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NEW TECHNIQUES TO CHARACTERIZE SOFT RUBBER MATERIALS USED IN TIRES

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Abstract

Evaluating the elastic properties of rubber is important for improving tire performance. Here new ultrasonic techniques and results are reported for rubber materials, used in automotive tires.

INTRODUCTION

The purpose of this experiment was to simulate a delamination in a tire, and use Electronic Speckle Pattern Interference (ESPI) to detect a delamination in soft rubber. ESPI was chosen for this because it can measure out-of-plane displacements of just several microns.

ANALYSIS

The theory behind ESPI is based on the analysis of fringe patterns resulting from the interference of reference beam and an object beam. The object is subjected to load and responds with displacement. Here we consider primarily the out-of-plane displacement.

For constructive interference, the two patterns are:

$$\Delta\Phi(r) = 2*n*\pi \tag{1}$$

$$\Delta\Phi(r) = (2*\pi*z\ ) / \lambda* [\cos(\theta_1) + \cos(\theta_2)] \tag{2}$$

n = # of fringes

Eds.: J. Eberhardsteiner, H.A. Mang, H. Waubke

z = out of plane displacement
λ = wavelength of laser used
θ_1 = angle of incidence
θ_2 = angle of reflection

Setting (1) equal to (2) results in

$$2*n*\pi = (2*\pi*z) / \lambda* [\cos(\theta_1) + \cos(\theta_2)] \tag{3}$$

This simplifies to

$$n = z/ \lambda * [\cos(\theta_1) + \cos(\theta_2)] \tag{4}$$

In this setup, $\theta_1 = \theta_2 = 45$ degrees, and $\lambda = 0.633$ µm, so (4) becomes

$$n = 2.2341*z \tag{5}$$

Experimental apparatus

The ESPI system is powered by a 35mW He-Ne laser, and views a test sample and reference sample, both of which are squares of rubber. The laser beam is split into two paths, a reference path and an object path. Both beams are filtered by a spatial filter and then focused on their respective rubber samples by lenses. The reflections from the samples are then focused onto the camera lens with other lenses, vertically polarized, and recombined before they hit the CCD camera lens. The camera is connected to a computer, so the pictures taken by it are sent directly to the computer where they can be processed. A schematic of this setup is shown in Figure 1.

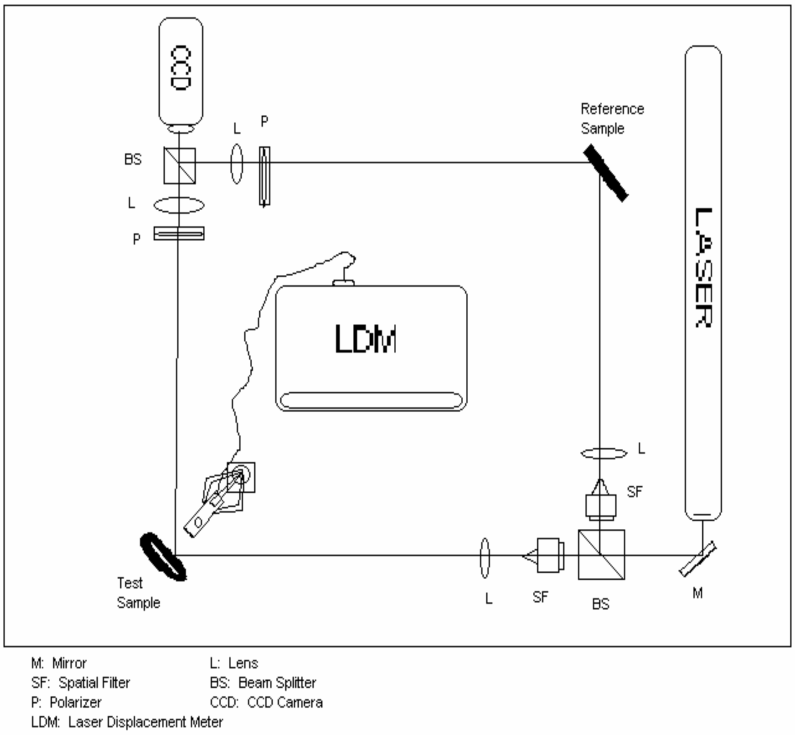

Figure 1 Diagram of Electron Speckle Interferometer (ESPI) system

A Laser Displacement Meter (LDM) was positioned in front of the test sample to measure the out of plane displacement of the rubber piece concurrently with the ESPI system. The LDM consists of a semiconductor laser emitted through a transmitter lens, reflected off of the test sample, and received back through a receiver lens. Behind the receiver lens is a position sensitive detector. As the test sample is moved, the position of the reflected beam on the detector changes, and the LDM calculates the test sample displacement based on the change in laser spot position on the detector. In fringe set 3, a small (3 mm diameter) piece of tape was placed on the test sample to aid in the reflection of the LDM laser. To get proper readings from the LDM, the received beam must have an intensity of at least 50 as measured by the LDM. The tape also creates a more regular reflection, as opposed to the diffuse reflection caused by the rubber surface. A diffuse reflection greatly reduces the LDM’s ability to make accurate measurements.

The test sample was made up of two rubber squares, 6cm to a side, glued together on three of the four edges. The remaining edge was left unglued so compressed air could be blown in between the two rubber pieces causing them to bulge out on the sides, simulating a delamination in the material (Figure 2). The ESPI system monitored a 2 inch diameter area on the test sample.

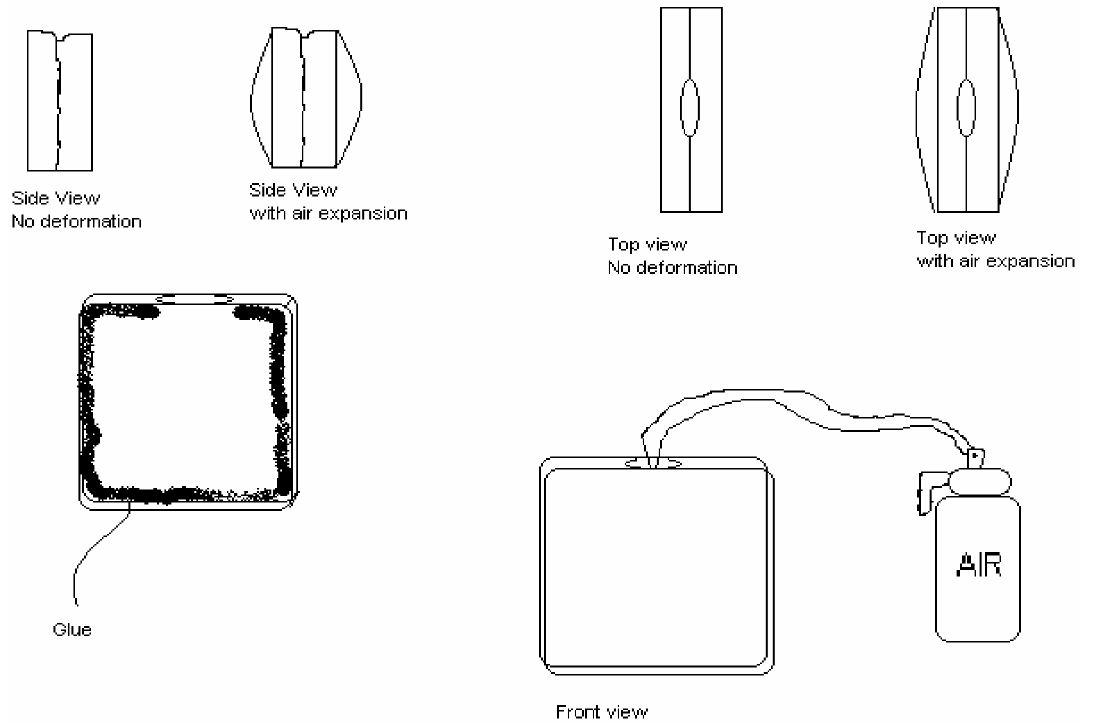

Figure 2 Diagram showing the side, top, and front views of the rubber sample and the arrangement for causing a delamination with compressed air between layers of rubber.

To observe the effects of different boundary conditions on the resulting fringe patterns, the test sample was clamped in two different ways. In fringe sets 1, 2, and 3, (not shown) the sample is clamped at the bottom with no support on the back or sides. Fringe set 4 was clamped on the bottom and both sides, and was completely supported on the back.

Procedure

In order to see fringes caused by displacement, pictures taken before and after the deformation are needed. The CCD camera was set to take a series of 20 pictures in a span of several seconds, encompassing the time in which the deformation took place. A typical sequence would consist of starting the camera recording and then squeezing the air can trigger to inflate the test sample. The sample quickly inflates and deflates as the camera takes pictures. With proper timing, the sample will be completely deflated at the time the camera stops recording.

The LDM was aimed at the center of the test sample where the maximum deflection was expected to occur. It is then set to record the peak displacement value during the deformation. This number is recorded as the measured maximum displacement for that set of pictures.

The sequence of pictures is then exported to Photoshop to be processed. One of the pre-deformation pictures, usually the first picture, is used as a reference picture, and the subsequent images of deformation are subtracted from the reference. The resulting images will show fringes, with the number of fringes increasing as the air is pumped in, and the number of fringes decreasing when the air stops and the sample deflates. The picture containing the maximum number of fringes from that set of pictures is found, and the fringes are counted. The number of fringes is plugged into equation (5) as n to find z. This z represents the theoretical maximum displacement of the sample, and is then compared to the max z recorded by the LDM

RESULTS

The results are presented in the form of ESPI Fringe patterns imaged across the front of the rubber specimens.

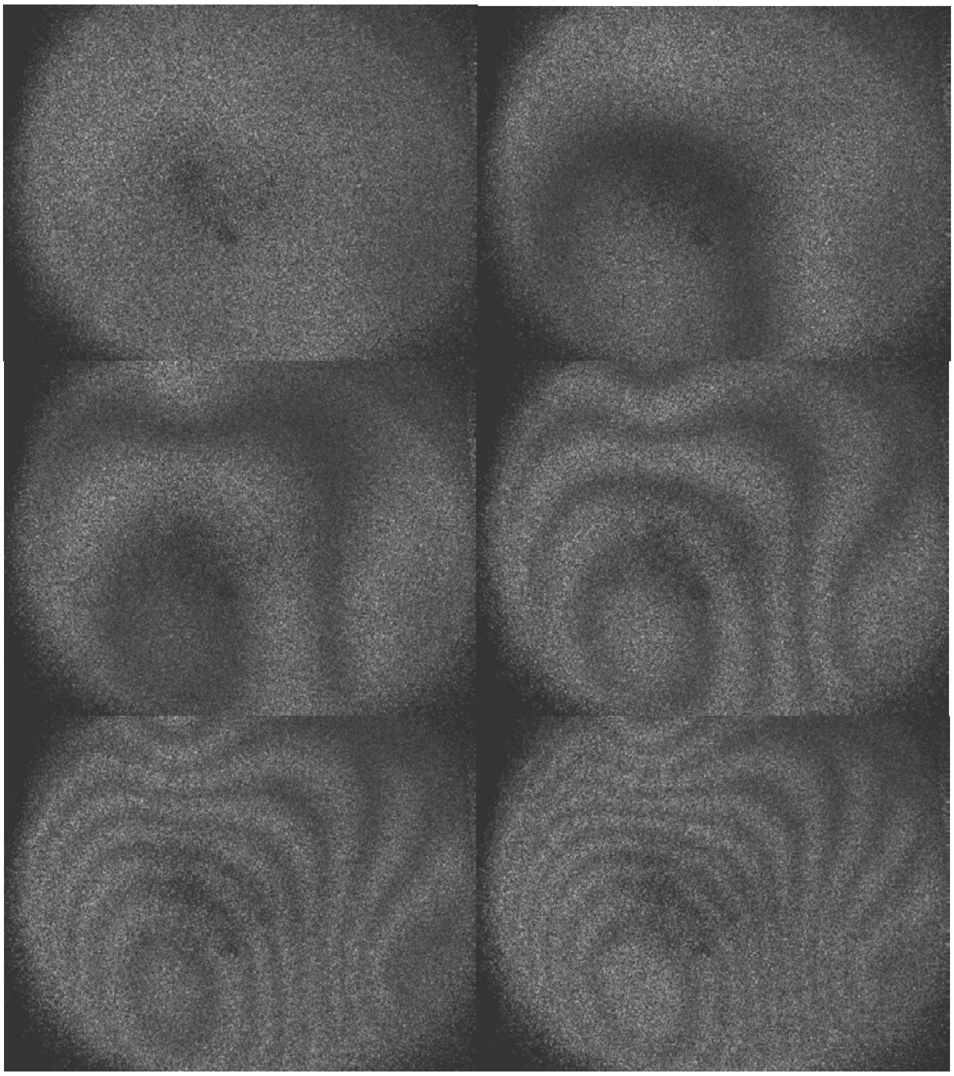

Figure 3 Series Fringe Set Four

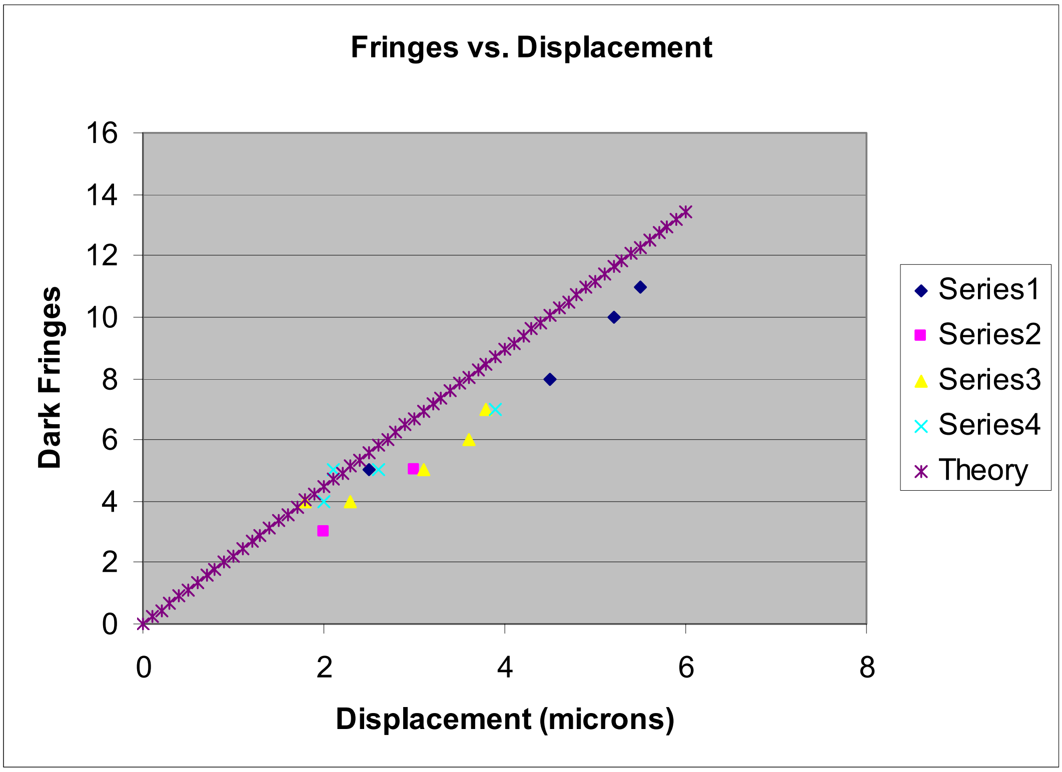

Figure 4 Comparison between Theory and data from 4 series of Experiments

Discussion

The concentric circles seen in sets 1 and 2 appear very much as they were predicted to. The change in boundary conditions on the fourth set caused a change in the fringe pattern. The rings are no longer perfect circles, but appear more like squares with rounded corners.

The results obtained by the LDM and predicted values from equation (5) are compared on Figure 3. The 'Theory' line is equation (5), and the other points are plotted with the LDM reading for displacement, and the max number of fringes on the fringes axis. This compares the accuracy of equation (5) to the readings from the LDM. Ideally, all of the points would be on the 'Theory' line. Each point represents one series of 20 pictures. Points with similar colors were taken at a similar time of the day. For example, the all of the yellow points may be from data taken Monday morning, while the pink points are from data taken Thursday afternoon. Changes to the setup may have been made between these sets, and could explain big differences between color sets.

The data points do not match up perfectly with the predicted values, but if the points were connected, the slopes of those lines would be very close. It is not surprising that the measured values do not match perfectly. Since fringes only occur in whole numbers and are still separated by a finite distance, there will be a small range of displacements which all will appear to have the same number of fringes.

Also making it difficult to get good measured data is the inability of the system to see large amounts of fringes. As the number of fringes in a picture increases, the thickness of the fringes decreases. Beyond about 10 fringes in a picture, they become so close together that it is difficult to count them accurately. This puts an upper limit on the displacements that can be measured by the ESPI system with any particular setup. It is possible to change lenses and zoom in on the sample to make larger numbers of fringes discernable, but at the same time this will change the lower limit of displacement that is observable by the system.

One other method to increase the number of fringes observable is to change the position of the ESPI system on the sample. If the number of fringes only and not the shape of them are important, the system can be positioned to view a corner of the sample, as is done in fringe set 1. Focusing only on a corner of the circle increases the number of fringes that can be counted, but sacrifices the ability the see the entire fringe pattern.

The piece of tape on the sample for fringe set 4 clearly alters the deformation of the rubber. Comparing fringe sets 2 and 3, the fringes change from very circular to almost heart shaped. The distortion of the circles occurs exactly where the tape was placed (top-middle of the picture). The fringes at this spot are compressed more than around the rest of the shape, which indicates that there is a greater slope of displacement at this particular point. It is possible that the tape hinders the rubber's ability to deform smoothly, or that the rubber underneath deforms as normal, while the tape on the surface does not.

POSSIBLE REASONS FOR ERRORS

If equation (5) is not correct, all of the calculated values would be off. The wavelength of the light is not debatable, but the values of θ_1 and θ_2 could be incorrect. Those were both measured at about 45 degrees, but could actually be slightly different. The sum of the two angles is fixed at 90 degrees, so any combination other than 45 and 45 would result in a lower coefficient for z in equation (5). So if there was an error in measuring the angles, the actual theory line on figure 3 would have a slightly smaller slope.

The measurements made are based on the assumption that the edges of the sample do not move out of plane. The LDM measures displacements from the original position, which assumes the entire sample to be in the same plane. The ESPI system also measures the out of plane displacement relative to the starting position. Since the fringes are counted from the center to the edges, if the edges shift out of plane as well, the fringe count will not accurately correlate with the displacement. For this reason, fringe set 4, which has the clamped edges and back, is likely the most accurate.

If the LDM was not positioned exactly at the point of maximum displacement it would read a lower than max value. This would cause the displacement calculated from the fringes to appear larger than the displacement recorded by the LDM.