A service provided by the
British Stainless Steel Association

Stainless Steel Advisory Service
Tel: 0114 267 1265 Fax 0114 266 1252

Magnetic Properties of Stainless Steel

Ferritic, martensitic and duplex stainless steels are usually classified as ‘magnetic’, whilst austenitic stainless steels are often described as ‘non-magnetic’. This is because ferritic, martensitic, duplex and most precipitation hardening stainless steel types exhibit a strong response (or pull) to a hand-held magnet whereas, by comparison, the austenitic stainless steels have a negligible response.

For some applications, it is necessary to use a stainless steel, which has very low or negligible response to electromagnetic fields. A limit is then usually specified on the relative magnetic permeability of the steel (more often described simply as ‘permeability’). The lowest relative magnetic permeability of any material is 1. This means that the magnetic response of the material is the same as "free space" or a complete vacuum. The values for steels (which are classified as "ferromagnetic") are usually high with values of around 14. Non-ferromagnetic steels, which includes the austenitic stainless steels have relative permeabilities of 1, or slightly more.

The principal metallic phases in most steels at room temperature are ferrite and martensite (both of which have high permeability). Austenitic stainless steels, by definition retain their austenitic structure at room temperature and so have much lower permeabilities.
The permeability of any given steel is therefore dependent on the distribution of ferrite, martensite and austenite in the structure. The ferritic and martensitic stainless grades ("400" series) are generally free from austenite and have "high" permeabilities, and so will attract a magnet. They are classed ferromagnetic. These steels can be magnetised in an electric field and so can be used for electric solenoid cores, where good corrosion resistance is required. An example of this type of steel is the "soft" ferritic 430 (1.4016).
Duplex stainless steels with a balance of austenite & ferrite phases (around 50 / 50) are also ferromagnetic but would classed as "harder" due to their higher mechanical strength.
The hardenable martensitic stainless steels can be classed as "hard" magnetic materials which, although ferromagnetic, will not magnetise and demagnetise as easily as the ferritic or duplex grades and so could be regarded as having magnetic properties closer to those of materials used for permanent magnets.

The permeability of austenitic stainless steels is quite different and can be classed as "paramagnetic" with relative permeabilities of 1. (generally in the range of 1.003 to 1.05 in the fully annealed condition)
These low permeabilities enable these steels to be used where "non-magnetic" materials are required.
Such applications include casings for medical equipment, such as body scanners, and concrete reinforcing bars for radar installations.
Permeabilities above 1 are associated with the amount of either ferrite or martensite phases the "austenitic" steel contains and so are dependent on:-
Chemical composition and Cold working and heat treatment conditions.

Compositional Effects

Grades 304 (1.4301), 321 (1.4541) and 316 1.4401) have "balanced" compositions to

enable them to be readily weldable. This is achieved by ensuring that in their normal annealed (softened) condition, they contain a few percent of delta ferrite.
This results in permeabilities slightly over 1.
Additions of nickel and nitrogen promote and stabilise the austenite phase, whereas molybdenum, titanium and niobium stabilise ferrite
The lowest permeability austenitic stainless steels are therefore the nitrogen bearing 304LN (1.4311) and 316LN (1.4406) types or the high nickel 310 (1.4845) and 305 (1.4303) types.
In contrast, higher permeabilities can be expected in grades such as 301(1.4310), 321 (1.4541) & 347 (1.4550), with either lower nickel contents or additions of titanium or niobium, which are powerful ferrite stabilising elements.

During the welding of these steels, structural changes occur. Some of the austenite, in the parent material, can transform to delta ferrite at high temperatures and on cooling this is partly retained at room temperature. Welding filler rods and wires are usually "overalloyed" to prevent dilution in the fusion zone but more importantly are balanced to have deliberately high ferrite levels of 5% or sometimes 10%, to minimise the risk of hot cracking during welding.

Consequently the permeability of the metal in the weld, and the surrounding heat affected zone, can be significantly higher than in the original parent material. Similar effects can occur following plasma or flame cutting austenitic stainless steels.

Cold Work and Heat Treatment Effects

Cold working of austenitic stainless steels can partially transform austenite to martensite. As martensite is "ferromagnetic" this means that austenitic types which would be expected not attract a magnet can show a degree of "pull".
This usually occurs at sharp corners, sheared edges or machined surfaces but can be detected on wrought products such as rods or bars which may have been cold straightened, following the final hot rolling or annealing in the mill.

The degree to which this occurs depends on the compositional effects of austenite stabilising elements noted above, high nickel or nitrogen bearing grades tolerating more cold working before localised increases in permeability are noticed.

These increases in permeability can be reversed by a full solution annealing (at temperatures around 1050 / 1100 °C with rapid cooling). This transforms any cold-formed martensite back to austenite, the non-magnetic phase, which is then retained on cooling.

The best austenitic stainless steel types for low permeability applications are those with high austenite stability as these have low permeability in both annealed or cold worked conditions.
These include the nitrogen bearing types, 304LN (1.4311) and 316LN (1.4406) or the high nickel types such as 310 (1.4845).

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