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Steel Plates with Excellent HAZ Toughness

Abstract:

JFE Steel has developed high strength steel plates for offshore structures, which meet the low temperature specification. The range of products has expanded corresponding to the rising demand for the steel used for the offshore structure arising form robust oil resource development in recent years. Excellent properties of the plates and their welded joints are obtained by micro-alloying technology, and latest controlled rolling and accelerated cooling technology using Super-OLAC^{TM} (On-Line Accelerated Cooling). High strength steel plates which are designed for excellent weldability thorough the low weld cracking parameter P_{CM} value have been developed by Super-OLAC^{TM} for up to 550 MPa class in yield stress, up to 101.6 mm in thickness with 420 MPa class in yield strees, and satisfying −40°C of crack tip opening displacement (CTOD) temperature specifcetion for offshore structure. They have achieved already a lot of actual application results.

1. Introduction

Recent years have seen robust development of petroleum resources accompanying rising global energy demand. Construction of large-scale offshore structures has increased in response to these trends, and the range of installation is progressively] T r y A s ʿ ve] ι

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ments for steel plates and has an extensive record of application in actual projects. **Table 1** shows examples of steel plates for offshore structures developed by JFE Steel. At present, it is possible to meet yield point (YP) requirements up to 690 MPa class. Among these plates, YP 550 MPa and lower class steels can be manufactured by either the thermo-mechanical control process (TMCP) utilizing controlled rolling and controlled cooling or direct quenching and tempering (DQ-T). These products meet the performance requirements of all relevant specifcations, and manufacturing qualifcations have already been obtained in all cases. In the future, JFE Steel plans to further expand this product line by developing larger thickness and higher performance products.

Among steel plates manufactured utilizing the TMCP or DQ-T processes by JFE Steel, the properties of the base material are secured in heavy thickness plates, and

Table 1 Available strength and thickness of steel plates for offshore structures

YP Class (MPa)			

A ȯ v offshore structures which meet these severe requ

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Ti treatment[2–4], together with optimization of the material microstructure by nonmetallic inclusion control. The relationship of the Ti/N ratio and notch toughness of a simulated HAZ under a heat cycle is shown in **Fig. 2**. Since an optimum value exists in the Ti/N ratio, the contents of Ti and N are strictly controlled[5,6].

The ICCGHAZ is formed by recheating CGHAZ, which is formed by prior welding pass, to the dual-phase region between the Ac_1 point and Ac_3 point by the welding heat of succeeding passes. In reheating to the dual-phase region, carbon concentrates in reverse-transformed austenite, and then martensite-austenite constituent (MA): the brittle oʿ en han rustexase

3.2 Mechanical Properties of Base Materials

Examples of the microstructures of the base steel plates are shown in **Photo 1**. Steel B has a bainitic main microstructure containing fine acicular ferrite, and substantially the same microstructure is also obtained in Steels A and C. Steel D comprises a single phase microstructure of fine bainite.

The results of tensile tests and Charpy impact tests of the base materials are shown in **Table 4**. All plates satisfy the target values for strength and toughness including the middle thickness shown in Table 1. With Steel B having a thickness of 101.6 mm, strength and toughness after post weld heat treatment (PWHT) also satisfy the target values.

3.3 CTOD Property of Base Materials

The fracture toughness characteristics of the base steel plates were evaluated by the 3-point bending CTOD test. **Table 5** shows the test results. All the steels showed enough CTOD values at the required temperatures.

3.4 Strain Aging Property

The Charpy impact test was performed after aging treatment at 250°C for 1 hour under a maximum prestrain of 10%. **Table 6** shows the test results. Alth î e te s.p llr a

Table 8

target property. In particular, Steel B and Steel C showed extremely good strain aging properties at the required temperature of $_{\mathrm{V}}T_{\mathrm{S}}$: −50°C with 8% strain for Steel B and $_{\mathrm{V}}T_{\mathrm{S}}$: −105°C under 10% strain with Steel C.

4. Properties of Welded Joints

4.1 Welding Conditions

The welding conditions applied with the respective steel plates are shown in **Table 7**. Welded joints were produced by multilayer gas metal arc welding (GMAW) with the welding heat input of 0.8 kJ/mm and by multilayer submerged arc welding (SAW) with heat inputs of 1.5–5.0 kJ/mm. In the case of Steels A and B, performance evaluations were performed with joints produced using 3 welding heat input levels. **Photo 2** shows the macrostructures of the welded joints of Steel B at each heat input.

4.2 Mechanical Properties of Welded Joints

The results of tensile tests and Charpy impact tests of the welded joints are shown in **Table 8**. Both of the tensile strength of the welded joints and Charpy absorbed energy of HAZ satisfy the target values of each steel plate.

4.3 CTOD Properties of Welded Joints

The results of the CTOD test of the welded joints are shown in **Fig. 4**. CTOD tests and evaluations were performed with the notch position in the weld metal (WM), CGHAZ, and sub-critically HAZ (SCHAZ) were performed based on BS 7748 Part 2 (1997) and API RP 2Z[8)]. The CTOD values of the CGHAZ with welding heat inputs up to 5.0 kJ/mm were Steel A: 0.60 mm or more at −10°C, Steel B: 0.40 mm at −10°C, and Steel C: 1.39 mm at −40°C. The CTOD values of the SCHAZ were Steel A: 0.42 mm or more, Steel B: 0.67 mm or more, and Steel C: 2.22 mm or more. Thus, the test results satisfied the targets in all cases, and the joints showed sufficiently high resistance to occurrence of brittle fracture. The proportions of the CGHAZ and SCHAZ in the crack tips of these test pieces all satisfied the provisions of API RP 2Z.

5. Conclusion

As high performance steel plates for offshore structures, the properties of a heavy thickness YP 420 MPa steel plate with thicknesses up to 101.6 mm, a low temperature specification material with a CTOD temperature of −40°C considering use in cold regions, and a high strength YP 500 MPa steel plate were introduced. These steel plates were developed by using a combination of advanced composition design and plate manufacturing technologies, beginning with JFE Steel's *Super*-OLAC$^{\mathrm{TM}}$ accelerated cooling device. In all cases, the materials possess satisfactory base material and welded joint performance.

As the development of petroleum resources continues to expand into arctic and deepwater regions, it can be predicted that the need for high performance steel

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