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ANNA BLIM, LESZEK JARECKI, SLAWOMIR BLONSKI

MODELOWANIE PNEUMATYCZNEGO FORMOWANIA SUPERCIENKICH WŁÓKIEN W DYSZY LAVALA

MODELING OF PNEUMATIC MELT DRAWING OF SUPER-THIN FIBERS IN THE LAVAL NOZZLE

Institute of Fundamental Technological Research, Polish Academy of Sciences
Pawinskiego 5B, 01-106 Warsaw, Poland
ablim@ippt.gov.pl

slowa kluczowe: superthin fibers, air drawing, pneumatic melt spinning, Laval nozzle

Melt spinning of the fibers by supersonic air jet in the Laval nozzle is a novel, efficient and energy saving method of formation of super-thin fibers. The technique is simpler and shows higher productivity in comparison with the melt blowing method which uses hot air blown from very narrow slot dies. The polymer melt extruded from a raw of orifices in the symmetry plane of the air jet undergoes fast drawing by the pneumatic forces. In the supersonic process, thin polymer filaments are drawn by the air friction forces acting on their surface due to high difference in the air and polymer velocities, accumulating on the processing axis. In the process modelling, distributions of the air velocity, temperature and pressure, as well as the dynamic functions of the polymer stream are computed. Influence of inter-filament interactions in a single row of thin polymer streams is neglected. The air fields predetermined at the absence of the filaments are used in the modelling. The air velocity, temperature and pressure distributions are computed from the k-ω aerodynamic model [1]. At long spinning beam, the air flow fields reduce to two-dimensional fields in the cross-section normal to the beam and is symmetrical with respect to the z-axis (Fig. 1). Then, the computational domain is a half-plane limited by the symmetry axis z. The simulations of the air fields are performed with the aid of the Fluent package using finite volume CFD method.

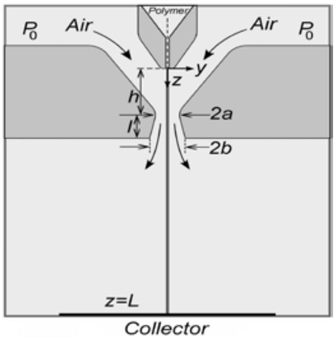

Fig. 1. Geometry of the die assembly in the process modelling.

The polymer stream is extruded to the air jet coaxially from the orifice located at the air jest symmetry axis where the highest air drawing forces are exerted on the filament. Computations of the polymer melt air drawing dynamics base on the fundamental mathematical model of melt spinning in single-, thin-filament approximation [2] adopted for the pneumatic process [3]. The stationary model of air drawing reduces to one dimension z and is valid in the range of z-axis where the air velocity exceeds velocity of the filament. Phan-Thien/Tanner non-linear viscoelasticity model is used. The polymer velocity $V(z)$, temperature $T(z)$, tensile stress $\Delta p(z)$ and rheological extra-pressure $p_{rh}(z)$ axial profiles are computed, considered as average values over the radial cross-section of the filament.

Example computations are performed for the process of nonwovens' formation from isotactic polypropylene at the fixed collector distance L=200mm, the melt extrusion temperature 300°C, the melt extrusion orifice diameter 0.7mm, the polymer mass output 0.04g/s and melt flow rate index MFR=12 (Mw=250,000).

Influence of the processing and material parameters involved in the technique such as geometry of the Laval nozzle, initial air compression, initial melt temperature, polymer mass output, diameter of the extrusion die is discussed. The role of the polymer molecular weight (melt flow rate index), the melt viscosity and relaxation time is considered. Example computations show influence of important processing and material parameters on the pneumatic process in the supersonic jet.

Steady-state profiles of the axial polymer velocity, temperature, tensile stress and rheological pressure are computed in the predetermined air velocity, temperature and pressure fields along the processing axis. The axial profiles of melt air drawing are computed using the Runge-Kutta fifth order method for solving the differential equations of the dynamic mathematical model of melt spinning adopted to the pneumatic process.

In the supersonic melt spinning process, high negative internal pressure is predicted in the polymer bulk which results under high elongation rates. The negative pressure may lead to cavitation and longitudinal burst splitting of the filaments into a high number of sub-filaments. A hypothetical number of the sub-filaments at the splitting is estimated from an energetic criterion. In the supersonic air jet, the diameter of the sub-filaments after the splitting may reach the range of nano-fibers. Burst splitting of the filaments was reported by Gerking [4] from an experimental research in the supersonic air jet where the average diameter of the sub-filaments after the splitting was observed in the range 2-15μm. A hypothetical diameter of the polypropylene sub-filaments at the splitting is predicted to be in the range between 10 and 5μm. The diameter decreases with increasing the air compression in the Laval nozzle inlet from one to 3 bars. Substantial influence of the Laval nozzle geometry is also predicted in the computations.

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