Fatigue Performance of Welded Steel Longitudinal Stiffeners

Jonas Hensel, Thomas Nitschke-Pagel and Klaus Dilger
Institute of Joining and Welding, Technische Universität Braunschweig
Braunschweig, Germany

ABSTRACT

The fatigue strength of welded structures is generally dominated by the most critical weld detail. How critical such a weld detail for the fatigue performance of the entire structure is, depends strongly on the geometrical notch effect, the present residual stress state and the loading conditions. The here presented investigations focus on the influence of the mentioned parameters on the fatigue life of longitudinal stiffeners. This type of structural detail is characterized by its strong geometrical notch and the distinctive residual stress conditions. Further the high level of constraints causes multiaxial stress states under loading. Research was undertaken on two steel grades, a low strength fine grain steel S355NL and a quenched and tempered fine grain steel S960QL. Residual stresses at the face sides of the stiffeners were determined by means of X-ray diffraction. The influence of the notch effect was captured by testing specimens in the as-welded condition and also after a TIG-dressing post weld treatment. Fatigue testing was performed under constant amplitude loading up to the high cycle fatigue region with N=5x107 load cycles. The presented tests were carried out under alternate tension and compression at a stress ratio of R~1. It was to study the effect of the varied parameters on the fatigue strength, the number of load cycles associated with the knee point of the S-N curve and the inclination k of the S-N curve.

KEY WORDS: Fatigue testing; longitudinal stiffener; TIG-dressing; knee point; residual stresses; notch effect.

INTRODUCTION

The fatigue strength of welded steel structures is of great importance for offshore engineering. Welded steel is used in various applications for ship building and offshore structures. All types of structures have in common to be exposed to highly dynamic loads from wind, waves and potentially machinery. The design of welded structures is therefore mostly governed by the fatigue limit state. For design purposes, S-N curves are provided in design guidelines, technical rules and fatigue design recommendations based on allowable nominal stresses (e.g. Eurocode 3, DNV-RP-C203 and Hobbacher, 2007). Characteristics of S-N curves such as the inclination k and the number of load cycles associated with the knee point are standardized and given by such regulations. The definition of design S-N curve parameters accounts for unfavorable influences on the fatigue life e.g. from fabrication on site. This is a safe and good assumption if fabrication tolerances are fully utilized. But in case of fabrication with controlled weld parameters and minimized geometrical tolerances, the design might be very conservative. Controlled fabrication can take place wherever tolerances can be held small, e.g. due to serial production or advanced quality assurance. Some regulations give guidance on how to treat positive fabrication effects from special quality control or post weld treatments (Hobbacher, 2007). These effects can lead to an increase of allowable stresses, considered in the design phase by a higher FAT-class. However, the positive effects on the number of load cycles associated with the knee point are not regarded. But especially the location of the knee point provides high potential for light weight design and/or better utilization of welded joints. A fixed knee point at a high load cycle value represents still conservative design conditions for welded details. Fig. 1 demonstrates the possible win in allowable stresses for a high cycle fatigue design with over N=109 load cycles. By moving the knee point from Nk1=1x107 load cycles as stated in typical design rules to Nk2=1x108 load cycles, the allowable stresses increase by a factor of 2.15. This would allow slender structures or a higher durability of welded details. A weld detail of special interest in this matter is the longitudinal stiffener. The knee point of S-N curves for these details ranges from 1x106 to 1x107 load cycles depending on the initial state of tested specimens (Somsino, 2007). Longitudinal stiffeners can be found as a not load-bearing attachment to structures for lifting purpose or as a stiffener in large plates or shells to avoid buckling. This weld detail has a comparatively low fatigue strength with FAT-classes from 56 to 80 (DNV-RP-C203) or even 50 to 80 (Hobbacher, 2007) depending on the length of the attachment. Thus it can govern the fatigue design although it is not necessarily part of the primary steel. A welded longitudinal attachment is characterized by its strong geometrical notch and the distinctive residual stress conditions. In general it is assumed that high tensile residual stresses are induced by the welding process, which may affect the fatigue performance strongly. These residual stresses are caused by geometrical constraints during the cooling phase after welding and by phase transformations in the weld itself and in the heat affected zone. The stability of the residual stress state under static and cyclic loading is also dependent on the geometrical constraints around.