If you find the words ‘green alloy’ a bit mystifying, well stainless steel is one of the very few alloys that are 100% recyclable. It can, therefore, be melted time and time again and reformed into a new product.

An average stainless steel object is composed of about 60% recycled material (25% coming from end-of-life products and 35% from manufacturing process scraps). If you wonder why the recycled content is not even higher, here's the reason. There are simply not enough end-of-life stainless steel scraps around because 20 to 30 years ago much less stainless steel was produced.

Actually, stainless steel is not consumed. It remains as a part of the sustainable closed loop system. Also, the manufacture and processing of stainless steel do not cause adverse effects on the health of workers. Plastic, on the other hand, is a major pollutant when manufactured or disposed of. Plastic items that clutter landfills may leach out dangerous chemicals. As you can see, environmental credentials of stainless steel are impeccable. It is indeed a green alloy!

Stainless steel is a common feature of today’s living. There can be few of us who have not seen or handled articles made from it. But how many of us really know what stainless steel is?

Well, stainless steel is a generic term for a family of corrosion-resistant alloy steels with the common family trait of containing a minimum of 10.5% of chromium. As we go on we shall learn about this fascinating family and the secret of their ‘stainless’ in more detail. But, let’s first get to know the story of the invention of stainless steel.

### Story of Steel

The story of stainless steel is long, tortuous but captivating. We shall make it short and recount only the significant stages of development.

The long and arduous search for corrosion-resistant steels began in 1819. In that year, Michael Faraday and James Stodart in Britain started experiments with different alloys to improve the quality of cutting instruments. They succeeded in making ferrochrome, and demonstrated that adding chromium increased iron’s resistance to corrosion.

Two years later, the French mineralogist, P. Berthier combined ferrochrome with carbon steel to form the first chromium steel containing around 1.25% chromium. He made a knife and a razor blade of fine quality from his alloy. He noted that chrome steels were excellent for making cutlery.

Others studied the effects of chromium in an iron matrix, but tests could be carried out only on low chromium content alloys. Chromium that was available on those days always contained carbon as an impurity. Adding chromium invariably entailed toting up carbon in the mix. The combination of high chromium and significant amount of carbon produced useless alloys that were as brittle as carrot! The impediment in developing high chromium steels was removed in 1895 with the invention of a process for producing carbon-free chromium by Hans Goldschmidt of Germany.

In 1904, French scientist Leon Guillet undertook extensive research on many iron-chromium alloys. He was the first person to produce and define the very important groups now known as ferritic, martensitic and austenitic stainless steels. In Germany, in 1911, Monnartz & Borchers discovered the correlation between chromium content and corrosion resistance. They found that there was a significant boost in corrosion resistance when at least 10.5% chromium was present. They also published detailed work on the effects of molybdenum on corrosion resistance.

Harry Brearley (1871-1948), a research metallurgist in a laboratory in Sheffield, is generally recognized as the initiator of the industrial era of stainless steel. In 1912, Brearley was given a task by a small arms manufacturer who wished to extend the life of their gun barrels that were eroding away too quickly. Brearley began experimenting with steel alloys containing chromium.

On 13 August 1913 Brearley created an alloy with 12.8% chromium and 0.24% carbon. Brearley found that his alloy resisted rusting and proceeded to test the sample with various chemicals, including lemon juice and vinegar. He was astounded to find that the alloy was still highly resistant, and recognised the potential of the alloy in the cutlery industry.
Bearley immediately made an effort to market his new invention. The new alloy, however, was not an instant success and Brearley was branded the inventor of the ‘knife that would not cut’!

Interestingly, Brearley had decided to name his invention ‘Rustless Steel’ but Ernst Stuart, cutlery manager of a local cutler, dubbed it ‘Stainless Steel’ after testing the alloy in a vinegar solution. And the name stuck!

That concludes the brief chronicle of stainless steel. As with many discoveries, it was the accumulated effort of all the above scientists and metallurgists (and all the many more who were not mentioned) that we have today such a rich and versatile alloy at our disposal!

The Secret of ‘Stainlessness’

It may seem paradoxical, but it is corrosion that protects stainless steel from corrosion! Curious? Read on to know the facts!

We know that if steel contains at least 10.5% chromium, it will qualify as stainless steel. This minimum amount of chromium is the ‘key’ for ‘unlocking’ stainless behaviour! This is what actually happens.

Chromium is extremely reactive with oxygen. The chromium in the steel readily combines with oxygen to form a thin, invisible layer of chromium oxide. The size of chromium atom and that of chromium oxide molecule is similar, so like friends they pack neatly together on the surface of the metal, forming a stable layer only a few atoms thick. (Iron rusts quickly because atomic iron is much smaller than its oxide, so the oxide forms a loose layer and flakes away.)

The oxide film is nonporous and continuous across the exposed surface of the metal. Although extremely thin (1 -5 nanometer thick), this inert film adheres firmly and prevents further corrosion by acting as a barrier. In fact, the film is much thinner than the wavelength of visible light (which ranges from about 400-700 nanometer) and so is invisible to the eye.

Thus, although the steel is corroded on the atomic level, it appears stainless. The corrosion resistance as well as other useful properties of the steel are enhanced by increased chromium content and the addition of other elements such as molybdenum, nickel and nitrogen.

An interesting feature of the film is that it is rapidly self-repairing in the presence of oxygen. If the metal is cut, dented or scratched and the film is disrupted, more oxide will quickly form and cover up the exposed surface, protecting it from corrosion. For example, over a period of years, a stainless steel knife can literally be worn away by daily use and occasional sharpening, but remains stainless by courtesy of the self-repairing process!

However, the passive film requires oxygen to self-repair, so stainless steels have reduced corrosion resistance in low-oxygen environments. You might have come across corrosion spots in stainless steel utensils stacked up for a long time in a poorly ventilated loft. You now know the reason!
It is important to appreciate that stainless steel is a solid material and not a special coating. Steels and, indeed, several other metals, are often coated or 'plated' with chromium, nickel or zinc to protect their surfaces. While coatings have some benefits and are widely used, such coatings offer little protection to corrosion in case they are penetrated or damaged.

**Stainless Steel Family**

With more than 60 'members', the stainless steel 'family' is pretty large! They are classified into five distinct metallurgical groups. Four are based on characteristic crystallographic microstructure (the structure of a metal as seen under the microscope). The fifth is based on the type of heat treatment (heating an alloy to a selected temperature, below its melting point, and then cooling it at some predetermined rate so as to obtain required properties) used, rather than microstructure. Let's meet these groups and get to know their 'distinctiveness'.

The straight chromium type is the simplest form of stainless steel. These are the ferritic stainless steels, so named because their crystal microstructure is called ferrite. The ferritic steels are magnetic like ordinary steel. They are often the least expensive stainless steels but can be more difficult to form and weld. These stainless steels typically contain 10.5% minimum chromium and less than 0.12% carbon. It is mainly used for automotive trim.

Increase the carbon content of ferritic stainless steels and you would produce the martensitic stainless steels used for items such as knives, razor blades and corrosion resistant bearings. Martensitic grades are strong and hard, but are brittle and difficult to form and weld. Like ferritic stainless steels, martensitic stainless steels are also magnetic. Martensitic stainless steels typically contain 12-18% chromium and more than 0.12% carbon. It is used for fasteners, pump shafts and turbine blades.

The most widely used stainless steel in the world is the austenitic stainless steel. About 70% of all stainless steel produced is of this type. These alloys have higher chromium content and, as a bonus, invariably have nickel in them. Some other elements like molybdenum may also be added. It is the nickel that modifies the physical structure of the steel and makes it non-magnetic.

Austenitic stainless steels are ductile, tough and, most importantly, easy to form and weld. The stainless steel utensils in your kitchen are of this grade. Surgical instruments are also made of austenitic stainless steel. People sometimes refer to stainless steels based on their chromium and nickel content. For instance, 18-8 stainless steels have 18% nickel and up to 7% molybdenum. It is used in the food, pharmaceutical, chemical, power, transportation and construction industries.

Halfway between the ferritic and austenitic stainless steels is a type called the duplex stainless steels, which are about 50% ferrite and 50% austenite. Duplex stainless steels are inherently stronger and are commonly used in tanks for seagoing chemical tankers where both strength and corrosion resistance are required. Typical composition: 18-25% chromium, 4-7% nickel and up to 4% molybdenum. It is also used for pipelines.

There is one more type – the precipitation hardening stainless steel. This is a specialised type that has very high strength achieved by adding elements such as copper, which form very fine particles during heat treatment. It is commonly used in the paper, aerospace and defence industries.

**Applications**

Stainless steel is a very versatile and useful material. Because of its unique combination of properties that offers attractive benefits, stainless steel is used in a wide variety of products, ranging from the mundane kitchen sink to the sophisticated nuclear reactor. It has revolutionized most modern industries, including construction, transportation, food, pharmaceuticals, health-care and power.

Interestingly, stainless steel's versatility satisfied even the special requirements of individual industries. To illustrate this feature, let's take the construction industry. Stainless steel has long been the darling of architects and engineers on account of its visual flexibility. What is 'visual flexibility', you may ask. Well, it is the ability to blend...
Stainless steel has one of the most hygienic surfaces that are very easy to clean. Exterior cladding material of this building. The stainless steel has remained pristine with no sign of corrosion or erosion!

The transportation sector is increasingly using stainless steel. Railway engineers have realised that stainless steel is a better alternative to conventional materials. A succinct example is the difference in shell material of Kolkata and Delhi Metro coaches. Kolkata Metro coaches are made of ordinary steel but the Delhi Metro coach bodies are constructed of stainless steel.

Car makers, however, have been producing stainless steel cars for more than 70 years. Six stainless steel Model 68 Tudor Deluxe Sedans were made by Ford Motor as early as 1936. In 1981, automaker Delorean mass-produced a large batch of stainless steel cars. Stainless steel has also been used in a wide range of commercial road vehicles like bus, truck, trailer and tanker. Applications include body side skin, under-floor, wheel well, fuel tank and chassis structure. If you live in a big city, you have perhaps seen milk tankers with stainless steel tank transporting milk in bulk.

Stainless steel has one of the most hygienic surfaces that are very easy to clean, as the surface has no pores or cracks to harbour bacteria, dirt or grime. It will not affect the flavour, as it does not react with food. Even acidic foods like tomatoes and vinegar can be safely cooked in it. These features have made stainless steel indispensable for the preparation, delivery and storage of food.

Stainless steel is a standard in modern restaurant as well as household kitchens. Both the professional and amateur user value the fact that stainless steel pots, pans and cooking vessels do not stain, chip or rust, are robust, attractive and need minimal care. Volume production ensures that high quality finished goods, which with appropriate care can last a lifetime, are robust, attractive and need minimal care. Volume production ensures that high quality finished goods, which with appropriate care can last a lifetime, are available at competitive prices.

The operation theatre is undoubtedly one of the most demanding environments in the world. Surgeons trust their patients' lives to stainless steel surgical instruments, implants etc. Stainless steel resists oxidation at high temperatures, making the sterilization of medical instruments and devices possible.

The Future

Stainless steel, with its sleek, elegant surface, greater strength, long service life and excellent environmental credentials is a marvel of technology. Stainless steel paved the way for modern technology and continues to influence our lives every day. From the needle of a syringe to cooking pans or a huge chemical process plant, stainless steel is all around us.

With increasing fuel costs, and energy conservation awareness reaching new heights, the frantic search for novel products and processes to ‘save the environment’ continues. But could the answer be right under our noses? Many people think that stainless steel could be a viable solution. Why is that so?

Well, environmental issues are important criteria for material selection. In evaluating the environmental properties of a material, recycling is a key issue. Stainless steel objects hardly ever become waste at the end of their useful life. They are separated and recovered to go back into the recycling process. Reprocessing stainless steel is economically viable and technically proven.

The vast majority of the world's steel is plain carbon steel and alloy steel, with the more expensive stainless steel representing a small, but important segment. Of all steel produced, roughly 2% by weight is stainless steel. According to industry sales figures, there has been a steady annual increase in demand of stainless steel of around 5% to 8%. This shows that the popularity of stainless steel has continued to grow despite their higher cost.

However, when the total life cycle costs are considered, stainless steel is often the least expensive material option. After all, a few extra rupees spent upfront can save money down the road when the product can be used for a longer period without replacement. The future surely looks bright, shiny and unstained for stainless steel!

Mr Sujit Kumar Naha is a professional engineer. He is also a popular science writer, having published more than 250 articles in magazines and newspapers. He has also authored seven books on popular science in Bangla. Address: 23/1, Kalicharan Dutta Road, Kolkata-700061; sk.naha@gmail.com