Optical characterisation of complex structures, from engineering composites to bio-materials

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Abstract

Bio-materials and engineering composites share many common features, such as complex anisotropic structures and mixtures of materials with different properties. Engineering composites are typically composed of fibres in a resin matrix. Examples are Carbon Fibre Reinforced Polymer (CFRP) and Glass Fibre Reinforced Plastic (GFRP). These materials are used to make high performance structures such as the body and chassis of a Formula 1 race car and the blades of a wind turbine, respectively. An important structural biomaterial is wood, which can be considered to have a structure analogous to engineering composites. Softwood is a fibrous material composed of different cell types, whose cell types and the resulting material density and structure determine the moisture transport properties of the wood. Wood has many structural uses from the construction of furniture, buildings, early aircraft and as a support for panel paintings.

Bio-materials and engineering composites are challenging materials for structural characterisation due to their anisotropic structure and behaviour. Optical measurement techniques for these materials can be characterised into 2D surface metrology, 3D volume imaging and photomechanics techniques to measure the response of materials under an applied load. The surface profile of an object can be measured by using fringe projection, photogrammetry or white light interferometry. Structural applications of natural and manufactured composite materials commonly employ coatings for protection of the material from moisture, heat, scratches, and for aesthetic purposes. Optical coherence tomography (OCT) can measure the thickness of semi-transparent coatings and hyperspectral imaging can measure the chemical properties of the materials. 3D volume imaging is more challenging as many materials are not transparent. Semi-transparent materials such as GFRP may be structurally characterised using OCT. Dry wood is partially transparent to terahertz radiation and internal structural features may be assessed by their different absorption characteristics. One challenging aerospace composite to measure optically in 3D volume imaging is CFRP. The presence of carbon disturbs the propagation of electromagnetic waves in the material. The material is typically measured using ultrasonic waves, which can be used to reconstruct the internal structure in the mm scale. Photomechanics, the development and application of optical techniques for solid mechanics, is an active and growing topic for a wide range of materials. Composites of both bio-material and manufactured origin are anisotropic and as such have a non-uniform response to loading. This is partially at the materials level where different materials have different mechanical properties and partly at the interfaces between materials, where stress concentrations form under loading. Material properties may also vary due to environmental conditions, such as temperature and relative humidity. Solid mechanics employs a number of optical techniques, most of which are non-contact. Commonly used techniques are digital image correlation (DIC), holographic and speckle interferometry and Moiré.

This paper will review the field of optical measurements for complex anisotropic structures and mixtures of materials with different properties. Parallels will be drawn between applying these techniques to bio-materials and engineering composites. Examples will be given from engineering, bio-materials testing and cultural heritage.