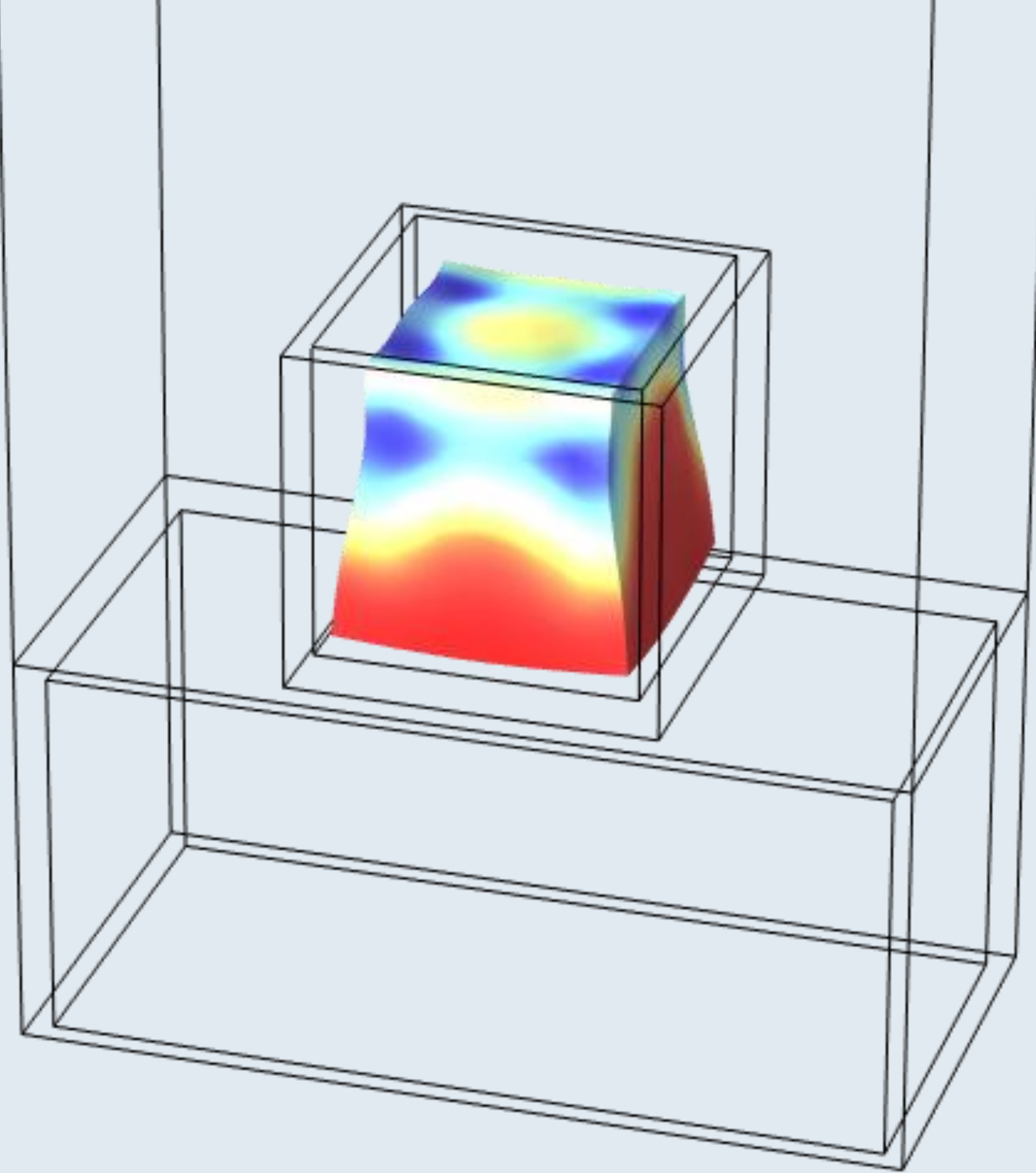




Multiphysics Modeling of Microwave-Induced Tissue Shrinkage Using a Rectangular Waveguide

A coupled Multiphysics model was developed to predict microwave-induced tissue deformation and validated against experimental measurements.

V. Mongkol¹, K. Junssook¹, W. Preechaphonkul², S. Vongpradubchai¹, and P. Rattanadecho¹

1. Mechanical Engineering, Thammasat University, Pathum Thani, Thailand

2. King Mongkut's University of Technology Thonburi, Bangkok, Thailand

Vannakorn.mo@gmail.com Raphadu@engr.tu.ac.th

Introduction & Goals

Microwave heating is widely used in medical applications, particularly microwave ablation (MWA), to destroy tumors through localized heating. The absorbed energy causes temperature elevation, water evaporation, thermal damage, and tissue shrinkage. Tissue shrinkage is expected to arise from damage-induced contraction and water-loss-induced hygroscopic strain. However, experimental data for the associated coefficients, particularly β , remain limited. This study experimentally estimates β using controlled rectangular-waveguide heating and assesses its consistency through numerical modeling. A coupled 3D model was

developed in COMSOL Multiphysics® by integrating the Electromagnetic Waves, Frequency Domain interface, the Heat Transfer in Solids interface with water evaporation, Arrhenius thermal damage, and the quasi-static formulation in the Solid Mechanics interface. The experimentally estimated β was used as a reference, while ξ and β were calibrated against measured temperature and deformation. Agreement between the experimental and calibrated coefficients, together with the predicted and measured responses, supports the model's ability to capture microwave-induced tissue deformation.

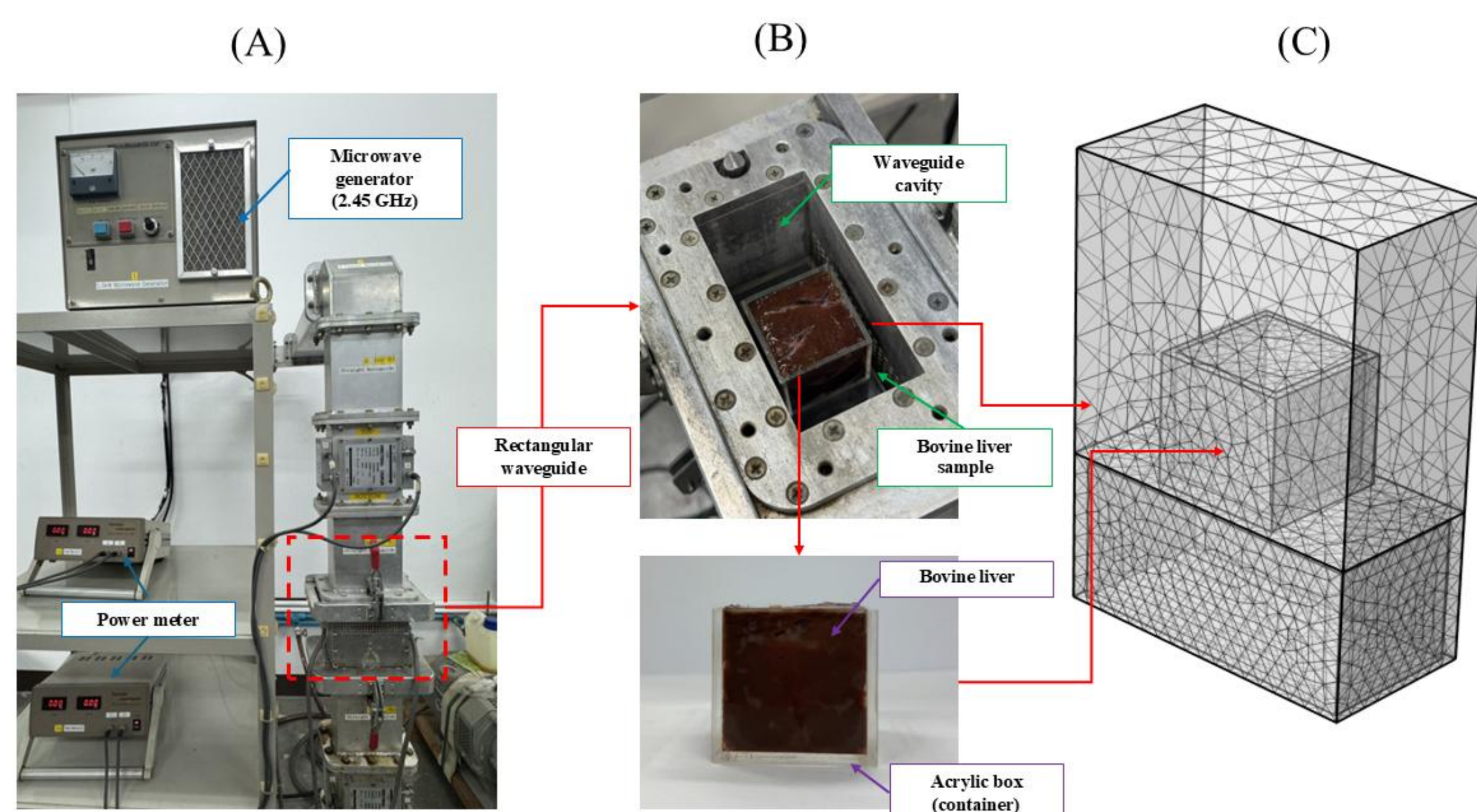


FIGURE 1. Experimental setup and 3D computational model: (A) microwave system, (B) waveguide cavity with liver sample, and (C) computational domain.

Methodology

- Electromagnetic wave propagation $\rightarrow$ SAR distribution
- Heat transfer $\rightarrow$ Temperature evolution (T) and Water loss ($W(T)$)
- Arrhenius equation $\rightarrow$ Thermal damage (θ_d)
- Solid mechanics $\rightarrow$ Thermal damage (ε_{td}) + Hygroscopic swelling (ε_{hs})
- The inelastic strain (ε_{inel}) is defined as:

$$\varepsilon_{inel} = \varepsilon_{td} + \varepsilon_{hs}$$

$$\varepsilon_{td} = -\xi\theta_d, \quad \varepsilon_{hs} = \beta(W - W_0)$$

Results

The results showed that increasing microwave input power produced higher tissue temperatures and greater volume reduction. As shown in Figures 2(A) and 2(B), the simulations reproduced the transient temperature rise and shrinkage trends measured experimentally for both cases. For Case 2 at 10 min, the simulated geometry in Figure 2(C) exhibited inward deformation and overall size reduction consistent with the experimental geometry in Figure 2(E). Comparison of the simulated and measured dimensions in Figures 2(D) and 2(F) showed absolute errors of approximately 2.2–6.6%. Overall, the model reasonably captured the coupled thermal and deformation responses under the investigated conditions.

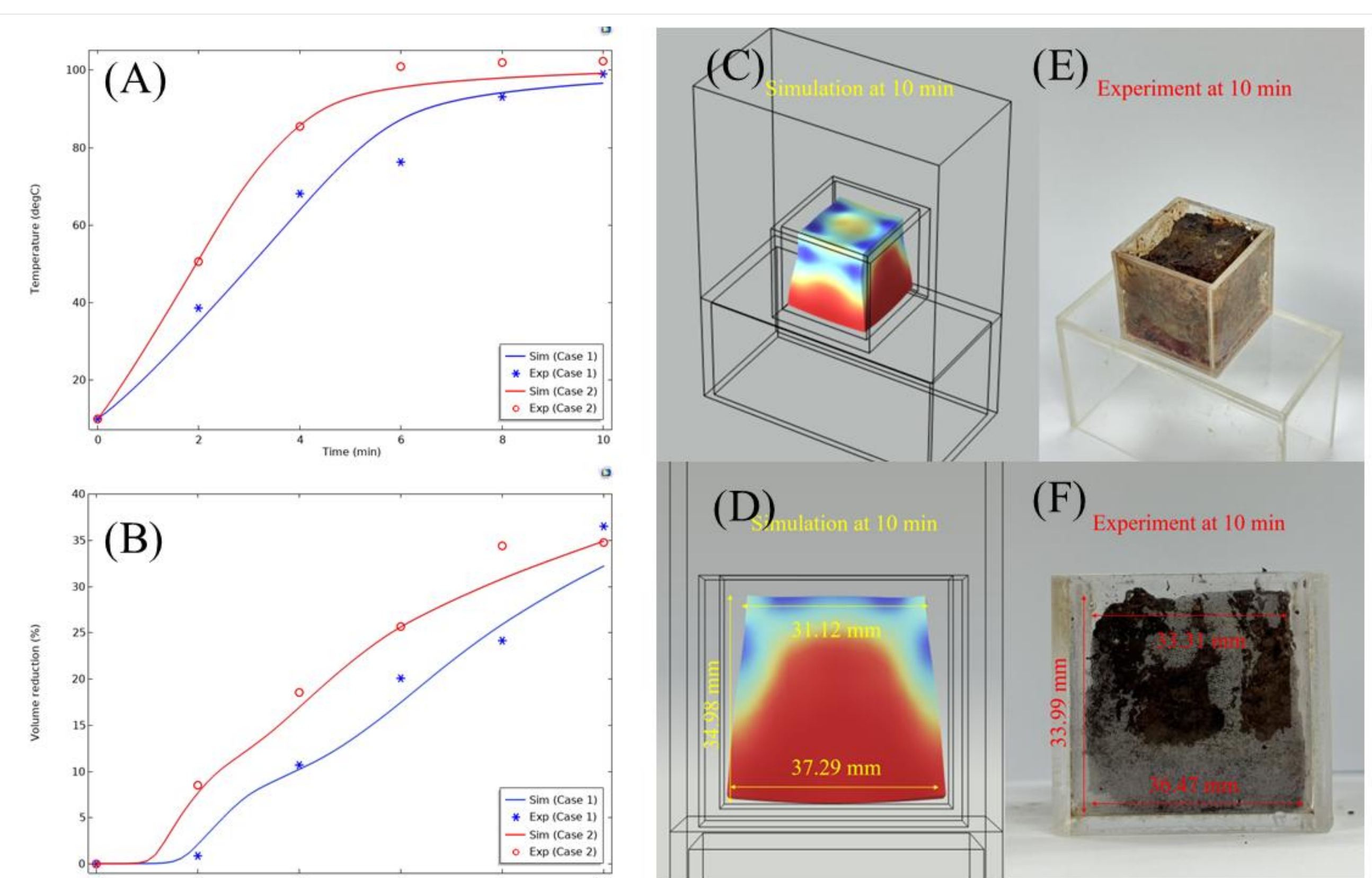


FIGURE 2. Simulated and experimental results: (A) temperature and (B) liver volume reduction for Cases 1 and 2; (C,D) simulated deformation and dimensions and (E,F) experimental geometry and dimensions for Case 2 at 10 min.

REFERENCES

- K. Chaiyo and P. Rattanadecho, Numerical analysis of heat-mass transport and pressure buildup of an unsaturated porous medium in a rectangular waveguide subjected to a combined microwave and vacuum system, *International Journal of Heat and Mass Transfer*, 65, 826–844 (2013)
- D. Yang et al., Expanding the bioheat equation to include tissue internal water evaporation during heating, *IEEE Transactions on Biomedical Engineering*, 54, 1382–1388 (2007).