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In-situ crack propagation measurement of high-strength steels including overload effects

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Abstract

In general, the requirements of endurable light-weight structures are challenging tasks for engineers. High-strength steels provide a major potential by replacing commonly applied construction mild steels. However, a higher notch sensitivity and increased crack propagation rates may decrease the benefit of high-strength steels and their practicability of application. Therefore, reliable assessment methods are demanded to assess fatigue life and crack propagation of welded as well as un-welded structures. For this purpose, an optical measurement system consisting of an industrial camera, telecentric lenses, and special LED components is set-up to analyze crack initiation and propagation of high-strength steels compared to common construction mild steels. Furthermore, an image processing program is developed to investigate the crack length during testing automatically. Indirect potential drop measurement method with crack gauge and optical-light microscopical investigations are utilized to calibrate the elaborated image measurement system. Constant amplitude tests including overloads are performed for high-strength and common construction mild steel specimens to specify the material's service strength. Based on the researched data, material parameters for crack propagation analysis are evaluated for these steel grades.

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Keywords: Crack measurement; Optical measurement; Crack propagation; Overload effects; High-strength steel

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1. Introduction

High-strength steel application for light-weight design is a common method to reduce weight and improve fatigue strength of structures. However, a higher notch sensitivity and increased crack growth rates may reduce the benefit of high-strength steel materials. In [1–3] fatigue strength of welded and un-welded base material mild and high-strength steel sheet specimens are investigated. Focus is laid on welded specimens with different weld toe stress concentration factors and the benefits of utilizing high-strength materials. Attention must be drawn on notches and imperfections, which lead to massive reduction on fatigue strength. In this work experimental fatigue crack growth testing is performed on common construction mild steel as well as on high-strength steel sheets. Proper assessment of both crack initiation and propagation stage is of particular interest during testing and subsequent evaluation. To this purpose two different crack growth measurement methods are applied and compared to determine surface crack initiation and propagation length. An optical measurement system consisting of an industrial high-resolution camera, a set of telecentric lenses and a high performance LED-illumination is calibrated for further crack propagation investigation. For image acquisition, the test machine is stopped between a defined number of load-cycles to obtain high accuracy of crack length measurement. The start-up phase and first measurements are given in detail in [4]. In [5,6] similar optical measurement systems are set up for flat test and round bar specimens and have been approved successfully. This paper additionally contributes with an indirect potential drop method to calibrate the optical measurement system. Constant amplitude (CA) loading as well as overload (OL) tests are executed for both material grades. Crack initiation and propagation are separately investigated to draw conclusion from different stages of fatigue life. Overload tests are performed by application of one single OL at a long-crack length of $a_{OL} = 8.5$ mm. Delayed crack growth retardation is observed and leads to an extension of remaining service life for both types of materials. In [7–12] similar investigations of CA loading and variable amplitude loading were performed on different materials enabling a direct comparison of the presented results.

Nomenclature

a_N	Depth of start notch
a_{OL}	Crack length at overload
a_s	Start crack length
CA	Constant amplitude
C_P	Crack growth rate coefficient according to Paris
K_{max}	Maximum stress intensity factor
m_P	Crack growth rate exponent according to Paris
N_{CA}	Number of load-cycles at constant amplitude loading
N_{Ci}	Number of load-cycles until crack initiation
N_D	Number of delay cycles
N_{DI}	Number of real delay cycles
N_{rout}	Number of run-out load-cycles
OL	Overload
R_{OL}	Overload ratio
$r_p(\varphi)$	Size of the plastic zone
$r_{p,OL}$	Size of the plastic zone at overload ($\varphi=0$)
R_σ	Stress ratio
Δa	Crack extension
ΔK	Stress intensity factor range
$\Delta\sigma$	Stress range
ν	Poisson's ratio
σ_y	Yield strength

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