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Effect of weld defects on the fatigue strength of ultra high-strength steels

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Abstract

Enhancing the lightweight potential of mobile steel structures by applying high-strength steels and reducing sheet thicknesses leads to a significant increase of energy effectiveness and a reduction of noxious emissions during operation. However, due to this increase of yield and tensile strength, fracture toughness decreases and notch sensitivity rises. Hence, the local weld geometry becomes more important, especially in case of ultra high-strength steels. This paper deals with the detection and assessment of common geometric weld defects, such as undercuts, and their effect on the fatigue strength of ultra high-strength steel joints. For this purpose, butt joint specimens are welded incorporating ultra high-strength steel as base material. All specimens are judged by visual testing and the detected weld defects undergo an additional surface topography measurement prior to fatigue testing. First, an image processing based *Matlab*©-Routine is built up to evaluate the local geometrical properties of the weld toe including undercuts. Second, a numerical model of the actual weld geometry is generated. This is utilized to perform numerical analyses in order to compute the actual stress concentration factors as well as fatigue parameters in terms of notch stresses. The experimental work covers fatigue tests of undercut-imperfected and defect-free specimens in order to contribute to the effect of such defects on fatigue life. Finally, an enhanced fatigue assessment of welds with undercuts and high-quality joints is performed based on numerical investigations and validated by experimental results.

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Keywords: Fatigue; ultra high-strength steel; welding; weld defects; weld topography

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1. Introduction

The today's trend of environmental friendly construction and operation of mobile crane, heavy freight or special purpose vehicles leads to increased requirements regarding to lightweight design. The application of high-strength or ultra high-strength steels enables a reduction of sheet thickness and is therefore used to reduce vehicle weight in prevailing static load cases. But for cyclic service loading, current fatigue design guidelines for welded structures such as [1] and [2] do not consider the effect of base material yield strength. It is conservatively reasoned that even good workmanship manufactured weld seams possess initial cracks. Besides, it is assumed that all construction steels exhibit a similar crack propagation behavior. Thus, the crack initiation phase is neglected resulting in a fatigue behavior of welded joints independent of the base material steel grade. On the other hand, recent publications tend towards increasing weld fatigue strength utilizing high-strength base materials [3, 4]. Basically, one condition for the applicability of the higher yield strength is the prolongation of the crack initiation phase. This can be ensured by manufacturing high quality welds assuring a smooth weld transition and the exclusion of any severe notches such as undercuts, pores or lack of fusion. One measure to meet these conditions is the optimization of the welding parameters maintaining a smooth and uniform weld topology [5]. Post-weld-treatment methods such as TIG-dressing [6] or HFMI-treatment [7] are further process options to affect the weld toe region beneficially.

This work investigates the effect of single undercuts as characteristic weld defects on the fatigue behavior of high quality ultra high-strength steel welds. A *6 mm* ultra high-strength steel *S1100* is used as base material for this investigation. The sheets are butt-welded in two passes using *G89MC* wire as filler metal. In order to produce small individual undercuts, the welding process parameters knowingly deviate from the optimum process settings. Subsequently, the sheets are cut to specimen shape; the weld root is ground flush to plate to focus on the topology of the weld toe. After removal of process slag from the weld toe, all specimens are visually examined for any weld defects on the surface. Ten of them exhibit undercuts in different shapes and sizes even visible to the naked eye, one is depicted in Fig. 1a. The defect-free specimens were fatigue tested immediately, whereas the defective ones undergo further investigations of the weld surface topography.

2. Weld topography

The local weld geometry is important regarding to the fatigue behavior of welded joints [8 – 10]. In particular, the undercuts shape has a significant influence on the crack initiation phase [11, 12]. Therefore, the weld toe topology of the ten undercut-defective specimens is measured in detail. For this purpose an optical 3D surface measurement device *Alicona InfiniteFocus®* utilizing the focus-variations measurement principle is used. Both weld toes of the butt joint are scanned using the same global coordinate system with a *2.5x* objective magnification. This keeps the resulting data on a manageable size level and allows a minimum measureable radius of *20 µm* and a corresponding maximum slope angle of *87°* [13].

2.1. Data processing

The data in form of the spatial xyz-coordinates is subsequently processed and analysed by a user-defined *Matlab®*-routine. The first steps within this procedure are the exclusion of outlying data points and the connection of the two separate scans for both weld toes using spatial interpolation of the weld reinforcement. Finally the number of data points is reduced by a surface fitting algorithm for further analysis. A sample result for the weld in Fig. 1a is shown in Fig. 1b.