Infrared deflectometry

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Abstract. This paper illustrate the use of deflectometry in the infrared spectrum to measure surface slopes on a plate deformed in bending.

Introduction

Deflectometry is a technique that measures surface slopes of specularly reflective objects. The motivation for this is mostly defect detection on shiny objects like painted car bodies [1]. In the experimental mechanics community, the technique is used to measure the slope deformation of plates loaded in bending. From the initial paper by Ligtenberg [2], the method has been used sporadically by a few groups worldwide, mostly for material characterization purposes. The main advantage of deflectometry is its very high sensitivity that can be tuned independently from the spatial resolution by tailoring the specimen to target distance. The slope resolution can reach down to 1 μrad [3]. In [4], using an ultra-high speed camera, Lamb waves were measured at the surface of glass and composite panels, with peak to peak amplitudes as low as 20 nm. More recently, deflectometry coupled to the Virtual Fields Method was shown to provide spatially and temporally-resolved pressure distributions [5, 6]. The main drawback of deflectometry however is that the surface under inspection needs to be specularly (or mirror-like) reflective. According to the Rayleigh criterion, a surface is predominantly specularly reflective if:

$$\frac{\lambda}{\sigma \cos\theta} > 8 \tag{1}$$

where λ is the wavelength of the light, σ the surface RMS roughness and θ the light incidence angle from the surface normal. For normal incidence, in the visible spectrum ($\lambda \approx 500$ nm), specular reflection (SR) is predominant for $\sigma < 60$ nm. Most as-manufactured engineering surfaces do not comply with this and coatings had to be devised to make surfaces reflective. However, imaging in the long infrared significantly relaxes this constraint. Indeed, at 12 μm, surfaces up to 1.5 μm RMS roughness are reflective at normal incidence.
To the best knowledge of the present authors, infrared (IR) deflectometry has first been reported in 2005 [7] and since then, only a handful of papers were published on it, all on defect detection [8]. This communication will show an example of application of IR deflectometry on a bending test. Full details have been published in [9].

Experimental set-up

The experimental set-up is shown in Figure 1. The first element is a brushed aluminium plate, not reflective in the visible spectrum but so in the IR spectrum. This plate was held in a test frame to allow for bending deformation to be applied. The detailed bending configuration is shown on the left image in Figure 1. The second element is the target grid. This was obtained by printing black squares onto a brushed aluminium plate. The difference in emissivity between the ink and the aluminium means that an IR pattern is generated when the plate is heated up. Here, the plate was heated with a hair dryer, up to about 50°C. Finally, an infrared camera was used to image the reflection of the grid pattern onto the test specimen. A micro-bolometer array camera, FLIR A655SC 25°, was used to record the reflected images.

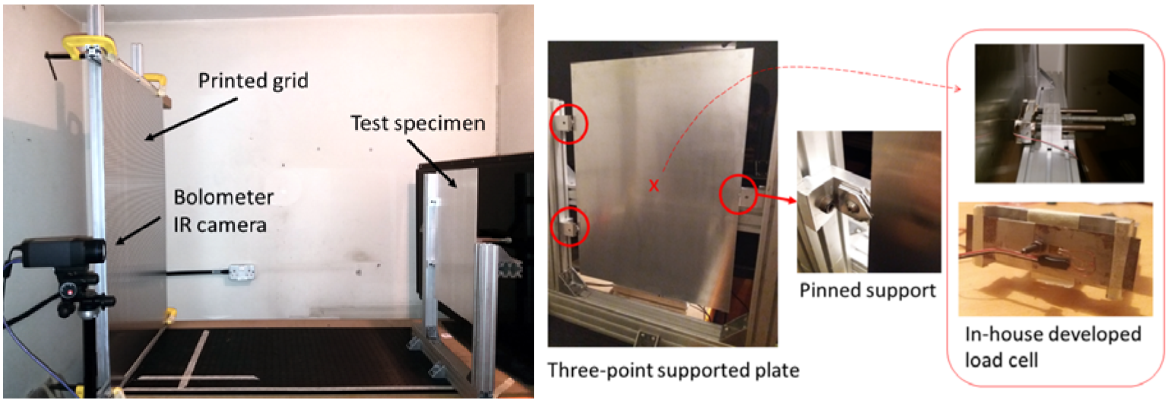

Figure 1: Experimental set-up.

Results

Figure 2 shows a comparison between measurements and a finite element model. The slope fields have been extracted from the grid images using the grid method [10]. One spatial differentiation using centred finite difference over three data points provided the curvature, which multiplied by half the plate thickness led to surface strains, according to Love-Kirchhoff thin plate theory. It is worth noting that no spatial smoothing was applied on neither the slopes nor curvatures thanks to the very high sensitivity of the technique. The comparison is striking considering the very low levels of strains, levels unattainable with standard Digital Image Correlation.

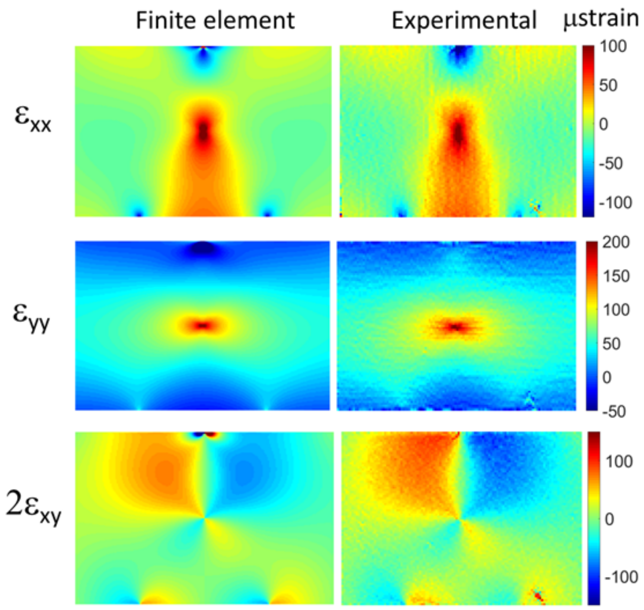

Figure 2: Comparison between finite element and experimental surface strains.

Conclusion

This paper demonstrates that it is feasible to measure the deformation of plates in bending with infrared deflectometry, something that, to the best knowledge of the authors, had not been achieved before. The rapid expansion of the technology of micro-bolometer array IR sensors opens-up the way for IR deflectometry. The next stage is to extend it to curved surfaces using the algorithm presented in [11].

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