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On the Fatigue Strength of Bolting Assemblies Made from Carbon Steel and Stainless Steel for Machinery

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Due to their corrosion resistance, bolting assemblies manufactured from stainless steel are becoming more and more important in various applications, such as in offshore structures and machinery. An enhanced level of knowledge based on publications of the last few years offers opportunities of using preloaded bolting assemblies. However, missing design rules and insufficient data on the fatigue strength of stainless steel bolting assemblies limit their application. Neither Eurocode 3 for structural engineering nor VDI 2230-1 for mechanical engineering provide sufficient design rules regarding the verification of the fatigue strength of stainless-steel bolts. A total of 345 fatigue tests at constant amplitude loading up to 10^7 load cycles were carried out on bolting assemblies made from austenitic, duplex stainless steel and carbon steel in nominal sizes, M6, M12, and M20, with strength grades, 80 and 100 (8.8/10.9).

NOMENCLATURE

A_s	Stress cross section
$A_{s,nom}$	Nominal stress cross section
d	Nominal diameter
$F_{0.2min}$	Bolt load at the minimum 0.2 % proof stress
F_m	Mean load
F_{Mzul}	Permissible assembly preload
F_{SAo}	Upper (max.) axial additional bolt load
F_{SAu}	Lower (min.) axial additional bolt load
F_{Sm}	Average bolt load
k	Slope parameter
k_2	Second slope parameter
k_{var}	Variable slope parameter
N	Number of cycles
N_D	Number of stress cycles associated with the endurance limit ($N > 2 \cdot 10^6$)
N_Z	Number of cycles within the fatigue strength range ($10^4 < N < 2 \cdot 10^6$)
P_S	Probability of survival
R	Stress ratio
$R_{p0.2,min}$	Nominal minimum yield strength or 0.2% proof stress
σ_A	Stress amplitude
σ_a	Continuous alternating stress acting on the bolt
$\sigma_{A,99\%}$	Stress amplitude at 99% probability of survival
$\sigma_{A,VDI,99\%}$	Stress amplitude at 99% probability of survival acc. to VDI 2230-1
σ_{ASG}	Stress amplitude of the endurance limit of bolts rolled after heat treatment
σ_{ASV}	Stress amplitude of the endurance limit of bolts rolled before heat treatment
σ_{ax}	Normal stress
σ_{AZSG}	Stress amplitude of the fatigue strength of bolts rolled after heat treatment
σ_{AZSV}	Stress amplitude of the fatigue strength of bolts rolled before heat treatment
σ_b	Bending stress
$\Delta\sigma$	Stress ranges

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KEY WORDS: Stainless steel, bolting assemblies, bolted joint, fatigue strength, VDI 2230 – Part 1, Eurocode 3.

INTRODUCTION

Stainless steel is becoming more important in mechanical engineering, energy, oil and gas, and maritime and offshore sectors due to its corrosion, acid, temperature, and hydrogen resistance. Components made of stainless steel require fasteners that are also corrosion-resistant, and due to installation reliability and maintenance, usually bolting assemblies are used. Cyclically loaded components require high-strength preloaded joints, whose durability with respect to the applied preload level has been proven in recent studies (Stranghöner et al., 2020).

In machinery components and systems, verification of fatigue strength is an essential design criterion. However, the fatigue-resistant design in the finite life region and at the endurance limit ($N > 2 \cdot 10^6$ cycles) of stainless steel bolts is insufficient due to the low number of fatigue tests reported in the literature, the difficulty in comparing results due to varied test conditions (Hechler, 2008; Wang et al., 2019; Stranghöner and Ehrhardt, 2023), and the outdated database (Wiegand et al., 1967).

The lack of knowledge about the axial fatigue strength of stainless steel bolted joints leads to normative deficits compared to carbon steel bolts. This can cause uncertainties in the fatigue design of bolted joints using stainless steel bolts, as defined in existing standards, such as the VDI 2230-1 (VDI, 2015), particularly in the endurance limit. Neither EN 1993-1-9, of the European Committee for Standardisation Eurocode 3 for steel structures (CEN, 2010b) nor VDI 2230-1 for mechanical engineering provide specific recommendations regarding the fatigue resistance of stain-