Hyper duplex stainless steel for deep subsea applications

This article looks at the development of hyper-duplex stainless steels by Sandvik (SAF Sandvik 3207 HD) for use in subsea umbilicals to connect platform control stations and wellheads on seabeds where some of the demanding environmental conditions faced are water depths often greater than 2500 and pressure ratings above 15000 psi. This new generation of umbilicals has arisen to meet the challenges for ever increasing strengths, better fatigue life and better corrosion resistance.

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Subsea umbilicals are used as a connection between platform control stations and the wellheads on the seabed to supply necessary control signals and to inject chemicals to subsea oil and gas wells. A stainless steel umbilical has an outer plastic sheeting with stainless steel tubes and cables (electric and others) inside (Fig. 1). The umbilical tube materials are required to have excellent corrosion resistance and high fatigue properties. Super duplex stainless steel, Sandvik SAF 2507, has been one of the most common choices of material since it was introduced in 1993. Today the oil exploration strives to deeper waters [1,2]. New projects where the water depth is over 2500 m or the pressure ratings are rising above 15000 psi are being looked at. For these projects super duplex stainless steels can be used, but the wall thickness may need to increase and the tubes may need coating for added corrosion protection. With the increase in wall thickness super duplex stainless steels are reaching to the point where they cannot support its own weight. Increased wall thickness increases costs for the installation step. The cross-sections of the umbilical will

Fig. 1. Schematic section diagram of a subsea umbilical.

[1] The art of technology, Printed matter. Nexans, Oslo.
[2] Integrated production umbilical™, Homepage: www.akersolutions.com, visited 2008-07-03.

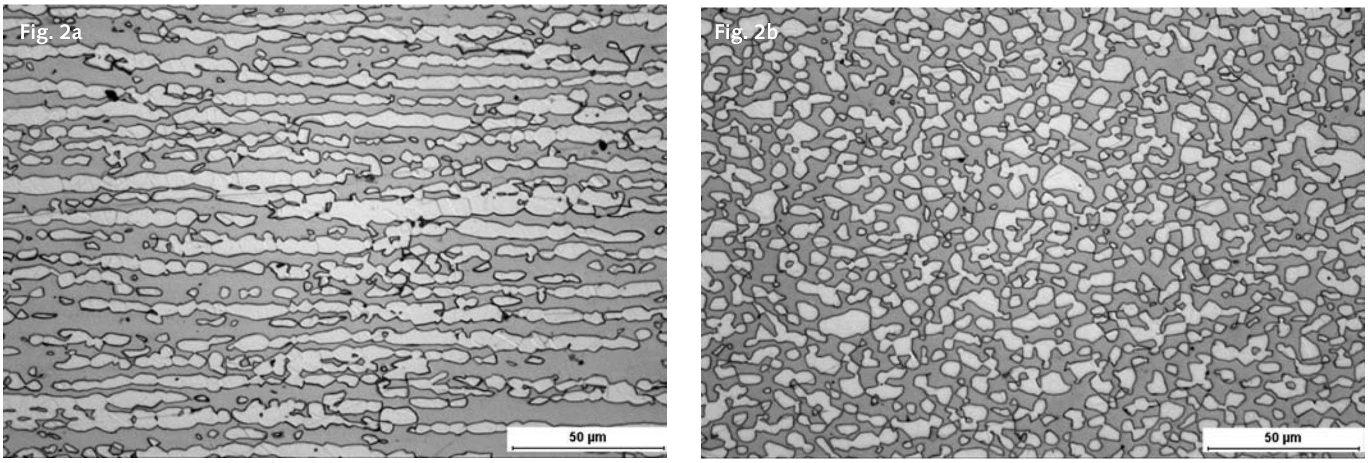


Fig. 2. Microstructure of Sandvik SAF 3207 HD tube material with a dimension of 14.7 x 1 mm. The white phase is austenite, and the grey phase is ferrite: (a) longitudinal direction, (b) transversal direction.

increase and thereby fitting less length onto an installation vessel, subsequently increasing costs. In recent development the umbilical is combined with incorporation of a central gas lift or a production flowline [3,4]. This leads to a much higher temperature than conventional umbilicals normally see. Consequently, other new projects with a working temperature above 65°C can also be seen.

These new challenges require improved new umbilical tube materials with a higher strength, better fatigue life and a better corrosion resistant. This has actually led to the development of the hyper-duplex Sandvik SAF 3207 HD material. This new material has a yield strength 20% higher than that of the super duplex stainless steel and a service temperature up to 90°C as an umbilical tubing. The benefits when it comes to building umbilicals are considerable. Thinner walls and lighter installations make it possible to reach and operate ultra-deep wells that were previously too costly or too complex to exploit. At the same time, the temperature and pressure window widens. This paper will provide an introduction of this new duplex stainless steel grade.

Hyper duplex stainless steels

Modern duplex stainless steels will mainly be alloyed with Cr, Mo, Ni and N. Table 1 shows the nominal chemical compositions of Sandvik SAF 3207 HD and Sandvik SAF 2507 duplex stainless steels. Sandvik SAF 3207 HD contains even higher amounts of these alloying elements. The nitrogen content is up to about 0.5%. The high contents of Cr, Mo and N together can give the alloy with a very high strength and simultaneously a good workability for extrusion into seamless tubes. This is the major technology leap for this development. For duplex stainless steels, the pitting corrosion resistance is proportional to pitting corrosion resistance equivalent number, PRE, of an alloy, which can be calculated as follows:

$$PRE= \%Cr + 3.3\%Mo + 16\%N \text{ (\% by weight)} \quad (1)$$

Table 1 Nominal chemical composition of two duplex stainless steels

Grade	UNS	C_max	Cr	Ni	Mo	N	PRE
Sandvik SAF 3207 HD	S32707	0.03	32	7	3.5	0.5	50
Sandvik SAF 2507	S32750	0.03	25	7	4	0.3	42.5

The pitting corrosion resistance equivalent numbers, PRE, of these two alloys are also shown in Table 1. Sandvik SAF 3207 HD has a minimum PRE number of 50, comparing 42.5 to Sandvik SAF 2507. A duplex stainless steel with a PRE number above 48 is nowadays designated as hyper duplex stainless steel (HDSS). Sandvik SAF 3207 HD is therefore a hyper duplex stainless steel.

Sandvik SAF 3207 HD has a well-balanced composition for structure stability. The microstructure consists of approximately 50% austenite and 50% ferrite to give high ductility. Fig. 2 shows typical microstructures of the umbilical tube material in the transversal and longitudinal directions.

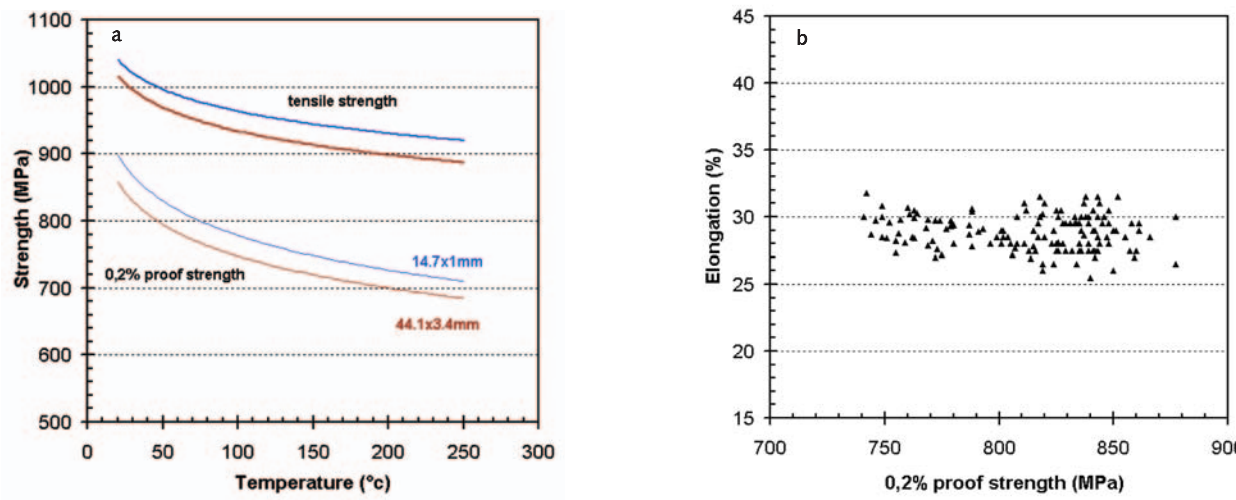


Fig. 3. Tensile properties of SAF 3207 HD tube materials: (a) 0.2% proof strength and tensile strength versus temperature, (b) elongation versus 0.2% proof strength.

[3] J-D. Otchoumou, Integrated production bundle: an attractive flexible raiser. solution for severe deep water flow assurance requirements, Homepage www.technip.com, visited 2008-07-03.
[4] K. P. Inderberg, Solutions 1-2008, AkerSolutions, Oslo, 2008, 8.

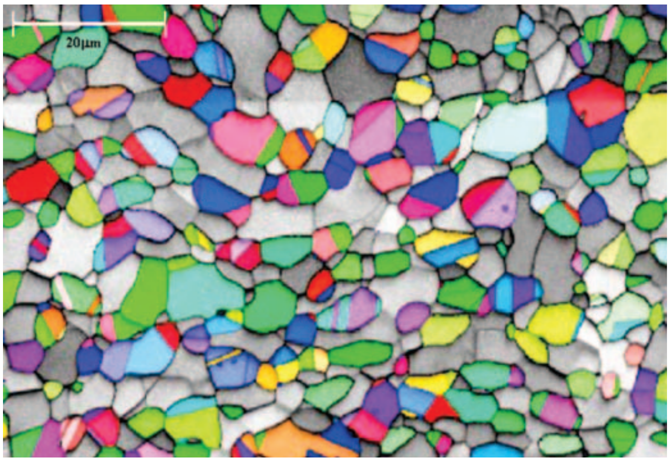


Fig. 4. Grain structure in a SAF 3207 HD umbilical tube with a dimension of 14.7 x 1 mm. Color grains are austenitic phase (3.6 µm), and grey grains are ferritic phase (5.1 µm).

Corrosion properties of hyper duplex stainless steels

The critical pitting temperature, CPT, determined in 6% $FeCl_3$, the ASTM G48A test solution, and the critical crevice corrosion temperature, CCT, determined with the MTI-2 crevice former, are two important corrosion properties for the umbilical tube materials. For both test methods the testing time was 24 hours and same specimen throughout each CPT/CCT measurement. Table 2 shows comparisons of CPT between Sandvik SAF 3207 HD and Sandvik SAF 2507. The CPT of both the base materials and welds are higher for Sandvik SAF 3207 HD than for Sandvik SAF 2507.
Table 3 shows the CCT obtained in 6% $FeCl_3$ for Sandvik SAF 3207 HD. The result for Sandvik SAF 2507 is a typical value. Sandvik SAF 3207 HD has a 25ºC higher CCT than for UNS S32750.
The most interesting for umbilical tubes is the fitness test for service, testing in conditions simulating service conditions inside an umbilical. The testing is performed with welded specimens in synthetic seawater saturated with air with crevices simulating one umbilical design. The testing duration

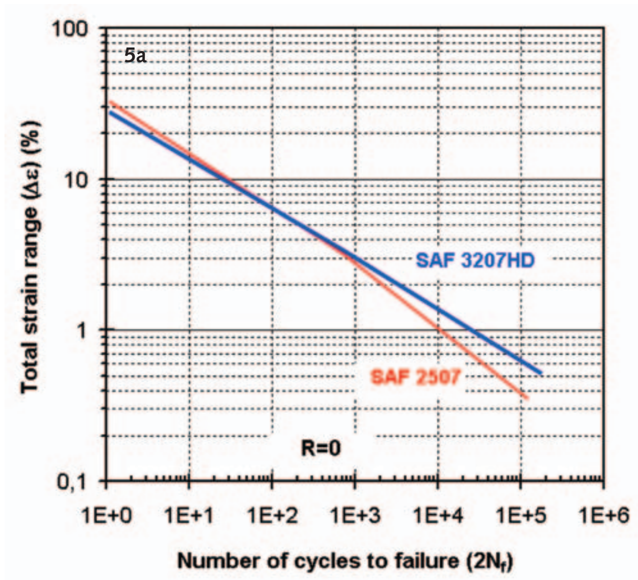
Table 2 CPT for Sandvik SAF 3207 HD tubes with dimensions up to 44.1x3.4 mm.

Base materials		Welds	
SAF 3207 HD	SAF 2507	SAF 3207 HD	SAF 2507
85-93	65-75	69	55

is one month. As safety margins both a polarization of +100 mV vs. to the open circuit potential with a potentiostat and an increase of the clamping force compared to the umbilical were used [5]. Sandvik SAF 3207 HD has passed the test at 90ºC. However, Sandvik SAF 2507 has only passed at 70ºC. The results strongly indicate that the maximum service temperature is significantly increased for Sandvik SAF 3207 HD.

Tensile properties and ductility of hyper duplex stainless steel

Due to high amounts of alloying elements and fine microstructure, Sandvik SAF 3207 HD shows very high tensile properties. Actually, the Sandvik SAF 3207 HD material in the quenched-annealed condition shows the highest strength among the existing duplex stainless steels. It is 20% higher than that of super duplex Sandvik SAF 2507 material. Fig. 3 shows the influence of temperature on the 0.2% proof strength and tensile strength of two SAF 3207 HD tube materials. The strength slightly decreases with increasing temperature. For the umbilical tube materials, the strength depends strongly on its size. The strength generally decreases with the increase of tube diameter and wall thickness.
In spite of high strength, Sandvik SAF 3207 HD still shows high ductility. The elongation of the material in the quenched - annealed condition is higher than 20%. It is interesting to mention that the elongation of Sandvik SAF 3207 HD tube materials changes little with increasing the yield strength as shown in Fig. 3b. This can be attributed to the very fine grained austenitic and ferritic phases in the material. Fig. 4 shows the grain structure in a SAF 3207 HD umbilical tube with a dimension of 14.7x1mm. The average grain size is 3.6µm for the austenitic phase and 5.1µm for the ferritic phase. The average grain size is 4.4µm. As known, a fine grained material increases both the yield strength and ductility.



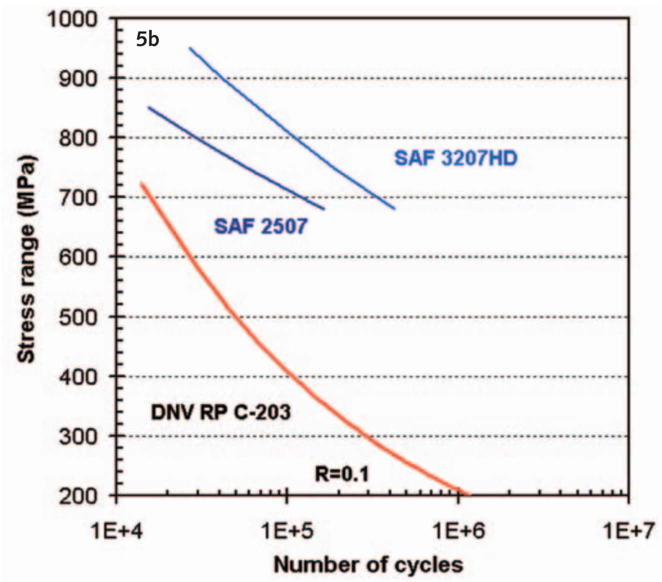
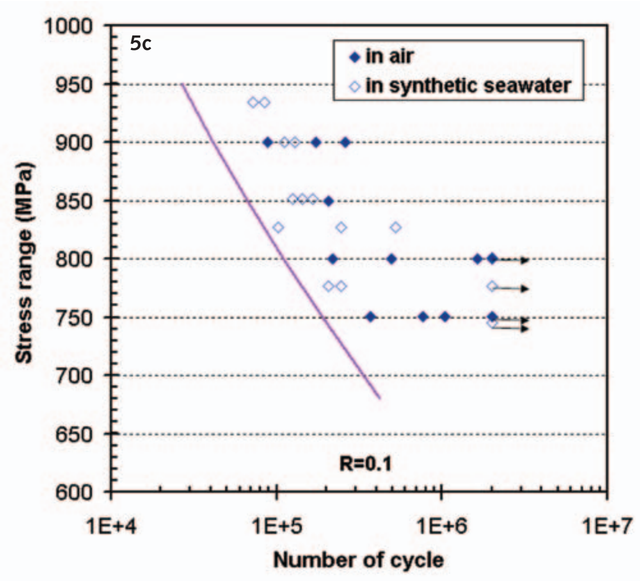
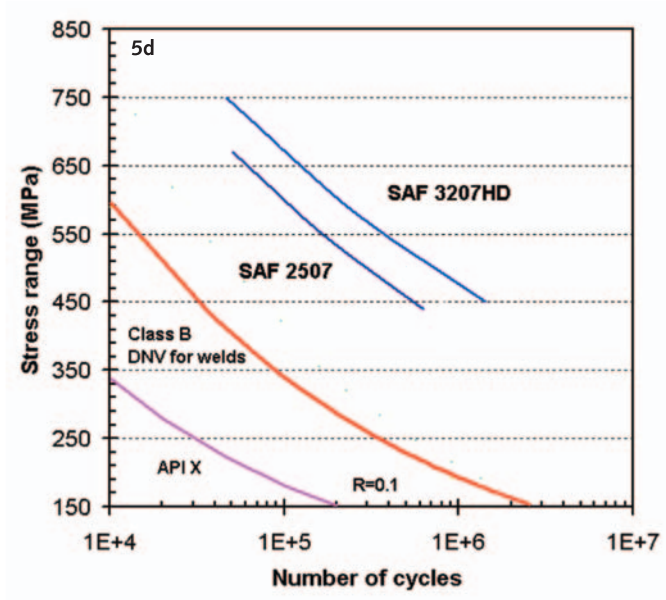


Fig. 5 Fatigue properties of Sandvik SAF 3207 HD tube materials: (a) LCF in air, tubes: 14.7 x 1 mm, (b) HCF in air, tubes: 14.7 x 1mm, (c) HCF in air and in synthetic sea water, tubes: 21.25 x 1.05 mm, (d) welded material, tubes: 14.7 x 1 mm. All HCF curves have a survival probability of 97.5%.

[5] U. Kivisäkk and P. Novak, Corrosion'2005, NACE International, Houston, 2005, paper 05228.





Fatigue properties of hyper duplex stainless steel

A subsea umbilical can undertake both low cycle fatigue (LCF) and high cycle fatigue (HCF). Fig. 5 shows the fatigue properties of Sandvik SAF 3207 HD tube materials comparing with that of Sandvik SAF 2507 tube material. For LCF (Fig. 5a), Sandvik SAF 3207 HD shows a higher fatigue life in the small strain range, but not in the large strain range. This is due to the fact that the LCF life is controlled mainly by the strength of the material in the small strain range, but is controlled by the ductility in the large strain range. Sandvik SAF 3207 HD has a higher strength than Sandvik SAF 2507, but they have similar elongation. As expected, Sandvik SAF 3207 HD has a higher HCF life (Fig. 5b). The influence of synthetic seawater on the fatigue life of Sandvik SAF 3207 HD tube materials is relatively small (Fig. 5c). This can be attributed to the excellent corrosion resistance of Sandvik SAF 3207 HD material.

A weld is always the weakest link to fatigue failure. Fig. 5d shows the fatigue properties of the material with welds. As expected, the fatigue properties of the welded Sandvik SAF 3207 HD tube material are better than that of the welded Sandvik SAF 2507 tube material, but worse than that of the base material. However, the fatigue life of the welded Sandvik SAF 3207 HD tube materials is much higher than the DNV design curve Class B for welds [6].

Table 3 Average CCT for Sandvik SAF 3207 HD.

Material	CCT (°C)
Sandvik SAF 3207 HD	≥75
UNS S32750	50

Table 4 Example for weight saving ($^{1}/_{2}$″ ID (12.70 mm) 15000 psi)

Grade	ID	Nominal wall thickness	Wall thickness reduction	Weight save
	(mm)	(mm)	(%)	(%)
Sandvik SAF 2507	12.70	2.50		
Sandvik SAF 3207HD	12.70	1.66	21	22

Problem solution

The good combination of extra high strength and high ductility makes it possible for Sandvik SAF 3207 HD material to allow substantial reduction in wall thickness, which leads to a reduction of weight and consequently the total cost of the installation. Table 4 shows an example. By using Sandvik SAF 3207 HD to replace Sandvik SAF 2507 tube material, 21% of the wall thickness of the tube can be reduced, and 22% of the weight can be saved. This indicates that it makes it now possible to manufacture an umbilical with a length longer than 2500m or an application for ultra-deep wells.

Extreme high critical pitting temperature, CPT, and critical crevice corrosion temperature, CCT, of Sandvik SAF 3207 HD allow the material to be used in the areas where the service temperature is above 65°C. Fig. 6 schematically shows possible solutions or applications with Sandvik SAF 3207 HD. In all these situations the alloy's superior properties can be fully utilized to ensure good reliability, minimum cost and the overall projects success.

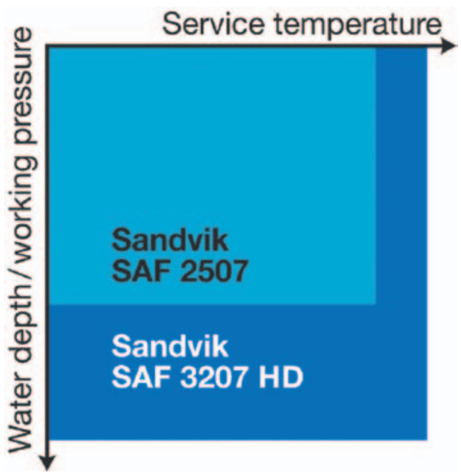


Fig. 6. Problem solution with Sandvik SAF 3207 HD tube materials

Summary

Hyper-duplex Sandvik SAF 3207 HD tube materials can provide a combination of very high strength, excellent corrosion resistance and high fatigue strength. This makes it possible for the material to be used as umbilical tube material for ultra-deep wells, and also makes it safe and economical to operate in tougher places.

Extreme high critical pitting temperature, CPT, and critical crevice corrosion temperature, CCT, of Sandvik SAF 3207 HD allows the material to be used in a wider operational temperature range.

Acknowledgement

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[6] DNV-RP-C203, Fatigue design of offshore steel structures, April, 2008.

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