
Atlas Tech Note No. 11

Magnetic Response of Stainless Steels

Magnetic response – or the lack of it – is often one of the first things that people think of as a basic property of stainless steels. The response of stainless steels to a magnet is an interesting physical property and can be a useful sorting test but it is not as clear-cut as is often thought.

What are the Basic Magnetic Properties of Materials?

Ferromagnetic Materials

Materials that are strongly attracted to a magnet (either permanent or electro) and that can themselves form permanent magnets. This is the usual property when a material is said to be “magnetic”.

Magnetic Permeability

The ease by which a magnetic material can be magnetised is expressed by the Magnetic Permeability. Values close to 1.0 show the material is non-magnetic.

Hard or Soft Magnetic Characteristics

Magnetic materials can be classified as “Hard” or “Soft”. Hard magnetic materials retain a large amount of residual magnetism after exposure to a magnetic field. Soft magnetic materials can be magnetised by a relatively small magnetic field and when this is removed they revert to low residual magnetism.

Non-magnetic Materials

Materials that show no response to a magnet.

Curie Temperature

Some metals have a temperature at which they change from ferromagnetic to non-magnetic. For common carbon steels this happens at about 768°C.

Which Metals are Magnetic?

All common carbon steels (including mild steel), low alloy steels and tool steels are ferromagnetic. Some other metals such as nickel and cobalt are also ferromagnetic. All stainless steels with the exception of the austenitic grades are also magnetic – all ferritic grades (e.g. 430, AtlasCR12, 444, F20S), all duplex grades (e.g. 2205, 2304, 2101, 2507), all martensitic grades (e.g. 431, 416, 420, 440C) and all precipitation hardening grades (e.g. 630/17-4PH). Even although the duplex grades are mixtures of austenite and ferrite they are still strongly attracted to a magnet.

Which Metals are Non-Magnetic?

Most non-ferrous metals such as aluminium and copper and their alloys are non-magnetic. Austenitic stainless steels, both the common 300-series (Cr-Ni) and the lower nickel 200-series (Cr-Mn-Ni) are non-magnetic. It is common for wrought austenitic stainless steels to contain a very small amount of ferrite, but this is not sufficient to significantly affect magnetic performance except in very critical applications.

Welds and Castings

Castings in austenitic stainless steels have slightly different compositions compared to their wrought counterparts. The cast version of 316L for instance is grade CF-3M. Most “austenitic” cast alloys are very deliberately made so that they have a few percent of ferrite – this helps prevent hot cracking during casting.

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A weld can be viewed as a small, long casting, and for the same reason as detailed above austenitic welds have about 4 – 8% ferrite. In the case of both welds and castings the small amount of ferrite results in a small amount of magnetic response, but it can be readily detected with a good hand-held magnet. With a suitable “ferrite meter” this magnetic response can in fact be used to measure the amount of ferrite in a weld.

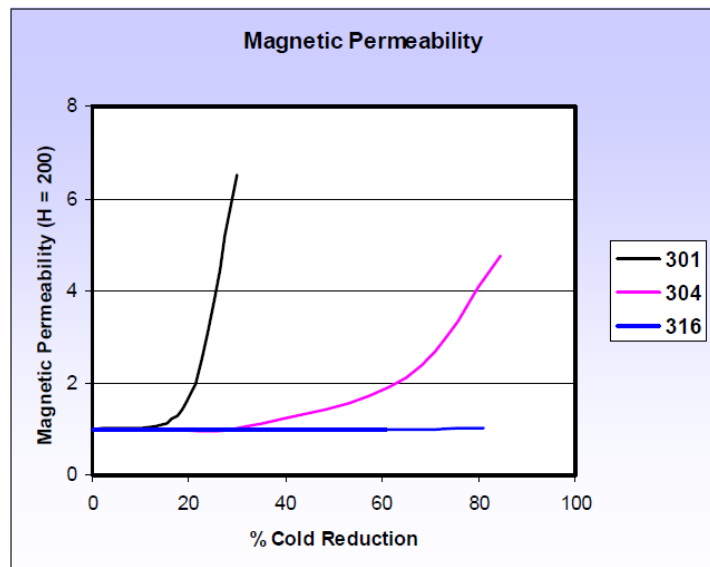
Ferrite-Free Austenitic Stainless Steels

If a weld is required to be zero ferrite content special consumables are available. “Ferrite-free” 316L plate can also be sourced (it has a higher content of nickel than standard 316L), or existing stock 316L plate can be tested to confirm ferrite level. “Ferrite-free” products are specially produced for a few specific corrosive conditions, not usually for their magnetic properties.

The Effect of Cold Work

Even although wrought austenitic stainless steels are non-magnetic in the annealed condition they may develop magnetic response when cold worked. Cold work can transform some austenite to martensite. This has a dramatic effect on tensile strength and even more so on yield strength; a heavily cold drawn grade 304 wire can achieve a tensile strength of up to around 2000MPa. Such a highly worked 304 will also be very strongly attracted to a magnet.

Grades with higher amounts of austenite forming elements – nickel, manganese, carbon, copper and nitrogen – form less martensite when cold worked, so do not become so strongly magnetic. This can be evaluated as the ratio of austenite former elements divided by ferrite former elements, or simply as the Ni/Cr ratio. Grade 316 products usually only become slightly magnetic and 310 and 904L are almost totally non-magnetic no matter how severely cold worked. Grade 301 on the other hand has a lesser amount of nickel and work hardens even more rapidly than does 304 and becomes strongly magnetic after even a small amount of cold work.



These comparisons are shown in the graph above. Note that different heats of steels of the same grade may exhibit different magnetic responses because of minor differences in the amounts of each element.

Heat Treatment

If a piece of austenitic stainless steel has been made to respond to a magnet by cold work this can be removed by a solution treatment – the standard treatment of heating to about 1050°C (depending on the grade) followed by water quenching or other rapid cooling. The high temperature allows the “strain-induced martensite” to re-form as austenite and the steel returns to being non-magnetic. It is also returned to being low strength.

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Does Magnetic Response Matter?

Magnetic response has no effect on any other property. Cold drawn 304 (and to a lesser degree 316) is attracted to a magnet, but this has no effect on the corrosion resistance. Some of the most highly corrosion resistant stainless steels are strongly magnetic... examples are the duplex and super duplex grades and highly alloyed ferritic grades such as 29-4C. Cold drawn 304 also has high tensile strength, but this is not due to the magnetic response – both the magnetic response and the high strength are due to the cold work.

Applications where absence of magnetic response may be required include MRI equipment and in naval mine-hunter vessels. Specialist guaranteed low magnetic response stainless steels can be sourced for such applications.

Magnetically Soft Stainless Steels

Magnetically soft steels are used in electrical applications involving changing electromagnetic induction. Solenoids and relays are typical examples: the magnetic field must be able to collapse when the electric current is shut off, releasing the solenoid plunger. Where these components also need to have corrosion resistance a ferritic stainless steel can be a good choice. For critical applications specialist ferritic bar grades are available (subject to mill enquiry) with guaranteed magnetic properties.

Sorting of Steels

The magnetic response of a piece of steel is a quick and qualitative test that can be useful for sorting grades of steel. Other qualitative tests are listed in Atlas Tech Note No. 1.

Grade Sorting by Magnetic Response

What Can Be Sorted

Austenitic (both 300-Series and 200-series) stainless steels from other steels. All other steels are attracted to a magnet, including all the ferritic, duplex, martensitic and precipitation hardening stainless steels. The only other non-magnetic steels are the austenitic 13% manganese steels.

Method

Note response, if any, when a permanent magnet is brought close to the steel.

Tips & Traps

Some austenitic grades, particularly 304, are to some degree attracted to a magnet when cold worked, e.g. by bending, forming, drawing or rolling. Stress relieving at cherry-red heat will remove this response due to cold work, but this stress relief may sensitise the steel and should not be performed on an item which is later to be used in a corrosive environment. A full anneal is acceptable, however.

Even although duplex grades have only half the amount of the magnetic ferrite phase compared to fully ferritic grades such as 430, the difference in “feel” of a manual test is unlikely to be enough to enable sorting duplex steels from ferritic, martensitic or precipitation hardening grades.

Austenitic stainless steel castings and welds are also usually slightly magnetic due to a deliberate inclusion of a small percentage of ferrite in the austenitic deposit. The % ferrite can be measured by the amount of magnetic response, and special instruments are available for this.

Safety Precautions

No hazards associated with this test.

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References & Further Information

- Atlas Tech Note No. 1 “Qualitative sorting tests for stainless steels”.
- Nickel Institute Publication 2978 “Mechanical & physical properties of austenitic chromium-nickel stainless steels at ambient temperatures”
- ASM Specialty Handbook “Stainless steels”
- ASSDA Technical FAQ No 3 “Magnetic effects of stainless steels”.

Limitation of Liability

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