Objective speckle method using stick-on foil and its applications

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Abstract. Objective speckle from a stick-on foil is a new approach to applying the objective white light speckle method to in-plane displacement measurements. By a relatively easy technique a thin aluminum foil is mounted onto the specimen surface and a random grating is scratched onto it, yielding high reflectance and fine optical details. After double exposure by a direct recording system without using a lens, the resulting holographic film possesses a broad spatial spectrum and displacement information. Full-field contour maps of equal displacement can be obtained that are of good contrast and high sensitivity and that have a large adjustable measurement range. The method can be applied to practical engineering problems for both plane and developable curved surfaces.

Subject terms: photomechanics; speckle method; random grating.

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CONTENTS

1. INTRODUCTION

The close-range objective white light speckle method,[1] in which the speckle field is the radiance distribution of the object surface when that surface is illuminated by white light, is a new strain measurement technique that requires no special environmental stability and only a simple recording system. Neither a laser light nor a camera is needed, and the method can be applied to either flat or developable curved surfaces. Two factors are extremely important in the performance of this method. One is the high reflectance of the specimen surface, which is required for the production of satisfactory whole-field speckle fringe patterns, and the other is the fine spatial content. Metal surfaces possess both characteristics. However, to extend the method to concrete, rock, carbon fiber composite, glass fiber reinforced epoxy, and other nonmetal materials, some modifications are needed. One possibility is to transfer onto the specimen surface a thin layer of silver, which is then scratched by a fine abrasive paper into fine furrows. Whole-field speckle fringe patterns with high sensitivity and large adjustable range can thus be obtained. However, the applicability is limited by the complexity of the transfer procedure, and it is suitable only for flat surfaces.

In this paper, we present a simple new approach, that of using a stick-on foil for the application of the objective speckle method to various materials. It is suitable for both flat and developable curved surfaces.

2. PROCEDURE

Most nonmetal materials have low reflectance. To circumvent this difficulty, we cement an aluminum foil onto the model material surface. This aluminum foil, which is commercially available in large quantities, consists of three layers (see Fig. 1). The aluminum foil itself, only 1 or 2 μm thick, is bonded onto a plastic film by a transparent separable adhesive. The plastic film serves as a backing, or carrier, that can be stripped off after the aluminum foil is mounted onto the material surface.

2.1. Aluminum foil mounting method and adhesives

The thin aluminum foil, which is very fragile and easily distorted, wrinkled, or torn, must be transferred from the plastic film to the specimen surface without distortion. This can be accomplished if both the correct adhesive and proper mounting procedure are employed.

The preparation of the component surface for mounting an aluminum foil is the same as that for mounting a moire grating: First, the area to be studied is sanded to give a smooth but not highly polished surface. Next, solvents are employed to remove all traces of oil or grease. Finally, the surface is treated with a basic solution to give it the proper chemical affinity for the adhesive.

The aluminum foil on its strippable film is positioned onto the specimen (the aluminum side being in contact with the specimen) by use of a rigid transparent tape. Its position is maintained by the tape as an adhesive is applied, and the film is pressed into place by squeezing out the excess adhesive. After the foil is installed, the adhesive is subjected

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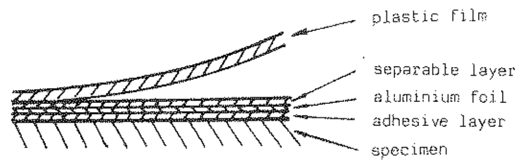
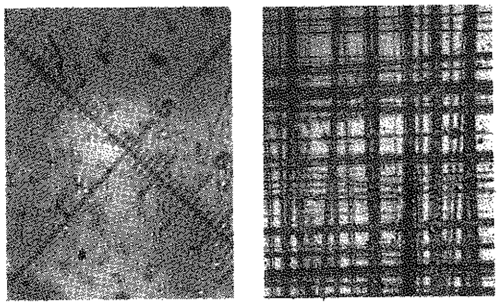


Fig. 1. Aluminum foil on specimen.



(a) (b)

Fig. 2. Magnified views of mounted aluminum foil: (a) before scratching and (b) after scratching.

to a proper combination of pressure and temperature for a suitable length of time to ensure complete curing.

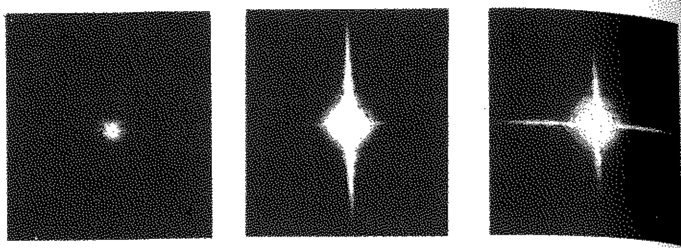
A wide variety of adhesives are available for mounting the aluminum foil. Factors influencing the selection of a specific adhesive include the carrier material, curing temperature, and curing time. We commonly use two kinds of adhesives, epoxy cement and cyanoacrylate cement (Eastman 910 SL). Epoxies are a class of thermosetting plastics that, in general, exhibit a higher bond strength and a higher level of strain at failure than other types of adhesives. They are usually quite viscous and easy to use. A modest clamping pressure of 35 to 140 kPa is recommended during the curing period to ensure as thin a bond line (adhesive layer) as possible. We also use for this purpose a modified form of Eastman 910 adhesive. It is fast and requires only room-temperature curing. When the adhesive is spread into a thin film between the aluminum foil and the specimen, a gentle pressure is applied for 1 or 2 min to induce polymerization. Once initiated, the polymerization will continue at room temperature without the pressure required initially. The performance of this adhesive system, however, deteriorates with time owing to absorption of moisture.

After curing is complete, the plastic film can be gently stripped from the aluminum foil. Remaining on the specimen surface is a thin layer of aluminum that has a reflectance as high as that of a mirror. Its radiance distribution is quite uniform when the surface is illuminated by a light source.

2.2. Random grating formation

As we know, the smoother a function is, the more rapidly its transform will approach zero with increasing frequency. In other words, the functions containing only slowly varying components have narrow spectra, whereas those with rapidly varying components have spectra with a broad overall width. Thus, it is necessary to scratch the aluminum foil to form random furrows in order to generate a random radiance distribution function with rapid oscillations, sharp peaks, and discontinuities. Its Fourier transform will have high frequency components and broad overall spectral width.

The treatment is quite easy. A fine brass brush or a piece of fine emery paper can be employed to form the random grating with furrows running along one direction or in two perpendicular directions. Magnified views of the aluminum foil before and after scratching are shown in Fig. 2. Their Fourier transform spectra are shown in Fig. 3.



(a) (b) (c)

Fig. 3. Spectra of specklegram: (a) before scratching, (b) after scratching along one direction, and (c) after scratching along two perpendicular directions.

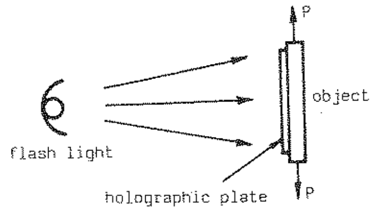


Fig. 4. Direct recording system.

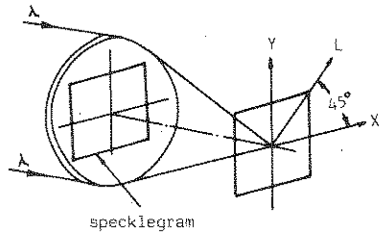


Fig. 5. Optical arrangement for whole-field filtering.

3. EXPERIMENTAL VERIFICATION

A direct recording system, shown in Fig. 4, is employed in this study. A holographic plate is attached close to the area to be studied, with the emulsion side against the scratched foil. After double exposure, before and after loading, the developed plate is put into the optical Fourier transform system, as shown in Fig. 5.

The first example is a plate made of organic glass under tension (Fig. 6). Fringe patterns of displacement components U and V with a spatial frequency of 244 ℓ/mm are shown in Fig. 7. One can use these patterns to determine the modulus of elasticity and Poisson's ratio of the material.

The second example is a carbon fiber composite box beam under bending (Fig. 8). The size of the aluminum foil is 80 mm × 60 mm. Three full-field contour maps with spatial frequencies of 304 ℓ/mm, 304 ℓ/mm, and 277 ℓ/mm are obtained, depicting equal displacement in the X, Y, and L directions, respectively (see Fig. 9).

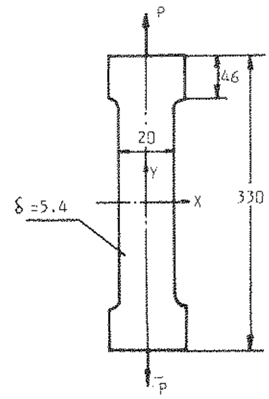
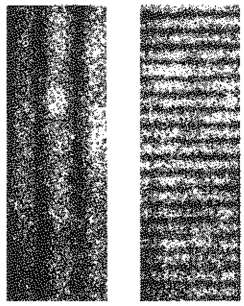


Fig. 6. Geometry of an organic glass plate specimen under tension. Dimensions are in millimeters.



(a) (b)

Fig. 7. Typical pair of isothetic fringes of an organic glass plate under tension: (a) U-field and (b) V-field.

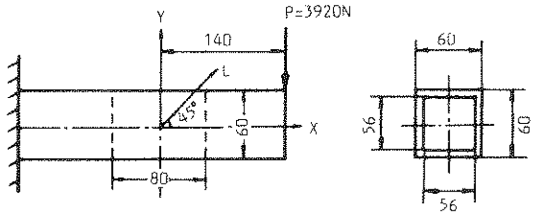
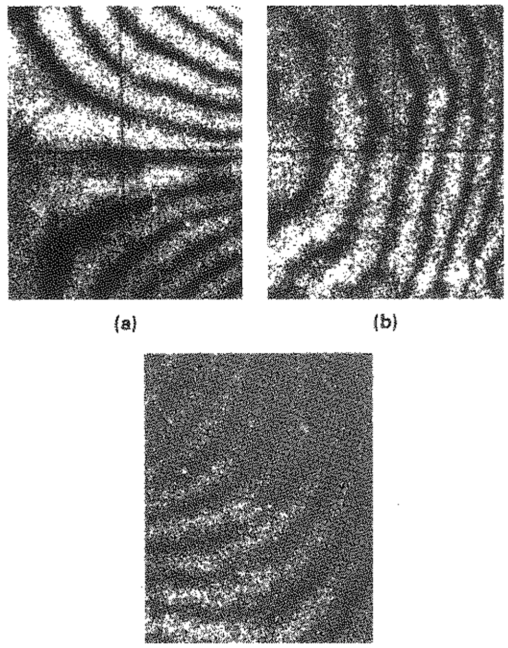


Fig. 8. Carbon filter composite box beam under bending. Dimensions are in millimeters.

4. CONCLUSION

We have developed a speckle method using a stick-on foil that can be applied to a variety of materials. If a thin aluminum foil is transferred onto the specimen surface and scratched gently to create random gratings, the resulting surface has both high reflectance and broad overall spectrum width. The aluminum foil is bonded to a plastic film that can be stripped off after the foil is mounted, so the reinforcing effect can be neglected. The method employs a direct recording system without a lens and white light illumination. The double-exposed specklegram contains high frequency Fourier components of the speckle field. Full-field contour maps can be obtained with clear fringes of equal displacement in different directions. The aluminum foil on strippable film is available commercially in large quantities. The mounting procedure is similar to that of a moire grating. The method can be applied to both plane and developable curved surfaces.



(a) (b) (c)

Fig. 9. Full-field contour maps of equal displacement: (a) in X-direction with spatial frequency of 304 ℓ/mm, (b) Y-direction, 304 ℓ/mm, and (c) L-direction, 277 ℓ/mm.

5. ACKNOWLEDGMENT

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6. REFERENCE

1. M. Tu, "Experiment and analysis for measuring whole field surface strain distribution by speckle correlation in reflection hologram," Mechanica Sinica 5, 516–521 (Sept. 1983) (in Chinese).

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