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Editorial

Nondestructive Testing in Composite Materials

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1. Introduction

A composite material is made of two or more constituents of different characteristics with the intent to complete the shortcomings of the individual components and to get a final product of specific characteristics and shape [1] to fulfil the user's demand. The most extraordinary example of composite is found in nature; in fact wood, which appears so strong and resistant, is composed of long fibers of cellulose held together by the lignin that is a weaker substance. Human beings observing and copying nature have always strived to develop composite materials. An example of composite material comes from afar: mud bricks; these were created when the ancients realized that mixing mud and straw gave them a resistant building material such as mud bricks. Later on, concrete was originated from the combination of cement, sand and gravel, and was widely used in the construction sector. Many types of materials have been developed and continue to be developed to meet the different needs of the modern world. Different types of matrices and reinforcements are being used that are derived from petrochemical resources or extracted from the vegetable world [2], which also allows us to comply with safety at work concerns and waste disposal. Indeed, the combination of two elements represents for many composite materials a strength and weakness at the same time. In fact, several different types of defects [3] may occur during the fabrication of composites, with the most common being: fiber/play misalignment, broken fibers, resin cracks or transversal ply cracks, voids, porosity, slag inclusions, non-uniform fiber/resin volume ratio, disbonded interlaminar regions, kissing bonds, incorrect cure and mechanical damage around machined holes and/or cuts. The presence of defects may result in a considerable drop of the composite mechanical properties [4]. Therefore, effective non-destructive evaluation methods able to discover defects at an incipient stage are necessary to either assure the quality of a composite material prior to putting it into service, or to monitor a composite structure in service.

2. Nondestructive Testing

We all would like to live in a safe house that would not collapse on us. We would all like to walk on a safe road and never see a chasm open in front of us. We would all like to cross a bridge and reach the other extreme safely. We all would like to feel safe and secure to take the plane, the ship, the train or to use any equipment. All this may be possible with the adoption of adequate manufacturing processes, non-destructive inspection of final parts and monitoring during the in-service life. This requires effective non-destructive testing techniques and procedures. The intention of this special issue was to collect the latest research to highlight new ideas and the way to deal with challenging issues worldwide. There were 19 papers submitted of which 12 were accepted and published. Going through the special issue, different types of materials and structures were considered; different non-destructive testing techniques were employed with new approaches of data treatment proposed as well numerical simulation.

The degradation of concrete, the material of which many widely used goods are made of such as roads, bridges and the home in which we live, is certainly a cause of anxiety and demands for safety. Milad Mosharafi, SeyedBijan Mahbaz and Maurice B. Dusseault dealt with the problem of corrosion of steel in reinforced concrete [5]. The authors reviewed previous literature and focused on the self-magnetic behavior of ferromagnetic materials, which can be exploited for quantitative condition assessment. In particular, they performed numerical simulation to get information on the possibility to detect the rebar degradation with the passive magnetic inspection method and to establish detectability limits of such method. Of great relevance for all us is the safeguard of the cultural heritage, which represents our history; the paper by Grazzini [6] can be inserted in this context. Grazzini describes a technique to detect plaster detachments from historical wall surfaces that consist of small and punctual impacts exerted with a specific hammer on the plastered surface. This technique was applied to frescoed walls of Palazzo Birago in Turin (Italy).

Most of the papers of this special issue involve fiber reinforced composites [7–12]. These include different types of matrices and fibers that are used for different applications going from the transport industry (aircraft, trains, ships, etc.) to goods for daily life. The most popular are those based on resin epoxy matrix reinforced with either carbon or glass fibers and are named CFRP for carbon fiber reinforced polymer and GFRP for glass fiber reinforced polymer; these materials are also called carbon/epoxy and glass/epoxy. These materials can be non-destructively evaluated by using different techniques, amongst them ultrasonic testing (UT) and infrared thermography (IRT). Ultrasonic testing in reflection mode (pulse-echo) can be accomplished with a single probe (SEUT), which acts to both send and receive sound waves, or with a phased array (PAUT). The superiority in terms of the signal noise ratio of PAUT over SEUT was assessed by Hossein Taheri and Ahmed Arabi Hassen through a comparative study on a GFRP sample [7]. The authors of Ref. [7] used the same PAUT for guided wave generation to detect flaws in a CFRP panel.

In addition to the use of the direct wave, the diffuse wave can also be exploited for inspection purposes. The information contained in diffuse waves are mostly useful in seismology and in civil engineering, but can be also used for health monitoring and the nondestructive evaluation of fiber reinforced composites. Zhu et al. [8] applied this method to the inspection of carbon/epoxy and found it promising for early crack detection. A critical aspect for defect localization is to distinguish signals from noise, and this requires more investigation.

Carbon fiber reinforced polymer laminates are also considered by Toyama et al. [9]. The latter authors used non-contact ultrasonic inspection technique through visualization of Lamb wave propagation for detecting barely visible impact damage in CFRP laminates. Ultrasonic testing is generally a contact technique, but this poses problems in materials and structures in which the contact fluid (water, gel) may be hurtful for the surface; thus, the non-contact deployment is of great interest and ever more investigated. The results reported in Ref. [9] are promising but, as also concluded by the authors, the method based on Lamb waves requires further investigation with particular regard to the signal-to-noise ratio improvement.

Teng et al. [10] investigated the suitability of the recurrence quantification analysis in ultrasonic testing to characterize small size defects in a thick, multilayer, carbon fiber reinforced polymer. The authors conclude that their proposed method was able to detect artificial defects in the form of blind holes, but further research is necessary to improve and update the method to address real discrete defects. Niutta et al. [11] used the detecting damage index technique in combination with the finite element method to evaluate residual elastic properties of carbon/epoxy laminates damaged through repeated four-point bending tests. As a conclusion, the authors of Ref. [11] affirm that their methodology allows us to locally assess the residual elastic properties of damaged composite materials. By mapping the elastic properties on the component and considering the assessed values in a finite element model, a precise description of the mechanical behavior of the composite plate is obtained and, consequently, the health state of a damaged component can be quantitatively evaluated and decisions on its maintenance can be made by defining limits on the acceptable damage level.

Infrared thermography is widely used in the inspection of materials and structures, amongst them composites, thanks to its remote deployment through the use of a non-contact imaging device. Lock-in thermography coupled with ultrasonic phased array was used by Boccardi et al. [12] to detect impact damage in basalt-based composites. In particular, two types of materials that include basalt fibers as reinforcement of two matrices were considered: polyamide and polypropylene. The obtained results show that both techniques can discover either impact damage or manufacturing defects. However, lock-in thermography, being non-contact, can be used with whatever surface while contact ultrasonic cannot be used on hydrophilic surfaces that get soaked with the coupling gel. Infrared thermography lends itself to being integrated with other techniques to allow the inspection of both thin and thick structures such as in Ref. [13], in which a joint use of infrared thermography with a ground penetrating radar (GPR) allowed us to assess the conditions of archaeological structures.

In particular, IRT was able to detect shallow anomalies while the GPR followed their evolution in depth. The integration of infrared thermography with other techniques is also deployed with IRT for the detection of defects, and the other technique is exploited for thermal stimulation. An example of this deployment is ultrasound thermography [14], in which elastic waves are used for selective heating and infrared thermography detects buried cracks. An example of integration between infrared thermography and eddy current is given by Li et al. in Ref. [15] of this special issue, in which the pulsed eddy current is used for thermal stimulation to detect welding defects.

The paper by Zhang et al. [16] is concerned with a technical solution that combines the adaptive threshold segmentation algorithm and the morphological reconstruction operation to extract the defects on wheel X-ray images. The obtained results show that this method is capable of accurate segmentation of wheel hub defects. The authors claim that the method may be suitable for use in other applications, but warn about the importance of using the proper parameter settings. Na and Park [17] investigated the possibility to transform the electromechanical impedance (EMI) technique into a portable system with the piezoelectric (PZT) transducer temporarily attached and detached by using a double-sided tape. Regardless of the damping effect, which may cause the impedance signatures to be less sensitive when subjected to damage, the results from this study have demonstrated its feasibility. The authors are convinced that, by conducting simulation studies, the PZT size can be further reduced for a successful debonding detection of composite structures.

At last, Zhou et al. [18] made an overview of nondestructive methods for the inspection of steel wire ropes. The authors first analyzed the causes of damage and breakage as local flaws and the loss of the metallic cross-sectional area. Then, they reviewed several detection methods, including electromagnetic detection, optical detection, ultrasonic guided wave method, acoustic emission detection, eddy current detection and ray detection, by considering the advantages and disadvantages. They found that the electromagnetic detection method has gradually been applied in practice, and the optical method has shown great potential for application, while other methods are still in the laboratory stage.

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