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# Comment on "Disentangling longitudinal and shear elastic waves by neo-Hookean soft devices" [Appl. Phys. Lett. 106, 161903 (2015)]

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In a recent Letter, Chang *et al*. proposed a method to disentangle pressure and shear elastic waves by using soft hyperelastic materials.[1] In particular, they exploit a compressible neo-Hookean model to analyse elastic wave propagation in the material undergoing simple shear deformation. Yet it is known that "simple shear is not so simple,"[2] and neo-Hookean model might not properly predict the response of the soft isotropic materials under simple shear deformation.[3] One can see from Fig. 1 that we need a more complicated material model than neo-Hookean one to describe the behaviour of materials undergoing large simple shear deformation. Recently, Lopez-Pamies proposed a model[3] with the strain-energy function (1) properly describing the behaviour of soft isotropic materials under simple shear deformation (see Fig. 1)

$$W = \sum_{k=1}^{2} \frac{3^{1-\alpha_k}}{2\alpha_k} \mu_k \left( I_1^{\alpha_k} - 3^{\alpha_k} \right) - \mu \ln J + \frac{\lambda}{2} (J-1)^2, \qquad (1)$$

where $\alpha_1, \alpha_2, \mu_1$, and $\mu_2$ are material parameters, and $\lambda$ and $\mu = \mu_1 + \mu_2$ are the first and second Lame constants at the undeformed state, respectively. For the strain-energy function (1), slowness curves of S-waves differ significantly from the slowness curves of S-waves for the neo-Hookean material model (Fig. 2). Thus, the divergence angle $\Delta\theta = |\theta_s - \theta_p|$ between S-wave and P-wave for the Lopez-Pamies material model intriguingly varies with propagation direction in contrast to the neo-Hookean material model. In particular, the divergence angle can be significantly increased by choosing the right inclination angle. For example, the maximum divergence angle is $\Delta\theta_{max} = 33°$ for $\tan\gamma = 1/3$ when incident angle is $\phi_0 = 16°$ (see Fig. 3(a)). Moreover, the maximal divergence angle $\Delta\theta = 18.4°$, achievable for neo-Hookean material model at $\tan\gamma = 1/3$, can be reached at much smaller simple shear deformation ($\tan\gamma \approx 0.11$) with inclined propagation direction ($\phi_0 \approx 19°$). Fig. 3(b) shows that the divergence angle has maxima for certain inclined propagation directions and it varies with applied deformation. Thus, the divergence angle of 41° can be achieved at $\tan\gamma = 0.25$ for Lopez-Pamies material model, while it is only $\Delta\theta = 14°$ for neo-Hookean material model.

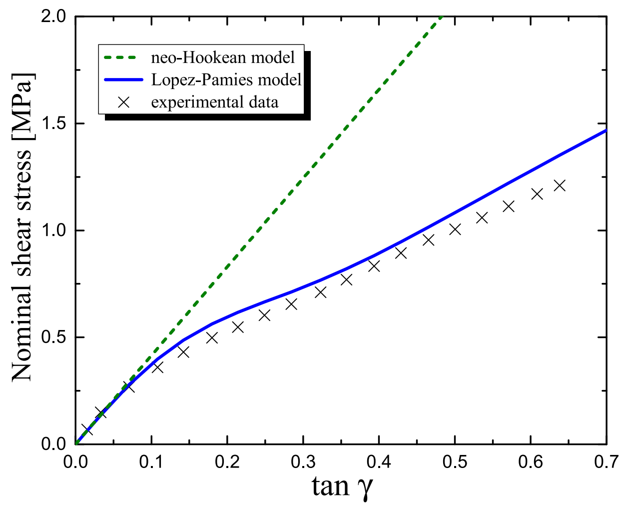


FIG. 1. Lopez-Pamies model (1) and the neo-Hookean model with material parameters: $\alpha_1 = 0.6$, $\alpha_2 = -68.73$, $\mu_1 = 2.228$ MPa, $\mu_2 = 1.919$ MPa, $\mu = 4.147$ MPa, and $\lambda = 2$ GPa, compared with the data of Lahellec *et al.*[4] (2004) for simple shear deformation.

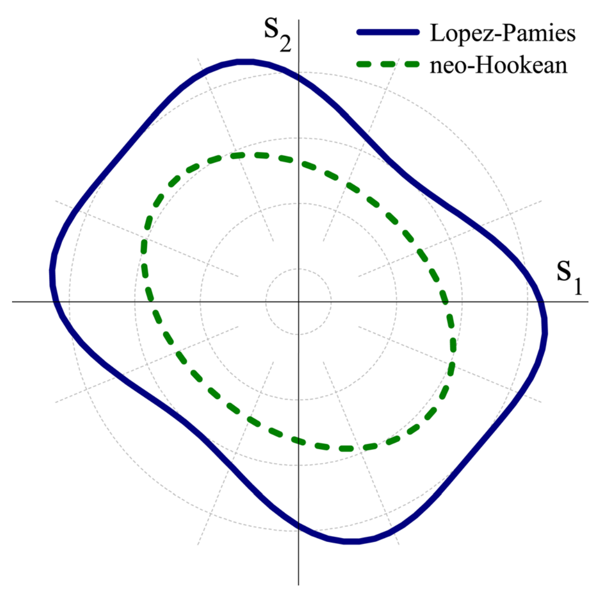


FIG. 2. Slowness curves of S-waves for nearly incompressible Lopez-Pamies (solid blue) and neo-Hookean (dashed green) material models under simple shear deformation with $\tan\gamma = 1/3$ (material parameters are the same as in Fig. 1).

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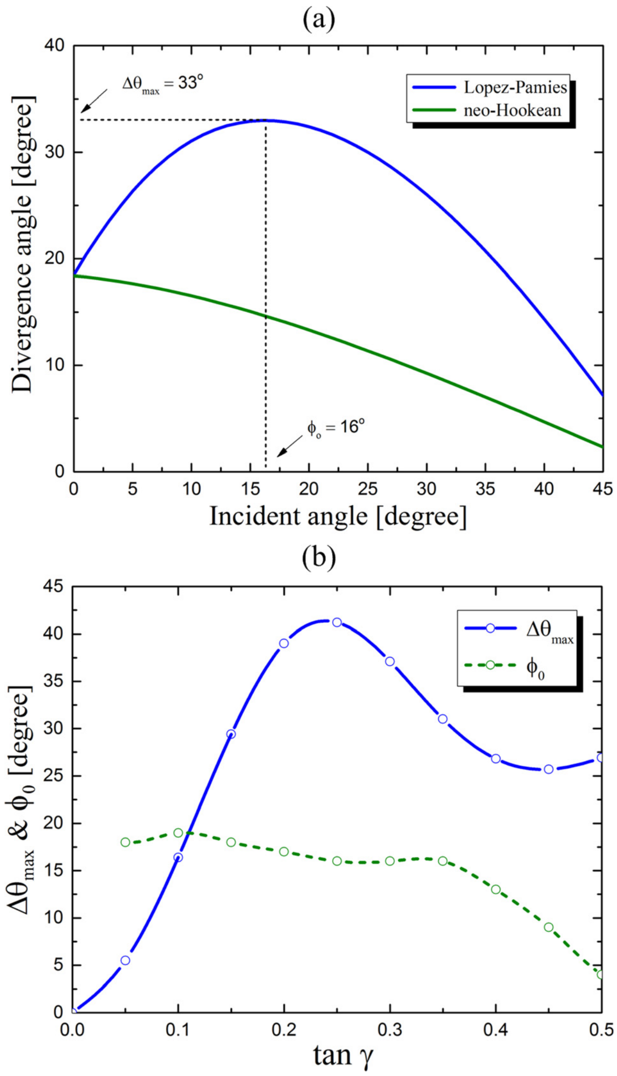


FIG. 3. Divergence angle as a function of incident angle for $\tan\gamma = 1/3$ (a); divergence and corresponding incident angle as a function of simple shear deformation (b) for nearly incompressible Lopez-Pamies material model.

Another important aspect is the influence of material compressibility on refraction angles of elastic wave modes. While for the neo-Hookean material model the S-wave refraction angle $\theta_s$ is independent of material compressibility, for Lopez-Pamies material model the $\theta_s$ reduces significantly with the increase in the material compressibility (see Fig. 4). Furthermore, the P-wave refraction angle $\theta_p$ slightly increases for the neo-Hookean material model, and it rapidly increases the other way round for the Lopez-Pamies material model (see Fig. 4). These effects seem to influence significantly the phenomenon of the disentangling elastic wave modes in soft materials and should be studied experimentally.

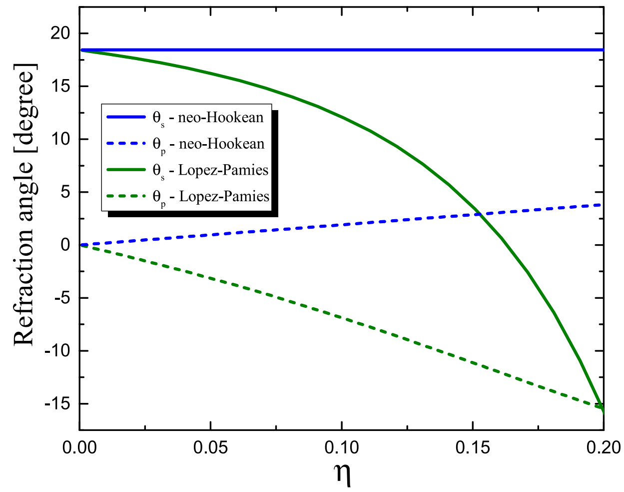


FIG. 4. Refraction angles $\theta_p$ and $\theta_s$ of P- and S-waves in the case of $\tan\gamma = 1/3$ as the functions of the material compressibility $\eta$ for the Lopez-Pamies and neo-Hookean models.

[1]Z. Chang, H.-Y. Guo, B. Li, and X.-Q. Feng, "Disentangling longitudinal and shear elastic waves by neo-Hookean soft devices," Appl. Phys. Lett **106**, 161903 (2015).
[2]M. Destrade, J. Murphy, and G. Saccomandi, "Simple shear is not so simple," Int. J. Non-Linear Mech. **47**, 210–214 (2012).
[3]O. Lopez-Pamies, "A new i1-based hyperelastic model for rubber elastic materials," C. R. Mec. **338**, 3–11 (2010).
[4]N. Lahellec, F. Mazerolle, and J. Michel, "Second-order estimate of the macroscopic behavior of periodic hyperelastic composites: Theory and experimental validation," J. Mech. Phys. Solids **52**, 27–49 (2004).