

# Measurement Capabilities

## *In-plane Measurements*

- In-plane longitudinal velocities along MD ( $v_{L,MD}$ ) and CD ( $v_{L,CD}$ )
- In-plane shear velocities along CD ( $v_{S,MD-CD}$ ) and at 45 deg. with respect to MD ( $v_{S,45}$ )
- In-plane specific stiffnesses:

$$Q'_{11} = (v_{SO-MD})^2 \quad (\text{MD longitudinal specific elastic stiffness constant})$$

$$Q'_{22} = (v_{SO-CD})^2 \quad (\text{CD longitudinal specific elastic stiffness constant})$$

$$Q'_{66} = (v_{S-MD-CD})^2 \quad (\text{MD-CD or CD-MD shear specific elastic stiffness constant})$$

$$Q'_{12} = \left\{ \left[ 2v_{s-45}^2 - \frac{(Q'_{11} + Q'_{22})}{2} - Q'_{66} \right]^2 - \left[ \left( \frac{Q'_{11} - Q'_{22}}{2} \right) \right]^2 \right\}^{\frac{1}{2}} - Q'_{66}$$

- In-plane elastic stiffness constants (assuming that density can be computed):

$$Q_{11} = \rho Q'_{11}$$

$$Q_{22} = \rho Q'_{22}$$

$$Q_{66} = \rho Q'_{66}$$

$$Q_{12} = \rho Q'_{12}$$

- In-plane engineering constants:

$$v_{MD-CD} = v_{12} = \frac{Q_{12}}{Q_{11}} = \frac{Q'_{12}}{Q'_{11}} \quad (\text{MD-CD Poisson's ratio})$$

$$v_{CD-MD} = v_{21} = \frac{Q_{12}}{Q_{22}} = \frac{Q'_{12}}{Q'_{22}} \quad (\text{CD-MD Poisson's ratio})$$

$$E_{MD} = Q_{11} - \frac{Q_{12}^2}{Q_{22}} = Q_{11}(1 - \nu_{12}\nu_{21}) \quad (\text{MD Young's modulus})$$

$$E_{CD} = Q_{22} - \frac{Q_{12}^2}{Q_{11}} = Q_{22}(1 - \nu_{12}\nu_{21}) \quad (\text{CD Young's modulus})$$

$$G_{MD-CD} = Q_{66} \quad (\text{MD-CD shear modulus})$$

- In-plane stiffness anisotropy ratio:

$$R_{MD-CD} = \frac{E_{MD}}{E_{CD}} = \frac{Q_{11}}{Q_{22}} = \frac{Q'_{11}}{Q'_{22}}$$

- Polar diagram with 15-degree angular increment:
  - Stiffness orientation angle (SOA)
  - MD/CD stiffness ratio
  - Max/Min stiffness ratio

### ***Out-of-plane Measurements***

- Soft-platen thickness (loading pressure set to 50 kPa)
- Out-of-plane longitudinal velocity:  $v_{L-ZD}$
- Out-of-plane longitudinal specific stiffness:

$$C'_{33} = (v_{L-ZD})^2$$

- Out-of-plane longitudinal elastic stiffness constant (assuming that grammage is available):

$$C_{33} = \rho C'_{33}$$