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Starve-fed single-screw extrusion of polymer blends

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In contrast to flood-fed extrusion, two distinct stages of melting are observed during starve-fed extrusion and a novel melting mechanism is thus proposed.

Extrusion is the process by which molten plastic is pushed by a rotating screw through a shaping die, to produce pipes, rods, sheets, or films. Extruders may be categorized as either single-screw or twin-screw extruders, and these may be flood-fed or starve-fed. It is usual for single-screw extruders to be flood-fed, whereas gravitational-feeding twin-screw extruders are generally starve-fed (i.e., there are starved and fully-filled regions along the screws). For the latter machines, mixing and melting actions are substantially better than for the single-screw versions, and these advantages have thus led to the concept of starve-feeding for single-screw extruders. Melting of a solid polymer is one of the fundamental tasks during extrusion—in both single-screw and twin-screw extruders—and melting within flood-fed single-screw extruders is generally well understood and modeled. A model of melting in these machines was first proposed in 1970, from which the first global model of conveying and melting of solids, as well as melt flow in a single-screw extruder was developed.[1] Similar studies for starve-fed single-screw extrusion, however, are very limited.[2,3]

Indeed, in some of our previous work, we proposed the first model for melting in starve-fed single-screw extruders.[4] According to this model, two stages of melting can be distinguished in starve-fed extruders. In the partially filled region of the screw, the polymer granules collect at the active flight and are melted by conduction. In the fully filled region, however, the unmolten polymer particles are suspended in the molten polymer and melting is caused by heat dissipation. With the use of this model, we were then able to develop a global model for conventional starve-fed single-screw extrusion,[5] and subsequently for non-conventional screw configurations.[6,7] All these previous studies were limited to the investigation of neat thermoplastics. The recent and extensive development of advanced polymeric materials (e.g., polymer blends, polymer composites, and highly filled compounds), however, means that such conventional, neat polymers are rarely used in modern extrusion applications. It is therefore necessary for extruder designs to

Figure 1. *Photographs of the screws pulled out of the machine after extrusion of the polypropylene/polystyrene blend, at a screw speed of 50rpm and metered feed rates of (a) 11kg/h, (b) 12kg/h, and (c) a flood-feed rate of 13kg/h. Arrows mark the beginning of the fully filled region.*[8]

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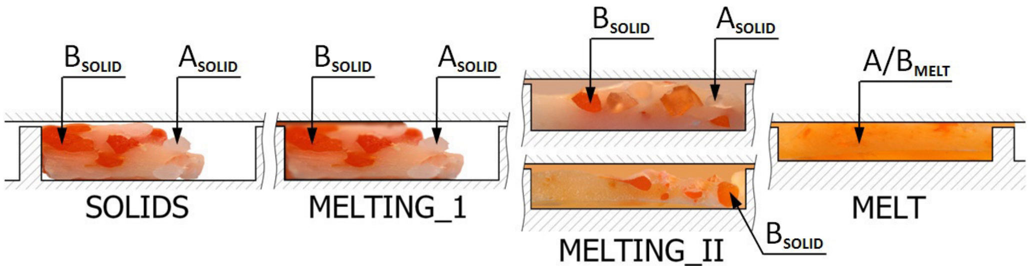

Figure 2. Schematic depiction of the four-section melting mechanism for polymer blends in a starve-fed single-screw extruder. A and B: Major and minor components of the polyblend material. SOLIDS: Solid conveying of the material occurs in the partially filled region. MELTING_1: Melting occurs via conduction. MELTING_II: Both conduction and dispersive melting of one/two of the blend components occurs. MELT: Melt flow takes place.[8]

enable the processing of complex polymeric systems (but which have much more complicated melting processes during extrusion than neat polymers).

In our most recent work,[8] we have thus studied the melting process of low-viscosity/high-viscosity polymer blends in a starve-fed single-screw extruder. In particular, the blends we used were a high-density polyethylene/polystyrene (HDPE/PS) blend, a polypropylene/polymethyl methacrylate (PP/PMMA) blend, and a PP/PS blend. All our blends were composed of 85% of the major (i.e., first) component and 15% of the minor (second) component. Although all our materials are commonly used plastics (with favorable properties for various applications), there have been no previous reports on their starve-fed extrusion. To study the extrusion process, we used the 'screw pulling-out' technique. In this method, after the machine has reached a steady state, the screw rotation is stopped and the barrel is cooled to room temperature. We then increase the barrel temperature to the polymer melting point and subsequently pull the screw out from the barrel. We were then able to investigate the melting mechanism by stripping the polymer samples from the screw (see Figure 1).

We find that the mechanisms of melting for the polymer blends in the flood-fed extruders and in the starve-fed extruders are fundamentally different. A classical Tadmor melting mechanism was clearly visible in the flood-fed extrusion of the polyblends (i.e., for a flood-feed rate of 13kg/h). Specifically, we note that the molten polyblend accumulates at the active flight of the screw and that the solid bed is gradually reduced by the combined effects of heat conducted from the barrel and from viscous dissipation within the melt. In the case of starve-fed extrusion (i.e., for metered feed rates of 11 and 12kg/h), however, we observe two distinct stages of melting. One stage occurs in the partially filled region of the screw and the other takes place in the fully filled region. In the first of these regions, the polyblend granules collect at the active flight of the screw and are melted by conduction. However, we find that the lower-viscosity polymer melts first and then encapsulates the granules of the second component, which slows its melting. If the polyblend is not completely molten when the screw channel is fully filled with material, the unmolten solid particles of one/both components of the polyblend become suspended in the previously molten material. This suspension flows to the die, and melting progresses mainly through heat dissipation (dispersive melting). The size and number of unmolten solid particles then continuously decrease until the material is completely molten.

According to these observations, we have proposed a new mechanism for the melting of polymer blends in the starve-fed single-screw extrusion process (see Figure 2). In particular, we distinguish four different sections in the extrusion process. First, solid conveying occurs in the partially filled region (SOLIDS). Next—MELTING_1—melting occurs via conduction. In the third section (MELTING_II), melting occurs by both conduction and through dispersive melting of one or two components of the polyblend. In the last region (MELT), melt flow occurs.

In summary, we have studied the melting mechanism of polymer blends in a starve-fed single-screw extruder. We observed a classical Tadmor melting mechanism for flood-fed extrusion, but not for starve-fed extrusion. Instead we find that there is two-stage melting for the starve-fed process (for all our studied polyblends), where there is conductive melting in the partially filled region of the screw channel and dispersive melting in the fully filled region. We have thus provided evidence for substantial differences between the melting of neat polymers and of polymer blends and have proposed a new mechanism for melting of polymer blends in the starve-fed single-screw extrusion process. In the partially filled region of the screw, a mixture of the two solid polymers is melted by conduction, and in the fully filled region a dispersion of solid particles (of one/two of the polymers) in a molten matrix may be observed. In our future work, we will examine how modeling of

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melting of polymer blends in a starve-fed single-screw extruder is different from that of single polymers.

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