A. Estimation of the Elasto-Plastic Notch Stress-Strain For Low Cycle Fatigue Design of Welded Ship Structure

by Yooil Kim, Chun-Sik Shim, Joong-Kyou Kang and Joo-Ho Heo, DSME

Introduction

Quite recently, many cracks have been reported in welded ship structure which voyaged less than five years after delivery. Considerable works have been carried out on these cracks to find out the cause of failure ending up with no solution within the context of existing ship classification society's fatigue design recommendations. This raised concerns of ship owner and shipyard not to speak of classification society about structural soundness of their vessels, quality of design and its procedure. At the same time, it also ignited research works focusing on the basic understanding of low cycle fatigue in ship structure as well as standardization of design methodology against low cycle fatigue.

This study has been carried out to meet the needs of the industry that is primarily on the building design guidance on low cycle fatigue in ship structure based on the fundamental understanding of it and relevant material/fatigue test data. One of the difficulties being there with low cycle fatigue of welded joint is that there are so many uncertainties related to the fatigue governing parameters such as, geometry of weld, which can be represented by SCF, and heterogeneous material properties, which is important in low cycle fatigue regime only. Basically, fatigue test under high stress low cycle regime was carried out under strain controlled condition with welded joint specimen which was fabricated according to the shipyard's practice. Obtained nominal strain based test data need to be converted into notch stress/strain based one to be consistent with existing high cycle fatigue design recommendation which is based on notch stress at the very weld toe. Direct nonlinear finite element analysis was carried out using nonlinear kinematic hardening model which was calibrated based on the experimentally determined material properties. Simplified nonlinear analysis which take advantage of stabilized cyclic stress-strain relation was also carried out to reduce time required for transient analysis. Finally, by comparing numerical results and experimental data, conclusion was made on how well each analysis method compare with each other. Also, suggestion was made on what material curve should be used in conjunction with Neuber/Glinka's rule to take into account the effect of material heterogeneity in its prediction.

Conclusions

Material model of nonlinear kinematic hardening was established based on the experimental data. It turned out that isotropic hardening component was not considerable for the material that is covered in this study. Averaged kinematic hardening parameters is thought to be a good approximation for given material and analysis model. Spatially varying material property was assigned to HAZ region. Linearly varying material parameters are obtained by interpolating hardening parameters C, keeping γ constant.

Fatigue test result of partially penetrated nonload carrying fillet welded joint was converted into pseudo notch stress based SN curve based on the nonlinear FE analysis results. It was observed that test data is in good agreement with current design curves when it is extended to low cycle regime without slope correction.

In view of conservative fatigue design, conventional Neuber's approximation rule seems to be the most conservative one in the estimation of elasto-plastic notch stress-strain state. Cyclic stress-strain relation of weld metal should be used in conjunction with Neuber's formula, when dealing with weld toe crack. Use of base metal material property turned out to be way too conservative. Both Neuber and Glinka's rule did not work properly when net section yielding occurs.