NOVATEUR PUBLICATIONS
INTERNATIONAL JOURNAL OF INNOVATIONS IN ENGINEERING RESEARCH AND TECHNOLOGY [IJIERT]
ISSN: 2394-3696
VOLUME 2, ISSUE 11, Nov.-2015

LITERATURE REVIEW ON FRACTURE TOUGHNESS AND IMPACT TOUGHNESS

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ABSTRACT

The present paper gives a technical review of fracture toughness, and impact toughness for metallic materials in terms of the linear elastic fracture mechanics. This includes the early investigations and recent advances of fracture toughness test methods and practices developed by various agencies and societies. The review describes the most important fracture mechanics parameters: such as the elastic energy release rate G, the stress intensity factor K, the J-integral, the crack-tip opening displacement (CTOD) and the crack-tip opening angle (CTOA) from the basic concept, definition, to, test methods. Attention is paid to guidelines on how to choose an appropriate fracture parameter to characterize fracture toughness for the material of interest, and how to measure the fracture toughness value defined either at a critical point or in a resistance curve format using laboratory specimens. The effects of loading rate, temperature and crack-tip constraint on fracture toughness as well as fracture instability analysis are also reviewed.
Keywords: Fracture toughness, Impact toughness, CTOD, CTOA.

INTRODUCTION

Fracture toughness is generally used as a "generic term for measures of material resistance to extension of a crack." Fracture toughness testing and evaluation has been a very important subject in development of fracture mechanics method and its engineering applications. The experimental measurement and standardization of fracture toughness plays an important role in application of fracture mechanics methods to various evaluation methods such as

1. structural integrity assessment,
2. damage tolerance design,
3. fitness-for-service evaluation,
4. residual strength analysis for different engineering components and structures

The fracture toughness values are also used as a basis in following

1. Material characterization,
2. Performance evaluation,
3. Quality assurance for typical engineering structures, including
4. Nuclear pressure vessels and piping,
5. Petrochemical vessels and tanks,
6. Oil and gas pipelines,
7. Automotive,
8. Ship and aircraft structures

Therefore, we have concentrated to review the work done by engineers and scientists on results of fracture mechanics tests, which are directly applicable to fracture control and to fracture test in describing the material property for a crack to resist fracture.

The stress intensity factor K (or its equivalent partner – the elastic energy release rate G), the J-integral, the crack-tip opening displacement (CTOD), and the crack-tip opening angle (CTOA) are the most important parameters used in fracture mechanics. The K factor was proposed in 1957 by Irwin [1] to describe the intensity of elastic crack-tip fields, and symbolizes the linear elastic fracture mechanics. The J-integral was proposed in 1968 by Rice [2] to characterize the intensity of elastic– plastic crack-tip fields, and symbolizes the elastic–plastic fracture mechanics. The CTOD concept was proposed in 1963 by Wells [3] to serve as an engineering fracture parameter, and can be equivalently used as K or J in practical applications. The CTOA parameter was used in the recent decade to describe fracture behavior of stable crack extension for thin-walled materials. Different experimental methods have been developed for measuring these parameters to describe fracture toughness of materials. The detailed descriptions of these fracture mechanics parameters and their applications can be found in the textbooks of fracture mechanics, such as those by Broek [4], Kanninen and Popelar [5], Hertzberg [6], Anderson [7] and others. The basic fracture mechanics concepts were summarized by Irwin and Dewit [8]. Recently, Erdogan [9] and Cotterell [10] reviewed the history and development of fracture mechanics. Extensive applications of fracture mechanics methods via fracture toughness in structural integrity and assessment were documented in a set of 11-volume comprehensive books compiled by Milne et al. [11]. Standard terminology relating to fracture toughness testing and evaluation has been defined in E1823 [12] by the American Society for Testing and Materials (ASTM) in the United States. All terms and concepts pertaining to fracture tests used in this work are consistent with those defined by ASTM E1823.

LITERATURE SURVEY

The literature survey on the fracture toughness and impact toughness has been carried out to get more out of it. Following are the important research papers which are reviewed.

Xian-Kui Zhu, James A. Joyce "Review of fracture toughness (G, K, J, CTOD, CTOA) testing and standardization" Engineering Fracture Mechanics 85 (2012) 1–46

This paper gave a systematic technical review of fracture toughness testing, experimental evaluation, test methods and standardization for metallic materials in reference to both the linear elastic fracture mechanics and the elastic–plastic fracture mechanics. This review described the most important fracture parameters of the elastic energy release rate G, the stressntensity factor K, the J-integral, the crack-tip opening displacement d, and the crack-tip opening angle (CTOA) and presented, basically in the chronological order, the historic and state-of-the-art developments of these fracture parameter test and evaluation methods. The basic concept, definition, experimental estimation, early fracture test practice, test method, recent development, critical point-value toughness evaluation, and resistance curve testing as well as ASTM standardization

Effort of fracture test methods were described in detail for each fracture parameter of K (or G), J, CTOD, and CTOA. The effects of loading rate, temperature, crack-tip constraint and fracture instability on fracture toughness measurements were also reviewed. Three typical fracture mechanics constraint theories, i.e. the J–T approach, the J–Q theory and the J _ A2 three-term

Solution and their applications to quantifying the constraint effect on fracture toughness were briefly reviewed

Yasuhito Takashima, Mitsuru Ohata, Fumiyoshi Minami "CTOD toughness correction for laser welded joints with narrow hardened zone" 20th European Conference on Fracture (ECF20)

This paper discussed the influences of very narrow weld bead and highly strength overmatching on the fracture toughness of laser beam welded components with focus on the difference of plastic constraint in fracture toughness specimen and structural components with crack in the weld metal. The equivalent CTOD ratio, β, for the correction of CTOD toughness for constraint loss in structural components was numerically analyzed.

Ganesh Puppala, Aniruddha Moitra, S. Sathyanarayanan, Rakesh Kaul, G. Sasikala, Ram Chandra Prasad, Lalit M. Kukreja "Evaluation of fracture toughness and impact toughness of laser rapid manufactured Inconel-625 structures and their co-relation'

The paper demonstrated that laser rapid manufactured structures of Inconel-625 are associated with fairly good fracture toughness. Laser rapid manufactured specimens; in as-laser rapid manufactured and heat treated conditions (at 950 _C) exhibited stable crack growth behavior during CTOD test without any popin. CTOD fracture toughness (dm) was found to be in the range of 0.28–0.54 mm, which is relatively lower than those reported for IN-625 weld metal. Fracture toughness parameters, viz. CTOD–di and JiD estimated from instrumented impact test results of unprecrcked Charpy specimens, were in close agreement with the experimentally evaluated data considering appropriate empirical relations proposed in the open literature.

Abdel-Hamid I. Mourad, Aly El-Domiaty, Yuh J. Chao Fracture toughness prediction of low alloy steel as a function of specimen notch root radius and size constraints

The experimental results in this paper show the dependence of the fracture toughness on the specimen thickness and the ligament length. Acritical notch root radius was found at which the fracture toughness is completely independent of the notch root radius for all specimens with different ligament lengths. The predicted fracture toughness using the developed models is in good agreement with the measured data.

Mario S.G. Chiodo, Claudio Ruggeri J and CTOD estimation procedure for circumferential surface cracks in pipes under bending

This work provides an estimation procedure to determine the J-integral and CTOD for pipes with circumferential surface cracks subjected to bending load for a wide range of crack geometries and material (hardening) based upon fully-plastic solutions. A summary of the methodology upon which J and CTOD are derived sets the necessary framework to determine nondimensional functions h1 and h2 applicable to a wide range of crack geometries and material properties characteristic of structural, pressure vessel and pipeline steels.

Yifan Huang, Wenxing Zhou J-CTOD relationship for clamped SE(T) specimens based on three-dimensional finite element analyses

In this work three-dimensional (3D) finite element analyses (FEA) of clamped single-edge tension (SE(T)) specimens are performed to evaluate the plastic constraint factors (m) that are used to relate the crack tip opening displacement (CTOD) and the J-integral (J). The analysis covered both plane-sided and side-grooved specimens with a range of specimen configurations (a/W = 0.2 to 0.7 and B/W = 1 and 2) and strain hardening exponents (n = 5, 8.5, 10, 15 and 20). Based on the analysis results, a new empirical m-factor equation is proposed as a function of a/W, B/W, the yield-to-tensile strength ratio and the loading level.

S.Yoshizu, H.Nakai, K.Shibanuma, H.Yoshinari, S.Aihara Probabilistic Fracture Mechanics Analysis on the Scatter of Critical CTOD

The paper proposes a new model which more precisely predict fracture toughness's as well as fracture initiation points. The present model incorporates micro crack nucleation and propagation in a volume element and applies the weakest link mechanism to the volume elements in a process zone. The model was validated by the CTOD tests of a structural steel. That is, the model can predict the distribution of fracture initiation points, as well as that of critical CTOD values

CONCLUSION

The literature survey done in this paper basically highlights the various parameters analyzed while dealing with fracture toughness and impact toughness. Also high quality work of some of the esteemed researchers showed that importance of fracture toughness and impact toughness in selecting engineering materials.

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