International Journal of Solids and Structures 48 (2011) 463–471

Contents lists available at ScienceDirect

International Journal of Solids and Structures

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

The effect of contact conditions and material properties on plastic yield inception in a spherical shell compressed by a rigid flat

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ARTICLE INFO

Article history:
Received 8 July 2010
Received in revised form 24 September 2010
Available online 20 October 2010

Keywords:
Spherical shell
Yield inception
Contact condition
Stick

ABSTRACT

The onset of plastic yielding in a spherical shell loaded by a rigid flat is studied for stick and slip contact conditions using finite element analysis. The effect of various material properties on the critical normal load, critical interference and critical contact area at the onset of plastic yielding is investigated and the location where plastic yielding first occurs is determined. A comparison is made with results obtained previously for slip contact condition. Substantial differences are found at low to medium Poisson's ratio values, while some similarities are found to occur for high Poisson's ratio values. In particular, a spherical shell is more prone to yield under stick than under slip contact condition.

1. Introduction

The contact behavior of a deformable spherical shell loaded by a rigid flat is a problem of great interest in contact mechanics. It involves applications such as the cornea of the eye (Schwartz et al., 1966), collision of vehicles (Kitching et al., 1975), the physics of a 'ping pong' ball (Pauchard and Rica, 1998), and hard disk drive suspension (Raeymaekers et al., 2010), to name a few.

Reissner (1947) investigated the elastic contact of a shallow spherical shell and provided expressions for stresses in the meridian and circumferential direction. Following Reissner's work, the load-interference relationship of a spherical shell loaded by a rigid flat was investigated by many other researchers, such as Naghdi (1956), Essenberg (1962), Updike and Kalnins (1970, 1972a), Pauchard and Rica (1998). A limited number of studies combining theoretical and experimental investigations can also be found in the literature. Schwartz et al. (1966) treated the problem of a thin-walled shallow shell compressed by a rigid surface. They showed that for an interference larger than 1/3 of the shell thickness, the validity of the pressure distribution is questionable due to possible shell instability. Their experiments showed good correlation with theory for the load-interference relation. Gupta and Gupta (2006, 2009) conducted theoretical and experimental studies on buckling of hemispherical shells of different thickness ratios, t/R, subjected to axial loads by a rigid flat. Experimental and theoretical results of the deformed shell shapes and their corresponding load-interference curves were found to be in good agreement.

All of the above investigations were limited to elastic deformations where the stress–strain relationship remains linear even up to the onset of buckling. In many practical cases, however, plastic yielding of the compressed spherical shell can take place see, for example, Updike and Kalnins (1972b) or Hutchinson (1972). Large plastic deformations are preceded by onset of plastic yielding and hence, justify the interest in this subject. Recently, Li et al. (2011), investigated the yield inception of a spherical shell with a Poisson's ratio $\nu = 0.31$, compressed by a rigid flat under perfect slip contact condition. They found that the critical load and critical interference for yielding depend on a dimensionless shell parameter, which is a function of the material properties E/Y and the spherical shell geometry ratio t/R. It was suggested by Li et al. (2011) that the critical load and interference of spherical shells may be used to normalize load and interference, respectively, thereby enabling a universal dimensionless expression for the elastic–plastic load-interference relationship as was done for a solid sphere where $t/R = 1$ (Kogut and Etsion, 2002; Jackson and Green, 2005; Etsion et al., 2005; Kadin et al., 2006; Shankar and Mayuram, 2008).

It should be noted here that the above studies concern only the limiting case of frictionless contact, i.e., the case where slip is

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doi:10.1016/j.ijsolstr.2010.10.015