Evaluation of the fatigue resistance of butt welds in steel towers of wind turbines by fatigue tests and numerical based design with local approaches

Ralf Glienke a,b, Florian Kalkowsky b, Adolf Hobbacher c, Alexander Holch b, Benjamin Ripsch b, Hans-Peter Günther d, Roy Kersten e, Knuth-Michael Henkel f

a) University of Applied Sciences Technology, Business and Design, Wismar, Germany
b) Fraunhofer-Institute for Large Structures in Production Engineering IGP, Rostock, Germany
c) Jade University of Applied Sciences, Wilhelmshaven, Germany
d) Stuttgart University of Applied Sciences, Department of Civil Engineering, Building Physics and Business Management
e) Enercon GmbH, Aurich, Germany
f) University of Rostock, Faculty of Mechanical Engineering and Marine Technologies, Chair of Joining Technologies, Rostock

ABSTRACT
The fatigue strength verification of constructional details in towers of wind turbines is generally carried out using nominal stresses acc. to the Eurocode 3, part 1-9. Butt-welded joints are one of the most common constructional details in these structures. In this paper, results from fatigue tests on transversely loaded butt welds and FEA using the effective notch stress and the crash propagation approaches are presented. By using macroscopic measurements and a 3D scan, the notch effect of the weld seam geometry was considered in the FEA. These results were compared with results from fatigue tests. Based on the successful alignment between simulation and experiment, the possibility to discuss the fatigue resistance influencing variables from the seam geometry is presented.

KEYWORDS: transversely loaded butt-weld, weld imperfections, wind turbine tower, fatigue strength, local approaches

INTRODUCTION
Electricity from on- and offshore wind farms is an important part in achieving the goal of increasing the share of renewable energies. This results in a rapid further development of wind turbines. The growing nominal power of wind turbines leads to an increase in rotor diameter and hub height and stricter requirements related to wear, material fatigue and corrosion protection systems. Due to its impact on the total costs, the optimization of the tower structure is one of the most important design factors. One of the most common constructional details in such tower structures are butt-welded joints with DV-weld geometry (see Fig. 1). For tubular steel towers steel grade S355 with plate thicknesses from 14 mm up to 70 mm is used. Monopiles for offshore foundations currently have plate thicknesses up to 170 mm. The butt-welds are welded through the whole profile and do not have a systematic axial misalignment e. The sub-merged arc (SMA) welding process is used due to the plate thicknesses and the required melting deposition rates. This fully mechanized welding process and the high manufacturing standard cause the intention to consider the high execution quality in the fatigue strength verification. The seam geometry of SMA welded joints with its reduced weld height h and smooth weld toe angles α results in a lower notch effect and likewise in a higher fatigue resistance (Drebenstedt, K.; et al., 2021). Therefore, the necessity to re-evaluate the FAT-class of transversely loaded butt-welds is obvious. The FAT-class of butt-welded joints according to the Eurocode 3 is based on n = 2,843 fatigue tests, while a complete documentation of the geometric weld dimensions is only available for a few test specimens. In addition, most of these tests were performed for plate thickness smaller than t ≤ 25 mm and the maximum of tested plate thickness was t = 40 mm. Based on these fatigue test, no significant effect of the thickness could be observed. (Feldmann, M.; et al., 2019) In contrast, the numerical studies with the effective notch stress approach in this project show a clear thickness dependency.

Fig. 1. Wind turbine from ENERCON (left), illustration of welded details in steel towers (centre) and manufacturing of a tower (right)

An overview of the available fatigue design codes is given and the main influencing parameters on the fatigue strength of butt-welded joints are briefly discussed in this paper. In addition, results from fatigue tests on butt-welded specimen with and without different plate thicknesses, up to a plate thickness of t = 40 mm, will be presented. A complete documentation of the weld seams geometry is available for these specimens and is presented in summary. All weld imperfections were measured and show the potential of higher weld seam quality acc. to ISO 5817 (ISO 5817:2014-06) by using the SMA welding process regarding fatigue resistance. The fatigue test results will be compared to results from the effective notch stress and the crack propagation