

## **Melting of Immiscible Physical and Compatibilized Polymer Blends in Single Screw Extruders**

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### **Abstract**

Melting is a major step in plasticating single screw extrusion, but most of the existing phenomenological know how was gathered by performing Maddock-type experiments with homopolymers. Given the current widespread industrial use of polymer blends, it is worth determining whether the same mechanisms and mathematical models apply, or whether different sequences develop. This work reports the results of Maddock-type experiments using a PA6/PP blend, both in its immiscible and compatibilized varieties. A melting mechanism combining the features of the classical Tadmor mechanism and of the dispersed melting mechanism, also previously reported in the literature, was observed.

**Keywords:** Melting, Melting mechanism, Polymer blends, Single-screw extrusion.

### **Introduction**

Experimental studies of melting of homopolymers in single screw extruders were initiated by Maddock (1959) and allowed a qualitative phenomenological understanding of the underlying mechanisms, while Tadmor *et al.* (1966) developed the corresponding mathematical description. The solid pellets are compacted and form a continuous bed separated from the inner barrel wall by a thin melt film, while the melt deposits in a pool near to the screw pushing flight. In contrast with the Maddock/Tadmor mechanism, melting of individual solid pellets suspended in the melt was observed by Jakopin and Nichols (1984), when using specific screw geometries. Rauwendaal (1989) put forward the first mathematical approach of this dispersed melting sequence. Since single-screw extruders are nowadays often used to manufacture extrudates from complex polymer systems such as polymer blends, it is important to use Maddock-type experiments to understand whether the conventional melting behavior is generally valid or otherwise.

### **Materials**

PA6 (DSM Akulon F 130), PP (REPSOL ISPLEN 030G1E) and PP-g-MA (ARKEMA OREVAC CA 100) were used to prepare PA6/PP blends, both in their physical and in situ compatibilized forms (in this case, PA6/PP/PP-g-MA).

### **Experimental Procedure**

The blends were prepared in a prototype modular single screw extruder, with a screw diameter of 30 mm and  $L/D = 30$ , fitted with material sampling devices and pressure transducers along the barrel and with a mechanical system for fast screw extraction. Maddock-type experiments were performed in order to investigate the effect on melting of changes in blend composition, screw speed, barrel temperature profile and screw geometry. Cross-sections were cut from polymer helices at regular down-channel intervals and immersed in epoxy for 24h before polishing. Later, the samples were submitted to a dyeing bath in order to tint PA6 and thus distinguish between PA6 and PP. The samples were photographed and the images were subsequently analyzed with the *Image-Pro Plus 4.5* software.

### **Results**

For each experiment, observation of sequences of cross-sections revealed that the melting mechanism of the PA6/PP system is much more complex than the traditional one observed in homopolymers.

Usually, the evolution of melting along the screw channel is depicted in terms of a reduced solids width,  $X/W$ , as the solid bed is assumed as approximately rectangular. Figure 1 shows also the evolution of melting in terms of the relative area of solids ( $A_s/A_t$  where  $A_s$  is the total cross-sectional area occupied by solids and  $A_t$  is the total area of the cross-section) and number of solid particles suspended in the melt. The data refers to PA6/PP physical blends with different compositions (80/20, 50/50 and 20/80 %), which were

processed under the same operating conditions (220 /230 /240 /240 /240 / 240°C from hopper to die, screw speed of 30 rpm) and identical screw geometry (compression ratio = 2.5, feeding compression and metering zones 10D long).

Differences between the axial profiles of X/W and As/At, especially for the blends richer in PP, are a sign that either the solid bed height no longer remains essentially constant, or that changes in the classical melting mechanism are taking place. This is confirmed by the plot of the evolution of the number of suspended solid particles, which is an evidence of the development of a parallel mechanism. Figure 2 shows the contribution of each polymer to the melting progress of the blend. Each plot refers to one of the compositions and represents the area of each molten blend component, as well as that of the blend, normalized to the area of the channel cross-section. The horizontal lines indicate the values expected for each polymer after complete melting, taking into account their relative density and relative percentage. In the feed zone, the melting rate of the blends is essentially determined by the PP melting rate, whereas in the compression zone the role of PA6 seems predominant. Moreover, in the feed zone, the higher the PP content in the blend, the higher the melting rate of this polymer. Conversely, the melting rate of PA6 is practically the same, but increases drastically in the compression zone.

Figure 2 shows also that despite of the differences in the melting temperature of the two blend components (circa 60°C) both materials start melting at approximately the same location, even if at different rates. Melting of each pellet will depend on its location in the channel.

### Conclusions

The melting sequence of polymer blends in conventional screw extruders follows a more complex mechanism than that reported for homopolymers. Instead, a competition between Tadmor's and dispersed mechanisms is observed, i.e., a "hybrid melting mechanism" develops.

For a complete understanding of the underlying physical phenomena, future work will concentrate on a finer observation scale, i.e., on monitoring the evolution of morphology upon melting.

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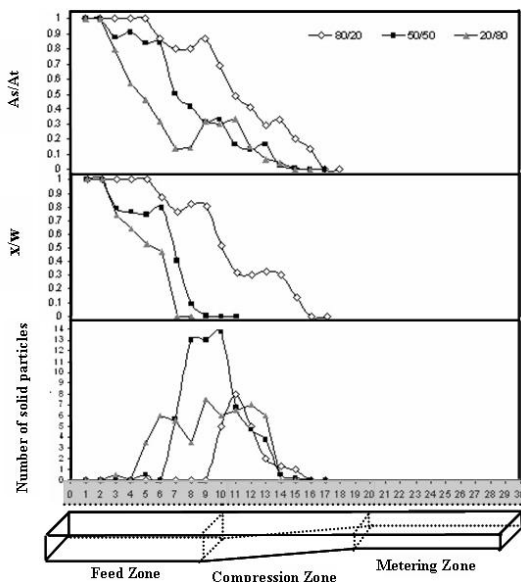


Figure 1: Evolution of melting along the extruder

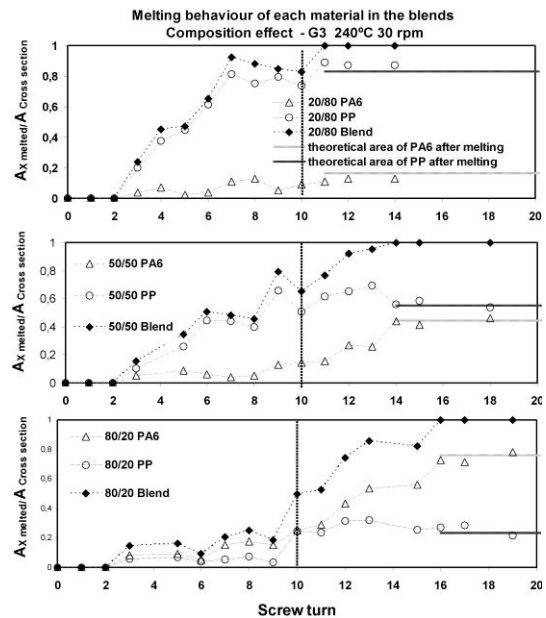


Figure 2: Contribution of each blend component to the melting evolution of the blend