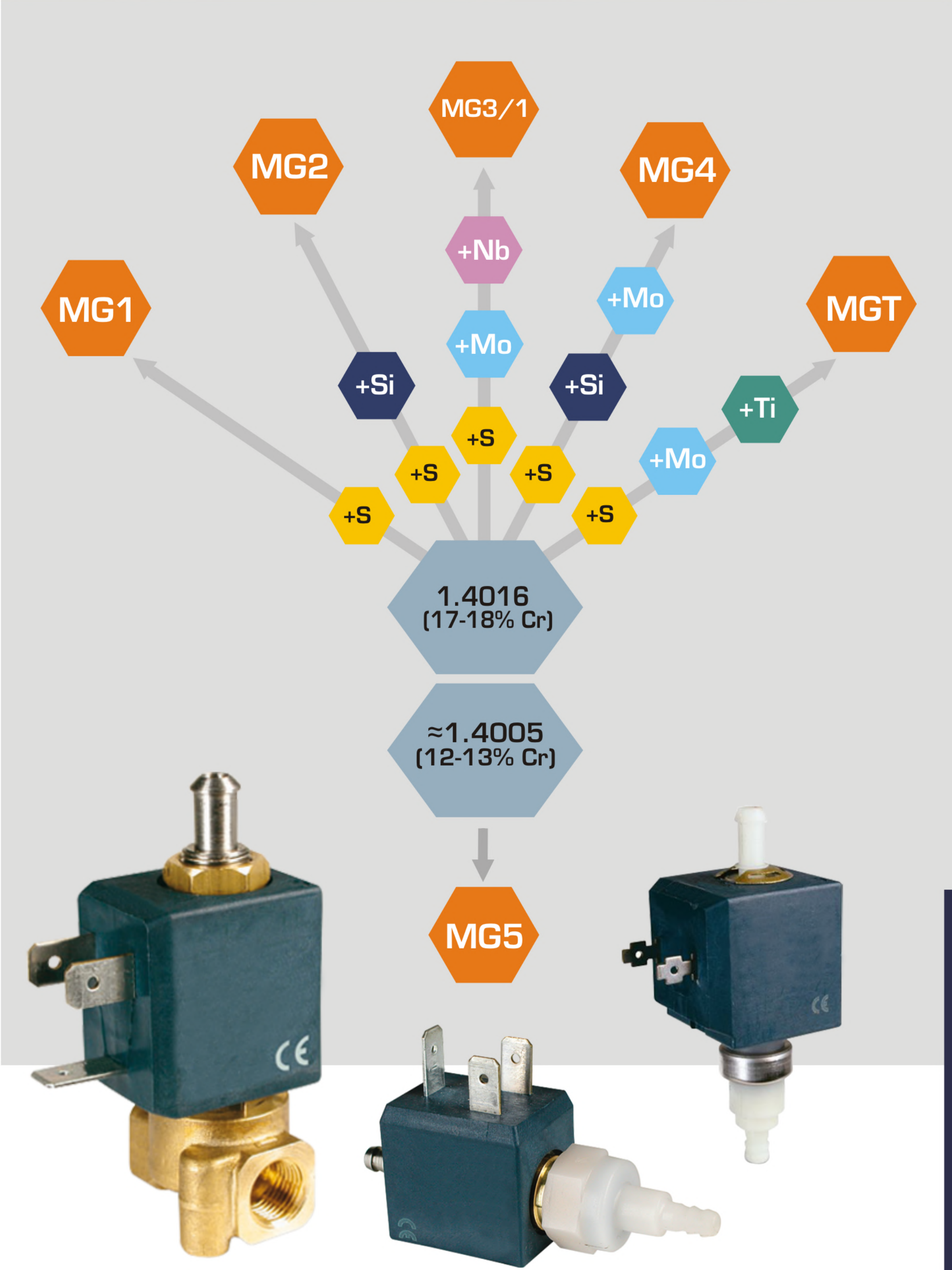
MAGIVAL
HIGH LEVEL OF MAGNETIC PERFORMANCE

Magival® is the Valbruna product line for free machining ferritic stainless steel designed for magnetic applications requiring high magnetic permeability and low coercivity. A carefully balanced chemical analysis and a special metallurgical process have been developed in order to obtain ferritic structures with high sensitivity to magnetic fields after magnetic annealing of bars, avoiding an expensive heat treatment of components after machining. Typical applications of these grades are:

- **Solenoid valves, pole pieces and magnetic cores**
- **Electromagnetic pumps**
- **Electromagnetic devices**
- **Electromagnetic switches and relays**
- **Antilock brake system**
- **Automotive applications: fuel injection components, sensors, actuators and fuel pumps**

Starting from the Standard Ferritic Stainless Steel grade 1.4016 (AISI 430L), Valbruna has developed the Magival® grades to satisfy a wide range of applications, thanks to their different characteristics aimed to provide:

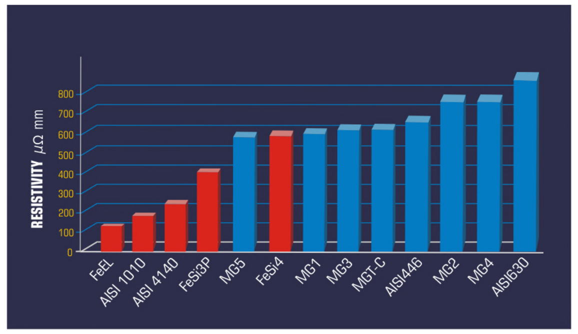
- Corrosion resistance (increasing the Mo content)
- Magnetic properties and resistivity (increasing the Si content)
- Machinability (increasing the S content)



All **Magival**® grades are available without soft magnetic annealing (potentially with a different grade name) as well, if customers application do not require high magnetic properties. For example, MG3/1 is widely used in such a condition for beverage dispenser pumps or, alternatively, soft magnetic annealing is run on machined components.

Magnetic properties criteria

When choosing a magnetic grade, the most important magnetic characteristics to consider should be the **Saturation Induction Bs (Js)**, the **Magnetic Relative Permeability $\mu_{r\ max}$** and the **Coercive Field Strength Hc**. Secondly, it is worth taking into consideration the **Electrical Resistivity ρ**.



Low Coercivity positively influences the capability 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 translates into smaller magnetic devices and significant energy savings.

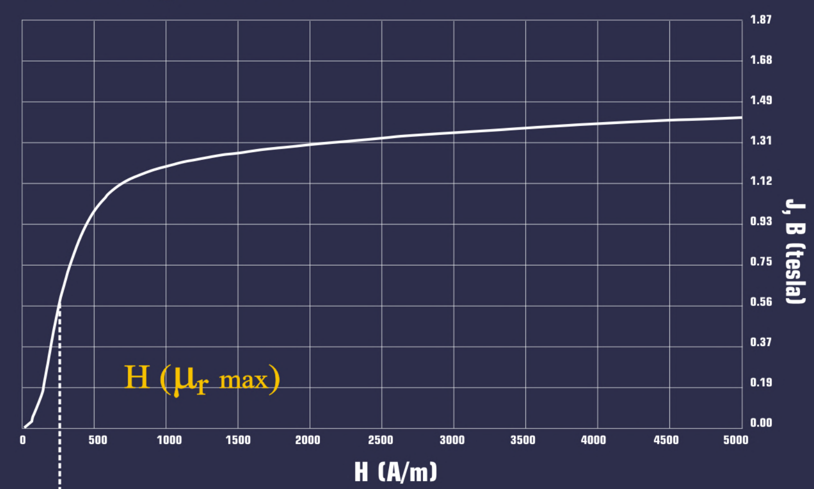
The evaluation of the first magnetization curve allows to acquire the value of Induction B at every value of magnetic field H. This knowledge helps to ensure the usage of proper material for the typical and useful area of the magnetic appliance (that is from zero to the knee of magnetization curve)

Saturation Induction should be as high as possible in order to allow the magnetic devices to operate with low energy. However, it is mandatory to underline that its value does not depend on magnetic annealing or on fabrication process, rather than basically on the chemical composition of each steel. More alloyed the grades, lower the Saturation Induction. Resistivity is strongly influenced by the alloy content as well. All Ferritic Stainless Steels have higher Resistivity than Electrical Iron and Fe-Si steel grades due to the content of main alloying elements such as Cr and Mo. A further increase of its values could be obtained by a Si addition. Resistivity has a significant influence on the possible reduction of eddy currents in AC circuits that are typical of solenoid valves.

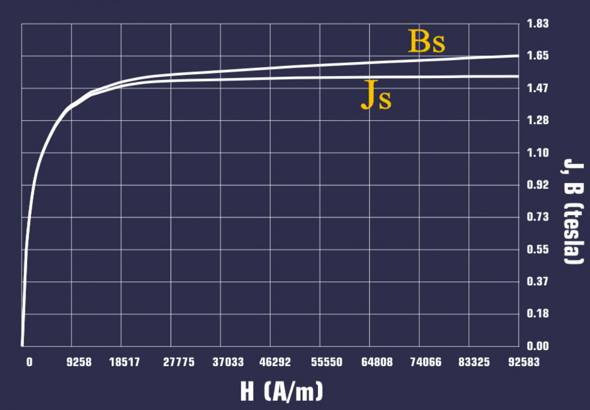
Magnetic Testing

Magnetic tests are performed according to ASTM A341/341M. Magnetic properties are verified by a Permeameter that provides a complete set of information such as the first magnetization curve (in saturation and at different H values), the magnetic relative permeability and the hysteresis loop.

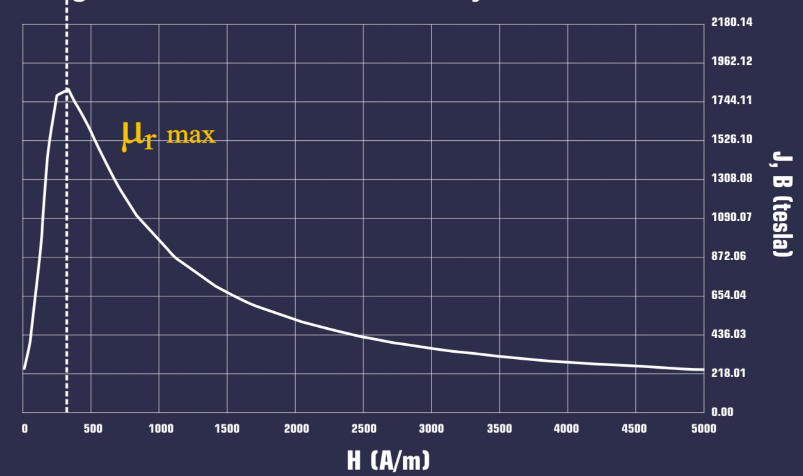
First Magnetization Curve



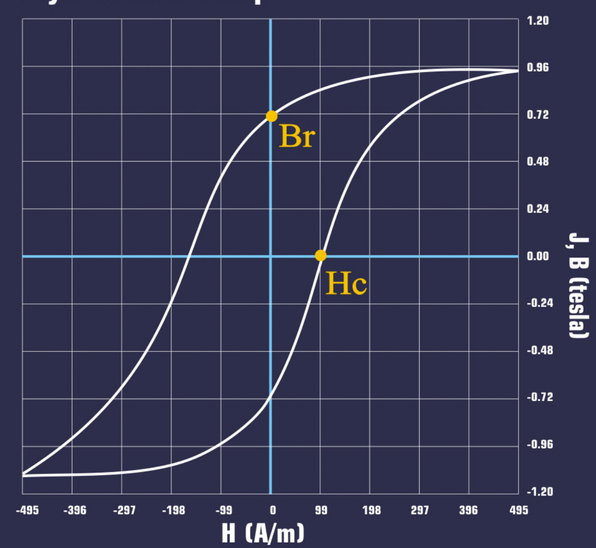
First Magnetization Curve in Saturation



Magnetic Relative Permeability Curve



Hysteresis Loop

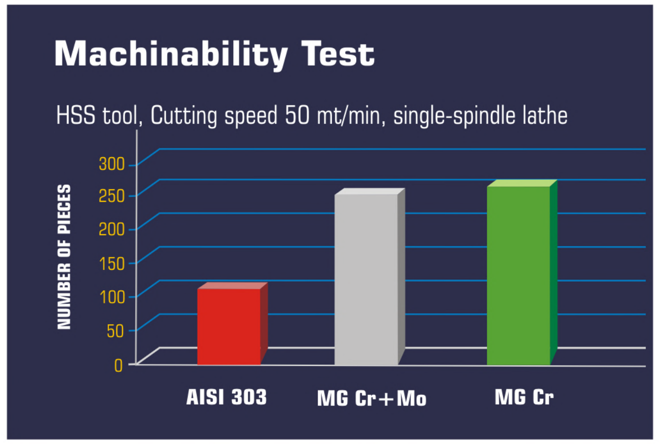


Machinability

These alloys are well known for their high machinability performance: there are slight differences through the grades, but in principle the machinability depends on many variables, such as the type of machines, tools material and geometry, cutting fluids, machine operations to produce the parts. As a general rule, lower Cr-alloy such as MG5 shows greater machinability than higher Cr-alloy, such as MG1 and MG2. Grades with higher corrosion resistance, MG3 and MG4, show slightly worse machinability due to the higher Mo. The grade MGT offers the highest corrosion resistance and a machinability performance comparable to MG3.

It is worth highlighting that, in the magnetic annealed condition, all grades have a coarse grain size and very low hardness with a possible negative effect on surface finishing and chip morphology. Within certain limits, a slightly harder structure - typical of a mill annealed and cold drawn bars - offers some advantages during machine operations and a better surface roughness.

Silicon Iron alloys are more difficult to machine due to their stringy chips and the formation of the Built Up Edge (BUE). This situation is typical of Fe-Si4. A moderate cold working has a positive effect on chips breakability and reduction of BUE for either Fe-Si4 and Fe-Si3P. This last alloy shows the best machinability due to its micro re-sulfured structure, together with the addition of Phosphorus. These adjustments help chip embrittlement, allowing it to break in short segments. Cutting fluids and tool geometry are always key factors to overcome machining challenges.

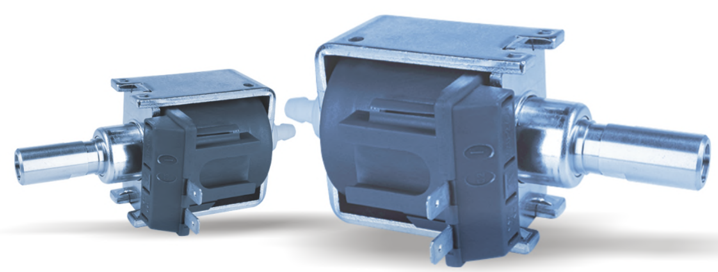


Corrosion resistance criteria

Corrosion resistance depends on the following key factors:

- **Chemical composition, especially Cr and Mo content**
- **Level of interstitial elements such as C and N**
- **Heat treatment**

In general, the more Cr and Mo with an addition of N, and a low C content, the more resistance to pitting and crevice corrosion is obtained. In free machining grades (FM), Sulfur is added to improve machinability and its influence on corrosion should be carefully evaluated, since MnS inclusions could trigger points of pitting when exposed to corrosive environments. By contrast, FM grades alloyed with Ti do not suffer from this local attack and also show good resistance to intergranular corrosion. Generally, all Ferrite grades have a higher resistance to stress corrosion cracking than Austenitic ones. Nevertheless, to achieve the best corrosion resistance, the surface of finished blanks should be free of tint, contaminants as cutting fluid, iron particles, dirt and scale. A final passivation is recommended.



Processes and costs

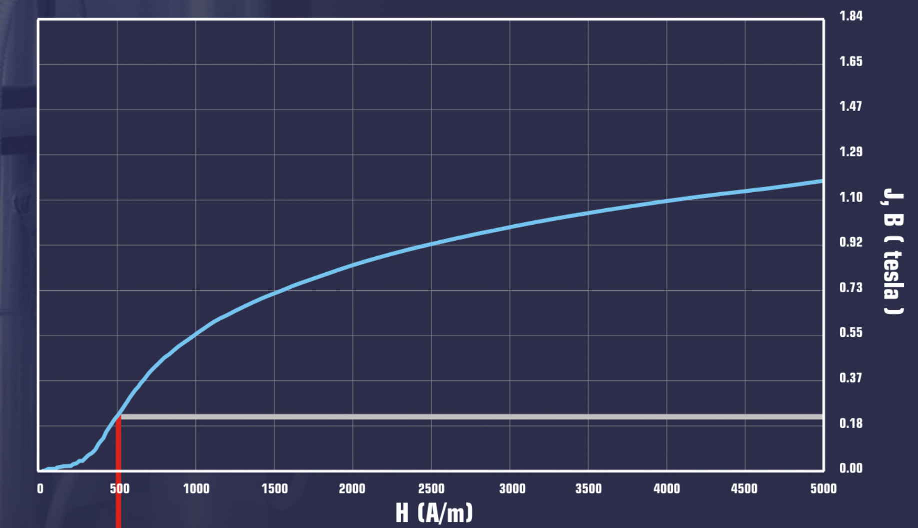
The choice among multiple designs and manufacturing processes of electromechanical devices should always keep into consideration that any kind of strain hardening or cold deformation on the material in use has a deleterious influence on magnetic properties. Therefore, in order to obtain the required characteristics for the best device performance, it must be carefully evaluated whether a magnetic annealing of finished machined components is required; under certain circumstances, the use of magnetic annealed bars can be satisfactory.

The first requires an inert annealing atmosphere (Hydrogen or vacuum) and a careful evaluation of dimensional tolerances stability as well as surface condition of finished components. The second option provides fully magnetic annealed bars ready to be machined; therefore, finished components do not need to be heat treated after machining with no risk of dimensional tolerances variation or surface tint. The choice depends on time & cost of the production process to obtain the final component.

Below data and graphics refer to tests carried out on a sample of Valbruna grade MG2 Ø 10 mm.

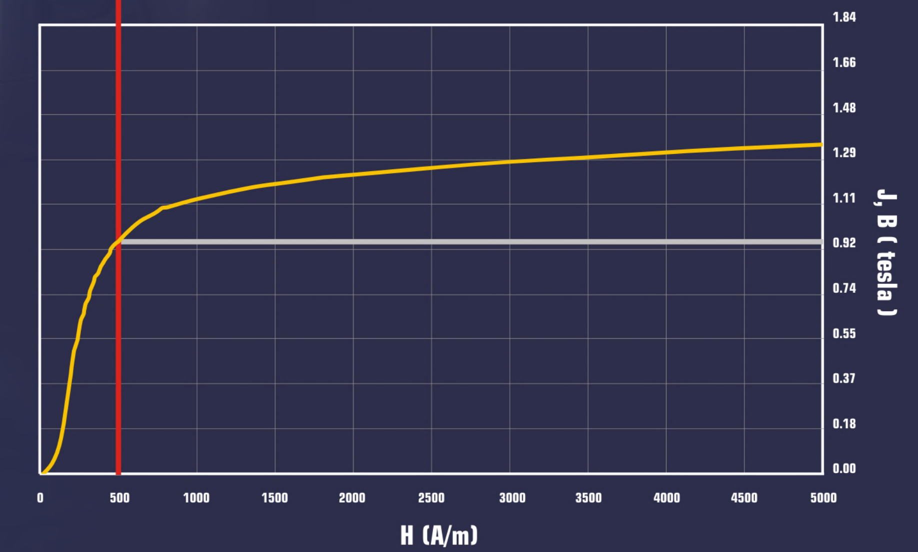
ANNEALED IN COILS
COLD DRAWN COIL TO BARS
GROUND

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



ANNEALED IN COILS
COLD DRAWN COIL TO BARS
SOFT MAGNETIC ANNEALED
GROUND

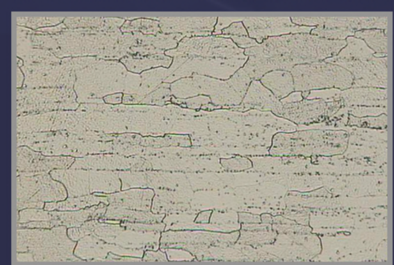
Hc = 117 A/m
H (μ max) = 252 A/m
μ max = 1972
Js = 1,54
Br = 0,80 T



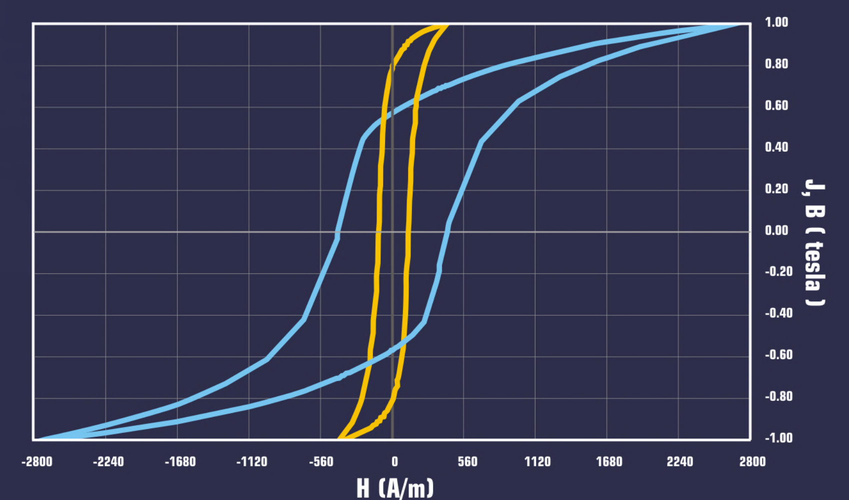
MG2 COLD DRAWN Grain size: 5

X 100

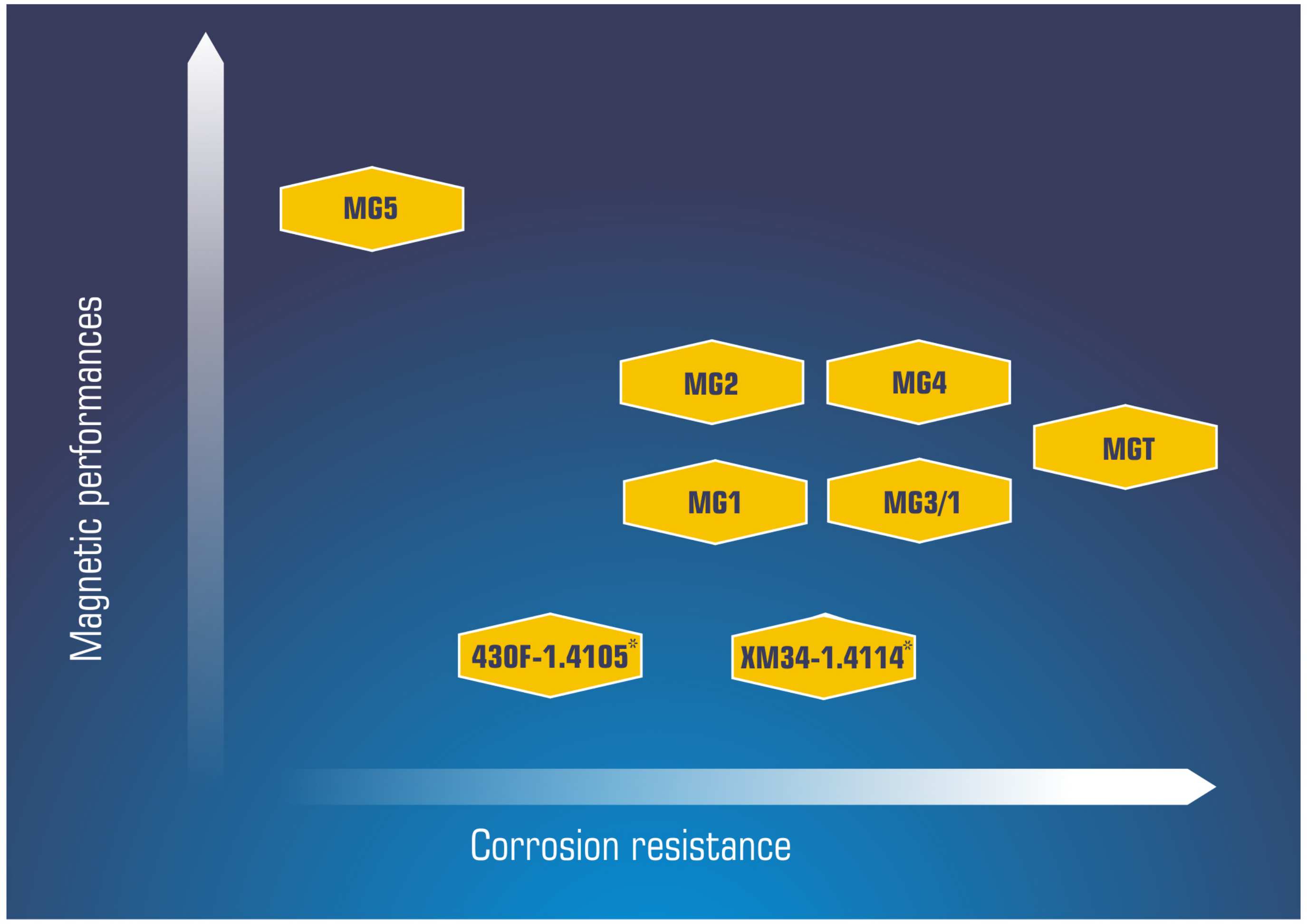
MG2 SOFT MAGNETIC ANNEALED Grain size: 2



X 100



MAGNETIC PROPERTIES VS CORROSION RESISTANCE
Relative behaviors of Valbruna grades



*Not soft magnetic annealed

This picture is Bosch registered and fully proprietary

MAGIVAL® GRADES TECHNICAL DATA

MG1 SOFT MAGNETIC ANNEALED

C% max	Mn%	Si%	Cr%	Ni% max	Mo%	P% max	S%	N% max
0,030	0,30-0,60	0,30-0,60	17,25-18,00	0,30	0,25-0,35	0,030	0,25-0,30	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} · K^{-1})	11,9
Curie Temperature (°C)	670
Modulus of Elasticity (GPa)	220

Typical Mechanical Properties

Rm (N/mm^2)	400-650
Rp0,2 (N/mm^2)	250 min.
E5d%	25 min.
Hardness HRB	75-90

Typical Magnetic Properties*

Saturation Flux Density Bs(T)	>1,6
Magnetic Relative Permeability $\mu_{r\ max}$	>1200
Coercive Field Strength Hc (A/m) ●	<240
Residual Induction Br (Tesla) ●	<0,85

● Induction at 1T
* Values could vary according to different size range and production cycle

Standard Reference

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

Data are purely indicative and represent typical properties only; therefore, data shall not be considered as binding characteristics for design intents.

MG2 SOFT MAGNETIC ANNEALED

C% max	Mn% max	Si%	Cr%	Ni% max	Mo%	P% max	S%	N% max
0,030	0,60	1,20-1,30	17,50-18,25	0,30	0,25-0,30	0,030	0,25-0,30	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} · K^{-1})	11,9
Curie Temperature (°C)	660
Modulus of Elasticity (GPa)	220

ACCIAIERIE VALBRUNA
High quality is our standard

Typical Mechanical Properties

Rm (N/mm^2)	400-650
Rp0,2 (N/mm^2)	250 min.
E5d%	25 min.
Hardness HRB	80-88

Typical Magnetic Properties*

Saturation Induction Bs (T)	>1,6
Magnetic Relative Permeability $\mu_{r\ max}$	>1700
Coercive Field Strength Hc (A/m) ●	<180
Residual Induction Br (Tesla) ●	<0,85

● Induction at 1T
* Values could vary according to different size range and production cycle

Standard Reference

ASTM 838; ALLOY 2
EN 10088-3; 1.4105

Data are purely indicative and represent typical properties only; therefore, data shall not be considered as binding characteristics for design intents.

MG3/1 SOFT MAGNETIC ANNEALED

C% max	Mn% max	Si%	Cr%	Ni% max	Nb%	Mo% max	P% max	S%	N% max
0,025	0,50	0,50-1,00	17,50-18,00	0,30	0,15-0,35	1,50-2,00	0,030	0,25-0,30	0,030

Typical Physical Properties

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

Typical Mechanical Properties

Rm (N/mm^2)	400-650
Rp0,2 (N/mm^2)	250 min.
E5d%	25 min.
Hardness HRB	75-90

Typical Magnetic Properties*

Saturation Induction Bs (T)	>1,6
Magnetic Relative Permeability $\mu_{r\ max}$	>1200
Coercive Field Strength Hc (A/m) ●	<240
Residual Induction Br (Tesla) ●	<0,85

● Induction at 1T
* Values could vary according to different size range and production cycle

Standard Reference

1.4114
ASTM A 582; XM34

Data are purely indicative and represent typical properties only; therefore, data shall not be considered as binding characteristics for design intents.

MG4 SOFT MAGNETIC ANNEALED

C% max	Mn%	Si% max	Cr%	Ni% max	Mo%	P% max	S%	N% max
0,020	0,30-0,60	1,25-1,40	18,00-18,50	0,250	1,50-2,00	0,030	0,25-0,30	0,020

Typical Physical Properties

Density (kg/dm^3)	7,78
Resistivity ($\mu\Omega$·mm)	765
Mean Coefficient of thermal expansion 20°- 500°C (10^{-6} · K^{-1})	12
Curie Temperature (°C)	680
Modulus of Elasticity (GPa)	220

Typical Mechanical Properties

Rm (N/mm^2)	400-650
Rp0,2 (N/mm^2)	250 min.
E5d%	25 min.
Hardness HRB	80-88

Typical Magnetic Properties*

Saturation Induction Bs (T)	>1,6
Magnetic Relative Permeability $\mu_{r\ max}$	>1500
Coercive Field Strength Hc (A/m) ●	<180
Residual Induction Br (Tesla) ●	<0,85

● Induction at 1T
* Values could vary according to different size range and production cycle

Standard Reference

1.4106

Data are purely indicative and represent typical properties only; therefore, data shall not be considered as binding characteristics for design intents.

MG5 SOFT MAGNETIC ANNEALED

C% max	Mn% max	Si% max	Cr%	Ni% max	Mo% max	P% max	S%	N% max
0,025	0,50	0,60	11,80-12,20	0,50	0,40	0,045	0,25-0,35	0,025

Typical Physical Properties

Density (kg/dm^3)	7,70
Resistivity ($\mu\Omega$·mm)	570
Mean Coefficient of thermal expansion 20°- 500°C (10^{-6} · K^{-1})	12
Curie Temperature (°C)	720
Modulus of Elasticity (GPa)	220

ACCIAIERIE VALBRUNA
High quality is our standard

Typical Mechanical Properties

Rm (N/mm^2)	350 min.
Rp0,2 (N/mm^2)	200 min.
E5d%	25 min.
Hardness HRB	75-92

Typical Magnetic Properties*

Saturation Induction Bs [T]	>1,7
Magnetic Relative Permeability μ_r max	>2000
Coercive Field Strength Hc (A/m) ●	<150
Residual Induction Br (Tesla) ●	<0,80

● Induction at 1T
* Values could vary according to different size range and production cycle

Standard Reference

Similar to 1.4005

Data are purely indicative and represent typical properties only; therefore, data shall not be considered as binding characteristics for design intents.

MGT SOFT MAGNETIC ANNEALED

C% max	Mn% max	Si% max	Cr%	Ni% max	Mo%	P% max	S%	N% max	Ti%
0,025	0,50	1,00	17,50-19,00	0,30	2,00-3,00	0,040	0,25-0,30	0,020	0,30-0,70

Typical Physical Properties

Density (kg/dm^3)	7,70
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 (GPa)	220

Typical Mechanical Properties

Rm (N/mm^2)	400 min.
Rp0,2 (N/mm^2)	250 min.
E5d%	25 min.
Hardness HRB	80-92

Typical Magnetic Properties*

Saturation Induction Bs [T]	>1,6
Magnetic Relative Permeability μ_r max	>1500
Coercive Field Strength Hc (A/m) ●	<180
Residual Induction Br (Tesla) ●	<0,85

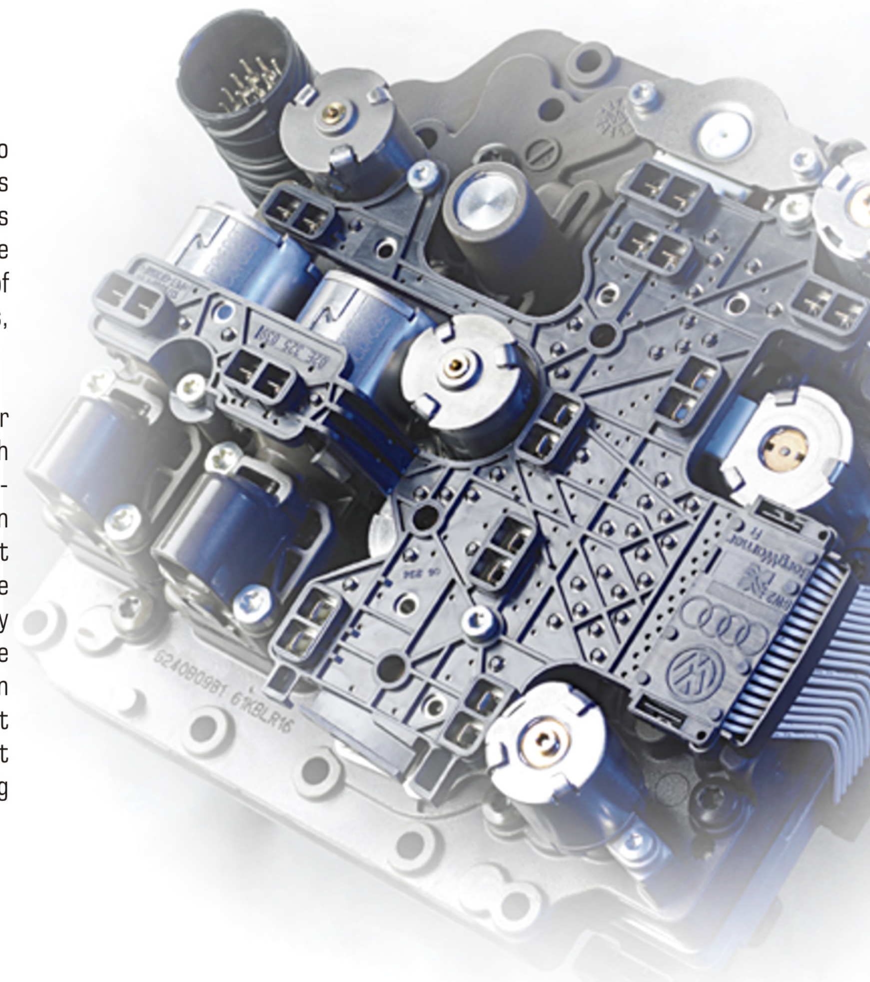
● Induction at 1T
* Values could vary according to different size range and production cycle

Standard Reference

EN 10088-3; 1.4523

Data are purely indicative and represent typical properties only; therefore, data shall not be considered as binding characteristics for design intents.

SILICON IRON ALLOYS



These Fe-Si grades are used for the manufacturing of electro mechanical devices that require greater magnetic properties than the ones provided by soft magnetic LC Iron and FMSS as Magival®. When corrosion is not a primary concern and the highest permeability is the primary necessity, the choice of these alloys yields the best results in making fuel injectors, solenoid switches and relays.

The main steel types are identified by Silicon content in order to ease the comparison among the Valbruna trademarks with different chemical analysis. Some grades are micro-resulfured in addition to higher contents of Phosphorus in order to improve machinability; actually, 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.

FeSi3P Silicon-Iron Steel: Fe-Si alloys with enhanced machinability due to Sulfur additions and P content are able to overcome some typical challenges of this process, without any significant influence on magnetic properties compared to standard alloys. High Resistivity with high values of magnetic permeability and low coercivity make this alloy the best choice in making relays, pole pieces, solenoid 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.

FeSi4 Silicon-Iron Steel: Fe-Si grades with the highest resistivity between the alloys are included in ASTM 867. This characteristic together with low values of coercivity strongly reduces the eddy currents effects in AC circuits. Pole pieces and relays are the main magnetic devices where this alloy has found applications. Even though machinability is poor compared to FeSi3P, this gap could be 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.

ALLOY		C%	Si%	Mn%	Cr%	Ni%	Mo%	Cu%	N%	P%	S%	Bs(T)	Hc (A/m)	μr max
FESI3P	min.	-	2,50	0,20	-	-	-	-	-	0,10	0,02	>2,00	<80	>4500
	max.	0,030	3,00	0,40	0,30	0,15	0,05	0,10	0,005	0,15	0,04			
FESI4	min.	-	3,80	0,20	-	-	-	-	-	-	0,02	>2,00	<60	>4500
	max.	0,030	4,20	0,40	0,30	0,15	0,05	0,10	0,005	0,03	0,03			

Magnetic properties Bs, Hc and μ_r refer to material soft magnetic annealed according to paragraph 6.2 of ASTM A867

ACCIAIERIE VALBRUNA
High quality is our standard

MG GRADES WELDABILITY

MG is a group of Free Machining grades whose chemical balance has been designed in order to couple good magnetic properties together with high productivity of machining processes. The most important element to improve machining performance is Sulfur, whose capacity to prime and cause hot cracks and porosity in the welding zone during the process is well-known: that is the reason why as general statement welding involving FM grades has to be carefully designed.

MG series contain very low percentages of C and N and/or a tailored balance of Ti and Nb in order to limit or avoid the formation of Austenite at highest temperature generated by high energy and rapid cooling of LW or GTAW. As a result, even hardening due to Martensite formation is reduced. Nevertheless, the grain size of HAZ must be carefully evaluated, together with the FZ boundaries, and the typical coarse grain size of magnetic annealed parts or bars. This is due to their influence on the ductility and toughness of weld zone which cannot be fully restored by PWHT. For Ferritic stainless steels, PWHT diffuses back the Chromium into the depleted zones close to grain boundaries restoring its intergranular corrosion resistance.

In case of autogenous welds, low heat inputs are required. Differently, in case a filler is used, a Ferritic grade filler should be chosen.

While the use of Austenitic filler to increase ductility of weld does not avoid the problem in HAZ, the low magnetic permeability of the Austenitic structure dramatically modifies the magnetic flux behavior of the weld zone in terms of flux leakage caused by the high difference between magnetic permeability.