**Appendix. Finite Element simulations of dynamic indentations of laminates with viscoelastic films overlay rigid and elastic substrates**

Commercial FE software ABAQUS/explicit (ver. 6.19) was used to analyze the dynamic indentation response of a laminate with a viscoelastic film overlayed on a rigid or an elastic substrate via [D5-D6]. An axisymmetric model with perfect binding conditions between the film and the substrate parts of the laminate, fixed boundary conditions at the bottom face of the film (rigid substrate case) or the substrate (elastic substrate case), and free boundary conditions on the lateral faces of the film-substrate laminate was considered. The laminate experiences an indentation via an infinitely rigid axisymmetric tip (spherical, conical and flat punch shape) that translates normal top the film (no horizontal translation and no rotation) with frictionless contact conditions between the tip and the film. The model dimensions were set sufficiently large to avoid undesired effects caused by the boundary conditions. A frictionless contact between the indenter and the layered model was considered. The simulations include two loading steps, an initial quasi-static indentation step (“DC-step”) which follows a secondary smaller-scale dynamic indentation step (“AC-step”). In the DC step, the film and substrate parts of the laminate are considered as isotropic materials with an elastic-perfectly plastic constitutive behaviour with Young’s moduli and , and hardness parameters and . The film and substrate Poisson ratios of both are considered as . The hardness-to-modulus ratios and characterize the onset of indentation damage in the substrate and film, respectively, and were set as as is commonly observed in both synthetic and biological materials [Lebonet, Miserez- Property maps for abrasion resistance of materials]. Axisymmetric, four-node, reduced integration quadrilateral elements with hourglass control (CAX4R in ABAQUS element library) with non-uniform segmentation of a finer mesh in the vicinity of the indentation regime were used. The meshing parameters were verified via mesh convergence pre-analysis. Adaptive meshing (ALE method) were used to incorporate non-linear effects of large deformations and plasticity, and to reduce element distortion effects. In the DC step, a progressive translation of the tip into the film up to the final indentation depth was applied; during the DC step, the built-up contact force between the tip and the film was recorded and the contact radius () at the point of maximum depth was recorded. At the end of the DC step, the deformed geometry of the tip-laminate configuration was recorded and used as an input for the sequential AC step. For the AC step (dynamic indentation), a frequency domain linear-viscoelastic constitutive behaviour was used for the film and a linear-elastic constitutive behaviour was used for the substrate, realized via axisymmetric, four-node, quadrilateral elements with hybrid formulation (CAX4H in ABAQUS element library). Harmonic displacement with fixed amplitude () was set for the elements of the film that are in contact with the tip (extracted using the DC step). Direct-solution steady-state dynamic analysis was used to identify their resultant harmonic reaction forces and calculate the dynamic contact stiffness () from the force-to-displacement relationships of the dynamic indentation. Then, the dynamic modulus of the laminate was calculated from the dynamic contact stiffness via the classical dynamic indentation formulations , where is the contact area and is the indentation tip-shape parameter [\*Fischer-Cripps book\*]. Finally, the storage and loss moduli of the laminate was extracted from the real and imaginary parts of ( and ), the modulus magnitude of the laminate from the magnitude of (), and the loss coefficient of the laminate from the ratio between the imaginary and real part of ().