Chapter 12
Surface Deformation with Simultaneous Contact Area Measurement for Soft Transparent Media due to Spherical Contact

A. McGhee, D. Nguyen, and P. Ifju

Abstract We present a method to measure surface deformations between a steel sphere and a flat PDMS surface. A sphere was chosen as the specimen to ensure the resulting deformation measurement can be compared to known theoretical models. A 36 mm diameter steel sphere was pressed into contact against flat, transparent polydimethylsiloxane (PDMS) sheets with a constant load rate controlled by an Instron testing machine. The modulus of the PDMS samples range from 241 kPa to 2.1 MPa. A digital image correlation technique was used to measure the surface deformation of the PDMS with increasing applied load.

Keywords Digital image correlation • Frustrated total internal reflectance • Polydimethylsiloxane • Spherical contact • Soft matter

12.1 Introduction

A method of investigating contact mechanics between two bodies using digital image correlation (DIC) through transparent media was developed in combination with frustrated total internal reflectance (FTIR). This combination of data enable deformation measurements with the respective contact measurement between the two surfaces. If the object causing the deformation is attached to a universal testing machine (UTM), the displacement and load measurements can be used to produce interesting results such as stress mapped to the contact plot.

The challenges with this method include correction for the index of refraction through the transparent medium as well matching the contact measurement from FTIR to the surface deformation from DIC. This method was created at the University of Florida to measure the contact with corresponding deformation between a hard rough surface and a soft polydimethylsiloxane (PDMS) sheet. To improve and expand upon this method we use a simple spherical surface as the indenter so we can directly compare the results to known deformation models. Furthermore, since the steel ball sticks to the PDMS surface, we measure the pull off deformation and compare it to theoretical models.

12.2 Experimental Method

Using an Instron-5969 to control for load rate, a 36 mm diameter steel ball was depressed into the PDMS and then pulled off. The surface deformation and contact area were measured during both the loading phase and pull off phase of the experiment. To measure the surface deformation, a speckle pattern was applied to the contact surface of the PDMS and imaged with stereoscopic cameras. The images were then analyzed using correlated solutions 3D DIC software. The contact area was measured using FTIR. In the FTIR method, a light source illuminates the surface of contact between two objects. Light will reflect internally in a medium until the angle made between the light ray and the surface is greater than some critical angle β determined by the relative index of refraction between the boundary. If a body with a higher index of refraction is spaced within a distance equal to the wavelength of light, the light will become frustrated and will become visible on the surface.

A. McGhee • P. Ifju (✉)
Department of Mechanical and Aerospace Engineering, University of Florida, Gainesville, FL, 32611, USA
e-mail: ifju@ufl.edu

D. Nguyen
Department of Civil and Coastal Engineering, University of Florida, Gainesville, FL, 32611, USA

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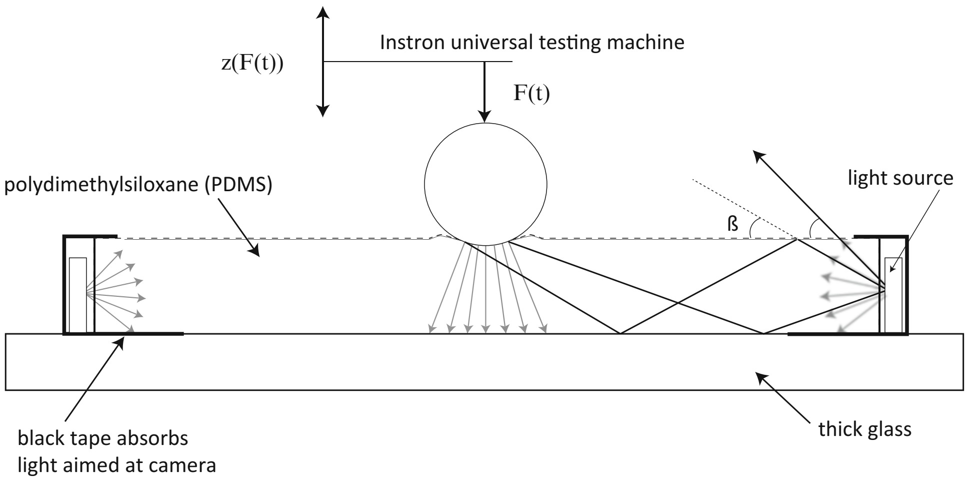

Fig. 12.1 A cartoon of the experimental setup. The steel sphere is connected to a universal testing machine which applies a load at a constant rate. The rays of light are shown escaping the material at angles greater than β and otherwise reflecting internally until the light hits the steel ball and reflects downwards towards the camera

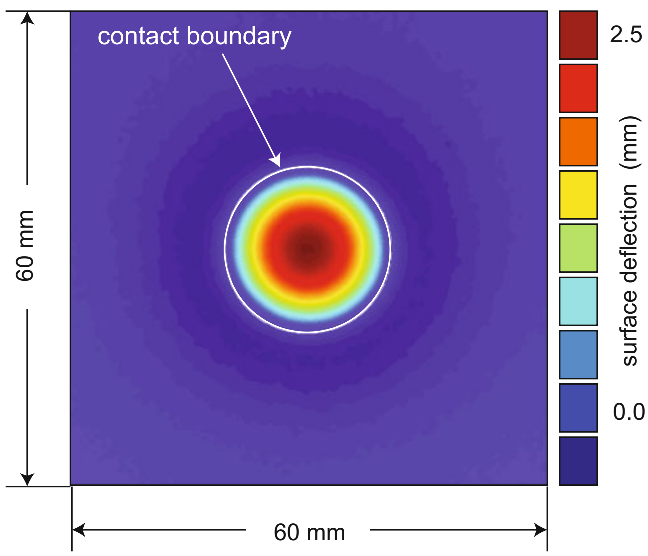

Fig. 12.2 A surface deflection field from the DIC analysis is presented with the contact boundary from the FTIR analysis shown as a white ring

Using a Nikon D7200 camera mounted directly underneath the specimen, the contact area between the PDMS surface and the steel ball was imaged. The aforementioned experimental setup can be seen in Fig. 12.1. This experimental procedure was done on three different PDMS samples which has a modulus range of 240 kPa to 2.1 MPa.

12.3 Results

The results of the analysis shows the outline of the contact boundary overlaid on top of the surface deformation as seen in Fig. 12.2. This deformation field shows the surface deflection in the z direction, with positive values corresponding to indentation and negative values to budging. The raw data of the displacement was larger than the values presented due to the fact that the images were taken through a glass and PDMS surface. To correct for this magnification, a plot of the maximum deflection from the DIC analysis was plotted against the displacement measurements from the universal testing machine and the slope of the given line was found to be 1.35; by dividing the DIC displacement by this slope the surface deflection measurement was corrected.

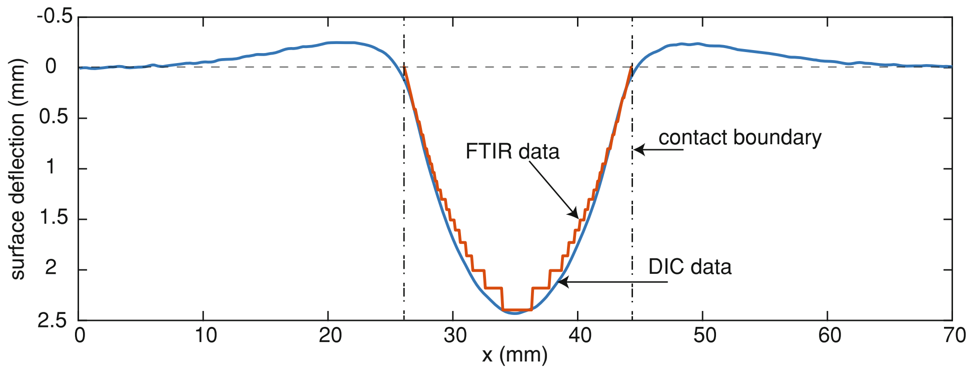

Fig. 12.3 A plot of the cross section of the surface deflection. The FTIR data was stacked with layers corresponding to the displacement data given by the universal testing machine which allows a 3D surface to be reconstructed from the contact measurement

The FTIR data was used to create a 3D surface by relating the contact area to the corresponding displacement data from the universal testing machine. The result of this analysis is shown in Fig. 12.3 as a cross section of the contact along with the surface deflection measurement of the DIC data. The FTIR data matches up with the surface of the DIC measurement at the edges of previous contact. The contact boundary is found by identifying the edge of the FTIR data.

12.4 Discussion

The resulting data found from this method has proven to yield high quality results which can easily be applied to any soft transparent media. Because the shape is so simple, the results can be used to calibrate the displacement data so that other more complex shapes can be tested. The calibration in the radial direction can be found by comparing extensometer displacement, in the radial direction, to the measured deformation. These calibration methods allow us to find the u, v, and w surface displacements which enable stain data to be found.

12.5 Conclusion

By indenting a steel ball on a flat PDMS surface with the DIC, FTIR setup, and a universal testing machine to control load rate we are able to obtain a rich set of data which defines the deformation. The analysis of a simple object with known theoretical models for displacement allows for a correction factor to be applied for the u, v, and w-displacements of the surface. This calibration can be used for all other surfaces that are tested on the same surface.

Alex McGhee is a graduate student in the mechanical engineering department at the University of Florida specializing in experimental soft matter mechanics.