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Thesis Title:

Effect of cross-sectional configuration on fiber formation behavior in bicomponent melt spinning process

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Summary of Thesis

In recent years, nanofibers are recognized as an exciting new class of material for various applications. Utilization of the preparation of islands-in-the-sea type bicomponent fibers (S/I fibers) for the production of nanofibers has an advantage of higher controllability of the diameter and mechanical properties in comparison with the newly developed methods such as electrospinning. After the formation of the S/I fibers, the sea component needs to be dissolved into solvent to obtain nanofibers.

To investigate the fundamental melt spinning behavior of the S/I fibers, high-speed bicomponent melt spinning of polystyrene (PS) and polypropylene (PP) with the composition of PS:PP=1:1 was performed for the preparation of the S/I fibers with 1519 islands. For comparison, high-speed melt spinning of sheath-core (S/C) fibers and blend fibers of the same composition were also carried out.

Observation of the spin-line near the spinneret revealed that the die-swell of the S/I spinning was much larger than that of the S/C spinning. When the S/C and S/I components were exchanged from PS/PP to PP/PS, the magnitude of swelling of the S/C spin-line decreased whereas that of the S/I spin-line did not show any significant change. For the blend spinning, the die-swell was larger and tended to develop in downstream in comparison with that of the S/C or S/I spinning. Possible factors for the origin of different die-swell behavior in the vicinity of spinning nozzle were thought to be: (1) effect of flow history in the spinning die, and (2) effect of interfacial tension between the two components. The former corresponds to the visco-elastic effect in this experiment since the reduction ratio of the cross-sectional area of flow in the sheath-core type spinning die was 16:1, whereas that in the 1519 islands-in-the-sea type spinning die was 3200:1. Effect of the latter was confirmed from the fact that the magnitude of die-swell increased with the increase of extrusion temperature in the blend spinning. The latter also tended to cause instability of the thinning behavior where even the thickening of the thick part of the spin-line was found to occur.

To clarify the characteristic behavior of filament deformation along the spin line, on-line measurement of diameter profile was also performed. Different thinning behavior was observed for the S/I, S/C, and blend fiber spinning. It was confirmed that different degree of swelling altered the thinning behavior of the spin-line. Thinning behavior in the downstream was largely governed by the PS component because of its high glass transition temperature. Comparison of the thinning behavior for the melt spinning of various cross-sectional configurations suggested that the development of temperature distribution in the fiber cross-section on cooling effectively affected the thinning behavior of the spin-line.

Numerical analysis of the spinning process was carried out incorporating the effects of die-swell, interfacial tension and temperature distribution in the cross section, and the calculated thinning profiles were compared with the experimental results. Overall thinning behavior under various spinning conditions could be reproduced, however, effect of interfacial tension observed for the results of simulation was not clearly seen in the experimental results even in case of the blend spinning. Through the preparation of the sheath-core bicomponent fibers consisting of high-density polyethylene (HDPE) and polyamide 6 (PA6) as the sheath and core components and also the multi-layered films consisting of HDPE and PA6 as the outer and core layers, difference and common characteristics in the processing of bicomponent fibers and films was investigated. Particular attention was paid for the effect of mutual interaction of the two components on the structure development behavior. It was revealed that the structure development of PA6 is mainly governed by the applied stress whereas the memory effect of the flow of molten polymer is more effective for the development of crystalline orientation in HDPE. Accordingly, high molecular orientation of PA6 was found only in the high-speed spun fibers, whereas HDPE showed oriented structure both in the fibers and films. Development of orientation of HDPE in the bicomponent films and fibers was suppressed in comparison with the respective single component films and fibers of HDPE.

There is a special interest on the formation of ultra-fine fibers with non-circular cross-section. The S/I fibers of non-circular overall cross section was prepared using a slit nozzle to investigate how the cross-sectional shape of the individual islands and entire fiber were affected. The cross sectional shapes of both islands and sea could be changed by spinning conditions. At high extrusion temperatures, flow velocity of the edge portion was found to be larger than that of the center portion, which leads to the wavy edge and corruption of the center part in the flat fibers. This was considered to be due to the insufficient pressure drop at the slit, which was originated from the low viscosity of the polymer melt. On the other hand, melt fracture or formation of shark skin was found to occur at low extrusion temperatures. Under stable extrusion conditions, cross-sectional configuration of the extruded fiber was investigated in detail. Non-circularity of the entire fiber was generally larger than that of the islands. The shape of islands showed significant distribution in the fiber cross-section, whereas such distribution did not show any significant variation along the spin-line. This result suggested that the designing of the spinneret plays a decisive role for the control of cross-sectional distribution of the islands.