Anisotropic $CaCO_3$ particles hybridized with PLLA and magnetic field orientation

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1. Introduction Although organic-inorganic hybrid materials, which combine polymers and inorganic fillers, have gained significant attention as next-generation functional materials, issues such as reducing environmental impact and uniform dispersion of fillers have hindered their practical use. In this study, we aimed to solve these issues by developing a hybrid material that combines poly(L-lactied) (PLLA), a biodegradable and environmentally friendly polymer, with calcium carbonate ($CaCO_3$), which is commonly used as a nucleating agent. Of particular note is that such hybrid systems can be given anisotropy by controlling the orientation of the inorganic filler. Therefore, we attempted to improve the mechanical properties of the resulting hybrid film by orienting the $CaCO_3$ filler within the PLLA matrix using a magnetic field.

2. Experimental Section and Results To enable magnetic alignment, the surface of $CaCO_3$ particles was functionalized with Fe_2O_3 nanoparticles, resulting in magnetically responsive $CaCO_3$@Fe_2O_3 composite particles. These particles were incorporated into PLLA, and hybrid films were fabricated under a magnetic field strength of 1.5 T to induce anisotropic alignment. The dispersion and orientation of the fillers within the PLLA matrix were analyzed using optical and electron microscopy.

Mechanical performance was assessed through tensile testing, and the results are summarized in Figure 1. The control sample without magnetic alignment (0 T) exhibited modest improvements in tensile strength compared to neat PLLA, confirming the reinforcing effect of the filler. Notably, the film in which the fillers were aligned parallel to the tensile direction (Parallel sample) demonstrated significant enhancements in both stiffness and ductility, with the toughness increasing by approximately tenfold relative to the pristine PLLA. In contrast, the sample with filler alignment perpendicular to the tensile direction (Vertical sample) showed a reduction in stiffness, while ductility was still improved.

These contrasting results can be attributed to the interaction between interfacial interactions and load transfer mechanisms. In the Vertical sample, shear displacement likely occurs more readily at the PLLA–particle interface due to poor stress transfer across the perpendicular alignment, resulting in reduced tensile strength. However, the improvement in ductility is thought to stem from the ordered alignment of fillers, which facilitates deformation under tensile stress by providing a more compliant microstructure at the macroscopic scale.

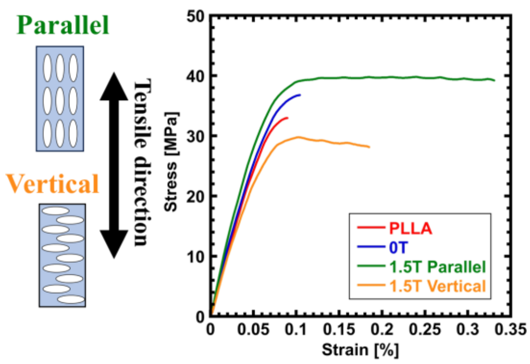

Figure 1. Stress–strain curves of hybrid films.