Study on Stress-Strain relation of Welded Joint with Experiment and Computation Based on GTN Model

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ABSTRACT

Ship steel structures are always fabricated with welding, while mechanical performance and fracture strength of welded joints will significantly influence the strength and service life of whole ship with considering the impact of actual practice and external loading. In this study, base materials of ship steel plate (Q345 and Q690) were examined with uniaxial tension tests to establish stress-strain curve, which can be employed for assessment of fracture performance. With Gurson–Tvergaard–Needleman (GTN) failure mode, computational code was programmed and a series of numerical analyses were carried out to investigate the fracture behavior of ship steel plate, while constitutive relations of examined ship steel plates were proposed with optimized parameters of GTN failure mode. In addition, computed results of stress-strain curve have a good agreement comparing with experimental data. Concentrating on the butt welded joints of ship steel plate with high welding quality, uniaxial tension test was also conducted to obtain stress-strain curves of welded joints. In order to consider the influence of micro welding defects and welding residual stress on fracture performance of welded joints, modified initial void volume fraction and plastic hardening parameters were proposed, while good agreement between computed results and measurement was observed for fracture performance of welded joints. The feasibility of predicting the mechanical performance of welded joint with the GTN model was verified.

KEY WORDS: GTN model; uniaxial tension test; stress-strain curve; fracture performance of welded joint; strain hardening with power function; searching algorithm for parameter optimization.

INTRODUCTION

Ship structures are generally fabricated with a large number of metal plates and components through welding process. Defects which start locally from the weld seam, will expand under the influence of external loads, resulting in failure of the entire ship structure. Therefore, it is particularly important to evaluate the mechanical performance of welded joints. Welding is a complex multi-physics coupling process. The heat effects of welding arc are local and transient, which inevitably produce microcosmic defects and welding residual stress, and the mechanical performance of the ship welded structure will change significantly. The stress-strain curve of the welded joints can be measured through uniaxial tension test, and then the fracture mechanical performance of the welded joints can be evaluated. However, due to the differences in plate thickness, welding groove, and welding method, there are many types of welded joints. The method based on experimental measurements is time-consuming and labor-intensive, and causes permanent damage to the ship structures. It is inappropriate to evaluate the mechanical performance and service life of the ship structures. Therefore, the method based on the standard tension test of the base materials of ship steel plate and GTN damage model can be used to predict the stress-strain curve of the welded joints and investigating its fracture mechanical properties, which has significant advantages and engineering application value. Gurson (1977) analyzed the hollow sphere made of ideal plastic Mises material and proposed the yield function of the material, which included the void volume fraction, the equivalent stress, the mean normal stress, and the yield stress of the matrix material. Tvergaard and Needleman (1984) then introduced adjusting parameters in the Gurson model in order to better simulate the loss of material stress carrying capacity during void growth and coalescence, and the new model was called the Gurson–Tvergaard–Needleman (GTN) damage model. The GTN damage model is widely used in fracture analysis of metallic materials, especially steel structures. Xiao et al. (2018) determined the GTN parameters of 6016 aluminum alloy taking the experimental force versus displacement curve, the fracture and the necking behavior as judgement criteria. Han et al. (2017) studied the failure phenomenon of 6061 aluminum alloy plate based on the modified GTN-Hill948 model. The finite element analysis was used to verify the correction of the GTN model parameters by using a tension model with a hole in the middle, and it can effectively predict the location of failure.