MIXED MODE FATIGUE CRACK GROWTH BEHAVIOUR UNDER MICROSTRUCTURAL VARIATION IN FLASH-BUTT WELDS

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Abstract

The strength loss due to welding process poses a high risk of catastrophic rolling contact fatigue failure in the heat affected zones of flash-butt rail welds. Accurate characterisation of fatigue crack growth behaviour in such regions can provide a database for developing safer and more efficient maintenance strategies. This extended abstract details an experimental study on fatigue crack growth behaviour in flash-butt welds in a hypereutectoid rail steel with a hardness level of over 400 HV. Groups of mixed mode fatigue crack growth tests were carried out at parent rail region, partially spheroidised region, fully spheroidised region, re-austenitised region and bond line region. Fractographic analysis was performed to aid the application of the marker band method as well as to analyse the morphology of fracture surfaces. Once all experiments are finished, an equivalent stress intensity factor formula will be fitted to quantify the mixed mode crack driving force in different regions, and modifications of crack growth direction prediction criteria will be proposed for crack growth under the influence of microstructural variation. The proposed model will be checked against all the experiment data. The current work will provide a reliable database for predicting rolling contact fatigue crack growth at different regions in flash-butt rail welds.

1. Introduction

In heavy haul railway systems, there are increasing demands for higher operating speeds, higher axle loads and longer rail lives for higher profitability. To reduce the risk of rail failures under these severe operating conditions; continuously welded rails (CWR), which provide a continuous and smooth rail surface, are used to limit dynamic loading at rail joints. The hypereutectoid rail steel grade R400HT is one of the common heat-treated high strength rail steels used in heavy haul railways. It can provide hardness levels above 400 HV and yield strengths of around 900 MPa in the heat treated condition. The use of such rail materials along with wear-adapted wheel and rail profiles has extended rail lives and reduced rail maintenance costs. The improvements in rail performance through the use of higher strength rail grades can be constrained by the performance of rail welds. In heavy haul railway systems, the most common welding technique used for CWR is flash-butt welding. Although this method does not require external materials as used in aluminothermic, it can still create extensive variations in microstructure and mechanical properties within the heat affected zone. In addition, the non-uniform temperature distribution which develops during the welding process results in tensile residual stresses that can have a detrimental effect on fatigue behaviour of the welds.

Given the importance of the integrity of rail welds to overall rail performance, it is necessary to address the common failure modes that affect rail welds. Among these, RCF failures have drawn the most recent attention in heavy haul railways due to their faster rate of development and potentially higher repair costs. However, these appear to be limited, if any, systematic studies of mixed mode RCF crack growth behaviour under microstructural variations in flash-butt rail welds. The influence of microstructural variations on crack growth direction as well as crack growth rate are therefore not clear and there is a lack of experimental data for accurate RCF crack growth predictions. In this study, experimental work was performed using the marker band method and fractographic analysis to address the aforementioned issues.

2. Methodology & Results

All specimens were prepared from new flash-butt welds manufactured under the same welding conditions. In order to eliminate the influence of residual stresses, all specimens were subjected to stress relief annealing at 550°C for one hour. The specimens are cut from the middle plane of the rail segment in different regions of welds as shown in Figure 2. The centres of the specimens were located at five regions with distinct microstructures that included parent rail region, fully spheroidised region, partially spheroidised region, re-austenitised region and bond line region in the order of distance from parent rail.

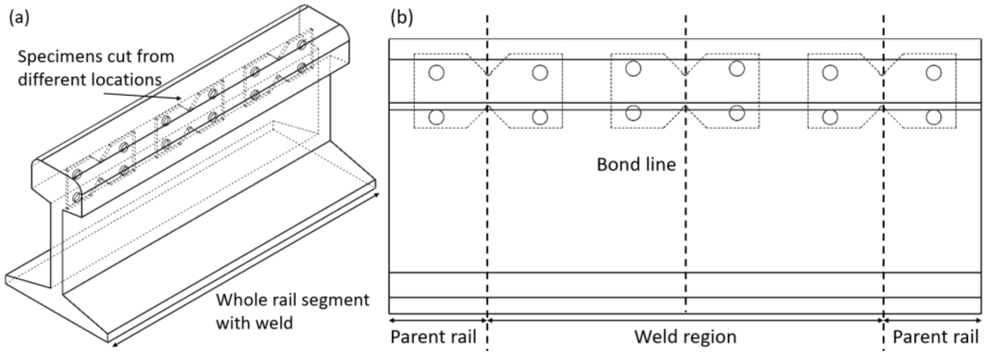

Figure 1. Illustration of the locations and orientations of specimens (three examples): (a) Isometric view. (b) Longitudinal section view.

The fatigue crack growth tests were conducted under mixed mode loadings applied at 0, 15, 30, 45, 60, 75 degrees using a 250 kN servo-hydraulic fatigue testing machine with corresponding data acquisition system. The loading spectrum consists of two alternating blocks with one of high R ratio at 0.8 and one of low R ratio at 0.1. The crack growth length during each block was determined by fractographic examination using a Olympus SZH stereo optical microscope. The calculations of stress intensity factors were performed using the static crack module in ABAQUS XFEM. Preliminary results from mode I tests in the parent rail are presented as shown in Figure 3a. Distinct marker bands for both high R and low R blocks are produced on the fracture surface. By measuring the thickness of each bands, which corresponds to the crack growth during the loading block, fatigue crack growth rate data are collected as shown in Figure 3b.

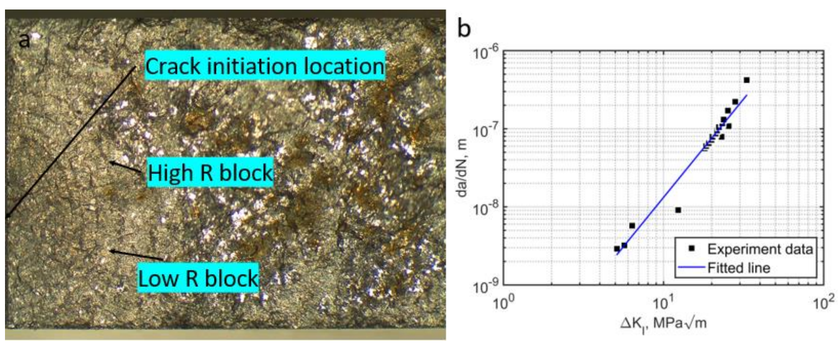

Figure 3. Preliminary results: (a) Fracture surface of one example parent rail test. (b) Fatigue crack growth rate in parent rail.

3. Conclusions

Based on the current results, the marker band method has been found to be suitable for obtaining the fatigue crack growth rates in a hypereutectoid rail steel. With the help of fractographic analysis, crack growth directions will also be determined after all tests are finished. The influence of welding induced microstructure variations on crack growth behaviour in flash-butt welds will be systematically analysed which will provide valuable data for RCF prediction in heavy haul rail flash-butt welds.

Acknowledgements

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