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The potential of yeast as eco-filler for waterborne polyurethane and its reinforcing mechanism

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ABSTRACT

The potential of using yeast as the eco-filler for waterborne polyurethane (WPU) has been investigated in this research. The composites are synthesized by dispersing yeast into the 3-Triethoxysilyl Propylamine modified WPU solution followed by drying at 85 °C. The effects of yeast on the chemical structure, optical properties, thermal properties and mechanical properties of the polyurethane (PU)-yeast composites have been investigated. Yeast is well dispersed in the composite matrix and can crosslink with the WPU. Unlike many other PU composites, the PU-yeast composite has a higher clarity. It has a better thermal stability than the pure PU. Its stiffness, tensile strength and elongation at break are improved simultaneously because yeast can reinforce the composite with its cell wall and induce crazing during plastic deformation. As a result, yeast is an excellent eco-filler for the WPU and can be a low cost replacement for nano-cellulose.

1. Introduction

Due to the growing public awareness of environmental problems and the increase in petroleum price, synthesizing eco-plastics with more renewable raw materials becomes an important topic. This can be achieved by adding some low cost, high stiffness eco-fillers such as wood [1], bamboo [2], cuttlebone [3] and rice husk [4]. They can make the plastic more biodegradable and, at the same time, enhance the stiffness of plastics. However, they have poor filler dispersion in composite matrix and poor interfacial adhesion with polymer component [5,6], resulting in weak composite strength [7]. Nano-cellulose polymer composites have excellent dispersion degree and mechanical properties but nano-cellulose is still too expensive for commercial applications [8]. As a result, it is important to develop a low cost eco-composite with good mechanical properties, high dispersion degree and strong polymer–filler adhesion.

The polyurethane (PU) composite which consists of yeast and 3-Triethoxysilyl Propylamine (APTS) modified waterborne polyurethane (WPU) is a potential candidate to achieve this objective. Unicellular baking yeast can be easily obtained at a low cost. It can be dispersed in aqueous solution so that a good dispersion of yeast in waterborne polymers such as WPU can be predicted. Furthermore, Young's modulus of yeast is 150 MPa which is much higher than that of PU due to its rigid cell wall [9]. As a result, the mechanical properties of PU are expected to be enhanced by adding yeast. The interfacial adhesion can also be enhanced by grafting and crosslinking [10,11]. One of the examples is the modification of polymer with APTS [12]. Silane groups present on APTS molecules can be hydrolyzed to become reactive silanol groups which can further react with hydroxyl groups via condensation [12,13]. The cell wall of yeast is so rich in hydroxyl groups [14] that the crosslinks between the APTS modified WPU and yeast

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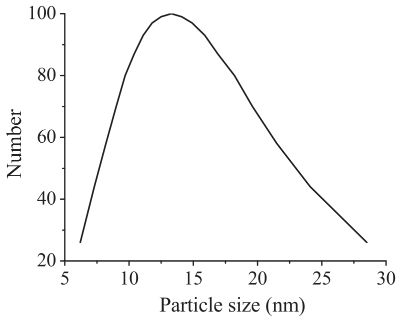

Fig. 1. Particle size distribution curve of the APTS modified WPU.

are likely to form. By means of this way, the excellent interfacial adhesion can be created.

In this research, the potential of using yeast as a filler for the APTS modified WPU has been investigated. The effects of yeast on the optical properties, chemical structure, thermal properties and mechanical properties of the PU-yeast composite have been investigated. The reinforcing mechanism of yeast present in the PU-yeast composite has been studied based on the characterization results.

2. Experimental

2.1. Materials

Polypropylene glycol 2000 (PPG 2000, Acros) and dimethylolbutanoic acid (DMBA, Accuchem) were dried at 80 °C in vacuum for 12 h. 4,4-Methylene diphenyldiisocyanate (MDI, Acros) was stored at 4 °C before being used 1,4-butanediol (BD, Fisher Scientific), acetone (Shell) and triethylamine (TEA, Acros) were dehydrated with the molecular sieve 3 Å (MS3A). Dibutyltin dilaurate (DBTDL, Sigma Aldrich) was first diluted to the mass concentration of 2% with acetone and was then dehydrated with MS3A. APTS (International Lab USA) was used as received. Baking yeast was purchased from a local supermarket and was used without any pretreatment.

2.2. The preparation of PU-yeast composite

APTS modified WPU solution was synthesized via acetone method. 13.77 g of MDI, 30 g of PPG 2000 and 3.23 ml of diluted DBTDL were mixed, and the solution was refluxed at 40 °C in N_2. After 10 min, 3.6 g of DMBA was added into the solution and then 1.5 h later, 0.807 g of BD was also added. After another 1.5 h of reaction, 2.44 g of APTS was added slowly into the solution which was then kept refluxing for 30 min. During the whole process, the solution was stirred constantly and acetone was added to keep the mixture stirrable. The solution was finally cooled to room temperature and was then neutralized with 3.63 g of TEA. After 15 min, 100 ml of deionized (DI) water was added dropwise into the solution with vigorous stirring. Acetone was then removed from the solution using the rotary evaporator at 30 °C. The WPU solution was finally diluted to 200 ml with DI water and its solid content was 25.6%. The resulting solution was a pale-yellow semi-transparent liquid. It was highly stable and could be stored up to eight months without any obvious phase separation.

A desired mass of yeast was dispersed in 40 ml of DI water via vigorous stirring and then mixed with 10 ml of the freshly prepared WPU solution. The composite films were obtained by drying the solution on a Teflon Petri dish at 85 °C for 12 h. The sample without any yeast was coded as PU-Pure. PU-yeast composites with 0.115 g, 0.207 g, 0.384 g and 0.532 g of yeast were coded as PUy1, PUy2, PUy3 and PUy4 respectively, accounting for 4.49%, 8.09%, 15.0% and 20.8% of the weight of PU. The thickness of the prepared films was about 0.2 mm.

2.3. Characterization

The particle size of the APTS modified WPU was measured with ZetaPlus, Brookhaven Instruments equipped

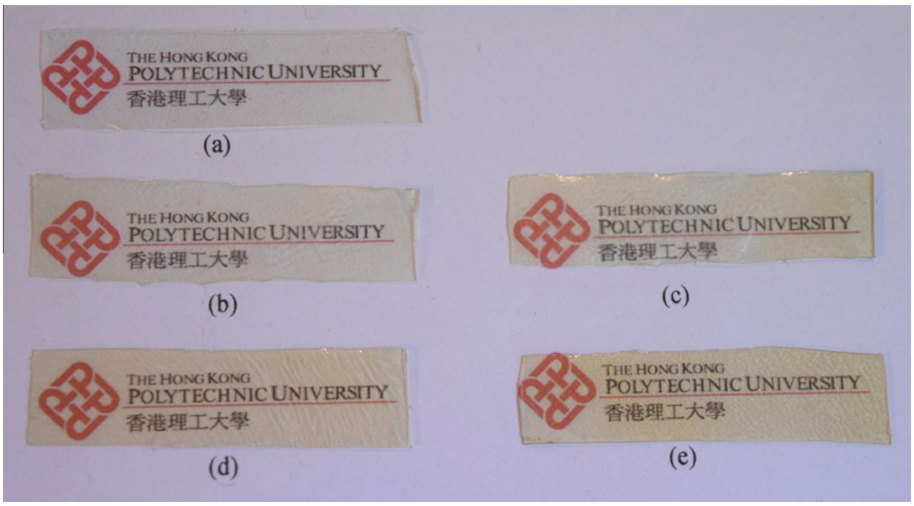

Fig. 2. Pictures of (a) PU-Pure, (b) PUy1, (c) PUy2, (d) PUy3 and (e) PUy4.