

# Synthesis and Characterization of Recycled Polycarbonate/Organo-montmorillonite Nanocomposites

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## ABSTRACT

This study aims to synthesize recycled polycarbonate (RPC)/organo-montmorillonite (o-MMT) nanocomposites and investigate their electrical, chemical and thermo-mechanical properties. RPC was obtained by mechanical and chemical stripping of post-consumer compact discs. Formulations of 1, 3, 5 and 10% o-MMT content in the RPC matrix were processed by in-melt intercalation using the two-roll mill. The changes in the absorption bands of the FTIR spectra of the nanocomposite systems confirmed the miscibility of the o-MMT in the RPC matrix. Electrical characterization of the RPC/o-MMT systems showed an increase in electrical resistance with the increase in o-MMT loading. Dimensional stability, thermal stability and modulus of elasticity were improved at higher clay loadings compared with the unfilled RPC.

**Keywords:** *nanocomposites, polycarbonate, organo-montmorillonite, compact discs*

## INTRODUCTION

Polymer-based nanocomposites are among the important types of nanostructured materials. These nanocomposites have numerous advantages over the conventionally-filled polymer composites. Enhanced properties of nanocomposites are exhibited with minimal filler loading of organically modified clays. Some of these properties are thermal stability, flame retardant properties, optical clarity, tensile strength, modulus, dimensional stability, and decreased permeability to gases, water and hydrocarbons [1].

Polycarbonate is an engineering thermoplastic used in various applications because of its good properties like optical clarity, toughness, dimensional stability, high impact resistance, and thermal stability, making it suitable for producing compact discs [2]. Researchers observed that about 150 to 200 million of these compact discs were scrapped due to rejects. Every year, more than two million compact discs are manufactured from polycarbonate, but due to copyrights and software updates, some compact discs were rejected and destroyed [3,4]. Other compact discs were usually disposed by the consumers in the trash or in landfills. However, high quality of polycarbonate from compact discs can be recovered by means of recycling. This study aims to synthesize RPC/o-MMT

nanocomposites from post consumer CDs and investigate the electrical, chemical, and thermo-mechanical properties at various clay loading. This will provide useful information on the effect of organoclay-filled RPC compared with unfilled RPC for possible partial replacement of commercial product in packaging and different electrical casings.

## METHODOLOGY

### Raw materials

1. The CDs used in the process were post-consumer wastes composed of VCD, DVD, and audio CDs.
2. The organo-montmorillonite was processed from the local bentonite ore deposit in Albay, Philippines. The clay was beneficiated to recover montmorillonite nanoparticles and was organically modified using the technical grade quaternary ammonium salt, dialkyldimethyl ammonium chloride (C22).

### Recovery of polycarbonate from post consumer CDs

Mechanical abrasion, using an electric grinder and silicon carbide abrasives, was used to remove the top coatings of the CDs in order to recover the polycarbonate substrate. For easy handling in the process, the stripped CDs were cut into ~1cm fragments. The residual coatings were further removed by chemical washing with 10% acetic acid (HOAc) solution, 5% sodium hydroxide (NaOH) solution, and deionized water. Oven drying at 80°C was used to dry the pure polycarbonate substrate.

### Synthesis of RPC/o-MMT Nanocomposites

A two roll mill (LabTech Engineering Co. LTD) was used in the in-melt intercalation of the RPC/o-MMT nanocomposites. The two roll mill operates with a front roll rotating at 20rpm at a temperature of 235°C, and the back roll rotates at 20rpm at a temperature of 225°C. The RPC/o-MMT mixtures of 1, 3, 5 and 10% clay loading were annealed in the two roll mill for 10 minutes. This process was done in order to have a complete diffusion of polycarbonate molecules into the intergallery spacing (Van der Waals gaps) of the layered silicate clay [5]. Shinto

Compression Molding Machine Model No. FA-37 was used to compress the samples into square plates 160mm wide and 2mm thick. The compression molding temperature was 250°C, and the pressure at the cylinder side and pump side were 50kg/cm<sup>2</sup> and 250kg/cm<sup>2</sup>, respectively, with a processing time of 7 minutes.

### Characterization of the RPC/o-MMT nanocomposites

The presence of organic molecules in the clay as a result of its organic treatment and chemical interactions were determined using the Perkin Elmer Spectrum RX1 FTIR Spectrometer. The dielectric strength of the RPC/o-MMT nanocomposites was measured by a high potential tester. The tester can measure up to 5kV AC at a standard current of 20mA. The electrical resistance was determined by a Megger insulation tester using a thin film sample of 0.01mm. Thermomechanical Analyzer (TMA) was used to test the physical properties of the samples. The Thermo-Mechanical Analysis Q400 worked in conjunction with a controller and associated software to make up a thermal analysis system. This equipment operated over a temperature range of -150°C to 1000°C using heating rates up to 200°C/min. Dynamic Mechanical Analysis (DMA) confirmed the stiffness and damping characteristics of the nanocomposites with respect to temperature, frequency or time. The DMA data was measured from a SCINCO Triton DMA-smart.

## RESULTS AND DISCUSSION

### Effects of clay loading on the chemical structure of the nanocomposites

The FTIR spectra of the RPC/o-MMT nanocomposites at various clay loadings are shown in Figure 1. It confirms the presence of the alkylammonium cations in the RPC/o-MMT system. The C-H and N-H stretching of the quarternary alkylammonium salts are given by the wave numbers 2854 cm<sup>-1</sup> and 2927 cm<sup>-1</sup> respectively, indicating the interaction between the alkylammonium cations and the o-MMT [6-8]. As the clay loading increases, the absorbance peaks also increases, indicating higher interactions of the o-MMT with the RPC matrix [6,7].

### Effect of clay loading on the electrical properties of the nanocomposites

**Dielectric strength.** The dielectric strength of the RPC/o-MMT nanocomposites is shown in Figure 2. It was observed that as the clay loading increases, the dielectric strength decreases. It seems that the clay nanocomposite material with dispersed clay in the polymer matrix has terminated the regular long chain of polymer, and become random and shorter chains [5,9]. The highest voltage endurance occurs for composite with strong covalent bonding between the matrix and the filler. The increase in clay loading caused the decrease in the nanocomposite's

dielectric strength because o-MMT may have created microvoids, which made the material reach its breakdown faster than loading without o-MMT.

**Electrical resistance.** The electrical resistance of the local RPC/o-MMT nanocomposites is shown in Figure 3. Results showed that the electrical resistance is a function of clay loading. The particle size and shape, the mixing time, filler concentration, processing technique, and filler/matrix interactions were significant factors affecting the electrical resistance [10]. Increasing the clay loading resulted to an increase in the electrical resistance.

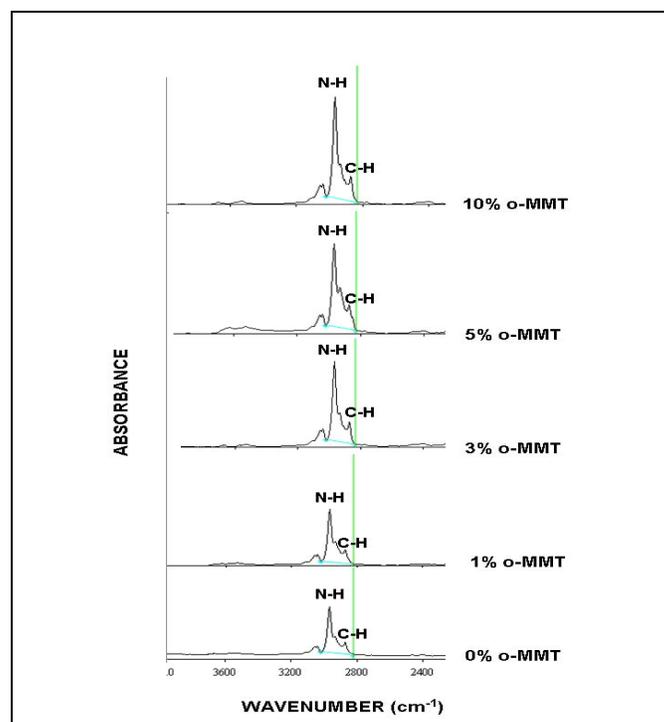


Figure 1. The FTIR spectra of the RPC/o-MMT at different clay loading.

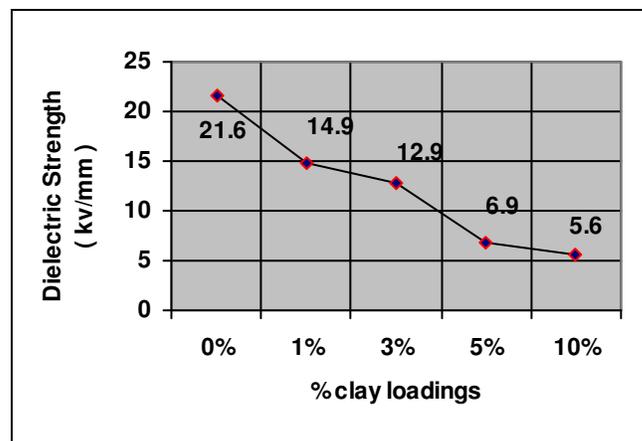


Figure 2. Dielectric strength of local RPC/o-MMT as a function of clay loading.

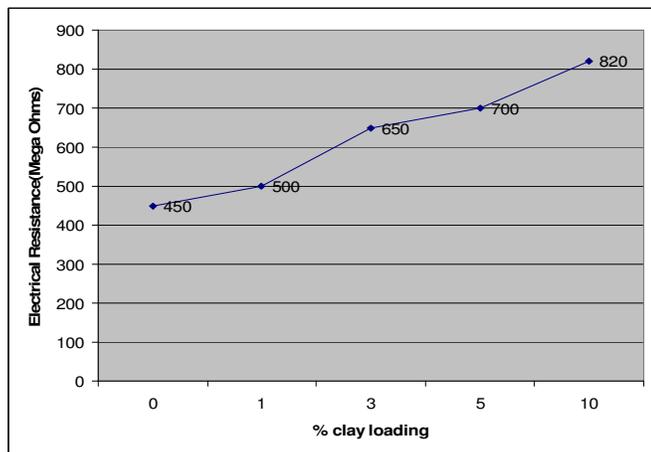


Figure 3. Electrical resistance of Local RPC/o-MMT as a function of clay loading.

### Thermo-mechanical properties as a function of clay loading.

**Glass transition temperature.** The glass transition temperature of the local RPC/o-MMT as a function of clay loading decreases with the increase in clay content (Fig. 4), similar to the study of Desabelle [6]. It was also observed by Tseng [9] that when organoclay was added, there was an increase of the glass transition temperature ( $T_g$ ) of the polystyrene. The segmental motion of the polystyrene matrix was retarded by the silicate layers that resulted to an increase in the glass transition temperature of the material [9]. According to Xu [11], the o-MMT clay acted as a plasticizer in the polymer matrix, in his study on polyvinyl chloride nanocomposites. He found that the different types of treated MMT can lead to a decrease or an increase in the glass transition temperature.

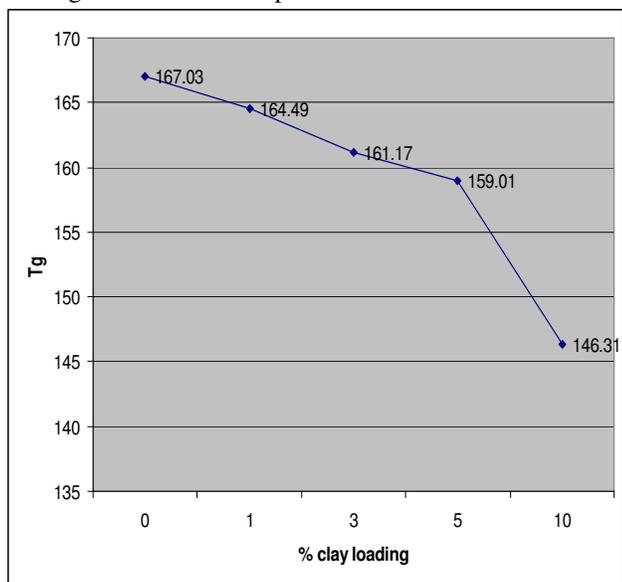


Figure 4. Glass Transition Temperature of Local RPC/o-MMT Nanocomposite

**Coefficient of thermal expansion.** The coefficient of thermal expansion decreases with the increase in clay loading (Fig. 5). This phenomenon may be due to the high aspect ratio of the clay that resulted to the reinforcing effect in the matrix. The results also indicate that whenever the thermal expansion decreases, the stiffness of the material increases. In another study by Gilman, et al. [12], they observed an improved thermal stability in the sample using monoalkyl- and dialkyl-imidazolium surfactants in the synthesis or organo-montmorillite compared with an alkyl ammonium equivalent wherein the decomposition was increased by 100°C.

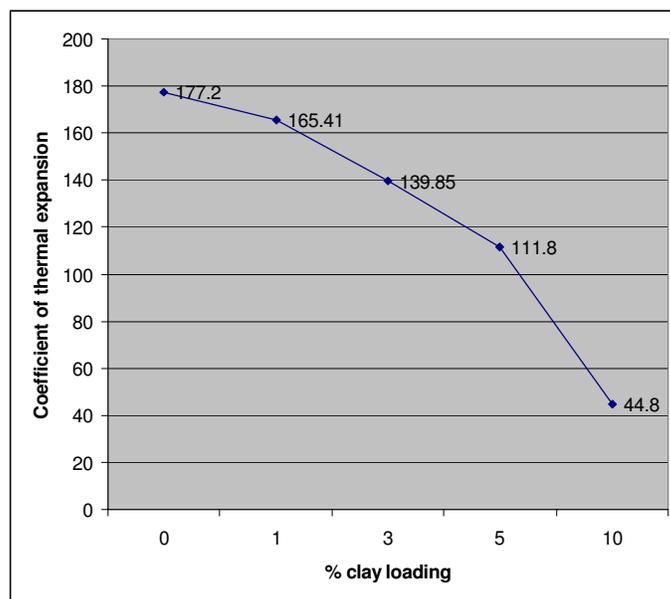


Figure 5. Coefficient of Thermal Expansion of Local RPC/o-MMT

### Dynamic mechanical properties as a function of temperature and clay loading

In the graph shown in figure 6 and Table 1, the modulus increases as the temperature increases. Based on the study of Wang, et al. [13], the graph signified a viscoelastic behavior of the polymer sample based on the stress and strain curve. In this study, the measurement was based on the RPC/o-MMT systems that indicate differential orientation of the various segment of the macro molecule during the creep and recovery process.

According to Starr, et al. [14], the effect of the polymer/nanoparticle interactions, surface-to-volume ratio, and boundary conditions on the structure can be observed on the dynamic mechanical properties of the polymer melt. They also observed that the chains near the nanoparticle surface were elongated and flattened, and that this effect was independent for the range of interactions. A gradual change of the polymer dynamics approaching the nanoparticle surface caused the change in the  $T_g$ . [14].

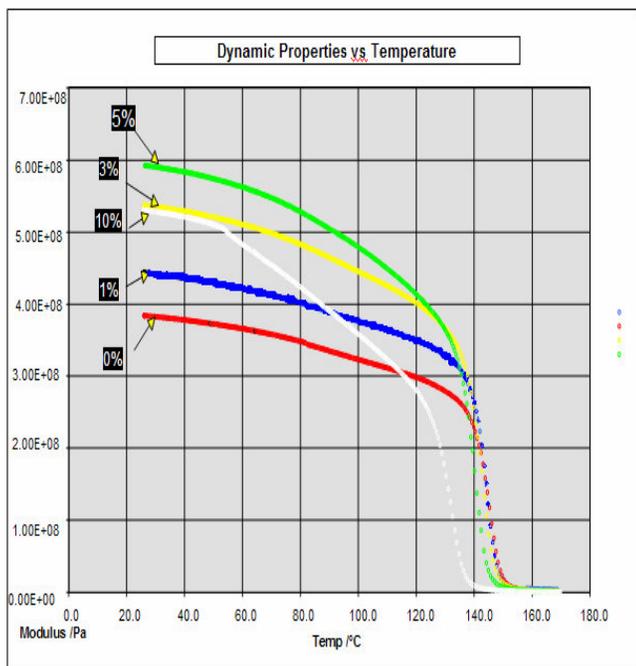


Figure 6. Dynamic properties as a function of temperature of RPC/o-MMT nanocomposites.

| SAMPLE   | 25%      | 100%     | 150      |
|----------|----------|----------|----------|
| 0% o-MMT | 3.82E+08 | 3.22E+08 | 1.66E+07 |
| 1% o-MMT | 4.43E+08 | 3.76E+08 | 1.45E+07 |
| 3% o-MMT | 5.37E+08 | 4.45E+08 | 1.13E+07 |
| 5% o-MMT | 5.92E+08 | 4.81E+08 | 7.30E+06 |
| 10%o-MMT | 5.30E+08 | 3.58E+08 | 1.90E+06 |

Table 1. Dynamic properties as a function of temperature of RPC/o-MMT nanocomposites.

## CONCLUSIONS

Polycarbonate can be recovered from CD post-consumer wastes by mechanical abrasion and chemical stripping. Recycled polycarbonate/o-MMT nanocomposites can be synthesized through melt-compound method by melting and annealing using a two roll mill. Changes in the peak of FTIR spectra implied that fillers were interacted and dispersed in the matrix. Furthermore, the nanofiller may have acted as a plasticizer to the polycarbonate due to the decrease in the glass transition temperature of the RPC/o-MMT nanocomposites as the clay content was increased. The increase in clay loading caused the decrease in the nanocomposite's dielectric strength because MMT may have created microvoids during processing, which made the material reach its breakdown faster than loading without MMT. As the loading of clay was increased, the modulus of elasticity also increased, resulting to a much stiffer and harder polycarbonate. The study also showed that loading 5% clay gave the optimum stiffness of polycarbonate.

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