

Understanding the Structure-Process-Property Balance in PC/PEI blends by Morphology (using Scanning Transmission Electron Microscopy in Field Emission - Scanning Electron Microscopy) and Correlative Deformation Mechanics

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Nanoparticle dispersion has been reported to have a critical impact on the properties of polymer composite materials [1, 2]. Here in, we present the application of STEM in FESEM to study the phase morphology and correlative deformation phenomenon in Polycarbonate (PC)/ Polyetherimide (PEI) blends to bridge the understanding between functional and failing material performance at different processing conditions. PEI is an amorphous, transparent engineering thermoplastic with a unique chemical structure. The aromatic backbone offers superior heat resistance with high Tg ~216°C, low smoke, hydrolytic and improved solvent resistance and modulus. However, high Tg poses a challenge for processability, brittleness and limit its broader use. The colorability of PEI is also limited due to its natural amber color with yellowness index (YI) > 50. Blending PEI with PC, offers gainful advantage for PEI processability, imparts toughness and excellent colorability to the blend. PC/PEI exhibits a distinctly phase separated morphology with PEI phase forming a discrete phase residing in the continuous matrix of PC with pigment dispersion (Figure 1a). For an immiscible blend, the properties are mainly dominated by the continuous phase, but other variables such as the composition, viscosity of the blend, and processing conditions can influence the nanoparticle pigment dispersion and distribution, discrete phase size and shape, and interfacial free volume (compatibilization) yielding different tensile stress vs strain behaviors (Figure 1b,c).

STEM in FESEM was investigated for PC/PEI blends as functional parts (control) compared to parts showing brittle failure, for bulk and edge phase morphology (Figure 2a, c). The specimen was cryo-microtomed and thin sections ~ 100-150 nm were collected on copper grids and vapor stained with RuO₄ for 3 minutes. Inset morphology highlights the contrasting differences in nanoparticle pigment dispersion, where the control exhibits a uniform homogenous dispersion and distribution for the pigment nanoparticles, and the failed (brittle) part presents pigment agglomeration and preferentially localization at the interface of PC/PEI (Figure 2b,d). Furthermore, the edge morphology illustrates interesting elongation and stretching of PEI domains indicating surface enrichment with PEI for the failed part morphology compared to the control part (figure 2e, f). These morphological differences resulted in correlative toughness of these blends as depicted in Figure 3a-c. Toughness is a property which describes the absorption and dissipation of energy during deformation prior to fracture. In this study, toughness was measured by the area under the tensile stress versus strain curves. For instance, the control morphology presenting a homogenous dispersion of pigment nanoparticles would promote plastic yielding and deformation processes on a nano- and microscale across the volume of the PEI/PC blend and exhibit a ductile fracture due to energy absorption. On the contrary, agglomeration of pigment nanoparticles at the PC/PEI interface and depletion of PC on the surface plays detrimental to impact toughness. If the adhesion between the particles and the matrix is poor, such as in this study for the failed part due to pigment deposition at the PEI-PC interface, the stress concentration at the particle–matrix interface can interfere with the interfacial compatibilization between PEI and PC, and may act as stress precursors resulting in cracks and brittle fractures. In summary, combining morphological, micromechanical, and understanding of the fracture performance of a polymer resin (by identifying its preferred deformation mechanism, e.g.,

crazing or shear yielding), optimizations in process, molding and formulation conditions can be carried out to tune the design space geared towards robust materials development.

References:

- [1] E. T. Thostenson, *et.al.*, "Nanocomposites in Context," *Composites Science and Technology*, 65 (2005) 3.
- [2] H. Khare and D. Burris D, *Polymer*, 51 (2010): 719.

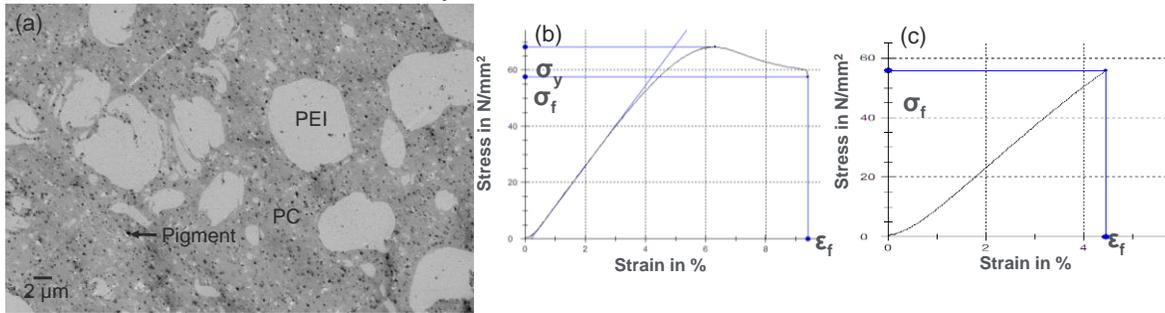


Figure 1. (a) STEM in SEM morphology of an immiscible PC/PEI blend with pigment nanoparticles (black dots) dispersed homogeneously. Typical tensile stress vs. strain response for (b) a ductile and (c) brittle fracture.

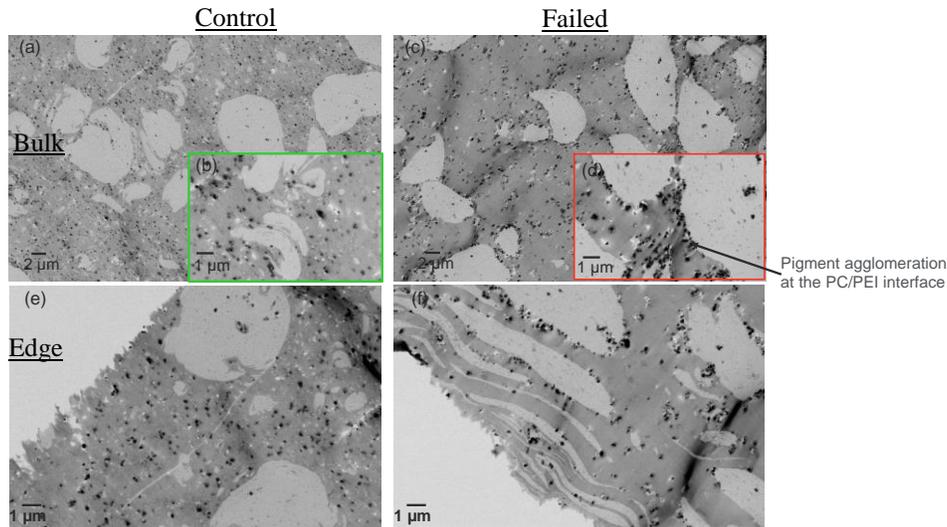


Figure 2. STEM in SEM morphology comparing bulk morphology for (a, b) control (c, d) failed PC/PEI blend. Inset (b) and (d) highlights the differences in pigment nanoparticle dispersion. Edge or surface morphology for control (e) and failed (f) PC/PEI blend.

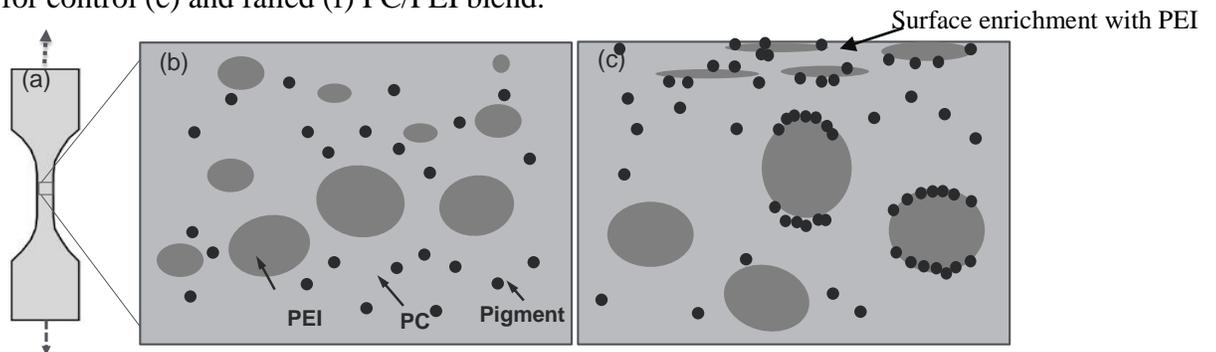


Figure 3. Root cause failure analysis mechanism linked to pigment nanoparticle dispersion and blend compatibilization.