Influence of material data input on accuracy of fatigue assessments for beam weldments

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This numerical study investigates the effects of fatigue material data and finite element types on accuracy of residual life assessments under HCF conditions. The bending of cross-beam connections is simulated in ANSYS Workbench for three different combinations of beam profiles. The weldments are made of the high-strength steel grades C350LO and C450LO according to AS3678. The stress analysis of weldments is implemented with solid and shell elements using linear material and geometry consideration. The stress distributions are transferred to the embedded fatigue code nCode DesignLife. For both variants of FE-mesh, the nominal stress in the weld toes is extracted by splitting the total stress into membrane and bending components and filtering out non-linear component. Considering the effects of bending, size and mean stress, failure locations and fatigue life are predicted using the Volvo method and rules from ASME BPV Code. Three different pairs of experimental S-N curves (stiff and flexible) are used as material data input for fatigue analysis. The obtained numerical predictions are compared to the experimental results for shell FE-models. The predictions using the S-N curves for an equivalent steel demonstrate the best accuracy proving the fact that specific material data input is more effective than a generic data.

The fatigue behaviour of weldments is studied in terms of the geometry of the members, the stresses to which they are subjected, and the materials of which they are fabricated. In regard to the choice of base material, there are experimental observations, which may explain its relation to the fatigue strength of corresponding weldments. Initially, when steels of widely differing grades are welded, the resulting S-N curves tend to fall within a single scatter band. The main reason for this is that superior fatigue strength of high-strength steels as base material is eliminated by the high residual stresses in welds, which may usually approach σ_y. However, closer examination of the fatigue curves slopes reveals that low-strength steels (with lower σ_u) tend to have better fatigue resistance in long-term domain under low loads while high-strength steels (with higher σ_u) tend to have better fatigue resistance in short-term domain under high loads. Therefore, provision of specific S-N curves for different groups of steels (e.g. mild, moderate and hard) may improve the quality of fatigue predictions. For examples of experimental studies for a few structural steels proving this idea please refer to [1]. This study addresses the comparison of specific S-N curve and generic S-N curves for investigation of accuracy of residual life predictions for welds.

The bending of cross-beam connections is simulated in ANSYS Workbench for three different combinations of structural member shapes: RHS-RHS, RHS-angle and RHS-Channel [2, 3]. The weldments are made of the high-strength steel of grades C350LO (σ_y = 350 MPa and σ_u = 430 MPa) and C450LO (σ_y = 450 MPa and σ_u = 500 MPa) according to the Australian Standard AS3678. The stress analysis of each weldment having specific profile size under specific cyclic loading is implemented using solid and shell elements using linear material and geometry consideration. The stress results are transferred to the embedded fatigue code nCode DesignLife [4] for the residual life prediction. For both variants of FE-mesh, the nominal stress in the weld toes is extracted by splitting the total stress into membrane and bending components and filtering out non-linear component. The membrane and bending stresses are combined with experimental pair of S-N curves, which represent the fatigue strength of a weld under pure membrane (stiff) and bending (flexible) loading conditions. Considering the effects of bending, size and mean stress, failure locations and fatigue life are predicted using the Volvo method [5] and rules from ASME BPV Code [6]. Three different pairs of experimental S-N curves are used [1] including conventional generic seam weld curves from nCode DesignLife, legacy generic seam weld curves from nCode FE-Fatigue, and curves for the Japanese steel JIS G3106-SM490B identified using the experimental data [7], which is equivalent to C350LO/C450LO.

The examples of fatigue life predictions for the connection of 75x50x3 RHS to 50x50x3 SHS beams together with blowup of the crack location are shown in Fig. 1a using solid FEs and in Fig. 1b using shell FEs. The advantage of all performed numerical predictions is that the crack has been predicted exactly in the same location as in experiments [2, 3] for all cases of geometry and loading – front part of the weld toe on the fillet of the bottom member. The obtained numerical predictions for shell FE formulation are compared to the experimental results [2, 3] as shown in Fig. 2.

Total aggregate discrepancies $\Delta_\mathrm{agg}^\mathrm{tot}$ for all considered experiments reveal the winner – S-N curves <A> of SM490B steel welds with slightly conservative result of 25.80%. It is more preferable to a much more conservative result of 113.24% produced by generic S-N curves <B> from nCode DesignLife and to a non-conservative result of -54.98% produced by generic S-N curves <C> from nCode FE-Fatigue. Predictions with S-N curves <A> in Fig. 2a are the most balanced about the diagonal of optimal match with only 5 predictions being out of the domain for factor of 2. Predictions with S-N curves <B> in Fig. 2b are accurate for the $N_* < 10^6$, but overconservative for long fatigue life durations with $N_* > 10^6$. Predictions with S-N curves <C> in Fig. 2c are accurate for long fatigue life durations with $N_* > 10^6$, but very non-conservative for

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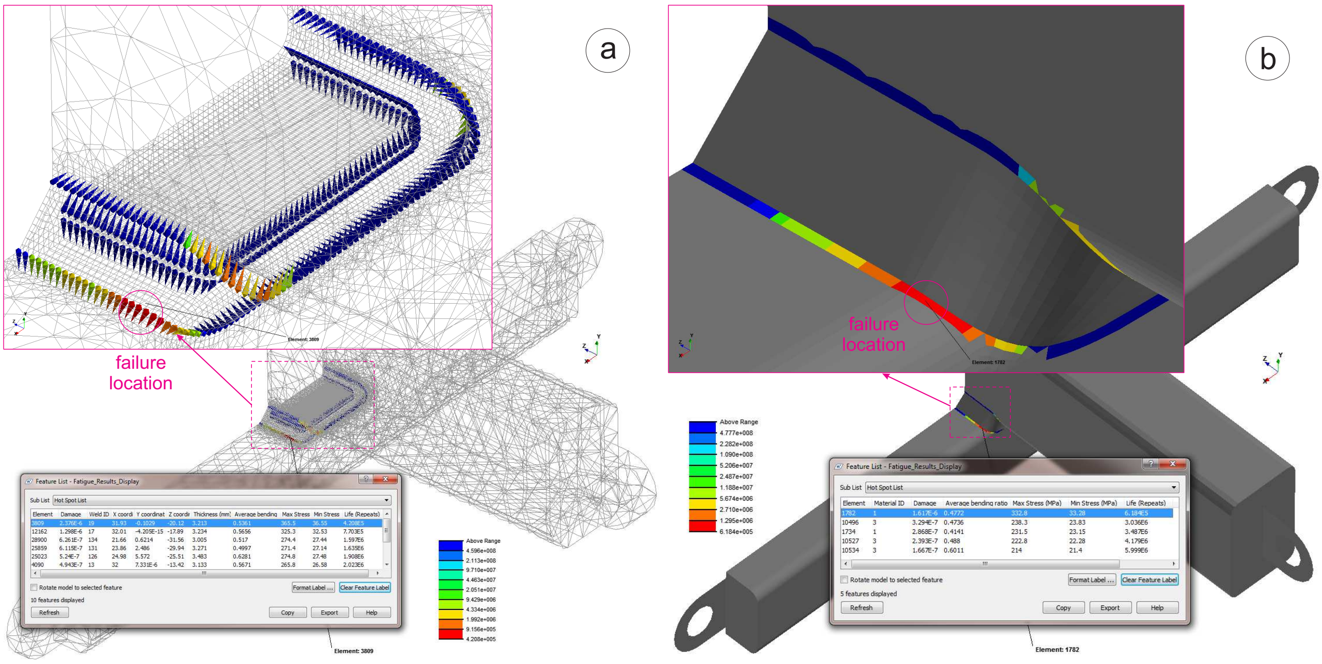

Fig. 1: Result of fatigue life predictions (cycles) for 75x50x3 RHS to 50x50x3 SHS connection for (a) solid and (b) shell FE-models.

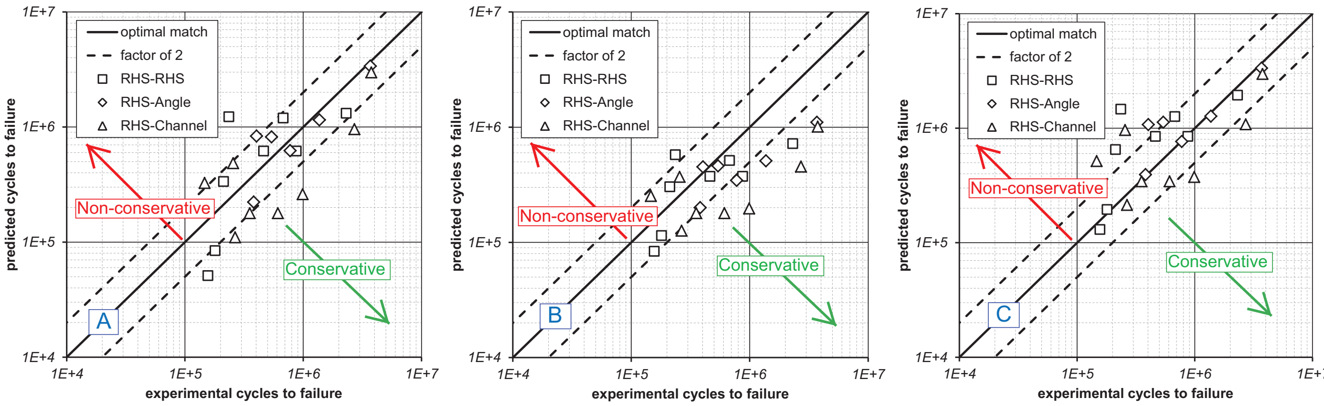

Fig. 2: Comparison of the observed and predicted cycles to failure using shell elements for: a) S-N curves for SM490B steel welds; b) new generic S-N curves in nCode DesignLife c) old generic S-N curves in nCode FE-Fatigue.

$N_* < 10^6$. Therefore, based on shell-FE results, one can conclude that the predictions using the S-N curves for SM490B steel demonstrate the best accuracy proving the fact that specific material data input is more effective than a generic data.

The total discrepancy of fatigue predictions using solid FE formulation was only partly examined in this work, since they require much more preprocessing than shell FE formulation. And they appeared to be about 10-30% more conservative then predictions with shell elements. In addition to high computational costs, solid elements approach requires a Weld Definition File (WDF), which describes the geometry of weld toe together with a surface normal and another vector to define the orientation of the weld. Recently the fatigue analysis in solid formulation has been drastically improved and accelerated with a release of ACT extension for ANSYS Workbench titled nCode Weldline [8], which automates the generation of WDF file.

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