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Fracture assessment of cracked welded structures considering the heterogeneity of welded joints

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Abstract

The crack-like defects often cause the failure of welded structures. Most of the fracture assessment procedures that are used for solving this problem are based on deterministic approaches, for example Zerbst (2007). But the experimental results show that the mechanical properties and fracture toughness of welded joints are significantly changing with a random variation. Taking this into account the fracture assessment of welded structures requires improved numerical approaches. A numerical model of heterogeneous welded joint with randomly varying yield strength was proposed. The results show that the mechanical heterogeneity leads to higher J-integral values for the defects. This implies that neglecting the mechanical heterogeneity of welded joints results in underrating of the risk of failure of welded structures. The proposed numerical estimation of the fracture toughness is used for some typical welded joints and thin-walled pressure vessel. The relations between the variation of yield strength in cracked welded joints and J-integral are presented as the correction functions for calculated parameter of crack resistance.

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Keywords: welded structures; weld joint; heterogeneity; crack; J-integral

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1. Introduction

The traditional methods for estimation of the fracture toughness of welded joints are mostly based on the stress intensity factor, the crack tip opening displacement and J-integral. These criteria consider applied loads, loading conditions and other factors. However, the effect of the mechanical heterogeneity on fracture of welded joints is not included directly in these parameters and needs to be studied. The mechanical heterogeneity of microstructure leads to significant nonlinear deformations in the cracked area. It requires the improvement of methods to estimate the fracture toughness of welded structures.

The nonlinear effects in welded joints are generally studied as “soft” and “hard” layers using finite-element modeling when mechanical properties are constant in each layer. But in fact, the mechanical properties in a welded joint such as yield strength change from one zone to another with some random variation.

2. The experimental study and numerical implementation of the mechanical heterogeneity of welded joints

To determine the real variations of mechanical properties and fracture toughness in different zones of welded joint the experiments on steels 9MnSi5 and X10CrNiTi18-10 were carried out as it was reported by Moskvichev (2013). The double-V welded joints which are shown in Fig. 1 were made of both steels and tested on hardness, yield strength, ultimate strength and failure parameter J_{IC}.

By processing the experimental data the mean values and coefficients of variation (CV) of the investigated parameters were estimated for each zone of the welded joint depending on the distance from the center of the welded joint x. These results were used to develop a finite-element model for evaluation of fracture toughness taking into account the mechanical heterogeneity of welded joints.

Table 1. The variation of microhardness, yield strength, ultimate strength and fracture toughness J_{IC} of welded joints of steels 9MnSi5 and X10CrNiTi18-10.

Weld zone	Microhardness		Yield strength		Ultimate strength		J_{IC}	
	Mean [HV]	CV	Mean [MPa]	CV	Mean [MPa]	CV	Mean [kJ/m^2]	CV
				9MnSi5				
Base metal	264	0,07	442	0,04	593	0,02	84	0,14
HAZ	263	0,05	466	0,07	631	0,01	87	0,26
Weld metal	269	0,08	414	0,06	571	0,04	89	0,07
				X10CrNiTi18-10				
Base metal	394	0,07	397	0,07	686	0,004	481	0,05
HAZ	400	0,07	406	0,05	668	0,02	545	0,19
Weld metal	432	0,10	420	0,16	661	0,07	495	0,04

The proposed model of the welded joint is shown in Fig. 2. It was represented as a set of finite elements with varying yield strength. Accordingly, the yield strength for each finite element was specified at random by the normal distribution with certain parameters. The mean value of yield strength was set as gradually changing from one zone to another according to the piecewise linear function $f(x)$ which represented the experimental data. Based on the proposed numerical model the fracture toughness of a welded plate with central crack was estimated. The problem was solved with the ANSYS software using APDL macro.