International Stainless Steel Forum (ISSF)

Founded in 1996, the International Stainless Steel Forum (ISSF) is a non-profit research organisation that serves as the world forum on various aspects of the international stainless steel industry. Whilst having its own Board of Directors, budgets and Secretary General, ISSF is part of the International Iron and Steel Institute (IISI). ISSF now comprises some 67 company and affiliated members in 24 countries. Jointly, they are responsible for around 85 percent of worldwide stainless steel production. A full list of members can be found on the ISSF website: www.worldstainless.org.
## Contents

Summary “The Ferritic Solution” by Jean-Yves Gilet  5
Foreword: “A steel whose time has come” by ICDA  6
What they’re saying about ferritics  9
The “fabulous ferritics”  13
Corrosion resistance properties  21
Mechanical and physical properties  27
Forming ferritic grades  31
Joining ferritic grades  37
Products and applications  45

Appendices:
The chemical composition of ferritic stainless steels  59
Surface finishes  63
References  64
ISSF membership  66
Acknowledgements  67
STRUCTURAL STEELWORK FOR HIGHWAY BRIDGE IN DURBAN, SOUTH AFRICA, OF PAINTED FERRITIC STAINLESS STEEL.
ISSF first discussed a project to promote ferritic grades in February 2004, many members having pointed out that no joint industry effort was being made in this direction.

Under the guidance of the Market Development Committee, an international group of experts, led by Philippe Richard, started by gathering market statistics on ferritic grades and applications. They received contributions from all around the world – especially Japan, where the ferritics market is the most developed.

The ICDA soon proposed to join the initiative and co-fund the project. This we accepted with great pleasure, as a concrete example of cooperation between international business organisations.

During the project’s start-up phase, nickel prices hit the roof and interest in more price-stable grades increased dramatically. ISSF then gave the project highest priority! I am now proud to present the results, which will ‘hit the market’ at just the right time.

I strongly believe that ferritic stainless steels can and should be much more widely used. The purpose of this publication is to bring about more extensive use of these grades.

Stainless steels are ‘stainless’ because their chromium content gives them remarkable resistance to corrosion. Ferritic grades, containing only chromium and possibly other elements (Mo, Ti, Nb, etc.), are no exception. Well-known standard ferritic grades 409, 410 and 430 are readily available all over the world. Very successfully used in important applications, such as washing-machine drums and exhaust systems, they actually have much broader application potential, in numerous fields.

More recently-developed ferritic grades, such as 439 and 441 meet an even broader range of requirements. They can be formed to more complex shapes and joined using most conventional joining methods, including welding. Thanks to the addition of molybdenum, the resistance of ferritic grade 444 to localised corrosion is at least equal to that of austenitic grade 316.

Since ferritic grades do not contain nickel, their cost is lower and more stable than that of austenitic stainless steels. They can therefore:
- complement type 304 within the stainless steel family (although 304 remains a versatile and commonly used grade);
- be an alternative to the 200 series (offering generally better usage properties);
- substitute for other materials in many areas (e.g. carbon steel, Cu, Zn, Al, plastic, etc.), thanks to their special technical properties – the drivers for replacement being, usually, technical and Life Cycle Cost benefits.

Ferritic stainless steels’ magnetism is not a ‘negative’ quality, somehow associating it with ordinary carbon steel. On the contrary, magnetism is a special asset of these excellent stainless steels, marking them out from other stainless steel grades.

To get the best results from ferritics, it is essential that:
- new users be trained in forming and joining techniques;
- the user consult his stainless steel producer regarding correct grade selection;
- the user acquire his material from a reliable source, able to offer proven guarantees as to the grade, quality and origin of the material supplied.

The high quality of the team’s efforts and the strong support of the ICDA allow us today to present a reference document for our stainless steel business. It benefits from highly interesting testimonials from customers, showing a lively interest in new developments. ISSF is grateful for all these contributions.

Jean-Yves Gilet  
Chairman  
Market Development Committee  
ISSF
Foreword

“A STEEL WHOSE TIME HAS COME”

BY FRIEDRICH TEROERDE OF THE INTERNATIONAL CHROMIUM DEVELOPMENT ASSOCIATION

I must first thank ISSF for inviting the ICDA to write the foreword to The Ferritic Solution – a publication that is inevitably eloquent on the subject of chromium.

The ICDA was set up in Paris, in 1990, and currently boasts some 96 Members from 26 countries across 5 continents. Our mission is to tell the world the positive story of chromium.

Chromium is used in iron and steel to produce stainless steel and other alloys. In stainless steel, chromium is a special ingredient. It is the alloying element that makes stainless steel “stainless”, giving it its remarkable corrosion and oxidation resistance. Chromium is both readily available and easily recycled in its stainless steel form, posing no threat to the environment.

As a body representing the chromium producers, we are sponsoring this handbook because we believe it will develop the chromium industry. Chromium is never used alone. The Market Development Committee of ICDA has therefore been implementing projects of common interest with sister organisations like ISSF for some years. Chromium is the basic element of all families of stainless steel – at an average content level of 18 percent. The annual consumption of stainless steel is increasing at a compound growth rate of 5 percent and the material is used in an increasing number of applications in the food, beverage, mining and automotive industries and in architecture.

You will be aware that nickel, used in “austenitic” stainless steels is subject to considerable price fluctuations, due to stock market factors. In fact, in the last few years, the nickel price has increased to unprecedented levels, greatly affecting the cost of austenitic grades.

Ferritics, the second great family of stainless steels, contain no nickel. They do, however, contain chromium. In the context of our own development, given the exceptional growth in the stainless steel market, we feel we should strongly encourage the broader use of ferritic grades, at this time.

We were therefore delighted when ISSF asked us to support its project to identify and develop new ferritic market applications. The admirable aim of this project is to achieve sustainable growth in the stainless steel market and build a bright future for these excellent grades.

Looking at information already available on ferritic grades, one finds plenty of material on stainless steel in general but little dedicated specifically to ferritics – although such grades have existed for almost 100 years! This lack has encouraged ISSF to create the current handbook. It provides essential information on the technical properties, advantages and potential applications of ferritic grades and gives fabrication recommendations. It also attempts to correct certain popular misconceptions regarding the use and characteristics of ferritic stainless steels.

In conclusion, ICDA is aware that the volatility of nickel presents a major problem for stainless steel users. We are keen to support the industry and its customers by participating in the search for alternative solutions. It is clear to us that, thanks to its proven technical qualities and cost advantages, ferritic stainless steel is a steel whose time has come.

The following pages will guide existing and potential stainless steel users in extending the use of ferritic grades into new and exciting application areas.

Friedrich Teroerde
Chairman
Market Development Committee
ICDA
FERRITIC STAINLESS STEEL IS IDEAL FOR THE EXTERNAL SURFACES OF PROFESSIONAL KITCHEN EQUIPMENT.
The shining appearance of ferritic is a symbol of cleanliness and hygiene in food-contact applications.
What they’re saying about ferritics

The economic advantages and technical merits of ferritic grades have been appreciated by certain market sectors for a number of years. The following testimonials, representing both existing and evolving markets, show that these benefits are becoming more widely understood.

**STEFAN RAAB**

DIRECTOR CORPORATE PURCHASING OF PRODUCT MATERIALS, BSH BOSCH UND SIEMENS HAUSGERÄTE GMBH, MUNICH, GERMANY

“We use stainless steel in about a third of our products. Our reason for using this material is partly functional, because of its corrosion resistance, and partly aesthetic. The share of ferritic stainless steel is approximately 50 percent at this time. Our intention is to increase this, mainly because ferritic gives the customer the benefits of stainless steel in terms of functional qualities and design, in many application areas, but within a limited cost frame. We will use ferritic grades wherever corrosion resistance and formability allow.”

**ROBERTA BERNASCONI**

MANAGER, GLOBAL TECHNOLOGY – MATERIALS, WHIRLPOOL CORPORATION, CASSINETTA DI BIANDRONNO, ITALY

“As a manufacturer of home appliances, we use ferritics for our refrigerators and washing machines and are evaluating conversion to ferritics for cooking appliances and dishwashers. The cost advantage is such that it makes sense for us and our customers that we should make more use of these grades.

“We accordingly design our products with the necessary manufacturing considerations in mind and occasionally select a coated grade and even a fingerprint-protected coated grade, if need be, to ensure long service life. We may, on occasion, use a higher-alloyed ferritic grade. The important thing is to benefit from the economic advantages of using ferritics.

“We find them excellent for our applications and, given the high cost of nickel, the future, in our case, definitely lies with these excellent steels.”

**JEAN-LOUIS LALBA**

MARKET BUYER FOR GROUPE SEB, (TEFAL, ROWENTA, KRUPS, MOULINEX, ARNO, ALL CLAD, PANEX, ETC.), RUMILLY, FRANCE

“We use about 15,000 metric tons of stainless a year, of which some 40 percent is ferritic. Our group originally used ferritics for cookware lids, for which they are ideal, for the stamped or brazed bases of induction cookware and for oven housings. This has extended to include frying pans, in those cases where the result is entirely satisfactory for the end-user.

“Often, in such applications, the corrosion resistance, deep drawing and polishing characteristics of ferritics have proved very acceptable both for us and our customers. There are cases where very demanding manufacturing or in-service requirements will exceed the limits of ferritic grades, in terms of one or more of these qualities or in terms of ease of processing. And there is even irrational prejudice against ferritics in some countries! However, we find these grades to be a perfect choice in many instances. Indeed, their magnetic nature is essential to stainless steel induction cookware. And, of course, the price of ferritics is stable and reliable.

“Given our good experience of ferritics, we intend to extend their use to other applications.”
IN THE SUGAR INDUSTRY, FERRITIC STAINLESS STEEL HAS PROVED SUPERIOR TO CARBON STEEL ON EVERY LEVEL.
GAETANO RONCHI

SENIOR MANAGER, METALS PROCUREMENT, IKEA

"We use stainless steel for pots & pans, cutlery – including knives – and bathroom and kitchen accessories. Our current annual consumption, of 60,000 tons a year, is growing by about 15 percent a year. A substantial part of this is ferritic.

"In mid-2003, IKEA decided to adopt ferritic grades as general-purpose stainless steels, largely due to the material's stable, predictable price. Tests showed that articles with welded seams require a grade with higher chrome content than standard 430 for optimum corrosion resistance and that welded components need further processing to meet requirements. However, the decision represented a breakthrough for our development of stainless steel articles. Our sales growth and the use of stainless steel in new-product design would have been seriously jeopardised had we stayed with austenitic grades.

"A significant number of IKEA’s stainless steel articles are manufactured by an Asian OEM and the success of our transition to ferritics has been due to educating and training the Group’s purchase offices in Asia and its OEM subcontractors. Our target is to phase out austenitic grades completely, replacing them with upgraded ferritics. We are currently testing new ferritic grades with enhanced deep-drawing or corrosion-resistance properties."

MICHAEL LEUNG

ASSISTANT MANAGER,
YIU HENG INTERNATIONAL COMPANY LIMITED, MACAO

"The main products of our subsidiary Xinhui RiXing Stainless Steel Products, based in Guangdong Province, China, are stainless steel cookware and kitchen utensils. At the time of writing, the company consumes about 800 metric tons of stainless steel per month, of which 66-70 percent is ferritic. When we launched our factory, in 1999, we just used 400-series grades on the bottom of cookware. We began using them for cookware bodies in 2002.

"Low cost is not the only reason for favouring ferritics. Ferritic grades are magnetic and have good thermal conductivity. They are easy to recycle, which helps save the planet’s resources. Changing from 304 to ferritic means that the manufacturer becomes more competitive and the consumer gets a safe product at a lower price. We must correct the unfounded prejudice that because ferritics are magnetic they are low-quality and have poor corrosion resistance.

"In factories where 304 is predominantly used, changing to ferritic grades means adjusting the manufacturing process and dies. This is costly. Our experience, however, shows that total production costs can be lowered with ferritics.

"Overall, we are very satisfied with ferritics. A good range of ferritic grades has been developed, to meet a wide variety of requirements. We hope ferritic stainless steel becomes widely available in steel service centres and becomes more extensively used in a broad range of sectors."

ATUSHI OKAMOTO

MANAGER OF NO.1 PRODUCTION SECTION, OSAKA WORKS,
TAKARA STANDARD CORP., JAPAN

"Takara Standard is a major Japanese manufacturer of kitchen and bathroom products. We use stainless steel for sinks and top panels of built-in kitchens and for bathtubs and mounting components of built-in baths. This company has used ferritic grades for about 40 years, for the simple reason that their properties are sufficient for these applications.

"We are successful with ferritics because our product design takes into account the specific mechanical properties of these grades and we have appropriate press-forming and die technology. We have met no major problems with ferritic grades. When an intricate shape is required, we carry out trials, to establish the best processing parameters.

"To conclude, we are very satisfied with ferritic stainless steels. I would like to see guidelines issued to help companies choose the right ferritic grade for their application."

OTHER TESTIMONIALS FOLLOW ON THE LEFT-HAND PAGES BEFORE EACH CHAPTER...
As a major Brazilian manufacturer of household goods and tools, with an intense export activity, Tramontina currently uses about 850 tons of stainless steel per month, of which almost 30 percent is ferritic. The products for which we mainly use ferritics are economical trays and cutlery, sinks and the base of pans.

“We have used ferritics since 1974, when we started to produce pans and serving sets at our plant in Farroupilha. Our main reason for introducing ferritics was the lower cost of this raw material, coupled with the fact that their characteristics and properties are very satisfactory for these applications.

“In terms of deep-item manufacturing, such as lay-on sinks, ferritics are not as easy to work with as austenitics and require an intermediate rolling process. However, I still consider ferritic stainless steel as a good choice, due to the cost/benefit ratio. Being easy to clean and maintain, the material is hygienic. It also has all the aesthetic merits of stainless steels and is available in various surface finishes.

“To sum up, we’re happy with ferritics and have used them for a long time now. In fact, we’re always looking for new applications in which to use them and benefit from the cost advantage.”
The “fabulous ferritics”

In the face of an explosion in raw-material costs, ferritic stainless steels are emerging as a useful solution in many applications where cost-saving material substitution has become an imperative.

In recent years, prices of raw materials such as aluminium, copper, zinc and nickel have exploded. Stainless steel producers and users, notably, are greatly affected by the high and volatile nickel price – which fluctuates daily. Nickel is a constituent of the widely used “austenitic” (300-series) stainless steel grades.

Stainless steel producers have no control over these phenomena, whose inevitable effect is to both push up and destabilize the cost of their nickel-containing grades. This situation is forcing some existing users of these grades to seek materials that cost less than austenitics but which might still provide fabrication and in-service characteristics adequate for their product or application.

The situation can also scare off potential users of stainless steel, who may believe that stainless steels possessing the qualities they need are financially out of reach.

LOWER COST, STABLE PRICE

The good news is that ferritic (400-series) stainless steel grades – low and stable in price yet boasting impressive technical characteristics – are waiting in the wings, ready to prove an excellent alternative material for many supposedly “austenitic-only” applications.

Containing no nickel, ferritic grades basically consist of iron and chromium (min. 10.5%). The price of chromium – the ingredient that makes “stainless” steel especially corrosion resistant – is historically relatively stable. Certain ferritic grades contain additional alloying elements, such as molybdenum, to enhance specific properties.

Ferritic stainless steels share most of the mechanical and corrosion-resistance properties of their more expensive cousins, the austenitics, and even improve on austenitics in certain characteristics. Why pay for nickel if you don’t have to?

Users of copper, aluminium or austenitic stainless steels in search of another solution can take heart. Ferritics are often an affordable and technically ideal way to benefit fully from stainless steel’s unique qualities.

“Why pay for nickel if you don’t have to?”
THE 5 FERRITIC “FAMILIES”

Ferritic grades fall into five groups – three families of standard grades and two of “special” grades. By far the greatest current use of ferritics, both in terms of tonnage and number of applications, centres around the standard grades. Standard ferritic stainless steels are plainly, therefore, totally satisfactory and entirely appropriate for many demanding applications.

<table>
<thead>
<tr>
<th>STANDARD FERRITIC GRADES</th>
<th>~91% of total volume in 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group 1</strong></td>
<td></td>
</tr>
<tr>
<td>10%-14%</td>
<td></td>
</tr>
<tr>
<td>30%</td>
<td></td>
</tr>
<tr>
<td>Types 409, 410, 420</td>
<td></td>
</tr>
<tr>
<td>Cr content: 10%-14%</td>
<td></td>
</tr>
<tr>
<td><strong>Group 2</strong></td>
<td></td>
</tr>
<tr>
<td>14%-18%</td>
<td></td>
</tr>
<tr>
<td>48%</td>
<td></td>
</tr>
<tr>
<td>Type 430</td>
<td></td>
</tr>
<tr>
<td>Cr content: 14%-18%</td>
<td></td>
</tr>
<tr>
<td>Types 430Ti, 439, 441, etc.</td>
<td></td>
</tr>
<tr>
<td>Include stabilising elements such as Ti, Nb, etc.</td>
<td></td>
</tr>
<tr>
<td><strong>Group 3</strong></td>
<td></td>
</tr>
<tr>
<td>14%-18% stabilised</td>
<td></td>
</tr>
<tr>
<td>13%</td>
<td></td>
</tr>
</tbody>
</table>

Group 1 (type 409/410L) has the lowest chromium content of all stainless steels and is also the least expensive. This group can be ideal for non- or lightly-corrosive environments or applications where slight localised rust is acceptable. Type 409 was originally designed for automotive exhaust-system silencers (exterior parts in non-severe corrosive environments). Type 410L is often used for containers, buses and coaches and, recently, LCD monitor frames.

Group 2 (type 430) is the most widely used family of ferritic alloys. Having a higher chromium content, Group 2 grades show greater resistance to corrosion and behave most like austenitic grade 304. In some applications, these grades are suitable to replace type 304 and are usually of high enough grade for indoor applications. Typical uses include washing-machine drums, indoor panels, etc. Type 430 is often substituted for type 304 in household utensils, dishwashers, pots and pans. For information on its welding characteristics, see p. 38.

Group 3 includes types 430Ti, 439, 441, etc. Compared with Group 2, these grades show better weldability and formability. Their behaviour is even, in most cases, better than that of 304 austenitic grades. Typical applications include sinks, exchanger tubes (the sugar industry, energy, etc.), exhaust systems (longer life than with type 409) and the welded parts of washing machines. Group 3 grades can even replace type 304 in applications where this grade is an over-specification.

“Standard ferritic stainless steels are totally satisfactory and entirely appropriate for many demanding applications.”

<table>
<thead>
<tr>
<th>SPECIAL FERRITIC GRADES</th>
<th>~9% of volume in 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group 4</strong></td>
<td></td>
</tr>
<tr>
<td>Added Mo</td>
<td></td>
</tr>
<tr>
<td>7%</td>
<td></td>
</tr>
<tr>
<td>Types 434, 436, 444, etc.</td>
<td></td>
</tr>
<tr>
<td>Mo content above 0.5%</td>
<td></td>
</tr>
<tr>
<td><strong>Group 5</strong></td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td></td>
</tr>
<tr>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>Cr content: 18%-30% or not belonging to the other groups</td>
<td></td>
</tr>
</tbody>
</table>
Group 4 includes types 434, 436, 444, etc. These grades have added molybdenum, for extra corrosion resistance. Typical applications include hot water tanks, solar water heaters, visible parts of exhaust systems, electrical-kettle and microwave oven elements, automotive trim and outdoor panels, etc. Type 444’s corrosion-resistance level can be similar to that of type 316.

Group 5 (types 446, 445/447 etc.) has additional chromium and contains molybdenum, for extra corrosion and scaling (oxidation) resistance. This grade is superior to type 316 in respect of these properties. Typical uses include applications in coastal and other highly corrosive environments. The corrosion resistance of JIS 447 is equal to that of titanium metal.

IMPRESSIONS REFERENCES
Among the success stories of ferritic stainless steels, two typical and extremely demanding applications stand out. For years, ferritic grades have been very extensively used in two extremely demanding applications: automotive exhaust systems and washing-machine drums.

Exhaust systems are exposed to high temperatures and corrosive environmental conditions. The use of stainless steel (ferritic) makes it possible to extend the warranty period of these parts.

Washing-machine drums have to withstand detergents and a virtually constantly humid environment. In this context, however, localised corrosion would be utterly inadmissible.

Car owners and householders will readily testify to their satisfaction with the long life of their washing machines drums and exhaust systems. For manufacturers of these products, “fabrication friendliness” and major economic advantages are additional factors making ferritic stainless steel the obvious choice.

“...in many cases, ferritics are emerging as a better choice than more expensive materials.”

Other current uses of ferritic grades range from kitchenware and catering equipment to indoor furniture and decorative items, automotive trim, superheater and reheater tubes, burners, air-conditioning ducts, barbecue grills, etc. Many new applications are waiting to emerge.

TODAY’S EXCELLENT FERRITICS
Top-quality ferritic stainless steels have existed for some years now and much intensive research and development has gone into defining the remarkable grades currently available.

They are neither new to the market nor to their highly-experienced producers. Strangely, though, attitudes to these steels seem tinged with misconception and ignorance, for largely historical reasons. Grade 430 was once the only grade available and early, pioneering users may have received insufficient technical support regarding the use of this grade – especially, perhaps, in the case of welded structures or more corrosive conditions. In any event, the false idea took hold, in some quarters, that ferritics are “inferior” and that only austenitics will do.

Ferritics moved on a long time ago! Full technical support is available today and the range of grades has greatly increased and diversified, to meet users’ needs, in terms of properties. Since these properties are broadly comparable to those of austenitics, it is wrong to see ferritic grades as either inferior or superior. They are just different – and usefully so.
indeed, in many cases, ferritics are emerging as a better choice than more expensive materials. They may more closely match the actual specification of a particular application, providing just the qualities needed – no less and, equally importantly, no more.

FINE FOR FORMING
Every bit as malleable as carbon steel, ferritic grades are suitable for most forming operations. They are less malleable than austenitic stainless steels, which have exceptional properties, but in many cases austenitics are “over-specified”.

Carbon steel and ferritic stainless steel demonstrate equivalent forming behaviour. One need only think, therefore, of the complex shapes into which carbon steel is currently formed (e.g. car bodies) to appreciate the broad possibilities for ferritic stainless steels. Given correct adaptation of tooling and choice of grade, countless shapes may be formed using ferritic grades.

PROUD TO BE MAGNETIC
A widely held misconception is that because ferritics are magnetic they are not “real” stainless steels and will rust like carbon steel. This is nonsense. Purely for reasons of atomic structure, some stainless steels are magnetic and some are not. Corrosion resistance is not a matter of atomic structure but one of chemical composition – in particular chromium content. Magnetism has nothing to do with it.

In fact, the magnetism of ferritic grades is one of the material’s major assets, having many existing and potential uses and advantages, ranging from sticking memos on the fridge to storing knives and other metallic implements. Indeed, it is essential that pans used in “induction” cooking are magnetic, since the process involves generating heat in the cookware itself by transfer of magnetic energy.

SPECIAL TECHNICAL ADVANTAGES
Stainless steel is an especially durable, low-maintenance material, with considerable Life Cycle Cost advantages over carbon steel. It is also 100% recyclable: over 60% of new stainless steel is made from melted scrap.

Stainless steel’s main properties can be summarised as follows:
- corrosion resistance
- aesthetic appeal
- heat resistance
- low lifecycle cost
- full recyclability
- biological neutrality (meets EU RoHS requirements)
- ease of fabrication

Ferritic stainless steels boast all the advantages that stainless steels have over carbon steels in terms of corrosion resistance, low Life Cycle Cost and longevity. In addition, their advantages over their close cousins, the austenitic grades, do not just stop at costing less. Ferritics actually outshine austenitics in several characteristics.
FERRITIC SPECIAL TRUMP CARDS

- Ferritics are magnetic.

- Ferritics have low thermal expansion (they expand less than austenitics when heated).

- Ferritics have excellent high-temperature oxidation resistance (they are less prone to scaling than austenitics).

- Ferritics have high thermal conductivity (they conduct heat more evenly than austenitics).

- Ferritics stabilised with niobium have excellent creep resistance (they deform less than austenitics in response to long-term stresses).

- Ferritics are easier to cut and work than austenitics (which require special tools and more powerful machines and generate greater tooling wear).

- Ferritics are significantly less prone to springback than austenitics, during cold forming.

- Ferritics have higher yield strength (similar to that of popular carbon steels) than type 304 austenitics.

- Ferritics, unlike austenitics, are not prone to stress corrosion cracking.
PERFECTION IS MATCHING THE SPEC

In current market conditions, existing and potential users should, above all, avoid “over-specifying” when choosing a steel for a given application.

Historically, austenitic grade 304 has been the most widely developed and readily available stainless steel grade, due to the broad spectrum of applications for which it is suitable. Today’s ferritic stainless steel grades, properly specified, can often be substituted for 304, to excellent effect.

Close and realistic examination of the fabricating and in-service qualities required will often reveal that an economically advantageous ferritic grade can perfectly adequately meet these specifications, for both fabricator and end-user.

“Today’s ferritic stainless steel grades, properly specified, can often be substituted for 304, to excellent effect.”

Sometimes, a reasonable in-service compromise (e.g. advising end-users to clean their product’s surface regularly) is all that is required to keep a particularly inexpensive ferritic grade immaculately corrosion-free for the life of the product.

“A STEEL WHOSE TIME HAS COME”

Given the quality of today’s ferritic grades, their price advantage and the exceptional properties that can be obtained by using additional alloying elements, the opportunities for ferritic stainless steels seem unlimited.

This brochure tries to make the qualities of ferritics easily understandable, describing them in relatively simple terms. Its aim is to encourage the greater use of stainless steels in general by increasing awareness of the merits of these lower-cost grades. This is part of a stainless steel industry initiative to help users specify the correct grades for their application.

The following pages examine the properties of today’s ferritics, the roles of the various alloying elements and the many existing and potential applications of these steels.
In certain environments ferritic stainless steels provide an aesthetic, durable and economical solution for urban furniture requirements.
“As a worldwide automobile equipment supplier, Faurecia’s main use of stainless steels is in exhaust systems. Of the 200,000 metric tons or so of stainless steel that we use for this purpose annually, some 90 percent is ferritic. In fact, we’ve been using ferritics since the mid-1970’s, when we started producing catalytic converters conforming to U.S. emission standards. Ferritics have much lower thermal expansion characteristics than austenitics, which was a crucial factor in the durability of these catalytic converters.

“Ferritics are a success story for us because our deep understanding of the specific behaviour of the grades in different exhaust environments means we can choose the right grade for the right application. Of course, formability limitations and the need to avoid intergranular corrosion need to be taken into account in both product design and manufacturing process. We increasingly require continued progress with ferritics in the areas of high temperature performance above 900°C and corrosion resistance. We believe that such improvements to ferritic grades will bring them closer to the performance of austenitics, but still at a lower and more stable cost. That said, we’re already very satisfied with ferritics.”
Corrosion resistance properties

Stainless steels are “stainless” because their chromium content gives them exceptional resistance to corrosion.

All steels are prone to corrosion, to varying degrees. Stainless steels, however, are significantly more corrosion resistant than carbon steels, due to the chromium they contain. Chromium (not nickel, as is sometimes imagined) is the key ingredient in the corrosion resistance of stainless steels.

LOCALISED CORROSION RESISTANCE

Stainless steel applications are mostly maintenance-free but, in some cases, light maintenance (removal of deposits, for example) may be necessary, to ensure corrosion-free service life.

The corrosion resistance of stainless steels is determined more by chemical composition than by austenitic or ferritic atomic structure. Indeed, in terms of resistance to corrosion, ferritics and austenitics can be seen as two interchangeable stainless steel families.

...ferritics and austenitics can be seen as two interchangeable stainless steel families.

A comparison of the corrosion–resistance properties of the five ferritic “groups” with those of austenitic type 304 clearly highlights the key role of chromium and shows that the corrosion resistance of nickel-containing (austenitic) grades can be matched by the majority of ferritic families.

The above chart shows that only molybdenum-containing ferritic grades have better localised (“pitting”) corrosion resistance than 304. However, stabilised ferritic standard grades, although positioned slightly below 304, still have very good resistance to pitting corrosion.
Group 1 ferritics are best suited to non-severe conditions, such as inside the home (where the material is either not exposed to water contact or gets regularly wiped dry) or outdoors in contexts where some superficial corrosion is acceptable. In such contexts, this group of ferritics has a longer life than carbon steel.

Group 2 grades are effective in contexts involving intermittent contact with water, in non-severe conditions.

Group 3 grades are suitable for similar contexts to those appropriate for Group 2 grades, but are easier to weld.

Group 4 ferritics are more corrosion resistant than type 304 and are suitable for a wide variety of uses.

Group 5 includes, for example, grades with a very high chromium content of around 29% Cr, plus 4% Mo, which makes them as corrosion resistant in seawater as titanium metal.

THE PRE FACTOR

The “PRE” or Pitting Resistance Equivalent number is a measure of the relative pitting corrosion resistance of a stainless steel grade in a chloride-containing environment. The higher a grade’s PRE value, the more corrosion resistant that grade will be.

<table>
<thead>
<tr>
<th>PREN = %Cr + 3.3 x % Mo + 16 x %N</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AUSTENITIC/FERRITIC PRE COMPARISON</strong></td>
</tr>
<tr>
<td>------------------------------------</td>
</tr>
<tr>
<td><strong>PRE</strong></td>
</tr>
<tr>
<td><strong>SEA WATER 20°C</strong></td>
</tr>
<tr>
<td><strong>COASTAL ENV. 20°C</strong></td>
</tr>
<tr>
<td><strong>PURE WATER</strong></td>
</tr>
</tbody>
</table>

The PRE comparison table shows at a glance that for every austenitic grade there is a ferritic grade with comparable corrosion resistance.

In the commonly used shortened form of the PRE formula \( \text{PRE} = \% \text{Cr} + 3.3 \times \% \text{Mo} \), molybdenum (Mo) is expressed as being 3.3 times more effective than chromium against pitting corrosion. However, chromium is always essential for providing the basic corrosion resistance. Molybdenum cannot replace this “base” amount of chromium in stainless steels, but can be used to boost corrosion resistance.

Nickel content is not considered in the formula, since in most applications it plays no role in resistance to pitting corrosion.

AVOIDING CORROSION

Stainless steel’s “passive” layer (see p. 59) needs oxygen to remain intact. An accumulation of deposits can deprive the steel of oxygen at critical points, which could lead to corrosion. Propagation of corrosion may lead to eventual rupture of the part.
CORROSION RISK FACTORS

- embedded particles
- superficial deposits
- surface defects
- structural discontinuities
- salinity (salty areas, seawater, etc.)
- increase of temperature
- highly acidic conditions (strong acids)
- a strongly “reducing” environment

CORROSION-PREVENTING FACTORS

- a clean surface
- a smooth surface
- a pre-passivated surface
- ageing of the surface
- the washing effect (e.g. rain)
- higher chromium content
- oxidising conditions \( (O_2 – \text{not too strong}) \)
- adding molybdenum
Corrosion sets in when pH reaches a critically low value (low pH = high acidity). The “pH” level is a unit of measure describing the degree of acidity or alkalinity of a solution. This is measured on a scale of 0 to 14.

**ATMOSPHERIC CORROSION**

This type of corrosion occurs on a steel surface, in the thin, wet film created by a combination of humidity in the air and impurities. It is often initiated by the presence of chlorides or sulphur compounds – in an industrial environment. Typical conditions could be, for example, chloride deposits in a humid, marine atmosphere.

**CHOICE OF GRADE**

Ferritic grades can be used in atmospheric environments of widely varied corrosive severity. All parameters concerning in-service conditions should be closely considered in selecting the appropriate grade.

If slight localised surface rust (pitting corrosion), for example, is of no importance in a certain application or environment, a lower-cost grade might well be the correct material choice.

**RULES OF THUMB**

- In the case of an aggressive environment, select a grade with a higher chromium and/or molybdenum content.
- Avoid rough surface finishes – favour a fine-polished surface with a low Ra value.
- Optimize design for “washability” (e.g. min. 15° slope on upward-facing surfaces).
- Avoid “crevice-like” geometries.
- Keep surface clean, by regular washing, to avoid staining and dust accumulation.

“**Ferritic grades can be used in atmospheric environments of widely varied corrosive severity.**”
**OXIDATION RESISTANCE**
Unlike the two above types of corrosion, high-temperature cyclic oxidation is “dry corrosion” occurring at high temperatures (>500°C) and in oxidizing atmospheres, with or without thermal cycle.

When stainless steels are heated, their chromium content forms a protective chromium oxide surface “scale” that delays further oxidation. The scale and the metal substrate will have different thermal expansion behaviour, which can affect the scale’s stability, especially in service conditions of frequent thermal cycling. The expansion coefficient of the scale is very low and if that of the metal is too high, excessive scale will be generated, which will spall or crack when the metal cools and contracts.

Thanks to their lower thermal expansion coefficient, ferritic grades are much less prone than austenitic alloys to high-temperature cyclic oxidation scaling. Where there is no spalling or cracking, there is no new oxidation. This is a particular advantage in applications such as heating systems, burners or exhaust systems, including manifolds.

**BROAD APPLICATION POSSIBILITIES**
These interesting corrosion-resistance properties are far from being ferritic stainless steel’s only attractions. They are already enough, however, to win friends for ferritics in the current climate of high material costs.

Close examination of the properties of ferritics tends to pay dividends. Some existing austenitic users might find, on examining their specification, that a ferritic grade is actually highly appropriate for their application.

---

*...ferritic grades are much less prone than austenitic alloys to high-temperature cyclic oxidation scaling.*

Potential stainless steel users may be surprised by the exceptional qualities of ferritics – and discover that stainless steel is a viable option after all!

**LIFE CYCLE COSTING: AN INVALUABLE GUIDE**
The value of carrying out a Life Cycle Costing study on any potential application cannot be stressed too highly. Such a study will often reveal that stainless steel – generally seen as a costly solution – is actually the lower-cost option, viewed long-term.

Stainless steel’s corrosion resistance means longer life, less maintenance, higher resale value, better appearance, etc. It renders painting or galvanizing unnecessary. And as if this were not inducement enough, the lower investment cost of ferritic grades can be a clinching argument in favour of stainless steel as a material choice.

Already widely used and respected, ferritic grades are nonetheless still being “discovered”. The numerous well-proven existing applications, however, light the way to many exciting new possibilities for these fine steels.

---

*...the lower investment cost of ferritic grades can be the clinching argument in favour of stainless steel...*
Seung Tae Baek
Team Leader Washing Machine Procurement, LG Electronics, Korea.

“We use ferritic stainless steels mostly in washing-machine drums and have done so from an early stage in our development of automatic washing machines. In fact, in 2006, we used some 15,500 tons of ferritics, against 2,500 ton of austenitics, so ferritics accounted for 86 percent of our stainless steel consumption.

“The advantage for us is simply that ferritic grades have very satisfactory mechanical qualities but are less costly than austenitics. Technically, advances in moulding technology and the development of higher-quality ferritic grades mean we can use ferritics very successfully these days. Cracking and creasing in the press remains an occasional source of defects and we need to improve aspects of the deep drawing process. However, with ferritics we get a result that satisfies everyone in terms of both price and quality.”
Mechanical and physical properties

Ferritic stainless steel grades are fabrication-friendly and suitable for a very wide range of applications.

Ferritics have good mechanical properties, occupying an intermediate position in this respect when compared to the other stainless steel families. They have higher yield strength than austenitics, while their elongation and forming properties are equivalent to those of carbon steels. Their physical properties include two characteristics in which they out-perform austenitic grades: thermal expansion and thermal conductivity.

MECHANICAL PROPERTIES

Generally speaking, the mechanical properties of a metallic alloy are those that describe the material’s ability to compress, stretch, bend, scratch, dent or break. The most commonly used criteria for evaluating mechanical characteristics are:

• **Strength**: the degree of resistance of a material to deformation. Two critical values are generally considered:
  • yield strength, or the stress the material can be subjected to before permanent plastic deformation occurs;
  • tensile strength, or the stress it can be subjected to before rupture/failure.

• **Hardness**: the degree of resistance to indentation by an applied load.

• **Toughness**: the capacity to absorb deformation energy before fracture.

• **Ductility (or plasticity)**: the ability to deform plastically without fracturing.

Some of these properties can be measured by a tensile test. The resulting stress-strain curves make it possible to determine yield strength (YS), ultimate tensile strength (UTS) and total elongation at failure (E). These tests result in the definition of a stress-strain curve charting the performance of the metal in response to various loads.

UTS is measured in MPa (1MPa = 1N/mm² = 145PSI = 0.1kg/mm²) and represents maximum resistance at failure. YS refers to the beginning of the “plastic” phase, where elongation no longer disappears when the stress is removed.

The stress-strain curves show that while ferritic grade 430 has its limits, it clearly performs exceptionally well within those limits.

...ferritics and austenitics can be seen as two interchangeable stainless steel families.”
Ferritic stainless steels have stress-strain curves fairly similar to those of plain carbon steels. With moderately high yield strength (generally higher than that of austenitics), moderately high ultimate tensile strength and good total elongation performance, they offer good ductility.

The above table expresses properties in terms of U.S., Japanese and European standards, comparing ferritic grades with standard austenitic grade 304. Rm = ultimate tensile strength, Rp02 = yield strength and A5/A80 = elongation to fracture.

### PHYSICAL PROPERTIES

The physical properties of a metallic alloy concern the material's ability to conduct heat, conduct electricity, expand or shrink, etc.

Ferritics are magnetic. They also have some other useful advantages over austenitic grades. Their thermal conductivity, for instance, is notably high. This means that they spread heat comparatively efficiently – which makes them highly suitable for applications such as electric irons or heat exchangers (tubes or plates).

The thermal expansion coefficient of ferritic stainless steels is similar to that of carbon steel and much lower than that of austenitic stainless steel. As a result, ferretics distort less when heated.

### MECHANICAL PROPERTIES (COLD ROLLED)

<table>
<thead>
<tr>
<th>Type of stainless steel</th>
<th>Density</th>
<th>Electric resistance</th>
<th>Specific heat</th>
<th>Thermal conductivity</th>
<th>Thermal expansion coefficient</th>
<th>Young's modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>g/cm³</td>
<td>Ω mm²/m</td>
<td>J/kg • °C</td>
<td>W/m • °C</td>
<td>0-200°C</td>
<td>0-400°C</td>
<td>0-10°C</td>
</tr>
<tr>
<td>409/410 10%-14% Cr</td>
<td>7.7</td>
<td>0.58</td>
<td>440</td>
<td>28</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>430 14%-17% Cr</td>
<td>7.7</td>
<td>0.60</td>
<td>440</td>
<td>26</td>
<td>10.5</td>
<td>11.5</td>
</tr>
<tr>
<td>Stabilised 430Ti, 439, 441</td>
<td>7.7</td>
<td>0.60</td>
<td>440</td>
<td>26</td>
<td>10.5</td>
<td>11.5</td>
</tr>
<tr>
<td>Mo &gt; 0.5% 434, 436, 444</td>
<td>7.7</td>
<td>0.60</td>
<td>440</td>
<td>26</td>
<td>10.5</td>
<td>11.5</td>
</tr>
<tr>
<td>Others 17%-30% Cr</td>
<td>7.7</td>
<td>0.62</td>
<td>440</td>
<td>25</td>
<td>10.0</td>
<td>11.0</td>
</tr>
<tr>
<td>304</td>
<td>7.9</td>
<td>0.72</td>
<td>500</td>
<td>15</td>
<td>16</td>
<td>18</td>
</tr>
<tr>
<td>Carbon steel</td>
<td>7.7</td>
<td>0.22</td>
<td>440</td>
<td>50</td>
<td>12</td>
<td>14</td>
</tr>
</tbody>
</table>

The modulus of elasticity of ferritic grades (at 20°C) is superior to that of 304 austenitic. IS units: g/cm³ = kg/dm³  – J/kg • °C = J/kg • °K – W/m • °C = W/m • °K – 10-6/°C = 10-6/°K – N/mm² = MPa.
As strong as carbon steel, low-chromium ferritic grades are also corrosion resistant. Ferritic rail ore wagons therefore have a lower life cycle cost (LCC).
As one of the world’s leading white goods home-appliance manufacturers, the Haier Group uses ferritics in a broad range of products, including washing machines, dishwashers, gas cookers, kitchen extractor hoods and microwave ovens. Having started using these grades before the year 2000, we currently use around 14,500 metric tons of ferritics a year, representing about 85% of our total stainless steel consumption. Ferritic grades are less costly than austenitic grades and are ideally suited to these applications.

“Compared with austenitic grade 304, standard ferritics neither meet the deep-drawing requirements of every part nor show as good corrosion resistance in chloride environments, nor do they have the same welding characteristics. However, they remain excellent materials for home appliances and, in terms of manufacturing, the adapted grades we use have good punching and drawing properties. So we’re happy with ferritics.

With the nickel price going up crazily, our purchasing costs for stainless steel have increased sharply. Replacing austenitics with ferritics not only lowers our raw-material costs but also saves resources and protects our environment.

I would go so far as to say that while austenitics dominate today’s stainless steel market, the future of stainless-steel consumption lies with ferritics.”
Forming ferritic grades

Thanks to their good drawing characteristics, ferritic stainless steels can meet the challenges of complex, three-dimensional designs.

Since their use in complex designs does not impair any of their remarkable corrosion resistant, heat resistant and decorative qualities, ferritic grades are often the right choice for both industrial and consumer products.

Cold forming operations change the shape of strip or sheet products by subjecting them to plastic strain. The forming operation involves complex combinations of tensile and compressive loading, using a combination of stretching and deep drawing deformations.

Although the overall drawing capacity of austenitic grades is better than that of ferritics, some ferritic grades (notably titanium-stabilised, 17% chromium grades) show excellent drawing performance.

DRAWING FERRITIC GRADES

Drawing is the process most commonly used for forming hollow objects from a flat sheet or “blank”. The good drawing behaviour of ferritic stainless steels, coupled with their considerable price advantage, can make ferritics the optimum choice.
SUCCESSFUL DRAWING MEANS
- The absence of fracture
- Excellent surface aspect
- Minimum material consumption
- High fabrication productivity
- Low tool wear

THE LDR FACTOR
The Limited Drawing Ratio (LDR) is an important deep-drawability parameter.

Limited Drawing Ratio (LDR) refers to the quotient of the maximum blank diameter (D) that can be deep drawn into a cylinder in one step and the diameter of that cylinder. LDR = D/d.

Ferritics have higher LDR values than austenitics, which makes them particularly suitable for drawing.

STRETCH-FORMING FERRITIC GRADES
Ferritic grades are inferior to austenitics in pure stretch-forming.

In stretch-forming, the drawn area becomes thinner.

The table below compares the stretching performance of various grades. "Dome height" refers to the maximum degree of deformation before "necking" (the phase just before failure) of a blank undergoing stretching.

"Ferritics have higher LDR values than austenitics, which makes them particularly suitable for drawing."
FORMING LIMIT CURVES

In practice, industrial forming operations involve a combination of both pure drawing and pure stretch-forming deformation, in a series of “passes”.

Forming limit curves are a useful guide to maximum deformation before failure, in both deep drawing and stretching processes. Established for the principal stainless steel grades, they can be used to analyse a forming operation.

These curves define local deformations during and after forming in terms of two principal “true strains”: longitudinal (“major strain”) and transverse (“minor strain”). The curves plot the effects of the various combinations of these two strains, up to the point of fracture. The higher the position of its curve the better a grade’s formability.

HOW FERRITICS BEHAVE

Generally, the work hardening and elongation characteristics of ferritic stainless steels are comparable to those of high-strength carbon steels. They are not the same as those of austenitic grades.

Design, construction and fabrication parameters and the material properties of the ferritic grade concerned must be considered together, in order to get the best out of the drawing process.

“Titanium-stabilised grade 430Ti is often chosen to replace an austenitic in applications involving deep drawing.”

“RIDGING”

After certain forming operations, ferritic grades are sometimes prone to surface phenomena known as “ridging” and “roping”.

This defect takes the form of a series of lines or ridges, parallel to the sheet rolling direction. “Ridging” describes the overall profile of the deformed surface and includes both the microgeometry modifications and the “roping” undulations caused by the deformation.

The addition of a stabilising element, such as titanium, will bring improvement here. Titanium-stabilised grade 430 Ti gives remarkable results in this regard and is thus often chosen to replace an austenitic in applications involving deep drawing.
LUBRICATION
Good lubrication of the blank and the tooling is essential for successful drawing, to avoid altering the surface appearance and to prevent sticking phenomena detrimental to tool life.

If ferritic stainless steels are delivered with a bright, smooth surface, a high-viscosity drawing lubricant may be used. Lubricants used with stainless steels are special oils with high pressure resistance and containing little or no chlorine. Uniformly applied on the blank, they are easily removable from a stainless steel component after drawing.

TOOLING
Using the right tooling is vital, since it has a decisive influence on friction conditions and thus on metal flow during the forming operation. In special cases, tooling (mold and die) can be made of copper, iron or aluminium bronze.

Surface treatments, such as a TiCN layer, may be applied, to increase the life of the tooling. The blank holder and die tools have to be carefully polished. The punch can remain rough.

“The lubricants used with stainless steels are easily removable from a component after drawing.”

THE FORMING PROPERTIES OF THE MAIN STEEL GROUPS
The table below compares the forming properties of ferritic stainless steels (which have a specific metallurgical structure and hence specific behaviour) to those of carbon steel and austenitic stainless grades. It uses standard criteria applied in defining deformation characteristics. “Bcc” (body-centred cubic) and “fcc” (face-centred cubic) refer to the particular atomic structure of each type of steel.

<table>
<thead>
<tr>
<th></th>
<th>Carbon Steel</th>
<th>Ferritic SS</th>
<th>Austenitic SS</th>
</tr>
</thead>
<tbody>
<tr>
<td>structure</td>
<td>bcc</td>
<td>bcc</td>
<td>fcc</td>
</tr>
<tr>
<td>work hardening</td>
<td>low</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>springback</td>
<td>low</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>deep drawing</td>
<td>excellent</td>
<td>good</td>
<td>good</td>
</tr>
<tr>
<td>stretch forming</td>
<td>good</td>
<td>good</td>
<td>excellent</td>
</tr>
<tr>
<td>ridging</td>
<td>no</td>
<td>can occur</td>
<td>no</td>
</tr>
</tbody>
</table>

Surface treatments, such as a TiCN layer, may be applied, to increase the life of the tooling. The blank holder and die tools have to be carefully polished. The punch can remain rough.

“Lubricants used with stainless steels are easily removable from a component after drawing.”
THE CASE FOR FERRITICS

While the tables and curves show that austenitics are superior, overall, in terms of formability, the ferritic cost advantage is such that looking into the use of a ferritic grade can often pay clear dividends. Favouring the drawing method, especially, allows a remarkably wide use of ferritic grades. Indeed, in certain specific cases – such as deep drawing or springback effects – ferritics behave better than austenitics.

Users should thoroughly discuss technical questions regarding the use of ferritic grades with a reputable material supplier. Stainless steel industry expertise is always on hand, to help users find ways to make ferritic grades work and to ensure that the most appropriate grade is chosen for any given application.

“...favouring drawing allows exceptionally wide use of ferritic grades.”
Bernhard Blaeser, Director, Macadams Baking Systems (PTY) Ltd, South Africa

“My company makes baking ovens and provers. With the substantial increases in austenitic prices in the recent past, many players in the industry have moved away from or are in the process of moving away from stainless steel altogether. This is especially so in non-heat applications, like the external panels of ovens, and other bakery equipment not directly in contact with food. As ferritic prices have not been as severely affected, an alternative is to substitute ferritic. In essence then, manufacturers should consider substituting austenitics with ferritics, rather than dropping stainless steel entirely.”

Increasingly stringent anti-pollution regulations plus technical and economic requirements make ferritic the basic material for exhaust systems.
Joining ferritic grades

Ferritic grades are well suited to all the numerous methods of joining stainless steels.

“Ferritic grades have some useful advantages over austenitics, when it comes to welding…”

**Joining methods**

- **Welding**: achieving complete joining of two or more materials through melting and re-solidification of the base and filler metals.
- **Soldering**: producing joining of materials by heating them to soldering temperature (below the solidus of the base metal) in the presence of filler metals with a liquidus of < 450°C.
- **Brazing**: the same as soldering but coalescence occurs at > 450°C.
- **Mechanical joining**: includes clinching, seaming, riveting and mechanical fasteners.
- **Adhesive bonding**: achieved by pressing clean, activated surfaces together after applying a bonding agent that bonds using either oxygen, water or a chemical reaction.

**WELDING**

Of the many welding processes developed for carbon steels that can be used with stainless steels only a few are really appropriate for these materials and have become standard: arc, resistance, electron, laser-beam and friction welding. Welding is the most efficient and least costly way to join metals. The process makes possible structures of lighter weight (through the optimal use of materials), joins all commercial metals and provides design flexibility.

The welding characteristics of stainless steels are affected by chemical composition, metallurgical structure and physical properties. Ferritic grades have some useful advantages over austenitics when it comes to welding, since they feature lower thermal expansion, lower electrical resistivity and higher thermal conductivity.

**STABILISED AND UNSTABILISED FERRITIC GRADES**

On average, ferritic stainless steels tend to be less prone than austenitics to the intergranular corrosion that can result from welding.
This is especially true of “stabilised” ferritic grades, which contain strong carbide formers, such as titanium (Ti) and niobium (Nb). These tie up the carbon in the steel, during the welding process, preventing it combining with chromium to form chromium carbide. With consequent chromium depletion at grain boundaries prevented, stabilised ferritic grades are virtually immune to intergranular corrosion.

To ensure complete stabilisation, Ti content must be five times greater than carbon content, or Nb plus Ti must be three times greater than carbon content. Sometimes, the introduction of nitrogen into this formula can be advisable, to refine the grain in the melted zone.

Unstabilised ferritic grades contain no Ti or Nb and can therefore be susceptible to intergranular corrosion in the heat affected zone, due to chromium carbide formation. This effect is called “sensitisation”. Its extent depends mainly on the carbon level.

The corrosion resistance of sensitised steels can, however, be restored by annealing, at a temperature range of 600-800°C.

OVERMATCHING FILLER METALS
To ensure that a weld will be corrosion resistant, any ferritic filler metal used should slightly overmatch the composition of the base metal in terms of Cr, Mo, Ti and/or Nb alloying elements. This is because heating will tend to cause a loss of chrome in the weld zone. Alternatively, austenitic filler metal can be used, with an overmatch of Cr and Mo alloying elements.

PROTECTIVE GASES
Being high in chromium, stainless steels are highly oxidizable in the molten state. If they are not protected from air during the welding process, chromium will be lost and oxides will form, resulting in lack of soundness and decreased corrosion resistance in the weld. Protection of the weld surface and neighbouring area is usually ensured by the provision of an inert gaseous shield. This shielding gas can either be an inert gas of pure argon (Ar) or helium (He) or a mixture of Ar and He.

For the welding of ferritics, these shielding gases should be pure argon or argon-helium mixtures. Argon-hydrogen mixtures, often used for austenitic grades, bring a risk of hydrogen embrittlement in the weld joint, in the case of ferritic grades. Argon is the most commonly employed backing gas (protecting the rear of the workpiece). Nitrogen must not be used with ferritic grades.

TROUBLESHOOTING FERRITIC WELDING PROBLEMS
As well as the risks referred to above, there can also be risks of embrittlement by “phase formation” and “grain coarsening” at high temperatures. Their solutions are listed in the following “remedies” table.
**ARC WELDING**
Arc welding is the form of welding most commonly employed with ferritic grades.

**GAS TUNGSTEN ARC WELDING (GTAW OR TIG/WIG)**
In this process (also known as the Tungsten or Wolfam Inert Gas process), the energy needed to melt the metal is supplied by an electric arc between the tungsten electrode and the workpiece.

**GAS METAL ARC WELDING (GMAW OR MIG)**
Unlike the GTAW process, in GMAW (also known as the Metal Inert Gas process), the electrode is consumable. The arc is struck between the molten filler wire and the workpiece. The shielding gas, injected through the torch, around the wire, is usually argon with an addition of 2% to 3% oxygen, though more complex mixtures may be used for certain welding modes.

Since the weld is essentially composed of filler metal, it is vital that the filler metal’s composition should promote penetration and perfect wetting of the base metal. This high-productivity process is more difficult to perform than GTAW welding but results can be excellent when the process is well controlled.

**RESISTANCE WELDING**
In resistance welding, an electric current is passed through the parts to be joined and welding is caused by resistance heating.

Stainless steels are always welded in the straight-polarity DC mode (the electrode being the negative pole), under an inert atmosphere. If a filler metal is used, this will be in the form of uncoated rods (manual welding) or coiled wire (automatic welding).
Several resistance welding techniques exist, the most common being spot welding and seam welding. In both cases, the major advantages of resistance welding are:
- the limited modification of the microstructure in the heat affected zones (HAZ);
- the virtual absence of surface oxidation, if the sheets are correctly cooled;
- the very low level of distortion of the sheets after welding;
- “forging” deformation during welding, which is particularly useful for the joining of ferritic steels.

Compared to the requirements of mild steel, the main differences in process parameters for stainless steel are the lower and more precisely adjusted welding powers (due to low electrical and thermal conductivities) and higher electrode forces.

OTHER PROCESSES
Other welding processes applicable to ferritic stainless steels include electron and laser beam welding and friction welding.

SOLDERING AND BRAZING
Soldering and brazing are processes for joining metallic components in the solid state by means of a fusible filler metal that has a melting point well below those of the base metals. Soldering employs soft filler alloys with melting points below 450°C, whereas brazing alloys are harder and melt at higher temperatures.

The advantages of these joining techniques include the following convenient features:
- They require only a low-temperature heat source.
- Joints can be permanent or temporary.
- Dissimilar materials can be joined.
- The rate of heating and cooling is slow.
- Parts of varying thicknesses can be joined.
- Realignment is easy.
- They require less heat than welding.

In deciding on the suitability of soldering or brazing for a specific structural joint, care should be taken to evaluate carefully the strength or performance required of the joint.

In all cases, while carrying out the joining, it is essential to ensure perfect wetting of the two solid parts by the molten filler material.

Sensitisation will occur more readily in the case of unstabilised grades.

PICKLING, PASSIVATION AND DECONTAMINATION

The slight discoloration resulting from welding should be eliminated by either mechanical descaling or a chemical treatment called pickling.

Pickling is carried out in a fluonitric solution (10%HNO₃ + 2%HF) or using pickling pastes designed specially for welds.

It can be followed by a passivation and decontamination treatment – to help the passive layer (see p. 59) reform quickly and remove organic metallic residues (iron-rich particles). The process involves immersion in a cold 20%-25% nitric acid bath.

Local passivation of weld zones can also be carried out by means of special passivating pastes.
**MECHANICAL JOINING**

Mechanical joining techniques used for carbon steels can be equally successfully used with stainless steels.

<table>
<thead>
<tr>
<th>Mechanical joining of stainless steels</th>
<th>Mechanical fasteners</th>
<th>Riveting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Screws</td>
<td>Without any</td>
<td></td>
</tr>
<tr>
<td></td>
<td>additional part</td>
<td></td>
</tr>
<tr>
<td>Self-piercing and thread-forming screws</td>
<td>Clinching</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Seaming</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Self-piercing rivets</td>
<td></td>
</tr>
</tbody>
</table>

Mechanical joining has certain advantages:
- Dissimilar materials can easily be joined.
- There is no heat affected zone (HAZ).
- Parts of varying thicknesses can be joined.
- There is no thermal expansion.

Consideration should, however, be given to the fact that the mechanical properties of mechanical joints may have certain weaknesses, since there is no complete coalescence of the joining partners. The joining operation method may also require two-side access.

It is vital to ensure that none of the surfaces in contact are liable to induce corrosion due to galvanic coupling. To avoid this risk, parts to be joined should preferably be made from the same stainless steel or an equivalent grade. Certainly any screws, bolts, fasteners or rivets should be of stainless steel.

**SCREWING AND BOLTING**

Stainless steel screws and bolts are available in all the principal grades. While 17% Cr ferritic grades are best suited to use in only mildly aggressive environments, their corrosion resistance in chloride-containing media is enhanced by the addition of 1% to 1.5% molybdenum.

**RIVETING**

This technique is always carried out at ambient temperature, using rivets of a maximum diameter of about 5 mm. It is strongly recommended that joints be designed in such a way that the rivets are loaded in shear rather than in tension.

**CLINCHING**

This relatively recent joining technique can be readily applied to stainless steels, thanks to their high ductility. Being a cold forming process, it causes no structural modification or surface oxidation. Since the sheets to be joined must overlap, clinching is usually combined with an adhesive bonding, producing a hermetically sealed joint, to avoid risk of crevice corrosion. This can also damp vibrations.

**SEAMING**

In this mechanical sheet-joining technique, the edges of one or both of the sheets concerned are bent through an angle of 180°, to produce a tight seam. As with clinching, different materials can be joined – for example, an austenitic and a ferritic grade.

Perfectly leak-proof joints can be achieved with this technique, which is widely used in the manufacture of domestic appliances.
ADHESIVE BONDING

Adhesive bonding can be employed to reinforce mechanical joints, and in its own right for joining thin stainless steel sheets.

The advantages of adhesive bonding are:
- There is no modification of the surface appearance, geometry or microstructure of the assembled areas.
- Dissimilar materials can be joined easily and aesthetically.
- Correctly designed, joints can have excellent fatigue strength.
- The method can provide thermal, electrical or acoustic insulation.
- Parts of varying thickness can be joined.

Points to take into consideration, however, include the fact that such joints will tend to have a temperature limit of 200°C and will have a certain sensitivity to moisture. Adhesive joints will not be as strong as joints produced by welding or brazing. For this reason they are mostly used to produce lap joints, with the load spread over a sufficient area to limit local stresses.

It is also possible that a smooth-surfaced stainless steel (especially bright annealed) will not have good adhesive properties.

After roughening, surfaces should be very clean, dry and well prepared. The essential condition for good bonding is satisfactory wetting of the substrate by the adhesive.

As an example of adhesive bonding, bus and coach manufacturers now often construct a body frame of stainless steel shaped sections, often in ferritic grade 1.4003/410. The skin (sheet and/or glass) is adhesively bonded to this body frame. This approach increases the vehicle’s life and reduces its weight.
Established in 1971, Lincat has been a front runner in the manufacture of professional kitchen equipment for 36 years. Grade 430 ferritic stainless steel, which we’ve used from the start, is the absolute bedrock of our product range.

"This grade ideally matches the spec of these applications and is an economical way of enjoying the advantages of stainless steel, which are so important when dealing with food preparation and presentation. In addition, 430’s relatively low thermal expansion characteristic is a big technical plus in high-temperature applications. We make virtually everything in 430 ferritic, except some components, such as the inner tanks of wet-well bains-marie, where we are still using 304. On the fabrication side, our products are designed to be very easy to keep clean and 430 is an easy material to work with in this respect.

“Staying closely in touch with our customers’ needs, we’ve built a reputation for outstanding product reliability and sturdy, durable construction. Grade 430 ferritic is an essential part of the equation. We and our customers are very satisfied with it.”
Ferritics are often associated with decorative trim, sinks and car exhausts. Their actual and potential usefulness extends far beyond these narrow confines...

Ferritic stainless steels are straight chromium steels, containing no nickel. They resist corrosion and oxidation, are highly resistant to stress corrosion cracking, are usefully magnetic and offer a host of other technical, aesthetic and practical advantages. They often prove better value in the long run than carbon steel and are significantly less costly than their nickel-containing, austenitic cousins.

Their range of uses is currently under-explored and the pages that follow show something of the range of possible uses of these materials. The chapter covers applications from many sectors of the market and many parts of the world.

This publication aims to inspire actual and potential users of ferritic stainless steels by illustrating existing, successful applications. It further aims to encourage responsible and informed material selection – optimal matching of material and application has never been more important.
<table>
<thead>
<tr>
<th>AUTOMOTIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DECORATIVE TRIM</strong></td>
</tr>
<tr>
<td><img src="image1" alt="Decorative Trim" /></td>
</tr>
<tr>
<td>Grade SUS430, S. Korea</td>
</tr>
<tr>
<td><strong>DECORATIVE TRIM</strong></td>
</tr>
<tr>
<td><img src="image2" alt="Decorative Trim" /></td>
</tr>
<tr>
<td>Grade 1.4016/430, black-coated trim, USA</td>
</tr>
<tr>
<td><strong>DECORATIVE TRIM</strong></td>
</tr>
<tr>
<td><img src="image3" alt="Decorative Trim" /></td>
</tr>
<tr>
<td>Grade 1.4113/434, USA</td>
</tr>
<tr>
<td><strong>S.U.V. FRONT ELEMENT</strong></td>
</tr>
<tr>
<td><img src="image4" alt="S.U.V. Front Element" /></td>
</tr>
<tr>
<td>Grade 1.4513, Plastic Omnium, France</td>
</tr>
<tr>
<td><strong>CAR BOOT SILL</strong></td>
</tr>
<tr>
<td><img src="image5" alt="Car Boot Sill" /></td>
</tr>
<tr>
<td>Grade 1.4510/430Ti, Peugeot 307, France</td>
</tr>
<tr>
<td><strong>HEADLIGHT</strong></td>
</tr>
<tr>
<td><img src="image6" alt="Headlight" /></td>
</tr>
<tr>
<td>Grade 1.4513, headlight trim, Italy</td>
</tr>
<tr>
<td><strong>TRUCK</strong></td>
</tr>
<tr>
<td><img src="image7" alt="Truck" /></td>
</tr>
<tr>
<td>Grade 1.4113, truck decorative trim, USA</td>
</tr>
<tr>
<td><strong>CLAMPS</strong></td>
</tr>
<tr>
<td><img src="image8" alt="Clamps" /></td>
</tr>
<tr>
<td>Grades 1.4509/441 and 1.4016/430</td>
</tr>
<tr>
<td><strong>FILTERS</strong></td>
</tr>
<tr>
<td><img src="image9" alt="Filters" /></td>
</tr>
<tr>
<td>Grade 1.4512/409L, Taiwan</td>
</tr>
<tr>
<td><strong>BRAKE DISCS</strong></td>
</tr>
<tr>
<td><img src="image10" alt="Brake Discs" /></td>
</tr>
<tr>
<td>Grade 1.4028/420</td>
</tr>
<tr>
<td><strong>THERMOSTAT</strong></td>
</tr>
<tr>
<td><img src="image11" alt="Thermostat" /></td>
</tr>
<tr>
<td>Grade 1.4512/409, France</td>
</tr>
<tr>
<td><strong>PADDLE WHEEL</strong></td>
</tr>
<tr>
<td><img src="image12" alt="Paddle Wheel" /></td>
</tr>
<tr>
<td>Grade 1.4512/409, 1.5 mm thick, France</td>
</tr>
</tbody>
</table>
BUILDING & CONSTRUCTION

ACCESSORIES

**IRONMONGERY – WINDOW HINGES & FASTENERS**
- Grade 1.4016/430, Europe

**GUTTERING**
- Grade 1.4510/430Ti, tin-coated, Europe
- Grade 1.4521/444, Europe

**CHIMNEY DUCT**
- Grade 1.4521/444, Europe

**CONSTRUCTION**

**SQUARE-TUBE EXTERIOR INSULATING MEMBERS**
- Grade SUH 409L (1.4512/409), JSSA, Japan

**EMERGENCY HOUSING**
- Grade 1.4016/430, painted, VERNEST® and Centro Inox, Italy

**COMMUNICATION-SYSTEM SHELTER**
- Grade SUS 436L (1.4526/436), JSSA, Japan

**FACTORY BUILDING**
- Grade 1.4003, Columbus new finishing mill, S.Africa

**ROOF STRUCTURE**
- Roof-support: a potential application for ferritics.

**BUILDING**
- Grade 445J1L & 445J2, Nakano Sakaue Bldg., 1996, Japan
- Resin coated SUS445J2, Phoenix Resort, 1994, Japan
- Outer parts SUS445J1, inner SUS304, Nihonbashi Mitsui Bldg., 2005, Japan
NOISE-ABSORBING PLATE FOR OVERPASS
Grade SUS 436 (1.4526/436), JSSA, Japan

STRUCTURAL STEELWORK OF BRIDGE
Grade 1.4003/410 painted, SASSDA, South Africa (bridge in service for over 8 years).

INNER WALL OF TUNNEL
Grade SUS 430J11 (1.4016/430), JSSA, Japan

INNER WALL OF TUNNEL
Grade 1.4016/430, painted, Monte Mario Tunnel, Centro Inox, Italy

WINDBREAKER FENCE
Grade SUS 445J2, JSSA, Japan

PLATFORM SCREEN DOOR
Grade 1.4510/439, hair-line finish, KOSA, S. Korea

ELECTRIFICATION MASTS
Grade 1.4003 [first major application in 1982, along seashore – 10m from surf, no corrosion], S. Africa

POWER GENERATION
Grade 1.4003/410, X-grid cooling tower packing, S.Africa

CLADDING

BUILDING FAÇADE CLADDING
Grade SUS 445M2, low-reflectivity matt finish, ASSDA, Australia

BUILDING FAÇADE CLADDING
Grade 1.4521/444 brushed no. 4 (horizontal panels), Vivo Building, Rio de Janeiro, Nucleo Inox, Brazil (coastal environment)

BUILDING FAÇADE CLADDING
Grade SUS 445J2, Future Science Museum, JSSA, Japan

BUILDING FAÇADE CLADDING
Grade 1.4526/436, Ugine & Alz Steel Service Centre, Arcelor Mittal Stainless, Katowice, Poland
LIFTS

**ESCALATOR STEPS**
Grade SUS 430LX (1.4016/430), Japan

**LIFT PANELS**
Grade 1.4510/439

**ROOFING**

**MEDIADOME ROOF**
Grade SUS 445J2, Kitakyushu Mediadome (Fukuoka Pref.) 1998, Japan

**SCHOOL ROOF**
Grade 430Ti (standing seam technique), Ugine & Alz, Austria

**GYMNASIUM ROOF**
Grade 445, KOSA, S. Korea

**CANOPY**
Grade 446, KOSA, Seoul, S. Korea.

**CHALET ROOF**
Grade 1.4510/430Ti (standing-seam technique), Ugine & Alz, Germany.

**AIRPORT ROOF**
Grade SUS 447J1, Kansai Airport terminal building (architect Renzo Piano), JSSA, Osaka, Japan

**URBAN FURNITURE**

**LAMP POST**
Grade 1.4510/439, electro-polished welded pipe, KOSA, Seoul, S. Korea

**POST BOXES**
Grade 1.4003/410, painted, SASSDA, South Africa. "Utility" ferritics are often painted, when aesthetic considerations are important.

**TICKET MACHINE ON RAILWAY PLATFORM**
Grade 1.4003/410, painted (15 years in service), SASSDA, UK

**ELECTRIFICATION BOXES**
Grade 1.4003/410, painted (15 years in service), SASSDA, South Africa
FOOD COMMERCIAL EQUIPMENT

BAKERY OVEN
Grade 430, Macadams Baking Systems (PTY) Ltd, S. Africa

GAS COOKING EQUIPMENT
Grade 430, Lincat, UK

COFFEE SERVER
Grade SUS430J1, JSSA, Japan

HEATED MERCHANDISER
Grade 430, Lincat, UK

CONVEYOR TOASTER
Grade 430, Lincat, UK

MICROWAVE OVEN
Grade 430 (interior and exterior), JSSA, Japan

BURNER RANGE
Grade 430 (gas hob), POSCO, S. Korea

REFRIGERATOR
Resin-coated SUS 430 J1L panel, JSSA, Japan

COFFEE MACHINE
Grade 430, Lincat, UK

RESTAURANT TROLLEY
Grade 430

DISPLAY MERCHANDISER
Grade 430, Lincat, UK

WALL CUPBOARD
Grade 430, Lincat, UK
HOME & OFFICE

In the following applications, ferritic (400-series) grades are now established as ideal, on grounds of their aesthetic quality, their resistance to cleaning and disinfection agents, their low thermal expansion coefficient and their magnetism [for induction cooking]. They also offer considerable economic advantages over other materials.

DOMESTIC COOKING EQUIPMENT

**GAS COOKER**

KOSA, S. Korea

**VARIOUS**

TKN, Germany

**MICROWAVE OVEN**

Grade SUS430J1, JSSA, Japan

**GAS COOKING TOP**

TSSDA, Thailand

**COOKWARE AND POTS**

**BARBECUE**

Grade 1.4016/430, windscreen and brazier, Compagril and Centro Inox, Italy

**BARBECUE**

Grade 1.4016/430 barbecue, USA

**WOK**

**INDUCTION COOKWARE**

Groupe SEB (Tefal)

**PRESSURE COOKER**

Grade 430, Groupe SEB

**PANS**

Grade 430, POSCO, S. Korea

**DISHWASHER**

Grade 430 interior panel

**DISHWASHER**

Resin coated SUS430J1L outer panel, JSSA, Japan
**ELECTRICAL APPLIANCES**

**DISHWASHER**
Grade 430 (exterior and interior panel), Haier, PRC

**MIXER**
Grade 1.4513, TKN, Italy

**MIXER**
Grade 430

**ELECTRIC RICE COOKER**
Resin coated SUS430, JSSA, Japan

---

**EQUIPMENT**

**ELECTRIC KETTLE**
Resin coated SUS430, JSSA, Japan

**SHELVES**
Grade 1.4016/430, horizontal shelves, Graepel and Centro Inox, Italy

**RUBBISH CONTAINER**
Grade 1.4016/430, Graepel and Centro Inox, Italy

**PARTITION**
Grade 430, POSCO, S. Korea

---

**HOODS**

**HANDRAIL**
Grade 430 welded tube

**LCD FRAME**
Grade 410, POSCO, S. Korea

**KITCHEN HOOD**
Grade 430, Blanco, TKN, Germany

**KITCHEN HOOD**
Grade 430, Falmec, Nucleo Inox, Brazil
<table>
<thead>
<tr>
<th>KITCHENWARE</th>
<th>REFRIGERATORS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LIQUID DISPENSER</strong></td>
<td><strong>FRIDGE &amp; FREEZER</strong></td>
</tr>
<tr>
<td>[Image of Liquid Dispenser]</td>
<td>Grade 430 panel</td>
</tr>
<tr>
<td>Grade 430</td>
<td>[Image of Fridge &amp; Freezer]</td>
</tr>
<tr>
<td><strong>ELECTRIC KETTLE</strong></td>
<td><strong>PASTA COOKING POT</strong></td>
</tr>
<tr>
<td>[Image of Electric Kettle]</td>
<td>Single layer SUS430J1L (induction heating), JSSA, Japan</td>
</tr>
<tr>
<td>Grade 430, Groupe SEB</td>
<td>[Image of Pasta Cooking Pot]</td>
</tr>
<tr>
<td><strong>PASTA COOKING POT</strong></td>
<td><strong>FRIDGE &amp; FREEZER</strong></td>
</tr>
<tr>
<td>[Image of Pasta Cooking Pot]</td>
<td>Grade 430 panel</td>
</tr>
<tr>
<td>Single layer SUS430J1L (induction heating), JSSA, Japan</td>
<td>[Image of Fridge &amp; Freezer]</td>
</tr>
<tr>
<td><strong>SINKS</strong></td>
<td><strong>WASHING MACHINES</strong></td>
</tr>
<tr>
<td><strong>FRIDGE &amp; FREEZER</strong></td>
<td><strong>DOMESTIC KITCHEN SINK</strong></td>
</tr>
<tr>
<td>[Image of Fridge &amp; Freezer]</td>
<td>Grade 430, Tramontina, Brazil</td>
</tr>
<tr>
<td>Grade 430 door panel, TKN, Germany</td>
<td>[Image of Domestic Kitchen Sink]</td>
</tr>
<tr>
<td><strong>DOMESTIC KITCHEN SINK</strong></td>
<td><strong>DRUM</strong></td>
</tr>
<tr>
<td>[Image of Domestic Kitchen Sink]</td>
<td>Grade 430 (drum and exterior panel), TKN, Germany</td>
</tr>
<tr>
<td>Grade 430, Tramontina, Brazil</td>
<td>[Image of Drum]</td>
</tr>
<tr>
<td><strong>DRUM</strong></td>
<td><strong>DRUM</strong></td>
</tr>
<tr>
<td>[Image of Drum]</td>
<td>Grade 430 drum, LG Electronics, S. Korea</td>
</tr>
<tr>
<td>Grade SUS430, JSSA, Japan</td>
<td>[Image of Drum]</td>
</tr>
<tr>
<td>Grade 409, Whirlpool, Europe</td>
<td>[Image of Drum]</td>
</tr>
<tr>
<td>Grade 430</td>
<td>[Image of Drum]</td>
</tr>
<tr>
<td>Grade 430</td>
<td>400-series grades, IKEA</td>
</tr>
<tr>
<td><strong>DRYERS</strong></td>
<td><strong>TABLEWARE</strong></td>
</tr>
<tr>
<td><strong>DRUM</strong></td>
<td><strong>ASIAN SPOON</strong></td>
</tr>
<tr>
<td>[Image of Dryer]</td>
<td>Grade 430</td>
</tr>
<tr>
<td>Grade SUS430, JSSA, Japan</td>
<td>[Image of Asian Spoon]</td>
</tr>
<tr>
<td>Grade 409, Whirlpool, Europe</td>
<td>[Image of Tableware]</td>
</tr>
<tr>
<td>Grade 430</td>
<td>400-series grades, IKEA</td>
</tr>
</tbody>
</table>
Ferritic is extensively used where the maintenance of carbon steel is a virtual impossibility.

### INDUSTRY

#### DAM OUTLET PIPES
- Painted grade 1.4003/410, Columbus, S. Africa

#### FLOOD CONTROL GATES
- Painted grade 1.4003/410, Columbus, S. Africa

#### TANKS
- Grade SUS430J1L, coloured-resin coated (outer jacket), JSSA, Japan

#### FRACTIONATING COLUMN
- Grade 410S, Europe

#### BURNERS
- Grade 1.4509/441 [high oxidation resistance]

#### BOILERS
- Grade SUS430, boiler gas burner, JSSA, Japan.

#### BOILER INNER TUBE
- Grade 1.4521/444, KOSA, S. Korea

#### CONVEYOR BELT
- Grade 410S, Europe

#### “HYDROBOIL” INSTANT BOILING WATER HEATER
- Grade 1.4521/444, ZIP Industries and ASSDA, Australia

#### BOILER
- Grade 444, Europe

#### HOT WATER TANK
- Grade 1.4521/444, Europe

#### HOT WATER TANK
- Grade SUS444, JSSA, Japan
Food Processing

Walls & Ceilings
Grade 445M2, Melbourne, Australia

Heat Exchangers
Moisture Separator Reheater Welded Tubes
Grade 1.4510/439, Valimet, Europe

Feedwater Heater Welded Tubes
Grade 1.4510/439, Valimet, Europe

Condenser Welded Tubes
Grade 1.4510/439, Valimet, Europe

Solar Water Heaters
Solar Water Heater
Grade SUS444, Suncue Company Ltd. and YUSCO, Taiwan

Sugar Industry
Solar Water Heater
Grade 1.4509/441, Sun Tank and SASSDA, S. Africa

Slate Carrier
Grade 1.4003/410, Columbus, S. Africa. This machine has been in service 22 years.

Scalding Juice Heater Cover
Grade 1.4003/410, Columbus, S. Africa. Carbon steel (top) compared to ferritic (bottom) after 6 years in service.

Heat Exchanger Tubes
Grade 1.4521/444, Nucleo Inox, Brazil

Crystaliser & Diffuser
Grade 1.4003/410, Columbus, S. Africa

Substitution from cupro-nickel (due to erosion by vapour and migration of copper), carbon steel (erosion problems) and 304 (higher thermal expansion than the carbon steel frame).
**TANKS**

<table>
<thead>
<tr>
<th>WATER TANKS &amp; PIPES</th>
<th>WATER TANK</th>
<th>WATER TANK</th>
<th>WATER TANK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 444, Brazil</td>
<td>Grade 444, KOSA, S. Korea</td>
<td>Partially in grade SUS 444, finish no. 4, JSSA, Japan</td>
<td>Partially in grade SUS 444, finish no. 4, JSSA, Japan</td>
</tr>
</tbody>
</table>

**FERMENTATION AND STORAGE TANK**

| Grade 444, Nucleo Inox, Brazil | Grade 444, Nucleo Inox, Brazil | Grade 1.4512/409L, YUSCO, Taiwan | Grade 1.4509/441, Centro Inox, Italy. The new Vespa ET2 is equipped with a ferritic catalytic silencer. |

**MOTORCYCLE EXHAUST**

| Grade 409L | Grade 409L, Acesita, Brazil | Grade SUS410SM1, JSSA, Japan | Grade 420 brake dics, 1.4113 decorative trim, Italy |

**DISC BRAKE ROTOR**

**VARIOUS**

**INDUSTRY**
**TRANSPORTATION**

**BUS & COACH BODY FRAME**

Grade 1.4003/410, Columbus, S. Africa.

**BUS & COACH BODY FRAME**

Grade 1.4003/410 (lower part painted), Columbus, S. Africa.

**BUS BODY FRAME**

Grade 1.4003 welded tubes and panel, Solaris Bus & Coach Co. Poland

**CONTAINER**

Grade 1.4003/410 (frame and panels), POSCO, S. Korea

**CONTAINER**

Grade 1.4003/410, painted (frame and door panels)

**COAL WAGON**

Grade 1.4003/410 (panels), Columbus, S. Africa. In service for over 20 years.

**COAL WAGON**

Grade 1.4003/410 (panels), Columbus, S. Africa. In service for over 15 years.

**COAL WAGONS**

Grade 1.4003 (interior of previous), SASSDA, S. Africa

**COAL WAGON**

Grade 1.4003/410, painted, Europe

**COAL WAGON**

Grade 409/410, painted, TISCO, PRC

**COAL WAGON**

Grade 1.4003, SASSDA, S. Africa

**TRAMWAY**

Grade 1.4003/410 (body frame and painted panels), Europe
APPENDICES

The chemical composition of ferritic stainless steels

Ferritic stainless steels have properties similar to those of mild steel but show much better corrosion resistance. Their development began over a century ago.

EARLY FERRITICS
Stainless steel was “discovered” around 1900–1915. As with many discoveries, it was actually the result of the accumulated efforts of several scientists. Research was published in England, France and Germany on alloys with compositions that would be known today as the 410, 420, 430, 442, 446 and 440C grades. Stainless steels must have a very low level of carbon. For many years it was difficult to obtain such a low carbon level, which explains the late arrival of good ferritic grades (in the 1980s).

THE GRADES AND THEIR CHEMISTRIES
Chromium (Cr) is by far the most important alloying element in the production of stainless steel. It forms the “passive” surface film that makes stainless steel corrosion resistant and increases scaling resistance, wear resistance and tensile strength.

A minimum of 10.5% chromium content (by weight) is required for the protective, self-repairing surface layer of chromium oxide to form reliably. The higher the chromium content, the stronger the passive layer.

If the stainless steel surface is machined or accidentally damaged, the passive layer instantaneously re-forms, in the presence of air or water.

CHEMICAL COMPOSITION AND INTERNATIONAL STANDARDS
The following tables show the chemical analysis of the five groups of ferritic stainless steels.

<table>
<thead>
<tr>
<th>THE PASSIVATION PROCESS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GROUPS</strong></td>
</tr>
<tr>
<td><strong>1</strong></td>
</tr>
<tr>
<td><strong>2</strong></td>
</tr>
<tr>
<td><strong>3</strong></td>
</tr>
<tr>
<td><strong>4</strong></td>
</tr>
<tr>
<td><strong>5</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>THE 5 GROUPS OF FERRITIC GRADES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GROUP 1</strong></td>
</tr>
<tr>
<td>10%-14%</td>
</tr>
<tr>
<td>Types 409, 410, 420</td>
</tr>
</tbody>
</table>
## GROUP 1

<table>
<thead>
<tr>
<th>AISI, ASTM</th>
<th>Chemical component [Maximum weight %]</th>
<th>Standard</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C  Si  Mn  Mo  P  S  Cr  Mo  Ti  Nb  Cu  Al  N  Ni</td>
<td></td>
<td></td>
</tr>
<tr>
<td>403(M)</td>
<td>0.15 0.5 1.0 0.04 0.03 11.5-13.0</td>
<td>JIS</td>
<td>SUS403</td>
</tr>
<tr>
<td>0.12-0.17</td>
<td>1.0 1.0 0.04 0.015 12.0-14.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>405</td>
<td>0.08 1.0 1.0 0.04 0.03 11.5-14.5</td>
<td>UNS</td>
<td>S40500</td>
</tr>
<tr>
<td>0.08 1.0 1.0 0.04 0.015 12.0-14.0</td>
<td>EN</td>
<td>1.4000</td>
<td></td>
</tr>
<tr>
<td>0.08 1.0 1.0 0.04 0.015 12.0-14.0</td>
<td>EN</td>
<td>1.4002</td>
<td></td>
</tr>
<tr>
<td>0.08 1.0 1.0 0.04 0.03 11.5-14.5</td>
<td>JIS</td>
<td>SUS405</td>
<td></td>
</tr>
<tr>
<td>0.1-0.3</td>
<td>0.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>409L</td>
<td>0.03 1.0 1.0 0.04 0.02 10.5-11.7 6x(C+N)-0.5 0.17</td>
<td>UNS</td>
<td>S40910</td>
</tr>
<tr>
<td>0.03 1.0 1.0 0.04 0.02 10.5-11.7 6x(C+N)-0.5 0.1</td>
<td>UNS</td>
<td>S40910</td>
<td></td>
</tr>
<tr>
<td>0.03 1.0 1.0 0.04 0.015 10.5-12.5 6x(C+N)-0.5 0.03 0.5</td>
<td>UNS</td>
<td>S40920</td>
<td></td>
</tr>
<tr>
<td>0.03 1.0 1.0 0.04 0.015 10.5-12.5 6x(C+N)-0.5 0.03 0.5</td>
<td>UNS</td>
<td>S40930</td>
<td></td>
</tr>
<tr>
<td>0.03 1.0 1.0 0.04 0.015 10.5-12.5 6x(C+N)-0.5 0.03 0.5</td>
<td>UNS</td>
<td>S40945</td>
<td></td>
</tr>
<tr>
<td>0.03 1.0 1.0 0.04 0.015 10.5-12.5 6x(C+N)-0.5 0.03 0.5</td>
<td>UNS</td>
<td>S40977</td>
<td></td>
</tr>
<tr>
<td>0.08 0.7 1.5 0.04 0.015 10.5-12.5 0.05-0.35 0.5-1.5</td>
<td>EN</td>
<td>1.4512</td>
<td></td>
</tr>
<tr>
<td>0.03 1.0 1.0 0.04 0.03 10.5-11.75 6x(C)-0.75</td>
<td>JIS</td>
<td>SUS409L</td>
<td></td>
</tr>
<tr>
<td>0.75</td>
<td>0.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.75</td>
<td>0.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.03 1.0 1.0 0.04 0.03 11.5-13.5</td>
<td>JIS</td>
<td>SUS410</td>
<td></td>
</tr>
</tbody>
</table>
| 14% - 18% Cr

<table>
<thead>
<tr>
<th>AISI, ASTM</th>
<th>Chemical component [Maximum weight %]</th>
<th>Standard</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C  Si  Mn  Mo  P  S  Cr  Mo  Ti  Nb  Cu  Al  N  Ni</td>
<td></td>
<td></td>
</tr>
<tr>
<td>410(M)</td>
<td>0.08-0.15 1.0 1.0 0.04 0.03 11.5-13.5</td>
<td>JIS</td>
<td>SUS410</td>
</tr>
<tr>
<td>0.08-0.15 1.0 1.5 0.04 0.015 11.5-13.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.15</td>
<td>1.0 1.0 0.04 0.03 11.5-13.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.03 1.0 1.5 0.04 0.03 10.5-12.5</td>
<td>JIS</td>
<td>SUS410</td>
<td></td>
</tr>
<tr>
<td>0.03 1.0 1.5 0.04 0.03 10.5-12.5</td>
<td>JIS</td>
<td>SUS410</td>
<td></td>
</tr>
<tr>
<td>0.03 1.0 1.5 0.04 0.03 11.0-13.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.03 1.0 1.5 0.04 0.015 10.5-12.5</td>
<td>EN</td>
<td>1.4003</td>
<td></td>
</tr>
<tr>
<td>0.08 1.0 1.0 0.04 0.03 11.5-13.5</td>
<td>JIS</td>
<td>SUS410</td>
<td></td>
</tr>
<tr>
<td>0.08 1.0 1.0 0.04 0.03 11.5-13.5</td>
<td>JIS</td>
<td>SUS410</td>
<td></td>
</tr>
<tr>
<td>0.16-0.25 1.0 1.0 0.04 0.03 12.0-14.0</td>
<td>JIS</td>
<td>SUS420J1</td>
<td></td>
</tr>
<tr>
<td>0.16-0.25 1.0 1.5 0.04 0.015 12.0-14.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.26-0.40 1.0 1.0 0.04 0.03 12.0-14.0</td>
<td>JIS</td>
<td>SUS420J2</td>
<td></td>
</tr>
<tr>
<td>0.26-0.35 1.0 1.5 0.04 0.015 12.0-14.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.36-0.62 1.0 1.0 0.04 0.015 12.5-14.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.43-0.50 1.0 1.0 0.04 0.015 12.5-14.5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## GROUP 2

<table>
<thead>
<tr>
<th>AISI, ASTM</th>
<th>Chemical component [Maximum weight %]</th>
<th>Standard</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C  Si  Mn  Mo  P  S  Cr  Mo  Ti  Nb  Cu  Al  N  Ni</td>
<td></td>
<td></td>
</tr>
<tr>
<td>420</td>
<td>0.08 1.0 1.0 0.04 0.03 13.5-15.5 0.3-0.5 1.0-2.5</td>
<td>UNS</td>
<td>S42035</td>
</tr>
<tr>
<td>0.08 1.0 1.0 0.04 0.015 13.5-15.5 0.2-1.2 0.3-0.5 1.0-2.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>429</td>
<td>0.12 1.0 1.0 0.04 0.03 14.0-16.0</td>
<td>JIS</td>
<td>SUS429</td>
</tr>
<tr>
<td>0.12 1.0 1.0 0.04 0.03 14.0-16.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>429J1(M)</td>
<td>0.25-0.40 1.0 1.0 0.04 0.03 15.0-17.0</td>
<td>JIS</td>
<td>SUS429J1</td>
</tr>
<tr>
<td>430</td>
<td>0.12 1.0 1.0 0.04 0.03 16.0-18.0</td>
<td>JIS</td>
<td>SUS430</td>
</tr>
<tr>
<td>0.08 1.0 1.0 0.04 0.015 16.0-18.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.12 0.75 1.0 0.04 0.03 16.0-18.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.4017</td>
<td>0.08 1.0 1.0 0.04 0.015 16.0-18.0</td>
<td>EN</td>
<td>1.4017</td>
</tr>
<tr>
<td>1.4017</td>
<td>1.2-1.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>440(M)</td>
<td>0.6-0.75 1.0 1.0 0.04 0.03 16.0-18.0</td>
<td>JIS</td>
<td>SUS440A</td>
</tr>
</tbody>
</table>
### GROUP 3

<table>
<thead>
<tr>
<th>AISI, ASTM</th>
<th>Chemical component (Maximum weight %)</th>
<th>Standard</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>430J1L</td>
<td></td>
<td></td>
<td>JIS</td>
</tr>
<tr>
<td>430LX</td>
<td></td>
<td></td>
<td>JIS</td>
</tr>
<tr>
<td>439</td>
<td></td>
<td></td>
<td>UNS</td>
</tr>
<tr>
<td>430T1</td>
<td></td>
<td></td>
<td>JIS</td>
</tr>
<tr>
<td>441</td>
<td></td>
<td></td>
<td>JIS</td>
</tr>
</tbody>
</table>

### GROUP 4

<table>
<thead>
<tr>
<th>AISI, ASTM</th>
<th>Chemical component (Maximum weight %)</th>
<th>Standard</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>415</td>
<td></td>
<td></td>
<td>UNS</td>
</tr>
<tr>
<td>434</td>
<td></td>
<td></td>
<td>UNS</td>
</tr>
<tr>
<td>436</td>
<td></td>
<td></td>
<td>UNS</td>
</tr>
<tr>
<td>436J1L</td>
<td></td>
<td></td>
<td>JIS</td>
</tr>
<tr>
<td>444</td>
<td></td>
<td></td>
<td>UNS</td>
</tr>
</tbody>
</table>

### GROUP 5

<table>
<thead>
<tr>
<th>AISI, ASTM</th>
<th>Chemical component (Maximum weight %)</th>
<th>Standard</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>445</td>
<td></td>
<td></td>
<td>UNS</td>
</tr>
<tr>
<td>445J1</td>
<td></td>
<td></td>
<td>JIS</td>
</tr>
<tr>
<td>445J2</td>
<td></td>
<td></td>
<td>JIS</td>
</tr>
<tr>
<td>444</td>
<td></td>
<td></td>
<td>UNS</td>
</tr>
<tr>
<td>447</td>
<td></td>
<td></td>
<td>UNS</td>
</tr>
<tr>
<td>448</td>
<td></td>
<td></td>
<td>UNS</td>
</tr>
</tbody>
</table>
IMPRESSION USE OF FERRITIC WELDED TUBES IN A POWER STATION CONDENSER.
### Surface finishes

Surface finishing treatments applied to stainless steels can take many forms. The main finishes are described below. Ferritic surface finishes are the same as those for austenitic and other grades.

<table>
<thead>
<tr>
<th>Description</th>
<th>ASTM</th>
<th>EN 10088-2</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot rolled</td>
<td>1</td>
<td>1E/1D</td>
<td>A comparatively rough, dull surface produced by hot rolling to the specified thickness, followed by annealing and descaling.</td>
</tr>
<tr>
<td>Cold rolled</td>
<td>2D</td>
<td>2D</td>
<td>A dull, cold rolled finish produced by cold rolling to the specified thickness, followed by annealing and descaling. May also be achieved by a final light pass on dull rolls.</td>
</tr>
<tr>
<td>Cold rolled</td>
<td>2B</td>
<td>2B</td>
<td>A bright, cold rolled finish commonly produced in the same way as No. 2D finish, except that the annealed and descaled sheet receives a final cold roll pass on polished rolls. This is a general-purpose cold rolled finish and is more readily polished than No. 1 or No. 2D.</td>
</tr>
<tr>
<td>Bright Annealed</td>
<td>BA</td>
<td>2R</td>
<td>BA finish produced by performing bright annealing in an inert atmosphere after cold rolling. Smoother and brighter than No. 2B.</td>
</tr>
<tr>
<td>Brushed or dull polished</td>
<td>No. 4</td>
<td>1J/2J</td>
<td>A general-purpose bright polished finish obtained by finishing with a 120-150 mesh abrasive, following initial grinding with coarser abrasives.</td>
</tr>
<tr>
<td>Satin polished (matt)</td>
<td>No. 6</td>
<td>1K/2K</td>
<td>A soft satin finish having lower reflectivity than brushed (or dull polished) finish. It is produced by a Tampico brush.</td>
</tr>
<tr>
<td>Bright polished (mirror)</td>
<td>No. 8</td>
<td>1P/2P</td>
<td>The most reflective finish commonly produced. It is obtained by polishing with successively finer abrasives then buffing with a very fine buffing compound. The surface is essentially free of grit lines caused by preliminary grinding operations.</td>
</tr>
<tr>
<td>Electropolished surfaces</td>
<td>-</td>
<td>-</td>
<td>This surface is produced by electrolytic attack. This electrochemical process improves the surface finish by removing peaks of surface irregularity.</td>
</tr>
</tbody>
</table>

(NB: the above table is not official and should be used only as a guide)
APPENDICES

References


APPENDICES

List of members

COMAPNY MEMBERS
Acciaierie Valbruna
Acerinox S.A.
Acesita S.A.
Aichi Steel Corporation
Arcelor Mittal
Baoshan Iron and Steel Co. (Stainless Steel Branch)
Cogne Acciai Speciali S.p.A.
Columbus Stainless (Pty) Ltd
Daido Steel Co. Ltd.
Deutsche Edelstahlwerke GmbH
Hyundai Steel Company
Industeel
JFE Steel Corporation
Jindal Stainless Ltd.
JSC Dneprospetsstal
Ningbo Baoxin Stainless Steel Co., Ltd.
Nippon Kinzoku Co., Ltd.
Nippon Metal Industry Co. Ltd.
Nippon Steel and Sumikin Stainless
Nippon Yakin Kogyo Co., Ltd.
Nisshin Steel Co., Ltd.
North American Stainless
Outokumpu Oyj
Panchmahal Steel Limited (PSL)
POSCO
POSCO Specialty Steel Co., Ltd.
Shanghai Krupp Stainless (SKS)
SIJ - Slovenska industrija jekla d.d./Slovenian Steel Group
Steel Authority of India Ltd. (SAIL)
Sumitomo Metal Industries, Ltd.
Taiyuan Iron and Steel (Group) Co. Ltd. (TISCO)
Takasago Tekko K.K.
Tang Eng Iron Works Co. Ltd.
Thainox Stainless Public Company Limited
ThyssenKrupp Acciai Speciali Terni S.p.A.
ThyssenKrupp Mexinox S.A. de C.V.
ThyssenKrupp Nirosta GmbH

Ugine & ALZ
Ugitech S.A.
Viraj Group
Walsin Lihwa Corporation
Yieh United Steel Corporation (YUSCO)
Zhangjiagang Pohang Stainless Steel Co. Ltd. (ZPSS)

AFFILIATED MEMBERS
Australian Stainless Steel Development Association (ASSDA)
British Stainless Steel Association (BSSA)
Cedinox
CENDI
Centro Inox
Edelstahl-Vereinigung e.V.
Euro Inox
EUROFER
Institut de Développement de l’Inox (ID Inox)
Informationsstelle Edelstahl Rostfrei (ISER)
Indian Stainless Steel Development Association (ISSDA)
Japan Stainless Steel Association (JSSA)
Jernkontoret
Korea Iron and Steel Association (KOSA)
New Zealand Stainless Steels Development Association (NZSSDA)
Nucleo Inox
Southern Africa Stainless Steel Development Association (SASSDA)
Special Steel and Alloys Consumers and Suppliers Association (USSA)
Specialty Steel Industry of North America (SSINA)
Stainless Steel Council of China Specialist Steel Enterprises Association (CSSC)
Swiss Inox
Taiwan Steel and Iron Industries Association (TSIIA)
Thai Stainless Steel Development Association (TSSDA)
Union de Empresas Siderúrgicas (UNESID)
Acknowledgements

ISSF is grateful to Friedriche Teroerde (ICDA) for writing the Foreword to this brochure and to Philippe Richard (Arcelor Mittal Stainless, France), who coordinated a working group consisting of Jacques Charles (Ugine & Alz, France), Peir-Teh Huang (Yusco, Taiwan), Kwangyuk Kim (Posco, South Korea), Jochen Krautschick (ThyssenKrupp Nirosta, Germany), Juan Antonio Simon (Acerinox, Spain) and Hideaki Yamashita (JFE, Japan). Thanks also go to Benoît Van Hecke (Euro-Inox, Belgium) for checking the text and to Paul Snelgrove, freelance consultant and English-language writer (Paris, France), for his invaluable help in preparing the brochure.

Thanks are also due to de blauwe peer (Ghent, Belgium) for design and production, to MBCOM (Paris, France) for designing the cover and to Stevens Creative Printing, Merelbeke, Belgium for printing.

PHOTO CREDITS

ISSF wishes to thank the companies and individuals who have contributed photographs to this publication. In those cases where the original source of a photograph used is not known, ISSF extends its apologies to the copyright owner.


DISCLAIMER

Every effort has been made to ensure that the information presented in this publication is technically correct. However, the reader is advised that the material contained herein is intended for general information purposes only. ISSF, its members, staff and consultants specifically disclaim any liability or responsibility for loss, damage or injury resulting from the use of the information contained in this publication (in printed, electronic or other formats).