SOFT MAGNETIC STEELS
Stainless Steels & Iron Silicon Alloys

ACCIAlERIE VALBRUNA
High quality is our standard

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SOFT MAGNETIC STEELS
Stainless Steels & Iron Silicon Alloys

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.

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 oxides, contaminations as cutting fluid, iron particles, dirty and scale. A final passivation should be considered.

ITALY:
- Venzone
- Robecco

USA:
- Fort Wayne

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VALBRUNA…
SUCH A GREAT REALITY!
Our extensive and strategic distribution network is our cornerstone in a global market, granting not only a worldwide commercial presence but also a continuous feedback with our customers.
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 Br (μJ), the Magnetic Permeability μmax and the Coercive Field Strength Hc. Secondly, the Electrical Resistivity ρ and the Residual Induction Br. Particularly, a low Curie Temperature enhances 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 resisting to large amounts of electrical current. This results in dimensionally small magnetic devices and an important energy savings. The evaluation of magnetization curves allows one to know the relative induction Br at every value of Hc. 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 Kind 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 is 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. Alphanumeric Stainless Steels have higher Resistivity than Electrical Iron and Fe-3 steel grades due to the content of main alloying elements Cr and Mo. A further increase of its values could be obtained by a Ni addition. Resistivity has an important impact with a considerable reduction of eddy current losses in AC circuits typical of industrial values.

Magnetic Testing

All magnetic testing of bars or finished components are performed according to International Norms in terms:

Magnetic properties are verified by a Permeameter and/or Coercimeter. It should be of knowledge that only the Permeameter provides a complete hysteretic 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 Beast. e.g.: Hc measured at B = 1 T. Coercimeter provides only the value of Hc from Saturation Induction.

Alloys Machining

These alloys are the essence 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 and type of machine, tools material, tools geometry, cutting fluids and kind of machine operation on the part produced. As a rule, the lower Zr-alloy MG2 exhibit better machinability than higher Cr-alloy MG/MG2. The more corrosion resisting grades MG2 and MG3 have a machinability a little lower due to the higher Mo content necessary to inhibit the sulfur effect. Grades MG2 and MG3 after the higher corrosion resistance and a machinability nearly to the MG2. 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-Boron alloys are more difficult to machine because their strong chips and BUE tendency. This situation is typical of Fe-5B. An adequate cold working has a beneficial effect on chipability and reduction of BUE for either Fe-5Si4 and Fe-5B:5. This test alloy shows the best machinability due to its microstructure in correspondence with a Peripherous 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 550 m/min, single-spindle lathe

<table>
<thead>
<tr>
<th>NUMBER OF PIECES</th>
<th>MG D &gt; M5</th>
<th>MG D &gt; M4</th>
<th>MG D &gt; M3</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>200</td>
<td>150</td>
<td>100</td>
</tr>
<tr>
<td>250</td>
<td>200</td>
<td>150</td>
<td>100</td>
</tr>
<tr>
<td>200</td>
<td>150</td>
<td>100</td>
<td>75</td>
</tr>
<tr>
<td>150</td>
<td>100</td>
<td>75</td>
<td>50</td>
</tr>
<tr>
<td>100</td>
<td>75</td>
<td>50</td>
<td>25</td>
</tr>
<tr>
<td>50</td>
<td>25</td>
<td>12.5</td>
<td>6.25</td>
</tr>
</tbody>
</table>

ACIAIERIE VALBRUNA
Productivity and knowledge
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 a slow cooling to avoid the creation 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 are 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.

MAGIVAL®

Magival® is a group of free machining ferritic stainless steel designed for magnetic application requiring high magnetic permeability and low coercivity. 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, solenoids and magnetic core
- Electromagnetic pumps
- Electromagnetic devices
- Fuel injection components
- Electromagnetic switches and relays
- Antilock brake system
- Automotive applications as sensors, actuators and fuel pumps

The free machining grades have described are normally preferred because of their machinability but other Standard Ferritic Stainless Steels are available AISI 430L, AISI 434L, 3. If the primary requirement is corrosion resistance.

The machinability of these Standard Ferritic Stainless Steels is poor if compared to Free Machining grades. Their more resulting 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 brittle microstructure that prone and cause hot cracks and porosity in fusion zone is well-known to welding process that is the reason why the whole Free Machining grades are not recommended for welding. Even if F3J series have a very low content of C and N and also a high content 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 D7 or TIGM so to block hardening due to Martensite formation is reduced, a careful evaluation of grain size of HAZ and FZ boundaries in addition with typical large grain size of magnetic annealed parts or bars should be considered in terms of ductility and toughness of weld zone whereas restoring can only partly be done by PWHT.

In case of autogenous welds, few heat inputs are required while if a filler wire is used a Ferritic grade filler should be chosen. Austenitic filler to increase ductility of weld doesn’t solve the problem in HAZ while a lower magnetic permeability of Austenite structure dramatically modified the magnetic flux behavior of weld zone in terms of flux leakage caused by highest difference between magnetic permeability.
**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 applications.

### Mechanical Properties in the soft magnetic annealed condition

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rm (N/mm²)</td>
<td>504</td>
</tr>
<tr>
<td>Rp0.2 (N/mm²)</td>
<td>337</td>
</tr>
<tr>
<td>AS%</td>
<td>35</td>
</tr>
<tr>
<td>RA%</td>
<td>67</td>
</tr>
<tr>
<td>Hardness Hrb</td>
<td>81-83</td>
</tr>
</tbody>
</table>

*measured on a specimen ø 9.00 mm

### Magnetic Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturation Flux Density Bt</td>
<td>1.67</td>
</tr>
<tr>
<td>Magnetic Permeability µ μm</td>
<td>1600</td>
</tr>
<tr>
<td>Coercive Field Strength Hc [m]</td>
<td>155</td>
</tr>
<tr>
<td>Residual Induction Br [Tesla]</td>
<td>0.83</td>
</tr>
</tbody>
</table>

*measured on a specimen ø 9.00 mm

**Reference Norms**

- ASTM A 308 ALLOY 1
- ASTM A 582 439 F
- EN 10083-3, 1.4105

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**MG2 SOLENOID QUALITY**

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

### Mechanical Properties in the soft magnetic annealed condition

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rm (N/mm²)</td>
<td>510</td>
</tr>
<tr>
<td>Rp0.2 (N/mm²)</td>
<td>345</td>
</tr>
<tr>
<td>AS%</td>
<td>34</td>
</tr>
<tr>
<td>RA%</td>
<td>65</td>
</tr>
<tr>
<td>Hardness Hrb</td>
<td>81-83</td>
</tr>
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### Magnetic Properties

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<td>1600</td>
</tr>
<tr>
<td>Coercive Field Strength Hc [m]</td>
<td>155</td>
</tr>
<tr>
<td>Residual Induction Br [Tesla]</td>
<td>0.76</td>
</tr>
</tbody>
</table>

*measured on a specimen ø 9.00 mm

**Reference Norms**

- ASTM A 582 439 F
- W-Nr: 1.4144

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**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.

### Mechanical Properties in the soft magnetic annealed condition

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rm (N/mm²)</td>
<td>504</td>
</tr>
<tr>
<td>Rp0.2 (N/mm²)</td>
<td>337</td>
</tr>
<tr>
<td>AS%</td>
<td>35</td>
</tr>
<tr>
<td>RA%</td>
<td>67</td>
</tr>
<tr>
<td>Hardness Hrb</td>
<td>81-83</td>
</tr>
</tbody>
</table>

*measured on a specimen ø 9.00 mm

### Magnetic Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturation Flux Density Bt</td>
<td>1.67</td>
</tr>
<tr>
<td>Magnetic Permeability µ μm</td>
<td>1600</td>
</tr>
<tr>
<td>Coercive Field Strength Hc [m]</td>
<td>155</td>
</tr>
<tr>
<td>Residual Induction Br [Tesla]</td>
<td>0.76</td>
</tr>
</tbody>
</table>

*measured on a specimen ø 9.00 mm

**Reference Norms**

- ASTM A 308 ALLOY 1
- ASTM A 582 439 F
- EN 10083-3, 1.4105
**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 Resilience allows to reduce the eddy currents in AC applications.

### Mechanical Properties in the soft magnetic annealed condition

<table>
<thead>
<tr>
<th>%C max</th>
<th>Mn% max</th>
<th>Si% max</th>
<th>Cr% max</th>
<th>Ni% max</th>
<th>Mo% max</th>
<th>P% max</th>
<th>Mn% max</th>
<th>Si% max</th>
<th>Cr% max</th>
<th>Ni% max</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.020</td>
<td>0.30-0.60</td>
<td>1.25-1.50</td>
<td>18.00-18.50</td>
<td>0.250</td>
<td>1.50-2.00</td>
<td>0.010</td>
<td>0.25-0.35</td>
<td>0.203</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Typical Physical Properties**

- Density (g/cm³): 7.78
- Resistivity (µΩ·cm): 765
- Mean Coefficient of thermal expansion (20° - 500°C) (10⁻⁶ · K⁻¹): 12
- Curie Temperature (°C): 660
- Modulus of Elasticity (GPa/mm²): 220

**Magnetic Properties**

- Saturation Flux Density Bₛ (Tesla): 1.85
- Magnetic Permeability µₛ: 1739
- Coercive Field Strength Hc (A/m): 129
- Residual Induction Br (Tesla): 0.72

* Measured on a specimen @ 9.00 mm

**Reference Norms**

- EN 10088-3, 1.4005

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**MG5 SOLENOID QUALITY**

Free Machining grade with similar corrosion resistance and magnetic properties than MG7 but with better machinability.

### Mechanical Properties in the soft magnetic annealed condition

<table>
<thead>
<tr>
<th>%C max</th>
<th>Mn% max</th>
<th>Si% max</th>
<th>Cr% max</th>
<th>Ni% max</th>
<th>Mo% max</th>
<th>P% max</th>
<th>Mn% max</th>
<th>Si% max</th>
<th>Cr% max</th>
<th>Ni% max</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.025</td>
<td>0.75-1.00</td>
<td>0.50-1.00</td>
<td>12-13</td>
<td>0.30</td>
<td>0.35-0.60</td>
<td>0.045</td>
<td>0.25-0.35</td>
<td>0.205</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Typical Physical Properties**

- Density (g/cm³): 7.70
- Resistivity (µΩ·cm): 620
- Mean Coefficient of thermal expansion (20° - 500°C) (10⁻⁶ · K⁻¹): 12
- Curie Temperature (°C): 720
- Modulus of Elasticity (GPa/mm²): 220

**Magnetic Properties**

- Saturation Flux Density Bₛ (Tesla): 1.67
- Magnetic Permeability µₛ: 1577
- Coercive Field Strength Hc (A/m): 167
- Residual Induction Br (Tesla): 0.81

* Measured on a specimen @ 9.00 mm

**Reference Norms**

- W.Nr.: 1.4114 + Nb
MGT SOLENOID QUALITY

Free Machining grade with magnetic properties as M44 but with better jetting and crevice corrosion resistance due to its Mo and Ti contents allowing applications in more severe corrosive environments. Similar machinability than M54.

<table>
<thead>
<tr>
<th>C% max</th>
<th>Mn% max</th>
<th>Si% max</th>
<th>Cr% max</th>
<th>Ni% max</th>
<th>Mo% max</th>
<th>P% max</th>
<th>S% max</th>
<th>N% max</th>
<th>Ti% max</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.005</td>
<td>0.50</td>
<td>1.00</td>
<td>17.50-19.00</td>
<td>0.30</td>
<td>2.00-2.50</td>
<td>0.040</td>
<td>0.25-0.35</td>
<td>0.005</td>
<td>0.30-0.70</td>
</tr>
</tbody>
</table>

Typical Physical Properties

- Density (kg/m³): 7.7
- Resilience (G-Pt/m²): 620
- Mean Coefficient of Thermal expansion (20° - 500°C) (10⁻⁶ K⁻¹): 11.9
- Cure Temperature (°C): 680
- Modulus of Elasticity (GPa/m²): 220

Mechanical Properties in the soft magnetic annealed condition

- Tm (N/mm²): 540
- Rp0.2 (N/mm²): 350
- AS%: 34
- R%: 59
- Hardness Hv: 82.64

* Measured on a specimen ø 0.80 mm

Magnetic Properties

- Saturation Flux Density Br (Tesla): 1.86
- Magnetic Permeability µ (max): 1849
- Currose Field Strength Hc, Air: 812
- Residual Induction Br (Gauss): 0.71

* Measured on a specimen ø 0.80 mm

Reference Norms

EN 10038-3-1, 14329

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 LG iron and Free Machining Stainless Steels as Maguva™. Where corrosion is 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-resource 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 bulk-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.

<table>
<thead>
<tr>
<th>VALBRUNA GRADE</th>
<th>ASTM</th>
</tr>
</thead>
<tbody>
<tr>
<td>FeSi1P</td>
<td>ASTM A B67 - TYPE 1F</td>
</tr>
<tr>
<td>FeSi3</td>
<td>ASTM A B67 - TYPE 2F</td>
</tr>
<tr>
<td>FeSi3P</td>
<td>ASTM A B67 - TYPE 2F</td>
</tr>
<tr>
<td>FeSi4</td>
<td>ASTM A B67 - TYPE 3F</td>
</tr>
</tbody>
</table>
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 Resilinity with highest value of magnetic permeability and lowest coercivity have brought this alloy to become the best choice in making reays, 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. 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.

<table>
<thead>
<tr>
<th>%Si max</th>
<th>Mn% max</th>
<th>S%</th>
<th>Cr% max</th>
<th>Ni% max</th>
<th>Mo% max</th>
<th>P%</th>
<th>S% max</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.030</td>
<td>0.50</td>
<td>0.10</td>
<td>0.050</td>
<td>0.050</td>
<td>0.10, 0.15</td>
<td>0.020, 0.035</td>
<td></td>
</tr>
</tbody>
</table>

Typical Physical Properties

- Density (g/dm³): 7.05
- Resistivity (μΩ-mm): 500
- Mean Coefficient of thermal expansion (20° - 460°C): 15°C
- Curie Temperature (°C): 750

Mechanical Properties in the annealed and cold drawn condition

- Rm (N/mm²): 710
- Rp0.2 (N/mm²): 668
- A%: 28
- H%: 72
- Hardness HB: 218

*M measured on a specimen at 1.00 mm

Magnetic Properties

- Saturation Flux Density Bts (Tesla): 2.05
- Magnetic Permeability (μ max) (length specimen): 5027
- Coercive Field Strength Hc A/m: 96
- Residual Induction Br (Tesla): 0.73

*M measured on a specimen at 16.00 mm soft magnetic annealed according to ASTM A 887

Reference Norms

ASTM A 887 - TYPE 2

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FeSi4 Iron - Silicon Steel

Fe-Si grade with the highest resistivity between the alloys included in ASTM A 887. This characteristic together with low values of coercivity strongly reduces the eddy currents effects in AC circuits. Pole pieces and reays are the main magnetic devices where this alloy has found applications.

Mechanical Properties in the annealed and cold drawn condition

- Rm (N/mm²): 628
- Rp0.2 (N/mm²): 448
- A%: 22
- H%: 66
- Hardness HB: 189

*M measured on a specimen at 14.00 mm

Magnetic Properties

- Saturation Flux Density Bts (Tesla): 2.02
- Magnetic Permeability (μ max) (length specimen): 4054
- Coercive Field Strength Hc A/m: 54
- Residual Induction Br (Tesla): 0.71

*M measured on a specimen at 16.00 mm soft magnetic annealed according to ASTM A 887

Reference Norms

ASTM A 887 - TYPE 3