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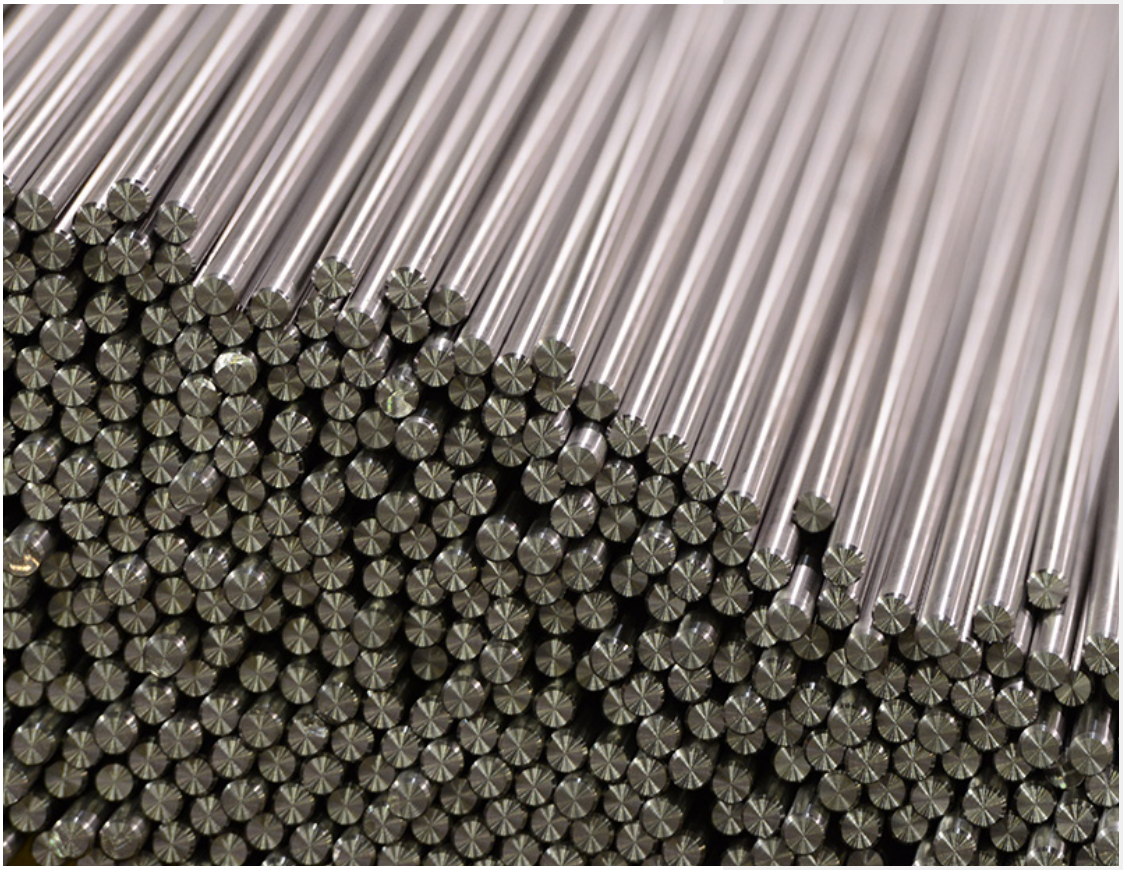

SOFT MAGNETIC ALLOYS WITH IMPROVED CORROSION RESISTANCE

Maximizing optimum magnetic properties, cost, and fabricability

SUMMARY

Soft magnetic alloys designed for corrosive environments

Soft magnetic alloys with improved corrosion resistance have been developed for critical control devices and systems that must function flawlessly in a wide variety of corrosive environments. A number of alloys are commercially available for this type of service, but many demonstrate limited resistance.

Alloys combining good magnetic properties and corrosion resistance are required for automotive applications such as fuel injection, fuel pump laminations, antilock braking systems, and automatically adjusting suspension systems. Such alloys should be considered for use with fuels containing ethanol or methanol, which may contain corrosive contaminants. Aqueous environments also can be quite severe, especially when chlorides are present to cause attack in the crevices inherent in solenoid valves.

Applications go well beyond the automotive industry. This newer generation of alloys can be considered for solenoid valves, pumps, fittings, and a host of electromechanical devices requiring some degree of corrosion resistance, such as refrigerators, washing machines, steam irons, taps for soda and beer, coffee pots, irrigation, vending machines, and parts/components exposed to mild chemicals.

Also to be considered is the extended shelf life these alloys can give to products that must be stored in mildly corrosive environments until placed in service.

Here we investigate a family of soft magnetic alloys designed for a range of corrosive environments while maintaining optimum magnetic properties, cost, and fabrication characteristics.

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ALLOY REQUIREMENTS

Electronic controls have been integrated into a large number of automotive and industrial functions. Critical to the performance of these controls are soft magnetic alloys that can optimize the output and response time of electro-mechanical components, such as cores, armatures, relays, and solenoid valves.

Properties important to these materials include:

High saturation induction (B_s)

allows development of a strong magnetic field, enabling control devices like solenoids and fuel injectors to work with as little energy output as possible.

High permeability (μ)

induces high magnetism, allowing the design of smaller, more efficient components.

Low coercive field strength (H_c)

permits rapid magnetization and demagnetization, both essential in opening and closing valves and injectors quickly.

Freedom from magnetic aging

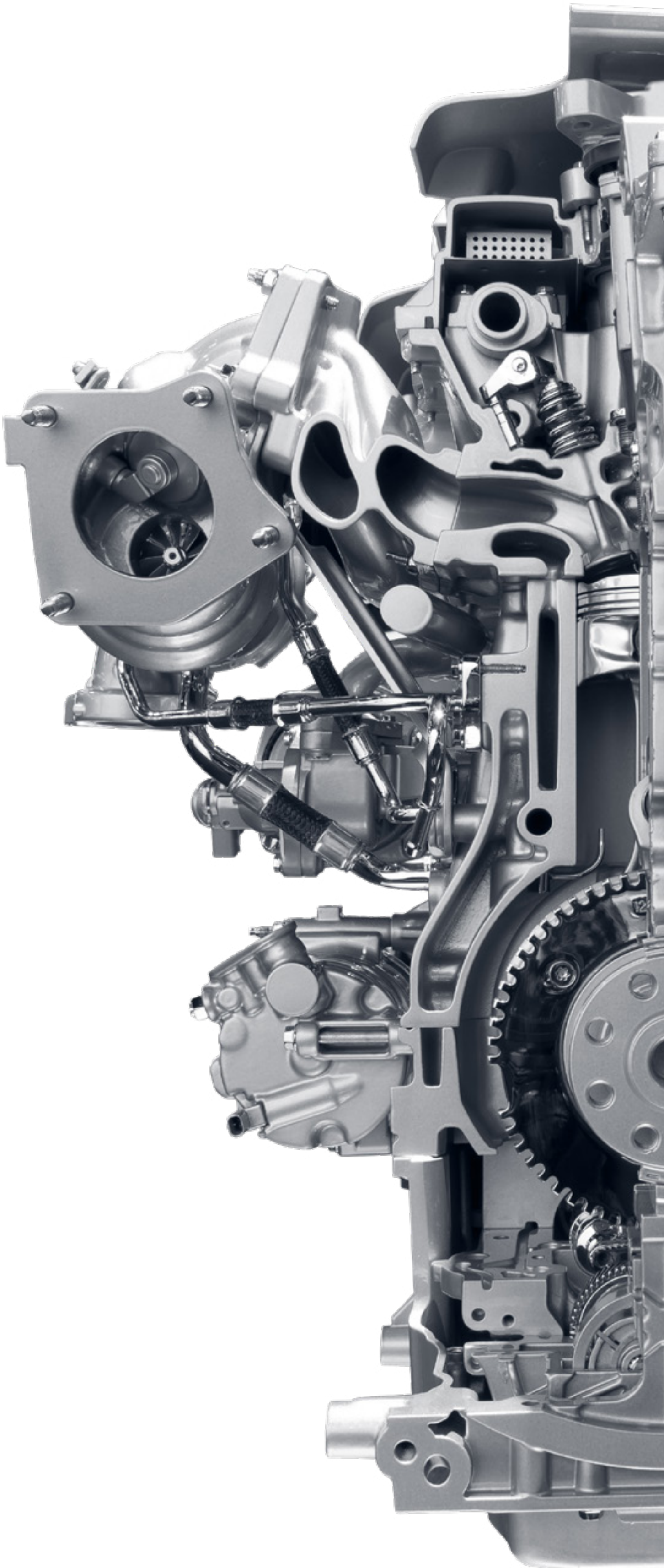
enables critical parts to retain their magnetic properties for a long time.

Electrical resistivity

is essential for efficient functioning of solenoid valves.

Corrosion resistance

is critical for materials in the service environment, particularly today, as corrosive conditions proliferate in number and severity.



Successful application of soft magnetic alloys requires that magnetic properties be consistent both over time and over the area of the magnet. These properties are controlled by the metallurgical structure developed through heat treatment, and by the uniformity of the alloy's chemistry, managed by control of residual elements. Annealing of electromagnetic components after fabrication is sometimes necessary to obtain the desired soft magnetic properties. Annealing relieves residual stresses, recrystallizes the grain structure, and, under appropriate conditions, can remove impurities such as carbon, oxygen, nitrogen, and sulfur.

There are four basic families of soft magnetic alloys — magnetic core irons, high magnetic saturation alloys, high permeability alloys, and ductile permanent magnet alloys — with various combinations of magnetic and mechanical properties for different applications.

COMPOSITION OF SOFT MAGNETIC ALLOYS (MAGNETIC CORE IRONS) IN WEIGHT PERCENT

ALLOY	C	Mn	Si	S	P	Cr	Mo	OTHER*
Electrical iron	0.02	0.12	0.12	0.010	0.010	0.2	—	0.05 V
Silicon Core Iron A	0.03	0.15	1.00	—	—	—	—	—
Silicon Core Iron B	0.03	0.15	2.50	—	—	—	—	—
Silicon Core Iron B-FM	0.03	0.40	2.50	0.12	—	—	—	—
Silicon Core Iron C	0.03	0.15	4.00	—	—	—	—	—
Chrome Core 8	0.03	0.50	0.50	0.03	0.03	8.00	0.30	—
Chrome Core 8-FM	0.03	0.50	0.50	0.30	0.03	8.00	0.30	—
Chrome Core 12	0.03	0.50	0.50	0.03	0.03	12.00	0.30	—
Chrome Core 12-FM	0.03	0.50	0.50	0.30	0.03	12.00	0.30	—
Chrome Core 13 alloy	0.01	0.40	1.50	0.25	0.015	13.00	0.30	—
Chrome Core 18-FM	0.015	0.40	0.90	0.30	0.02	17.50	1.75	0.25 Nb
430F Solenoid Quality Stainless	0.065	0.80	0.50	0.30	0.03	17.75	0.40	—
430FR Solenoid Quality Stainless	0.065	0.80	1.25	0.30	0.03	17.75	0.40	—

**Balance iron*

ELECTRICAL IRONS

These relatively pure, low-carbon irons have been used for magnetic circuit cores and relays, and solenoids that activate electrical controls. Premium quality core irons, produced by vacuum melting, are stabilized with vanadium to minimize degradation of magnetic properties over time and provide properties that are more uniform over the entire area of the magnet.

Electrical iron, offering the least corrosion resistance in the four alloy families, provides good direct-current soft magnetic properties. These properties can be customized by the mill to conform with the condition requested.

Electrical irons provide good direct-current soft magnetic properties. Silicon irons offer minimal resistance to corrosive media.

SILICON IRONS

Adding silicon to low-carbon iron increases both hardness and electrical resistivity. Offering minimal resistance to corrosive media, they have been used typically for solenoid switches, armatures, pole pieces, relays, cores, etc. These alloys are frequently plated for use in corrosive environments. The two free-machining versions have offered up to 40% improvements in machinability.

Several types of silicon irons are available:

Silicon Core Iron A

has magnetic properties similar to those of electrical iron. However, its electrical resistivity is 25 μΩ·cm, compared with 13 μΩ·cm for electrical iron. Silicon Core Iron A-FM, with phosphorus added, has free-machining characteristics with similar magnetic properties.

Silicon Core Iron B

has electrical resistivity of 40 μΩ·cm and is generally used in applications requiring very low hysteresis loss, high permeability, low residual magnetism, and freedom from magnetic aging. Silicon Core Iron B-FM offers the bonus of improved machinability.

Silicon Core Iron C

offers electrical resistivity of 58 μΩ·cm, the highest of any alloy in this group. It also offers maximum initial permeability, minimum hysteresis loss, low residual magnetism, and negligible magnetic aging.

CHROMIUM-IRON MAGNETIC STAINLESS STEELS

These alloys provide good corrosion resistance for devices exposed to weather, fuels, or other corrosive environments. Although these steels have adequate magnetic properties for core applications, they allow higher core losses and provide lower saturation and permeability than silicon irons in such uses.

430F Solenoid Quality Stainless

has superior magnetic properties and low residual magnetism when compared with other stainless steels. With its high chromium content (18%) and small molybdenum addition, this alloy has been used for corrosive service for many years.

430FR Solenoid Quality Stainless

offers the best combination of magnetic properties and lowest residual magnetism of any stainless steel. It also has improved wear resistance, higher resistivity (76 µΩ·cm), and increased hardness, along with good corrosion resistance.

Chromium-iron magnetic stainless steel alloys provide good corrosion resistance for devices exposed to weather, fuels, or other corrosive environments.

430FR

This family of alloys, developed by Carpenter Technology, provides a good combination of corrosion resistance, magnetic properties, cost, and fabricability. They are all controlled-chemistry, ferritic, chromium-iron alloys designed for use in magnetic components that require corrosion resistance superior to that of pure iron, low carbon steel, and silicon-iron alloys. At the same time, they have demonstrated immunity to the substantial decrease in saturation induction associated with the 18% chromium ferritic stainless steels. These alloys have withstood corrosive fuels containing ethanol and methanol, and the contaminants sometimes included.

Chrome Core 8, 8-FM, 12, and 12-FM

Chrome Core 8 and 8-FM, and Chrome Core 12 and Chrome Core 12-FM, containing 8% and 12% chromium respectively, are the original members of this group. Both FM versions have enhanced machinability to facilitate component fabrication.

When exposed to CM 85A fuel, with and without aeration, Chrome Core 12 and Chrome Core 12-FM displayed corrosion resistance similar to or approaching that of Chrome Core 430F/430FR Solenoid Quality Stainless. Resistance is also significantly better than that of Silicon Core Iron B-FM. The flux densities of Chrome Core 8-FM and Chrome Core 12-FM approach those of Electrical Iron and Silicon Core Iron B-FM at magnetic field strengths greater than about 800 A/m (Table 2).

All four grades were evaluated in an SAE CM85A corrosive fuel mixture consisting of 15% gasoline and 85% aggressive methanol. The test provided an oxidizing chloride environment and was, therefore, more severe than many expected service environments.

After 250 hours in an autoclave at 80°C (no deaeration), Chrome Core 8-FM was far superior to Silicon Core Iron B-FM, with a further improvement for Chrome Core 8. Chrome Core 12 and 12-FM specimens approached the corrosion resistance of 430F Solenoid Quality Stainless (Reference 1 and 2).

MAGNETIC PROPERTIES AND CORROSION RESISTANCE OF SELECTED MAGNETIC ALLOYS

ALLOY	SATURATION MAGNETIZATION B_S(T)	RESISTIVITY (µΩ·cm)	COERCIVITY H_C (A/m)	CANDIDATE SERVICE ENVIRONMENTS	CANDIDATE APPLICATIONS
Electrical Iron	2.1	13	56	Dry air	Relays, solenoids, pole pieces
Silicon Core Iron B-FM	2.1	40	56	Dry air	Relays, solenoids, pole pieces, armatures
Chrome Core 8 and 8-FM	1.8	49	200	Fuels, mild atmospheres	Corrosion-resistant laminations
Chrome Core 12 and 12-FM	1.7	57	200	Corrosive fuels, fresh water	Fuel injectors, ABS solenoids
Chrome Core 13-XP	1.7	78	127	Corrosive fuels, fresh water	Fuel injectors, ABS solenoids
Chrome Core 18-FM	1.5	75.5	200	Chloride environments, beverages, mild chemicals	Antilock braking systems, automatically adjusting suspension
430FR Solenoid Quality Stainless	1.5	76	200	Mild aqueous environments, beverages, dairy products	Antilock braking systems, automatically adjusting suspension

Chrome Core 13-XP

has been developed as a candidate for electromechanical devices that require optimum magnetic properties in a stainless free-machining alloy. This material was designed with higher chromium (13%) and silicon than that of Chrome Core 12-FM to increase electrical resistivity while providing good corrosion resistance and stable ferrite.

Corrosion tests in simulated corrosive fuel environments (at room temperature and in boiling corrosive water) showed this newer alloy to have corrosion resistance similar to that of Chrome Core 12-FM. Its magnetic properties also are very good. Chrome Core 13-XP has provided coercivity less than 120 A/m with relative permeability of 4200. The alloy, therefore, can be considered a candidate for stringent automotive and industrial applications.

Chrome Core 18-FM Stainless

is the newest alloy in this group and has been developed to combine good machinability and magnetic properties with corrosion resistance superior to that of the other materials in this family.

This 18% chromium alloy is designed for operation in more corrosive environments than tolerated by 18%Cr 430 Stainless. It has corrosion resistance superior to that of 430FR Stainless, with generally similar magnetic properties, and corrosion resistance equivalent to that of Type 316. Chrome Core 18-FM Stainless can be considered when chlorides are present in order to resist attack in the crevices of solenoid valves.

Both molybdenum and niobium have been used to improve resistance to crevice attack. Niobium is used to stabilize this inherently free-machining stainless steel composition. Niobium was chosen instead of titanium to produce larger sulfides, which typically correlate with better machinability.

Material with a niobium addition and about 1.5% to 2% Mo has provided corrosion resistance up to 30/35°C (equal to that of T316) when crevice corrosion tested in a mixture of 5% FeCl3 and 1% NaNo3 for 24 hours, beginning at room temperature.

The composition of Chrome Core 18-FM Stainless is balanced to provide resistivity similar to that of 430FR Stainless. High resistivity is beneficial in applications involving AC excitation due to the suppression of eddy current losses.

Chrome Core alloys provide a good combination of corrosion resistance, magnetic properties, cost, and fabricability.

CONCLUSION

Magnetic performance with corrosion resistance

Soft magnetic alloys have been used for a wide variety of critical control devices and systems. Typically, candidate alloys possess magnetic properties that can be matched cost effectively to job requirements. Some free-machining versions of these alloys are available to minimize fabrication costs.

Current trends reflect a growing need for soft magnetic alloys that have provided good magnetic performance while, at the same time, offering improved resistance to corrosive fuels, road salt, aqueous media, chlorides, mild chemicals, and other challenging environments.

Carpenter Technology's ChromeCore® alloys, available in both strip and bar forms, provide both good corrosion resistance and magnetic characteristics, some with superior machining characteristics for productivity improvement. Corrosion resistance varies with each grade. The latest alloy in this family offers corrosion resistance similar to 316 Stainless and better than 430FR Solenoid Quality Stainless, along with the magnetic properties required for reliable performance control parts and components.

Finally, alloy users searching for the right material can benefit substantially by working closely with the material supplier. That's because the properties of soft magnetic alloys can be affected greatly by how the metal is processed. That, in turn, should be based on the specialized requirements of the application, and how well they are communicated.

Users searching for the right material can benefit substantially by working closely with the material supplier.

References

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2 *DeBold, T. A.: "Corrosion Resistant Magnetic Alloys", in Proceedings of Stainless Steels Conference, VEDH Dusseldorf, Germany, June 3-5, 1996.*

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