Residual Fatigue Life of Flash Welded Steel Joints: microstructural and overloading effects

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ABSTRACT: *The objective of the present work is to study the fatigue crack growth behaviour in a structural steel used in offshore mooring systems. Accordingly, the study was extended to evaluate crack growth rate also in flash welded chain links. These were fatigue tested in the as-welded and welded and heat treated conditions and the results were then compared with those obtained with the base material. In an effort to extend the fatigue life, a single overload cycle was applied and the observed life extension is presented and discussed in light of the intensity of overloading as well as microstructural characteristics of the fatigued specimens.*

INTRODUCTION

The rate of fatigue crack propagation together with the critical crack size are the determining factors of the residual fatigue life of cracked components subjected to cyclic loading. Crack growth retardation, therefore, represents an important undertaking that will result in extending the lifetime of such components. It is well established that overload cycles of sufficient magnitude can lead to a transient retardation of fatigue crack growth at the baseline level [1-2]. However, in order to achieve the maximum benefit from fatigue overloading, one should try to optimise the level and timing of overload cycles by observing the crack behaviour at and after overloading.

The purpose of this work is to study fatigue crack growth behaviour in an R3 grade structural steel. As the steel is used in offshore mooring systems, the study was extended to cover the behaviour of flash welded joints. The study of the effect of a post-weld heat treatment, consisting of quenching and tempering, on the kinetics of crack growth is also an important part of the present work. Finally, extension in fatigue life caused by the application of a single overload cycle is presented and discussed in light of the intensity of overloading as well as microstructural aspects of the cyclically loaded specimens.

EXPERIMENTAL PROCEDURE

The R3 grade steel was received in the form of hot rolled round bars with a nominal diameter of 85 mm. The bars were bent in conformity with the typical stud link geometry before they were butt flash welded [3]. Following the welding procedure, a number of stud links were subjected to a post-weld heat treatment consisting of an austenitization at 900°C for 90 minutes, quenching in water and tempering at 620°C for 90 minutes

Compact tension (CT) specimens were machined in the L-T orientation from the welded region of the link as well as from the opposite region, in accordance with the ASTM E647-99 recommendation [4]. The CT specimen width (W) and specimen thickness (B) were adopted equivalent to 32 mm and 8 mm, respectively, and a starter notch was machined to a depth of 7.0 mm. Four different microstructural conditions were contemplated: as-received and heat treated base metal (designated as BM and BH, respectively) and as-welded and heat treated joints (designated AW and WH). Fatigue crack propagation was followed to determine crack size (a) in terms of the number of cycles (N) under constant amplitude loading. The tests were carried out, at room temperature, in a servohydraulic machine operated at a frequency of 20 Hz, with the applied load cycling between a maximum of 9 kN and a minimum of 3 kN. Crack length was monitored using a travelling microscope. Single overload cycles were applied at an a/W ratio of 0.33 adopting overload ratios (R_{OL}), i.e., the ratio between the applied overload and the maximum load corresponding to the baseline level, of 1.5 and 1.8.

RESULTS AND DISCUSSION

Figure 1 shows the variation of a with N for all microstructural conditions considered in this work. One can notice the adverse effect of flash welding on fatigue life and the marked improvement due to post-weld heat treatment. This improvement, as can be seen from the figure, is brought about by a combination of a decrease in the crack growth rate (manifested by the displacement of the a-N curve to higher values of N) and an increase in the critical crack size. Critical crack size corresponds to the onset of unstable fracture and is determined for a given loading condition by the material's toughness, which, in turn, is dependent on the microstructural characteristics of the material.

For the as-welded joints, the microstructure of the metal adjacent to the weld plane is essentially the result of phase transformation that occurred during the welding process and is generally characterised by low fracture resistance [5]. The microstructure of the heat-treated joints, on the other hand, is composed of tempered martensite, which is tougher than the microstructure predominating the weld region in the as-welded joints. Consistent with this explanation is the marked improvement in tensile ductility that accompanies the post-weld heat treatment [6]. One can conclude that, although it does not significantly affect da/dN, the post-weld heat treatment promotes the joints' toughness, thus increasing the critical crack size and hence the fatigue life.

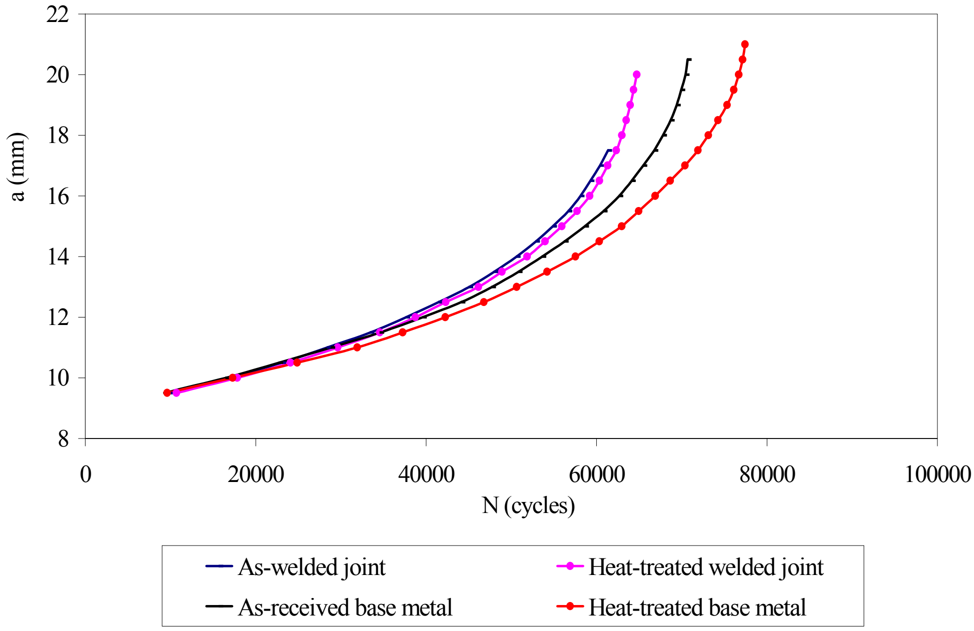

Figure 1: Variation of crack length (a) with the number of cycles (N) under constant amplitude loading.

As reported elsewhere [6], the post-weld heat treatment changes the steel's microstructure from a mixture of coarse pearlite and ferrite to tempered martencite and the mechanical properties were found to be promoted as a result of this change. This leads to an increase in the critical crack size together with a reduction in the fatigue crack rowth rate, giving rise to a considerable extension in fatigue life as can be verified from Figure 1.

A single overload of 13.5 kN, applied at a crack length of 10.5 mm was found, as shown in Figure 2, to extend the fatigue residual life for all microstructural conditions considered in this investigation. Comparing this figure to Figure 1, one can determine the extension in fatigue life expressed by the delay cycles number associated with the applied overload cycle.

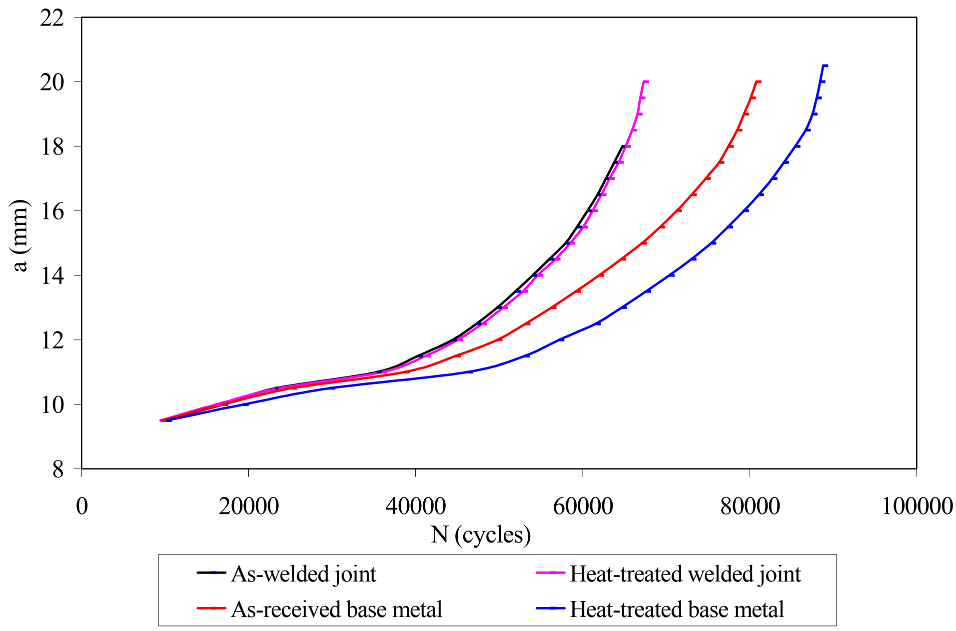

Figure 2: Variation of crack length (a) with the number of cycles (N) for a single overload of 13.5 kN.

It is well established [7] that fatigue crack growth retardation due to overloading is closely related to the residual compressive stress field induced within the overload plastic zone. Following an overload cycle, the fatigue crack starts to advance into that zone and the residual compressive stresses in an element just behind the crack tip are relaxed. This contributes to the level of crack closure in the wake of the crack tip, thus retarding crack growth. Based on this retardation mechanism and taking into account the observation that the yield stress level did not vary significantly from one microstructure to another [6], one may conclude that the extension in fatigue life due to an overloading of that magnitude (R_{OL}=1.5) should be of the same order for the microstructures in question. However, the extension in fatigue life, as observed by comparing Figures 1 and 2, does not correspond to this expectation. This may be associated with the fact that the weld plane represents a natural path for crack propagation.

An increase in the overload, applied at a crack length of 10.5 mm, to a level of 16.2 kN was found to result in a marked extension of fatigue life. An example of this is presented in Figure 3, where it is noticed that the increase in the overload applied to the as-welded joint (from 13.5 to 16.2 kN) results in a considerable shift of the a-N curve to larger N values and fatigue life becomes comparable to that of the heat-treated base metal subjected to a single overload of 13.5 kN. While this considerable extension in fatigue life caused by a high intensity overload can be partially attributed to an increase in the overload plastic zone size, that alone does not seam capable of accounting for the magnitude of the observed extension. One may thus conclude that other crack growth retardation mechanisms, which become operative only at high overloads, were activated as the overload was increased from 13.5 to 16.2 kN. Mechanisms such as crack blunting [8], strain hardening of the material within the overload plastic zone [9] and crack surface asperity [10] can have their efficiency increased by increasing the intensity of overloading. However, the reason such mechanisms become more efficient on increasing the overload requires further investigation.

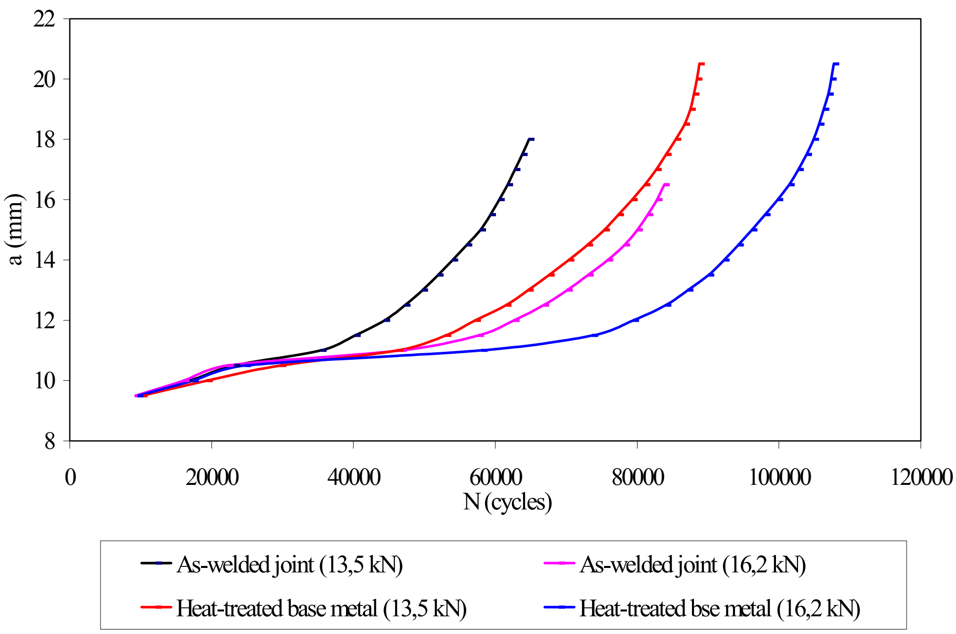

Figure 3: Effect of single overloads of 13.5 and 16.2 kN on the a-N curves.

CONCLUDING REMARKS

From the results presented above, the following conclusions can be drawn:

• The fatigue life of flash welded steel joints is improved by post-weld heat treatment, mainly due to an increase in the critical crack size. An increase in the critical crack size is the result of promoting microstructural homogeneity due to the post-weld heat treatment.

• The fatigue life of the as-received base material can be extended by adopting the same heat treatment applied to the welded joints.

• A single overload applied after a given interval of crack propagation was found to extend the fatigue life of both the as-welded and heat treated joints, as a result of a decrease in crack propagation rate.

• A single overload of higher intensity applied after some interval of crack growth is seen to be much more effective in extending fatigue residual life, particularly that of the heat-treated joints.

REFERENCES

1. Schivje, J. (1960) *Report MP-195*. National Luchtvaart Labratorium, Delft.
2. Decoopman, X., Imad, A., Nait-Abdelaziz, M. and Mesmacque, G. (1998). In: *Proceedings of the ECF 12*, pp. 265-270, Brown, M.W., de los Rios, E. R. and Miller, K.J. (Eds). EMAS LTD., Cradley Heath.
3. ABS (1999) *Guide for Certification of Offshore Mooring Chain*, New York.
4. ASTM (1999) *ASTM E647-99*, Warrendale.
5. Dadian, M. and Granjon, H. (1993) *De Ferri Metallographia IV – Part II*. Verlag Stahleisen M.B.H., Düsseldorf.
6. Lopes, M. R. (2001). MSc. Thesis, PUC-Rio, Brazil.
7. McEvily, A. J. and Ishihara, S. (2001). In: *Proceedings of the Fatigue 2001 SAE Brazil International*, pp. 145-150, Pimenta, P.M., Ricardo, L.C. and Camarão A.F. (Eds). SAE Brazil, São Paulo.
8. Hammouda, M. M. I., Ahmad, S. S. E., Sherbini, A.S. and Sallam, H. E. M. (1999) *Fatigue Fract. Engng. Mater. Struct*., **22**, 145.
9. Knott, J. F. (1977) *Metal Sci*., **11**, 399.
10. Suresh, S. (1983), *Engng. Fract. Mech.,* **18**, 577.