MAGNETIC RESPONSE OF STAINLESS STEELS & CAST EQUIVALENTS

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Lack of magnetism is often one of the first things that people think of as a basic characteristic of stainless steel, and therefore it is the basis of one of the most common misperceptions when users of cast stainless steel believe they have received bad material. The attraction, or lack of attraction, of stainless steel to a magnet is an interesting physical property. But can it be trusted as a useful sorting test? The answer is not as clear-cut as is often thought.

WHAT ARE THE BASIC MAGNETIC PROPERTIES OF MATERIALS?

Ferromagnetic materials are those 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". The ease by which a magnetic material can be magnetised is expressed by the *Magnetic Permeability*.

Hard or soft magnetic materials can be classified as "Hard" or "Soft" magnets. 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 are therefore those that show no response to a magnet.

WHICH METALS ARE MAGNETIC?

All common carbon or mild steel, low alloy steels, and tool steels are ferromagnetic. Some other metals such as nickel and cobalt are also ferromagnetic. All stainless steel grades - with the exception of the austenitic grades (200 and 300 series) - are also magnetic – all ferritic grades (eg 430, 444,), all duplex grades (eg 2205, 2304, 2101, 2507), all martensitic grades (eg 431, 416, 420, 440C) and all precipitation hardening grades (eg 17-4PH), are magnetic. Duplex grades are mixtures of austenite and ferrite, and they are 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. However, when it comes to the austenitic stainless steels, both the common wrought 300-series (Cr-Ni) and the lower nickel 200-series (Cr-Mn-Ni) are also 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.) For those not exactly sure what "wrought" designates, it simply means steels that have been *worked* in some way – drawn, forged, pulled, rolled, etc - whereby the metals structure is altered mechanically, and not equiaxed or uniform, such as a casting.

CASTINGS

Castings in austenitic stainless steels have slightly different compositions compared to their wrought counterparts, and are generally governed by specs such as ASTM or ACI. The cast version of 316L for instance is an ASTM grade called CF-3M. 316 is an ASTM grade called CF8M. Most "austenitic" cast alloys are very deliberately made so that they have a small percent of ferrite – this benefits the casting in several ways but the most critical reason for wanting ferrite is to prevent hot cracking during casting, or more specifically, during the solidification stage of casting. In fact, this is just as critical when welding stainless steels. When joining pieces of non-magnetic 300 series stainless steel pieces, a weld can be viewed as a small, long casting, and for the same reason as detailed above austenitic welds intentionally have about 4 – 8% ferrite.

In the case of both welds and castings, the small amount of ferrite results in various degrees of magnetic response, and 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.

It is important to point out that if an austenitic casting is required to be zero ferrite content for a specific reason, the composition may be able to be balanced in favour of this, but this comes with an increased chance for foundry related problems.

THE EFFECT OF COLD WORK ON WROUGHT STAINLESS

Even though wrought austenitic stainless steels are non-magnetic in the annealed condition they may develop magnetic response when cold worked. This is a DIFFERENT reason as to why magnetism can develop in wrought materials than the intentional rebalance of a composition to promote ferrite in castings, and the two should not be confused with each other. Cold work can transform some austenite to martensite, also a magnetic phase in steels.

Cold work 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.

In all cases, whether cast or wrought, the tendency towards magnet properties is 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, where as 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

Cast austenitic stainless steels cannot have their magnetic properties effected by heat treat, it is primarily a function of the Ni/Cr ratio.

However, 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.

CONCLUSION : DOES MAGNETIC RESPONSE MATTER?

The important bottom line for our Customers when they realize their 300 series stainless steel castings are magnetic, is that this magnetic response has no negative effect on any property. In fact, there are BENEFITS as a result. Often, this magnetism is discovered when doing a quick incoming inspection using a simple magnet, and leads to concern about the casting composition.

Further to this point, while cast 300 series stainless steel will be attracted to a magnet while their wrought equivalents will generally not, this means a sort test using magnetism in cases where the end user suspects improper materials were supplied is NOT a suitable test. While it is important that the end user understand this magnetism has no negative effect on the corrosion resistance of stainless steel, magnetism is also present in NON stainless steels, so it is not a finite method to sort stainless castings from other ferromagnetic materials either.

Cast austenitic stainless steels containing some degree of ferrite are stronger and more corrosion resistant than wrought grades because ferrite is inherently stronger and tougher than the base austenitic phase of the metal, and the ferrite "pools" are preferential areas for detrimental chromium carbides to form, rather than in the grain boundaries of the metal, which will lead to inter-granular corrosion. Further, 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.

Remember …. the benefits to the foundry and to the end user of the small amount of ferrite in a cast grade of a 300 series stainless steel far outweighs the concerns one may have for the magnetism, and although the Ni/Cr Ratio can be altered to favour non-magnetic castings, it comes with the risk of other concerns such as cracking, weaker metal, and reduced corrosion resistance in some cases.