



FATIGUE BEHAVIOR OF AISI 304 STAINLESS STEEL UNDER FRETTING

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ABSTRACT

Plain fatigue and fretting fatigue behavior of AISI 304 austenitic stainless steel has been investigated by carrying out fatigue tests and fretting fatigue tests using 304 austenitic stainless steel specimens with two different heat treatment conditions (solution treated and solution treated + sensitized condition). The results showed that the plain fatigue behavior (without fretting) was highly influenced by heat treatment conditions. However the fretting fatigue behavior was not significantly influenced by heat treatment conditions. The results were explained based on the crack initiation mechanisms and frictional stress measurement during fretting fatigue.

Keywords: fatigue, fretting fatigue, austenitic stainless steel and heat treatment.

INTRODUCTION

Austenitic stainless steels are widely used as a structural materials in nuclear, aerospace and energy applications, because of their exceptional properties of strength, corrosion resistance, and formability [1]. Fatigue failures are more common in structural applications [2]. In many engineering structures, the fatigue strength of the component has been reduced by a process called fretting fatigue. Fretting fatigue occurs when two components are in contact under load and subjected to cyclic loading [3, 4]. Fatigue and fretting fatigue behavior of stainless steel has been investigated by many researchers [5, 6].

Austenitic stainless steels under goes a phenomenon called sensitization, when subjected to temperature about 650 °C followed by slow cooling [7]. Sensitization process highly affects the mechanical properties, especially the fatigue properties. However there are very limited studies available on the effect of sensitization on fatigue properties of austenitic stainless steel. For the long term survivability of stainless steel structural components, it is important to understand the fatigue and fretting fatigue behavior of these under sensitized condition.

In the present study the plain fatigue and fretting fatigue behavior of AISI 304 stainless steel with two different heat treatment conditions; solution treated (ST) condition and solution treated + sensitized (STS) condition, has been investigated. The results showed that the plain fatigue (without fretting) lives were significantly

affected by the heat treatment condition. The sensitized steel showed lower plain fatigue strength compared to non-sensitized steel. However the heat treatment condition has no significant effect on fretting fatigue lives of AISI 304 stainless steel for the stress levels used in the present study. The results were discussed based on the crack nucleation mechanism in fatigue and fretting fatigue condition.

EXPERIMENT

Materials and heat treatment

The material used for the specimens for plain fatigue and fretting fatigue tests are 304 austenitic stainless steels, with two different heat treatment conditions (ST and STS). The chemical composition of AISI 304 stainless material used is given in Table-1. For solution treatment (ST), the samples (Size: 12 mm diameter and 135 mm length) were heated in vacuum furnace to 1050 °C and soaked for 2 hours and then quenched in water to room temperature. For solution treatment + sensitization treatment (STS), the samples were first subjected to solution treatment (ST) as mentioned earlier and then the samples were heated to 650°C and soaked for 48 hours and cooled in furnace to room temperature. For fretting fatigue tests the contact pads used were made of 304 austenitic stainless steels in ST condition.

Table-1. Chemical composition of AISI 304 stainless steel (wt %).

C	Si	Mn	P	S	Cr	Ni	Fe
0.05	0.6	1.02	0.02	0.004	18.1	8.05	Bal

**Table-2.** Mechanical properties of AISI 304 stainless steel at different heat treatment conditions.

AISI 304 austenitic stainless steel	Hardness HV ₁	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)
Solution treated (ST)	230	310	735	67
Solution treated + sensitized (STS)	210	295	715	69

Shape and dimensions of specimen for plain fatigue tests, fretting fatigue tests are the same. The dimensions of the fatigue specimen and contact pad used are shown in Figure-1. The specimens used for fatigue test (plain fatigue and fretting fatigue) have a gauge length of 30 mm, width 7mm and thickness 2 mm. For fretting fatigue, the contact pad used has a contact length of 2mm, contact width of 6 mm and foot height of 1 mm. The contact surfaces of the fretting fatigue test specimens and contact pads were polished up to 1500 grade emery paper and then cleaned with acetone before test.

Plain fatigue and fretting fatigue tests

Plain fatigue and fretting fatigue tests were conducted on a servo-hydraulic testing machine at a stress ratio of 0.1 with a frequency of 10 Hz in room temperature

(25 °C). The fretting fatigue test was performed according to JSME S015 [8], with a contact pressure of 100 MPa. A calibrated proving ring was used to apply constant contact pressures (100 MPa). The tangential stress (frictional stress) during fretting fatigue test were measures using a stain gauge bonded at the gauge portion of contact pad.

RESULTS AND DISCUSSIONS

Effect of heat treatment on tensile properties

The mechanical properties of solution treated and sensitized AISI 304 austenitic stainless steel are given in Table-2. As seen from the table ST specimens showed higher tensile strength and hardness values compared to STS specimen.

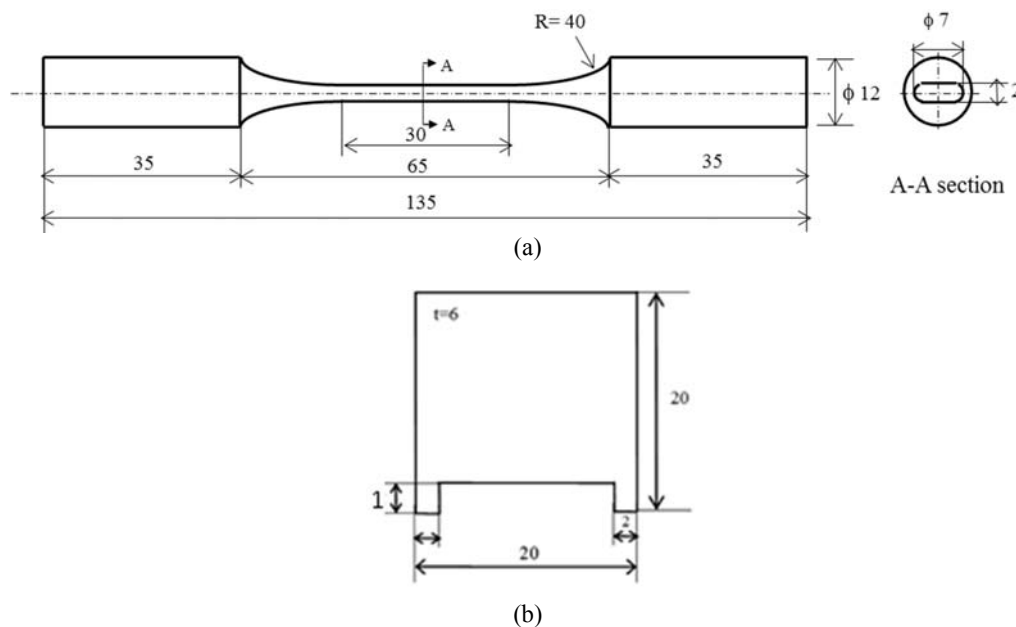


Figure-1. (a) Fatigue test specimen (plain fatigue, fretting fatigue), (b) Contact pad (all dimensions are in mm).

Effect of heat treatment on plain fatigue lives

Plain fatigue test results of ST and STS 304 stainless steel specimens are shown in Figure-2. As seen from the figure heat treatment had a significant effect on plain fatigue behavior of AISI 304 stainless steel.

The plain fatigue strength was decreased after sensitized. This might be due to the decrease in hardness and tensile strength (given in Table-2) in sensitized

specimen compared to solution treated specimens. Also it has been reported that sensitization treatment in stainless steel result in formation of Cr carbide precipitate at the grain boundaries. The large Cr carbide precipitates at the grain boundaries act as a nucleation site for fatigue crack and degrade the fatigue properties [9].



Effect of heat treatment on fretting fatigue lives

Fretting fatigue test results of ST and STS stainless steel specimen is shown in Figure-3. As observed from the figure unlike plain fatigue tests, fretting fatigue test results showed heat treatment had no or only a little significant effect of on fretting fatigue lives of AISI 304 austenitic stainless steel.

In fretting fatigue, the fatigue crack always nucleate at the contact interface. The tangential stress at the contact interface is responsible for crack nucleation. The tangential stress is usually expressed as tangential force coefficient (tangential stress coefficient = tangential stress / contact stress). The tangential stress coefficient values measured during fretting fatigue test for ST and STS samples were shown in Figure-3.

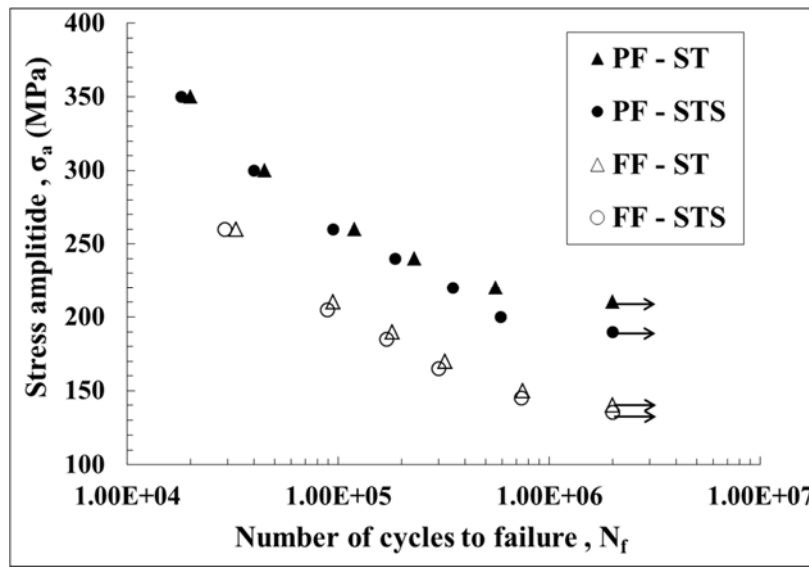


Figure-2. Plain fatigue and fretting fatigue test result (arrow indicates run out) (PF - Plain fatigue, FF- Fretting fatigue, ST- Solution treated, STS - solution treated + sensitized).

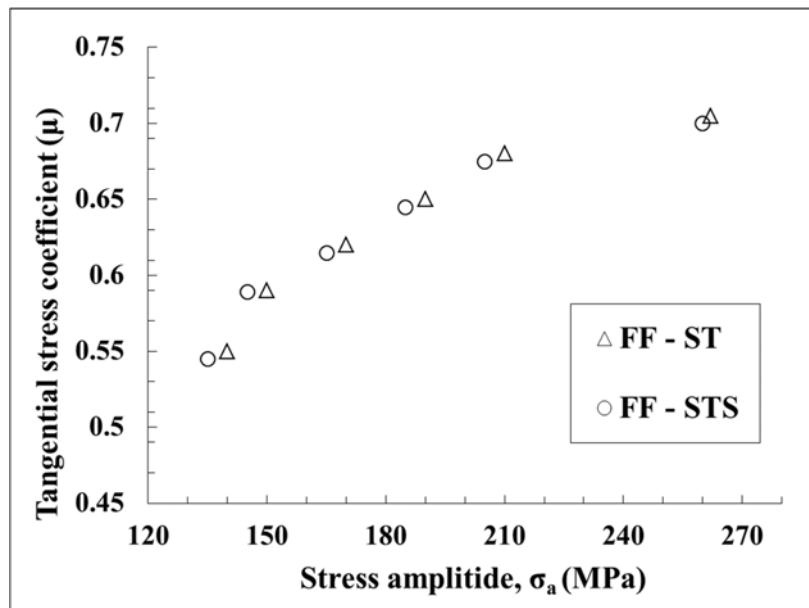


Figure-3. Relationship between tangential stress coefficient and stress amplitude for ST and STS specimen.

As seen from the Figure-3, the tangential stress coefficient at contact interface was almost same for both

ST and STS stainless steel specimens. The fatigue crack initiation life must be same for both ST and STS stainless



steel specimens. This might be the reason that the heat treatment conditions have no significant effect on fretting fatigue lives of AISI 304 stainless specimens.

Effect of fretting on fatigue lives of 304 stainless steel

The effect of fretting on fatigue lives of 304 stainless steel specimen is shown in Figure-3. As observed from the Figure for the loading condition and contact pressure used in the present study, the fatigue strength is reduced 50-60 % due to fretting. The reduction in fatigue lives might be due to the accelerated crack nucleation at the contact influenced by high tangential stress at contact interface [4].

CONCLUSIONS

In the present study, the plain fatigue fretting fatigue behavior of AISI 304 stainless steel at two different heat treatment conditions (ST and STS) has been investigated by carrying out plain fatigue and fretting fatigue test. The important results obtained were summarized as follows.

- 1) The hardness and ultimate tensile stress values are higher for ST samples compared to STS samples.
- 2) Plain fatigue lives of AISI 304 austenitic stainless steel was lower in STS condition compared to ST condition. This might be due to decrease in hardness, tensile strength and early crack nucleation at the Cr carbide precipitates in ST specimen.
- 3) The fretting fatigue lives were not significantly affected due to heat treatment conditions. The fretting fatigue lives of solution treated and sensitized stainless steel specimen almost shows the same.
- 4) The tangential force coefficient values during the fretting fatigue of AISI 304 stainless steel at different heat treatment conditions shows almost same.
- 5) In fretting fatigue the crack nucleates at the contact which is highly influenced by tangential stress coefficient, since the tangential stress coefficient shows almost same in both the heat treatment conditions, the fretting fatigue lives also not much changed due to heat treatment condition in the present study.

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