High and super high strength duplex stainless steels for wire applications

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Introduction

Duplex stainless steels are today to be regarded as workhorses in many applications [1, 2]. This is mainly due to the fact that these steels have an attractive combination of high strength, high toughness and excellent corrosion resistance. Duplex stainless steels in the annealed condition possess approximately double the strength of corresponding austenitic stainless steels. SAF 2205 is a traditional medium-alloyed duplex stainless steel with high corrosion resistance, high mechanical properties and good weldability. The difference between SAF 2205 and other 2205 types of duplex grades is that SAF 2205 has a narrower composition range. A typical composition is shown in Table 1. This has resulted in improved corrosion resistance. Figure 1 shows the critical pitting temperature, CPT, and SCC resistance of SAF 2205 and that of the standard austenitic grades. SAF 2205 shows both higher pitting resistance and stress corrosion cracking resistance in chloride-bearing solutions owing to its higher pitting resistance equivalent value and duplex structure [3].

C max.	Si max.	Mn max.	P max.	S max.	Cr	Ni	Mo	N
0.030	1.0	2.0	0.030	0.015	22	5.5	3.2	0.18

Table 1 Chemical composition (nominal) %

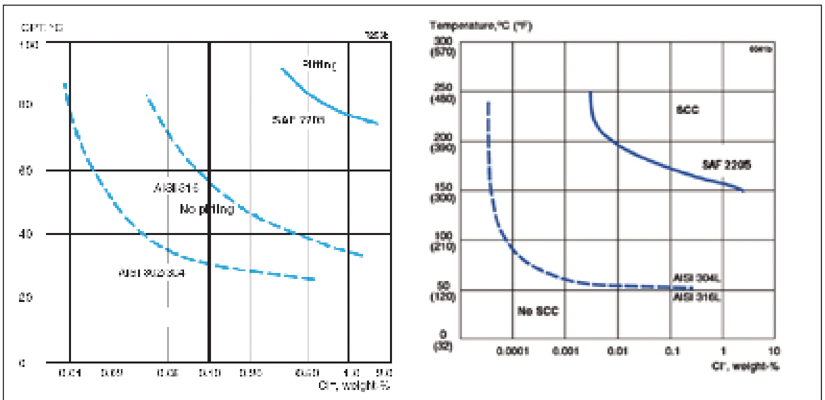

Figure 1 Comparison of the critical pitting temperature, CPT, and SCC resistance of SAF 2205 and that of austenitic stainless steels.

High and super high SAF 2205

High strength SAF 2205 has been developed mainly for tube applications, but has also been used for wire products for many years. Recently, high and super high strength wire products with unique properties have been developed using breakthrough techniques. This has provided opportunities for new applications despite the apparent maturity of the product. Figure 2a shows the yield and tensile strength of high/super high strength SAF 2205 wire products (or Springflex / Springflex SH) where tensile strength values as high as 3000 MPa can be achieved. Despite this super high tensile strength, the ductility of the wire material remains very good (Figure 2b).
Figure 2 (a) Tensile strength of high/super high strength Springflex wires in as delivered and tempered conditions. (b) Torsion properties of Springflex and AISI 302.

Fatigue properties of high and super high SAF 2205

Owing to its high strength and ductility, the high/super high strength SAF 2205 wire products and Springflex/Springflex SH, the spring wire grades adapted from SAF 2205, also demonstrate excellent fatigue properties. Figure 3a shows the

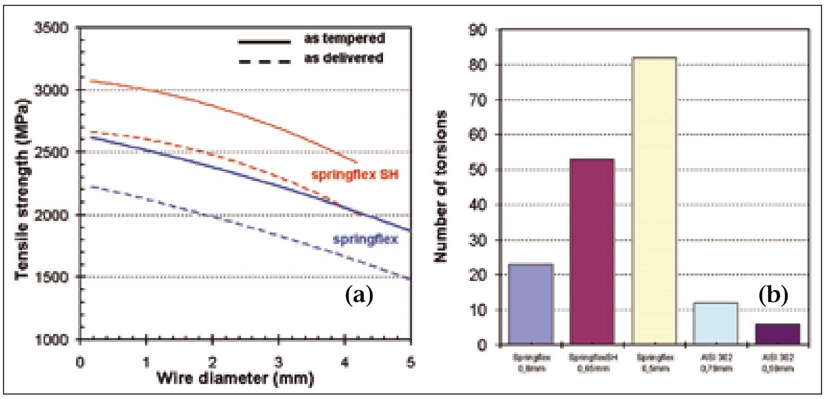

Figure 2 (a) Tensile strength of high/super high strength Springflex wires in as delivered and tempered conditions. (b) Torsion properties of Springflex and AISI 302.

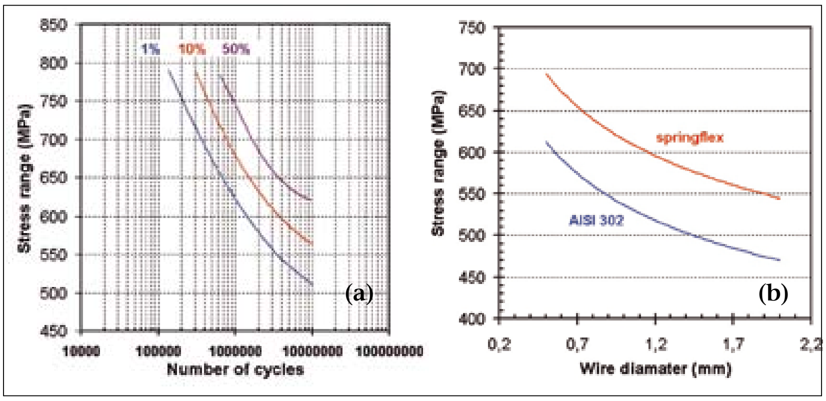

Figure 3 (a). Wöhler curves; diameter of 1mm, mean stress 450MPa, and 50%, 10% and 1% fracture probability, (b). A comparison of the fatigue strength with that of the austenitic grade.

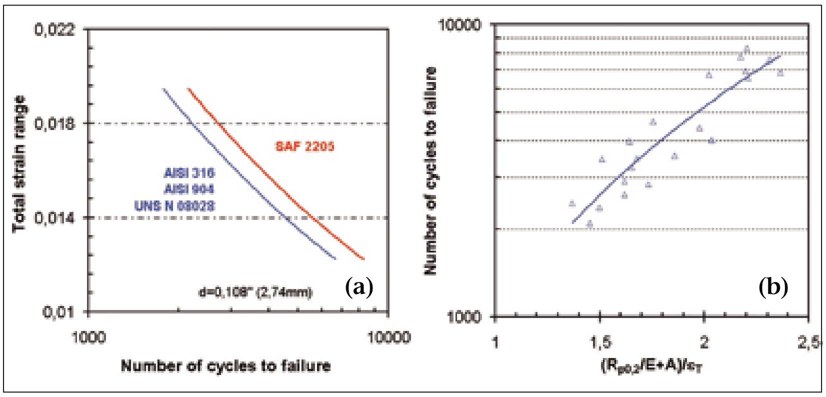

Figure 4 Comparison of the low cycle fatigue properties of a SAF 2205 duplex stainless steel wireline and some austenitic stainless steel wirelines. $R_{p0,2}$: yield strength; E: modulus of elasticity; A: elongation; ε_T: applied total strain range.

Wöhler curves of high strength Springflex wire with a diameter of 1mm with 50%, 10% and 1% fracture probability. The high strength of the material has also raised the maximum applied stresses/stress ranges or breaking loads. Springflex also shows higher fatigue strengths than that of the austenitic grade (Figure 3b).

In some wire product applications, low cycle fatigue or plastic strain controlled cyclic load can be critical. Figure 4 shows a comparison of the low cycle fatigue properties of a SAF 2205 duplex stainless steel wireline and some austenitic stainless steel wirelines. The SAF 2205 wireline shows not only higher yield strength or tensile strength but also longer fatigue life, i.e. a higher fatigue resistance. This is mainly attributable to a combination of high strength and good ductility of the material as shown in Figure 4b.

Stress relaxation of high and super high SAF 2205

Stress relaxation is an important property in many wire products such as springs. Stress relaxation is the load-loss or the time-dependent decrease in stress in a solid under a constant strain and temperature. The relaxation rate is determined by the relaxation test using the following equation:

$$R(\%) = \frac{F_1 - F_2}{F_1} .100$$

where R is the stress or load loss, F_1 is the initial load, and F_2 is the load at a given time. Most of the stress relaxation occurs at the starting-point, with the relaxation rate decreasing exponentially. Stress relaxation rate is usually defined as the stress/load loss under constant strain for 24 hours due to the fact that the stress relaxation after 24 hours has become insignificant. Figure 5a shows comparisons of the stress relaxation of SAF 2205 and that of the standard austenitic grade. The SAF 2205 material, Springflex, shows a comparatively low stress relaxation rate. This can be explained by the fine-scaled microstructure in combination with the presence of the two phases that show heterogeneous mechanical behaviour. The balance of the micro stresses between the individual phases can hinder stress relaxation. However, an increase in temperature can usually increase the relaxation rate. Figure 5b shows the influence of temperature on the stress relaxation of SAF 2205 and AISI 302 wire materials with an applied stress of 800MPa. The difference in the stress relaxation rates becomes more pronounced at elevated temperatures where SAF 2205 still retains a high relaxation resistance.

Applications of high and super high SAF 2205

Owing to the extremely good corrosion resistance, very high strength and not least the excellent ductility which high/super high duplex steel wires provide, they have been used in many applications. The following are some examples.

Sandvik Springflex and Springflex SH are adapted from Sandvik SAF 2205 and Sandvik SAF 2205SH, where the SH appendage in both

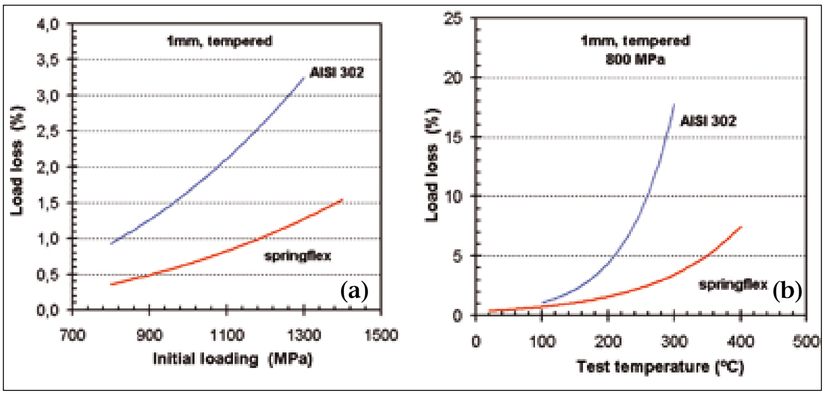

Figure 5. Relaxation after 24 hours and the influence of temperature on the relaxation behaviour of SAF 2205 and some austenitic stainless steels.

cases indicates Super-High strength. Sandvik Springflex is the most versatile material available in the Sandvik spring wire palette and can be used in many applications. It is particularly suitable in demanding environments where both good corrosion resistance and favourable mechanical properties are needed. Springflex has often replaced 302 grades for spring applications, as the higher strength of the material leads to greater spring power and both better relaxation and fatigue properties. Springflex is also far superior to 302 where corrosion resistance is concerned. In addition, Springflex offers a lower thermal expansion. At high temperatures Springflex will not expand as much as a type 302 steel, a clear advantage in spring applications.

Sandvik SAF 2205 is a popular grade for wirelines used in servicing oil and gas wells. The combination of high breaking loads and resistance to chloride environments both offshore and onshore make it eminently suitable. The super-high strength of Sandvik SAF 2205SH is currently being introduced and the additional breaking loads available are of great interest to service companies and oil companies in this extremely demanding application. In geothermal applications, temperatures can be as high as 300°C. Even in these temperature ranges, Sandvik SAF 2205 and Sandvik SAF 2205SH will retain their ductility. Most high alloy austenitic steels have shown themselves to be extremely unsuitable in high temperature applications. SAF 2205SH has been able to replace these alloys in geothermal applications where H2S levels were low.

316-type steels have often been replaced by SAF 2205SH in oil and gas wireline applications, partly for the higher breaking loads available - as much as 40% higher. In a 1% chloride solution, the critical pitting temperature (CPT) for SAF 2205 is double that of a 316-type steel, also making Sandvik SAF 2205SH an attractive proposition for its corrosion resistance. The combination of extremely high breaking loads, excellent corrosion resistance and superb ductility, all add up to a very suitable wireline product for the oil and gas industry.

Root canal file (dental reamer) is another extremely interesting application for duplex steel owing to the excellent twistability of the material in combination with high strength.

Concluding remarks

High strength SAF 2205 and particularly the super high strength SAF 2205SH, are recent wire developments. They combine strength with good ductility and demonstrate both better high-cycle fatigue strength and longer low-cycle fatigue life compared to the austentic grades. Uses include high performance springs, wirelines in the oil and gas industry and some medical applications.

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About the authors

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Guocai Chai Ph D, Docent is a senior specialist in mechanical metallurgy at R&D, Sandvik Materials Technology. He graduated at Beijing University of Science and Technology in 1982, and got Ph D at Stockholm University in 1994. During 1994 to 1995 he was working as a research fellow or postdoctoral at University of Windsor, Canada, and then came back to Sweden, and worked as a research scientist at Studsvik Material AB until he joined Sandvik in 1997.

He has published about 80 papers and two books, and has received the Howard F. Taylor Award of the American Foundrymen's Society (AFS) in 1992.

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Anders Söderman M.Sc, Technical Manager, product area Wire at Sandvik Materials Technology. Anders acquired his M.Sc at Dalarna University in 1995 and has since then worked within the steel industry at various positions. He joined Sandvik Materials Technology in 1999 and spent 3 years as a research engineer with the R&D organisation. After 5 years as R&D manager for wire products, he has now moved to the Wire mill as Technical manager.

Phil Etheridge

Phil is 54 years-old, was born in London but has lived in Sweden for 30 years. Married with a 9-year-old daughter, he has been a music nerd his whole life and still plays in a pop band. Hobbies amount to a home studio, mostly for recording music, but also for voice-over work. 28 years with Sandvik, 17 of them in marketing. After 22 years within the tube organisation including 9 years in QA, 6 years marketing nuclear pipe, 3 years as commercial manager for a Sandvik plant in France, and 2 years as sales and marketing manager for various products in Tube, Phil moved to product area Wire as manager for Energy products. His current assignment is Technical Marketing and support.