Experimental Mechanics (2013) 53:1245–1263
DOI 10.1007/s11340-013-9718-5

A Comparison of Contact Stiffness Measurements Obtained by the Digital Image Correlation and Ultrasound Techniques

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Received: 28 September 2012 / Accepted: 9 January 2013 / Published online: 2 February 2013

Abstract The digital image correlation (DIC) and ultrasound techniques have both previously been employed to measure the contact stiffness of real engineering interfaces, but a comprehensive comparison of these techniques has not previously been carried out. Such a comparison is addressed in the present paper. The principal novelty in this work is that DIC and ultrasound are used to simultaneously measure contact stiffness in the same tests and on the same contact interface. The results show that ultrasound measures somewhat higher contact stiffness magnitudes than DIC: at an average normal contact pressure of 70 MPa, ultrasound was around three times stiffer. Given that the techniques are vastly different in their measurement approach (DIC measures micron-scale relative displacements from external side-on images of the interface, while ultrasound uses the reflection of an Ångstrom scale ultrasonic perturbation from the interior of the interface itself), this level of agreement is thought to be encouraging. The difference in results can partly be explained by consideration of inherent physical differences between the techniques which have previously received little attention. Ultrasound measurement will always give the local elastic 'unloading stiffness' (even at a plastically deforming contact); whereas, a load-deflection technique like DIC, will give the 'loading stiffness'. The reason for this difference is discussed in the paper and tests carried out under increasing tangential load in the pre-sliding regime illustrate this difference experimentally. Under normal loading, the increase in real contact area obscures the effect to some extent as both DIC and ultrasound stiffnesses increase with normal load. The results suggest that rough interfaces may be satisfactorily modelled as a variable stiffness spring whose stiffness increases with contact pressure as the smooth contact case is approached.

Keywords Contact stiffness · Digital image correlation · Ultrasound · Titanium alloy

Abbreviations

DIC	Digital image correlation
FE	Finite element
FFT	Fast Fourier transform
RMS	Root mean square
UPR	Ultrasound pulser-receiver

Nomenclature

c	Wave speed
$E_{1,2}$	Young's modulus of bodies 1 and 2
E^*	Material stiffness of the interface pair $\left(E^* = \left\{(1-\nu_1)^2/E_1 + (1-\nu_2)^2/E_2\right\}^{-1}\right)$
f	Coefficient of friction
f_u	Ultrasound frequency
H	Hardness
P	Total normal force
p_m	Mean normal pressure
Q	Total tangential force
R	Reflection coefficient
S_q	Areal root mean square roughness (standard deviation of surface heights)
x, y, z	Cartesian coordinates, (z is normal to a surface)
Z	Acoustic impedance
Z_1, Z_2	Acoustic impedance in bodies 1 and 2
κ	Contact stiffness per unit nominal area

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