Recently, several austenitic and ferritic grades have been launched in response to the rising costs of alloying materials, especially nickel and molybdenum. The nickel price is less of an issue than it was a few years ago; even so, certain of the 400 grades offer other advantages over nickel-bearing austenitic grades. This article examines several new ferritic grades and traces their fortunes in the marketplace.

By James Chater
drive innovation

The frame of the new Citymood bus (manufactured by BredaMenaribus in Bologna, Italy) can be made of stainless steel grade 1.4003 (AISI 410) or carbon steel. Photos courtesy of Centro Inox.
The first 14 years of the 21st century have seen a spectacular rise in the production share of ferritics compared with other stainless categories, from 5.5% in 2001 to 25.6% in 2013 (ISIF figures). This increase is largely motivated by the drive to reduce costs by replacing nickel- and molybdenum-bearing austenitic grades. True, nickel is well off its highs (over 20 USD/lb in 2006; about USD 13 in 2011), currently drifting at around 7-8 dollars. Molybdenum, too, is languishing below 10 USD/lb, the lowest it has been since the recession of early 2009. This provides less of an incentive for alloy reduction or substitution than when prices spiked; even so, there are plenty of other reasons for preferring ferritics for certain applications. Apart from their well-known resistance to stress corrosion cracking, ferritics can, on occasions and for certain applications, show superior corrosion resistance, higher thermal fatigue resistance, improved deep drawability, and easier machinability and weldability than austenitics. Reason enough for several suppliers to come up with new grades.

**Ferritics for nuclear**

New ferritic alloys are candidates for use in high-temperature applications of nuclear plants. Nano-reinforced powder metal alloys could be used in heat exchangers tubes or plates. Oxide Dispersion Strengthened (ODS) alloys, the most known of the nano-reinforced alloys, possess high creep strength and high resistance to radiation damage. New nano-reinforced alloys called Nitride Dispersed Strengthened (NDS) are also being considered for nuclear applications and could exhibit higher ductility as well as being easier to fabricate (2).

In an effort to improve thermal efficiency in power plants, the US Department of Energy is researching advanced materials with superior high-temperature strength. To this end it is studying zirconium-containing ferritic stainless steels for use in advanced reactors. These ferritics offer resistance to radiation-induced void swelling that is about ten times higher than austenitics at temperatures above 300°C. Also important is their high thermal conductivity and low thermal expansion. It is thought that Zr alloying will improve strength and toughness, enhance creep resistance and reduce sensitization and radiation-induced segregation (3).

**Automobile grades**

Stringent regulations are forcing car makers to produce lighter, less polluting vehicles, a factor that will lead to an increase in sales of stainless steels to the auto industry, as they offer a more favourable strength to weight ratio. Another factor specific to exhaust systems is the drive towards greater heat resistance without using expensive alloys, which will reduce pollution. To this end, Arcelor (now Aperam) offers two grades for auto exhaust systems, K41X and K44X. They conform respectively to the requirements of AISI 441 and AISI 444. The grades were developed specifically to obtain higher thermal fatigue resistance due to the vehicle’s starting and stopping. K41X can withstand temperatures of up to 950°C, whereas K44X, which has higher chromium content and added molybdenum, can withstand 1050°C. Apart from the exhaust system in vehicles, another possible area of use is in the interconnects of solid oxide fuel cells and high temperature electrolysis developed for hydrogen production (1).

**Table. Percentage of production of the CrNi, CrMn and Cr (400) series. (Source: ISSF.)**

<table>
<thead>
<tr>
<th>Year</th>
<th>2013</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>CrNi</td>
<td>52</td>
<td>54.6</td>
</tr>
<tr>
<td>CrMn</td>
<td>20.9</td>
<td>18.6</td>
</tr>
<tr>
<td>Cr (400)</td>
<td>25.6</td>
<td>25</td>
</tr>
</tbody>
</table>

**Table 1. Chemical composition of K41X and K44X.**

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>N</th>
<th>Si</th>
<th>Mn</th>
<th>Cr</th>
<th>Ti+Nb</th>
<th>Nb</th>
<th>Mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>K41X</td>
<td>0.02</td>
<td>0.015</td>
<td>0.60</td>
<td>0.25</td>
<td>17.7</td>
<td>0.55</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>K44X</td>
<td>0.015</td>
<td>0.015</td>
<td>0.60</td>
<td>0.30</td>
<td>19</td>
<td>-</td>
<td>0.6</td>
<td>1.9</td>
</tr>
</tbody>
</table>

Also designed for auto applications is JFE Steel’s TF-1 heat-resistant ferritic grade, which offers strong resistance to thermal fatigue. In 2014 it won an award from the US science and technology publication R&D Magazine. Made without molybdenum, the grade instead contains aluminium and copper. It is suitable for exhaust manifolds and catalytic converters.

**NSSC’s FW grades**

In 2010 the Japanese company scored a world first when it added tin to ferritic grades in order to boost corrosion resistance and save alloying material costs. FW1 (14Cr-Sn-Ti-Nb-LC-N) and FW2 (16Cr-Sn-Ti-Nb-LC-N) have a maximum chromium content of 18% and 17% respectively, and there is no nickel or molybdenum content. Compared to grade 304 (18Cr-8Ni), FW2 can save both Cr and Ni by 40%. Compared to grade 430 (17Cr), FW1 can save Cr by 18%.

With a typical Cr content of 14%, FW1 can achieve a corrosion resistance of a 17% Cr steel (types 430 or 439),
Ferritics are a favourite material for use in kitchens. Photos courtesy of Outokumpu.

because tin strengthens the passivity film. Similarly, FW2’s typical 16% Cr content can deliver the same corrosion resistance as 18-8 (type 304). Both types can be used in kitchenware, domestic goods and architectural applications.

21%+ Cr ferritics
Higher corrosion resistance can be obtained by raising the level of chromium to 21% and beyond. JFE Steel’s 21Cr steel is called JFE443CT, which is claimed to have a corrosion resistance equal to or superior to type 304, as well as better formability. Commercialized in 2005, the grade can be used in architecture (roofs, escalators etc.), some types of industrial machinery, auto components, kitchenware, household articles and electric appliances. Under the name 404GP™, the grade was imported by Austral Wright into Australia, where it has been widely used (Table 3).

<table>
<thead>
<tr>
<th>Grade</th>
<th>Cr</th>
<th>Cu</th>
<th>C</th>
<th>Ti</th>
<th>Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>404GP™</td>
<td>21.0</td>
<td>0.4</td>
<td>0.01</td>
<td>0.3</td>
<td>–</td>
</tr>
<tr>
<td>304</td>
<td>18.2</td>
<td>–</td>
<td>0.05</td>
<td>–</td>
<td>8.2</td>
</tr>
<tr>
<td>430</td>
<td>16.5</td>
<td>–</td>
<td>0.06</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

Austral Wright has also imported a marine ferritic grade from Japan, Nisshin Steel’s 445M2, which has been used in Japan since 1993. Part of Nisshin’s Tough-Tain series, it is composed of 22% chromium and 1.2%. It can provide resistance to heat and salt while delivering raw material savings compared to type 316. For even tougher salt resistance, Nisshin offers 447M1, with as much as 30% Cr and 2% Mo. According to Austral Wright, 445M2 is easier to form and weld than 316 and behaves like carbon steel, with cleaner cuts, less distortion, longer tool life and cost savings. Its corrosion resistance has sometimes proved to be superior to that of 316, with less “tea staining”. It has been used in Australia and New Zealand for a number of years, in architecture and food manufacture. When Croydon Industries installed air conditioning and ventilation on the roof of the Applied Science Building at the University of New South Wales, it chose 445M2 for the ducts of the roof, which were exposed to a marine atmosphere created by surf from a nearby beach. Other notable applications include insulation cladding of sulphuric acid plant at nickel smelters in Ravensthorpe and Kalgoorlie, the roof of the Sentinel Building in Auckland, New Zealand, and numerous other instances along Australia’s vast coastline.
New-generation ferritics formed one of the areas of research carried out by Outokumpu, the University of Oulu and Aalto University within Finland’s FIMECC DEMAPP research consortium (see box). The project set out to solve the technical problems in manufacturing high-chromium ferritic grades so as to improve their corrosion resistance, formability and toughness. By experimenting with various manufacturing parameters it was found that problems such as brittleness and roping after forming operations could be overcome.

The result was Outokumpu’s 21Cr ferritic grade, 4622 (EN 1.4622). Its corrosion resistance is comparable to common austenitic grades 1.4301 (304) and 1.4307 (304L), and even superior in certain environments. Apart from its resistance to chloride-induced stress corrosion cracking, the grade has better deep drawing properties than austenitic grades, good corrosion resistance after welding and good machinability.

Table 4. The chemical composition of 445M2 compared to 316.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Cr</th>
<th>Mo</th>
<th>C</th>
<th>Ni</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>445M2</td>
<td>22.1</td>
<td>1.2</td>
<td>0.01</td>
<td>-</td>
<td>Nb and Ti</td>
</tr>
<tr>
<td>316</td>
<td>18.2</td>
<td>2.2</td>
<td>0.5</td>
<td>10</td>
<td>-</td>
</tr>
</tbody>
</table>

The steel, which was introduced in 2013 after being tested by potential users worldwide, is a candidate material in several applications, including automotive, building facades, elevators, household items, kitchenware, panels and storage tanks.

Table 5. Chemical composition of 1.4622.

<table>
<thead>
<tr>
<th>C</th>
<th>Cr</th>
<th>Mn</th>
<th>Fe</th>
<th>Ti + Nb</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.02</td>
<td>21</td>
<td>0.4</td>
<td>Balance</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Financial competence

Much of the new thinking in 200-, 300- and 400-series alloys has come from FIMECC DEMAPP (Finnish Metals and Engineering Competence Cluster). DEMAPP is short for “demanding applications”), a public-private partnership programme of 26 companies and five research organizations. Active from 2009 to 2014, FIMECC DEMAPP has just issued its final report. The object of the industry-driven development has been to tackle challenges related to critical wear, corrosion, friction and fatigue, and to develop solutions for demanding applications in the process, energy and engineering industries. The research projects related to corrosion covered: (1) new-generation ferritics with enhanced corrosion resistance; (2) fabrication and service performance of advanced stainless steels for demanding exhaust applications; (3) development of manganese- and nitrogen-alloyed stainless steels for alkaline environments; and (4) new methods for optimizing the performance of welds in corrosive industrial environments. Much of the work consisted of overcoming the manufacturing problems of high-chromium ferritics. It was this effort that led to the development of Outokumpu’s new ferritic grade 4622, as well as new cast aluminium alloys (by Alteams) and new wear-resistant and ultra-high-strength steels (by SSAB Europe) (4).

A recent addition to the 400 family is CHROMESHIELD® 22, from AK Steel. This grade offers enhanced protection against oxidation and temperature-related stress and fatigue fractures, so can withstand extreme changes in temperature better than nickel-bearing grades used in comparable applications. It has been approved by NSF International, a health and public safety organization, as safe for food contact. It can be used in appliance and food service equipment, tubing, cookware, automotive exhaust components and heat exchangers.

Conclusion

Several manufacturers have risen to the challenge of offering affordable and in many cases superior alternatives to traditional austenitic grades. This has involved novel alloy additions (such as tin in the case of FW1 and FW2) and experimenting with different manufacturing parameters and adopting new techniques, such as powder metallurgy. Of fundamental importance has been the collaboration between suppliers, end users and research institutes, as exemplified by Finland’s FIMECC. This suggests that more and more innovation will come from partnership between suppliers and end users.

Did you know?

In 2013 Chinese stainless steel production accounted for over half of global output for the first time: 30.5%, to be exact. More than 20 million tonnes were melted, 16% more than in 2012. Although the Chinese economy is slowing, stagnation in Europe means that this trend will probably continue.

References

(1) www.nucleoinox.org.br/inox-
2010/downloads/trabalhos/W5-
Ferritic+HT%28AMittal%29.pdf.
(2) www.sciencedirect.com/science/
article/pii/S0022311514005674.
(3) www.energy.gov/sites/prod/
files/2013/09/f2/2-Tan-NEET12-
Matls-CrossCut-2013.pdf.
(4) The report, “Breakthrough Materials
for Demanding Applications – from
Science to Solutions” is available at:
http://itghitech.fimecc.com/results/
final-report-demapp-breakthrough-
materials-for-demanding-applica-
tions-from-science-to-solutions. An
English summary can be found at:
www.fimecc.com/news/all-first-
fimecc-final-reports-now-published.