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Fatigue life of welded high-strength steels under Gaussian loads

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Abstract

Within the scope of the investigation of welded high-strength steels for application in crane structures, a Gaussian-like test spectrum is derived from an analysis of recorded load time histories. In addition to stress-controlled fatigue tests under constant amplitude loading, the test spectrum is used for the experimental investigation of MAG-welded butt joints and tubular sample components under variable amplitude loading. A linear damage accumulation using Palmgren-Miner-Elementary is conservative for a damage sum of $D = 0.5$. Application of the theoretical damage sum $D_{th} = 1$ results in a closer approximation of the Gaßner-curve. For further improvement of this approximation, a rotation of the calculated Gaßner-curve, i.e. a variable damage sum, is suggested for both butt joints and sample components.

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Keywords: low cycle fatigue; high-strength fine-grained steels; welded butt joints; tubular sample components, Gaussian load spectra, linear damage accumulation, Palmgren-Miner-Elementary;

Nomenclature

CAL	constant amplitude loading	*a*	amplitude
D	damage sum	calc	calculated
D_{real}	real damage sum	exp	experimental
D_{spec}	damage content of the spectrum	*n*	number of cycles, nominal

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D_{th}	theoretical damage sum	rot	rotated
HCF	high cycle fatigue	t	time
N, $\bar{N}$	number of cycles to failure (CAL and VAL)	$t_{8/5}$	cooling time from 800°C to 500°C
L_s	sequence length	$\Delta\sigma$	stress range
LCF	low cycle fatigue	σ, $\bar{\sigma}$	stress (CAL and VAL)
R, $\bar{R}$	stress ratio (CAL and VAL)		
T_N, $\bar{T}_N$	fatigue life scatter between P_s = 10% and 90% (CAL and VAL)		
VAL	variable amplitude loading		

1. Introduction

The typical fatigue life of crane structures is related to the low cycle fatigue (LCF) regime with a focus on critical details of MAG-welded joints. In order to achieve increasing carrying capacities and to enable lightweight design, high-strength fine-grained steels with a good weldability are applied in the design of highly loaded truck and crawler cranes. When focusing on the reserve in life time, variable amplitude loading (VAL), in addition to the LCF under constant amplitude loading (CAL), of operating truck cranes will be decisive. Therefore, service loads were analysed to derive a test spectrum and a load-time-function for investigations on butt welded high-strength steel specimens and tubular sample components.

Since 2004, truck cranes can optionally be equipped with a data logging system, recording data for the calculation of stress-time histories at highly loaded positions of the crane's telescopic boom. The sampling time varies from 5.0s to 6.6s for different datasets. The stresses were calculated from the external load with respect to geometrical configurations arising from the set-up of the crane and the extent of the telescopic boom. For two truck crane types, eighteen datasets and corresponding stress-time histories were available. The stress-time history of dataset 1 is shown in Fig. 1.

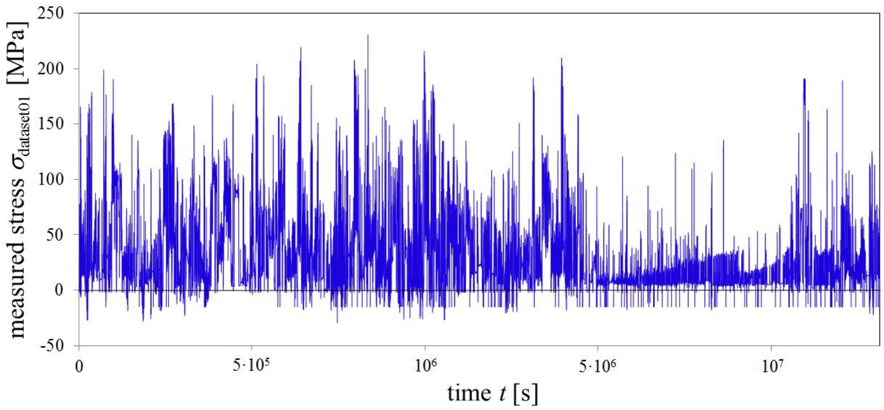

Fig. 1. Stress-time history calculated from measured data of dataset01.

For the realisation of variable loading experiments in the LCF regime, the stress-time history of each dataset was analysed by level-crossing and range-pair counting. The results of the range pair counting, shown in Fig. 2 (a), include maximum values for stress ranges $\Delta\sigma$ between 250 MPa and 350 MPa and still have a sequence length L_s larger than 10^4 cycles. Each spectrum has a Gaussian-like appearance neglecting small stresses (Fig. 2 (b)). Therefore, a mathematical Gaussian distribution was used as a basis. This is furthermore conservative towards a linear spectrum, which is recommended by [1] for service loading by superposition of measured spectra. The gradient between the two highest load levels was increased to account for special high load events (Gaussian-like spectrum), which are typical for truck cranes. In contradiction to widely-used load sequences with L_s = 50.000, an appropriate load sequence for the LCF was finally found using a randomly generated stress-time history with L_s = 200 and the maximum stress at the 113th cycle (Fig. 3). However, for a failure at 1000 to 2000 cycles, an experiment requires 5 to 10 repetitions of the sequence. This is in good agreement with a valid VAL test due to a service-like-load mixing [2, 3].