Development and Evaluation of a New Transient Thermoreflectance Technique*

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Introduction

Photothermal methods have proved suitable for the testing of composite [1,2], coatings [3-5], ceramics [6], and anisotropic materials [7]. In the methods thermal waves are generated by sample absorption of modulated or pulsed laser and sensed by using an appropriate detection scheme. In this project, thermal wave is generated by pulse laser heating of a small volume of the sample which causes rapid localized temperature rise up to ⊔ 10K and hence expansion of the surface layer before the temperature decays to ambient and subsequently the surface returns to its original form. The resulted changes in temperature and hence, in infrared radiation emission from the sample surface can be conveniently detected by a wide-band infrared detector as in [2-4]. However in the case of highly reflecting sample as in this work, the thermal infrared signals were too weak to be directly detected by using the infrared detector. Therefore, a laser probe was used instead to monitor the appreciable deformation on the sample surface as it underwent temperature change. The shift in the reflected probe beam spot on a detector depends on the slope of the deformed surface and to much smaller extend on index gradient in the ambient which can be neglected for sample surface temperature change around 10K in this work. Hence the shift in the reflected probe beam spot is dependent only on the thermoelastic property of the sample.

Materials and Methods

532 nm pulse laser derived rom Spectron Nd:YAG laser is used for heating. It is focused on to the sample with spot diameter about 100 μm by using a focusing lens. The He-Ne probe beam is delivered to the sample heated area with spot diameter about 15 μm by using a combination of a pair of adjustable mirror and a lens. This arrangement offers flexibility to vary the distance between centers of probe and heating beam spot while maintaining the spot diameter. The detection system consists of a fast photodiode and a monochromater slit. The recorded signal is digitized and analyzed by using digital storage oscilloscope (Lecroy 9301A) interfaced with a PC. The oscilloscope was triggered by a signal derived from heating beam by using a photo-detector. All samples were diamond spray polished (particle size 0.25 μm) to get a good quality surface of sufficiently flat and low roughness.

Results and Discussion

Typically the photothermal signals obtained from the samples of aluminium, brass, copper and stainless steel sharply rise to a peak value before slowly decay as heat diffuses inti ambient and subsequently the sample surface returns to its original form. Because of good agreement with the theory, variation in the laser beam profile [8] and non-linearity effect in the sample thermoelastic properties is not causing significant systematic error. From the visual inspection of the data, three familiar features are of interest in this work i.e. rise time, fall time and amplitude of the signals. The rise time is consistently decreasing with increasing thermal conductivity, indicating that the rate at which the surface expands is dependent on the speed of the heat conducted in the material. Higher thermal conductivity materials conduct heat faster and hence shorter time taken the temperature to reach maximum. Thus, stainless steel with lowest thermal conductivity among the samples tested, displayed slowest rise time and then followed by brass, aluminum and copper in turn. Similar pattern of dependence is also evident in the case of fall time versus thermal diffusivity. However, the data for sample of brass is a bit unusual that we believe is due to the high in-homogeneity of the alloy sample when was probed at an area of diameter ⊔ 15 μm in this work.

Since the part of the surface area investigated was taken at random, there was no way to ascertain that the part truly represented the bulk property of the whole sample. Variation of 2-4% in the sample major compositions (i.e. Cu & Zinc) is already confirmed from the manufacturer data {9} taken from the spots of ⊔ 3 mm in diameter. Otherwise the curves decay faster with increasing thermal diffusivity as expected. This is because high thermal diffusivity materials are more efficient in dissipating heat that leads to faster decay. On the other hand, signal amplitude exhibited opposite trend i.e. signal amplitude increased with thermal expansion coefficient as expected. Theoretically, the signal amplitude changes with the slope of the surface deformation, which in turn increases with, surface displacement and hence thermal expansion of the material.

Conclusions

The results presented new potential of photothermal technique as applied to remote examination of laser induced surface deformation on highly reflecting opaque sample. In particular, from a single measurement, it has capability to examine the formation and reduction of the induced surface deformation and described them in terms of three important thermal constants i.e. expansion coefficient, conductivity and diffusivity. The indirect detection scheme, though proved more sensitive in this work, is much more difficult to operate in comparison to direct detection by using an infrared detector. Further work can be carried out in simplifying the operation and improving the ability of extracting information from the experimental data.

Benefits from the study

It is a noble technique for non-contact and non-destructive measurement on deformed surface. It is also a new technique that simultaneously retrieves three important thermal constants from a single measurement.

Literature cited in the text

None.

Project Publications in Refereed Journals

Bertolotti, M, Ferrari, A., Liakhou, G.L., Voti, R.L., Marras, A., Ezquerra, T.A. and Balta-Calleja, F.J. 1995. Thermal anisotropy of polymer carbon fiber composites as revealed by photodeflection method, *J. Appl. Phys.* 78: 5706-5712.

Enguhard, E., Boscher, D., Deom, A. and Balageas, D. 1994, Measurement of thermal diffusivity of anisotropic materials by converging thermal wave technique, *Mat. Sci. Eng. B.* 5: 172-176.

Grozescu, I.V., Yunus, M.M. and Moksin, M.M. 2000. Effect of Q-switched pulse laser temporal shape on induced temperature profile of laser absorbing materials, *J. Phys. D:Appl. Phys.* 33: 677-680.

Grozescu, I.V., Yunus, W.M.M. and Moksin, M.M. 2000. Effect of Q-switched pulse laser temporal shape on induced temperature profile of laser absorbing materials, *J. Phys. D: Appl. Phys.* 33: 677-680.

Moksin, M.M., and Almond, D.P. 1995. Nondestructive evaluation of paint coatings using the thermal wave interferometry technique, *J. Mat. Sci.* 30: 2251-2253.

Moksin, M.M., Grozescu, I.V., Salleh, M.M., Wahab, Z.A. and Yunus, W.M.M. 2001. Photothermal investigation of laser induced surface deformation, *J. Mat. Sci.* (submitted)

Moksin, M.M., Grozescu, I.V., Yunus, W.M.M. and Azmi, B.Z. 1999. Effect of boron carbide composition in Si/B_4C composite on surface temperature decay as revealed by thermal wave method, *Nondestr. Test. Eva.* 13: 239-245.

Moksin, M.M., Grozescu, I.V., Yunus, W.M.M. and Wahab, Z.A. 1999. Thermal diffusivity measurement of black and metallic graphite paint coatings, *Meas. Sci. Technol.* 10(1): 7-10.

Seibeneck, H.J., Hasselman, P.H., Clevelend, J.J. and Bradt, R.C. 1977. Effect of grain size and microcracking on the thermal diffusivity of $MgTi_2O_5$, *J. Am. Cer. Soc.* 60: 336-338.

Zimmermann, P., Ristau, D. and Welsch, E. 1994. Potentiality of photothermal surface displacement technique for precisely performed absorption measurement of optical coatings, *Appl. Phys.* A5, 377-383.

Project Publications in Conference Proceedings

None.

Graduate Research

Ionel Valeriu Grozescu. 1998. Applied Optics [PhD]. Universiti Putra Malaysia.

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