THERMAL FATIGUE CRACK INITIATION AND PROPAGATION BEHAVIOR OF STEELS FOR BOILER

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ABSTRACT

Thermal fatigue tests were conducted for steels such as mild steel, SB410 and austenitic stainless steel, SUS310S for boiler. The higher the heating temperature the smaller the number of heat cycles for thermal fatigue crack initiation is. The higher the heating temperature the faster the crack propagation rate is. These phenomena were observed for both SB410 steel and SUS310S steel. The thermal fatigue crack propagation rate of SB410 steel was faster than that of SUS310S steel. Plural thermal fatigue cracks were observed on the bottom of the electric discharged notch for SB410 steel. The crack branching was observed on the specimen tested at 873K. Striation was observed on fracture surfaces of SB410 steel. Striation was predominant on fracture surfaces of SUS310S steel. The striation spacing per cycle ,S obtained from the measured striation spacing ⊿S versus ⊿K curve was well coincident with the da/dN ～⊿K curve in relatively higher ⊿K region at all heated temperature. It can be concluded that thermal fatigue crack of boiler steels such as SB410 steel and SUS310S steel propagate in association with striation.

Introduction

Engineering components in various machines and structures experience thermal fatigue. Generally speaking we have fewer data for thermal fatigue as compared with that for high temperature fatigue. One of the authors conducted thermal fatigue tests on SKD61 steel for hot forging die and Inconel625 and 21/4Cr-1Mo steel for heat recovery plant by use of a laboratory made thermal fatigue testing apparatus and clarified thermal fatigue behavior of these structural materials[1][2].
Thermal fatigue cracks might be anticipated due to frequent start and stop operation for small scaled one through boiler. In fact thermal fatigue cracks were observed on the upper part of water tube.
In the present work an investigation of the thermal fatigue crack initiation and propagation behavior of steels such as SB410 for boiler water tube and SUS310S for boiler burner was undertaken. In this paper thermal fatigue crack initiation and propagation behavior of the both steels is reported.

Experimental

Chemical compositions and mechanical properties of tested materials are shown in Table1 and Table2, respectively. A laboratory made thermal fatigue testing apparatus with basically same device formally presented [1][2] was used. This apparatus consisted principally of a heating device using oxygen and LPG gas, a temperature control device for the heated zone and a rapid cooling device for the specimen. During thermal fatigue tests the heating and cooling cycles were repeatedly loaded on the specimen just placed on the specimen holder. City water was used as a cooling medium. The heating temperatures were 673K, 773K and 873K.Cololing was sprayed on the specimen surface placed on the specimen holder through a nozzle. As it was difficult to measure the surface temperature of the specimen, small holes for a thermocouple were prepared for one side of the specimen to measure the temperature of the notch during the thermal fatigue tests. Thus the measured temperatures were used as the testing temperatures. The plate specimens with an electric discharged notch at the bottom of the mechanical U notch was used. The thicknesses of the specimen was 12mm for SB410 steel and SUS310S steel.

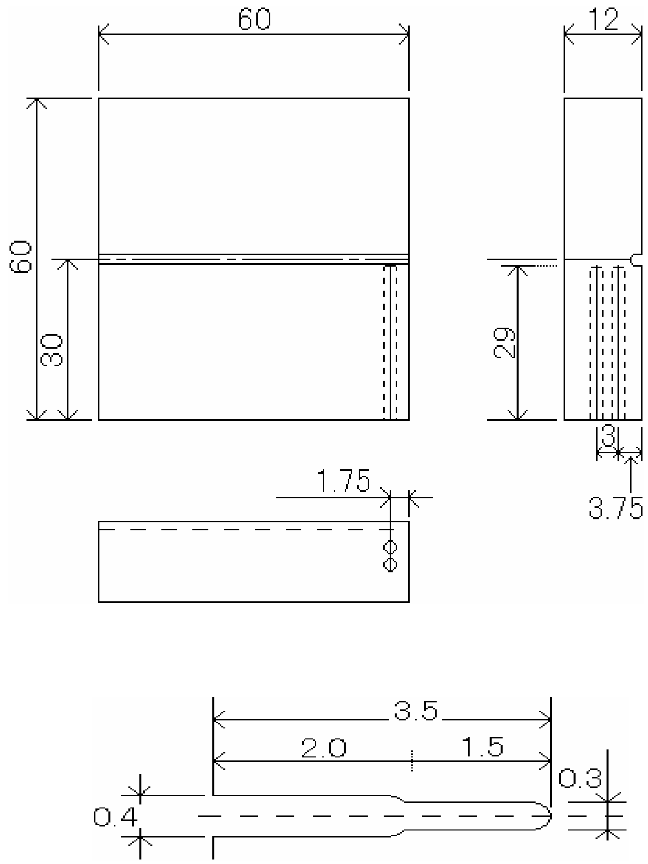
The specimen with 24 mm thickness was also prepared for SB410 steel in order to evaluate the thickness effect for thermal fatigue crack initiation and propagation behaviour. The thermal fatigue tests were conducted up to 300 cycles for specimens with 12mm thick and 100 cycles for specimens with 24 mm thick.

Table1. Chemical compositions of tested steels

	Chemical compositions (mass%)						
Material	C	Si	Mn	P	S	Cr	Ni
SB410	0.2	0.21	0.66	0.012	0.004		
SUS310S	0.04	1.01	1.77	0.029	0.001	24.49	19.85

Table 2 . Mechanical properties of tested steels

	Mechanical properties		
Material	$\sigma_{0.2}$(MPa)	σ_B(MPa)	El (%)
SB410	300	460	30
SUS310S	288	542	61



Detail of notch

Figure 1. Thermal fatigue test specimen

Figure 1 shows the shapes and dimensions of the thermal fatigue test specimen with thickness 12mm. The electric discharged notch with 1.5 mm length was introduced at the ahead of U notch with 2.0mm length .The thermal fatigue crack length was measured at every ten cycles by use of a viewing microscope with magnification of 20 after interrupting thermal fatigue tests at both A and B side of the specimen. The A is the side with thermocouple hole and the B is the opposite side. The thermal fatigue cracks were examined by an optical microscope and thermal fatigue fracture surfaces were examined by a JEOL scanning electron microscope (JSM5500S).Before observation by scanning electron microscope fracture surfaces were pickled with 5% H_2SO_4 aqueous solution including inhibitor to remove surface oxide film.

Results and Discussion

Figure 2 shows crack propagation curves for SB410 steel with12mm thickness. The number of cycles for crack initiation at the

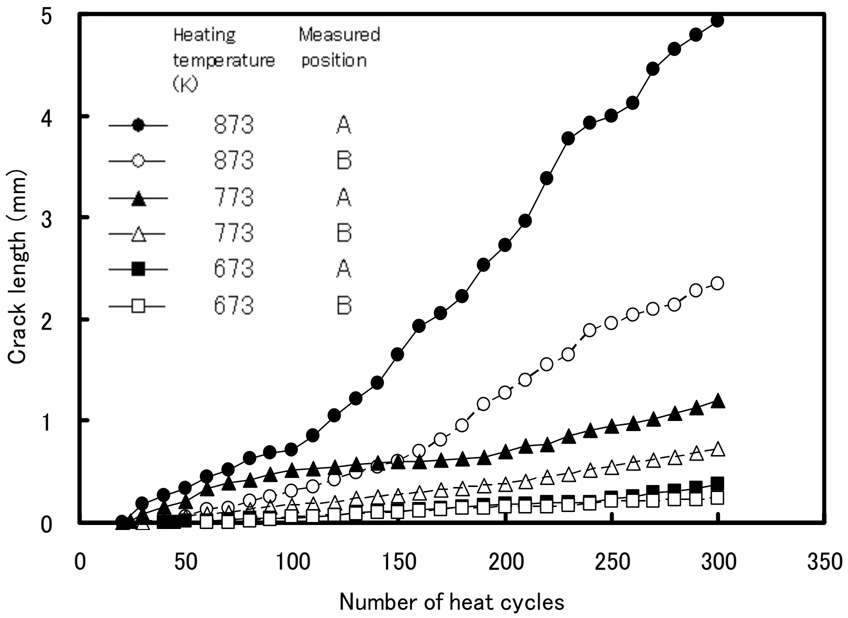


Figure 2. Thermal fatigue crack propagation curves , SB410 steel,12mm

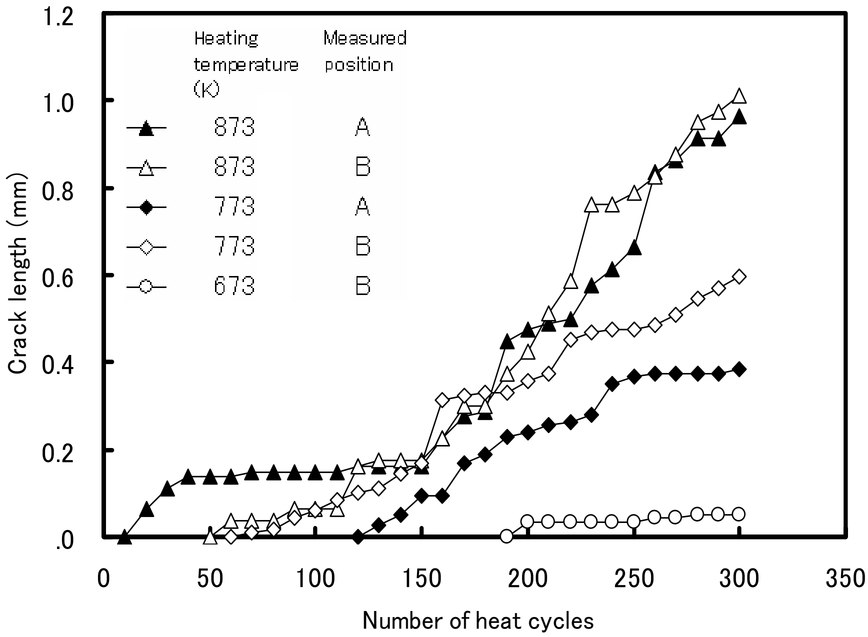


Figure 3. Thermal fatigue crack propagation curves, SUS310S steel, 12mm

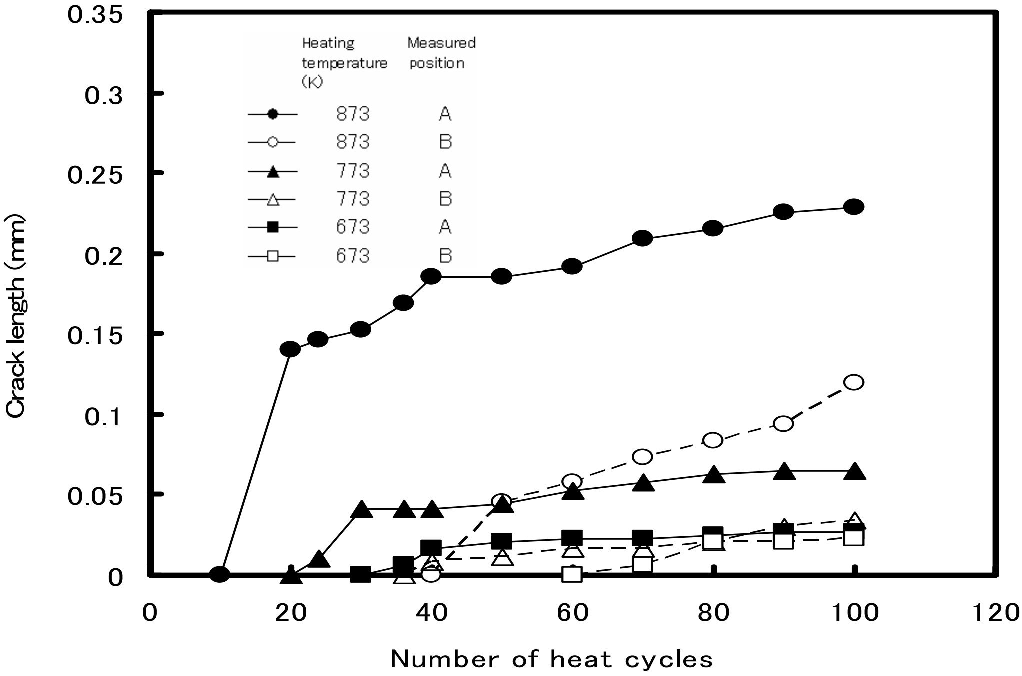


Figure 4. Thermal fatigue crack propagation curves ,SB410 steel ,24 mm

A side is 30 at 873K , 24 at 773K and 45 at 673K. The bigger the difference of temperature between heating and cooling, the higher the thermal stress loaded for specimen is. In the result the higher the heating temperature the smaller the number of cycles for fatigue crack initiation is. The crack length at the A side after 300 cycles is 4.93mm at 873K, 1.20 mm at 773K and 0.38 mm for 673K. The higher the heating temperature the faster the thermal fatigue crack propagation rate is. Figure3 is the crack propagation curves of SUS310S with 12 mm thick. The number of crack initiation at the A side is 20 at 873K and 130 at 773K. Crack was not initiated at 663K. The higher the heating temperature the lower the number of cycles for crack initiation is. The crack length at A side after 300 cycles is 0.96 mm at 873K and 0.38 mm at 773K. The higher the heating temperature the faster the crack propagation rate is. These phenomena are as same as those observed on SB 410 steel specimen with 12 mm thick. As compared with those of SB410 steel the number of crack initiation is larger and the crack propagation rate is slower for SUS310S steel. This difference is due to the difference of thermal conductivity between SB410 steel and SUS310S steel.

Figure 4 shows the crack propagation curves for SB410 steel with 24mm thick. The number of cycles for crack initiation at the A side is 20 at 873K, 23 at 773K and 36 at 663K. After 100 cycles at 553K crack was not initiated at both A and B side. Only a very fine crack was observed by optical microscopic observation. The crack length at the A side after 100 cycles is 0.23 mm at 873K, 0.06mm at 773K and 0.02mm at 663K. These phenomena is as same as those observed on the specimen with 12 mm thick, while crack propagation rate is decelerated in the specimen with 24 mm thick as compared with that of the specimen with 12mm thick. Thus the thickness effect for thermal fatigue crack initiation and thermal fatigue crack propagation rate is clearly observed. This is because that the both heating rate and cooling rate for specimen for 12 mm thick is larger than those of specimen with 24mm thick. Figure 5 shows da/dN～⊿K for SB410 steel and SUS310S steel with 12mm thick. It is obvious that crack propagation rate of SB410 is higher than that of SUS310S. It is also observed that the higher the heating temperature the faster the crack propagation rate is. The ⊿K is calculated for bending with single edged specimen.

Thermal fatigue test was conducted up to 100 cycles for U notched specimen without electric discharged notch at 873K. After 100cycles crack was not initiated. The influence of stress concentration on thermal fatigue crack initiation can be observed from this fact. In this test specimens were just placed on the specimen holder without clamping. The difference of crack propagation is prominently observed at A side and B side for SB410 steel specimen with 12 and 24 mm thick at 873K.

Figure 6 shows the typical thermal fatigue crack observed at the notch for SB410 steel with 12 mm thick. The plural thermal fatigue cracks with transcrystalline path and crack branching can be observed. These cracks were observed for SUS310S steel with12mm thick and SB410 steel with 24 mm thick. These cracks are very similar with cracks observed on actual failed boiler tube. Therefore it can be mentioned that the thermal fatigue test by use of the laboratory made thermal fatigue testing apparatus is available to evaluate thermal fatigue behavior of tube and burner of actual boiler. Striation was predominantly observed on fracture surfaces for SB410 and SUS310S steel. Striation was partially observed on fracture surfaces of SB410

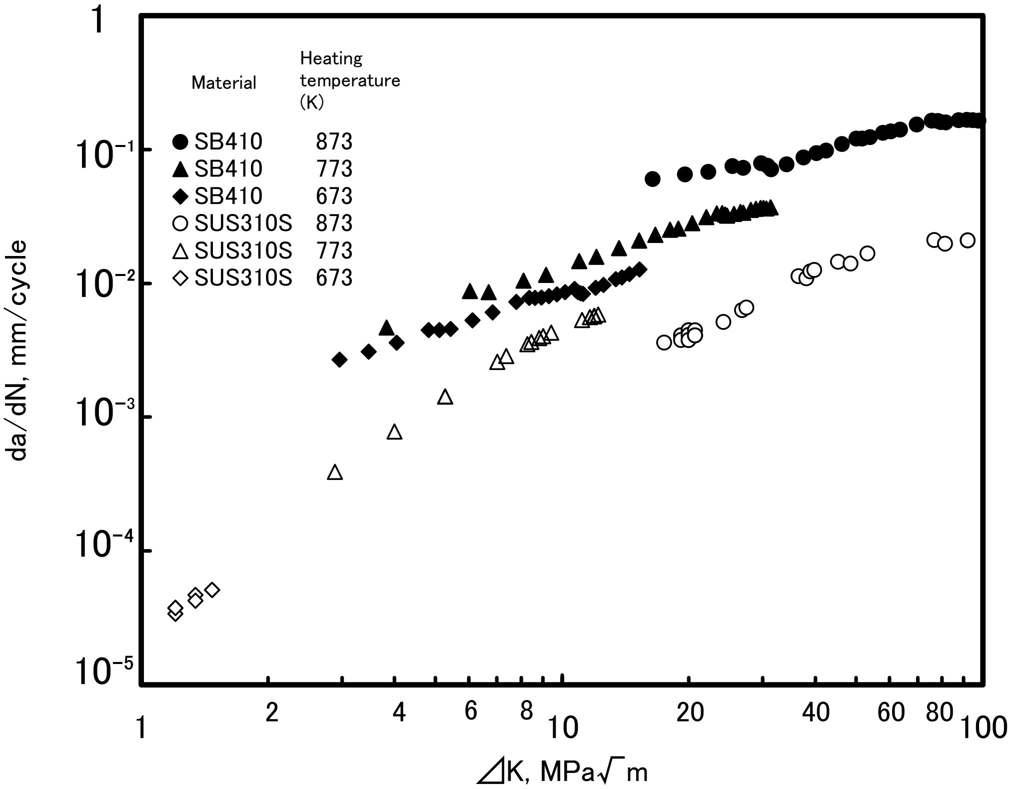


Figure 5 Thermal fatigue crack propagation rate as a function of ⊿K for SB410 and SUU310S steel

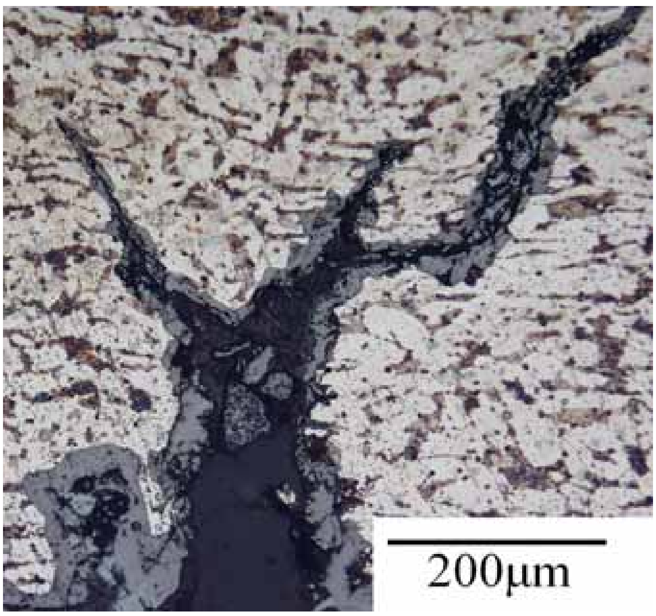


Figure 6 Thermal fatigue cracks after 200 heat cycles
SB410 steel, 873K, A side

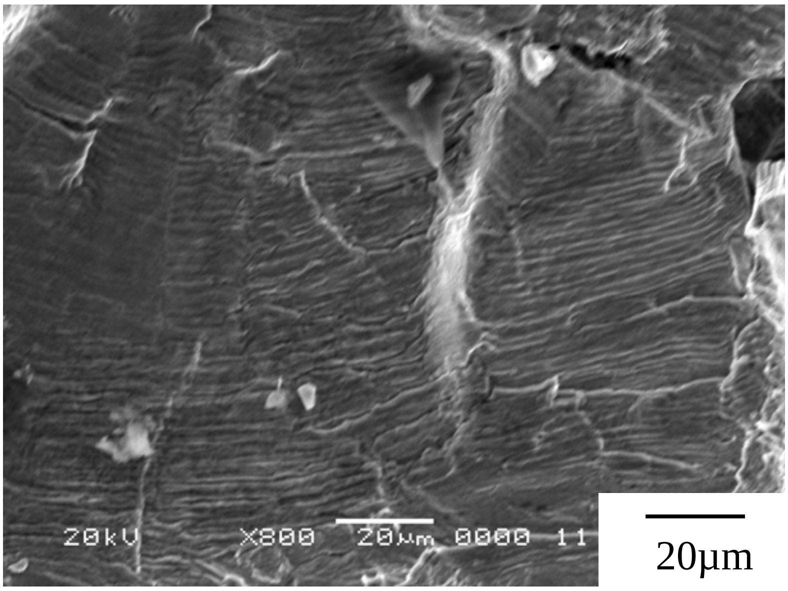


Figure 7 Striation observed on thermal fatigue fracture surface
SUS310S, 0.1mm from notch tip

steel because of the heavily oxidized fracture surface, while striation was clearly observed on fracture surface of SUS310S.In the former investigation striation and striation like pattern were also observed on fracture surface of hot forging die steel, Inconel625 and 214Cr-1Mo steel[1][2]. It can be mentioned that more defined striation was observed on fracture surfaces of materials such as Inconel625 and SUS310S steel with austenitic micro structure. The striation spacing per cycle S obtained from measured striation spacing ⊿S versus ⊿K curve was very well coincident with the da/dN～⊿ K curve in a relatively high crack propagation rate. Therefore it can be concluded that thermal fatigue crack of boiler steels such as SB410 steel and SUS310S steel propagate in association with striation.

Conclusions

(1) The higher the heating temperature the small the number of cycles for crack initiation is. Thermal fatigue crack initiation resistance of SUS310S is superior to that of SB410 steel.

(2) The higher the heating temperature the faster the crack propagation rate is. Thermal fatigue crack propagation rate of SB410 steel is faster than that of SUS310S steel at 673K, 773K and 883K.

(3) The crack propagated predominantly with a mode of transgranular for SB410 steel and SUS310S steel. Plural cracks and crack branching were also observed.

(4) Striation was predominant on fracture surface of SB410 steel and SUS310S steel. It can be concluded that thermal fatigue crack of boiler steels such as SB410 steel and SUS310S steel propagate in association of striation.

(5) The striation spacing per cycle S, obtained from measured striation spacing ,⊿S versus ⊿K curve was well coincident with the da/dN～⊿K curve in the relatively higher crack propagation rate at 673K,773K and 873K.

References

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