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Analysis of stress concentration around a spheroidal cavity under asymmetric dynamic loading

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ABSTRACT

The fracture and fatigue properties of porous materials are strongly influenced by stress concentrations around the pores. In addition, failure of structural components initiates at locations of high stress concentration which is often caused by holes, inclusions or other discontinuities. In view of this, the stress concentration around a spheroidal cavity embedded in an elastic medium is studied under dynamic loading conditions. While solutions abound for static loads, only limited solutions exist for dynamic loads. The stress field around a spheroidal cavity is determined by using a hybrid methodology that combines the finite element technique with a spherical wave function expansion method. The stress concentrations within the matrix are found to be dependent on the frequency of excitation, aspect ratio of the cavity and the Poisson's ratio of the matrix. The study reveals that dynamic stress concentrations can reach much higher values than those encountered under static loading.

1. Introduction

A certain volume of empty space tends to occur in any material. This space is distributed within the solid material in the form of cavities of various shapes and sizes. When the material is subjected to a load, a stress concentration develops around the cavities. Determination of this stress concentration is a problem of considerable interest in many branches of material science and applied mechanics, since it effectively lowers the overall strength, fracture and fatigue properties of the material.

The influence of stress concentrations on the mechanical properties of porous materials has long been recognised (Hasselman and Fulrath, 1964; Wang, 1984; Panakkal et al., 1990; Danninger et al., 1993; Maitra and Phani, 1994; Boccaccini et al., 1995; Boccaccini, 1998). For instance, an equation of the form

$$E = E_0(1-p)^m$$

has been shown to predict the Young's modulus (E) of sintered powder metals and porous ceramics (Maitra and Phani, 1994). In the above, E_0 is the Young's modulus of the nonporous material, p is the volume fraction of pores and m is related to the stress concentration factor around the pores. Similar relationships have also been proposed to calculate the fracture strength of porous materials (Danninger et al., 1993).

In the applied mechanics literature, the study of stress concentrations goes back to Kirsch (1898) who considered an infinite plate subjected to static tensile loading. Many investigations have since been conducted for cavities and other forms of stress raisers such as notches, inclusions and reinforcements. The review articles by Sternberg (1958) and Neuber and Hahn (1966), although somewhat dated, provide a wealth of information on the subject which continues to attract the attention of researchers. The monograph by Tan (1994) provides a comprehensive coverage on stress concentrations in laminated composites. Some recent works on stress concentrations caused by holes or cavities may be found, for instance, in the works of Yu et al. (2008), Yang et al. (2008), and Prokic et al. (2009).

All these investigations considered static loading, where the inertia of the medium can be ignored. This simplification cannot be made when dynamic loading is considered. The energy of the dynamic load is transmitted in the form of waves travelling through the medium. At a discontinuity, these waves are reflected, refracted and scattered giving rise to elevated local stress states. The phenomenon of dynamic stress concentration may, therefore, be regarded as one of scattering of elastic waves.

Scattering of elastic waves by a discontinuity such as a cavity or an inclusion has been the subject of many investigations. The excellent monograph by Pao and Mow (1973) gives a comprehensive coverage of this and other related subjects. Solutions for two dimensional problems have been presented by Bogan and Hinders (1993) and others. In three dimensions, scattering by spherical, spheroidal and ellipsoidal discontinuities has been studied by Datta (1977), Willis (1980), Paskaramoorthy et al. (1988) and many others. More recent contributions on this subject have been presented by Meguid and Wang (1997), Hayir and Bakirtas (2004),

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