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An individual fatigue assessment approach considering real notch strains and local hardness applied to welded joints

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ABSTRACT

Fatigue crack initiation in welded joints is a complex process influenced by various factors. Although these factors are discussed in the literature, the incorporation of them in assessment procedures is often insufficient or lacking. In this paper we present a novel assessment procedure based on the strain-life approach. The influence of the material in the weld area is considered by applying relations between hardness and fatigue properties taken from the literature. In addition, stress concentrations on the weld surface are captured realistically by using 3D-laser scans of the weld surfaces. The suggested approach is demonstrated on four specimens which are typically used in the construction of steel bridges and promising results are obtained. Nevertheless, more research is necessary in order to verify the exact accuracy of this method for the prediction of fatigue life.

1. Introduction

The task of designing a structure or a component against fatigue crack initiation and growth takes on great importance in the industrial field. For practical design purposes, advisement for different assessment procedures as well as indications of related material parameters are provided in codes and guidelines for example in [1, 2, 3]. Even though, by applying these assessment procedures, safe design can be achieved in most cases, a direct comparison of calculated and experimentally determined fatigue lives often shows high deviations. One possible explanation for this shortcoming lays in the great variety of parameters which influence the process of fatigue. Some of them are difficult to consider in an assessment approach. The structure or the component itself, the surface condition, the material, the loading as well as the sequence of loading and the environment can be considered as the main governing parameters [4]. Many assessment approaches applied in design suffer from two major problems. Firstly, when the approaches are based on the assumption of elastic material behaviour, non-physical high stresses in notched areas have to be corrected before they can be compared to a value such as the fatigue strength of the material. Such correction procedures (support-approaches) are said to be more or less empirical relations neglecting the actual failure mechanisms [5] and often lack a sufficient background in material science. Secondly, some of these assessment approaches are not able to consider the influence of the before mentioned factors satisfactorily, factors which are known to have an impact on fatigue life. By taking into account the above mentioned considerations and by working on these two issues, our goal is to achieve an improvement of the accuracy of assessment and a decrease of the deviations between laboratory tests and computations. When comparing the approaches applied in practical design, the strain-life (ε-N) concept appears to be more advanced, at least from a theoretical point of view. Although the main equation is also an empiric relation between strain amplitude and the fatigue life, the ε-N concept offers two major advantages. Local yielding in highly stressed areas can be considered either by adapting simple elastic-plastic correction procedures or directly by applying finite element (FE) calculations. The material behaviour during cyclic loading can be described by utilising the cyclic stress-strain curve and by presuming a stabilised hysteresis after some initial cycles. Compared to rather simple correction methods such as the Neuber hyperbola, the direct consideration of elastic-plastic material behaviour in the FE calculation provides the possibility of modelling the redistribution effect due to plasticity more realistically [6].

From a practical point of view, the ε-N procedure suffers from a strong dependence on the applied material data sets [7]. The reason for this issue may lay in the basic ideas of the approach. By applying material data derived from laboratory experiments for the design of real structures, it is assumed that the material behaves identically in a real life component as in a controlled tested specimen, which in the most cases is smaller than the real part and it is loaded unaxially and without notches or mildly notched [4]. For practical design purposes, this assumption has to be considered with care because the surface condition, residual stresses, highly stressed volume etc. may be different in real components [4]. As the practical application is concerned, another issue ought to be considered: using fatigue parameters obtained from the literature means that data such as the test conditions and a sufficient

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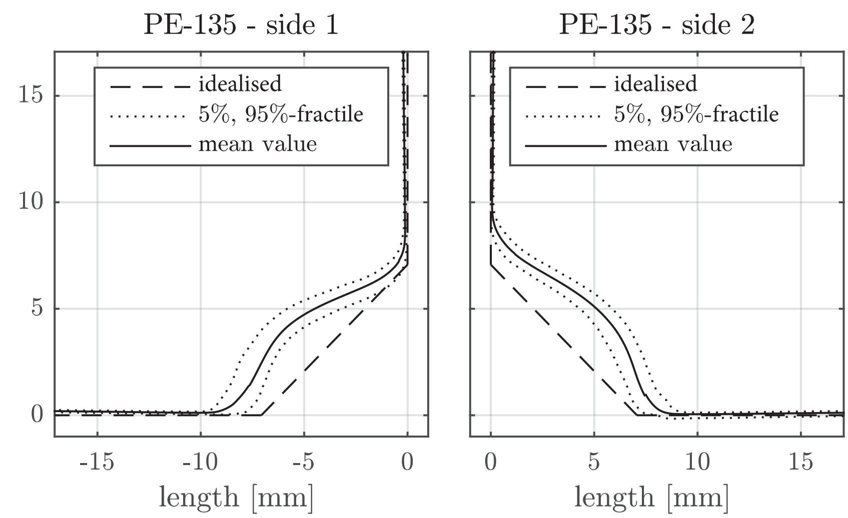

Fig. 1. Deviation from the idealised weld geometry in fillet welds [20].

description of the test specimens is often not available, hence these parameters are applied without adequate knowledge of their validity. That is why, in the literature it is sometimes advised to apply certain approximation formulas for the material properties regarding the fatigue behaviour [7]. Besides the Uniform Material Law (UML) and the Modified Universal Slope Method, there are other alternative methods to predict the fatigue behaviour which depend on a few material properties. The accuracy of these formulas has been investigated and discussed in the literature [8,9,10,11]. In addition to the relation to tensile properties, other researchers have suggested to estimate properties from hardness measurements [12,13,14] and promising results have been reported [15, 16] for similar concepts. This procedure seems particularly interesting when welded joints have to be assessed. Because of the weld process, three different material zones have to be considered. The base material (BM), the material in the heat affected zone (HAZ) and the weld material (WM) itself, which may not have the same material properties [17,18]. Therefore, a link between the hardness in these regions and the fatigue behaviour is desirable. In nearly all assessment procedures applied to welded joints, the question of correct weld modelling is a further topic of interest. The weld form is not always known in detail and approximations are often applied. Sometimes the weld is modelled in a simplified manner by assuming an ideal form or in some cases it is even neglected, which may lead to an incorrect representation of stiffness and stress distribution [19]. Such procedures seem to be an issue as geometries of welds vary [20] and the imperfections on the weld surface may cause additional stress concentrations which are not considered when ideal weld geometries are applied. The consideration of real weld geometries obtained by 3D-laser scanning gained some interest recently as to capture component individual maximum notch stresses for further processing [21, 22, 23, 24]. Other contributions also try to consider a more realistic representation of the weld form in various frameworks [25, 26, 27, 28] or to address the relation of material hardness to fatigue properties [12, 16, 29]. Also the heterogeneity occurring in welds have been addressed recently [30, 31] as to its role in computations. The novelty of the presented approach is, therefore, the possibility to combine the described ideas in the framework of a single assessment procedure. In fact, the fatigue properties based on hardness as well as the real weld geometries obtained by laser scanning are taken into account. Section 2 describes a workflow to determine the fatigue properties based on existing ideas in the literature [13, 14]. In the following section (Section 3), the material properties obtained from

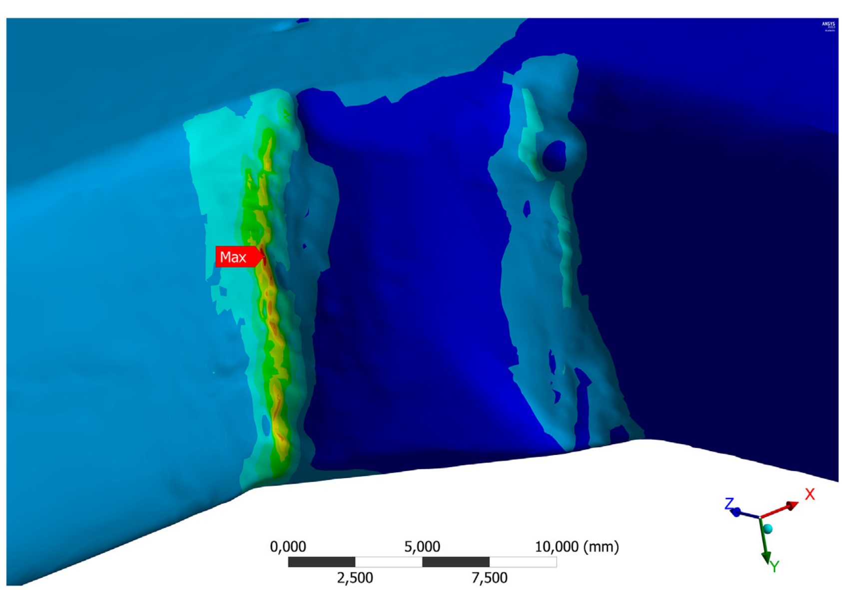

Fig. 2. Real notch stresses in a welded joint [48].