JFE TECHNICAL REPORT
No. 18 (Mar. 2013)

Corrosion Resistant High Cr Steel for Oil and Gas Wells†

1. Introduction

Oil and natural gas development in high temperature and high pressure environment or high corrosive environment in deep well has continued to increase in recent years. While high strength and high corrosion resistant oil country tubular goods (OCTG) are necessary under these conditions, demand for cost reduction to improve the profitability of oil and gas development is increasing. Moreover, larger fluctuations and a shorter cycle of change in crude oil and gas prices have heightened the focus on short-term recovery of development costs, and short delivery deadline requirements are also increasing.

JFE Steel is responding to the above-mentioned customer needs by developing high Cr stainless steel seamless OCTG that can provide high strength and high corrosion resistance while also meeting requirements for low cost and short delivery deadlines. The following introduces the JFE Steel's product line in detail.

2. High Cr Stainless Steel OCTG

2.1 Product Line

The problem of corrosion in OCTG can be broadly divided into CO_2 corrosion under sweet (CO_2) conditions and sulfide stress cracking (SSC) under sour (H_2S) conditions. Sweet (CO_2) conditions can be further divided into a pure sweet (CO_2) condition and a CO_2 + slight H_2S condition ($H_2S \leqq 0.01$ MPa). The materials applied under those conditions are 13% Cr steel (API-L80-13Cr, API: The American Petroleum Institute), modified 13% Cr steel, duplex stainless steel, and Ni based alloys. To date, JFE Steel has offered a product line from 13% Cr steel to modified 13% Cr steels (JFE-HP1-13CR, JFE-HP2-13CR). Recently, JFE Steel also developed new high Cr stainless steel OCTG with high strength and corrosion resistance[1–5], which can be economical substitutes for the existing materials. The applicable conditions of JFE Steel's high Cr stainless steel OCTG are shown in **Fig. 1** from the viewpoint of CO_2 corrosion resistance and sour resistance. The chemical compositions and mechanical properties of these high Cr steels are shown in **Tables 1** and **2**, respectively.

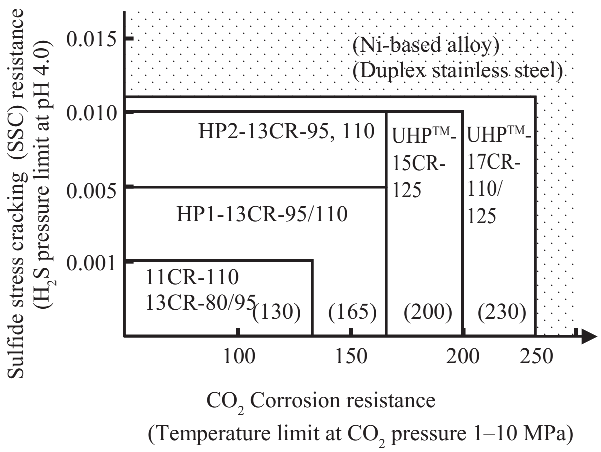

Fig. 1 Applicable condition of JFE Steel's high Cr steels

Table 1 Chemical composition of high Cr steels

(mass%)

Material	C	Cr	Ni	Mo	Others
JFE-13CR	0.15–0.22	12.0–14.0	Max. 0.50	—	Cu: Max. 0.25
JFE-11CR	Max. 0.04	10.0–12.0	2.0–3.0	—	Cu: Max. 0.60
JFE-HP1-13CR	Max. 0.04	12.0–14.0	3.5–4.5	0.8–1.5	—
JFE-HP2-13CR	Max. 0.04	12.0–14.0	4.5–5.5	1.8–2.5	—
JFE-UHP™-15CR	Max. 0.04	14.0–16.0	6.0–7.0	1.8–2.5	Cu: Max. 1.50
JFE-UHP™-17CR	Max. 0.04	16.0–18.0	3.5–4.5	2.3–2.8	Cu: Max. 1.50 W: 0.80–1.20

† Originally published in *JFE GIHO* No. 29 (Feb. 2012), p. 61–63

Table 2 Mechanical properties of high Cr steels

Grade	YS				TS		Hardenss
	Min.		Max.		Min.		HRC Max.
	(ksi)	(MPa)	(ksi)	(MPa)	(ksi)	(MPa)	
JFE-13CR-80	80	552	95	655	95	655	23
JFE-13CR-85	85	586	100	689	100	689	24
JFE-13CR-95	95	655	110	758	105	724	27
JFE-11CR-110	110	758	130	896	120	827	32
JFE-HP1-13CR-110	110	758	130	896	120	827	32
JFE-HP1-13CR-95	95	655	110	758	105	724	28
JFE-HP1-13CR-110	110	758	130	896	120	827	32
JFE-HP2-13CR-95	95	655	110	758	105	724	30
JFE-HP2-13CR-110	110	758	130	896	120	827	32
JFE-UHP™-15CR-125	125	862	150	1 034	135	931	37
JFE-UHP™-17CR-110	110	758	130	896	120	827	36
JFE-UHP™-17CR-125	125	862	150	1 034	135	931	37

YS: Yield strength TS: Tensile strength HRC: Rockwell hardness

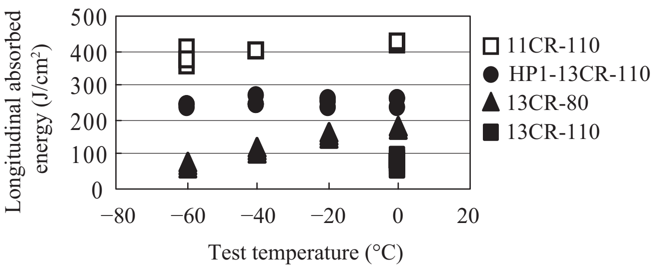

Fig. 2 Low temperature toughness of high Cr steels

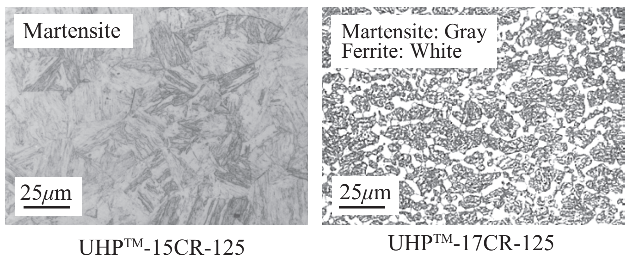

Photo 1 Microstructure of UHP™-15CR and 17CR

2.2 JFE-11CR-110

In cases where high strength of 110 ksi grade (specified minimum yield strength: 758 MPa) is necessary under pure sweet conditions in which 13% Cr steels can be applied, modified 13% Cr steel, which is a costly option but can secure high toughness, had been used as a substitute for 13% Cr steel, as the toughness of the 13% Cr steel deteriorates when its strength is increased. However, in such cases, the corrosion resistance of modified 13% Cr steel is excessive. Therefore, a low cost, high strength material of 110 ksi grade which combines the CO_2 corrosion resistance of 13% Cr steel and the high toughness of modified 13% Cr steel had been desired. To meet this need, JFE Steel developed a low carbon, Ni-added 11% Cr steel of 110 ksi grade, which was commercialized as JFE-11CR-110. The toughness of this product is compared with that of 13% Cr steel and modified 13% Cr steel in **Fig. 2**.

2.3 JFE-UHP™-15CR, 17CR

The upper limit temperatures of CO_2 corrosion for 13% Cr steel and modified 13% Cr steel when the allowable corrosion rate is 0.127 mm per year or less are around 130°C and 165°C, respectively. Under severe corrosion conditions with temperatures higher than these, duplex stainless steel or Ni based alloys had been applied. However, in order to obtain high strength of 110 ksi (specified minimum yield strength: 758 MPa) and 125 ksi (specified minimum yield strength: 862 MPa), which is required in deep wells, cold drawing is necessary with these materials. This causes various problems, including increased manufacturing costs, longer delivery periods, and restrictions on the available manufacturing size range (large diameter, heavy wall, long length), etc.

To solve these problems, JFE Steel developed a 15% Cr steel, which is a martensitic stainless steel, and a 17% Cr steel, which is a dual phase steel of martensite and ferrite (**Photo 1**), and commercialized these steels as JFE-UHP™-15CR and JFE-UHP™-17CR. Their features are presented below.

(1) Under CO_2 conditions and CO_2 + slight H_2S conditions at temperatures up to 200°C, JFE-UHP™-15CR is applicable and up to 230°C, JFE-UHP™-17CR is applicable. The CO_2 corrosion test results are shown in **Fig. 3**.
(2) As high strength of 125 ksi grade can be achieved

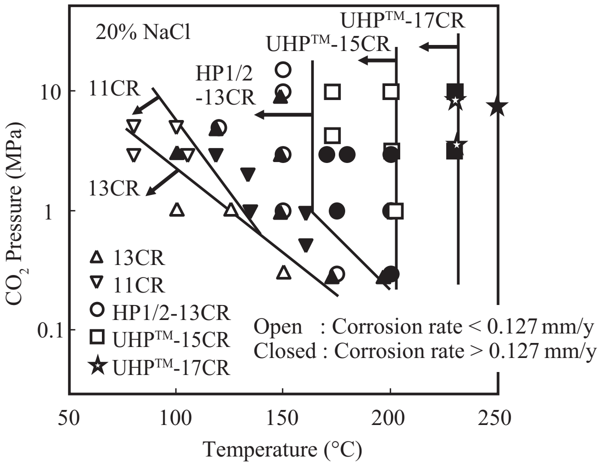

Fig. 3 CO_2 corrosion test results

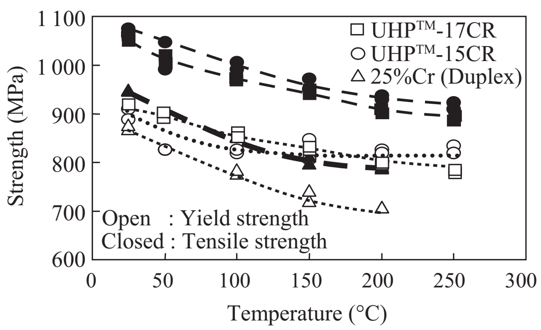

Fig. 4 Strength at elevated temperature

without cold drawing, these materials are superior to duplex stainless steels and Ni based alloys in terms of cost, delivery, and available size range (large diameter, heavy wall, long length).

(3) Because high strength is achieved by the martensitic structure and precipitation hardening, derating of strength at elevated temperature is less (**Fig. 4**) in comparison with duplex stainless steels and Ni based alloys, in which strength is secured by dislocation hardening induced by cold drawing. This is advantageous for well design, since the inner diameter can be enlarged by thinning the wall thickness.

(4) In recent years, formation fracturing technology using strong acid has been applied in an increasing number of cases in order to increase the flow rate and recovery rate of oil and gas. JFE-UHP™-15CR and 17CR are advantageous under this acidizing condition, as the severe selective corrosion observed with duplex stainless steels does not occur (**Fig. 5**, **Photo 2**).

3. Conclusion

JFE Steel has expanded its lineup of high strength

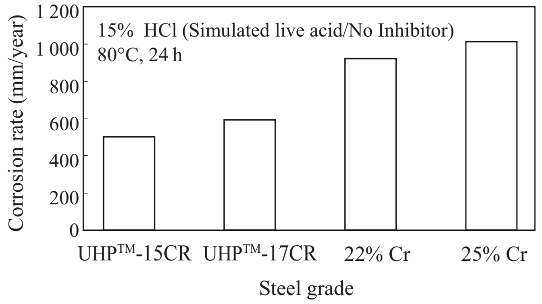

Fig. 5 Corrosion rate under acidizing condition

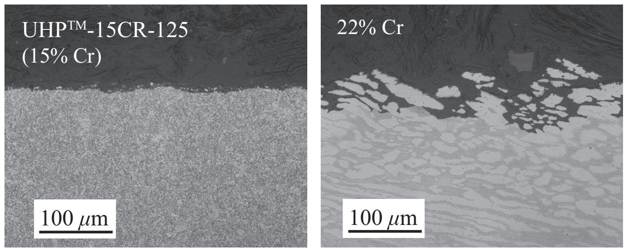

Photo 2 Corrosion under acidizing condition

and high corrosion resistant high Cr stainless steel seamless OCTG in order to provide new, economical options to users. As a result, the company has shipped 630 t of JFE-11CR-110 and 6 320 t of JFE-UHP™-15CR-25, which have obtained high evaluations from customers. Meanwhile, JFE-UHP™-17CR is in the final stage of material approval for adoption in a large-scale deepwater project.

In the future, oil and gas development conditions will become severer, and progress in drilling and production technology and the new technologies are expected. JFE Steel will continue to promote original development of materials that meet these environmental challenges in order to contribute to energy development.

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