4.2.23. ULTRASONIC NDT OF IN-PLANE STIFFNESS ANISOTROPY IN METALS AND COMPOSITES

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Majority of current state-of-the-art and newly developing materials (polymers, composites, ceramics, nano-structures, etc.) exhibit an evident elastic anisotropy which is an inherent background for anomalous physical properties and a wide range of applications. The measurements of elastic anisotropy are usually performed with either X-ray, optical Brillouin scattering, or electromagnetic techniques. These methods require sophisticated and expensive equipment which is not applicable to on-line testing in industrial environment. An alternative ultrasonic technique involves direct measurements of bulk wave velocities in various directions in the material. This is a time consuming procedure which normally requires cutting material in pieces and testing a number of specimens of various orientations. Mechanical performance of plate-like materials and components typical for automotive and aviation industries depends mainly on the in-plane anisotropy of stiffness. The application of ultrasound for NDT of the in-plane stiffness anisotropy is limited by the availability of only a single propagation direction across the thickness of the specimen.

In this paper, two new ultrasonic approaches to NDT of in-plane stiffness anisotropy have been developed and applied to various materials including long- and short-fibre reinforced polymer composites as well as metal components with residual stresses. Similar to optics, the first approach is based on polarization measurements of ultrasonic shear waves which manifest birefringence due to asymmetry of the in-plane stiffness. The shear wave birefringence is applied for monitoring fibre orientation and evaluation of in-plane stiffness anisotropy of uni-axial and multi-axial non-crimped fabric composite materials. The technique is shown to be sensitive to detect damage induced variation in stiffness anisotropy and is applicable to a number of fiber-reinforced materials: glass- and carbon-reinforced composites, single- and multi-ply lay-ups, non-fabric and multi-ply fabric composites. It also works reliably in determining internal stresses induced by cold work and manufacturing processes of friction stir welding in metals and alloys.

The other approach developed uses mode conversion of air-coupled ultrasound to zero-order plate waves for remote NDT of the in-plane stiffness anisotropy. The low-frequency values of the s_o – wave velocities along the principal axes of an anisotropic material lead to a direct estimate of Young`s moduli in these directions. However, the air-coupled measurements of the low-frequency $s_o$ – wave velocities fail due to negligible coupling to such an in-plane polarized mode. Alternatively, it is shown that non-contact ultrasonic evaluation of the in-plane anisotropy of Young`s modulus can be based on air-coupled measurements of the a_0 – wave dispersion extrapolated to a static case. The measurements also revealed that the plate wave velocities along the principal axes vary differently as functions of frequency which is an indication of frequency dispersion of elastic wave anisotropy. The s_o – wave anisotropy is strongly affected by frequency variation due to transition from high-modulus longitudinal to low-stiffness shear deformation. For a_o – waves, the contribution of longitudinal deformation to low-frequency bending stiffnesses provides maximum anisotropy in the static case. The phenomenology presented enables a rapid analytical quantification of frequency dispersion of anisotropy in materials with known elastic coefficients.