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Effect of Yield Strength on the Static and Dynamic Behaviours of Cylindrical Contact:
Plane State of Stress

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ABSTRACT

The paper considers the influence of yield strength on the static and dynamic behaviour of cylindrical contact interfaces. The semi-cylinder is assumed to be in plane stress condition. A quasi-static analysis is executed by means of finite element (FE) software package ANSYS 18.2 to obtain several contact parameters. A key parameter, quantifying nonlinearity for the single-asperity cylindrical contact system, is educed from the interference-contact force plot. The dynamic characteristics of the cylindrical contact interface is investigated by utilizing this parameter. In order to investigate the same, the contact interface is represented by a single degree of freedom spring-mass-damper system, and the analysis is carried out for free-undamped as well as forced-damped vibration. It is found that, with higher Young's modulus, the dynamic contact system becomes more nonlinear in nature. It is found that, with lower value of yield strength, the dynamic contact system becomes more nonlinear in nature. Moreover, the contact system is found to possess a hardening type of nonlinearity.

KEYWORDS

Contact Vibration, Cylindrical Contact, Finite Element Analysis

1. INTRODUCTION

Hemispherical and cylindrical contacts are two of the most fundamental problems of contact mechanics (Johnson, 1982, 1985). They are often considered to be the units of multi-asperity rough surface contact models. Fibrous and anisotropic material surfaces often consist of elongated/stretched asperities which could be efficiently modelled using cylindrical contact (Bush et al., 1979; Xu et al.,

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2021). Cylindrical contact analysis has been useful for modelling in different domains of analyses including electrical contact (Angadi et al., 2012; Jackson & Kogut, 2007), thermal contact (Jackson et al., 2012), mechanical seals (Green & English, 1992), cams etc.

Most of the earlier research works on cylindrical contact were concentrated on indentation contact problems with major focus on hardness test (Cinar & Sinclair, 1986; Dumas & Baronet, 1971). The first closed form complete elastic solution for cylindrical contact was derived by Johnson (1985). This work was based on the seminal work by Heinrich Hertz (1882). Although, it was considered for parabolic contact, it was found appropriate for elastic cylindrical contact. One of the earliest work on cylindrical contact was carried out by Radzimovsky (1953) which analysed two cylinders rolling together on one another with their axes parallel. The stress distribution as well as the strength condition of the cylindrical contact interface were investigated in this work. Hamrock (1994) provided similar closed form solutions as Johnson (1985) for cylindrical elastic contacts. Two other cylindrical contact models providing closed form contact force expressions were proposed by Lankarani and Nikravesh (1989) and Goldsmith (2001). All these previously mentioned analyses were based on elastic contact. While in loaded condition, most of the asperities go through plastic deformation. Therefore, it is necessary to analyse the cylindrical contact problem in elastic-plastic as well as fully plastic domain. Green (2005) provided the first analysis deriving the critical contact parameters (contact force, interference and half contact width) for the initiation of yielding based on von Mises yield criterion. He also investigated the effect of Poisson's ratio on the contact stresses. However, a long ago, Tian and Saka (1991a, 1991b) carried out one of the earliest analyses on elastic-plastic cylindrical contact (normal as well as sliding) using finite element analysis. In a later work, Jackson (2017) used analytical slip line theory to predict contact pressure results for cylindrical indentation of rigid-perfectly plastic substrate and compared with finite element results. The results were found to be in agreement for relatively low deformations. Zhupanska and Ulitko (2005) presented an analytical approach to obtain the exact solutions for the frictional indentation problem of rigid cylinder on elastic half-space. Doca and Andrade Pires (2014) carried out experimental as well as numerical study for the elastic-plastic contact interaction between a finite length semi-cylinder and a flat surface. Pereira et al. (2015) proposed a new improved cylindrical contact model based on the existing Johnson model (Johnson, 1985) and FE analysis. In order to predict the elastic-plastic contact behaviour efficiently for cylindrical contact, finite element (FE) simulation is found to be the most popular method in the recent few years. The works by Mu et al. (2017), Sharma and Jackson (2017), Xu et al. (2021) are some of the significant works that investigated cylindrical contact in plane strain and plane stress conditions, through finite element simulation. In another significant work, Vijaywargiya and Green (2007) investigated sliding contact interaction between two cylindrical asperities under plane strain condition. Recently, finite element based cylindrical fretting contact was investigated by Yang and Green (2018, 2019). Sliding contact analysis of cylindrical interfaces has been attempted by a number of researchers (Adams, 2014; Wang et al., 2020; Yang & Green, 2020). While most of the works on cylindrical contact adopts the contact taking place at the curved face of the cylinders for the analysis, some considers the same taking place at the flat end (Brutti, 2021; Hu & Hassan, 2019; Riccardi & Montanari, 2004). A number of researchers have investigated cylindrical contact with the effect of adhesion acting at the interface (Liu et al., 2015; Saito et al., 2016; Wu, 2019; Zhupanska, 2012). In a recent work, Guo et al. (2020) analysed an elastic–plastic cylindrical contact model under varying contact angles through analytical and numerical methods. The same group of researchers (Guo et al., 2021) carried out a similar study on the contact of two parabolic cylinders.

Apart from the static contact, dynamic contact interaction is quite common in machine elements, e.g. gear, cam, rolling contact bearing etc. This type of contact vibration can cause fatigue, wear and damage at the interacting surfaces. Therefore, unrestrained contact vibration has immense detrimental effect to any machine element. In order to control such vibrations, a thorough understanding on the dynamic behaviour the system of contact interface is essential. For the case of dynamic contact analysis of single asperity, Hertzian contact is the most frequently used model. One of the earliest

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