Fatigue Life of Shot Peened Welded Tubular Joint

G.H. Farrahi, G.H. Majzoobi, A.H. Mahmoudi and N. Habibi

Abstract—**The fatigue life and also the welding residual stress of the welded tubular X-joints are investigated experimentally. Furthermore, some joints are shot peened and the effect of shot peening on fatigue life of these joints is explored. The results of experiment show that the fatigue life of shot peened tubular joint is about twice of the original tubular joint. Cracks are initiated in all cases at weld toe. The in depth residual stress measurements on the joints, before and after the fatigue loading, show that fatigue loading causes the relaxation of residual stress created by welding and shot peening. The level of the residual stress on the surface is reduced to half of the original value**

Index Terms— **Welded joint, Fatigue, Shot peening, Residual stress, Stress relaxation**

I. Introduction

The majority of mechanical failures in engineering structures are due to fatigue. Offshore structures are usually made of pipes and tubular joints which are connected by welding. These structures are subject to fluctuating loading due to wind and sea waves' action. Therefore, fatigue life of subjected joints and estimation of theirs life should be investigated [1, 2]. Fatigue cracks in fabricated steel structures often occur at welded joints where stress concentrations due to joints geometry are relatively high. Some techniques rely on mechanical means to improve the weld profile by reducing the weld stress concentration; such as grinding. While some other techniques such as peening methods, overloading and stress relief treatments aim to relieve tensile residual stress and/or introduce compressive residual stress [3,4]. Residual stresses have important consequences on the performance of engineering components. High residual stresses may lead to dimensional instability, behavioral change in brittle materials and substantial reduction of fatigue life. Welding residual stresses are the result of non-uniform heating and cooling which occur during different welding processes in and around the weld seam [5]. Shot peening is a widely used technique for improving fatigue performance by introducing compressive residual stresses at the surface of a component. It has been shown [6] that the improvement in fatigue life due to shot peening is attributed to the maximum compressive residual stress and the work hardening of the material at the surface. The greater the magnitude and depth of the compressive stress layer, the greater the improvement in fatigue life. Experimental crack growth rates and fatigue life are considerably scattered [7]. An investigation into the effect of the residual stress field resulting from shot peening and indentation on fatigue crack closure and crack growth behavior indicated that shot peening and indentation process affected the fatigue crack behavior by delaying crack propagation [8].
In this paper, the effect of shot peening on fatigue life of welded tubular X-joints is investigated.

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G.H. Farrahi is Professor at School of Mechanical Engineering, Sharif University of Technology, Tehran, Iran (Corresponding author: phone: 98-21-66165533; fax: 98-21-66000021; e-mail: farrahi@sharif.edu).

G.H. Majzoobi is Professor at Department of Mechanical Engineering, Buali Sina University, Hamedan (e-mail: gh_majzoobi@yahoo.co.uk)

A.H. Mahmoudi is Assistant Professor at Department of Mechanical Engineering, Buali Sina University, Hamedan (e-mail: a.h.mahmoudi@gmail.com)

N. Habibi is PhD candidate at Department of Mechanical Engineering, Buali Sina University, Hamedan (e-mail: phd.st_habibi@yahoo.com)

II. Experimental Details

To investigate the shot-peening influence on fatigue life, four tubular X-joints are manufactured.

A. *Material and Specimens*

The tubular joints are made of St52 (S355) steel pipes. The chemical compositions and mechanical properties are presented in Tables 1 and 2 respectively.

TABLE1
CHEMICAL COMPOSITION OF ST52 (WT %).

C	Mn	Si	P	S	Fe
0.17	0.61	0.204	0.01	0.007	reminder

TABLE 2
MECHANICAL PROPERTIES OF ST52.

Hardness HB	Elongation (%)	Ultimate Strength (MPa)	Yield Stress (MPa)
158	33.9	510	355

The tubular X-joints are produced by welding two pipes of 32 cm in length into a pipe of 50 cm of length.
For the first pass (root pass), Bohler-E7016 electrode and for the second (filling) and the third pass (precision), Bohler-E7018 electrode are used. The welding conditions of the three passes and mechanical properties of electrodes are given in Tables 3 and 4. A completed specimen is shown in Fig. 1. In order to perform the experiment, a fixture is required. The designed fixture consists of upper plate and

lower plate. The assembled fixture with the specimen in position is illustrated in Fig. 2.

The endurance limit of St52 is 257 MPa. Using Marin factors [9], the endurance limit of our specimens is calculated as 199 MPa.

TABLE 3
WELDING CONDITIONS IN VARIOUS PASSES

Welding Velocity (mm/min)	Electrode Diameter (mm)	Welding Current (A)	Arc Voltage (V)	Pass Number
30-45	3.2	80-140	25	First
60-80	3.2	110-150	22	Second
95-160	3.2	110-150	22	Third

TABLE 4
PROPERTIES OF USED ELECTRODES

Elongation (%)	Ultimate Strength (MPa)	Yield Stress (MPa)	Electrode
29	540	445	E7016
29	540	445	E7018

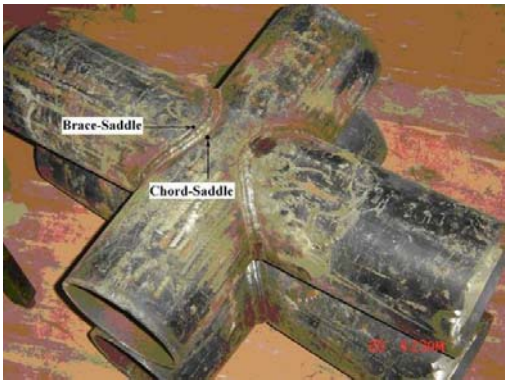

Fig. 1: Welded X-joint

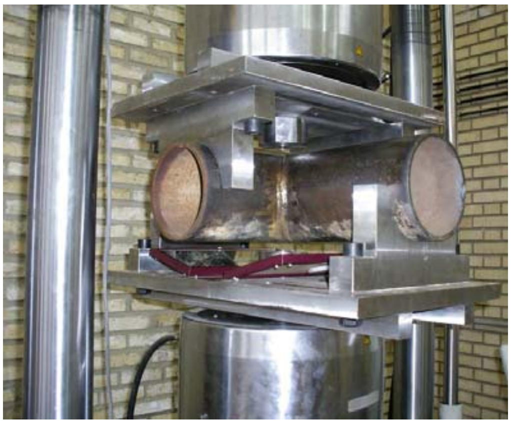
Fig. 2 The fixture and the specimen on place

B. *Shot peening of tubular X-joints*

Shot peening is performed on two specimens. Steel shots of average 0.3 mm diameter and hardness of 45 R_C are used. Turbine-type machine with rotational speed of 3000 rpm is employed, resulting in shots projection speed equal to 50 m/s, and Almen intensity of 8A.

C. *Residual Stress Measurement*

Incremental center hole drilling (ICHD) [10-12] is a well known technique to measure near-surface residual stress. A strain gauge rosette is attached to the surface of the specimen on a certain location. A small hole is then drilled into the specimen through the centre of the rosette. Residual stresses along the axis of the hole are then reconstructed using elastic finite element analysis. ICHD measurements are made on the components using RS200 drilling rig. FRAS-2-11 rosettes with 7 mm gauge centre diameter are used. Strain gauges are installed within 5 mm from the weld line. Analysis of the ICHD strains is based on the Integral method explained in [10] and [11]. Residual stresses are measured at two points and in directions of normal, parallel and 45^0 inclined to the weld line. The stresses in the three forgoing directions are called longitudinal, transverse and shear stresses, respectively.

D. *Fatigue tests*

A servohydraulic Instron testing machine with a loading capacity of 600 KN is used. Sinusoidal cyclic loading of 265 MPa with a frequency of 5 Hz and a stress ratio of 0.1 is applied. Fatigue tests were carried out in accordance with the ASTM E466-07 [13]. Crack initiation is considered at 2 mm of crack length and the final crack is about 80 mm where the test stops and the specimen is removed.

III. RESULTS AND DISCUSSION

The in depth residual stress measurement is performed in 5 mm distance from the weld toe. Fig. 3 shows the residual stress distribution due to the welding process of the joint and it can be seen that the residual stress on the surface is compressive. The compressive nature can be explained by the grinding of fillet weld which was performed after welding. Residual stress created by shot peening, which is quite significant, is shown in Fig. 4.

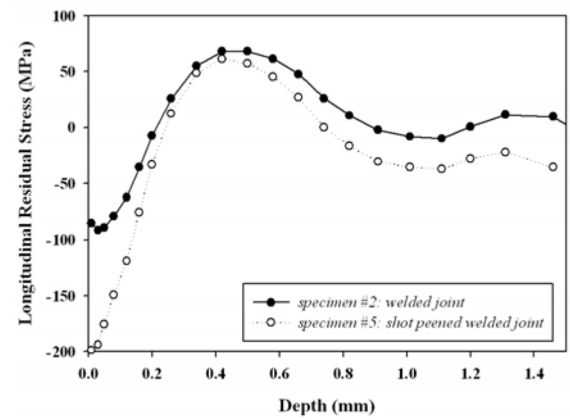

Fig. 3 Distribution of residual stress on Specimen #2 (welded joint), before and after the fatigue test

The details of fatigue tests and results are shown in Table 5. As the Table shows, four specimens were undergone fatigue test. Two specimens were shot peened before the fatigue loading. Cracks occurred on chord branches near the weld line, were measured by optical means. The crack propagation curves versus fatigue life for specimens are illustrated in Fig. 5. As it can be seen, there is a scatter in higher applied stress while at lower stress level and also for shot peened specimens, the results of two identical

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conditions are similar and repeatable. It can confirm the fact that compressive residual stress induced by shot peening (Fig. 4) cause a reduction in overall stress acting on the material. It is also observed that shot peening improves the fatigue life about 75%. It has shown that Shot peening improves the fatigue life of welded joints in both regions of low and high cycle fatigue [14]. Beneficial compressive stress induced by shot peening modifies tensile weld stress distribution and reduces internal stress ratio to negative near the weld toe. The crack growth threshold value, _*K*th, is increased after shot peening and thus fatigue resistance is enhanced [15].

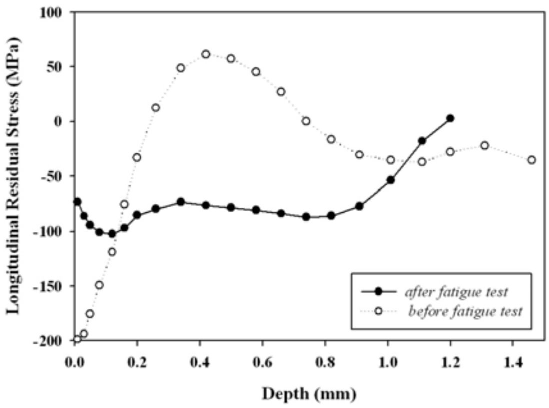

Fig. 4 Distribution of residual stress on Specimen #5 (shot peened welded joint), before and after the fatigue test

TABLE 5
DETAILS OF FATIGUE TESTS AND RESULTS OF TUBULAR X-JOINTS

Specimen no.	Shot peened	Crack initiation life (Number of cycles)	Final life (Number of cycles)
1	no	683298	916387
2	no	1017521	1289680
5	yes	1523000	1950000
6	yes	1604407	1913000

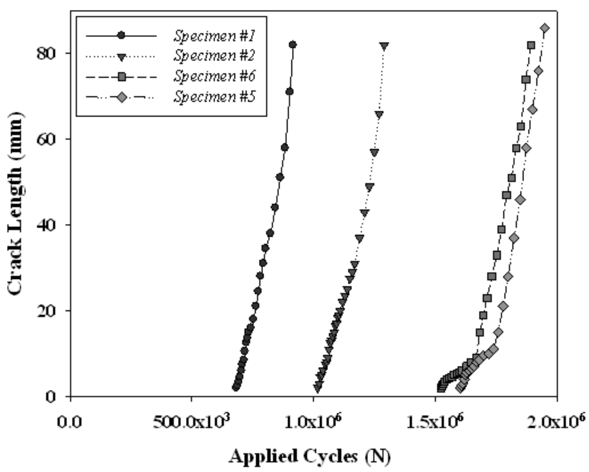

Fig.5 Crack length versus fatigue life of tubular X-joints; R=0.1, σ=265 MPa, f =5 Hz; (simple joints: specimenes 1 and2 and shot peened joints: specimenes 6, 5)

Experimental results revealed that the connection of the saddle in X-joint shows the most of fatigue damage. Enhancement of fatigue life is observed for the shot peened specimens. In some specimens, in addition to the cut of the weld on weld toe, a crack was observed near the weld line on the chord as well (Fig. 6). In Fig. 3, the relaxation of residual stress, due to fatigue loading, of the welded joint is shown. The level of the residual stress on the surface is reduced to half of the original value. The relaxation of residual stress, caused by fatigue loading, of the shot peened welded joint is shown in Fig. 4. Residual stress on the surface of this specimen also is reduced by more than 50%.

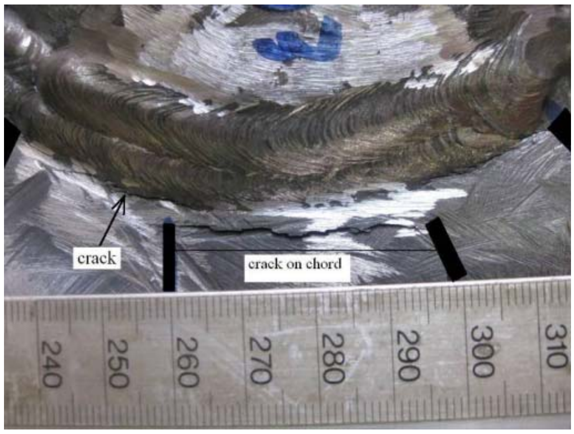

Fig. 6 Cracked joint

IV. Conclusion

The following conclusions are drawn from this work.
For all tubular X-joints (original and shot peened) crack was created at the weld toe.

For the unpeened specimens a variability of results was observed, while for shot peened specimens, the results of two identical conditions were similar and repeatable. It can confirm the fact that compressive residual stress induced by shot peening cause a reduction in overall stress acting on the material.

The in depth residual stress measurements on the joints show that fatigue loading causes the relaxation of residual stress created by welding and shot peening. The level of the residual stress on the surface is reduced to half of the original value.

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