Incorporation of Nanoparticles into Soy-based Polyurethane Foam

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ABSTRACT

Nanotechnology is one of the most effective ways to develop advanced materials. Nanophases including nanoclay and Polyhedral Oligomeric Silsequioxane (POSS), are often used to be incorporated into polymer resin systems to improve their thermal stabilities and mechanical properties. The shortage of petroleum and the increasing concern on the environmental issues have resulted in intensive interest in using renewable substances as building blocks for polymer applications. The major objective of this work is to develop soy-based polyurethane foam infused with nanopaticles to enhance the mechanical properties. Neat polyurethane is used as a control. Soy-based polyurethane/clay and soy-based polyurethane/POSS are synthesized. The compressive strength is tested for the soy-based polyurethane foams. The density and property relationship of soy-based polyurethane composites is evaluated.

Keywords: polyurethane foam, nanoclay, Polyhedral Oligomeric Silsequioxane (POSS), composites

1 INTRODUCTION

Polyurethane is one of the most versatile and intensively used polymeric materials. By proper selection of reactants and changing percentage of the component in the formula, the polyurethane can be processed into elastomer, thermoplastic, thermosetting, rigid and flexible foams. Among the global plastics consumption, five percent is polyurethane. In America, polyurethane usage is about 32 % of the whole world polyurethane consumption. Rigid polyurethane foam was the second most important foam that made up 26 % of the urethane markets in 2004 [1]. Rigid polyurethane foams can be used as construction materials: polymeric concrete components, insulating materials, sealants and signboard. Polyol, one of the major components to make polyurethane, is largely relied on petroleum crude oils and coals as feedstock. However, polyols have been developed from vegetable oils such as soybean oil, canola oil, palm oil and castor oil due to environmental and sustainable issues [2-6].

Develop bio-renewable feedstock for industry is very crucial now for both economic and environmental reasons. Soybean oil is an excellent annually renewable natural resource for the polyols. For each pound of soybean oil produced, 2.67 pounds of carbon dioxide are removed from the air [2]. It is cheap and available in large quantities. Soybean oil has a three arms triglyceride structure with several reactive functional groups such as double bonds, allylic hydrogens and esters (Figure 1). The chemical structure of the soybean oil can be tailored by these functional groups according to the specific application. For example, soy-based polyols (Figure 2) with various functionalities can be made by introducing the hydroxyl group to soybean oil unsaturated sites by hydrogenation [7], epoxidation followed by oxirane opening [8], ozonolysis followed by hydrogenation [9], and microbial conversion [10]. Dangling chains in soy-based polyols are the elastically inactive part and can act as a plasticizer that reduce polymer matrix rigidity and increase polymer flexibility. Soy-based polyols can be used in various polyurethane applications by selecting the proper functional group and side chain. Polyurethanes produced from soy-based polyols normally exhibit equivalent or improved physical and chemical properties due to the hydrophobic nature of triglycerides.

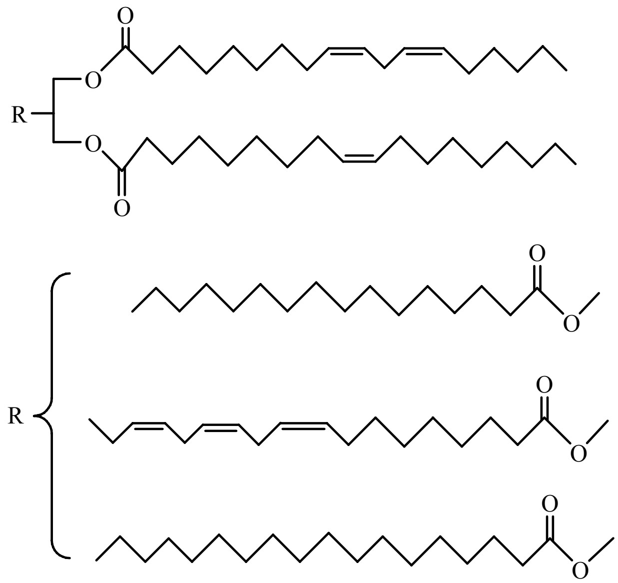

Figure 1: Representative structure of soybean oil

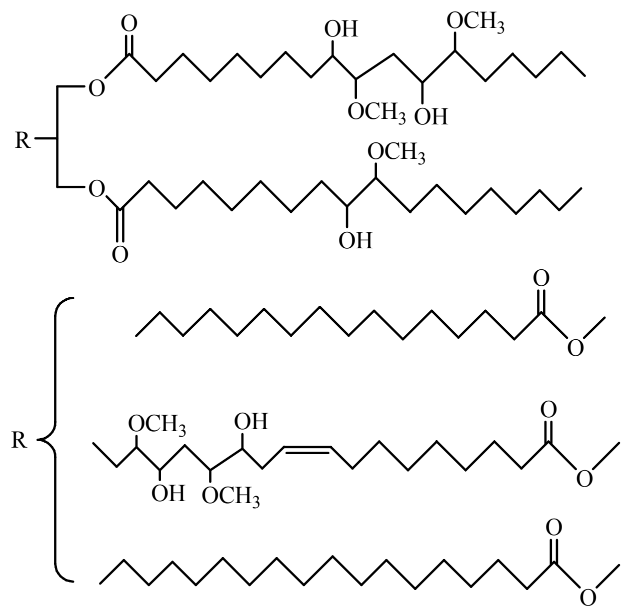

Figure 2: Representative structure of soybean based polyol

Nanotechnology is another promising research area in the field of material science. Dramatic improvement in thermal and mechanical properties can be achieved by incorporating nanoparticles into the polymer resin matrix. Nanoparticle is defined as having at least one dimension in the nanometer range. Three different types of nanoparticles, platelet nanoclay, rod-shaped carbon nanofiber and cage structure polyhedral oligomeric silsesquioxane (POSS) are selected to be incorporated into polyurethane foam.

The major objective of this work is to develop soy-based polyurethane foam infused with nanopaticles with enhanced mechanical properties. Neat polyurethane is used as control. Soy-based polyurethane/clay and soy-based polyurethane/POSS composites with 0.5, 1 and 3 wt% are synthesized. The mechanical properties are evaluated through the compression testing. The density and property relationship of soy-based polyurethane composites is investigated.

2 MATERIALS AND METHOD

2.1 Materials

Polymeric diphenylmethane diisocyanate (pMDI) from BASF Company and soy-based polyol from Bio-Based Technologies Company are used as reactants to make polyurethane foam. Distilled water is used as chemical blowing agent. Dibutin Dilaurate (DBTDL) and N, N-dimethylethanolamine (DMEA) are used as catalysts. Tegostab B8404 from Goldchmidt Chemical is used surfactant.

Nanocaly Cloisite 30B (Figure 3) modified by methyl tallow bis-2-hydroxyethyl ammonium from Southern Clay, TriSilanolPhenylPOSS (Figure 4) with three silanol groups (Si-OH) from Hybrid Plastics are used as nanoparticles incorporated into soy-based polyurethane foam.

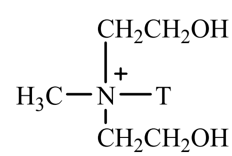

Figure 3: Chemical structure of pillaring agent of Cloisite 30B

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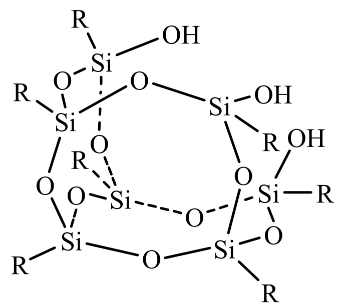

Figure 4: Chemical structure of TriSilanolPhenylPOSS (R = phenyl)

2.2 Foam Preparation

Polyurethane foams are prepared by one-pot and free-rising method as flowing steps: Weigh polyol, catalysts, surfactant and blowing agent (B-side material) into a disposable plastic cup and mix them with mechanical stirrer at 3000 rpm for 10 ~ 15 seconds; Allow the mixture to degas for 2 minutes; Rapidly add pMDI (A-side material) into the mixture and continue to stirring for another 10 ~ 15 seconds at the same speed; Allow the foam to rise and set at room temperature for 24 hours.

Nanoclay is dehydrated in an oven at 100 ^{o} C overnight before use. Sonication and mechanical mixing were used to aid nanoclay thoroughly mixed with the B-side material before adding pMDI. TriSilanolPhenylPOSS is incorporated into the polyurethane network by mechanically mixed with the B-side material.

2.3 Measurement

The bulk density of the foam was determined by measuring the weight and volume of the cubic samples following the procedure describing in ASTM D1622. Six specimens per sample were tested and the results were averaged.

The compressive properties of the control and composites were measured using an Instron universal testing machine (Model 5869) in accordance with the ASTM1621 standard on the 25.4 mm (length) × 25.4 mm (width) × 12.7 mm (thick) specimens. The orientation is parallel to the foam rise direction. The cross-head speed is 1.2 mm/minute. The load is applied until the foam is compressed approximately 13% of its original thickness. Six replicates of each sample were tested and results were averaged.

3 RESULTS AND DISCUSSION

Polyurethane foam composites containing nanoclay and POSS with 0.5, 1 and 3 wt% were synthesized at room temperature. Figure 5 shows the foam density as a function of nanoclay content. The densities of the foam are increased by adding nanoclay and the densities are increased as the loading level of nanoclay increased. Figure 6 shows the foam density as a function of POSS content. In the comparison of nanoclay polyurethane foam composites, the densities of the POSS foam decreased by adding POSS and also as the loading level of POSS increased. The overall densities of POSS polyurethane foam composites are lower than that of the neat polyurethane foam.

Both Cloisite 30B and TriSilanolPhenylPOSS have –OH groups which can react with the –NCO groups of pMDI. However, the effects of these two nanoparticles to the foam composites are different. Further investigation such as FTIR and SEM needs to be conducted to clarify this issue.

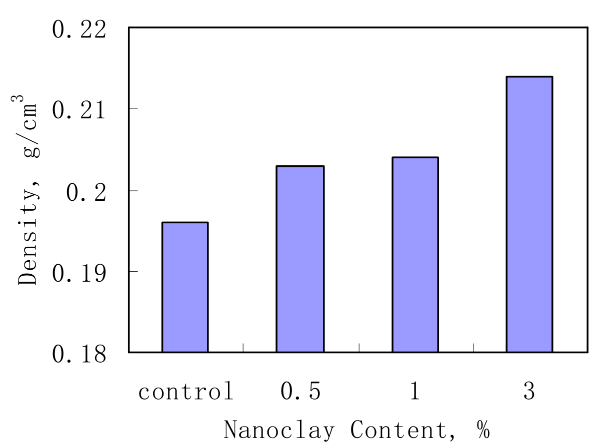

Figure 5: Foam density as a function of nanoclay content

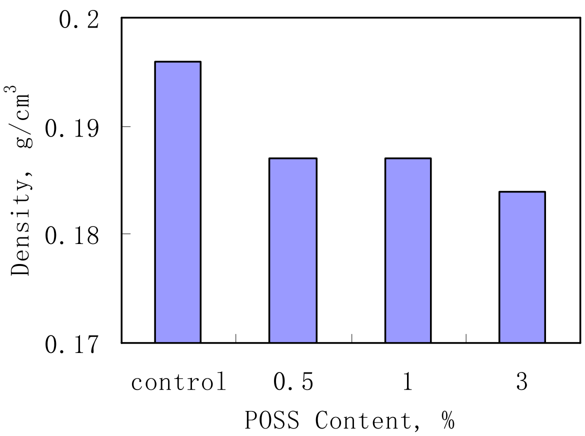

Figure 6: Foam density as a function of POSS content

Figure 7 shows the compressive strength as a function of nanoclay content. Figure 8 shows the compressive strength as a function of POSS content. Both Cloisite 30B and TriSilanolPhenylPOSS dramatically improve the compressive strength of the polyurethane foams. The effects of nanoclay Cloisite 30B on the compressive strength of the foam are stronger than those of TriSilanolPhenylPOSS. The compressive strength of the nanoclay foams are decreased as the loading level of nanoclay increased, while those of POSS foams are increased as the loading level of POSS increased

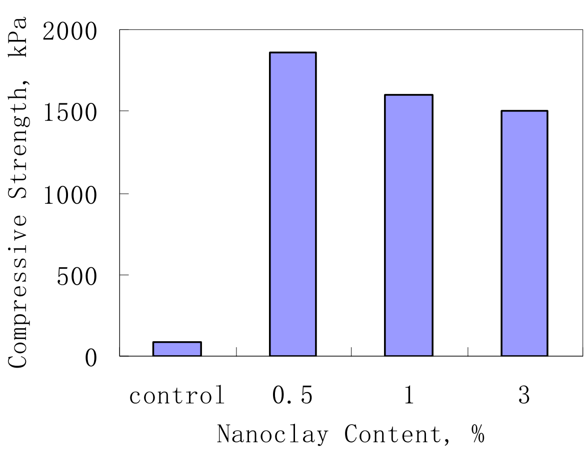

Figure 7: Compressive strength as a function of nanoclay content

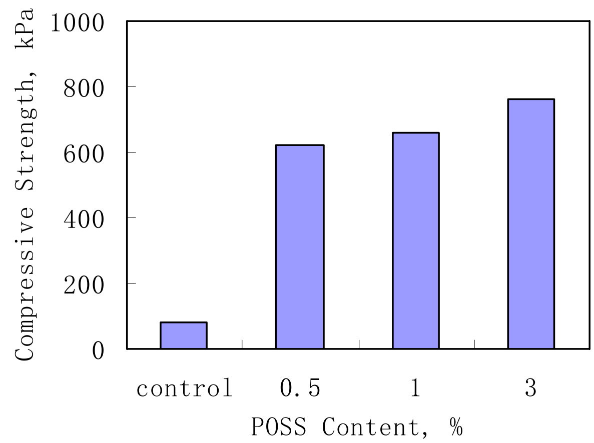

Figure 8: Compressive strength as a function of POSS content

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