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Editorial

Special Issue on Advances in Characterization of Materials with Optical Methods

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1. Introduction

Materials characterization is a basic field of science and engineering. The response of any system to a set of external stimuli in the presence of another set of boundary conditions is strictly related to the constitutive model of the material(s) included in the system. The design/development of new materials, as well as the broadening of the field of use of "classical" materials, relies on the availability of efficient characterization techniques. Different approaches can be used to identify material properties. They can be recovered in a direct way from experiments or via inverse analysis. The latter approach is very common and may entail the solution of system(s) of algebraic equations or the minimization of an error functional, depending on unknown properties.

Optical Methods (OMs) fit very well in the aforementioned context, owing to their inherent ability to gather full-field information without altering specimen conditions, very often in real time. OMs essentially measure specimen deformations and, hence, are naturally suited for the mechanical characterization of materials. The illuminating wave front is modulated by the object and directed to a sensor. The superposition of the modulated and reference waves provides a fringe pattern, encoding displacement information, which is then related to the material's properties. Other forms of light–matter (or, more generally, wavε–matter) interaction can be used to identify the thermophysical, optical, or magnetic properties from the macro- to the nano-scale.

2. Advances in the Characterization of Materials with Optical Methods

This Special Issue focuses on the advances in the characterization of materials with optical methods. The issue includes six articles, covering the mechanical characterization of soft hyperelastic materials, reverse engineering and residual strain determination of large-scale industrial components, multi-scale analysis for surface topography in tribology applications, design optimization of optical sensors, thermo-optical characterization of nanoparticles for photocatalysis applications, and painting dye technology for artwork preservation and production.

Boccaccio et al. [1] developed a novel hybrid framework for the mechanical characterization of soft hyperlastic membranes, combining (i) biaxial tests (planar and inflation), (ii) one-shot projection moiré (with two symmetric projectors that project cross gratings onto the inflated membrane and one camera), (iii) a mathematical model to extract three-dimensional displacement information from moiré measurements, and (iv) metaheuristic optimization combining the harmony search and JAYA methods. The three-dimensional deformation field of the inflated membrane was accurately sensed by the moiré set-up, exploiting connections between moiré and differential geometry. The characterization framework was successfully applied to a 100 mm diameter natural rubber membrane exhibiting non-isotropic mechanical response because thickness varied over the specimen. Several variants of the identification problem, including up to 324 unknown (i.e., local values of hyperelastic constants and thicknesses) were solved by minimizing the difference between moiré data and finite element simulations. The identified properties matched very

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well the values indicated in the literature, while thickness distributions were fully consistent with other experimental measurements carried out independently. The optimization process was very robust.

Genovese et al. [2] investigated the capabilities of a stereo–Digital Image Correlation (stereo–DIC) system to measure the weld-induced distortion of the front-plate of a bogie train bolster subassembly. The study was motivated by the fact that deviation from planarity of this surface is measured at a few points using a CMM in the post-weld cooled state. An additional machining process is then used to bring the surface within the tolerance required to join the welded assembly to the train body through a threaded flange. In [2], DIC was found able to provide accurate full-field distortion and strain maps over the entire 588 mm $\times$ 308 mm surface of the front plate. An unexpected deviation from the nominal geometry of the part was already found in the pre-assembly stage, highlighting the importance of always complementing numerical analyses based on nominal geometries with experimental data.

Surface topography and multiscale roughness analysis are very important in tribology applications. Since the observable scale range by three-dimensional optical profilometers is quite limited, all scales linked to a physical phenomenon might not be measured, which impedes correct surface analysis. Stitching of three-dimensional topographies combines elementary topographic maps into a larger one, thus increasing scale range. In view of this, Lemesle et al. [3] developed a novel three-dimensional topography stitching algorithm based on reflectance and multimapping; the proposed rising sun stitching algorithm had three variants (i.e., naïve reflectance, exhaustive enumeration reflectance, and two-step reflectance). The two-dimensional reflectance maps generated on elementary topographic maps serve to improve three-dimensional alignment of these elementary maps. Remarkably, the proposed algorithms outperformed other stitching algorithms currently available in the literature in the four selected test cases in [3] (i.e., polymer abrasion, mirror polished copper, arm skin replica, and titanium alloy abrasion).

An important question in materials characterization with OMs is the quality of recorded images, which may depend on the camera optical system. Stray light (i.e., non-imaging rays distributed on the imaging surface and rays reaching the imaging surface via abnormal optical paths) reduces optical transfer function and the signal-to-noise ratio. For refraction-type optical systems, the usual method to eliminate stray light is to add a baffle and a light-blocking ring. The optomechanical structure's ability to suppress stray light increases with the length of the designed baffle. The final design of the baffle should block non-imaging light from reaching the detector and make the effective imaging light smoothly enter the imaging surface. In view of this, Li et al. [4] optimized the optical system, the baffle, and the vanes of an airborne, aspheric surface camera. The designed baffle and shading ring effectively suppress the stray light of the optical system, which can provide a reference for the structure design of other lenses.

Photocatalsyis is one of the most important technologies in water pollution analysis. Titanium dioxide (TiO_2) nanoparticles are very promising photocatalysts in terms of reaction efficiency for many environmental and energy applications. However, activation of TiO_2 occurs mainly by UV irradiation, which is only 5% of solar light spectrum, thus providing relatively low photocatalytic efficiency. For this reason, Abdelhamid et al. [5] developed Cu- and/or Zr-modified TiO_2 nanoparticles, characterizing them with photothermal beam deflection spectrometry (BDS), UV–Vis spectro-photometry, X-ray diffraction (XRD), and energy-dispersive X-rays (EDXs) to determine their thermo-optical and transport parameters. Remarkably, modification of TiO_2 with Cu and Zr induced spectral shifts into the visible spectral region, thus enhancing the absorption capacity of a photon under solar light. Furthermore, the material's surface area was increased, thus enabling higher absorption of light at the photocatalyst surface, as well as better pollutant adsorption and photodegradation.

The last article of this Special Issue investigated light reflection and absorption properties of acrylic paints and related materials, considering how they can be used in fine arts and how to simulate them in printing [6]. For this purpose, two groups of acrylic dyes (carrying colors) were analyzed using spectroscopy to determine their light absorption properties in the visible (VIS) and near infrared (NIR) regions. Digital recordings were compared with video surveillance cameras that operate and record during the day and night. The same color had at least two formulations of dyes for print reproduction to simulate what the naked eye sees and to simulate light absorption in the NIR spectrum. Infrared design can be applied in fine arts to explore dimensions beyond the visible range of human sight. A procedure for creating a dual artwork was proposed and developed in [6] to digitally archive the entire process as a specimen.

3. Outlook

This Special Issue presented advances in the characterization of materials with optical methods. The high versatility of OMs is confirmed by the variety of topics covered by the articles included in this Special Issue. The analyzed materials ranged from soft matter (i.e., natural rubber, artificial tissue, and dyes) to metals (titanium alloy, copper) and hard nanoparticles (TiO_2), considering mechanical, thermal, optical, and chemical properties, as well as multiscale surface characterization. OMs are highly standardized for any investigation scale and can be practically used in any field of science and engineering. These important characteristics will certainly lead to the widespread use of OMs in the future.

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