What is stainless steel ?

Stainless steel is the generic name for a number of different steels used primarily for their resistance to corrosion. The one key element they all share is a certain minimum percentage (by mass) of chromium: 10.5%. Although other elements, particularly nickel and molybdenum, are added to improve corrosion resistance, chromium is always the deciding factor. The vast majority of steel produced in the world is carbon and alloy steel, with the more expensive stainless steels representing a small, but valuable niche market.

What causes corrosion?

Only metals such as gold and platinum are found naturally in a pure form - normal metals only exist in nature combined with other elements. Corrosion is therefore a natural phenomena, as nature seeks to combine together elements which man has produced in a pure form for his own use. Iron occurs naturally as iron ore. Pure iron is therefore unstable and wants to "rust"; that is, to combine with oxygen in the presence of water. Trains blown up in the Arabian desert in the First World War are still almost intact because of the dry rainless conditions. Iron ships sunk at very great depths rust at a very slow rate because of the low oxygen content of the sea water . The same ships wrecked on the beach, covered at high tide and exposed at low tide, would rust very rapidly. For most of the Iron Age, which began about 1000 BC, cast and wrought iron was used; iron with a high carbon content and various unrefined impurities. Steel did not begin to be produced in large quantities until the nineteenth century. Carbon steel can be defined as an alloy of a small content of carbon combined with well refined iron. Despite its various additions stainless steel still behaves as steel, it is not like the nickel alloys that are really alloys of a number of different metals, iron only being one. Even highly alloyed stainless steel grades such as 316 are a minimum of 62% iron.

Carbon steels without any protection will form a coating of rust which will in a sense protect the rest of the steel. So constantly removing the rust exposes a new fresh layer of steel to be attacked. This is called general corrosion. Various coatings will impede the rusting process, in particular painting, coating with zinc (galvanised steel), and epoxy resins. Another lateral way of reducing corrosion is to put corrosion inhibitors into the solutions that would otherwise cause iron to corrode. One of the most common examples of this is the corrosion inhibitors added to the coolant used in cars.

The unique advantage of stainless steel

For a wide variety of applications, stainless steel competes with carbon steels supplied with protective coatings, as well as other metals such as aluminium, brass and bronze. The success of stainless steel is based on the fact that it has one unique advantage. The chromium in the stainless steel has a great affinity for oxygen, and will form on the surface of the steel at a molecular level a film of chromium oxide. The film itself is about 130 Angstroms in thickness, one Angstrom being one millionth of one centimetre. This is like a tall building being protected from the rain with a roof the thickness of one sheet of ordinary copy paper. This layer is described as passive, tenacious and self renewing. Passive means that it does not react or influence other materials; tenacious means that it clings to the layer of steel and is not transferred elsewhere; self renewing means that if damaged or forcibly removed more chromium from the steel will be exposed to the air and form more chromium oxide. This means that over a period of years a stainless steel knife can literally be worn away by daily use and by being resharpened on a sharpening stone and will still remain stainless. Silver plated cutlery will eventually wear through to the base alloy, but stainless steel cutlery cannot wear through. Manhole and access covers in the water treatment and chemical industry are widely made out of both galvanised steel and stainless steel. In normal use galvanised steel can last many years without corrosion occurring and in these cases there would be little advantage apart from aesthetic reasons to switch to stainless steel. Where stainless comes into its own is where the galvanised coating is constantly being worn away, for example by chains being dragged over it, or constantly being walked over, or where very corrosive chemicals are being randomly splashed onto it.

This leads on to the important point that the initial investment cost of producing a component or fabrication in stainless steel will always be more expensive that using ordinary steel, not just because of the higher cost of stainless steel, but also because it is more difficult to machine. However it is the better life cycle costs of stainless steel that make it attractive, both in terms of much longer service life, less maintenance costs, and high scrap value on de-commissioning.

The development of stainless steel

The inventor of stainless steel, Harry Brearley, was born in Sheffield, England in 1871. His father was a steel melter, and after a childhood of considerable hardship, he left school at the age of twelve to get a job washing bottles in a chemical laboratory. By years of private study and night school he became an expert in the analysis of steel and its production. Having already established his reputation for solving metallurgical problems, Brearley was given the opportunity in 1908 to set up the Brown Firth Laboratories, which was financed by the two leading Sheffield steel companies of the day. This was a highly innovative idea for its time; research for its own sake on the problems of steel making.

In 1912 Brearley was asked to help in the problems being encountered by a small arms manufacturer, whereby the internal diameter of rifle barrels was eroding away too quickly because of the action of heating and discharge gases. Brearley was therefore looking for a steel with better resistance to erosion, not corrosion. As a line of investigation he decided to experiment with steels containing chromium, as these were known to have a higher melting point than ordinary steels. Chromium steels were already at that time being used for valves in aero engines. Iron has an atomic weight of 56, chromium 52, so chromium steel valves are lighter than their carbon steel counterparts, another reason why they were adopted so quickly by the emerging aircraft industry.

Using first the crucible process, and then more successfully an electric furnace, a number of different melts of 6 to 15% chromium with varying carbon contents were made. The first true stainless steel was melted on the 13th August 1913. It contained 0.24% carbon and 12.8% chromium. Brearley at this time was still trying to find a more wear-resistant steel, and in order to examine the grain structure of the steel he needed to etch (attack with acid) samples before examining them under the microscope. The etching re-agents he used were based on nitric acid, and he found that this new steel strongly resisted chemical attack. He then exposed samples to vinegar and other food acids such as lemon juice and found the same result.

At the time table cutlery was silver or nickel plated. Cutting knives were of carbon steel which had to thoroughly washed and dried after use, and even then rust stains would have to be rubbed off using carborundum stones. Brearley immediately saw how this new steel could revolutionise the cutlery industry, then one of the biggest employers in Sheffield, but he had great difficulty convincing his more conservative employers. On his own initiative, he had knives made at a local cutler's, R.F. Mosley. To begin with, Brearley referred to his invention as "rustless steel". It was Ernest Stuart, the cutlery manager of Mosley's who first referred to the new knives as "stainless" after in experiments he had failed to stain them with vinegar. "Corrosion resisting " steel would be really the better term, as ordinary stainless steels do suffer corrosion in the long term in hostile environments.

Other claims have been made for the first invention of stainless steel, based upon published experimental papers that indicated the passive layer corrosion resistance of chromium steel or patented steels with a 9% chromium content intended for engineering purposes. Brearley's contribution was that having come to a conclusion by purely empirical means he immediately seized on the practical uses of the new material.

Within a year of Brearley's discovery, Krupp in Germany were experimenting by adding nickel to the melt. Brearley's steel could only be supplied in the hardened and tempered condition; the Krupp steel was more resistant to acids, was softer and more ductile and therefore easier to work. There is no doubt that but for Brearley's chance discovery, the metallurgists at Krupp would have soon made the discovery themselves. From these two inventions, just before the First World War, were to develop the "400" series of martensitic and "300" series of austenitic stainless steels.

The First World War largely put a halt to the development of stainless steel, but in the early 1920s a whole variety of chromium and nickel combinations were tried including 20/6, 17/7 and 15/11. Brearley fell out with his employers regarding the patent rights to his invention of stainless steel, and he left to join another Sheffield company, Brown Bayleys. His successor at the Brown Firth Laboratories was Dr W.H. Hatfield, who is credited with the invention in 1924 of 18/8 stainless steel (18% chromium, 8% nickel) which, with various additions, still dominates the melting of stainless steel today. Dr Hatfield also invented 18/8 stainless with titanium added, now known as 321.

Most of the standard grades still in use today were invented in the period 1913 to 1935, in Britain, Germany, America and France. Once these standard grades became accepted, the emphasis changed to finding cheaper, mass-production methods, and popularising the use of stainless steel as a concept. This tended to stifle the development of new grades. However, after the Second World War, new grades with a better weight-to-strength ratio were required for jet aircraft, which led to the development of the precipitation hardening grades such as 17:4 PH . From the 1970s onwards the duplex stainless steels began to be developed. These have far greater corrosion resistance and strength than the grades developed in the 1920s and are really the future for the increasing use of stainless steel.

Product characteristics

Stainless steel can be selected for use compared to other materials for a number of different reasons, not just its resistance to corrosion. These include:

- Its aesthetic qualities: it can be polished to a satin or mirror finish.
- "Dry Corrosion" occurs to steel at higher temperatures where it oxidises or scales up. Stainless steel is far more resistant to this than ordinary carbon steel and grades such as 310 (25% chromium 20% nickel) were specifically developed for use at high temperatures.
- Non-contamination of the liquids stainless comes into contact with, because there is no coating to break down and dissolve.
- Weight savings: as thinner sections can be used, more innovative design structures can be used, with cost savings on foundations and platform weights.
- Many anti-corrosion coatings are fire hazards or the materials themselves have a low melting point.

Applications

The most everyday use of stainless steel is obviously in cutlery. Very cheap cutlery is made out of grades 409 and 430, with the finest Sheffield cutlery using specially produced 410 and 420 for the knives and grade 304 (18/8 stainless, 18% chromium 8% nickel) for the spoons and forks. The different grades are used as 410/420 can be hardened and tempered so that the knife blades will take a sharp edge, whereas the more ductile 18/8 stainless is easier to work and therefore more suitable for objects that have to undergo numerous shaping, buffing and grinding processes.

Very large amounts of stainless steel are used in food production and storage. The most commonly used grades are 304 and 316. Typical uses would be dairies, milk storage, ham curing, frozen and salted fish storage. Whereas 304 is used for normal temperatures and acid concentrations, 316 is used for harsher environments. For example 304 is used in cheese production, but where salted ham is being prepared 316 is used. For low concentrations of phosphoric acid (one of the constituents of cola) 304 is used, but at higher temperatures and concentrations 316 is used. Food slicers are made out of 420 and 440. Very often in food production stainless is used not because the food itself is corrosive but the use of stainless allows for faster and more efficient cleaning. For example in ice cream production 316 is specified so that strong anti-bacteriological cleaning and rinsing systems can be used. One of the great advantages of stainless steel is that imparts no taste to the food that it comes into contact with. This has created one interesting anomaly. Traditional winemaking uses barrels of oak. The newer wine-producing nations use very large vats and storage containers of stainless steel as this gives them far greater economies of scale. However in conventional winemaking the acid of the wine dissolves some of the wood to give an "oak" body taste. Using stainless steel vats oak chips deliberately have to be put into the vats to create the same effect and satisfy traditional wine drinkers.

The pumping and containment of oils, gases and acids has created a large market for stainless tanks, pipes, pumps and valves. The storage of dilute nitric acid was one of the first major success stories for 18/8 stainless steel as it could be used in thinner sections and was more robust than other materials. Special grades of stainless have been developed to have greater corrosion resistance. These are used in de-salination plants, sewage plants, offshore oil rigs, harbour supports and ships propellers.

Architecture is a growing market. Many modern buildings use stainless for cladding. When reinforced concrete first started to be used it was considered that the carbon steel used would not rust as cement, obviously derived from limestone, is alkaline. However, constantly using grit salt on bridges can change the pH to acidic thereby rusting the steel which expands and cracks the concrete. Stainless steel reinforcing bar, although initially expensive, is proving to have very good life cycle costings. The low maintenance cost and anti-vandal characteristics of stainless provides a growing market in public transport, ticket machines and street furniture.

The nuclear power industry uses large quantities of stainless, often specified with a low cobalt content, for both power generation and radiation containment. Special louvered ventilation shafts are made, which are designed to be used in emergencies to seal off plants for years if necessary. Steam and gas turbines use stainless because of its corrosion resisting and heat resisting qualities.

Especially clean melted stainless is used for medical implants and artificial hips. A great deal of medical equipment - such as orthopaedic beds, cabinets and examination machines - is made as standard from stainless because of its hygienic and easy-clean qualities. Pharmaceutical companies use stainless for pill funnels and hoppers and for piping creams and solutions.

Cars are making increasing use of stainless steel, primarily for exhaust systems (grade 409) and catalytic converters, but also for structural purposes. With greater attention being made to achieving low long term maintenance costs, less environmental impact and greater concern with life cycle costs, the market for stainless steel continues to improve.