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Fatigue Life Estimation of In-Service Welded Patch Using Multiaxial Fatigue Criteria

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ABSTRACT: The present research has investigated the fatigue life of in-service steel patch welded joints by experimental/numerical approaches. To this end, three types of welded panels with similar Welding Procedure Specification but different cooling conditions were constructed. Subsequently, test samples cut from the main panels were subjected to fatigue tests. A novel approach involving continuous hardness measurement at the welding section was employed to predict the mechanical and fatigue properties of different zones in welded specimens. Firstly, the mechanical properties and fatigue parameters of various weld regions and heat affected zone were calculated using microhardness measurement and metallography images. Then, stress analysis was conducted in the Abaqus. The fatigue life was predicted using the stress and strain values obtained from the finite element analysis, the UVARM subroutine, and multiaxial fatigue modeling codes. The life estimations obtained from the numerical models were ultimately compared by experimental fatigue test results. The experimental tests showed that the samples cooled with water at a speed of 0.5 m/s had an increase in life, and the samples cooled with water at a speed of 1.5 m/s had a decrease in life compared to the samples cooled in air. Moreover, to predict the fatigue life, Brown-Miller-Marrow and Glinka criteria were used, respectively, and the results showed that these two criteria are able to predict the fatigue life with the maximum average error of 20.16% and 34.68%, respectively.

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1- Introduction

Among the existing methods for joining metals, welding is still the most popular and widely used method. Usually, when the welded structures have large dimensions, decommissioning and dismantling them due to welding defects is a costly process. In structures and pressure vessels, the damaged area of the equipment is often covered with a piece (called a patch) and the patch and the main piece of the equipment are connected by welding. Generally, this type of repair connection is called patch-plate connection and it is widely used in various industries such as oil, gas, process plants, and power plants to restore the strength of structural members [1].

One of the critical challenges in various industries is investigating and studying the strength and life of structures and connections under cyclic loading [2, 3]. Also, due to the cooling effect of the passing fluid, the patch connections have different microstructure, mechanical, and fatigue properties in welding and heat-affected areas. However, they have the same geometry in appearance. Although extensive research has been carried out in recent years, the presented methods have been used for homogeneous parts. They do not consider the effect of weld microstructure and heat-affected areas. Therefore, the ability to predict the fatigue life of welded joints during operation will not have and will provide the same life expectancy for parts with different cooling [4-6]. In addition, most of these methods are for non-applied engineering purposes and require complex laboratory tests and various simulations [5]. This research investigates the effect of cooling rate on the fatigue life of patch welded joints to provide a practical and accurate fatigue life prediction method on steel patch welded joints.

2- Materials and Methods

This section presents the experimental work process and fatigue life prediction procedure. A516 GR.70 Normalized steel sheets with 8 and 10 mm thickness were used as the base plate and patch material, respectively. As presented in Fig. 1, the size of the welding panels is 500 x 400 mm, and fillet joints were used to connect the base plate and patch. The details of the test setup and welding panels are shown schematically in Fig. 1. In this research, three cooling conditions are considered. Initially, the main panel was cooled with the surrounding air. In the second and third cases, cooling water was used (with a speed of 0.5 and 1.5 m/s for parts No. 2 and 3, respectively). As presented in Fig. 1, water from the centrifugal pump discharge continuously entered the

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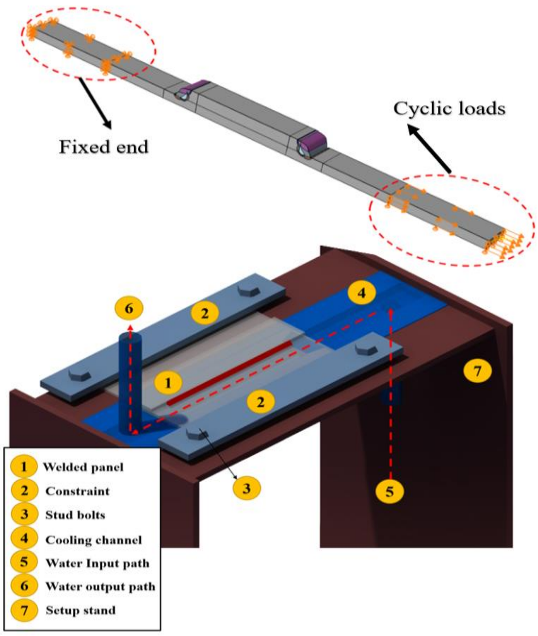

Fig. 1. Schematic of the in-service welding test rig and test sample loading

bottom of the cooling chamber at a temperature of 25°C. It exited from the top to cool the lower surface of the base plate (the surface under the main plate). From each panel, 12 test samples with a width of 22 mm and a length of 350 mm were extracted using waterjet cutting.

In Fig. 1, an example of fatigue test pieces is illustrated. Axial force-control fatigue tests were performed with a Zwick/Roell Amsler HB250 servo-hydraulic machine with a capacity of 250 kN. The microhardness data obtained in the experimental part have been used to estimate the mechanical properties and fatigue parameters of different weld areas of the welded samples in the numerical simulation. In addition to experimental tests, Abaqus finite element software [7] has been used for numerical simulation and stress analysis to predict fatigue life. By coding in FORTRAN, the output results from Finite Element Method (FEM) have been transferred to fatigue models by a UVARM subroutine, and fatigue life estimation has been done. The mechanical properties (including the yield and ultimate stress of each welding area) were calculated based on the process suggested in the research [8, 9]. Also, to define the fatigue properties of each welding area, the relevant equations were used, which are proposed by Zhao et al. [10] and Dowling [11]. In the next step, the estimation of fatigue life was done by two Brown-Miller-Morrow and Glinka's fatigue criteria, coded in Fortran language as a UVARM subroutine.

3- Results and Discussion

In this research, fatigue tests were performed on the three mentioned samples in the same stress ratio (*R=+0.1*), but different maximum applied stress (at six different stress levels). According to the results of fatigue tests, samples cooled with water at a speed of 0.5 m/s, samples cooled in air, and samples cooled with water at a speed of 1.5 m/s have longer fatigue lives. The average fatigue life of ORG-2 welded joints increases by 61% compared to the ORG-1 sample. In the case that in ORG-3 samples, the fatigue life compared to the basic state (ORG-1) is observed to decrease by 27%. Fig. 2 compares life estimation results with experimental fatigue test results for three different welded samples with two different fatigue life prediction criteria. The error index

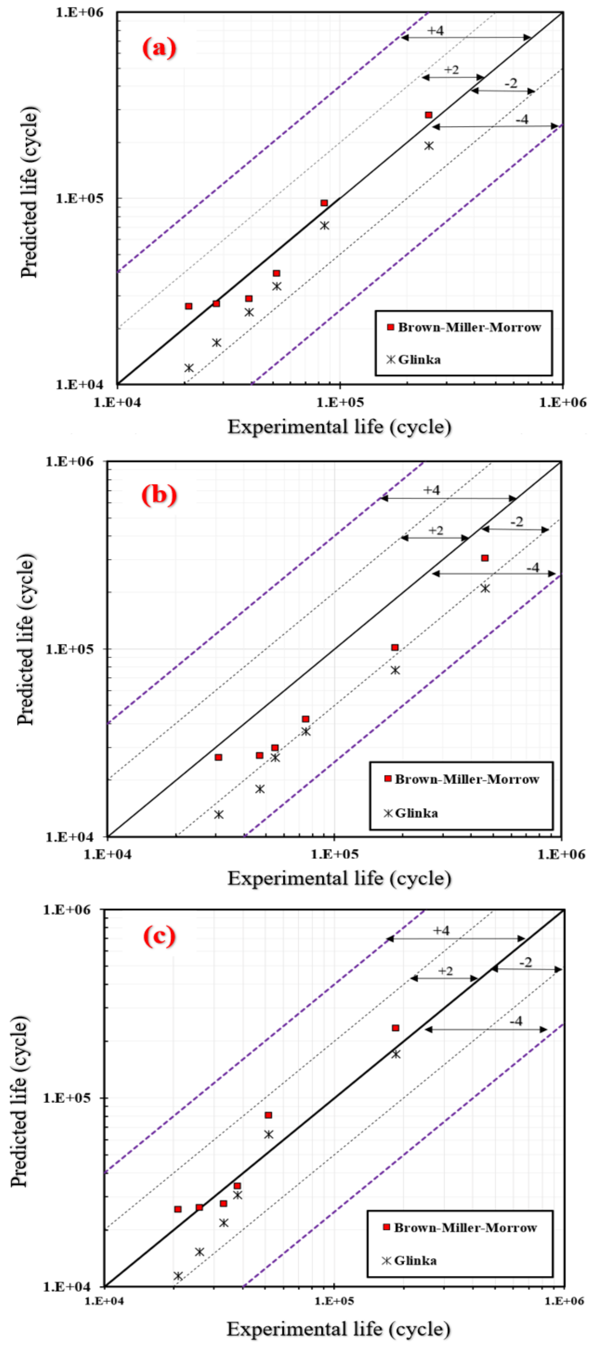

Fig. 2. Comparison among the estimated and experimental fatigue lives for three different specimens (a): ORG-1, (b): ORG-2, and (c): ORG-3

and the absolute values of the average errors were calculated to check the accuracy of the fatigue life prediction criteria. The Brown-Miller-Morrow criterion has more accuracy compared to the Glinka criterion.

4- Conclusions

In the research, experimental investigation and fatigue life estimation of in-service patch welding joints under three different cooling patterns were conducted. Stress analysis was done in Abaqus FE software to predict the fatigue life of the samples. In the next step, fatigue life prediction was done by the UVARM subroutine. For this purpose, two multiaxial fatigue criteria (i.e., Brown-Miller-Morrow and Glinka) were used. The results of the research are as follows:

- According to the results of experimental fatigue tests, the cooling rate has a two-way effect on the fatigue life of the samples. Cooling with water at a speed of 0.5 m/s has significantly increased the fatigue life, and cooling with water at a speed of 1.5 m/s has reduced the fatigue life compared to the samples cooled in the air.
- Brown-Miller-Marrow and Glinka criteria predict the fatigue life of in-service patch welded joints with the maximum average error of 20.16% and 34.68%, respectively.

References

[1] H. Mikihito, I. Yoshito, Fatigue characteristics of patch plate joints by fillet welding assisted with bonding, Weld. Int., 32(4) (2018) 243-253.

[2] H. Hatami, M. Shariati, Numerical and experimental investigation of SS304L cylindrical shell with cutout under uniaxial cyclic loading, Iranian Journal of Science and Technology, Transactions of Mechanical Engineering, 43(2) (2019) 139-153.

[3] M. Shariati, H. Hatami, Experimental study of SS304L cylindrical shell with/without cutout under cyclic axial loading, Theor. Appl. Fract. Mech., 58(1) (2012) 35-43.

[4] G. Zhou, J. Kuang, W. Song, G. Qian, F. Berto, Fatigue failure transition evaluation of load carrying cruciform welded joints by effective notch energy model, Eng. Fail. Anal., 138 (2022) 106328.

[5] H. Xin, J.A. Correia, M. Veljkovic, F. Berto, L. Manuel, Residual stress effects on fatigue life prediction using hardness measurements for butt-welded joints made of high strength steels, Int. J. Fatigue., 147 (2021) 106175.

[6] F. Samadi, J. Mourya, G. Wheatley, M.N. Khan, R.M. Nejad, R. Branco, W. Macek, An investigation on residual stress and fatigue life assessment of T-shape welded joints, Eng. Fail. Anal., 141 (2022) 106685.

[7] ABAQUS User's Manual, DS SIMULIA, Hibbit, Karlsson and Sorensen; 2017.

[8] S. Hassanifard, H. Alipour, A. Ghiasvand, A. Varvani-Farahani, Fatigue response of friction stir welded joints of Al 6061 in the absence and presence of inserted copper foils in the butt weld, J. Manuf. Process, 64 (2021) 1-9.

[9] S. Hassanifard, A. Ghiasvand, A. Varvani-Farahani, Fatigue Response of Aluminum 7075-T6 Joints through Inclusion of Al2O3 Particles to the Weld Nugget Zone during Friction Stir Spot Welding, J. Mater. Eng. Perform., 31(3) (2022) 1781-1790.

[10] E. Zhao, Q. Zhou, W. Qu, W. Wang, Fatigue Properties Estimation and Life Prediction for Steels under Axial, Torsional, and In-Phase Loading, Adv. Mater. Sci. Eng., (2020) 8186159.

[11] N. Dowling, C. Calhoun, A. Arcari, Mean stress effects in stress-life fatigue and the Walker equation, Fatigue Fract. Eng. Mater. Struct, 32(3) (2009) 163-179.

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