Effect of Viscosity Ratio on the Polymer/Polymer Interfacial Slip

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ABSTRACT: We investigated the effect of the molecular weight of individual layer and temperature on the polymer/polymer interfacial slip. As seen from this study, it is found that the polymer/polymer interfacial slip does not sensitive to the molecular weight, the polymer/polymer interfacial slippage has similar temperature dependence even when the concentric core-sheath samples has different viscosity ratio of individual layer.

1.   Introduction

Any polymeric products were made using various types of polymeric materials (e.g. molecular structure, molecular weight, molecular weight distribution etc…) under various condition (e.g. temperature, pressure, flow rate, etc…). These factors influence the viscoelastic properties of polymeric material. As a result, the flow behavior is affected by these factors. In case of multi-layer polymer processing, the multi-layer flow behavior and the interfacial properties would be affected by these factors as well, because two or more materials are extruded through a single die.

In addition, in case of immiscible polymer systems, the existence of slippage at the polymer/polymer interface might be expected, because the different polymer chains are weakly entangled leading to poor interfacial adhesion. Actually, some scientists [1] pointed out the existence of polymer/polymer interfacial slip in multi-layer flow. However, the determination of the polymer/polymer interfacial slip velocity in coextrusion is not straightforward when two or more polymers with different shear-rate dependent viscosities. Accordingly, nobody knows that the effect of the molecular weight of individual layer and temperature on the polymer/polymer interfacial slip in coextrusion.

Recently, Komuro et al. [2] proposed a novel method (the modified Mooney method) to estimate the slip velocity at a polymer/polymer interface in two-phase coaxial flow even when the concentric core-sheath samples has different shear-rate dependent viscosities. This method is an adaptation of the Mooney method [3] used to measure the wall slip velocity.

In this study, we investigated the effect of the molecular weight of individual layer and temperature on the polymer/polymer interfacial slip using the modified Mooney method [2].

2.   Experiments

The experimental samples were chosen three types of PP (PP1-3) and three types of PS (PS1-3) with the different molecular weights. PPs were kindly supplied by Sumitomo Chemical Corporation and Japan Polypropylene Corporation. PSs were kindly supplied by PS Japan Corporation. The interfacial slip velocity was evaluated using capillary dies of three different diameters D=1.0, 1.5 and 2.0 mm.
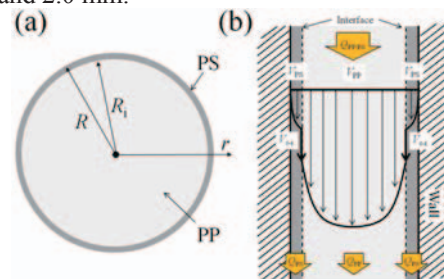

Fig. 1 (a) Cross section of PP coated with PS sample and (b) the boundary condition of flow velocity distribution in two-phase coaxial flow.

Fig. 1 shows the schematic illustration of the cross section of PP coated with PS sample and the boundary condition of flow velocity distribution in two-phase coaxial flow. The polymer/polymer interfacial slip velocity was evaluated using eq. (1). The detail of experimental procedure was written in ref. [2].

$$Q_{PP/PS} = \pi \left[R_i^2 V_{s-i} + \frac{R_i^3}{\sigma_i^3} \int_0^{\sigma_i} \sigma^2 \left(-\frac{dV_{PP}}{dr} \right) d\sigma + \frac{R^3}{\sigma_w^3} \int_{\sigma_i}^{\sigma_w} \sigma^2 \left(-\frac{dV_{PS}}{dr} \right) d\sigma \right].$$
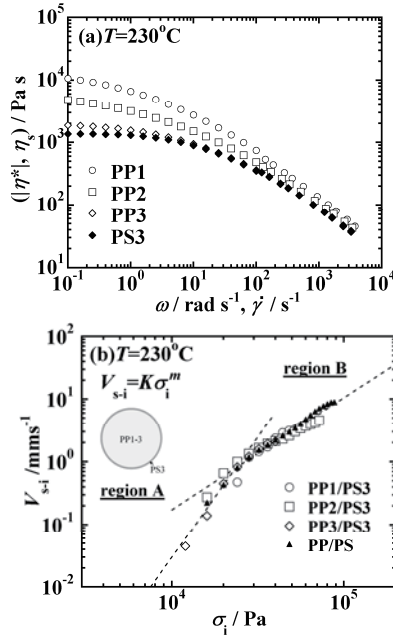
(1)

Fig. 2 (a) $|\eta^*|$ and η_s of PP1-3 and PS3 at 230°C. and (b) $V_{s\text{-}i}$ as function of σ_i for PP1-3/PS3 at 230°C.

3. Results and discussions

3.1 Effect of the molecular weight on the polymer/polymer interfacial slip:

Fig. 2(b) shows the log $V_{s\text{-}i}$ versus log σ_i for PP1-3/PS3. The $V_{s\text{-}i}$ exhibits the power-law dependence on σ_i ($V_{s\text{-}i} = K\sigma_i^m$), and the power-law dependence falls displays two distinct regimes with the power-law exponent at an critical interfacial shear stress ($\approx 2 \times 10^4$Pa). From the Fig. 2(b), the existence of interfacial slip transition at approximately 2×10^4Pa, the power-law exponent at the region A and B, the actual value of $V_{s\text{-}i}$ for several σ_i were almost same for PP1-3/PS3. These results suggested that the polymer/polymer interfacial slip does not sensitive to the molecular weight.

In addition, the polymer/polymer interfacial slip velocity at 230 ^{o}C using PP and PS with the quite similar viscoelastic properties over a range of shear rates were also shown in Fig. 2(b) [2]. Here, we focused on the PP/PS [2] and the PP3/PS3. Alghough the both of the PP/PS and the PP3/PS3 are the almost identical viscosities pair over a range of shear rates (($\eta_{PP} \approx \eta_{PS}$) > ($\eta_{PP3} \approx \eta_{PS3}$)), the moleculer weight of PP/PS are higher than PP3/PS3. From the comparison between the $V_{s\text{-}i}$ for
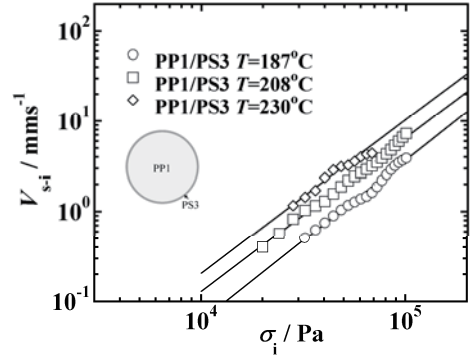

Fig. 3 $V_{s\text{-}i}$ as function of σ_i for PP1/PS3 at 230°C, 208°C, and 187°C.

PP/PS and PP3/PS3, it is found that the polymer/polymer interfacial slip does not sensitive to the molecular weight even if the concentric core-sheath samples has almost identical viscosities over a range of shear rates.

3.2 Effect of temperature on the polymer/polymer interfacial slip:

Fig. 3 shows $V_{s\text{-}i}$ as function of σ_i for PP1/PS3 at 230°C, 208°C, and 187°C.. As seen from these results, it is found that the polymer/polymer interfacial slippage has similar temperature dependence even when the concentric core-sheath samples has different viscosity ratio of individual layer.

4. Summary

[1] The polymer/polymer interfacial slip does not sensitive to the molecular weight.

[2] The polymer/polymer interfacial slippage has similar temperature dependence even when the concentric core-sheath samples has different viscosity ratio of individual layer.

References:
[1] e.g. Lee PC, Park HE, Morse DC, Macosko CW, *J. Rheol.*, 53:893-915, 2009 etc…
[2] Komuro R, Sukumaran SK, Sugimoto M, Koyama K, Slip at the Interface between Immiscible Polymer Melts I: Method to Measure Slip, *under review,* 2013
[3] Mooney M, *J. Rheol.*, 2:210-222 1931.