

# MICRO AND MACROMECHANICAL MODELLING AND SIMULATION OF BIO ELASTOMERIC COMPOSITES REINFORCED WITH NATURAL FIBRES FOR CRANIAL SKIN ULTRASOUND MEDICAL PHANTOMS

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## ABSTRACT

This paper focuses on the virtual development of elastomeric composites incorporating natural fibers (*Cordyline Australis*) and an eco-friendly silicone matrix for medical phantoms that replicate the acoustic properties of human cranial skin. Micro- and macro-mechanical finite element models in COMSOL Multiphysics will be developed to simulate the anisotropic stress-strain behaviour of the composites under different loading conditions. The acoustic wave propagation will be validated against literature data and existing phantoms. The study will analyse the effects of fibre ratio, orientation, and matrix compatibility to optimize elasticity, anisotropy, viscoelastic response, and durability. Compared to current ultrasound phantoms, which have a short shelf-life, this approach enhances longevity, making it a more sustainable solution. Additionally, by incorporating anisotropy this research advances both the realism of medical phantoms and the accuracy of simulations of human tissues.

## INTRODUCTION

Medical phantoms are essential tools in ultrasound imaging research, designed to mimic the mechanical/acoustic properties of human tissues. However, many commercially available and researched ultrasound phantoms, particularly those made from gelatin-based materials, have fast degradation and a short shelf-life, often requiring refrigeration/chemical additives to slow down decomposition (Rathbun et al., 2022). Additionally, these materials lack the anisotropic mechanical properties inherent in biological tissues, such as human skin, which exhibits direction-dependent stiffness due to the alignment of collagen fibers in the dermis along Langer lines (Elouneg et al., 2023). The lack of anisotropy in traditional phantoms limits their ability to replicate realistic tissue responses in ultrasound simulations/biomechanical studies. Consequently, there is a pressing need for novel phantom materials that not only enhance longevity but also improve biomechanical realism (Hocking et al. 2011).

As such, this study explores elastomeric composites reinforced with natural fibers (*Cordyline Australis*) and an eco-friendly silicone matrix (EcoArte silicone SG587). By employing micro- and macro-mechanical models, the anisotropic stress-strain behavior of these composites was simulated and validated their acoustic wave propagation properties against existing literature.

## RESULTS AND CONCLUSIONS

A simplified micromechanical model representing a single fibre embedded in silicone is employed to approximate the homogenized elastic properties of an individual layer. These derived properties are then integrated into a macro-mechanical model of the laminated composite, utilizing the Equivalent Single Layer theory. To assess the elasticity matrix in the micromechanical analysis, six distinct loading cases are considered to extract the homogenized elasticity matrix for a layer, as illustrated in Fig. 1 a).

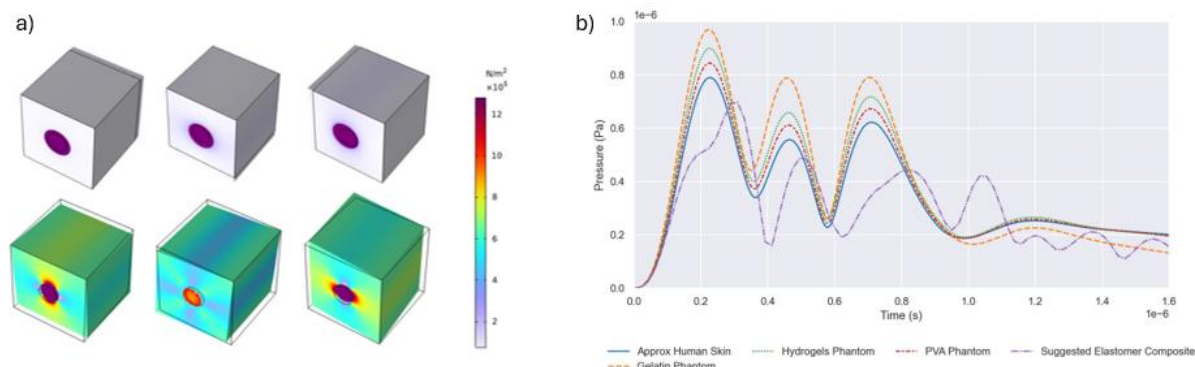


Fig.1 – a) Micro-mechanical Distribution of stress for six load cases of the Phantom, b) acoustic wave propagation

The homogenized elasticity matrix obtained from the micromechanical analysis was implemented to represent a laminate layer within the composite model. To simulate the mechanical behaviour of human skin, the bottom layer was modelled using this laminate structure, while the superficial layer consisted solely of the matrix material.

An approximated Ricker wavelet was used to simulate an acoustic wave propagating through the skin, initiating at the surface and traveling toward the bottom layer, using the acoustic-structure Multiphysics interaction in COMSOL. The wave propagation characteristics were then compared with those of commonly used medical phantom materials, such as gelatine, PVA, and hydrogels.

The results in Fig. 2 b) indicate that the suggested composite exhibits a wave propagation response comparable to current phantoms. While slight variations in peak pressure and wave attenuation are observed, the overall trend closely follows that of the skin approximation. Additionally, the proposed composite offers improved longevity compared to traditional phantoms, which degrade quickly and provides a more sustainable alternative.

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