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Fatigue life assessment of improved joints welded with alternative welding techniques

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ABSTRACT

In this study, the fatigue life improvement by adopting the toe weaving technique on non-load carrying cruciform welded joints has been investigated. Fatigue testing was conducted on two batches of specimens welded using double-pass manual welding. One batch had a straight second pass and the other was weaved. The influence of different weaving shape parameters was analyzed by performing crack growth analyses. The fatigue testing shows a slightly improved fatigue life for the two different batches compared to as-welded joints; the improvement is similar for both batches. The crack growth analysis concludes that the batch with the straight second pass should provide slightly higher fatigue life compared to the toe weaved batch. Measurements show a presence of undercuts in the vicinity of the crack initiation site. Nonetheless, an increased fatigue life is obtained, due to the low flank angle created during welding of the second pass, which reduces the stress concentration in the weld toe, prolonging the fatigue life.

1. Introduction

During the welding process, different types of material flaws and imperfections are induced into the resulting welded joint. Material flaws are for example; softening in the heat affected zone (HAZ) and residual stresses, which will have a great impact on the reduction of the fatigue life. The presence of weld imperfections such as undercuts, cold laps and small toe radii will increase the stress concentration in the vicinity of the weld toe and hence decrease the fatigue life [1–7]. Fatigue cracks are likely to initiate from these defects due to the increased stress concentration and material flaw in the weld toe. In welded joints, cracks are generally initiated in these defects at multiple locations along the weld seam and then propagate along the weld toe.

Methods to increase the fatigue life of a welded joint can be divided into two main groups: residual stress methods and weld geometry improvement methods [8]. Residual stress methods are primarily post-treatment methods, such as peening or HFMI (High Frequency Mechanical Impact) methods [9,10]. However, such post-treatment methods increase the cost of manufacturing in terms of extra work, extended inspection and longer production lead time. If the fatigue strength can be improved using an optimized welding process, the additional cost for post-treatment can be avoided. Optimizing the welding process includes selecting appropriate welding process parameters, filler material and shielding gas, which has been studied for high-strength steel in T-joints by Stoschka et al. [11]. Another welding technique that could be considered to

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be included in the group of weld geometry improvement methods is toe weaving. The geometry of the weaved toe line between the weld bead and the base material is irregular and contains a waviness, see Fig. 1. In transversal loaded joints, cracks initiate preferably at wave tip and then propagate along the toe line towards the cusp region. When crack tips from nearby waves intersect at the cusp region, the non-coplanarity of the crack faces will obstruct crack coalescence, reducing the crack growth rate and prolong the fatigue life [12–16]. In contrast to the above mentioned improvement techniques, there is no need for separate equipment for implementing toe weaving, it can be done by using the existing welding equipment.

There are a number of different techniques to produce a welded joint with toe weaving: arc rotation, variable arc voltage and variable weld speed, which were assessed by Chapetti and Otegui [12]. It was found that the only technique which had any measurable effect on the fatigue life was arc rotation, which is pendling of the arc in an elliptic pattern during welding. Matsumoto et al. [13] conducted a parametric study for the optimal geometry of the toe waviness regarding the opening angle χ and the period length P, see Fig. 1. An improvement in fatigue life was reported for specimens that were welded with a deep pendling shape and short period compared to a straight as-welded bead.

Otegui et al. [12,14,15] conducted a parametric study of χ and P for bead-on-plate joints. It was found that cracks tend to propagate along the toe line into the cusp region when $\chi > 100^\circ$ and bridge the waves for smaller opening angles. Opening angles $90^\circ < \chi < 120^\circ$ allowed for delayed crack coalescence compared to $\chi > 120^\circ$, which resulted in a reduced crack propagation rate and increased fatigue life. The study concluded that the period P should be as small as possible and that the opening angle χ should be kept at 100°.

Skriko et al. [16] performed a study for non-load carrying fillet joints and compared weaved and unweaved joints along with the influence of the toe radius, see Fig. 2. The results showed that the cracks did not propagate along the toe line; instead cracks bridged the waves and propagated into the base material. It was stated that the toe radius had more influence on the characteristic fatigue resistance (FAT) compared to the weaving pattern, defined by χ and P. The increased fatigue life was due to the effect of large toe radii and the absence of the notch effect when the crack propagated into the base material.

The specimens that were used in previous studies were manufactured using single pass welding. However, no fatigue assessment has been done on weaving applied with double-pass welding on cruciform joints. Double-pass welding allows sufficient penetration and fusion as opposed to single pass welding that requires a highly optimized process in order to produce the desired weaved geometry. In order to evaluate the influence of the weaving shape, a reference batch was manufactured using double-pass welding, where the second pass had a straight weld toe line. This reference batch is denoted as extended leg.

2. Test specimens

The test specimens used in this study are non-load carrying cruciform joints, see Fig. 3. The base material is S355MC with a thickness of 10 mm, the filler material is ELGA 100 MXX. Two batches, with 12 specimens each, were manufactured with double-pass using manual GMAW. The first pass – bead 1–4 – was welded with normal weld quality according to the Volvo weld quality standard STD 181-0004 [1], with a nominal throat thickness of 5 mm. The second pass, in case of the weaved joint – bead 5–8 – was performed by semi-elliptic pendling mode, as illustrated in Fig. 4.

3. Fatigue testing and evaluation

The fatigue testing was executed in a SCHENCK Hydroplus PSB (max ± 200 kN, 30 Hz) using constant amplitude. In order to examine the crack propagation, a beachmarking technique was adopted. The loading sequence was divided into two different blocks keeping the upper stress limit constant, see Fig. 5. The first block (type 1) is essential for crack propagation, whereas the second block (type 2) with an increased stress level ensures striation marks on the fracture surface. Due to the decreased crack growth in the type 1 blocks, the number of cycles for the type 1 blocks can be conservatively neglected and is not taken into account when the fatigue life of the specimens is evaluated [17].

The IIW recommendation [2] of the fatigue resistance for non-load carrying fillet joints is 80 MPa, which is the characteristic fatigue strength at 2 million cycles and a failure probability of 5% (FAT), with a constant inverse slope value of

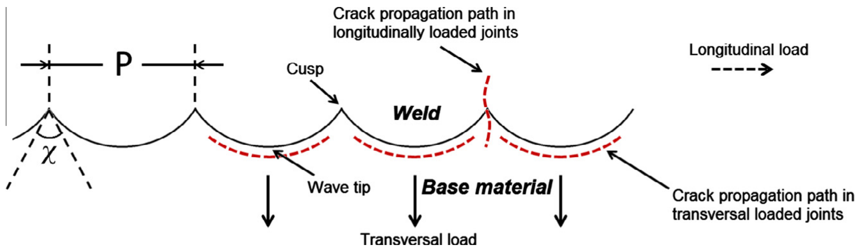

Fig. 1. Illustration of weaved toe line, the crack propagation paths for transversal and longitudinal loaded joints and the toe wave geometry; opening angle χ and period length P.