FRACTURE TOUGHNESS AND FATIGUE CRACK PROPAGATION BEHAVIOUR OF SEVERAL CAST STEELS FOR STRUCTURAL COMPONENTS OF HYDRO-TURBINES

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INTRODUCTION

In the thermal and nuclear power generations, there have been such problems as high fuel cost, environmental protection, etc. However, the hydro-electric power generation is mostly free from these restrictions and is recently re-evaluated all over the world. Many hydro-electric power plants with pumping turbines that actively utilize excess electric power have been constructed for the last few years. Recent hydro-power plants tend to increase in capacity, size, head and speed. As their important structural components such as runners increase in size, strength evaluation of the components by the method of fracture mechanics is more desirable. The metallic materials for the components must have high corrosion fatigue strength in river water.

In this work, experimental results of fracture toughness and fatigue crack propagation behaviour under an environmental condition similar to river water are described on several cast steels for hydro-turbine components.

MATERIALS TESTED

Materials tested are 13 % Cr cast steels of three different types which are mostly used for hydro-turbine runners, runner vanes, etc. A low carbon cast steel for welded structure is also tested in comparison with 13 % Cr cast steels. All of these cast steels are manufactured at Takasago Works, Kobe Steel, Ltd. Table 1 shows chemical compositions, conditions of heat treatment and mechanical properties at room temperature of these steels.

METHOD OF TESTS

The fracture toughness (K_{Ic}) test was conducted with 50 mm thick compact tension specimens in accordance with ASTM standard E 399-74. After this test, Charpy impact specimens with 2 mm V notch were sampled from the compact tension specimens. The instrumented Charpy impact test was carried out, and dynamic fracture toughness values (K_{Id}) were obtained by using fatigue cracked and side-grooved specimens [1-2].

Fatigue crack propagation tests were conducted with 5 mm thick compact specimens in air and in an environmental condition similar to river water using an Instron tensile testing machine (type 1115) under a triangular stress wave with a repeating frequency of about 0.3 Hz.

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In order to simulate the environment of river water, a corrosive solution was prepared by adding 100 ppm chlorine ion (0.0164 wt % as NaCl) into the pure water of more than 10^6 ohm-cm resistivity and saturated with air, but its temperature was not specially controlled. Although mean concentration of chlorine ion in the actual river water in Japan is about 10 ppm [3], this solution seems to be sufficient as a model river water. The crack of the specimen was soaked in the solution with the aid of a small liquid chamber tightly fixed around the specimen [4]. Fractographic examination of broken specimens was performed using a JEOL JSM - U3 scanning electron microscope.

RESULTS AND DISCUSSION

Fracture toughness values

Results of the static and dynamic fracture toughness tests are summarized in Figure 1 for three different 13 % Cr cast steels and a plain carbon cast steel. In 13 % Cr steels, since the static fracture toughness values (K_{Ic}) are compared with the dynamic ones (K_{Id}), the smaller the difference between them is, the stronger the 0.2 % offset yield stress. For the plain carbon cast steel, difference between static and dynamic fracture toughness is particularly large. According to results of other experiments on tensile strength, temperature dependence of yield stress is large for the carbon cast steel. Temperature dependence of K_{Ic} and K_{Id} generally shows linear relationship in Arrhenius plots.

Rate parameter T ln (A/$\dot{\varepsilon}$) is considered as a modified temperature with respect to strain rate, where T, A, $\dot{\varepsilon}$ are absolute temperature, frequency factor (10^8/sec for bcc metals) and strain rate, respectively [5-6]. In Figure 2, K_{Ic} and K_{Id} values of the cast steels are shown as functions of reciprocal rate parameter. For 13 % Cr cast steels, it seems to be difficult to represent K_{Ic} and K_{Id} values with a single curve. But for the carbon cast steel which is expected to have a large strain rate dependence of strength, K_{Ic} and K_{Id} can be almost expressed as a single curve. This fact shows that the static K_{Ic} can be estimated from the dynamic K_{Id} data obtained using such small size specimens as fatigue cracked and side-grooved Charpy specimens.

Crack propagation behaviour

Experimental results of fatigue crack propagation behaviour in air for cast steels are shown in Figure 3. Stress ratio R is adopted as 0.08. No difference between 13 % Cr - 1 % Ni and 13 % Cr - 1 % Ni - 0.25 % Mo cast steels is found in the crack propagation rates. The crack propagation rate of 13 % Cr - 3.8 % Ni cast steel is comparatively smaller than that of 13 % Cr - 1 % Ni steel. Increase of Ni contents in 13 % Cr cast steels seems to be effective to suppress crack propagation rate [7]. The crack propagation rate in the carbon cast steel is larger than that of 13 % Cr steels. This tendency is more apparent in the high range of stress intensity factor.

The observed crack propagation rates in the water environment which contains 100 ppm chlorine ion are summarized in Figure 4. The rate of every cast steel in the water is larger than in air. No difference between 13 % Cr - 1 % Ni and 13 % Cr - 1 % Ni - 0.25 % Mo cast steels was found in the rates in the water as in air. The propagation rate in 13 % Cr - 3.8 % Ni cast steel is smaller than that in 13 % Cr - 1 % Ni particularly in the low range of stress intensity factor. Increase of Ni contents also seems to decrease crack propagation rate in the water.

Photo. 1(a) and (b) shows typical microfractographs of 13 % Cr - 1 % Ni steel by the scanning electron microscope. Clear striations are observed for specimens tested in air (Photo. 1(a)). In the water environment, however, intergranular cracks are mainly observed instead of striations (Photo. 1(b)).

CONCLUSIONS

Experimental results of fracture toughness and fatigue crack propagation behaviour are described on 13 % Cr and plain carbon cast steels. These are summarized as follows:

1) The smaller the difference between static and dynamic fracture toughness for 13 % Cr cast steels is, the stronger the strength. On the other hand, the difference is particularly large for the plain carbon cast steel.
2) For the plain carbon cast steel, static and dynamic fracture toughness are described by a single curve with respect to the rate parameter, T ln (A/$\dot{\varepsilon}$).
3) Increase of Ni contents in 13 % Cr cast steels seems to decrease fatigue crack propagation rate both in air and in water environment.
4) By microfractographic examination of broken specimens, clear striations are observed for specimens tested in air, but intergranular cracks are mainly observed in water environment.

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Table 1 Material Data for Cast Steels Investigated

Chemical composition

Material	wt (%) C	Si	Mn	P	S	Ni	Cr	Mo
13Cr-1Ni	0.10	0.47	0.68	0.013	0.022	0.71	13.6	0.05
13Cr-1Ni-0.25Mo	0.10	0.51	0.57	0.025	0.012	0.98	12.4	0.25
13Cr-3.8Ni	0.05	0.40	0.56	0.010	0.037	3.80	12.9	0.09
SCW 49	0.20	0.44	0.84	0.012	0.014	0.37	0.15	0.05

Heat treatment

Material	Normalizing	Tempering
13Cr-1Ni	1030°C ACB	740°C AC
13Cr-1Ni-0.25Mo	1030°C FAC	740°C AC
13Cr-3.8Ni	1050°C FAC	690°C AC - 570°C AC
SCW 49	920°C FAC	-

Mechanical properties

Material	$\sigma_{0.2}$ (MPa)	σ_B (MPa)	δ (%)	ψ (%)
13Cr-1Ni	500	658	27.5	52.2
13Cr-1Ni-0.25Mo	419	623	32.6	68.2
13Cr-3.8Ni	727	827	25.0	57.3
SCW 49	332	506	36.6	63.9

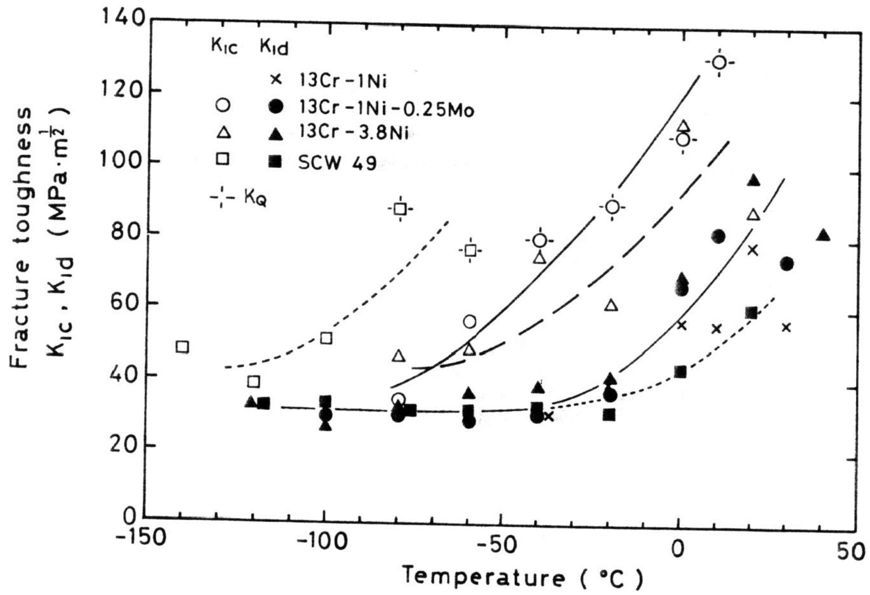


Figure 1 Temperature Dependence of Static and Dynamic Fracture Toughness for Several Cast Steels

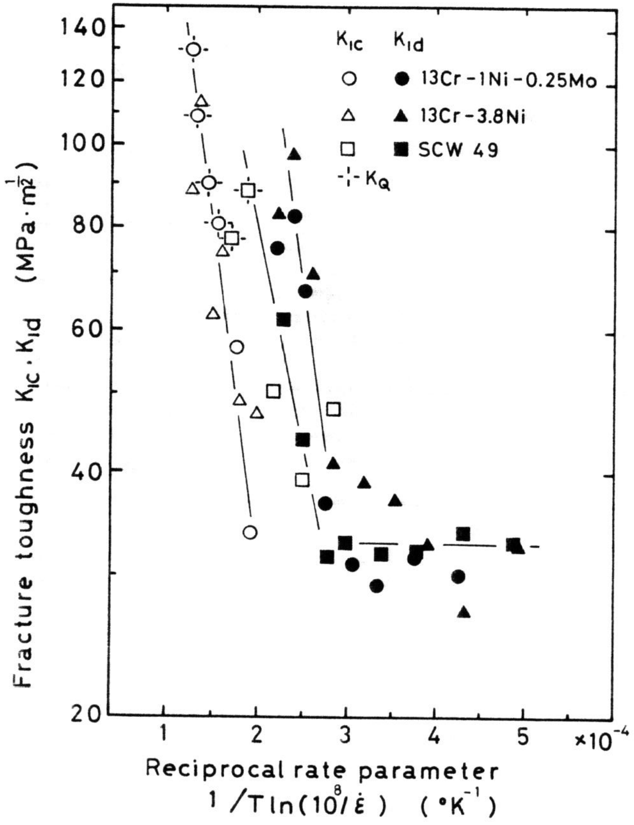


Figure 2 Fracture Toughness versus Reciprocal Rate Parameter Relation

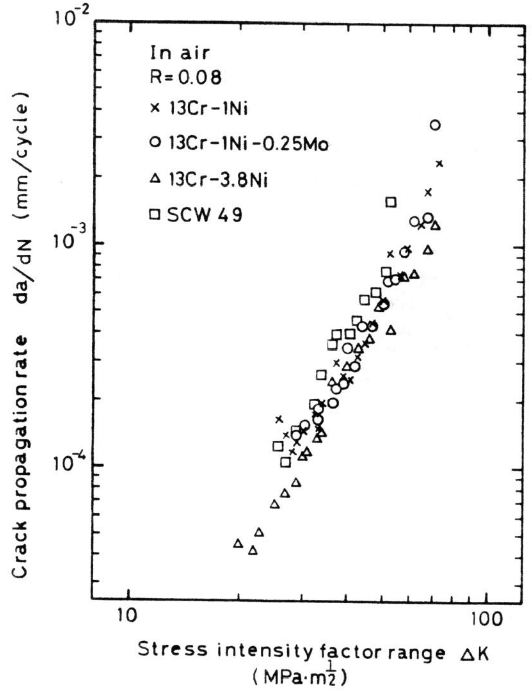


Figure 3 Fatigue Crack Propagation for Several Cast Steels in Air

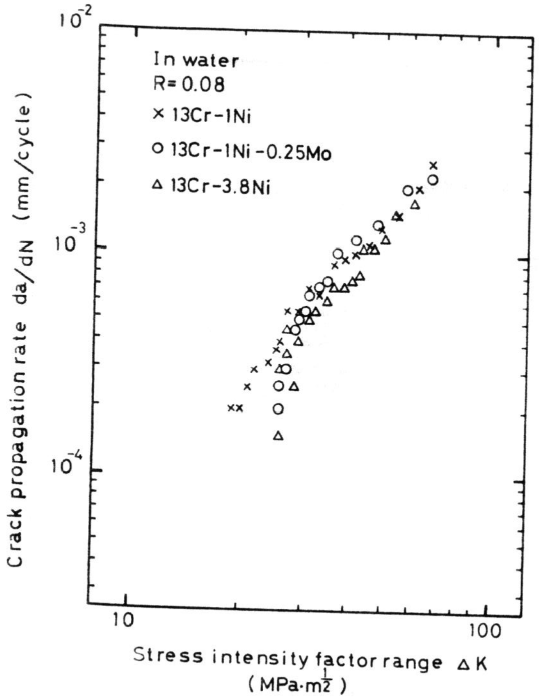
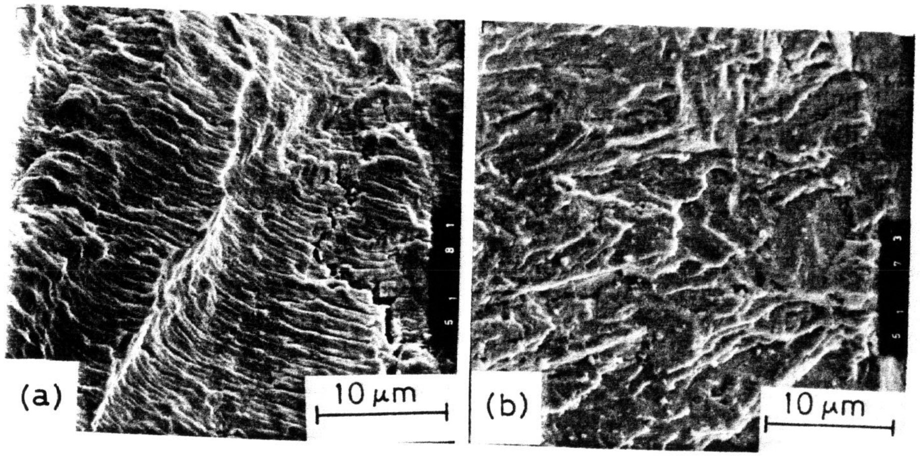


Figure 4 Fatigue Crack Propagation for 13% Cr Cast Steels in Water Environment



Photograph 1 Scanning Electron Micrographs of 13% Cr - 1% Ni Cast Steel Fracture Surfaces

a) In Air; b) In Water