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Procedia Structural Integrity 6 (2017) 269–275

Structural Integrity Procedia

www.elsevier.com/locate/procedia

XXVII International Conference "Mathematical and Computer Simulations in Mechanics of Solids and Structures". Fundamentals of Static and Dynamic Fracture (MCM 2017)

Study on Crack Branching Condition for Brittle Crack Propagation in Steels

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Abstract

In brittle material like glass, it is observed that crack branches when the crack speed gets more than the material critical velocity. When the crack branches, the driving force at running crack tip gets lower, so it is possible to prevent the structure from serious failure. In this paper, using the devised under-matched welded joint to implement the higher crack velocity, the mechanism of crack branching and surface roughening is investigated by experiments and the dynamic Finite Element Method (FEM) analysis.In the result, crack surface roughening happens when the crack velocity is around 800m/s, contrary to the findings of the elastic dynamic fracture mechanics. FEM analysis was conducted to explain the phenomenon and it is possible that the high stress triaxiality can be the critical condition for crack branching.

*Keywords:*Brittle crack propagation; Steel; Dynamic fracture; Finite Element Method analysis

1. Introduction

Large structure can collapse by brittle fracture, so technology is required for arresting brittle crack propagation[1]. In brittle material like glass or PMMA, it is observed that crack branching occurs when the crack speed gets more than the material critical velocity[2]. However, the amount of study is small which focuses on the crack branching behavior in steels. When the crack branches, the driving force near the crack tip gets lower, so the material gets less likely to collapse.

In this study, for investigating the possibility of utilizing the crack branching for arresting the crack propagation, critical condition for crack branching is examined with the brittle crack propagation test and FEM analysis.

10.1016/j.prostr.2017.11.041

2. Previous study

In the classical elastic dynamic fracture theory, it is thought that crack branching occurs when the crack velocity gets higher than the material critical value. Yoffe [3] calculated the analytical solution of stress distribution near the crack tip when the crack length is constant and showed maximum circumferential stress deviates from the straight crack direction when the crack velocity gets higher than $0.7v_R$.

Y.J.Jia etc.[4] simulated dynamic fracture behavior with discrete spring mass system and conducted the numerical analysis on crack propagating mechanism at several crack speed. From the results, maximum circumferential stress works at $60°\sim70°$ away from the straight path when the crack speed gets more than 1800m/s. Table 1 shows the critical speed and crack branching direction in previous study.

Table 1. The results of previous study on crack branching behavior

Source	Material	C_b/C_0
Yoffe	Theoretical Prediction	0.38
Anthony et al.	Glass	0.39
Bowden et al.	Glass	0.29
Congleton	Tool steel	0.26
Doll	Plate Glass, FK-52 Glass	0.28, 0.30
Hahn et al.	A533B Steel	0.10
Irwin et al.	Homalite-100	0.24
Kobayashi et al.	Homalite-100	0.22
Paxson et al.	Plexiglass	0.36
Schardin	Glass	0.30

3. Experiment

Specimen used in the experiment is shown in Fig. 1. The specimen is composed of part A (around the crack propagation area), part B (crack propagation area), part C (segregated from part A and B), and tab plates. Tensile load is applied on both sides of the specimen. In the experiment, the top of the specimen was stroke by air gun and the brittle crack was propagated. Crack gauges and strain gauges are instrumented in the crack propagation area (Fig. 2) for measuring the crack propagation velocity. The temperature was maintained at -100°C in entire region in test specimen. In the specimen with soft welded joint, high nickel steel is used as part A and N30 steel is used as part B. Mechanical properties of both are shown in Table 2.

Applied stress, σ_g, and the width of part B are changed in several experiment conditions. Each condition is shown in Table 3.

Table 2 Mechanical properties

Part A High-Nickel Steel	Manufacturing process	Tensile test			Charpy impact test	
		YS[MPa]	TS[MPa]	EL[%]	vE_{-196}[J]	vTrs[deg. C]
	Quench and Temper	677	718	29	202	-

Part B N30 steel	Manufacturing process	Tensile test			Charpy impact test	
		YS[MPa]	TS[MPa]	EL[%]	vE_{-20}[J]	vTrs[deg. C]
	Normalizing	416	541	27	295	-40