Determination of the Fatigue Life of Welded Various Steels by Using Finite Element Method

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ABSTRACT. *In this study, 17Mn4 pressure vessel steel and AISI 304 stainless steels were joined with using ER 309L TIG welding wire. Variation of hardness values along the welded specimens was determined. Finite element (FE) analyses were conducted by fixing 2-D models for welded component. After entering the linear and nonlinear properties of the materials for different regions on the welded samples, static analyses were conducted for the different stress values. Finally, fatigue analyses were performed in order to determine fatigue life of each region as the welded component.*

INTRODUCTION

Fatigue cracks can occur because of not only pores and inclusions but also shearing bands. Around the notches, the load on material can cause local plastic strain, and it causes the component to be broken in a stress value under yield stress of the material [1]. Fatigue limit of mechanical components can be described as the term of the initiation and propagation of cracks at notches [2-6]. The S-N curve is used to evaluate the fatigue strength of a material, and fatigue limit is defined as the stress value at 10^7 cycles for a material which has infinite fatigue life. [7]. Crack nucleation is much more consequential than initiation of a crack because crack initiation happens suddenly in most materials [8-10].

17Mn4 (P295GH) is a C-Mn steel and it is widely used for production of pressure vessel steels, piping systems, steam vessels, etc. which have high working temperature [11]. ER 309L is an austenitic stainless steel TIG welding wire which is used for welding of stainless steels, unalloyed and low alloyed steels. It can be used for the welding which is subjected to the temperature of up to 300 ˚C [12].

Determining fatigue life of a material by making fatigue tests appreciably requires a lot of time. Therefore, softwares are tried to be improved to save time. Finite Element (FE) Method is used to calculate fatigue life values of materials [13].

In this study, FE analyses were conducted by fixing 2-D models for welded 17Mn4 (P295GH) and AISI 304 stainless steel with using ER 309L. This study aims to investigate the fatigue limit of the regions with different material properties by using ANSYS software, which uses Finite Element Method (FEM) for calculation, to determine which component will be the determinant on fatigue limit of the construction.

2. EXPERIMENTAL STUDY

In this study, AISI 304 stainless steel and 17Mn4 pressure vessel steel were welded by using ER 309L austenitic TIG welding wire. The steel plates, which had 8 mm thickness, 150 mm width, and 300 mm length, were welded with TIG welding method as they had a V groove which had 2 mm root length, 2 mm root distance, and 50° groove angle.

The micro-hardness tests were conducted along the longitudinal direction of the specimens with the dimensions of 8x8x100 mm. SHIMADZU DUH-W201S model Vickers ultra micro-hardness test machine.

The surfaces of AISI 304 stainless steel and ER 309L weld metal were etched with 20 ml acetic acit, 20 ml nitric acit, 30 ml hydrochloric acit, and 10 ml glycerol, and the surface of 17Mn4 was etched with 2 % nital solution. The etched specimens were examined by using Nikon model ME600D optical light microscope. In weld region, the variations of the chromium, nickel, manganese, and iron amounts were obtained along the longitudinal direction of the specimens by EDS line analysis.

Specimens were fatigued by using four point bending fatigue test system. The loads were applied on the specimens at 10 Hertz. The data was processed on the computer by using GENIE software produced by American Advantech Corp.

3. THEORETICAL STUDY

Welded 17Mn4 and AISI 304 steels with ER 309L wire was modeled as 2D (Fig. 1). After the static analyses of the model, fatigue analyses were conducted for the nodes on the surface of the model. Plane 82 element type was used for the analyses.

Fatigue test was simulated for different stress values as 302.5 MPa, and 207 MPa. These stress values were chosen for the analyses because the crack occurred at 400 MPa maximum stress value in the fatigue test. In the analyses, 207 GPa for 17Mn4 [14], 200

GPa for ER 309L [15], and 185 GPa for AISI 304 [15] were used as the elastic modulus of the materials. True stress – true strain values determined by tensile tests were used for plastic region.
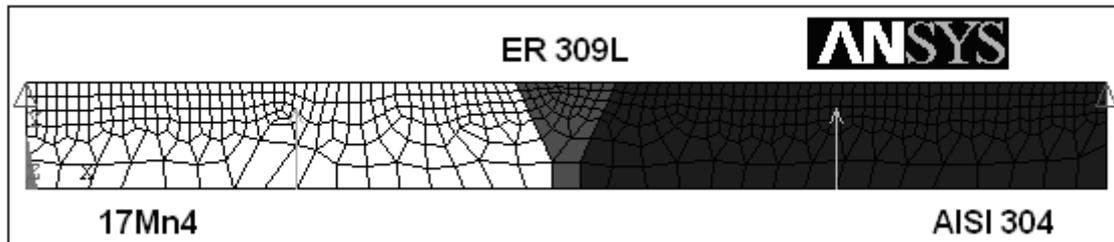
Fig. 1. Meshed model.

After the static analyses, fatigue analyses were conducted for 41 nodes which were selected symmetric to each others from the surfaces of 17Mn4 and AISI 304 and randomly from the surface of ER 309L. ANSYS software calculated the fatigue life values of the nodes by comparing the stresses on the nodes with the stress values which were acquired from the S-N diagrams of the materials [16,17].

4. RESULTS AND DISCUSSION

Vickers micro-hardness distribution is shown in Fig. 2. 17Mn4 has the lowest hardness. It is seen that there is no considerable hardness increase on the transition areas. No hardness increase on the surface of 17Mn4 shows that martensite phase did not occur after fast cooling of welding region.

In Fig. 3a, It is seen that the sizes of the ER 309L grains are smaller than the sizes of the AISI 304 grains. Fig. 3b shows the diffusion of the elements of chromium, nickel, iron, and manganese between the 17Mn4 and ER 309L. While iron diffused from 17Mn4 to ER 309L, chromium and nickel diffused from ER 309L to 17Mn4.
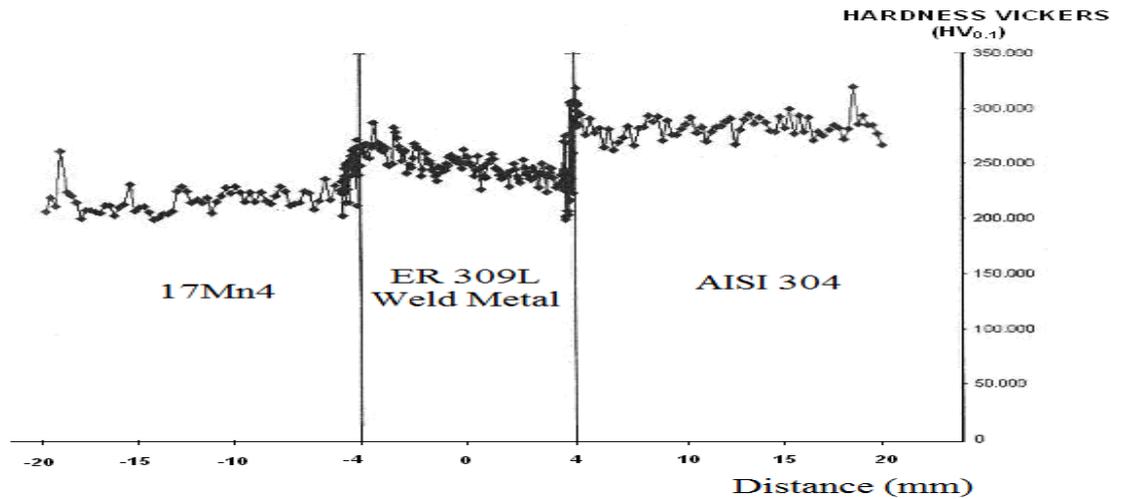
Fig. 2. Vickers micro-hardness distribution.
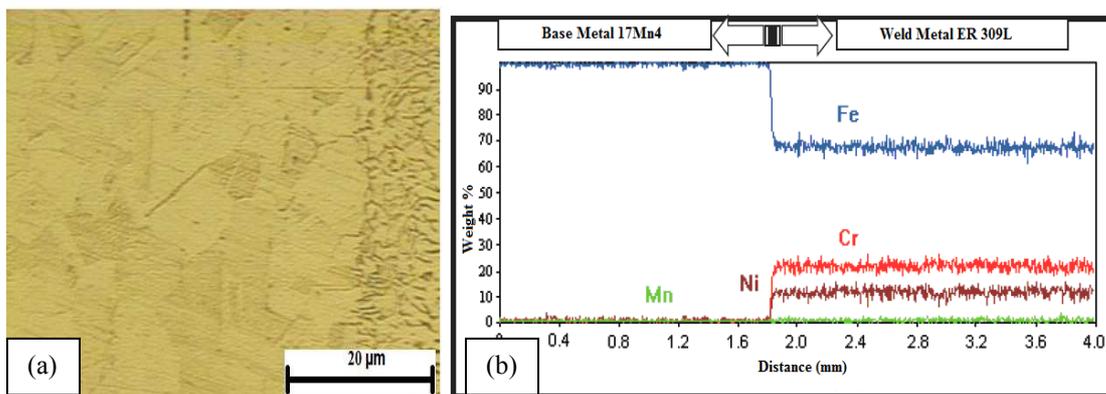
Fig. 3. (a) Transition region between AISI 304 and ER 309L. **(b)** Distribution of Cr, Ni, Fe, and Mn between 17Mn4 and ER 309L.

During the fatigue test, crack occured at 1,616,269 cycles. Fig. 4 shows the first crack which occurred on our construction for σ_{max}= 400 MPa and R= 0.1.

Fig. 4. The crack.

After the analyses for σ=302.5 MPa stress value, fatigue life expectancy for 17Mn4 was determined as infinite. As for ER 309L stainless steel, fatigue life was calculated 6,887,000 cycles for one of the two nodes which did not have infinite life, and safe fatigue life value was found 9,772,000 cycles for the other node. While fatigue life is infinite for one node on AISI 304 stainless steel, fatigue life values for the other nodes change between 1,780,000 cycles and 6,060,000 cycles (Fig.5). Also, a fatigue crack will most likely initiate on the surface of AISI 304 in 16 mm distance from the center.

Fig.6 illustrates that fatigue life values are infinite for all materials after the fatigue analyses for σ=207 MPa as a result of that stress values on the nodes are very low.
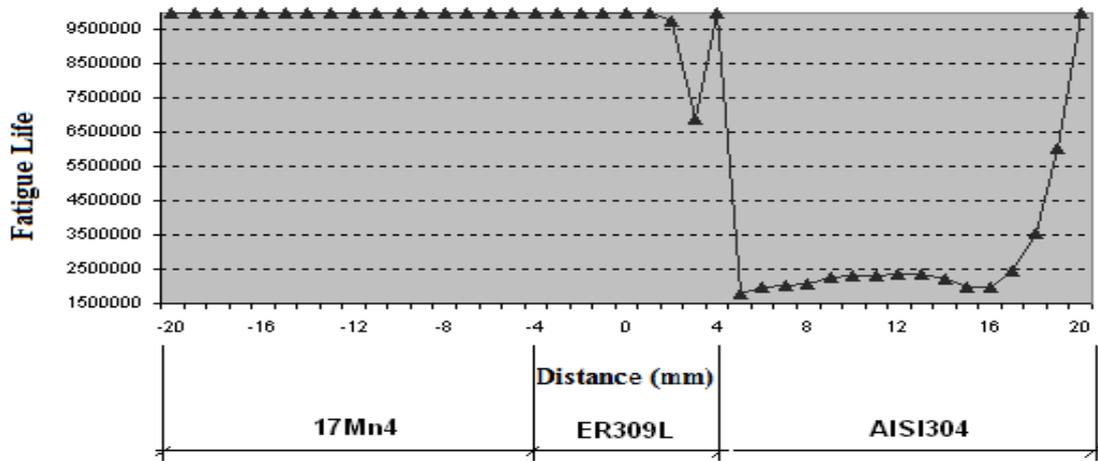
Fig. 5. Fatigue analyses results for σ=302.5 MPa.
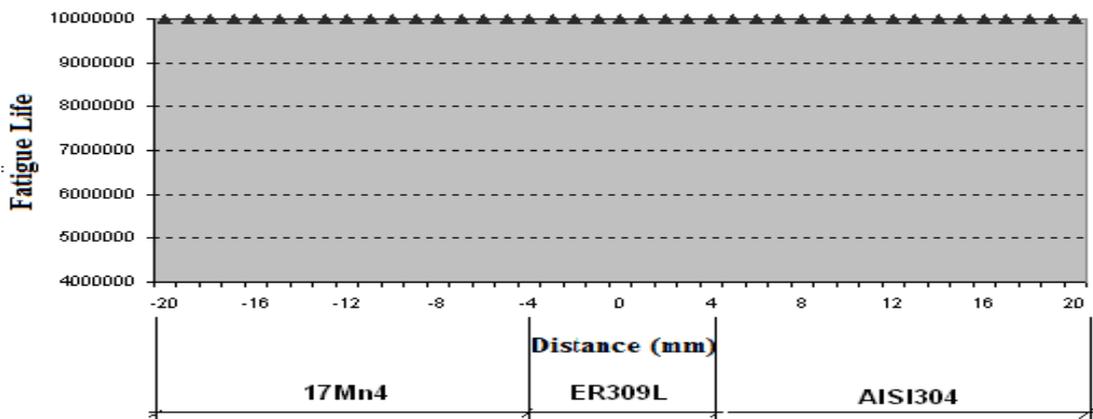
Fig. 6. Fatigue analyses results for σ=207 MPa.

5. CONCLUSIONS

As a result of this study, if the welded 17Mn4 pressure vessel steel and AISI 304 stainless steel construction with using ER 309L TIG welding wire is forced by cyclic

load, fatigue cracks begin to occur on AISI 304 stainless steel, which has the lowest yield and fatigue strength values, in the distance of 16 mm after welding point of ER 309L and AISI 304 stainless steels. If the construction is subjected to σ=302.5 MPa stress value, it can work 1,780,000 cycles properly. As for σ=207 MPa stress value, which is under the yield strength value of the materials, it can work permanently. Therefore, 10^7 cycles can be attributed as fatigue life of this construction for σ=207 MPa.

Acknowledgments

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