Global Journal of Researches in Engineering
Mechanical and Mechanics Engineering
Volume 14 Issue 1 Version 1.0 Year 2014
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Effect of Heat Treatment on Crack Initiation & Propagation of Stainless Steel (Ss-304)

By Soumya Mandal, Tonmoy Karmaker & Dr. Md. Nurul Islam
Rajshahi University of Engineering & Technology, Bangladesh

Abstract- Cyclic loading is common experimental practice for investigations of large structures like vehicles. Numerical analysis of cyclic loading conditions is also a well-established field of research and application. Theoretical and practical support is rare for evaluating growth of fatigue cracks under cyclic loading conditions. Cracks can occur naturally in engineered components due to combination of environmental effects and materials and geometric properties. In this study, the effects of heat treatment on crack initiation & propagation of stainless steel (SS-304) are investigated. The specimens are subjected to different cyclic load. The crack initiation & propagation and final fracture behavior are observed microscopically. The specimens are kept in the furnace at 500°C at a constant time 1 hour where cooling medium is used as air for heat treatment & the effects of heat treatment are investigated. The fatigue life of the tested specimen at 400MPa stress before & after heat treatment are 54900 cycles & 61000 cycles respectively. So, a better fatigue life is found after heat treatment.

Keywords: heat treatment, fatigue crack. fatigue crack growth, fatigue life.

GJRE-A Classification : FOR Code: 091399p

EFFECTOFHEATTREATMENTONCRACKINITIATIONPROPAGATIONOFSTAINLESSSTEELSS304

Effect of Heat Treatment on Crack Initiation & Propagation of Stainless Steel (Ss-304)

Soumya Mandal [α], Tonmoy Karmaker [σ] & Dr. Md. Nurul Islam [ρ]

Abstract- Cyclic loading is common experimental practice for investigations of large structures like vehicles. Numerical analysis of cyclic loading conditions is also a well-established field of research and application. Theoretical and practical support is rare for evaluating growth of fatigue cracks under cyclic loading conditions. Cracks can occur naturally in engineered components due to combination of environmental effects and materials and geometric properties. In this study, the effects of heat treatment on crack initiation & propagation of stainless steel (SS-304) are investigated. The specimens are subjected to different cyclic load. The crack initiation & propagation and final fracture behavior are observed microscopically. The specimens are kept in the furnace at 500°C at a constant time 1 hour where cooling medium is used as air for heat treatment & the effects of heat treatment are investigated. The fatigue life of the tested specimen at 400MPa stress before & after heat treatment are 54900 cycles & 61000 cycles respectively. So, a better fatigue life is found after heat treatment.

Keywords: heat treatment, fatigue crack. fatigue crack growth, fatigue life.

I. Introduction

Ultra-fine grained metals are becoming promising for engineering applications due to the recent progress in technology. Therefore, for envisaged structural applications of Ultra-fine grained metals, attention has been paid to fatigue performance, such as cyclic properties, S-N characteristics, the formation of shear bands (SBs) and persistent slip band (PSBs) [1].

In order to quantify the fatigue damage, it is important to understand what kind of change is brought about by cyclic loading, and to know the critical conditions for fatigue life. Using carbon steel (S45C) specimens, Murakami and Miller showed that crack initiation and growth could be regarded as the damage caused by fatigue loading and that fatigue life was almost equivalent to the number of cycles for the initiated cracks growing to the critical size[2]. Kamaya had done a research based on observation of Fatigue Crack Initiation and Growth in Stainless Steel [3]. The fatigue loading causes various microstructural changes such as an increased number of dislocations, formation of cell structures, and alternation of deformation properties. However, these changes have minor influence on the fatigue life under the same strain range. Therefore, the fatigue damage can be correlated to the crack size. It is possible to measure the fatigue damage by investigating the size of a crack initiated in components, or if no crack is found, it can be confirmed that damage has not been accumulated yet [3]. The fatigue life can be divided into two phases: the number of cycles to crack initiation (hereafter called initiation life) and the remaining life until the failure of the specimen (hereafter called growth life) [4].

In this study crack initiation and propagation behaviour are observed before and after heat treatment.

Cyclic loading is a common phenomenon for different structures. When cyclic loading is applied on metallic structures a common incidence occur called fatigue failure. Fatigue failure is a continuous process which starts with a small crack. The crack propagates up to failure of the structure. Sometimes it is seen then there are more than one cracks initiate and propagate, but their initiation time is not same for all, and the propagation is not homogenous for all of them. Some cracks propagate up to certain cyclic loading and then remain unchanged. They are not directly responsible for the failure of structure, although they weaken the structure and cause more cracks to initiate. Even the crack initiation and propagation nature of cracks are not same before and after the heat treatment. From this study it is found that, crack propagation time is greater after heat treatment i.e. fatigue life is better after heat treatment.

II. Test Material & Experimental Procedure

a) Material Properties

The material used for the fatigue test was Type 304 austenitic stainless steel, which was provided in a cylindrical bar shape. Its chemical composition (in mass %) was: C, 0.07; Si, 1.0; Mn, 2.0; P, 0.05; S, 0.02; Ni, 10.5; Cr, 19.5 and balance Fe. The ultimate tensile strength, yield tensile strength is 600MPa and 300MPa respectively. The material had an approximately equiaxial grain structure.

b) Procedure

The working procedure of this study is shown below-----

- The required metal (ss-304) was collected.
- The metal was assured by determining ultimate and yield strength by using universal testing machine.
- The suitable shape was given to the metal according to the requirement. Fig 2.1 shows the schematic diagram of the tested specimen.

Authors α σ ρ: Department of Mechanical Engineering, Rajshahi University of Engineering and Technology.
e-mail: rusho_moran@yahoo.com

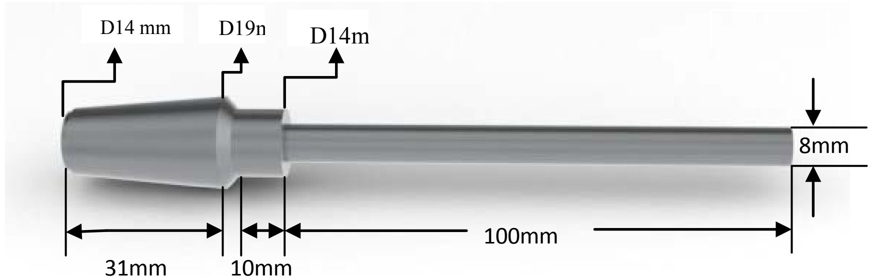

Figure 2.1 : Schematic diagram of Fatigue testing specimen

- By using various grades of emery paper such as P320C, 600AW, P1000C, P1200C, C1500CW, C2000CW specimen surface were polished smoothly.
- After polishing by the emery papers, Aluminum oxide (AL_2O_3) powder was used for fine polishing and ethanol was used to remove the black spots from the specimen.
- A load was chosen for which the stress was produced on the tested specimen lies between the ultimate (600MPa) and yield strength (300MPa).

σ = Stress

M = Moment

Moment of inertia, $I = \frac{\pi d^4}{64}$

$C = \frac{d}{2}$ = Perpendicular distance to neutral axis.

F = Load.

x = Distance between the load applied & stress developed point.

So stress, $\sigma = \frac{Mc}{I} = \frac{64Fx}{2\pi d^3}$

- By using this selected load the fatigue life (the number of cycle at which the structure fully fractured) of the tested specimen was determined with the help of fatigue testing machine.
- By selecting 10% of the fatigue life the specimen was examined with the help of fatigue testing machine.

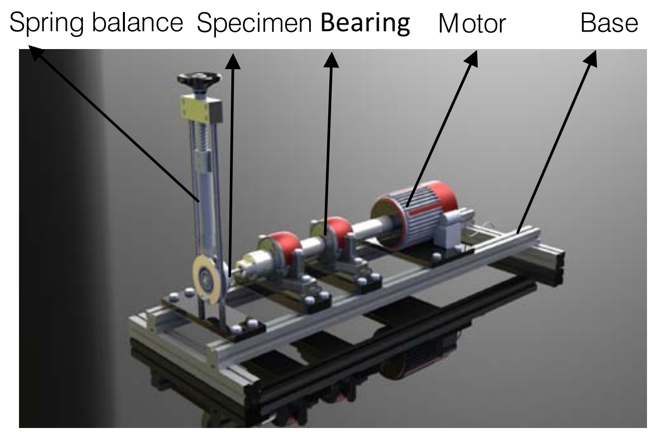

Figure 2.2 : Fatigue testing machine

The predicted space of the specimen was inspected microscopically to observe the crack initiation.

- The previous two steps were followed until the final crack of the tested specimen was occurred.
- Every times crack propagation of the tested specimen was observed microscopically.
- The above steps were performed after heat treatment of the tested specimen.

III. Results and Discussion

a) Observation of Crack Initiation & Propagation

Cyclic loading is one of the main reasons for crack initiation and propagation. Crack is microscopic in nature. For stainless steel (SS-304) the change of length of PSBs due to fatigue is observed by using Metallurgical Microscope. In optical microscopic image, it is shown that the PSBs length is increased with increasing cyclic load after starting the crack growth. Fig 3.1 represents the calibration scale through which the length of slip band is measured. Fig 3.2 represents the surface of the specimen before polishing. Fig 3.3 represents the surface of the specimen after polishing.

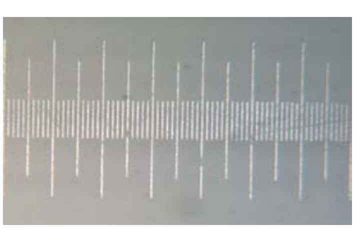

Figure 3.1 : Calibration scale

Figure 3.2 : Surface of the Specimen before polishing

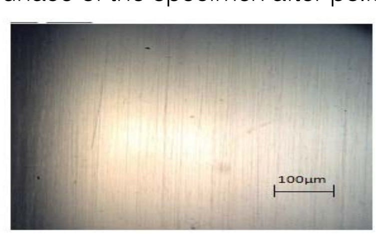

Figure 3.3 : Surface of the Specimen after polishing

b) Changing behavior of slip band length at 400MPa before heat treatment

Fig. 3.4 represents the optical microscopic images at a stress of 400MPa before heat treatment under different cycles. From the figure it is shown that, at N=0 cycle there is no crack in the tested specimen surface. At N=45750 cycles a crack is appeared on the surface of the tested specimen. At N=51850 cycles the crack propagates and after that at N=54900 cycles fatigue failure occurs.

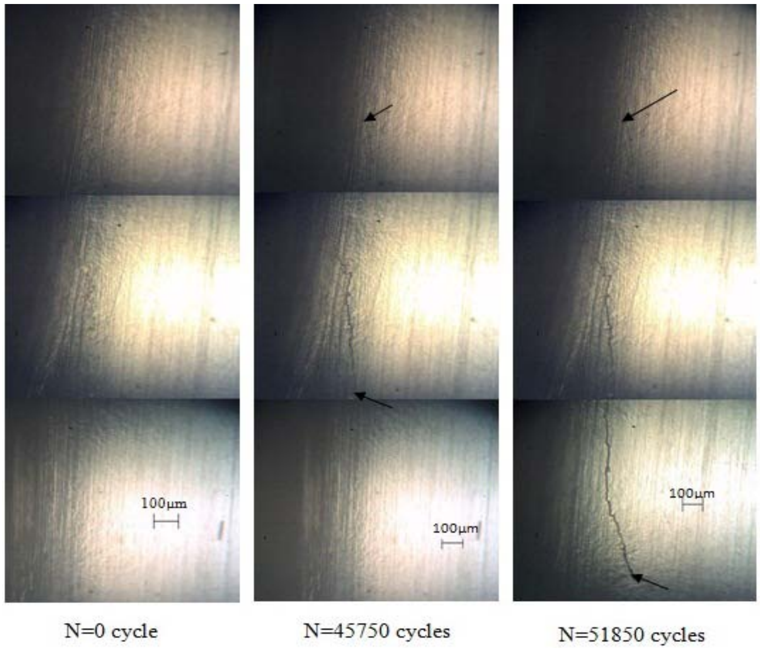

Figure 3.4 : Optical microscopic images at different cycle before heat treatment

Fig. 3.5 represents the number of cycle vs. length of slip band curve under 400MPa stress before heat treatment of the specimen. The length of slip band is determined with the help of calibration scale whereas the number of cycle is directly found from the fatigue testing machine. From the Fig. 3.5, it is shown that crack 1, crack 2, crack 3 propagates up to certain cycle but they do not cause the final fatigue failure. On the other hand, crack 4; crack 5 propagates up to the fatigue failure.

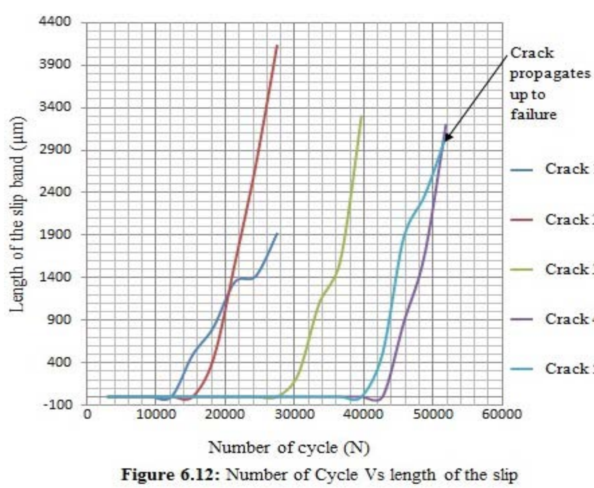

Figure 3.5 : Number of cycle vs. length of slip band curve

c) Changing behavior of slip band length at 400MPa after heat treatment

Fig. 3.6 represents the optical microscopic images at a stress of 400MPa after heat treatment under different cycles. From the figure it is shown that, at N=0 cycle there is no crack in the tested specimen surface. At N=42700 cycles a crack is appeared on the surface of the tested specimen. At N=57950 cycles the crack propagates and after that at N=61000 cycles fatigue failure occurs.

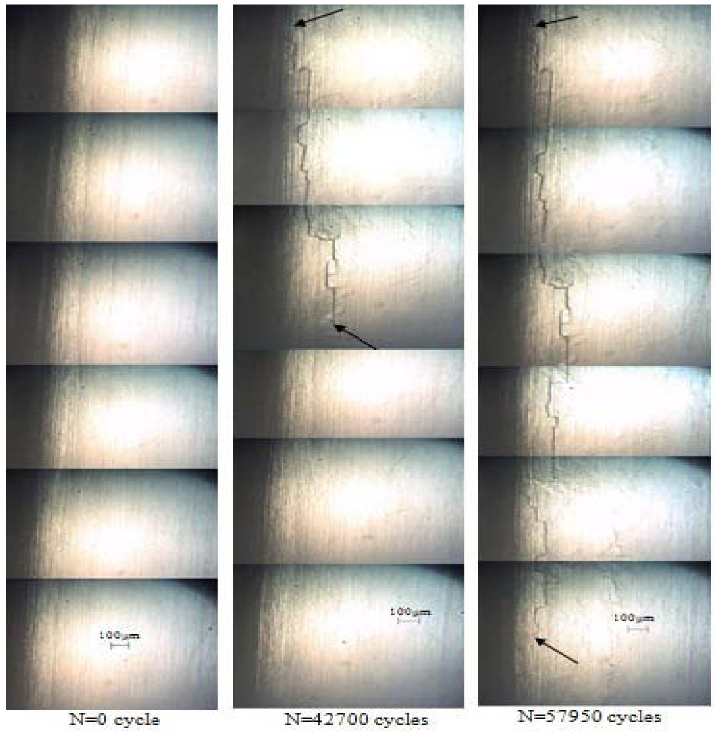

Figure 3.6 : Optical microscopic images at different cycle after heat treatment

Fig. 3.7 represents the number of cycle vs. length of slip band curve under 400MPa stress after heat treatment of the specimen. The length of slip band is determined with the help of calibration scale whereas the number of cycle is directly found from the fatigue testing machine. From the Fig. 3.7, it is found that crack 1, crack 2, crack 3, crack 4 propagates up to certain cycle but they do not cause the final fatigue failure. On the other hand, crack 5 propagates up to the fatigue failure.

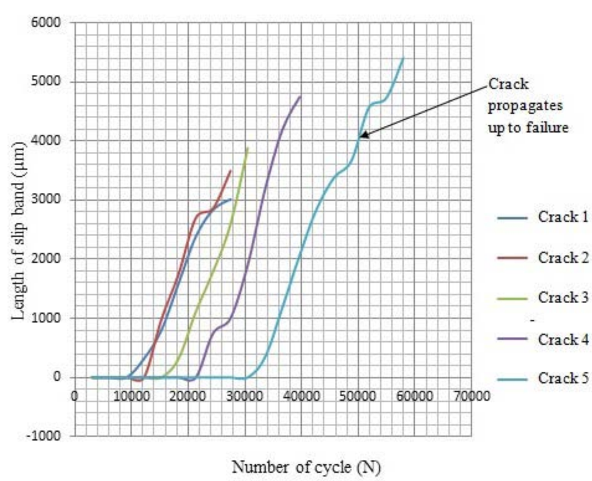

Figure 3.7 : Number of cycle vs. length of slip band curve

IV. Conclusion

Fatigue is one of the primary reasons for the failure of structural component. Fatigue cracks are microscopic in nature. The initiation & propagation of fatigue cracks are observed by optical method. Various stresses are applied on the tested specimen. It is found that, in every case more than one crack initiates & propagates. But the crack initiation & propagation nature are not same for all tested specimen. The fatigue life of the tested specimen at 400MPa stress before & after heat treatment are 54900 cycles & 61000 cycles respectively. The fatigue life reduces with the increasing stresses but for same stress fatigue life increases after heat treatment. So, better life of designed can be provided by considering the phenomenon of crack initiation and propagation. It also provides better longevity of materials.

Appendix A

Table A-1 : Data of length of slip band for 400MPa stress before Heat Treatment [Fig. 3.5]

Number of Cycle(N)	Length of Slip Band(μm)				
	Crack 1	Crack 2	Crack 3	Crack 4	Crack 5
3050	0	0	0	0	0
6100	0	0	0	0	0
9150	0	0	0	0	0
12200	0	0	0	0	0
15250	490	0	0	0	0
18300	820	450	0	0	0
21350	1350	1560	0	0	0
24400	1420	2730	0	0	0
27450	1920	4130	0	0	0
30500			260	0	0
33550			1100	0	0
36600			1600	0	0
39650			3300	0	0
42700				0	510
45750				870	1870
48800				1680	2370
51850				3200	3060

Table A-2 : Data of length of slip band for 400MPa stress after Heat Treatment [Fig. 3.7]

Number of Cycle(N)	Length of Slip Band(μm)				
	Crack 1	Crack 2	Crack 3	Crack 4	Crack 5
3050	0	0	0	0	0
6100	0	0	0	0	0
9150	0	0	0	0	0
12200	317	0	0	0	0
15250	795	976	0317	0	0
18300	1590	1748	1112	0	0
21350	2383	2700	1794	0	0
24400	2837	2860	2588	750	0
27450	3014	3495	3881	1100	0
30500				1950	0
33550				3178	341
36600				4188	1180
39650				4744	2065
42700					2860
45750					3383
48800					3666
51850					4562
54900					4721
57950					5403

References Références Referencias

1. Chopra, O. K., "Mechanisms and Estimation of Fatigue Crack Initiation in Austenitic Stainless Steel in LWR Environments", NUREG/CR–6787, ANL-01/25, Aug 2002.
2. Murakami, Y.; Miller, K. J., "What is fatigue damage? A view point from the observation of low cycle fatigue process", International Journal of Fatigue, Vol. 27, pp.991-1005(2005).
3. KAMAYA, M., "Observation of Fatigue Crack Initiation and Growth in Stainless Steel to Quantify

Low-Cycle Fatigue Damage for Plant Maintenance", E-Journal of Advanced Maintenance Vol.5, 185-200 (2013).
4. Kamaya, M.; Kawakubo, M., "Strain-based modeling of fatigue crack growth – An experimental approach for stainless steel", International Journal of Fatigue, Vol. 44, pp. 131-140 (2012).