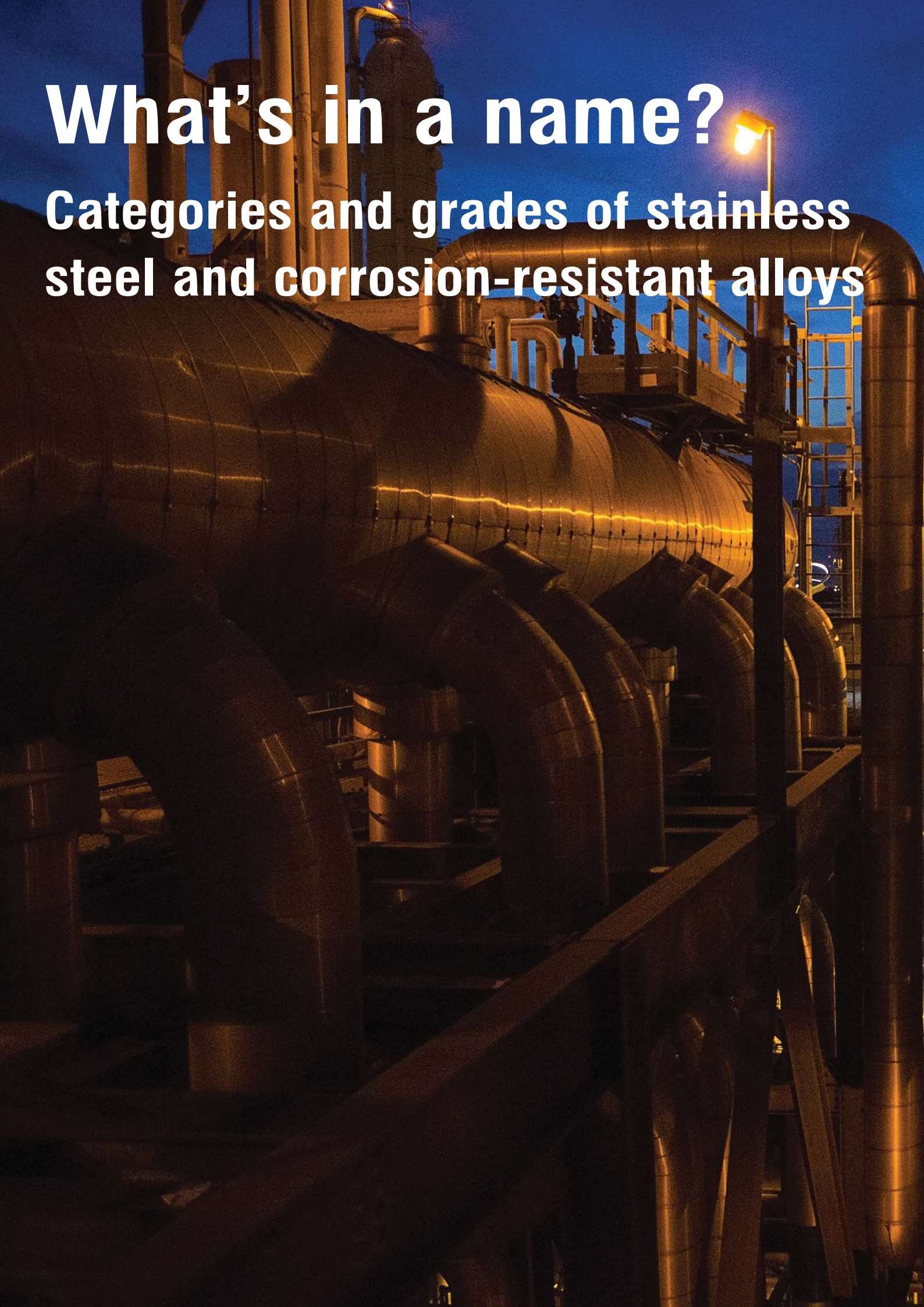



What's in a name?

Categories and grades of stainless steel and corrosion-resistant alloys





Navigating the complexities of terminology can be confusing if you don't have a degree in metallurgy. How are stainless steels and CRAs categorized and graded? What is the difference between a superaustenitic, a superalloy and a nickel alloy? How do all the grading systems gear with one another? This article attempts to guide you through the labyrinth of stainless steel and CRA terminology.

By James Chater

The petrochemical industry is a major consumer of corrosion-resistant alloys. Depicted here, a steam cracker at BASF Total Petrochemicals LLC, Port Arthur, United States.

[TERMINOLOGY]

What is stainless steel?

Wrong question! You should be asking: "What are stainless steels?"

Sorry I spoke.

That's ok, I use the singular form myself! I just wanted to stress that the term is an umbrella covering a distinct family of steels that are more resistant to corrosion than so-called "mild" steels. Apart from that, they are hugely varied.

So what do they have in common?

The most widely accepted definition of stainless steels is that they are alloys of iron and chromium, in which the Cr content is a minimum 10.5% by mass (1).

Why 10.5%?

Once the Cr content crosses the threshold of 10.5%, corrosion resistance increases sharply. What happens is that an invisible, very thin chromium-rich oxide film forms on the surface, protecting the material from corrosion.

Where did the term "stainless steel" originate?

It started life as a trademark. In the years just preceding World War I, Harry Brearley of Sheffield, England, developed a grade that was used in cutlery. It was what we would now call a martensitic. He wanted to call

A NON-RUSTING STEEL.

Sheffield Invention Especially Good for Table Cutlery.

According to Consul John M. Savage, who is stationed at Sheffield, England, a firm in that city has introduced a stainless steel, which is claimed to be non-rusting, unstainable, and untarishable. This steel is said to be especially adaptable for table cutlery, as the original polish is maintained after use, even when brought in contact with the most acid foods, and it requires only ordinary washing to cleanse.

"It is claimed," writes Mr. Savage in the Commerce Reports, "that this steel retains a keen edge much like that of the best double-shear steel, and, as the properties claimed are inherent in the steel and not due to any treatment, knives can readily be sharpened on a 'steel' or by using the ordinary cleaning machine or knifeboard. It is expected it will prove a great boon, especially to large users of cutlery, such as hotels, steamships, and restaurants. The price of this steel is about 26 cents a pound for ordinary sizes, which is about double the price of the usual steel for the same purpose. It also costs more to work up, so that the initial cost of articles made from this new discovery, it is estimated, will be about double the present cost; but it is considered that the saving of labor to the customer will more than cover the total cost of the cutlery in the first twelve months."

The New York Times reports Harry Brearley's "non-rusting steel" for cutlery.

his invention a "rustless steel", but his friend and collaborator Ernest Stuart suggested the more appealing "stainless steel". At about the same time the Krupp Iron Works in Germany developed a stainless steel called "Nirosta" (non-rusting). The German term is in fact "rostfreier Stahl", whereas the French and the Italians prefer the term "inox" (non-oxidizing).

Are you seriously telling me stainless steel never rusts?

Actually the term is a bit misleading. It's all relative, and some grades are more corrosion-resistant than others. But "stainless steel" has a nice ring to it, so the term persisted. Also, the materials which fall under the "stainless steel" umbrella have other attractive properties: easy to clean, doesn't leach, looks nice (depending on the finish), heat-resistant, tough, ductile, hard, light yet strong, etc., depending on the grade.

How many grades of stainless steel are there?

About 100. The basic ingredients are always iron and a minimum of 10.5Cr. You can add nickel, molybdenum, manganese, copper, titanium, nitrogen, carbon or other elements to obtain different properties, but if the iron and the 10.5Cr isn't there, it's not stainless steel.

What is it then?

We'll get to that.

I might find it hard to memorize 100 different grades!

You're not alone. It helps to remember that stainless steels are grouped into families. The basic groups are austenitic, ferritic, martensitic and duplex (combining austenitic and ferritic), depending on their microstructure. Very helpfully, the American Iron and Steel Institute (AISI) developed a system which classifies the first three groups into three series:

AISI designation	Group
200 series	Austenitic (chromium-manganese)
300 series	Austenitic (chromium-nickel)
400 series	Ferritic
	Martensitic
-	Duplex (austenitic-ferritic)

Each group has its strengths and limitations. Austenitics have good formability and ductility, and types 304 (18-20%Cr and 8-10.5%Ni) and 316 (16-18%Cr and 10-14%Ni) are among the most frequently specified grades. Nickel being more expensive than manganese, many end users prefer to



Highly reflective stainless steel 316L from Outokumpu helps to lend Anish Kapoor's Cloud Gate sculpture in Chicago's Millennium Park the appearance of mercury.

specify the 200-series grades provided the corrosion is not too severe. Ferritics, which do not contain nickel, tend to be cheaper than austenitics. They are rather like mild steel, but with better corrosion resistance. Unlike austenitics, they are magnetic. Except in a few applications this is not disadvantage; indeed it can be an advantage, for instance in energy-efficient induction cookware. Martensitics are rather like ferritics, and like them are magnetic, but with added carbon, which makes them hard and strong. Duplex grades are a hybrid of austenitic and ferritic, and are much stronger relative to their weight. Depending on the grade, they can resist several types of corrosion.



Induction cookers can direct the heat through the magnetic pans with such precision that surrounding objects (such as the newspaper or the chocolate in these photos) remain unburnt. For this reason magnetic ferritic stainless steels are the most suitable material for induction cookers.

Haven't you forgotten precipitation-hardening materials?

Some metallurgists posit a fifth category called precipitation-hardening or age-hardening materials. But actually this is a process, not a distinct family of materials, a heat treatment carried out to increase yield strength. It can be applied to several materials, most of which do not fall into the stainless steel category: certain aluminium or nickel alloys, and maraging (martensitic + aging) steel. The most common precipitation-hardening

stainless grade is 17-4PH (AISI 630), used at high temperatures and in moderately corrosive conditions.

What does the letter "L" mean in stainless steel grades?

"L" stands for "low carbon", usually a maximum of 0.03% instead of the normal level of around 0.08-0.15%. The C level is limited to prevent the Cr being depleted during welding. 304L and 316L are both popular grades for use in welded products.

What does "moly 6" mean?

Austenitic grades such as 314 and 316 can withstand mild corrosion, but to prevent stress corrosion cracking or chloride-induced pitting and cracking, higher-alloyed grades are needed. One such group is referred to as "moly 6". In these, the molybdenum content is increased to 6% to improve corrosion resistance. For instance, alloy 254 contains 6% molybdenum and 18% nickel, compared to 2-3%Mo and 10-14%Ni for AISI 316. Another popular moly 6 grade is 904L (23-28%Ni, 4-5%Mo).

What is a superaustenitic?

A superaustenitic is sometimes defined as an austenitic grade in which the non-ferrous elements exceed 50%. As such they are not considered stainless steels. This means that a moly 6 grade such as 254 counts as a stainless steel (just), whereas other moly 6 grades, for example 904L, do not. (Nevertheless, alloy 254 is sometimes termed a superaustenitic.) Alloy 654 SMO® (22%Ni and 7.3%Mo) is a "moly 7" superaustenitic designed for severe corrosion service in the offshore oil and gas industry.

What is the difference between a stainless steel and a corrosion-resistant alloy?

CRA is rather a subjective term. For some, all stainless steels are CRAs, whereas others reserve the term for steels that can withstand only the severest types of corrosion: superaustenitics, duplex and super duplex, nickel alloys etc. Some insist that CRAs are non-ferrous, i.e. do not contain steel. And for the American Petroleum Institute, CRAs are non-ferrous materials in which any combination of titanium, nickel, cobalt, chromium or molybdenum comprises at least half of the material by mass (2).

What is the difference between a nickel alloy and a superalloy?

A nickel alloy (or nickel-based alloy) is an alloy in which nickel is the chief alloying element by mass. In many such alloys, nickel makes up over half the material. They are typically used in severe corrosive conditions, especially at high temperatures, in the oil & gas, chemical and petrochemical industries, and in the turbines of power stations and jet engines. They are typically known by their trademarks, for instance Hastelloy, Inconel, Waspaloy, René, etc. Some of these are also termed "superalloys" or "high-performance alloys" because of their high corrosion resistance or their ability to withstand the extreme thermal conditions of modern gas turbines and jet or rocket engines.

Apart from nickel, other materials can constitute the chief alloying element of superalloys, including cobalt and titanium.



Inconel alloy 625 is suitable for seawater applications because of its excellent corrosion resistance and resistance to chloride-ion stress-corrosion cracking. Depicted here, a shell and tube heat exchanger in alloy 625. Photo: Titan.

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What is the difference between lean duplex, normal duplex, super duplex and hyper duplex?

The difference is measured by their ability to withstand chloride-induced pitting, as measured by the pitting corrosion resistance equivalent (PRE or PREN). This is calculated by the formula $PREN = 1 \times Cr + 3.3 \times Mo + 16 \times N$. Alloys with a PRE of more than 40 are considered super duplex; SAF 2507 SD has a PRE of 42.5. A grade is called "hyper duplex" if its PRE number is 48 or more; SAF 2707 HD has a PRE of 48, and SAF 3207 HD has a PRE of 50. The lower-alloyed, less corrosive resistant duplex grades (e.g. LDX 2101 and 2304) are considered lean. Conveniently, duplex grades are often designated by a four-digit number that indicates the chromium percentage in its first two digits and the nickel percentage in its last two. Thus lean duplex grade 2304 contains 23%Cr and 4%Ni.



Super duplex 2750 seamless pipe with brand name *Dingxin*, from China.

There are various different numbering systems for the different grades. How do they all gear with one another?

Most of the advanced industrial countries have their own grading systems. The best-known system is that devised by AISI and now maintained by SAE International (Society of Automotive Engineers). Most designations are of three digits, beginning with a 2, 3 or 4. A few other systems derive at least partly from the AISI system. The United Numbering System (UNS), managed jointly by ASTM International (American Society for Testing and Materials) and SAE International, has grade names that start with an "S" (standing for "stainless") followed by a five-figure number, of which the first three digits often match the AISI numbers. Likewise, the Japanese JIS system and that of the BSI (British Standards Institution) incorporate the AISI numbers. The classification system of the ISO (International Organization for Standards) incorporates the last four digits of the EN number followed by the three digits of the AISI number.

Equivalent grade numbers of stainless steels and CRAs (selective) (3)

USA		EU	Japan	UK	Trademark or other
UNS	AISI	EN	JIS	BSI	
AUSTENITICS					
S30400	304	1.4301	SUS 304	304S15, 304S16	-
S30403	304L	1.4306, 1.4307	-	304S11	-
S31600	316	1.4401	SUS 316	316S31	-
S31600	316	1.4436	SUS 316	316S33	-
S31603	316L	1.4404	-	316S11	-
S31603	316L	1.4435	-	316S13	-
FERRITICS					
S40900	409	1.4512	SUS 409	409S19	-
S43000	430	1.4016	SUS 430	430S17	-
MARTENSITICS					
S40300	403	1.4000	SUS 403	403S17	-
S41000	410	1.4006	SUS 410	410S21	-
DUPLEX					
S32101	-	1.4162	-	-	LDX 2101®
S32304	-	1.4362	-	-	2304
S32205	-	1.4462	SUS 329J3L	-	2205
S32750	-	1.4410	-	-	2507

In Europe, since 1988, a new series of standards, the EN (Europäischen Normen) has started to replace the national standards of 18 countries. The numbering system for stainless steels, which corresponds to the German Werkstoffnummer system, starts with a figure "1" and a point, followed by four figures. For a time Germany, Italy and Spain operated a designation system which incorporated a partial description of the grade's chemical composition.

Will the various systems ever be unified?

You might as well ask for world government! The problem is that the numbering systems are inextricably bound up with standards, i.e. codes of practice for the manufacture of stainless steel products, and these vary from country to country. Only the EU has introduced a system to replace those of its individual member states, but the national systems linger on, at least for the time being.

How can I set myself up as a stainless steel supplier?

With a lot of hard work, expertise and good luck! Also, a subscription to *Stainless Steel World* won't go amiss.

Shouldn't that be "Stainless Steels World"?

Touché!

With thanks to...

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