J. of Korean Oil Chemists' Soc.,
Vol. 32, No. 2. June, 2015. 320~325
ISSN 1225-9098 (Print)
ISSN 2288-1069 (Online)
http://dx.doi.org/10.12925/jkocs.2015.32.2.320

Flow Marks of Polypropylene (PP) Composites in the Injection Molding

Hyeon-Taek Jeong* · Yong-Ryeol Kim†

*† *Department of Chemical Engineering, Daejin University, Pocheon, 487-711, Korea*

(Received May 31, 2015; Revised June 20, 2015; Accepted June 20, 2015)

Abstract : Flow mark is a sort of surface defect on the composite that can arise during the filling stage of the injection molding process. The purpose of this study is to clarify a mechanism of the flow mark which appears on the surface of injection molded Polypropylene (PP) through the characterization of the surface structure. The materials used in this report are PP/rubber and PP/talc compounding, which are widely used in automobile part. The flow mark shows two different constitutions, such as a luster part and a cloud part on the surface of the injection molded PP. We have investigated the surface structure of PP/rubber and PP/talc composites by using scanning electron microscope (SEM), energy dispersive x-ray spectroscopy (EDAX) and optical microscopy (OM). As a result, the cloud part contains higher contents of the rubber and talc compare to the luster part.

Keywords : Flow mark, injection molding, Polypropylene (PP), cloud part, luster part.

1. Introduction

Injection molding is one of the most popular processing techniques for polymers and occupies the dominant position in the mass production of plastic products. Recently, resins with enhanced optical and physical properties have been developed; consequently, the injection molding process is becoming more important in the manufacturing of the products such as camera lenses, compact disk, automotive parts including bumper and console body. In such application, exterior surface quality is crucial and defect on the molded surface may become a major problem.

†Corresponding author
(E-mail: yrkim@daejin.ac.kr)

The wavelike flow mark phenomenon is one of the surface defects that can occur during the injection stage of the process. It is characterized by a surface with periodic hills and valleys running perpendicular to the direction of the movement of the flow front[1]. In many cases, the flow marks are asynchronous or out of phase on opposite surfaces of the part, with a cloud part on one surface of the part located across from a luster part on the opposite surface. The cloud part is termed the flow mark, while the luster part is termed "the out-of-flow mark". Wavelike flow marks are commonly observed in the areas on a molding where the flow front velocity is relatively low. Injection molding machine operators can be eliminated these defects by increasing of the injection rate or mold temperature [2]. Surface defects are known as wavelike flow marks in injection molding and encountered with a variety of thermoplastic materials, including neat polymer, filled polymers, and polymer blend[3-5]. These defects have been reported at resin flow velocities ranging from 1 to 200 mm/s with wavelengths from 1000 to 10 μm and at a depth between 150 and 0.01 μm[6-8].

Visual observations are reported by several researchers have demonstrated that flow marks are caused by a flow transition at the advancing melt front from stable symmetric fountain flow to unstable, oscillating and asymmetric flow[9]. The two most common mechanisms have been proposed to unstable flow are slip at the wall or instability at the point of stagnation[10]. Perturbed melt flow in the mold cavity is characterized by a shift of the stagnation point from the mid-plane of the channel towards one of the mold walls, as shown in Figure 1. This also leads to flow paths of different lengths from stagnation point to the opposing walls, with the melt experiencing different strain histories on the two flow paths. The morphology of the dispersed phase in the cloud part is quite different from the luster part. The dispersed phase is highly stretched to cylindrical strands in the luster part and retracted in the cloud parts to extent. This phenomenon has been observed by Patham et al.,[9] in the injection molded blends of PP and EPR(ethylene-propylene random copolymer) elastomers. Furthermore, the concentration of the dispersed phase in the cloud part might be different from the luster part. Hamada and Tsunasawa have studied the morphology of injection-molded tensile bars prepared by the blends of polycarbonate(PC) and acrylonitrile-butadiene-styrene(ABS) and reported a similar flow transition with the flow of these PC/ABS blends. They also have reported different phase concentrations at the surface in different regions with these blends: the glossy out-of-flow-mark region was polycarbonate rich at the surface, while the flow-mark region exhibited both components at the surface.

In this study, we have investigated the flow mark on polymer blend in the injection moldings. The materials used in this report are the PP/rubber composites and PP/talc composites, which also are applicable for automobile part. The PP/rubber and PP/talc composites are fabricated and the mechanism for appearance of a flow mark is clarified through characterizations of the structure of the injection moldings.

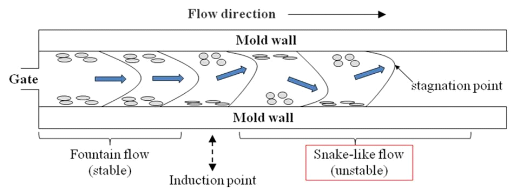

Fig. 1. Schematic of flow transition at advancing melt front from a stable symmetric fountain flow to an unstable asymmetric flow.

2. Experimental

2.1. Matrials

Polypropylene (PP) was purchased from Hanwa Total Company. The melt index of PP is 10 g/10 min at 230℃. Rubber and talc were obtained from DOW Chemical (KOREA) Ltd. and KOCH(KOREA), respectively. The average particle size of talc was 1 μm. PP and talc were vacuum-dried at 70 ℃ for 24h before melt mixing. PP was melt blended with the talc and the rubber to fabricate composites.

2.2. Processing Conditions

PP/talc composites and PP/rubber composites were prepared by a melt compounding in a Bautek equipped with a twin-screw extruder. The temperature of the heating zone, from the hopper to die, was 230, 230, 230, 220, 220, 200, and 160 ℃. The screw speed was 70 rpm. Extruded composite pellets were dried at 70℃ for 24hr. The loading level (X) of talc particle and rubber were 8, 15, 20, and 25 wt%, which were coded into PP/talc-X and PP/rubber-X. The extruded composite pellets were injection molded by using a BOY injection-molding machine, and spiral shaped specimens were fabricated. The processing conditions were 230 ℃ of cylinder temperature, 25 ℃ of cavity temperature, 100bar of injection pressure, and 75 cm^3/s of injection speed. Fig. 2. shows the flow mark of the injection molded specimens. The thickness of the specimens was 1.6 mm.

Fig. 2. Photo of injection molded specimen showing the flow mark.

2.3. Surface Analysis

The Surface morphology and fractured surface were characterized by using scanning electron microscopy (SEM) (HITACHI, model S-4100). The rubber component was etched out in a cyclo-hexane, and the sample was coated with platinum. The sample was immersed in 60℃ of the etching solvent for 3 hrs and then, the component of the PP/talc composite surface was examined by using energy dispersive x-ray spectroscopy (EDAX) accessory. The cross-section morphology along the longitudinal direction of the samples was also examined by SEM. The constructions of the surface were examined by using a FT-IR with a ATR measurement (THERMO MATTSONMODEL INFINITY GOLD FT-IR) in the range of 400~4000 cm^{-1} at room temperature. FT-IR spectra were obtained by using a spectral resolution of 4 cm^{-1} and were averaged over 64 scans.

3. Result and discussion

3.1. Appearance of the Flow Marks

Fig. 3. illustrates schematic drawing to calculate the flow mark length percent. The flow mark length percent is given by this equation, Flow mark length percent = (overall length - induction length) / overall length whereas, induction length is from gate to the beginning point of flow mark. A flow mark shows two different alternating parts, such as a luster part and a cloud part, as shown in Fig. 3. As mentioned in introduction part, there is a flow transition at the advancing melt front from stable flow to unstable flow. In other words, the flow mark does not exist in the beginning of injection molded specimen. The flow marks are appear after the induction point.

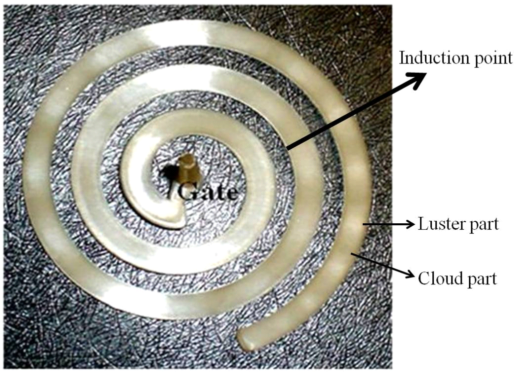

Fig. 3. Schematic drawing of the induction point from out-of-flow mark to flow mark.

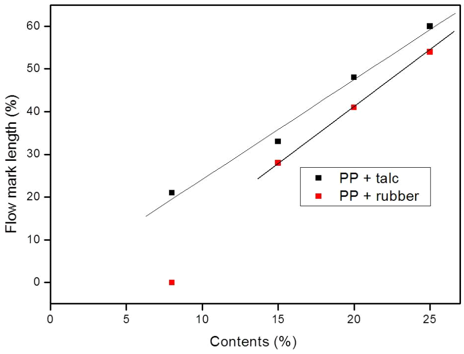

Fig. 4. Flow mark length percent of PP/talc and PP/rubber composites.

Fig. 4. shows the flow mark length percent of PP/talc and PP/rubber composites for the content of fillers. The high contents of filler are increased the flow mark length percentage. PP/talc composites have higher flow mark length percentage than PP/rubber composites at the same concentration. PP/talc-20, PP/talc-25, PP/rubber-20, and PP/rubber-25 composites show up to 40 % of flow mark length percentage. The PP composite with up to 40% of flow mark length percentage is not suitable for automobile application. However, the filler should be contained around 20 wt% to maintain physical and mechanical properties of the composite. The trade-off between contents of filler and properties of the composite should be considered. Interestingly, in the case of PP/rubber composites, the PP/rubber-8 has not shown the flow mark on the composite surface, indicating that percolation threshold concentration of the rubber to induce the flow mark is higher than talc.

3.2. Surface Structure

Fig. 5(a) and (b) gave a cloud part and a luster part of PP/talc-25 composite on the surface, respectively. The cloud part shows rougher surface than the luster part. The cloud part shows more white particles on the surface than the luster part. In order to investigate a chemical composition of the white particles, EDAX accessory was carried out. Fig. 6. represents the data of EDAX, which shows that the peak of Si and Mg is dominant, indicating that the white particles indicated talc with chemical formula of $Mg_3(OH)_2Si_4O_{10}$.

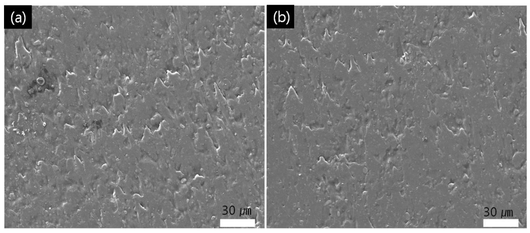

Fig. 5. SEM images of the flow marks of PP/talc-25: (a) cloud part (b) luster part.

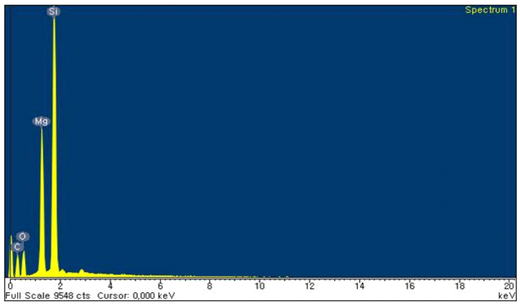

Fig. 6. EDAX data of the white particles on the surface.

Fractured surface structure near wall of flow mark of PP/talc-25 composites as revealed by SEM micrographs is demonstrated in Fig. 7(a) and (b) which show a cloud part and luster part of cross-sections along the perpendicular direction of PP/talc-25 composites, respectively. The trace of talc components remains at the surface layer and becomes pore or halls. The cloud part shows a lot of halls and rough surface due to high contents of talc which indicating that the talc contents on the cloud part are higher than the luster part at the surface layer.

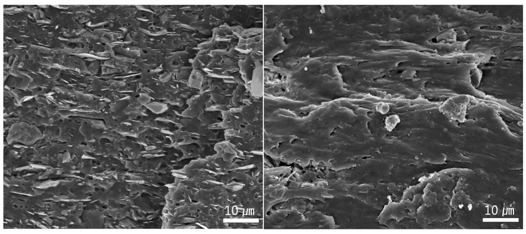

Fig. 7. SEM micrographs of a cross-section along the perpendicular direction of PP/talc-25 composites: (a) cloud part (b) luster part.

The surface morphology of a cloud part and a luster part of PP/rubber-25 after etching is shown in Fig. 8. There are also difference between cloud part and luster part on the surface. The rubber components etched out then it showed a lot of space with the pore on the surface. This result is corresponding to the Fig. 7.

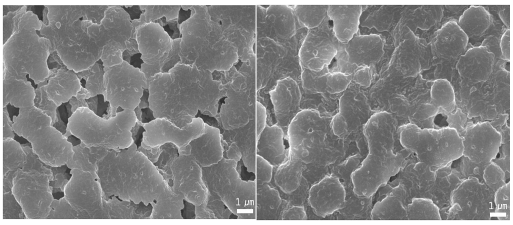

Fig. 8. SEM images of PP/rubber-25 composites on the surface after etching: (a)cloud part (b) luster part.

4. Conclusion

The flow marks of PP/talc and PP/rubber compositesin the injection moldings are investigated. As a result, the luster and cloud part showed different structures from analysis of the surface structure. The morphology of the dispersed state was demonstrated a difference between the cloud and luster part. In the case of PP/rubber composites, the surface structure near the wall is different between cloud part and luster part, as shown SEM images. Appearance of a flow mark is concerned with the difference of flow behavior of resin, and the mechanism of a flow mark appearance could be clarified by the characterizing of the surface structure. Moreover, processing conditions could be effect on the flow mark on surface of the composite.

References

1. S. Y. Kang, S. M. Kim, and W.U. Lee, “Finite element analysis for wavelike flow marks in injection molding”, *Polym. Eng. Sci,* **47**, 922 (2007).
2. L. Tredoux, I. Satoh, and Y. Kurosaki, “Investigation of wavelike flow marks in injection molding: A new hypothesis for the generation mechanism”, *Polym. Eng. Sci,* **40**, 2161 (2000).
3. M. C. Heuzey, J. M. Dealy, and D.M. Gao, “The Occurrence of Flow Marks during Injection Molding of Linear Polyethylene”, *Intern Polymer processing,* **XII**, 403 (1997).
4. B. Patham, P. Papworth, K. Jayaraman, C. Shu and M. D. Wolkowicz, “Flow marks in injection molding of polypropylene and ethylene-propylene elastomer blends: Analysis of morphology and rheology”, *J. of Appl. Poly. Sci.,* **96**, 423 (2005).
5. L. Tredoux, I. Satoh, and Y. Kurosaki, “Investigation of wave-like flow marks in injection molding: Flow visualization and micro-geometry”, *Polym. Eng. Sci,* **39**, 2233 (1999).
6. A. C. B. Bogaerds, M. A. Hulsen, G. W. M. Peters, and F. P. T. Baiijens, “Stability analysis of injection molding flows”, *J. Rheol,* **48**, 765 (2004).
7. M. Yoshii, H. Kuramoto, and K. Kato, “Experimental study of transcription of smooth surfaces in injection molding”, *Polym. Eng. Sci,* **33**, 1251 (1993).
8. B. Patham, P. Papworth, K. Jayaraman, C. Shu, and M. D. Wolkowicz, “Flow marks in injection molding of polypropylene and

ethylene-propylene elastomer blends: Analysis of morphology and rheology", *J. Appl. Polym. Sci,* **96**, 423 (2005).

9. S. A. Edwards and N. R. Choudhary, "Variations in surface gloss on rubber-modified thermoplastics: Relation to morphological and rheological behavior", *Polym Eng Sci,* **44**, 96 (2004).

10. S. A. Edwards, N. Roy Choudhury and M. Provatas, "Visualization of surface and subsurface morphology: The effect of processing on a rubber-modified thermoplastic", *J. Appl. Polym. Sci.,* **87**, 774 (2003).