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ORIGINAL PAPER

# Non-linear viscoelastic behavior and damping factor of polypropylene/clay nanocomposites

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**Abstract** The non-linear viscoelastic properties of pure polypropylene and its clay nanocomposites are studied to establish structure–property relationship in conjunction with clay concentrations. First, flow birefringence is performed through a slit-die to obtain centerline principal stress difference during elongational flow for clay nanocomposites. The centerline stress profile of clay nanocomposite reveals additional viscoelastic nature even at low silicate concentrations, while similar short-time chain relaxation is observed. The effects of higher clay concentrations are further examined during the simple shearing flow to consider damping properties of the clay nanocomposites. The step strain, dynamic shear and steady shear are performed. All the samples show time-strain separable melt flow behavior adequately demonstrated through Wagner's exponential damping function. The damping coefficient is found to be strongly dependent on clay percentage revealing viscoelastic differences therein. We have also used a time-strain separable Kaye-Bernstein Kearsley Zapas (K-BKZ) type constitutive equation to predict steady shear stress. The suggested constitutive model satisfies simple shear at lower fractions of clay while the damping function behaves similar to pure polymer thought to result from the absence of filler–filler interactions and chain length degradation. The unusual rheological behavior for maximum clay concentration studied is explained on experimental as well as theoretical basis. Thus, the results of this investigation would improve the theoretical understanding of possible molecular orientations at different clay concentrations during elongational and shearing flows.

**Keywords** Non-linear viscoelasticity · Polyolefin-clay nanocomposite · Damping function · Wagner constitutive equation · Flow birefringence

## Introduction

Polymer-layered silicate nanocomposites have achieved considerable industrial interest due to the commercialization of polyamides, elastomers and non-polar thermoplastic olefin and polypropylene-based nanocomposites [1–3]. Understanding the melt flow properties of polymer-layered silicate nanocomposites is important to enhance their processability. The rheological investigations are considered to be as fundamental as other characterization techniques to understand melt flow properties, which play a key role during polymer processing [4–6]. The differences in rheological properties of pure polymer and their clay nanocomposites could be possible as the filler particle size, structure and surface characteristics could affect the interfacial attractions resulting in complex flow behavior [7, 8]. Earlier studies on these two phase-systems reveal increased broad-spectrum features and low-frequency independent dynamic moduli at the percolation threshold showing non-terminal behavior [9–11]. Krishnamoorti et al. [12, 13] studied the rheology of different intercalated, delaminated and end-tethered clay nanocomposites. They reported low-frequency non-terminal behavior and suggesting for other anisotropic materials like lamellar di-block copolymers and smectic liquid crystals [14]. Larson et al. [14] explained that all complex fluids having layered structure could reveal identical rheology during long-time scale dynamic measurements due to the presence

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