Computational Materials Science 46 (2009) 906–911

Contents lists available at ScienceDirect

Computational Materials Science

journal homepage: www.elsevier.com/locate/commatsci

Effect of thermomechanical loads on the propagation of crack near the interface brittle/ductile

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A R T I C L E I N F O

Article history:
Received 22 January 2009
Received in revised form 11 March 2009
Accepted 28 April 2009
Available online 29 May 2009

Keywords:
Bimaterial
Residual stresses
Crack propagation
Interface adhesion
Mixed mode
J-Integral

A B S T R A C T

The purpose of this paper is to understand the combined effect of thermal and mechanical loading on the initiation and behaviour of sub-interface crack in the ceramic. In this study a 2D finite element model has been used to simulated mixed mode crack propagation near the bimaterial interface. The assembly ceramometalic is subjected simultaneously to thermomechanical stress field. The extent of a plastic zone deformation in the vicinity of the crack-tip has a significant influence on the rate of its propagation. The crack growth at the joint specimen under four-point bending (4PB) loading and the influence of residual stresses was also evaluated by the maximum tensile stress criterion. The *J*-integral at the crack tip is generally expressed by the thermomechanical local stresses. The results obtained show the effect of the temperature gradient ΔT, the size of the crack and the applied stresses on the *J*-integral.

1. Introduction

Ceramics posses a wide range of properties and characteristics that make them attractive for a variety of advanced technology applications. They are used in various industrial sectors such as electronics, electromechanics and energetic. However, effective and widespread use ceramics in these applications often requires it to be functionally or structurally interfaced with metallic structures. Hence, joining technologies are crucial to the exploitation of these new ceramics. Joining ceramics to metals is inherently difficult because of their distinctly different properties, but considerable efforts devoted to the development of joining technologies in recent years have led to significant successes. Residual stresses have a significant influence on the fatigue strength of the structures, and it is well known that high tensile residual stresses have a detrimental effect on fatigue life and compressive residual stresses could have a favorable effect on fatigue life. The combination of residual stresses with operating stresses to which engineering structures and components are subjected can promote failure by fatigue. The effect of the residual stresses on the propagation of the crack under cyclic loading was studied by several authors [1–4]. This influence is regarded as one of the most significant factors to predict the crack growth rates. The tensile residual stresses decrease the fatigue life of the structure and those of compression increase the fracture resistance, contribute to the crack closure and reduce the crack opening profile [5–7].

The specimens with initial subinterfacial crack are made for four-point bending tests. The mechanical stress field developed is given according to the bending moment and the dimensions of a cross section of bimaterial [8–11]. When a crack is situated in the vicinity of bimaterial interface, around which there exists a residual stress field, the crack will propagate under a critical stress that is determined by the superposition of residual stress field and externally applied stress.

Numerous studies on metal–ceramic bonding have been performed. However, despite recent extensive efforts by researchers from different disciplines metal–ceramic interfacial toughness is still not fully understood. The case of crack along an interface between brittle and ductile materials has been investigated extensively, both experimentally [12] and theoretically [13,14]. The case of the crack oriented parallel to the interface a small distance away from it received less attention [15,16]. The solution of an interface crack was adapted to a crack slightly displaced off the interface [17]. This was extended to a crack in ductile material near the interface with a brittle material; the crack path was found numerically using the finite element analysis [18–20].

Finite element analysis was performed to obtain the residual stresses and four-points bending stresses of the $Al_2O_3/Cu/Al_2O_3$ joint in two dimensions using the computation software ABAQUS [21]. The sub-interface crack is located in the ceramic particularly in the free edge of the specimen. Our Analysis highlighted the

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0927-0256/$ - see front matter © 2009 Published by Elsevier B.V.
doi:10.1016/j.commatsci.2009.04.039

influence of residual and bending stresses on the variation of the *J*-integral at the crack-tip.

2. Geometrical model

The realization of the ceramic–metal assembly is made in a solid state bonding. The bimaterial joints typically contain residual stresses [22–34] that arise during fabrication process when the joints are cooled from high temperature T_{el} (near to the melting point of metal) until the ambient temperature T_{am}. The temperature distribution in an assembly was assumed to be homogenous. Fig. 1a shows the dimensions of the specimen and four-points bending (4PB) test schematically. The initial edge crack length is a_0, it is started at the vicinity of the interface ceramic–metal and oriented parallel to this interface. The combined effect of residual stresses and applied load may cause an assembly to fail sooner than expected, to have reduced durability due to damage mechanisms.

In this numerical analysis by the finite element method, the specimen is modelled in two dimensions under plane strain conditions. It is meshed by quadrilateral elements with eight nodes as shown in Fig. 1b. The mesh contains 42805 nodes and 14076 isoparametric elements. In order to obtain accurate stresses the mesh is relatively fine at both interface and crack-tip, respectively (see Fig. 1c).

3. Thermomechanical properties of materials

Mechanical tests (4PB) showed that the breaking strength of the interface and ceramics in the vicinity of the junction depends on the difference between the mechanical properties of the two assembled materials [25–27]. The cohesive ruptures in alumina are observed on levels of stresses much lower than that the fracture of same material not joined with a metal [28,29]. Generally, the melting point and a mechanical resistance of the alumina have been higher than those of copper. Consequently, a ductile material has an elastoplastic behavior and that of a brittle material is purely elastic.

3.1. Thermomechanical properties of alumina

Alumina is the first basic compound for technical ceramics because it has an exceptional versatility: abrasion, wear, refractory, biomedical...etc. Alumina is classified in ceramics of the oxides type. It defines the structure corundum where oxygen's form a compact stacking hexagonal with the aluminum ions in two thirds of quote octahedral, which lowers overall symmetry towards the space group rhomboedric. Alumina is used because of its strong atomic connections, its high performances mechanical and thermal (high hardness, high modulus of elasticity, satisfactory mechanical resistance, wear resistance and good tribological properties and refractivity) and it is known by formula Al_2O_3 [30]. A dense ceramics as alumina and with fine grains has the following properties as shown in Table 1.

3.2. Thermomechanical properties of copper

The physical and mechanical properties of copper are available in the literature [32–35]. This ductile material with a crystalline

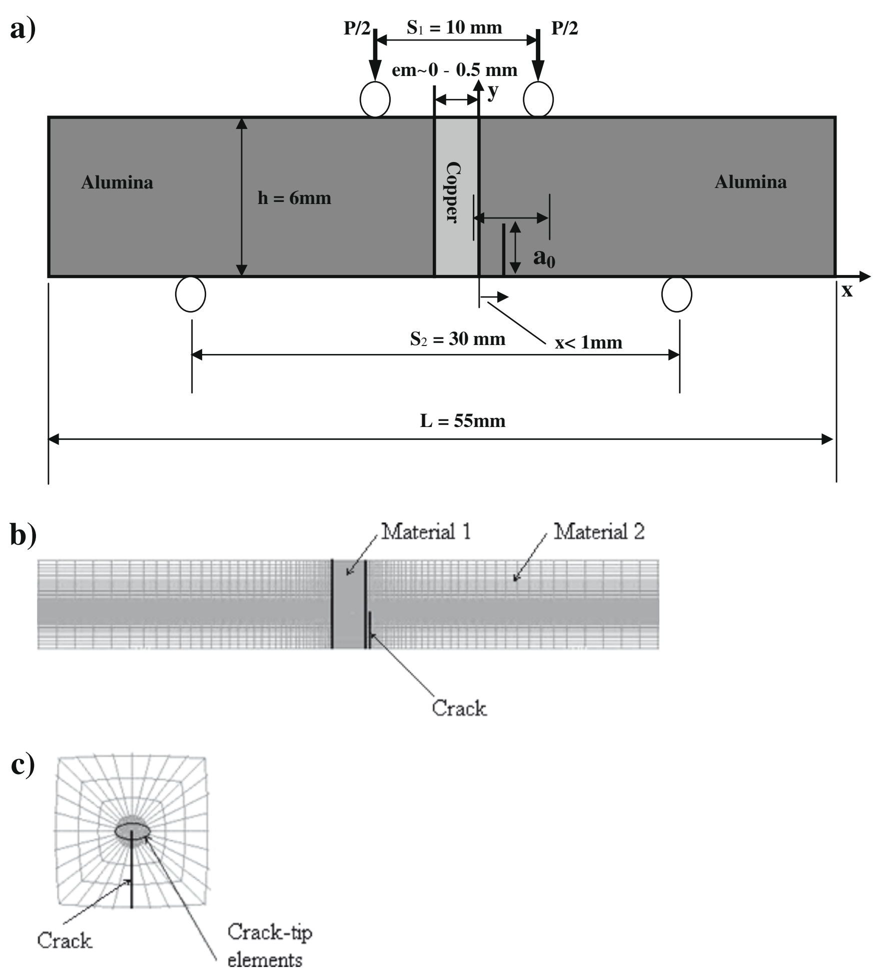

Fig. 1. (a) Geometrical model [11]. (b) Representative finite-element mesh of assembly and (c) mesh near the crack-tip.