

A Review on Bi-Component Yarn Spinning Technology (BCY) in the Global Textile Industry

Ömer Fırat Turşucular*

R&D Chief, Hatın Textile, and Hatın Tex Weaving Companies, Turkey

ISSN: 2578-0271



***Corresponding author:** Ömer Fırat Turşucular, R&D Chief, Hatın Textile, and Hatın Tex Weaving Companies, DOSAB, 16245, Bursa Province, Turkey
Orcid 0000-0003-1162-0742

Submission: June 24, 2024

Published: July 05, 2024

Volume 10 - Issue 2

How to cite this article: Ömer Fırat Turşucular*. A Review on Bi-Component Yarn Spinning Technology (BCY) in the Global Textile Industry. Trends Textile Eng Fashion Technol. 10(2). TTEFT. 000732. 2024. DOI: [10.31031/TTEFT.2024.10.000732](https://doi.org/10.31031/TTEFT.2024.10.000732)

Copyright@ Ömer Fırat Turşucular. This article is distributed under the terms of the Creative Commons Attribution 4.0 International License, which permits unrestricted use and redistribution provided that the original author and source are credited.

Abstract

In this theoretical review study included its importance, formation mechanism principle, yarns used, and general properties for Bi-Component spinning technology (BCY) were explained in detail, supported by visuals, and preparing a main table from various sources. In addition, the production processes of BCY yarns and how BCY process parameters affect both the rheological, and mechanical and thermal properties of BCY yarns were explained. Finally, the effects of BCY yarn types and various process parameters on various fabric properties on textile-based woven and knitted fabric forms were explained. The purpose of this study was BCY was the optimization of the production process parameters of BCY yarn production based on yarn types by summarizing the information of various experimental studies on yarn spinning technology (BCY). The purpose of this study was BCY was the optimization of the production process parameters of BCY yarn production based on yarn types by summarizing the information of various experimental studies on yarn spinning technology (BCY). According to the results, polymers such as PLA, PHBV, PA 6, PE, PP, PET, PTT, and PBT are widely used in BCY yarn production. They can be used either 100% pure or in their mixtures with various percentages with C/S, I/S and S/S nozzle profiles. Especially, PTT/PET, and PBT/PET BCY yarns are widely used in thermal comfort behavior in textile areas for their water absorption and fast drying properties. Moreover, this thermal comfort behavior depends on the polymer type used, glass transition, crystallization and melting temperatures, percentage, viscosity, molecular weight, orientation, crystallinity, polydispersity, biological, chemical, mechanical and thermal behavior, spinneret profile, spinneret diameter, extruder temperature and extruder length/diameter ratio (L/D), length and speed of the solidification zone, the temperature of the drafting rollers, their speed and drafting rate. Although it varies depending on the polymer type, in the production of BCY yarns, generally as the temperature increases, the viscosity decreases, the fiber diameter decreases, and it becomes easier to process. Before the production of PET and its derivative polymers, it is recommended to apply the alkaline (NaOH) pretreatment process in order to reduce the fiber diameter, facilitate processing, maintain dimensional stability, reduce surface smoothness, facilitate dyeability, and improve mechanical and thermal properties. PET/PET, PA 6/PA 6, PTT/PET, PBT/PET, PET/CoPET, PET/PE, PET/PP, PET/PA 6 polymers with 40/60 and 50/50 ratios, and C/S nozzle profiles can be widely used in BCY yarn production. PP/PA 6 polymer can be also used in BCY yarn production, too. Generally, the process parameters required for BCY yarn production of PA 6, PET, CoPET, PTT, and PBT polymers are extruder ratio 1/24, internal viscosity (η) range 0.62dl/g to 1.22dl/g, glass transition temperature (T_g) range 65 °C to 80 °C, crystallization temperature (T_c) 130 °C to 180 °C, melting temperature (T_m) 290 °C to 305 °C range, solidification zone from 1.5m to 3m, length, and draft ratio range from 1.5 to 3.5. The fixed temperature is recommended to be between 125 °C and 140 °C. Moreover, glass transition (T_g), crystallization (T_c), and melting (T_m) temperature values are lower in PE, PP, PLA, and PHBV polymers. PET/PE, PET/PTT, and PET/PA 6 polymers are widely used in BCY yarns thanks to their similar rheological behaviors. Recently, PLA-containing BCY yarns have started to be used, especially thanks to their biological advantages. BCY yarns containing PBT have started to be used thanks to their high maximum elongation at break and easy processability. Polymer with lower melting temperature (T_m) is generally used in the center (C) part, while polymer with higher melting temperature (T_m) is used in the shell (S) part in BCY yarns with C/S nozzle profile.

Keywords: Bi-Component Yarn Spinning Technology (BCY); Process parameters; Yarns; Fabrics; General properties

Introduction

In this theoretical review study included its importance, formation mechanism principle, yarns used, and general properties for Bi-Component spinning technology (BCY) were

explained in detail, supported by visuals, and preparing a main table from various sources. In addition, the production processes of BCY yarns and how BCY process parameters affect both the rheological, and mechanical and thermal properties of BCY yarns were explained. Finally, the effects of BCY yarn types and various process parameters on various fabric properties on textile-based woven and knitted fabric forms were explained. The purpose of this study was BCY was the optimization of the production process parameters of BCY yarn production based on yarn types by summarizing the information of various experimental studies on yarn spinning technology (BCY).

Importance, formation mechanism principle, yarns used and general features for Bi-Component Yarn Spinning Technology (BCY)

Yarn spinning technologies directly affect the final properties of the yarns produced, depending on the properties of the polymeric raw material, or raw materials used in its production [1-4]. In Bi-Component spinning technology (BCY), which emerged in the mid-1960s, two different melt, or dissolved polymeric raw materials, some nozzles profiles for their different cross-sectional profiles such as core/shell (C/S or core/sheath), side by side (S/S), segmented pie, segmented ribbon, trilobal, or islands in the sea (I/S) can be used depending on the rheological behavior of the polymers. If necessary, adding various chemical additives (CB, CNT, Ag, SiO₂, CS, GO, PEG, and AlPi in nanoparticle forms) in order to improve the rheological properties, or to add various finishing properties, and melting them together in the extruder. It is a yarn spinning technology produced by quenching in the cold and winding on empty bobbins after being drawn at the same time [1-21]. The fiber diameter values in BCY yarns generally do not exceed 100 micrometers (μm) [3]. Especially in BCY yarns with PA 6, PLA, PET, PTT, PBT, PHB, and PHBV structures, the quenching zone length is used as 1.4m, 2.8m, 3m, and 3.3m and the maximum air flow is 520m³/min. Moreover, BCY yarns are drawn in the chemically inert nitrogen (N₂) gas environment [5,7,12,20,22,23]. Regardless of the nozzle profile, it is recommended to use extruders with length/diameter (L/D) ratios of 16/1, 24/1, 25/1, or 30/1 in PET, PA 6, PE, and PP structured BCY yarns production [3,9,10,13]. Dosing pressure values applied in extruders range from 442 psi to 1455 psi [8]. In the production of PA 6, H-PET and L-PET (PTT) structured S/S BCY yarns, it is recommended to increase the extruder temperatures from 25 °C to 290 °C with a temperature increase rate of 10 °C/min. The reason for this situation is to ensure the time-dependent crystallinity of the polymers. In addition, a sudden and very high-temperature increase does not cause the polymers to undergo sudden and accelerated thermal degradation before being spun into BCY yarn. Moreover, the rollers must have a certain temperature during the drawing of BCY yarns. These temperature values are that the polymer used for the first draft cylinder must be at T_g temperature (°C) or slightly above (+5 °C). For S/S BCY yarns with PET and rPET structure, the initial drafting roller temperature is between 80 °C and 110 °C [13,19,21].

Moreover, it is necessary to gradually increase the draft rollers to values closer to the melting temperature after the first one. while the glass transition temperature (T_g) for H-PET is 79.7

°C and the cold crystallization temperature (T_c) is 155 °C, the thermal crystallization temperature for H-PET is 182 °C, and the thermal crystallization temperature for L-PET (PTT) is 197 °C. This causes L-PET (PTT) to be more sensitive to thermal crystallization compared to H-PET. Moreover, the melting temperatures (T_m) for both H-PET, and L-PET (PTT) polymers are 254 °C [13]. The cold crystallization temperature for PTT is in the temperature range of 63 °C to 85 °C, while the cold crystallization temperature for PET is in the temperature range of 130 °C to 170 °C [17]. H-PET/L-PET (PTT) structured S/S (60/40) BCY yarns have high elasticity, excellent elastic recovery behavior and very high dyeing affinity (dyeability) [14,16,17]. Usage areas of Bi-Component spinning technology (BCY) are military applications, biomedical applications, tissue scaffolds, home textile applications, sports applications, filtration, cleaning, optics, electronics, electrical conductivity, UV resistance, antibacterial, flame retardant (FR), or self-crimped yarns [1-11,16,24]. The most commonly used nozzle profile in BCY yarn production is the center-shell (C/S) profile. The most commonly used raw materials in BCY yarn production are SI, CO, PET, CoPET, H-PET, L-PET (PTT), PBT, HMPET, LMPET, MA, PA, PC, PS, PU, PE, LDPE, HDPE, PP, LPP, IPP, PAN, PANI, PMMA, PCL, PBA, PLA, PLLA, PLGA, COP, PEO, PNN, PVP, POP, PHB, PHVB, PBSL, PVDF, PPS and THV [1-30]. Especially BCY yarns with PA6, PE, PP, PTT, PBT, and PET structures are produced, which can be produced in various cross-sections in the range of yarn numbers from 60 dtex to 333 dtex [7,10,11,13,15-24].

While LMPET is used in the central part (C) of BCY yarns where high insulation and cleaning properties are required, HMPET is used in the shell part (S) [1]. In BCY yarns, where high tensile strength, abrasion, and pilling resistance properties are required, PET and PA fibers are used in the islands in the sea (I/S) nozzle profile, as the higher surface area and the mobility of the fibers within the yarn decreases as the amount of islands (I) increases [4]. Microfilament structures are generally used in BCY yarns [4,9,11]. High perspiration absorption, and fast drying properties are observed in woven, or knitted fabrics produced with BCY yarns with a hollow spinneret profile [11,24]. In BCY yarns, islands (I) between 16 and 37 are generally used in marine island (I/S) nozzle profiles. Microfiber diameters vary between 10 μm and 80 μm depending on the number of islands (I) [4,6,9]. Microfilaments used in BCY yarns (especially in the island (I/S) nozzle profile) provide higher surface area, high density, high flexibility, high water vapor permeability, low wind, and water resistance properties in woven, or knitted fabrics [5,10,11]. Process parameters affecting BCY yarn production are types of polymers, chemical, biological, mechanical, thermal, and electrical properties, ratios, concentration, viscosity, molecular weight (MA), capillarity state, interfacial bond strength, surface tension, polydispersity, adhesion, orientation, crystallinity, homogeneous distribution of fibers, nozzle inner diameter, nozzle channel length, nozzle general profile, nozzle fiber cross-section (profile), number of fiber channels inside the nozzle, inner fiber diameters of the nozzle, drafting roller speeds (m/min), drafting rate, and drafting environment [1,3-13,18-20,25].

In S/S BCY yarns, adhesion depends on temperature, molecular weight, chain orientation, polydispersity, molecular structure of the

polymer, and especially attraction ratio [13,17]. Moreover, thanks to phenomena such as Reynolds, Froude, Brinkman, Biot, Newtonian and Maxwell, which are the dimensional, and dimensionless quantities required for the experimental calculation of the computational fluid mechanics properties of mass conservation, linear momentum, and energy conversion equations that determine the rheological behavior of polymers, rheological behavior in BCY yarn production depends on the type of polymer. Although they vary, they are extremely important production process parameters [2]. Generally, as the temperature increases, the dynamic viscosity decreases, and the fiber diameter decreases. Moreover, this reduces the tensile strength of BCY yarns but increases the maximum percent elongation at break values [2,11,13]. As a result of this

situation, the fluidity properties of the polymeric raw materials of the BCY yarn to be produced increase, and it becomes easier to draw it in BCY yarn form. In addition, the maximum internal, axial, and surface velocities and average pressure values of the fluid increase due to the increasingly narrowing cross-sectional area ($\Delta A = A_{exit} - A_{enter}$) from the nozzle inlet to the nozzle exit. Thus, BCY dope facilitates high-speed dosing of the yarn towards the solidification (quenching) and drawing process stages after exiting the spinneret. In addition, all these fluidity values are fixed depending on the winding cylinder speed, which determines the drafting rate [2]. The theoretical overview of the Bi-Component spinning technology (BCY) machine was presented in Figure 1 [1].

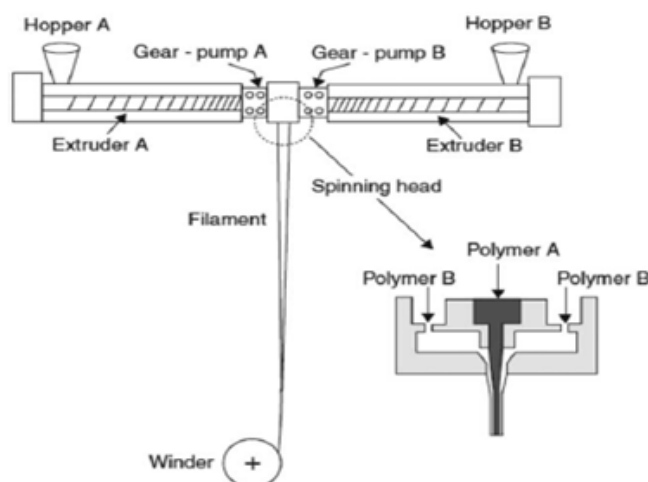


Figure 1: The theoretical overview of the Bi-Component spinning technology (BCY) machine [1].

The real overview of Bi-Component spinning technology (BCY) machine as laboratory scale was presented in Figure 2 [8].

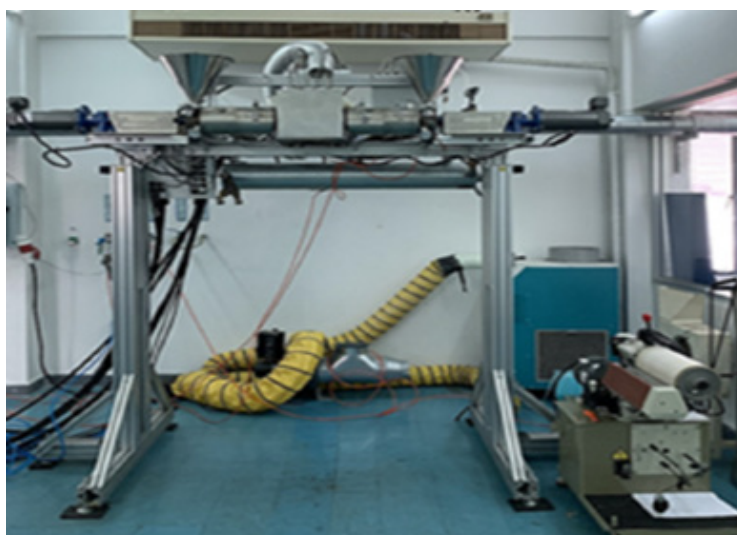


Figure 2: The real overview of Bi-Component spinning technology (BCY) machine as laboratory scale [8].

- | | |
|----------------------------------|---|
| a) centric center-shell (C/S), | e) sliced cake, |
| b) eccentric center-shell (C/S), | f) islands in the sea (I/S) |
| c) equal side-by-side (S/S), | as spinneret profiles of Bi-Component spinning technology |
| d) unequal side-by-side (S/S), | (BCY) were presented in Figure 3 [5]. |



Figure 3: a) centric center-shell (C/S), b) eccentric center-shell (C/S), c) equal side-by-side (S/S), d) unequal side-by-side (S/S), e) sliced cake, f) islands in the sea (I/S) as spinneret profiles of Bi-Component spinning technology (BCY) [5].

The formation mechanism of Bi-Component spinning technology (BCY) was presented in Figure 4 [2]. SEM (x2500) real image of BCY yarn with PP/PA 6 structured center-shell (C/S) nozzle profile was presented in Figure 5 [6]. Technical summary

information of various experimental studies on the production process parameters of BCY yarns produced with Bi-Component yarn spinning technology (BCY) was presented in Table 1 [3,5-13,18-21,25-29].

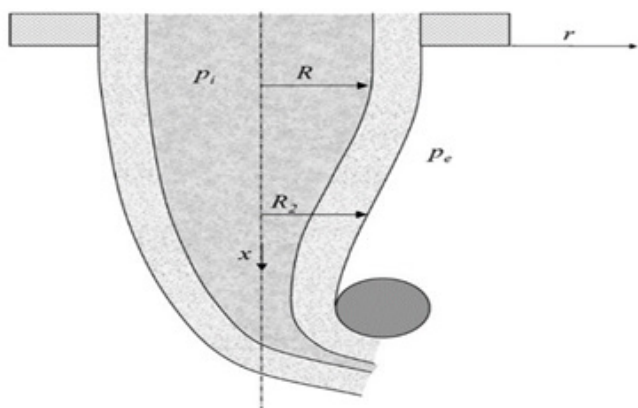


Figure 4: The formation mechanism of Bi-Component spinning technology (BCY) [2].

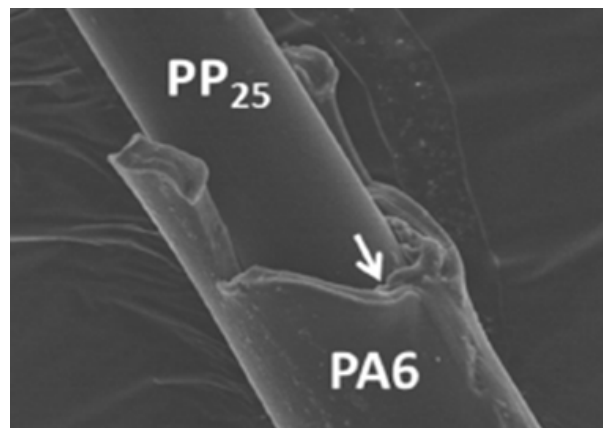


Figure 5: SEM (x2500) real image of BCY yarn with PP/PA 6 structured center-shell (C/S) nozzle profile [6].

Table 1: Technical summary information of various experimental studies on the production process parameters of BCY yarns produced with Bi-Component yarn spinning technology (BCY) [3,5-13,18-21,25-29].

Polymer Types	Nozzle Cross Sections (Profiles)	Mass flow rate (g/min, dl/g, cm ³ /min, m ³ /min), shear rate (1/s) and instrictric viscosity (η)	Polymer Ratios (%)	Melting Temperatures (T _m (°C))	Drawing Speeds (m/min)	Drawing Ratios	Sources
LDPE/PA 6	C/S	0.1 1/s	1-10	260	300-1050	3.5	3
PPS/PET	C/S	1.5-15 cm ³ /min	None	400	100-2000	20	5
PP/PA 6	C/S	10g/min-1000 1/s	None	230	None	None	6
PPS/PPS	C/S	0.62,0.62 instrictric viscosity, and 2000 1/s	35/65	305	800-1400	2-3.5	7
PET/PET	C/S		35/65	260	800-1400	2-3.5	
PPS/PET	C/S		35/65	260-305	800-1800	2-4	
PET/PPS	C/S		35/65	300-303	800-1600	2-4	
PP/CB+PP	C/S	None	Increasing and decreasing by 10 from 0/100 to 100/0	210-220	12-300	25	8
PET/PA 6	I/S, R,S/S	None	66/34,45/55,26/74	294, 293, 264	3000	1.53,1.53,1.23	9
PET/PA 6	C/S	20m ³ /s	50/50	235-245	135	3	10
Soluble in water PET/PA 6	C/S	None	50/50,40/60,30/70	278-285	3600	1.425	11

PE/PET	C/S	5.0g/min	50/50	290	500-5000		
PET/PE	C/S	5.0g/min	50/50	290	500-5000	None	12
PET/PE	C/S	5.0g/min	100/0	290	500-8000		
PE/PET	C/S	3.9g/min	0/100	290	500-3000		
H-PET/ H-PET, L-PET (PTT)/L-PET (PTT)	S/S S/S	0.908dl/g 0.502dl/g	50/50 50/50	325 276	2310-4200	1.818	13
PET/CoPET	S/S	0.64,0.66,0.68,0.66dl/g	50/50	290	1500	2.7-3.1	18
PET/rPET	S/S	0.60,0.75,0.82dl/g	40/60	285	1600	2.5-2.8	19
PBT/TPU	S/S	None	50/50	270	500-1100	1.67-3.67	20
PTT/PET	S/S	0.90,0.65 dl/g 1.00- 1.30/0.64 dl/g	30/70,50 /50,70/30	223-228,248- 255	2000-450	2.35	21
L-PBT/PLA,H- PBT/PLA	C/S	0.835-0.865dl/g/ None,1.180-1.220dl/g/ None	50/50	220,260	1000-6000	None	25
PHBV/PLA	C/S	None	59/41, 62/38, 66/34, 69/31, 29/71, 22/78	350	100-2000	1.5-6.0	26
POM/POM+PLA	C/S	None	100/0, 100/70- 30,100/50- 50,100/30-70	190-209	0.3	None	27
H-PLLA/H- PLLA, H-PLLA/ L-PLLA, L-PLLA/ L-PLLA	C/S	None	50/50	230	4000-10000	None	28
PLA/PP	S/S	None	50/50	240	2100-3500	3.3	29

Structural, physical, and mechanical properties for yarn form of Bi-Component Yarn Spinning Technology (BCY)

As the yarn count (dtex) decreases in BCY yarns, the draw ratio, crystallinity rate and tensile strength values increase [7]. Internal viscosity values (Pa.S) in BCY yarns vary depending on the type of polymer used [6,7]. In PP/PA 6 structured C/S BCY yarns, the internal viscosity value is generally used between 10 Pa.S and 900 Pa.S [6]. In PPS/PET BCY yarns, the internal viscosity value is generally used at 2000 Pa.S [7]. PP/CB+PP structured with C/S BCY had a maximum tensile strength and maximum elongation at break at 80/20 ratio for BCY yarns. While the lowest shrinkage value was 80/20 for PP/CB+PP structured with C/S BCY yarns, the highest shrinkage value was 100/0 for PP/CB+PP structured with C/S BCY yarns [8]. PET had a higher modulus of elasticity compared to PA 6 BCY yarns. The surface areas for PET and PA 6 BCY yarns were I/S, R, and S/S, respectively, from highest to lowest for their nozzle profiles. The fixing temperature was 130 °C. For PET/PA 6 structured with S/S BCY yarns, adhesion was maximum in the 45/55 ratio between 90 °C and 115 °C in the S/S nozzle profile.

The length/diameter (L/D) ratio of the extruders was 24/1 [9]. For PA 6/AlPi structured with C/S BCY yarns, 10rpm drawing roller speeds in the PA 6 (C) part, and 5rpm in the AlPi (S), 50 bar dosing pressure, 20m³/min air flow rate, and 15 °C solidification temperature was used. The fixing temperature was 130 °C. The length/diameter (L/D) ratio of extruders was 30/1. PA 6/PA 6 structured with C/S BCY yarns had the highest elasticity modulus and tensile strength values. Maximum percent elongation at break values (217%) was also extremely high [10]. 70/30 ratio was the

most comfortable for PA 6/PET structured with C/S BCY yarns. Moreover, water-soluble PET/PA 6 structured with C/S BCY yarns dyed at 110 °C and 40 minutes had the highest washing fastness, and pilling resistance [11]. For PET, and CoPET structured with S/S BCY yarns, the mass flow rate was 38.8g/min, the solidification speed was 0.45m/s, and the fixing temperature was in the range of 125 °C to 155 °C [18]. For PET/PE, and PE/PET structured with C/S BCY yarns, as the drawing speed and drawing ratio increased, the elasticity modulus and tensile strength values increased, but the maximum percent elongation at break, and fiber and yarn diameter values decreased. In the production of all with C/S BCY yarns, the internal viscosity (η) value was 0.62dl/g.

PET/PE structured with C/S BCY yarns had higher tensile strength, and higher maximum percent elongation at break values compared to PE/PET structured with C/S BCY yarns. The optimum drawing speed for high tensile strength and maximum percent elongation at break values was a drawing speed of 4000m/min. For tensile strength values, from highest to lowest, PET/PE structured with C/S (100/0), PET/PE structured with C/S (50/50), PE/PET structured with C/S (50/50), and PE/PET structured with C/S (100/0) were observed, respectively. For maximum percent elongation at break values, from highest to lowest, PE/PET structured with C/S (100/0), PE/PET structured C/S (50/50), PET/PE structured with C/S (50/50), and PET/PE structured with C/S (100/0) were observed, respectively. For % CV values, it was determined that PET/PE structured with C/S BCY yarns had higher % CV values compared to PE/PET structured with C/S BCY yarns. The reason for this situation is the radial pressure difference caused

by the different Poisson ratio values of PET and PE polymers [12]. Since the drawing ratio in PTT/PTT structured with S/S BCY yarns affected the shrinkage values of PET/PET structured with S/S BCY yarns more than PET, it enabled the formation of a self-crimped yarn structure [13,15,21].

The reason for this situation is that the self-crimped fold curvature increased as the ratio of the length of the long axis to the short axis of the nozzle profile (cross-section) increased. As the H-PET ratio increased and the L-PET (PTT) ratio decreased, shrinkage values increased. The optimum value for crimp stability, crimp modulus, and crimp ratio was observed at the H-PET/L-PET (PTT) structured with S/S (50/50) BCY yarns [13]. As the drawing ratio increased in PET and CoPET structured with S/S BCY yarns, crimp contraction, and recrystallization behaviors increased, but the maximum percent elongation at break values decreased. Fixing temperatures between 125 °C and 140 °C did not affect the dimensional stability of BCY yarns but did affect the crimp behavior. The reasons for this situation were that as the fixing temperature increased, the crystalline structure became more stable in terms of dimension stability and reduced the relaxation of the amorphous region orientation. Thus, as the fixing temperature increased, crimp contraction decreased. The maximum crimp shrinkage was observed as 42% at a drafting ratio of 3.1, a fixing temperature of 125 °C, and a drawing roller temperature of 80 °C [18].

The drawing ratio between 2.7 and 2.8 had no effect on the elasticity modulus and tensile strength values, but it had an effect on the crimp contraction behavior in PET/CoPET structured with S/S BCY yarns [19]. When the drawing ratio in PBT/TPU structured with S/S BCY yarns gradually increased from 1.67 to 3.67 so their elasticity modulus and tensile strength values increased, but the maximum percent elongation at break values decreased. The drawing ratio of 2.33 was optimum for their mechanical properties [20]. L-PBT/PLA and H-PBT/PLA structured with C/S BCY yarns were produced by drawing at different internal viscosities and drawing speeds. For the S-PLA part, crystallization reached its maximum level at a drawing speed of 1000m/s thanks to the high effect of internal viscosity, while for the N-PLA part, crystallization reached its maximum level at a drawing speed of 4000m/s and its above. For the H-PBT part, crystallization reached its maximum level at a drawing speed of 1000m/s thanks to the high effect of internal viscosity, while for the L-PBT part, crystallization reached its maximum level at a drawing speed of 2000m/s.

These situations proved that PBT had high crystallization even if the molecular orientation was not fully achieved. Moreover, there was evidence of higher crystallization and easy processability of PBT compared to PLA. For the S-PLA part, even at a drawing speed of 5000 m/s, the glass transition temperature (T_g) was observed at 60 °C, while the cold crystallization temperature (T_c) was determined at 80 °C. For the N-PLA part, the cold crystallization temperature (T_c) was determined at 80 °C at a drawing speed of 4000m/s. The general melting temperature (T_m) for the PLA part was observed in the temperature range of 160 °C to 170 °C. The general melting temperature (T_m) for the PBT part was determined in the temperature range of 222 °C to 228 °C. As the drawing speed

increased, the melting temperature (T_m) increased. Maximum elasticity modulus and tensile strength values were observed for the L-PBT/S-PLA part at a drawing speed of 4000m/s. In addition, maximum percent elongation at break as optimum (46%) and shrinkage values as optimum (6%) were observed. Moreover, as the temperature increased, the elastic modulus values decreased. Moreover, as the drawing speed increased, the elastic modulus values increased [25].

PHBV/PLA structured with C/S BCY yarns were produced with different drawing speeds and drawing ratios. As the PLA portion increased, tensile strength increased. Maximum elasticity modulus and tensile strength values were observed for PHBV/PLA structured with C/S BCY yarns (36/64) at a drawing ratio of 3.5. Moreover, the optimum maximum percent elongation at break (28%) was observed [26]. POM, POM/POM+PLA structured with C/S BCY yarns were produced at different drawing ratios. In POM/POM structured BCY yarns, the cross section was maximum and had a round profile. Moreover, as the amount of PLA increased in POM/POM+PLA structured with C/S BCY yarns, the cross-sectional size decreased and it had a round profile. Tensile strength, and thermal decomposition temperature were maximum in POM/POM structured with C/S BCY yarns at 392 °C. In POM/POM+PLA structured with C/S BCY yarns, as the PLA ratio increased, tensile strength, and thermal decomposition temperature decreased. Maximum percent elongation at break values increased. Moreover, while POM/POM structured with C/S BCY yarns had maximum dimensional stability, and their dimensional stabilities decreased as the PLA ratio increased in POM/POM+PLA structured with C/S BCY yarns [27].

H-PLLA/L-PLLA structured with C/S BCY yarns were produced at different drawing speeds. As the drawing speed increased in H-PLLA/L-PLLA structured with C/S BCY yarns, the elasticity modulus, and tensile strength values increased, while the maximum percent elongation at break values decreased. Moreover, the amount of crystallization, from highest to lowest, was H-PLLA, H-PLLA/L-PLLA, and L-PLLA, respectively. For H-PLLA, the crystallization amount increased significantly between 2000m/s and 3000m/s drawing speeds, and reached saturation at drawing speed of 3000m/s. While the amount of crystallization for L-PLLA started at a drawing speed of 4000m/s, it reached its maximum level at a drawing speed of 6000m/s [28]. PLA/PP structured with S/S BCY yarns were produced at different drawing speeds. As the drawing speed (except 2100m/s drawing speed) increased, while the elastic modulus, and tensile strength values increased, the maximum percent elongation at break values decreased. The optimum mechanical properties were observed at a drawing speed of 2100m/s and a draw ratio of 3.3 for PLA/PP structured with S/S BCY yarns. A glass transition temperature (T_g) of 61 °C was determined for the PLA part. In addition, while the cold crystallization temperature (T_c) for PLA was 109 °C, the cold crystallization temperature (T_c) for PP was 116 °C. Moreover, the melting temperature (T_m) for PLA was observed at 177 °C, while the melting temperature (T_m) for PP was observed at 165 °C. The fixing temperature is recommended as 142 °C due to these thermal behavior situations [29].

Structural, physical, and mechanical properties for fabric forms of Bi-Component Yarn Spinning Technology (BCY)

Woven fabric form: POY PTT/PET structured C/S BCY yarns were used as weft yarns, and CO yarns were used as warp yarns, weaving in 5/2 satin woven fabric construction at various densities (weft yarn 40 weft/cm and 50 weft/cm and warp yarn 23 warp/cm) woven fabrics were produced. As the PTT ratio increased to low densities (weft density 40 weft/cm), plastic deformation, and elasticity ratio decreased, but elastic recovery behavior increased. At high density (weft density 50 weft/cm), as the PTT ratio increased, plastic deformation and elasticity ratio, and elastic recovery behavior differed. Plastic deformation, and elasticity ratio were maximum, but elastic recovery behavior was minimum for PTT ratio 50. In other words, it had maximum crimp behavior. Moreover, as the internal viscosity of PTT increased, plastic deformation, and elasticity ratio increased, but elastic recovery behavior decreased [21]. PTT/PET, PTT, and PET structured C/S BCY yarns were used as weft yarns, and DTY PET warp yarns were used as warp yarns to produce plain woven fabrics (warp and weft density ranging from 16 to 20), twill (warp and weft density ranging from 22 to 25.5). Various woven fabrics were also produced in woven fabric constructions such as satin (warp and weft density ranging from 26.5 to 31). All woven fabric samples had a fixing temperature of 100 °C, and a fixing time of 20 minutes. Twill and satin woven fabrics had higher elasticity compared to plain woven fabrics. The PTT/PET ratio should be 66.7, and the weft density should be low for optimum and maximum elasticity values of woven fabrics. Moreover, as the twist amount of PTT/PET S/S structured BCY yarns increased, the elasticity of woven fabrics decreased [22]. ZnO/(POY) PP structured S/S BCY yarns were produced with different ZnO ratios. Afterward, woven and knitted fabrics were produced. As the ZnO ratio increased, the surface irregularity, and surface area of woven, and knitted fabrics increased. The reasons for this situation were that as the amount of ZnO decreased, less agglomeration was observed. A slower flow time was present at 30wt% ZnO. Thus, the surface was smoother, and the shooting process can be applied more easily. Moreover, as the ZnO ratio increased, the melting temperature decreased with a temperature range of 1 °C to 2 °C. At 20% ZnO by weight, the thermal degradation temperature was maximum (450 °C). Moreover, the highest tensile strength and UV resistance values, and optimum crystallinity ratio were determined at 20wt% ZnO [30].

Knitted fabric form: In an experimental study on the dyeing of knitted fabrics knitted from H-PET/L-PET (PTT) structured S/S BCY yarns included 1:10 liquor ratio, 1g/l detergent, 2g/l Na₂CO₃ were subjected to pre-treatment process at 70 °C for 10 minutes before dyeing. The purpose of this pre-treatment process was to ensure high dye penetration and homogeneous dyeing. The pH of the dyeing medium was adjusted to 7 with the chemicals Na₂HPO₄, and C₆H₈O₇, in the dyeing process. Dyeing temperature from 100 °C to 130 °C and dyeing time from 25 minutes to 75 minutes were available. All dyed samples were subjected to the soaping process in order to increase washing fastness, that was, to remove residual dyestuffs remaining on the knitted fabric surfaces. The soaping

process was carried out in an environment with 36 °Be water hardness, 2g/l NaHS, and 2g/l NaOH solution in a bath (flot) ratio of 1:20, at 50 °C for 10 minutes. 1.2% dyestuff, and 1g/l dispersant chemicals were added to the dyeing bath within the first 15 minutes. Phthalamide-based non-toxic carrier chemical was also included in the dyeing bath at a rate of 6% to 12% to ensure adhesion to the fibers of BCY yarns. As the carrier ratio increased, K/S values increased. Moreover, the carrier chemical ratio provided for its optimum at 6%, and maximum at 12% for their dyeing efficiencies. The optimum dyeing time was 50 minutes, and the maximum dyeing time was 75 minutes. The optimum, and maximum dyeing temperatures were observed as 120 °C [14]. The maximum percentage breaking elongation values for PET, PTT and PET/PTT structured S/S BCY yarns did not exceed 30%. Elastic modulus, and tensile strength values, from highest to lowest, were PET, PET/PTT, and PTT, respectively. The fiber breaks occurred later in the PTT part than in the PET part. PET, PET/PTT, and PTT were the distortion behavior of the loop shape, respectively [15]. Knitted fabrics were produced from PTT/PET structured SS BCY yarns (60/40), and PU/PA 6 structured SS BCY yarns. In the production of PET, PTT, PTT/PET, and PET/PTT with C/S, and S/S structured BCY yarns, BCY yarn productions can be used in the form of POY, FDY or DTY yarns [16,17,21]. In FDY, the interface line was completely smooth, but in DTY, there was a crescent-shaped interface line. These were due to higher temperature, and smaller internal viscosity differences. Moreover, DTY had lower mechanical properties compared to FDY [17]. PET/PTT knitted fabrics had higher elastic recovery behavior both before and after the fixing process compared to PU/PA 6 knitted fabrics [16]. The reason for this was that the macromolecule chain of PTT was zig-zag, that was, it had a spring-like behavior [16,17]. The recrystallization of PET was slower compared to PTT due to its more rigid molecular structure. Additionally, while recrystallization was present in FDY, recrystallization was not present in DTY. Moreover, FDY had more physical locking compared to DTY [17]. PET/PTT knitted fabrics had higher elastic recovery behavior, and 5 times higher post-washing dimensional stability compared to PU/PA 6 knitted fabrics. In addition, PET/PTT knitted fabrics had more irregular loops, higher roughness, higher thermal conductivity, higher wrinkle resistance, and lower water vapor permeability compared to PU/PA 6 knitted fabrics. Moreover, both PET/PTT, and PU/PA 6 knitted fabrics can be easily used in sportswear applications. The reason why PET/PTT knitted fabrics had higher wrinkle resistance compared to PU/PA 6 knitted fabrics was that they had a higher elastic recovery angle [16]. FDY PTT/PET, and DTY PTT structured with C/S BCY yarns were used as weft yarns and DTY PET, and DTY PA 6 with C/S BCY yarns were used as warp yarns in RL rib knitted fabric construction for their densities. Their densities were 11 weft/cm, and the 11 warp/cm for warp yarn. Knitted fabrics were produced with those densities. Surface unevenness, and surface roughness were detected only in knitted fabrics knitted from BCY yarns with FDY PTT/PET structured. A solution to this situation can be found by adjusting the yarn tension, and yarn feeding speed. When wet heat process was applied, it revealed surface irregularity, and surface roughness in knitted fabrics more clearly. The reasons for this situation were not related

to the knitted fabric construction, or densities, but it depended only on the yarn structure used. Especially, PTT/PET structured with C/S BCY yarns caused this situation. Moreover, PTT/PET structured with C/S BCY yarns had large changes in crimp behavior before and after thermal processing. After the heat-treatment, the crimp behavior decreased significantly, the loop size decreased, and it turned into a more twisted, and closed yarn structure. In order to knitted fabrics with PTT/PET structured with C/S BCY yarns to be knitted with minimum surface irregularity, and minimum surface roughness, that was, on an extremely smooth surface for producing the PTT/PET structured with C/S BCY yarns must first be twisted. The fixing process should be applied by applying in the range of 70 °C to 100 °C temperatures and process time in the range of 20 minutes to 60 minutes [23]. Pre-treatment process with alkaline (NaOH) chemical was generally applied to improve the surface morphology, and mechanical properties of PET, CoPET, PLA and PP structured with C/S, or I/S BCY yarns [24,29]. Various knitted fabrics were produced from PET/CoPET structured with I/S BCY yarns, both warp and weft knitted fabrics, both without alkali pre-treatment process and by applying alkali pre-treatment process. Alkali pre-treatment process, NaOH chemical at 1% concentration was applied at 95 °C for 50 minutes. A decrease in the fiber diameters of PET and CoPET structured BCY yarns was detected in all knitted fabrics to which the alkali pre-treatment process was applied. Before the alkali pre-treatment process was applied, weft knitted fabrics had larger loop size, and porosity compared to warp knitted fabrics. The yarn tension of weft knitted fabrics was lower than that of warp knitted fabrics. Pores were considered as fluid transport channels. After the alkali pre-treatment process, the fibers started to separate and this fiber separation behavior was clearer and more obvious in warp knitted fabrics compared to weft knitted fabrics. Alkali pre-treatment process application reduced the shrinkage behavior in knitted fabrics by approximately 40% for both warp and weft knitted fabrics. The reasons for this situation were that it caused elastic relaxation in knitted fabrics immersed in water, elastic relaxation improves with the applied process temperature and time, and the fibers of PET/CoPET structured with I/S BCY yarns dissolve more easily in solution. Porosity and surface area values were higher after applying the alkali pre-treatment process compared to samples without the alkali pre-treatment process. Moreover, it was higher in weft knitted fabrics compared to warp knitted fabrics. The absorbency level was extremely high in both warp and weft knitted fabrics. The reasons for this situation were the decreasing in fiber diameters, and the increasing in porosity and surface area. As the fiber diameter decreased, the absorbency capacity, and absorbency speed increased. Thus, higher water absorption capacity, and water absorption rate were observed. This was the effect of capillarity in BCY yarns. Moreover, warp knitted fabrics had higher water absorption behavior than weft knitted fabrics [24].

Conclusion

According to the results that the polymers such as PLA, PHBV, PA 6, PE, PP, PET, PTT, and PBT are widely used in BCY yarn production.

They can be used either 100% pure or in their mixtures with various percentages with C/S, I/S and S/S nozzle profiles. Especially, PTT/PET, and PBT/PET BCY yarns are widely used in thermal comfort behavior in textile areas for their water absorption and fast drying properties. Moreover, this thermal comfort behavior depends on the polymer type used, glass transition, crystallization and melting temperatures, percentage, viscosity, molecular weight, orientation, crystallinity, polydispersity, biological, chemical, mechanical and thermal behavior, spinneret profile, spinneret diameter, extruder temperature and extruder length/diameter ratio (L/D), length and speed of the solidification zone, the temperature of the drafting rollers, their speed and drafting rate. Although it varies depending on the polymer type, in the production of BCY yarns, generally as the temperature increases, the viscosity decreases, the fiber diameter decreases and it becomes easier to process. Before the production of PET and its derivative polymers, it is recommended to apply the alkaline (NaOH) pretreatment process in order to reduce the fiber diameter, facilitate processing, maintain dimensional stability, reduce surface smoothness, facilitate dyeability, and improve mechanical and thermal properties. PET/PET, PA 6/PA 6, PTT/PET, PBT/PET, PET/CoPET, PET/PE, PET/PP, PET/PA 6 polymers with 40/60 and 50/50 ratios, and C/S nozzle profiles can be widely used in BCY yarn production. PP/PA 6 polymer can be also used in BCY yarn production, too.

Generally, the process parameters required for BCY yarn production of PA 6, PET, CoPET, PTT, and PBT polymers are extruder ratio 1/24, internal viscosity (η) range 0.62dl/g to 1.22dl/g, glass transition temperature (T_g) range 65 °C to 80 °C, crystallization temperature (T_c) 130 °C to 180 °C, melting temperature (T_m) 290 °C to 305 °C range, solidification zone from 1.5m to 3m, length, and draft ratio range from 1.5 to 3.5. The fixing temperature is recommended to be between 125 °C and 140 °C. Moreover, glass transition (T_g), crystallization (T_c), and melting (T_m) temperature values are lower in PE, PP, PLA, and PHBV polymers. PET/PE, PET/PTT, and PET/PA 6 polymers are widely used in BCY yarns thanks to their similar rheological behaviors. Recently, PLA-containing BCY yarns have started to be used, especially thanks to their biological advantages. BCY yarns containing PBT have started to be used thanks to their high maximum elongation at break and easy processability. Polymer with lower melting temperature (T_m) is generally used in the center (C) part, while polymer with higher melting temperature (T_m) is used in the shell (S) part in BCY yarns with C/S nozzle profile.

References

1. Naeimirad M, Zadhoush A, Kotek R, Neisiany RE, Khorasani SN, et al. (2018) Recent advances in core/shell bicomponent fibers and nanofibers: A review. *Journal of Applied Polymer Science* 135(21): 46265.
2. Ramos JI (2007) Thermal analysis of bicomponent fibres. *Applied Thermal Engineering* 27(2-3): 586-598.
3. Leal AA, Neururer OA, Bian A, Gooneie A, Rupper P, et al. (2018) Interfacial interactions in bicomponent polymer fibers. *Polymer* 142: 375-386.
4. Hufenus R (2011) Fiber development by multicomponent melt-spinning. 11th World Textile Conference Autex, pp. 518-522.

5. Anantharamaiah N, Verenich S, Pourdeyhimi B (2008) Durable nonwoven fabrics via fracturing bicomponent islands-in-the-sea filaments. *Journal of Engineered Fibers and Fabrics* 3(3): 1-9.
6. Ayad A, Cayla A, Rault F, Gonthier A, LeBlanc T, et al. (2016) Influence of rheological and thermal properties of polymers during melt spinning on bicomponent fiber morphology. *Journal of Materials Engineering and Performance* 25(1): 3296-3302.
7. Houis S, Schmid M, Lübbers J (2007) New functional bicomponent fibers with core/sheath-configuration using poly (phenylene sulfide) and poly (ethylene terephthalate). *Journal of Applied Polymer Science* 106(3): 1757-1767.
8. Srisawat N, Jingjit P (2021) Properties of polypropylene conductive fiber from sheath-core bicomponent fiber. *RMUTP Research Journal* 15(1): 39-50.
9. Choi YB, Kim SY (1999) Effects of interface on the dynamic mechanical properties of PET/nylon 6 bicomponent fibers. *Journal of Applied Polymer Science* 74(8): 2083-2093.
10. Horrocks AR, Sitpalan A, Kandola BK (2019) Design and characterisation of bicomponent polyamide 6 fibres with specific locations of each flame retardant component for enhanced flame retardancy. *Polymer Testing* 79: 106041.
11. Kim HA, Kim SJ (2018) Hand and mechanical properties of nylon high hollow fabrics in relation to the elution characteristics. *The Journal of The Textile Institute* 109(2): 160-171.
12. Kim HS, Cho HH, Ito H, Kikutani T, Okui N (1997) Tensile behavior of poly (ethylene terephthalate)/polyethylene bicomponent fibers prepared by high-speed melt spinning. *Seikei-Kakou* 9(6): 449-461.
13. Xiang G, Hua H, Gao Q, Guo J, Zhang X, et al. (2022) Fabrication and properties of self-crimp side-by-side bicomponent filaments composed of polyethylene terephthalates with different intrinsic viscosity. *Fibres & Textiles in Eastern Europe* 30(2): 68-74.
14. Chen SH, Wang SY (2010) Tensile and fracture behaviors of PET/PTT side-side bicomponent filament. *International Journal of Polymer Analysis and Characterization* 15(3): 147-154.
15. Yang Z, Wang F, Guan F, Luo J, Qiu Y, Zhang C (2022) Interfacial structure of polytrimethylene terephthalate/polyethylene terephthalate bicomponent filament. *Fibres & Textiles in Eastern Europe* 30(151): 71-76.
16. Oh TH (2006) Melt spinning and drawing process of PET side-by-side bicomponent fibers. *Journal of Applied Polymer Science* 101(3): 1362-1367.
17. Abbasi M, Kotek R (2019) Effects of drawing process on crimp formation-ability of side-by-side bicomponent filament yarns produced from recycled, fiber-grade and bottle-grade PET. *The Journal of the Textile Institute* 110(10): 1439-1444.
18. Khadse N, Ruckdashel R, Macajoux S, Sun H, Park JH (2022) Temperature responsive PBT bicomponent fibers for dynamic thermal insulation. *Polymers* 14(14): 2757.
19. Li Y, Joo CW (2013) Effect of filament size on the water transport of weft and warp knitted fabrics. *Fibers and Polymers* 14: 2169-2175.
20. Hufenus R, Reifler FA, Maniura Weber K, Spierings A, Zinn M (2012) Biodegradable bicomponent fibers from renewable sources: melt-spinning of poly (lactic acid) and poly [(3-hydroxybutyrate)-co-(3-hydroxyvalerate)]. *Macromolecular Materials and Engineering* 297(1): 75-84.
21. Suntamit B, Vanichvattanadecha C, Intasanta V (2021) Effect of ZnO Nanoparticles on Hydrophobicity, Biological and Mechanical Properties of Side-by-Side Bicomponent PP Fibers. *Fibers and Polymers* 22(1): 1607-1622.
22. Kawahara Y, Takarada W, Yamamoto M, Kondo Y, Tashiro K, et al. (2020) Fiber structure, tensile behavior and antibacterial activity of polylactide/poly (butylene terephthalate) bicomponent fibers produced by high-speed melt-spinning. *Journal of Macromolecular Science, Part B* 59(7): 440-456.
23. Roungpaisan N, Takarada W, Kikutani T (2019) High-speed melt spinning of sheath/core bicomponent fibers of poly (L-lactide)s with different molecular weight. *AIP Conference Proceedings* 2065(1): 1-6.
24. Souissi M, Khiari R, Zaag M, Meksi N, Dhaouadi H (2021) Effect of the morphology of polyesters filaments on their physical properties and dyeing performances. *Polymer Bulletin* 78: 2685-2707.
25. Zhao L, Hu H, Shen J, Rong H (2013) The use of a polytrimethylene terephthalate/polyester bi-component filament for the development of seamless garments. *Textile Research Journal* 83(12): 1283-1296.
26. Liu X, Jiao S, Wang FM (2013) Configuring the spinning technology of PTT/PET bicomponent filaments according to fabric elasticity. *Textile Research Journal* 83(5): 487-498.
27. Luo J, Wang F-M, Li D, Xu B (2011) Elasticity of woven fabrics made of polytri-methylene terephthalate/polyethylene terephthalate bicomponent filaments. *Textile Research Journal* 81(8): 865-870.
28. Luo J, Wang F, Xu G, Chuah HH (2011) Effects of fiber crimp configurations on the face texture of knitted fabrics made with PTT/PET bicomponent fibers. *Journal of Engineered Fibers and Fabrics* 6(1): 19-24.
29. Boonlertsamut J, Thumsorn S, Umemura T, Hamada H, Sakuma A (2019) Spinnability and characteristics of polyoxymethylene-based core-sheath bicomponent fibers. *Journal of Engineered Fibers and Fabrics* 14(1): 1-7.
30. Tran NHA, Hund R-D, Kemnitzer J, Schwarzer J, Cherif C (2019) An eco-friendly post-drawing process for splitting bicomponent filaments. *Materials Letters* 237(1): 258-261.