Exploring degradation as a viable end-of-life process for thermoset polymers

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There is a great need to recycle polymers to minimize their environmental impact, as the majority of produced polymers end up in landfills after their useful lifetime. Linear polyesters degrade rapidly, and their degradation behavior has been well studied, establishing phenomena of surface erosion in basic media and bulk erosion in acidic media. By contrast, thermoset polymers normally require harsh degradation conditions due to their highly crosslinked structures. We have explored the incorporation of hydrolytically cleavable linkages into the crosslinked network, to enhance their degradation rates under benign conditions. Epoxy resins are widely used thermoset polymers. The standard precursor to epoxy resins, the diglycidyl ether of bisphenol A (DGEBA), is derived from petroleum and lacks functional groups which can promote degradation under benign conditions. Epoxidized vegetable oils, phenolic acids, and vanillic acid, which contain ester linkages, were investigated as sustainable sources to produce degradable epoxy resins. The resulting phenolic acid-based and vanillic acid-based epoxy resins exhibited comparable thermal and mechanical properties to conventional DGEBA-based epoxy resins. The accelerated hydrolytic degradation behavior of the ester-containing epoxy resins was explored, through monitoring of the polymer mass loss after exposure to a basic solution at moderate temperatures. The biobased epoxy resins exhibited rapid degradation in the basic solution, in contrast to the slow degradation rate of DGEBA-based epoxy resin. A solid state kinetic model, the contracting volume model, was applied to describe the degradation behavior and the mechanism was confirmed as surface erosion through ester hydrolysis in basic media. Degradation behavior under mild acidic conditions was also explored. Biobased epoxy resins exhibited bulk erosion in acidic media, in agreement with the behavior of linear polyesters. A reaction order model with autocatalysis was employed to describe the degradation behavior in acidic media and the mechanism was bulk erosion through ester hydrolysis. Various factors which affected the degradation rates were discussed.