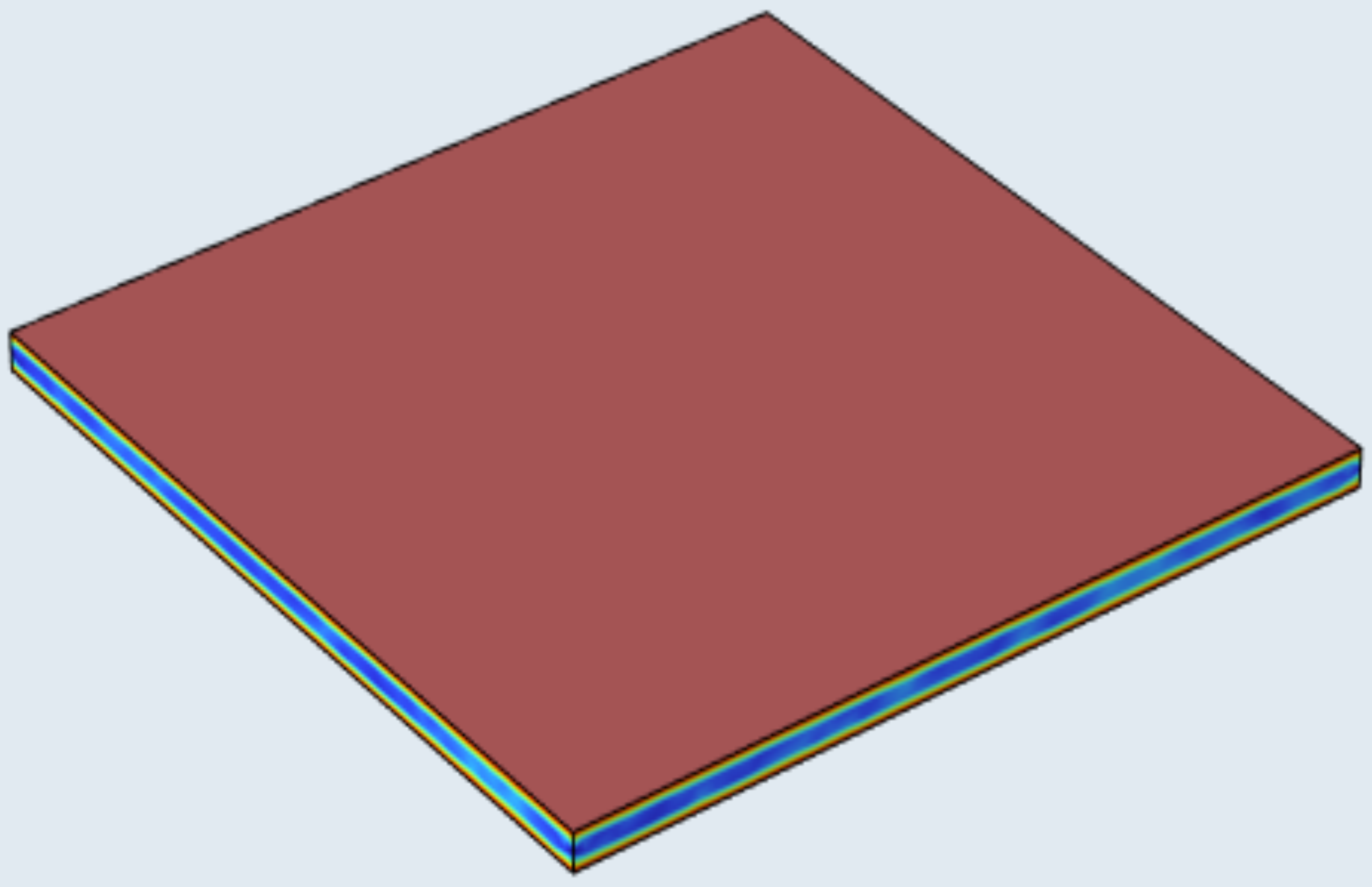

Modeling Moisture Diffusion and Deformation in Epoxy Resins

Understand the moisture diffusion and hygroscopic deformation in epoxy resins, critical in high pressure applications. Accurately modeling diffusion behavior can improve performance and durability of epoxy-based composites in moisture sensitive environments.

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Abstract

Epoxy resins are vital in high pressure applications such as water transport, oil and gas pipelines, and aerospace due to their enhanced mechanical strength and resistance to harsh environmental conditions (Ref. 1). However, their sensitivity to moisture diffusion under harsh conditions can lead to the degradation of its mechanical properties, limiting its long-term usability (Ref. 2). This study uses COMSOL Multiphysics® to model the moisture diffusion behavior in epoxy resin and the resulting hygroscopic deformations under harsh conditions. The simulations validated the experimental results, highlighting the importance of having finer meshes to capture the complex dual-Fickian behavior of the first absorption phase, while also showing a linear relationship between water content and hygroscopic deformation. These insights provide valuable guidance in enhancing the performance of epoxy-based composites in moisture-sensitive environments.

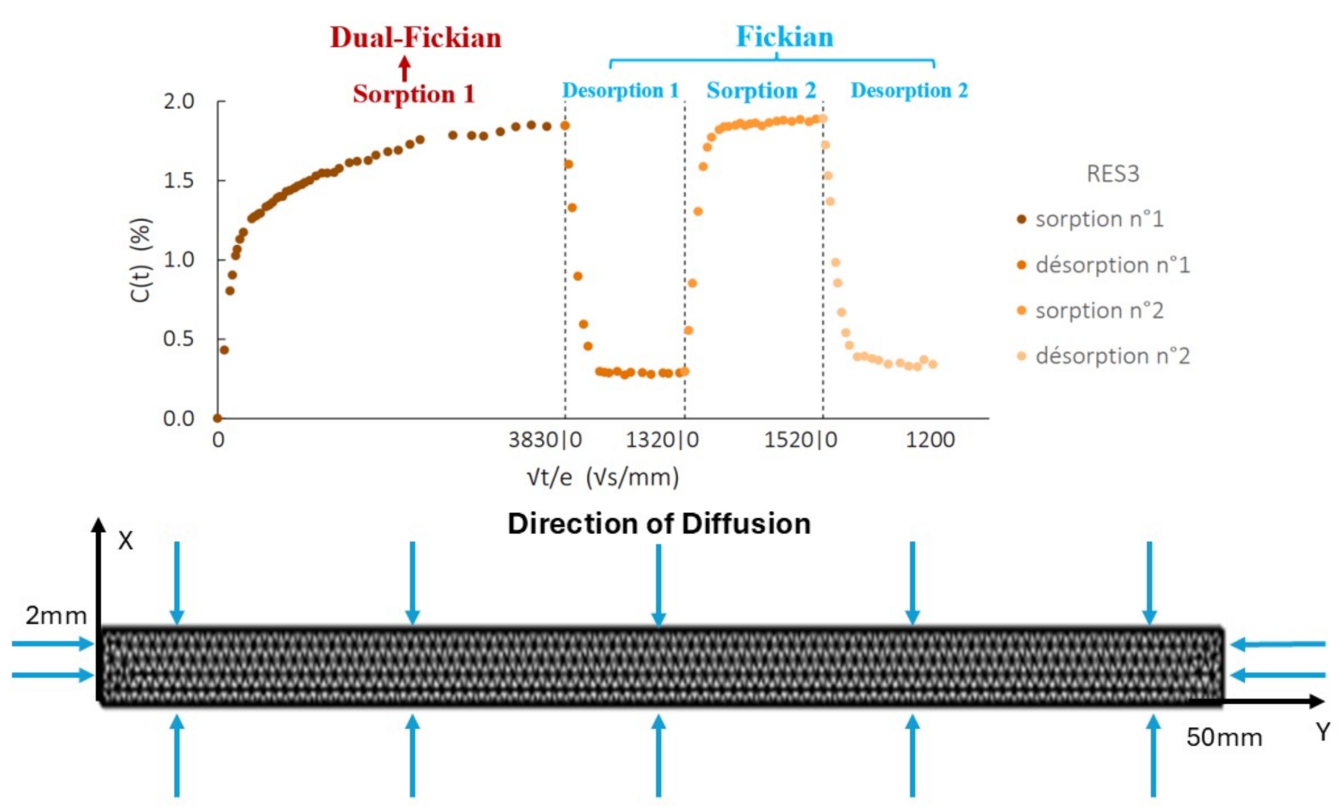

FIGURE 1. Top: Experimental results of water concentration C(t) for all diffusive phases across 30 months. Bottom: Test specimen mesh.

Methodology

The experimental 3D square epoxy specimen (50x50x2mm) was modelled in 2D as a 50mmx2mm rectangle to reduce computational effort. The Transport of Diluted Species (TDS) and Solid Mechanics interfaces, coupled for hygroscopic swelling, simulated moisture diffusion and hygroscopic deformations. Dual Fickian and Fickian behaviors were modeled across absorption-desorption cycles, with finer meshes for the first absorption phase. Moisture diffusion was governed using Fick's Law (Eq.1), and hygroscopic deformation was based on strain-stress relationship (Eq. 2):

$$\frac{\partial C}{\partial t} = \nabla \cdot (D\nabla C) \quad (1) \qquad\qquad \sigma = L:(\varepsilon - \beta\Delta c) \quad (2)$$

Results

Figure 2 (Top Left) shows the comparison of simulation (line) and experimental (dots) results for water concentration over a period of 30 months. A complex dual-Fickian behavior was observed in the first absorption phase (Sp1), with 0.5mm mesh closely matching the experimental data as compared to 0.7mm mesh, highlighting the need for finer meshes. Subsequent phases-desorption 1 (Dp1), absorption 2 (Sp2), desorption 2 (Dp2) are straightforward processes and do not require finer meshes. Figure 2 (Top Right) is the COMSOL® model showing variations of water concentration over time in Dp1.

Figure 2 (Bottom) displays a linear relationship between hygroscopic deformation and water uptake. Deformation remains constant across all phases with deformation of 0.35% for 1.8% water uptake.

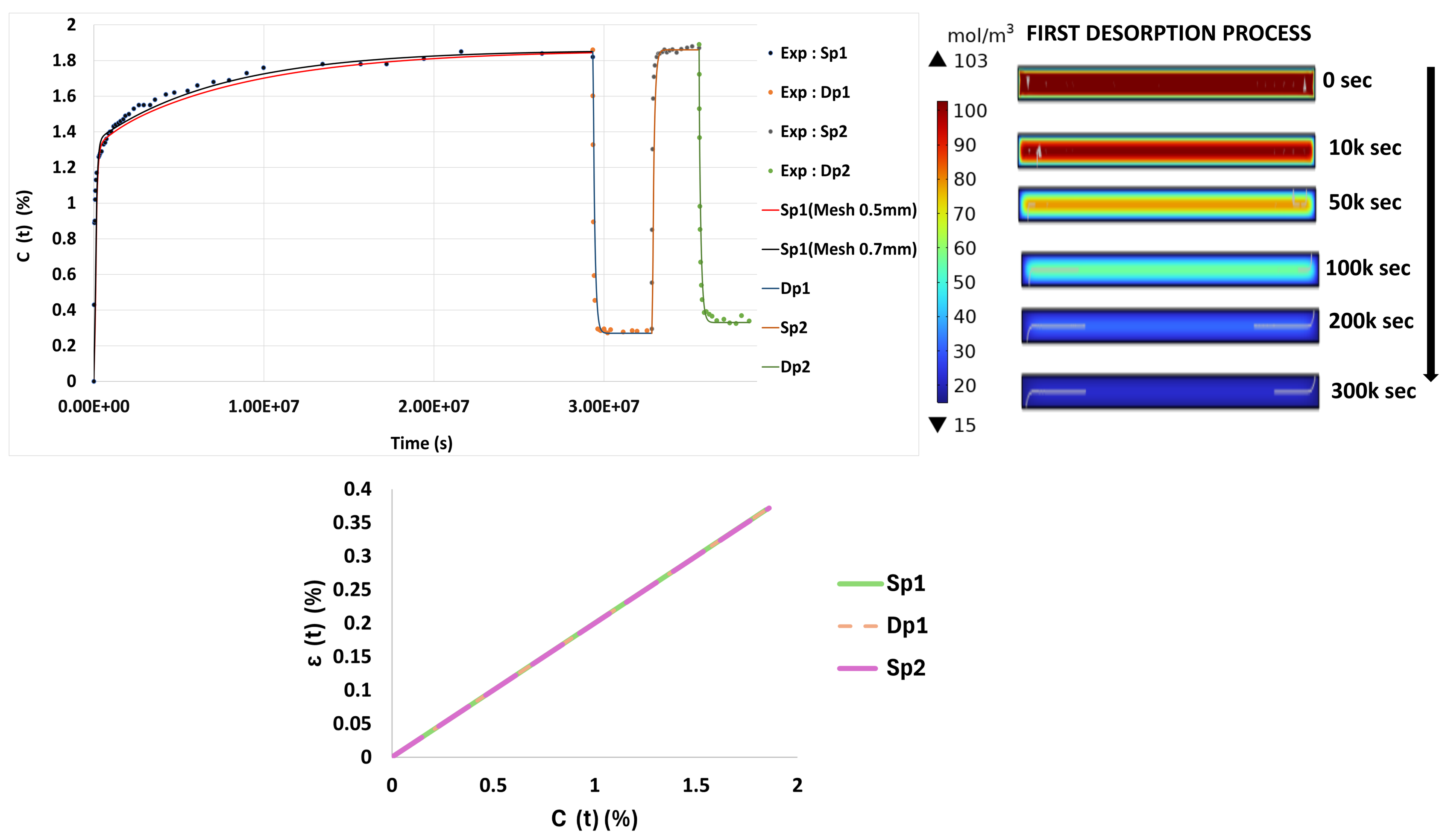

FIGURE 2. Top Left: Variation of water concentration over time (Dp1). Top Right: Simulation vs experimental water concentration. Bottom: Concentration vs deformation (All phases).

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