Fibers and Polymers 2002, Vol.3, No.1, 38-42

Improved Thermal Bonding Behaviour of Polypropylene Non-wovens by Blending Different Molecular Weights of PP

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(Received November 14, 2001; Revised March 8, 2002; Accepted March 15, 2002)

Abstract: Polypropylene filaments were spun from a mixture of PP chips of two different Melt Flow Index (MFI) (3 MFI and 35 MFI). A significant difference was observed in the melting characteristics of the resultant filaments from either of the individual components as observed from the DSC. The main difference being in the degree of melting achieved at any temperature in the initial stages of the melting range, which was found to be higher in case of the filaments spun from the blend. These filaments were then thermally bonded using silicon oil bath and heated roller method. Subsequently the bond strength of the filaments was measured on the Instron Tensile Tester using the loop technique. The values of the bond strengths obtained from the blend were compared with those made from the individual component. It was found that the bond strength of the bonds obtained from the blended filament at a given temperature was higher than that of the bonds made from the filaments of either of the individual components, which is also suggested by the DSC curves. The difference in the bond strength was found to be as high as 25% in case of the blend with 60:40 composition ratios of the 3 MFI and 35 MFI components respectively.

Keywords: Polypropylene, Thermal bonding, Silicon roller method, Heated roller method, Loop test

Introduction

Polypropylene (PP) is used extensively in the production of non-woven fabrics because of its resistance to microorganism and chemical resistance, hydrophobicity and low melting point. Non-woven made of PP is used in disposable baby diapers, surgical gowns and dressings. They are used in constructions to provide ground stabilization in road pavings to provide drainage and in soil retention applications for soil control. Thermal bonding is one of the important methods for the manufacturing of non-wovens. Thermal bonding process variables affecting the fabric properties are bonding temperature, nip-line pressure, contact time, calendar pattern and quench rate.

Imachi[1] showed that the maximum interfacial bonding between two thermoplastic components occurs at the melting point of the lower melting component. This implies that the maximum strength for the homopolymer should occur when the bonding temperature is close to the melting point. According to DeAngelis *et al.*[2] for a given nip line pressure and calendar speed, the breaking strength reaches a maximum at a critical temperature. The nip line pressure influences the heat transfer to and through the web and the melting point. Bechter *et al.*[3] found that if the position of maximum strength occurs in the softening region, higher pressure yield higher strength. On the other hand, if maxima occurs in the early melting region, a low calendaring pressure is desirable so that the thin melting zone is not disturbed. The contact time of the web in the nip is affected by roll diameter and production speed. DeAngelis *et al.*[2] studied the influence of production speed on tensile strength. At constant roll temperature and pressure, breaking strength decreases with speed. Quench rate affects polymer crystallization. According to these authors, critical quench rate for achieving maximum bond strength is affected by two competing processes. Initially, with an increasing quench rate, the crystal sizes are reduced and the flow between crystals is reduced, leading to stronger bonds. However as the quench rate increases further, the stress concentrations do not get sufficient time to relax, leading to decrease in bond strength.

In the present study, PP filaments have been spun from a blend of PP of two different MFI. The thermal bonding behavior of these filaments have been investigated and compared with that of the PP filaments spun from the individual components of the blend.

Experimental

Preparation of Filament

Commercial grade PP (3 MFI and 35 MFI) obtained from Reliance Industries Ltd. was used to prepare melt-spun monofilaments. For spinning the filaments, a laboratory model extruder (M/S Windser Klockner) was used. The feed zone, compression zone and the metering zone of the extruder were maintained at 180°C, 200°C, and 210°C respectively. The die and the spinneret were maintained at 235°C. Screw speed was maintained at 2 rpm. The length and diameter of the single orifice were 3 mm and 1 mm respectively. After extrusion the as-spun filaments were quenched in a water bath maintained at about 10°C and kept at a distance of 1 cm from spinneret. Samples with varying percentage composition of 35 MFI and 3 MFI PP were spun. The filaments were drawn on a laboratory scale drawing

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machine to a draw ratio of 4 at 65°C in the first stage and to a draw ratio of 1.5 at 120°C in the second stage.

Characterization of the Spun Samples

DSC of the samples was carried out using Perkin Elmer Delta DSC. The samples were heated to 50°C and were held at this temperature for 2 minutes in flowing nitrogen to drive of any residual moisture. Samples were then heated at a controlled rate of 10°C/min upto 200°C. The melt was held at this temperature to erase the thermo-mechanical history of the sample. The sample was then cooled at the rate of 10°C/min to 50°C.

Thermal Bonding

The spun filaments were thermally bonded using silicon oil bath and heated roller method. A schematic of the silicon oil bath assembly is shown in Figure 1. The system consists of silicone oil bath, which is heated by means of an immersion heater. Temperature of the bath was controlled to an accuracy of ±1°C using a PID type temperature controller. An "T" shaped element was used for holding the filaments under stress. The filaments were arranged in a loop form on the hooks. The element is moved into the heated silicone oil bath at the time of bonding. The bonding temperature was varied from 145°C to 160°C and the bonding time from 20 to 40 seconds. Removing the assembly out of the bath terminated bonding.

A schematic of heated roller method is given in Figure 2. This method is based on direct contact type of heating. It consists of two rollers-Silicone coated top roller and bottom metallic roller. Bottom roller was directly heated to desired temperature (145°C and 160°C). Filaments were held on a wooden frame in taut condition in loop form at a constant bond angle. Then the filaments were passed through the nip for bonding to occur. Frame was given transverse motion for a fixed number of times (5-7).

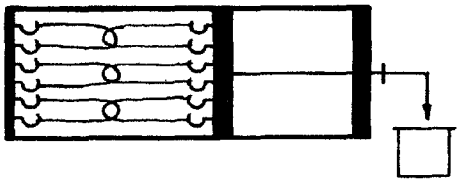

Figure 1. Schematic of silicon oil bath assembly.

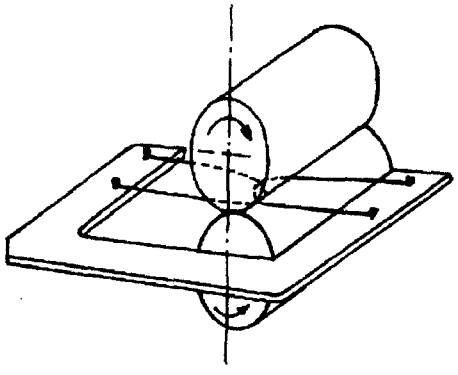

Figure 2. Schematic of heated roller assembly.

Characterization of the Bonded Sample

The original non-woven sample and the fractured sample were observed under Scanning Electron Microscopy.

The bonding strength was measured using Instron 4301 model Tensile Tester. The loop test method recommended by Mukhopadhyay *et al.*[4] was used to find out the bonding strength. The distance between the jaws was 100 mm and the crosshead speed was 10 mm/min.

Results and Discussion

DSC plot of the filaments having 3 MFI:35 MFI as 90:10, 80:20, 60:40 and 3 MFI samples for melting and cooling are shown in Figures 3 and 4 respectively. Some important observations from the DSC curves are listed in Tables 1 and 2. The progressive decrease in the onset temperature (a measure of the slope of the melting endotherm), with apparently no change in the peak temperature as observed in the DSC curves indicates that the degree of melting of crystallites at a given temperature in the initial part of the melting range increases with the increase in the 35 MFI component in the blend. It can therefore be expected that under the bonding conditions, the degree of melting of filaments made from the blend would be higher than that of

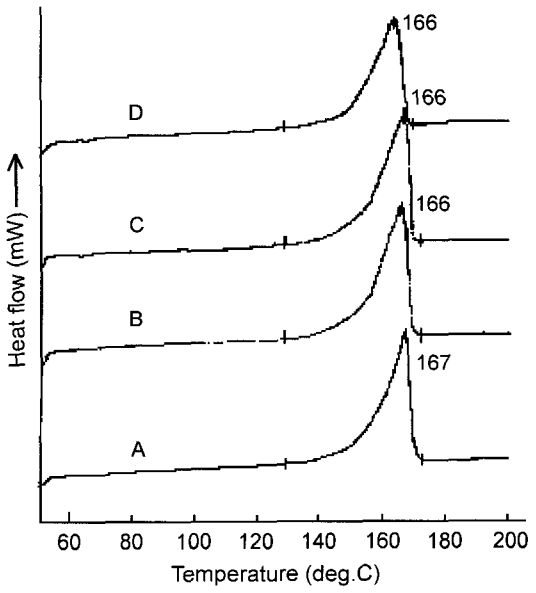

Figure 3. Melting curve: A. 3 MFI, B. 3 MFI:35 MFI = 90:10, C. 3 MFI:35 MFI = 80:20, D. 3 MFI:35 MFI = 60:40.

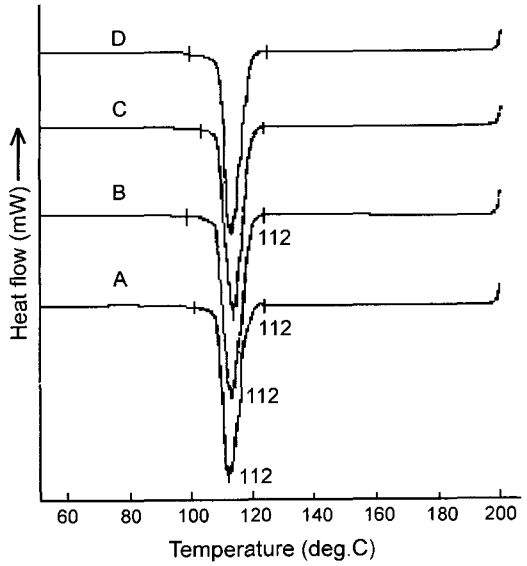

Figure 4. Cooling curve: A. 3 MFI, B. 3 MFI:35 MFI = 90:10, C. 3 MFI:35 MFI = 80:20, D. 3 MFI:35 MFI = 60:40.

Table 1. Features of the melting curve

Composition 3 MFI:35 MFI	Onset temperature	Enthalpy of melting (J/g)
90:10	154	102
80:20	155	92
60:40	152	93
3 MFI	158	96

Table 2. Features of the cooling curve

Composition 35 MFI:3 MFI	Onset temperature	Enthalpy of crystallization (J/g)
90:10	118	102
80:20	118	90
60:40	117	95
3 MFI	118	93

the filaments made from unblended chips. Alternatively, same degree of melting can be achieved at relatively lower

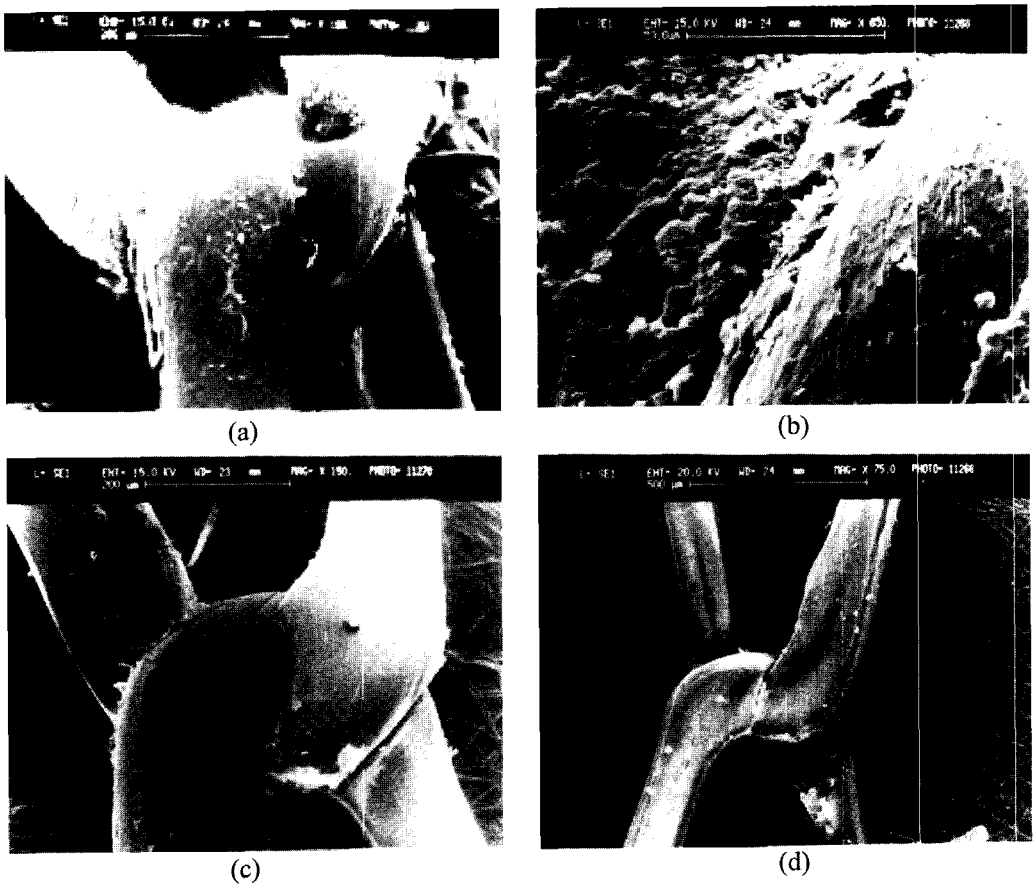

Figure 5. SEM micrographs of bonds: (a) 3 MFI:35 MFI = 80:20, Silicon Oil Method, 20 sec, (120×), (b) 3 MFI:35 MFI = 80:20, Silicon Oil Method, 20 sec, (660×), (c) 3 MFI:35 MFI = 80:20, Heated Roller Method, 5 Traverses, (120×), (d) 3 MFI:35 MFI = 80:20, Heated Roller Method, 5 Traverses, (58×).

Table 3. Bond strength of bonds made from Silicone oil bath method

Samples (3 MFI:35 MFI)	Bond strength (gpd)					
	148°C		152°C		156°C	
	20 sec	40 sec	20 sec	40 sec	20 sec	40 sec
3 MFI	No bonding	No bonding	0.40	0.42	0.42	0.42
95:5	No bonding	No bonding	0.41	0.42	0.42	0.42
90:10	No bonding	No bonding	0.42	0.43	0.43	0.44
85:15	No bonding	No bonding	0.41	0.41	0.45	0.42
80:20	No bonding	0.13	0.43	0.44	0.44	0.43
85:25	0.17	0.17	0.46	0.47	0.45	0.46
70:30	0.17	0.18	0.45	0.46	0.44	0.47
65:35	0.19	0.18	0.47	0.48	0.46	0.49
60:40	0.18	0.20	0.49	0.50	0.45	0.50

Table 4. Bond strength of bonds made from heated roller method

Samples (3 MFI:35 MFI)	Bond strength (gpd)					
	148°C		152°C		156°C	
	5 traverses	7 traverses	5 traverses	7 traverses	5 traverses	7 traverses
3 MFI	No bonding	No bonding	0.41	0.43	0.41	0.40
95:5	No bonding	No bonding	0.41	0.42	0.41	0.42
90:10	No bonding	0.12	0.43	0.43	0.42	0.41
85:15	0.12	0.12	0.44	0.45	0.44	0.45
80:20	0.13	0.14	0.45	0.47	0.45	0.46
85:25	0.14	0.16	0.48	0.49	0.45	0.48
70:30	0.16	0.19	0.49	0.48	0.48	0.49
65:35	0.16	0.19	0.49	0.50	0.50	0.52
60:40	0.19	0.21	0.50	0.52	0.50	0.51

temperature in case of the filaments made from the blended chips. Therefore bonding can be achieved at a lower temperature without affecting the bond strength. This leads to saving of energy.

The enthalpy change in melting as well as cooling is lower in case of blended filaments, except sample with 3 MFI:35 MFI as 90:10, when compared with the filaments made from unblended chips. This indicates that the overall crystallization is somewhat lower as a result of blending.

The bond area was translucent under optical microscope. Figure 5 shows the micrograph obtained from the SEM of bonds obtained by the two methods. Tables 3 and 4 show the bonding strength of the bonds made from the two methods. In case of silicon bath method marginal increase in strength was observed on moving from 20 sec to 40 sec in bonding time. Similar results were obtained in case of heated roller method on moving from 5 to 7 traverses. Good bonding cannot be achieved below 20 sec in case of silicon oil method and below 5 traverses for the heated roller method. Most of the loop melted and no bonding was observed for temperatures of 156°C and above in both methods. In certain samples, bonding strength at 156°C was less than 152°C. These observations can be explained by the observations of Schwartz[5,6]. According to him for maximum tensile properties and toughness, the bonds in the interior of the web need to be just weaker than filaments. The idea is that, when strain is applied to the web, some filament release from each other at the bond site, permitting more homogeneous load sharing, which increases strength and toughness.

Gibson and McGill[7] studied the effect of nip temperature on fabric properties. SEM photographs of stretched samples prepared at different nip temperatures indicate that at lower nip temperature failure occurs due to the disorientation of bond site. Filaments were found pulled out of the bond sites more often than filament rupture occurred indicating inadequate bond formation due to less melting. At higher bonding temperatures, filaments tend to break at the bond perimeter. As the bonding temperature was further increased, the authors suggested the failure mechanism would be due to brittle fracture of the bond sites themselves.

Similar observations on the failure mechanisms have been reported by Kwok *et al.*[8]. Debonding behaviour in which failure occurs at bond perimeter has highest bond strength. It can be seen from Tables 3 and 4 that there is an improvement in bond strength of upto 25% for the bond

made from the blended filaments having 3 MFI:35 MFI = 60:40 compared to the bond made from pure filaments. This can be explained by the DSC results of pure and blended filaments.

Conclusions

The PP filaments spun from the blend of 3 MFI:35 MFI were found to have significant difference in their melting as well as cooling characteristics. The degree of melting in the initial stages was found to be relatively higher in the blended filaments although no significant difference was observed in the peak temperature.

The results of the debonding test for the thermal bonds made from the blended filaments indicated an improvement in bond strength of upto 25% when compared with the bond strength of the bond made from unblended filaments under optimum conditions. The optimum temperature for bonding was found to be 152°C for the blended filaments.

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