Photomechanical response of PDMS+CNP composite under IR irradiation detected by dynamic speckle

I. M. Garnica-Palafox, F.M. Sánchez-Arévalo, J. Hernández-Cordero

Instituto de Investigaciones en Materiales. Universidad Nacional Autónoma de México. Apdo. Postal 70-360, Cd. Universitaria, México, D. F. 04510

M. Hautefeuille

Facultad de Ciencias, Depto. de Fsica, Universidad Nacional Autónoma de México. Cd. Universitaria, México, D. F. 04510

marisol.palafox@comunidad.unam.mx

Abstract: We demonstrate that dynamic speckle can be used to detect the photomechanical response of composites, based on PDMS and carbon nanoparticles, under IR irradiation.

OCIS codes: 120.6150,160.5470,160.5335, 250.2080, 350.5340.

1. Introduction

In recent years, it has been demonstrated that nanoparticles can provide changes in physical properties of polymers such as magnetic, thermal, electrical or even in optical responses [1]. Carbon nanotubes (CNT), carbon nanopowder (CNP) or graphene nanoparticles (GNP) have recently been blended with polydimethylsiloxane (PDMS) to obtain new composites with optically triggered responses [2]. These have been used in several applications taking advantage of photothermal effect displayed by these composites under infrared irradiation (IR) [3–6]. The photothermal effect produces a macromechanical response affecting the dimensions of the PDMS+CNP slabs in a light-controlled fashion. These composites could have potential applications for optical and mechanical actuators in microfluidics, drug delivery systems or even for photohermal therapies against cancer; all of them triggered by an external and minimally-invasive light beam. Although there are several reports about these composites; no study has addressed to evaluate the photomechanical response of PDMS+CNP under IR irradiation using dynamic speckle; furthermore, the aim of this work is to provide a methodology to evaluate the photomechanical response of PDMS+CNP under IR using dynamic speckle measurements.

2. Experimental setup

A dog-bone sample of the composite (PDMS+CNP) was placed between the grips of a mechanical tester and a instantaneous load was applied in order to align the polymeric chains [2]. Then, a continuos wave (CW) fiber-coupled diode laser (Thorlabs, 980nm, 800mW maximum output power) was used to irradiate the sample (spot size 125 microns). On the other side of the sample, a CCD camera with proper optical filters was coupled to the optical microscope to register the speckle pattern generated by the illumination of the expanded beam of a He-Ne laser (633nm) (See Fig. 1a).

To analyze and quantify the evolution of dynamic speckle, the time history speckle pattern (THSP) was used. Hence, the speckle activity dure to photomechanical actuation was registered by THSP. Data were evaluated by means of a cross-correlation function using the gray scale intensities of adjacent columns (i and $i+1$) of the THSP image. The normalized correlation index between pairs of columns of the THSP image was calculated using a cross-correlation function and then an average of the correlation index is obtained (Fig. 1b). The photomechanical response can be further linked to the macromechanical response of the composite by means of a load cell, which allows to obtain a stress *vs*. time curve showing the effects of laser irradiation on the composite. These were registered as peaks on stress vs. time curve evidencing an increase on the registered stress. The variations were associated to the photomechanical response of composite when IR laser was turned on and turned off; hence the stress optically induced was estimated as follows: $\Delta\sigma_{light} = \sigma_{LaserOff} - \sigma_{LaserOn}$.

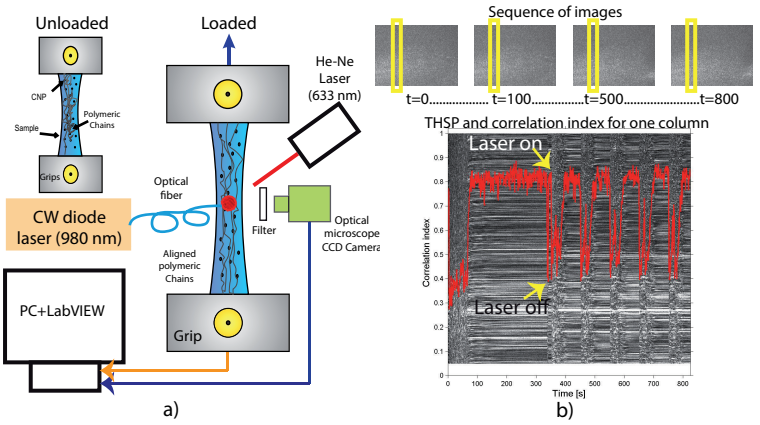

Fig. 1. Evaluation of the photomechanical response of PDMS+CNP composites under IR irradiation using dynamic speckle. a) Experimental setup for photomechanical experiments b) Time history speckle pattern (THSP) constructed image and its corresponding correlation index for one single column.

3. Results

Figure 2a) and b) show the experimental results of stress as function of time for both samples $PDMS+CNP$ and $PDMS+CNP+HCl_3$, respectively. These curves illustrate the behavior of the composites; first an instantaneous load is applied getting a stress value ranged between 3.643 and 3.867 MPa. As time passes (350 s), the relaxation of the composites occurred and a decrease of stress (around 1%) was registered for both samples. After this time, the IR laser was turned on (during 20 s) and a well defined peak appeared indicating an increment of stress at this point and we waited 80 seconds before the next IR pulse . This sequence was applied five times and then the average of $\Delta\sigma_{light}$ for each sample was obtained. The $\Delta\sigma_{light}$ were 25.5 $\pm$0.9 kPa and 22.4 $\pm$0.5 kPa.

The optical system was able to focus on the region of interest, registering the changes of the speckle pattern generated by the illumination of He-Ne laser, on the surface of the PDMS+CNP composite during the test; as a result, a sequence of images was obtained. The sequence was analyzed by reconstructing THSP for each column; then a normalized cross-correlation function was used in order to compare the subsequent columns through all the THSP image. This means that similar columns will show an index of correlation close to one and in the opposite case, when the columns look very different from each other the index of correlation will tend to zero. The index of correlation as a function of time was calculated for all the columns of the reconstructed image (THSP); these curves were averaged and the average of the index of correlation was obtained for each sample (see Figs. 2c) and d), respectively). The index of correlation for both samples began close to 0.9, then when the instantaneous load was applied, the index of correlation decreased to 0.45 and 0.5 for $PDMS+CNP$ and $PDMS+CNP+HCl_3$ samples, respectively. Then during the next 350 seconds, the THSP registered small changes due to the relaxation of the polymer ranging between 0.85 and 0.75. Subsequently, when the IR laser pulse irradiated the composites the index of correlation for both samples decreased from 0.85 to 0.5 approximately. These changes on the index of correlation indicate that dynamic speckle can detect the photomechanical response of $PDMS+CNP$ and $PDMS+CNP+HCl_3$ composites.

Conclusions

The expanded He-Ne laser beam was useful to generate an adequate speckle pattern on composite surface. It was found a good agreement between stress relaxation and index of correlation results; furthermore, it was demonstrated that dynamic speckle can be used to evaluate the photomechanical response of optically driven actuators based on PDMS and carbon nanoparticles.

Acknowledgements

This work was developed with financial support from PAPIIT, DGAPA-UNAM, through grants IT100215, IT101215 and TA100315. Support from Laboratorio Nacional de Soluciones Biomiméticas para Diagnstico y Terapia LaNS-BIODyT and CONACyT, grant 246988 is also greatly appreciated.

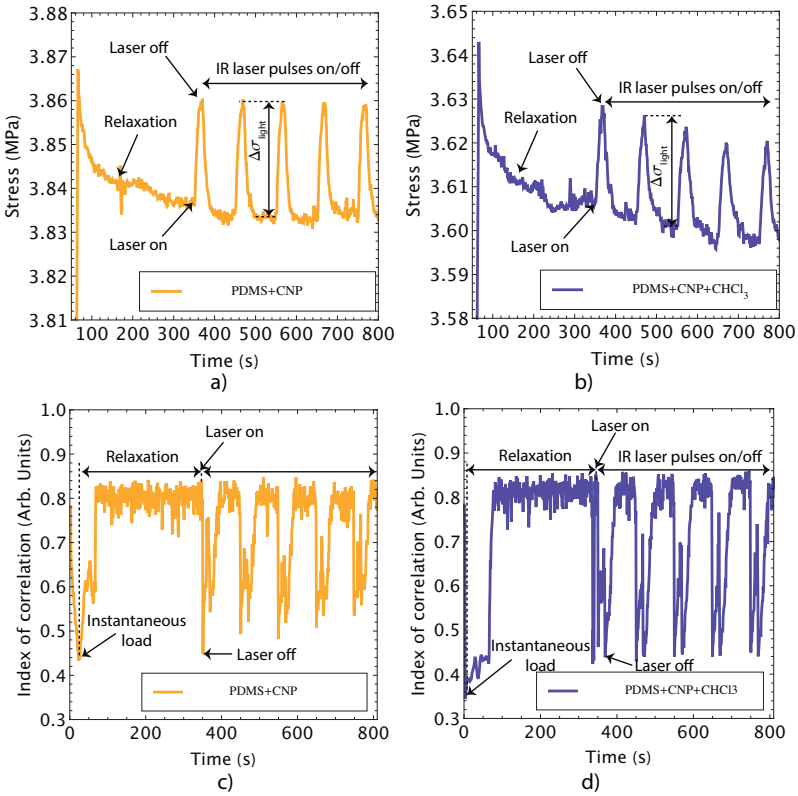

Fig. 2. Photomechanical response of $PDMS+CNP$ under IR Irradiation. a) Stress relaxation curve of $PDMS+CNP$ under IR laser pulses b) Stress relaxation curve of $PDMS+CNP+HCl_3$ under IR laser pulses c) Average of the index of correlation obtained from THSP analysis for $PDMS+CNP$ sample d) Average of the index of correlation obtained from THSP analysis for $PDMS+CNP+HCl_3$ sample

References

1. P. Schexnailder and G. Schmidt, "Nanocomposite polymer hydrogels" Colloid. Polym. Sci. **287**, 1–11 (2009).
2. R. Pimentel-Domínguez, A.M. Velázquez-Benítez, J. R. Vélez-Cordero, M. Hautefeuille ,F. M. Sánchez-Arévalo and J. Hernández-Cordero,"Photothermal Effects and Applications of Polydimethylsiloxane Membranes with Carbon Nanoparticles". Polymers **8** (4):84 (2016).
3. R. Pimentel-Domínguez, F. M. Sánchez-Arévalo, M. Hautefeuille and J. Hernández-Cordero, "Laser induced deformation in polydimethylsiloxane membranes with embedded carbon nanopowder" Smart Mater. Struct. **22**, 037001 (2013).
4. S. V. Ahir and E. M. Terentjev, "Photomechanical actuation in polymer-nanotube composites" NatureMater **6**, 491–495 (2005).
5. N. Hao, J. Y. Li, M. Xiong, X. H. Xia, J. J. Xu and H. Y. Chen, "Remote control of reversible localized protein adsorption in microfluidic devices" ACS Appl. Mater. Interfaces **15**, 11869–11873 (2014).
6. J. R. Vélez-Cordero, M. G. P. Zúñiga and J. Hernández-Cordero, "An optopneumatic piston for microfluidics" Lab. Chip. **5**, 1335–1342 (2015).