Springer

KSME

Journal of Mechanical Science and Technology 30 (11) (2016) 5093~5101
www.springerlink.com/content/1738-494x(Print)/1976-3824(Online)
DOI 10.1007/s12206-016-1027-3

Prediction of plastic deformation under contact condition by quasi-static and dynamic simulations using explicit finite element analysis †

W. A. Siswanto[1], M. Nagentrau[1,*], A. L. Mohd Tobi[1] and M. N. Tamin[2]

[1]*Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor, Malaysia*
[2]*Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, Johor Bahru, Johor, Malaysia*

(Manuscript Received October 29, 2015; Revised May 16, 2016; Accepted June 12, 2016)

Abstract

We compared the quasi-static and dynamic simulation responses on elastic-plastic deformation of advanced alloys using Finite element (FE) method with an explicit numerical algorithm. A geometrical model consisting of a cylinder-on-flat surface contact under a normal load and sliding motion was examined. Two aeroengine materials, Ti-6Al-4V and Super CMV (Cr-Mo-V) alloy, were employed in the FE analysis. The FE model was validated by comparative magnitudes of the FE-predicted maximum contact pressure variation along the contact half-width length with the theoretical Hertzian contact solution. Results show that the (compressive) displacement of the initial contact surface steadily increases for the quasi-static load case, but accumulates at an increasing rate to the maximum level for the dynamic loading. However, the relatively higher stiffness and yield strength of the Super CMV alloy resulted in limited deformation and low plastic strain when compared to the Ti-6Al-4V alloy. The accumulated equivalent plastic strain of the material point at the initial contact position was nearly a thousand times higher for the dynamic load case (for example, 6.592 for Ti-6Al-4V, 1.0 kN) when compared to the quasi-static loading (only 0.0072). During the loading step, the von Mises stress increased with a decreasing and increasing rate for the quasi-static and dynamic load case, respectively. A sudden increase in the stress magnitude to the respective peak value was registered due to the additional constraint to overcome the static friction of the mating surfaces during the sliding step.

Keywords: Cylinder-on-flat surface contact; Dynamic-explicit; Quasi-static; Equivalent plastic strain; Super CMV; Ti-6Al-4V

1. Introduction

Plasticity theory in contact mechanics is concerned with the distribution of plastic strains and stresses in a ductile material as the material deforms permanently when a force is applied [1]. Plastic deformation in contact mechanics is of prime importance in numerous engineering applications involving two-body contacts, such as in aeroengine and automotive engine applications. A conforming contact is defined when the surfaces of the two bodies fit closely or precisely without any deformation. The presence of any deformation at one of the contacting surfaces when there is an area of contact between the two bodies is known as a non-conforming contact [2].

It is significant to quantify the influence of the loading rate on plastic deformation of bodies with surface contact, along with plastic strain and stress distributions. A number of related studies considering both quasi-static and dynamic loading in contact mechanics in the elastic and plastic regime have been conducted [e.g., 3-7]. While quasi-static analysis is commonly found in sheet metal forming processes and collapse analysis [8], dynamic analysis is applicable to high speed machining processes [9, 10], including penetration and impact related problems [11-15].

Advanced materials such as Ti-6Al-4V and Super CMV alloys have found wide applications in gas turbines and aeroengines because of their ductility, high strength, excellent corrosion and fatigue resistance characteristics [16-20]. Local plastic deformation in contact-related problems, influenced by the loading rate in aeroengine and gas turbine applications, is a known problem. As such problem solving is costly and time consuming, finite element method has been widely employed to predict the plastic deformation associated with the contact mechanics analysis. In this respect, an appropriate numerical model must be employed to accurately reproduce the behavior of the contacting surfaces [21, 22]. Proper contact formulation should be assigned to the FE model to avoid non-convergent calculations while minimizing the simulated penetration between the mating surfaces [23, 24]. Such a complex physical problem of contact mechanics offers a challenging task, particularly for dynamic loading using the explicit FE analysis.

The strain rate-dependent mechanical response of various materials has been examined. Khan et al. [3] presented the calculated response of Ti-6Al-4V alloy under quasi-static and

*Corresponding author. Tel.: +60 17 4039241, Fax.: +60 7 4536080
E-mail address: nagentrau.rau17@yahoo.com
† Recommended by Associate Editor Heung Soo Kim