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Literature Review on Fracture Toughness of different Engineering materials

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ABSTRACT

The present paper gives a technical review of fracture toughness for engineering 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 societies. The Basic fracture mechanics parameters for analysis are stress intensity factor K, elastic energy release rate G, crack-tip opening displacement (CTOD) , J-integral and crack-tip opening angle (CTOA) from the basic concept, definition, to, test methods. The important aspect are to guidelines on how to choose an appropriate fracture parameter to characterize fracture toughness for the material of interest, and also how to measure the fracture toughness value defined at a critical point using laboratory specimens. The effects of loading rate, temperature and crack-tip constraint on fracture toughness as well as fracture instability analysis are reviewed.

Keywords: Fracture toughness, Energy Release rate, Stress intensity factor, J- integral, CTOD, CTOA

I. INTRODUCTION

In material science, Fracture Toughness is a property describes the ability of a material containing a crack to resist the fracture known as fracture toughness, and is one of the most important properties of any material for many design applications. Basically three modes of crack propagation as depicted in Fig. 1. are studied in fracture mechanics. Mode I and Mode II are the planar modes. Mode I is caused by stresses normal to the crack face while Mode II is due to shear stresses along the crack face. Mode III is an anti-plane mode caused by tearing loading.

The linear elastic fracture toughness of a material is obtained from the stress intensity factor (K) at which a crack in material begins to grow. It is denoted as K_{IC} and has the units of Pa.m$^{1/2}$ or Psi.in$^{1/2}$. Elastic - plastic fracture toughness (EPFM) is that how much energy needed to grow a crack denoted by J_{Ic} , with the unit of J/cm^2 .

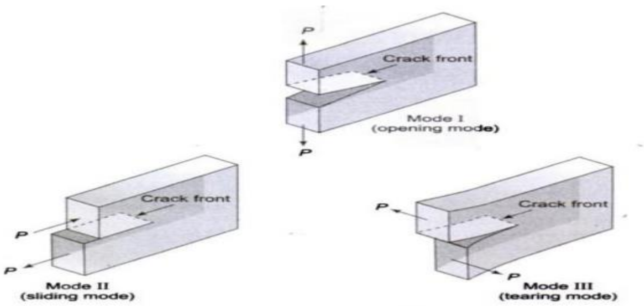

Figure 1: Modes of crack propagation

Fracture Toughness is a quantitative way of expressing a material's resistance to brittle fracture when a crack is present. If material has high fracture toughness it will probably undergo ductile fracture. In Brittle fracture, no plastic deformation takes place that means low fracture toughness. Fracture mechanics, which leads to the concept of fracture toughness, was broadly based on the work of A. A. Griffith[1] who studied the behavior of cracks in brittle materials.

Fracture toughness plays an important role for the experimental measurement and standardization.

Application of fracture mechanics methods are various assessment methods such as fitness-for-service evaluation, residual strength analysis, structural integrity assessment, damage tolerance design for different engineering components and structures.

The fracture toughness values are used in Performance assessment, Material characterization, Ship and aircraft structures, Quality assurance for typical engineering structures, nuclear pressure vessels, Petrochemical vessels and tanks, Oil and gas pipelines etc. There are some standardized Fracture mechanics test specimens as show in Fig. 2 for finding out fracture toughness of engineering materials.

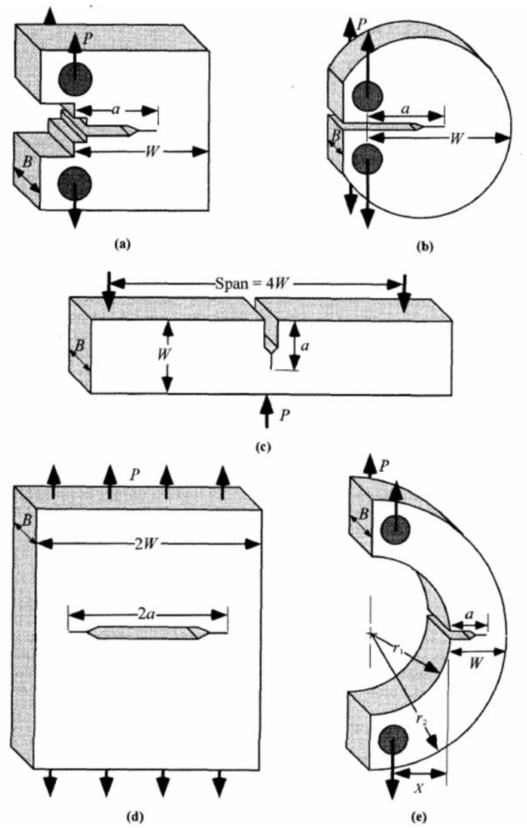

Figure 2: Standardize specimens

From Fig. 2 (a) Compact tension specimen(CT Specimen) (b) Disc-shaped compact tension specimen (DCT specimen)(c) Single edge notch bend specimen (SENB specimen) (d) Middle tension specimen and (MT specimen) (e) Arc-shaped tension specimen.

The relevant ASTM fracture toughness test standards considered in this paper are E561[3] for K–R curve testing, E813[4] for J_{Ic} testing, E1152[5] for J–R curve testing, E1737[6] for J_{Ic} and J–R curve testing, E1290[7] for CTOD testing, E399[2] for K_{Ic} testing, a combined common test standard E1820[8] for measuring the three parameters of K, J and CTOD.

II. LITERATURE REVIEW

Xian-Kui Zhu and James A. Joyce[09] "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 interpretation, test methods and standardization for metallic materials with respect to both the linear elastic fracture mechanics and the elastic–plastic fracture mechanics. That described the most important fracture parameters of stress intensity factor K, elastic energy release rate G, J-integral, crack-tip opening displacement , and crack-tip opening angle (CTOA).

Yifan Huang, Wenxing Zhou[10] 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 calculate the plastic constraint factors that are used to relate the crack tip opening displacement (CTOD) and the J-integral (J). The analysis carried out for 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). Analysis results, a new empirical m-factor equation is proposed, the yield-to-tensile strength ratio and the loading level.

Petri Makela and Christer[11] Fellers The aim of the present work was to develop an analytic procedure for determination of the fracture toughness of paper materials based on laboratory material test data. Closed-form analytic expressions for calibrating the material model based on tensile test data were developed. The analytically calibrated material model was shown to predict the non-linear tensile stress-strain behaviour of the investigated paper grades excellently. Analytical expression for determination of fracture toughness was developed based on the used material model and J-integral theory. The suggested analytic procedure for determination of the fracture toughness was shown to be in excellent agreement with determinations of fracture toughness based on finite element analysis.

Shah s.p[12] (1990) Determination of fracture parameters of plain concrete using three point bend tests in research paper This recommendation covers the determination of the Fracture toughness (critical stress intensity factor K_{IC}^S and the critical crack tip opening displacement CTODc) of mortar and concrete, using three point bend tests on notched beams. The critical stress intensity factor is the stress intensity factor evaluated at the critical effective crack tip, using the measured maximum load. The critical crack tip opening displacement is defined as the crack tip opening displacement calculated at the original notch tip opening displacement calculated at the original notch tipoff the specimen, using the measured maximum load and the critical effective crack length.
This testing method is unique in that all material properties (i.e. K_{IC}^S, $CTOD_C$ and E) can be determined from a single test performed on a notched beam specimen. As a result, the application of these material parameters to the associated effective crack model (i.e. the two –parameter fracture model) is self-consistent. Using these two parameters and the Young's modulus, it is also possible to predict the critical load under mixed mode loading conditions as well as for compact tension and wedge loaded cubical specimen.

III. METHODS AND MATERIAL

Fig. 3 show that Fracture toughness (plane strain), K_{IC} , against failure strength, σ_f .

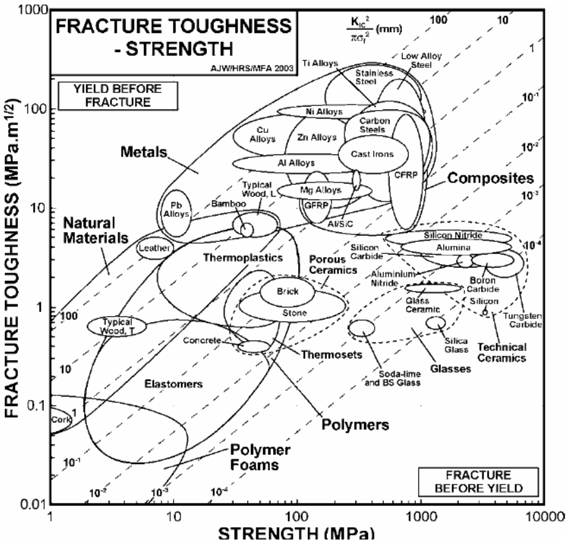

Figure 3: Fracture toughness VS. Strength of different materials

Fig. 3 shows that the value of different engineering materials for examples steel, aluminium, concrete, brick, stone etc. The contours show that approximately the diameter of the process zone at a crack tip. Application of linear elastic fracture mechanics (LEFM) using stress intensity factor K requires that the specimen and crack dimensions are large compared to this process zone. The design guide-lines are used in selecting materials for damage tolerant design.

For evaluation of fracture toughness based on E1820[8] for the engineering materials required crack length (total length of the crack starter configuration plus the fatigue crack) shall be between 0.45 and 0.70 W for crack tip opening displacement and J integral and determination, but is restricted to the range from 0.45 to 0.55 for K_{Ic} determination. For a straight-through crack starter terminating in a V-notch, the length of the fatigue crack on each surface of the specimen shall not be less than 2.5 % of W or 1.3 mm (0.05 in.) minimum, and for a crack starter tipped with a drilled hole, the fatigue crack extension from the stress raiser tipping the hole shall not be less than 0.5 D or 1.3 mm

(0.05 in.) minimum on both surfaces of the specimen, where D is the diameter of the hole. For a chevron notch crack starter, the fatigue crack shall emerge from the chevron on both surfaces of the specimen.

IV. RESULTS AND DISCUSSION

- This technical review of fracture toughness testing, experimental evaluation, test methods and standardization for engineering materials in reference to both the linear elastic fracture mechanics (LEFM) and the elastic–plastic fracture mechanics (EPFM).
- ASTM standardization has been a key part of fracture toughness testing and evaluation by providing a forum for fracture mechanics development and by providing consistent experimental procedures for measuring fracture toughness parameters.
- This review paper gave the application of fracture toughness parameter for different engineering material and this value helpful for the design consideration.
- The design of fracture toughness used to prevent fracture in structural members. Some of the esteemed researchers showed that importance of fracture toughness in selecting engineering materials.

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