

Supporting Information

Citric Acid-Crosslinked PVA/CMC Composite Membranes with Enhanced Wet-State Stability for Prevention of Postoperative Pericardial Adhesions

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S1. Optimization of glycerol content

The glycerol content was preliminarily optimized before systematically investigating the effect of CA content. As shown in Fig. S1a, increasing the glycerol content markedly changed the stress–strain behavior of the PVA/CMC membranes. The membrane without glycerol fractured at a very low strain, whereas the addition of glycerol progressively increased the deformation before fracture, accompanied by a gradual decrease in stress, indicating an effective plasticization of the PVA/CMC matrix. The quantitative results in Fig. S1b further confirmed this trend. Without glycerol, the membrane exhibited a high tensile strength of 146.51 ± 6.49 MPa but an elongation at break of only $2.2\% \pm 0.1\%$, indicating pronounced brittleness. At 40 wt% glycerol, the

elongation at break increased markedly to $56.6\% \pm 1.6\%$, while the tensile strength decreased to 39.41 ± 1.60 MPa. Further increasing the glycerol content to 50 wt% resulted in only a slight increase in elongation at break to $59.3\% \pm 1.2\%$, whereas the tensile strength further decreased to 34.48 ± 1.36 MPa. Therefore, 40 wt% glycerol was selected for the subsequent experiments because it provided sufficient membrane flexibility without the additional loss of tensile strength associated with a higher glycerol content.

The evolution of the tensile fracture morphology further supported this selection (Fig. S2a-f). Membranes containing 0 and 10 wt% glycerol exhibited rough and irregular fracture surfaces, consistent with predominantly brittle fracture. With increasing glycerol content, oriented and fibrillar structures gradually developed at the fracture surfaces, indicating increased deformation of the polymer matrix before failure. At 40 wt% glycerol, pronounced orientation was already observed, demonstrating that sufficient plasticization and a transition toward ductile fracture behavior had been achieved. Increasing the glycerol content to 50 wt% did not produce an obvious further improvement in the fracture morphology.

In contrast, the overall surface morphology remained relatively unaffected by glycerol content (Fig. S3a-f). All membranes exhibited smooth, dense, and homogeneous surfaces without obvious pores, cracks, or phase separation, suggesting that glycerol addition did not induce obvious surface defects or macroscopic phase separation over the investigated concentration range. Taken together, the mechanical and morphological results identified 40 wt% as an appropriate glycerol content: at this concentration, the membrane had already achieved a marked improvement in flexibility and ductile deformation, while further addition of glycerol provided little additional benefit but caused a continued reduction in tensile strength. Therefore, 40 wt% glycerol was used in all subsequent experiments investigating the effect of CA content.

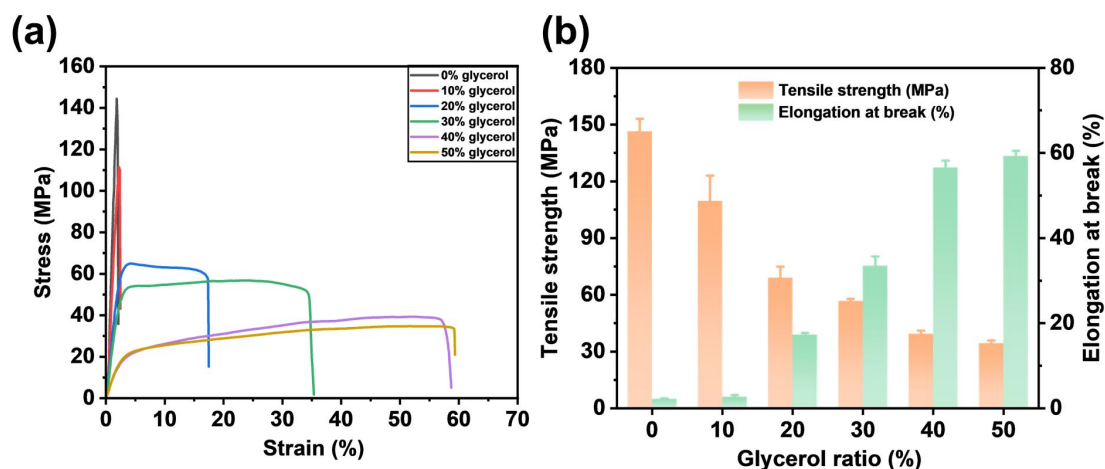


Fig. S1. Effect of glycerol content on the mechanical properties of PVA/CMC membranes: (a) representative stress–strain curves and (b) tensile strength and elongation at break.

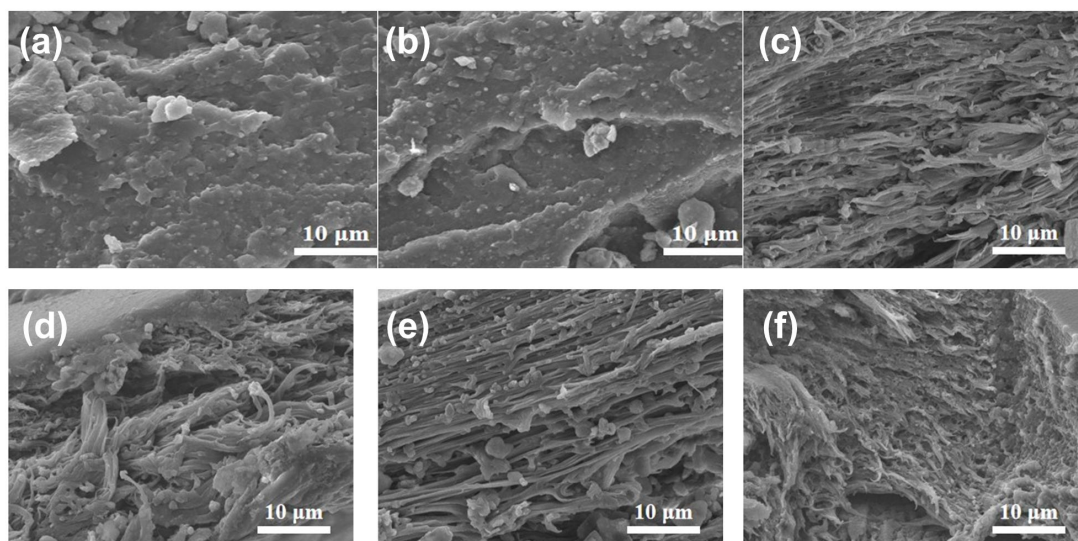


Fig. S2. SEM images of the tensile fracture surfaces of PVA/CMC membranes containing different glycerol contents: (a) 0 wt%, (b) 10 wt%, (c) 20 wt%, (d) 30 wt%, (e) 40 wt%, and (f) 50 wt%. Scale bars = 10 μm .

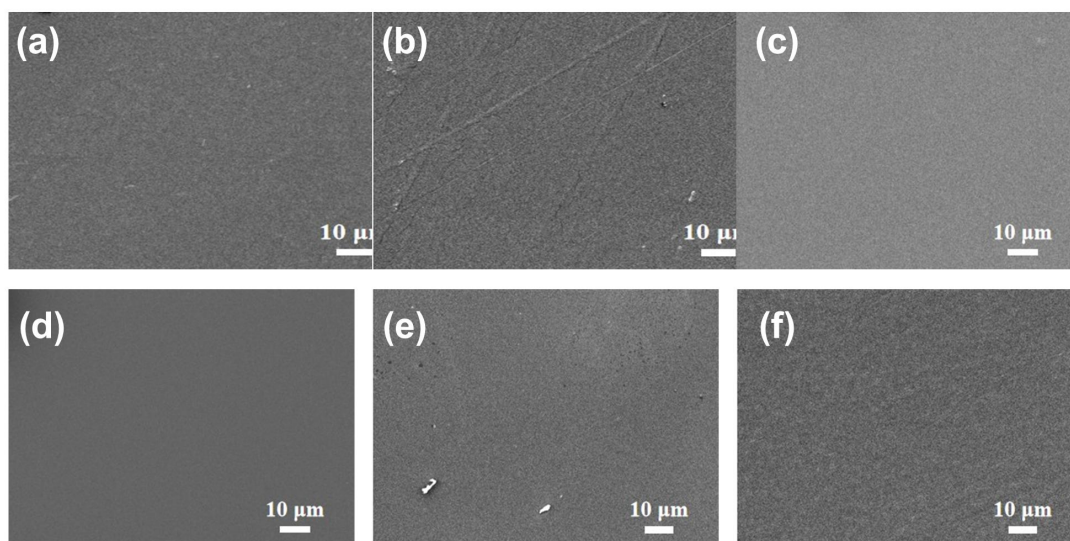


Fig. S3. SEM images of the surfaces of PVA/CMC membranes containing different glycerol contents: (a) 0 wt%, (b) 10 wt%, (c) 20 wt%, (d) 30 wt%, (e) 40 wt%, and (f) 50 wt%. Scale bars = 10 μm .