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Deformation and tearing of circular plates with varying support conditions under uniform impulsive loads

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Abstract

Transient dynamic finite element analysis of circular plates with varying support configurations under uniform single square wave form impulsive load has been carried out in FEA package ANSYS. Experimental results of Teeling-Smith and Nurick [The deformation and tearing of thin circular plates subjected to impulsive loads. Int J Impact Eng 1991;11(1):77–91] and Nurick et al. [Tearing of blast loaded plates with clamped boundary conditions. Int J Impact Eng 1996;18(7–8):803–27] for the onset of thinning and tearing at the boundary of clamped circular plates subjected to uniformly loaded air blasts have been used to compare and validate the numerical simulation and procedure. The Mode II failure with respect to clamped circular plates has been simulated using a rupture strain criteria. Mode III failure or plastic shear sliding, has been considered using a shear strain failure criteria as proposed by Wen and Jones for plates. A stiffness reduction scheme has been proposed to decide on the initiation and progression of tearing in conjunction with suitable failure model under Modes II and III. The evolution of deflections, plastic zones, rupture zones and failure modes under the blast loading conditions are found to match well with the experimental results. The validated numerical model has further been used to study the effect of plate thickness on the deformation and tearing response of the circular plates subjected to impulsive loads. The deformation, tearing and shock absorption response of clamped circular plates under uniform impulsive loads with ring support of varying edge configurations at the boundary have also been numerically studied. Further, the response of circular plate–tube combination with varying boundary support configurations has been studied. The plate has been considered at the mid-span of the tube of length equal to the plate diameter with the ends of the tube modelled as clamped. The numerical model has been used to study the effect of tube thickness variations on the deformation and tearing response of the circular plate under shock loads. The response of tube–plate combinations under uniform impulsive loads with ring support at the plate–tube junction have also been numerically studied.

Keywords: Tensile tearing; Shear sliding; Progressive degradation; Ring support; Plate–tube combination

1. Introduction

Menkes and Opat [1] were the first to study the dynamic failure of beams experimentally for blast loaded aluminium alloy 6061 T6 beams, while Jones [2] studied the problem analytically using a rigid plastic material

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model. They identified three modes of failure for the beams: Mode I—large permanent displacement deflections or damage without any material rupture; Mode II—tensile rupture at supports, which occurs when the maximum equivalent strain in a beam equals the equivalent dynamic rupture strain for the material; Mode III—transverse shear failure at supports, which occurs when the maximum transverse shear displacement $W = KH$, where K is a constant between 0 and 1 and H is the beam thickness. Jones [2] used an elementary failure criterion to establish the threshold velocities at the onset of Mode II and Mode III failure.

The large inelastic deformation response of thin plates subjected to uniformly distributed blast loads has received considerable attention [3–6]. The failure (Mode I) has been reported with satisfactory correlation between the predictions and experiments by Olson [4]. Plate tearing in tensile and shear (Modes II and III) modes have not been fully understood and have been of tremendous interest [7–10].

Teeling-Smith and Nurick [11] were the first to identify and report the failure Modes I, II and III for circular plates subjected to uniformly distributed pressure impulses. Nurick et al. [12] reported extensive experimental results for the study of the onset of thinning (necking) and hence subsequent tearing at the boundary of clamped circular plates subjected to uniformly loaded air blasts. They employed 1.6 mm thick commercially available mild steel sheets of diameter 60 to 100 mm. They undertook uniaxial tests to obtain values of static yield stress and strain at failure. The clamping of plates was done using thick heat-treated mild steel rings and high-strength bolts equally tightened by means of a torque wrench. They observed partial tearing at the plate boundary which was represented as Mode II* failure. These experimental results have been used to compare and validate the numerical simulation and procedure in this paper. The validated numerical model has then been used to study the effect of plate thickness on the deformation and tearing response of the circular plates subjected to impulsive loads. The deformation, tearing and shock absorption response of clamped circular plates under uniform impulsive loads with ring support of varying edge configurations at the boundary have also been numerically studied. Further, the response of circular plate–tube combination with varying boundary support configurations has been studied. The numerical model has been used to study the effect of tube thickness variations on the deformation and tearing response of the circular plate under shock loads. The response of tube–plate combinations under uniform impulsive loads with ring support at the plate–tube junction have also been numerically studied.

2. Blast modelling

The impulsive blast load (I) has been simulated in the FE model by the application of uniform pressure load (P) on the plate area (A). The duration t_b of the pressure load P is taken to be the actual burn time of the explosive, typically 15 μs [12]. The magnitude of the pressure is thus calculated by Eq. (1). The pressure pulse is taken to be uniformly distributed as a square function of time:

$$P = \frac{I}{t_b A}. \tag{1}$$

3. Failure criteria and damage evolution

Various criteria, such as maximum strain criteria, rupture strain, equivalent plastic work and damage models, have earlier been used towards simulation of tear phenomenon in plates under shock loads [12]. In this study, the Finite Element method is used to analyse the material failure in its various modes including tearing using a proposed progressive degradation scheme.

3.1. Mode I: large plastic deformation

The material model adopted for the large plastic deformation response is bilinear with isotropic hardening, incorporating a Mises yield criteria and associated flow rule. The strain rate sensitivity is incorporated using the Cowper Symond's model. A nonlinear FE formulation incorporating both geometric and material nonlinearity has been used under a transient dynamic solution scheme in small time steps over the load time history of the circular plate.