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Melt-spun poly(ethylene terephthalate-co-1,4-cyclohexanedimethylene terephthalate) (PETG) copolyester fibers: Synergistic effect of chemical and crystal structure regulation

Zhihao Zhang¹ | Zhiyuan Yao¹ | Yujing He² | Senlong Yu¹ | Meijia Chen¹ | Zhenjiang Shi¹ | Jiaxu He¹ | Hengxue Xiang¹ | Meifang Zhu¹
¹State Key Laboratory for Modification of Chemical Fibers and Polymer Materials, College of Materials Science and Engineering, Donghua University, Shanghai, China

²High-Tech Organic Fibers Key Laboratory of Sichuan Province, Chengdu, China

Correspondence

Senlong Yu and Hengxue Xiang, State Key Laboratory for Modification of Chemical Fibers and Polymer Materials, College of Materials Science and Engineering, Donghua University, Shanghai, China.
Email: ysl@dhu.edu.cn and hengxuexiang@dhu.edu.cn

Funding information

the National Key R&D Program of China (2021YFB3700300); the Shandong Province Key Research and Development Project (2023CXGC010611); the Open Project Program of High-Tech Organic Fibers Key Laboratory of Sichuan Province (PLN2023-16); the Fundamental Research Funds for the Central Universities (CUSF-DH-T-2023005)

Abstract

In this work, a series of 1,4-cyclohexanedimethanol (CHDM)-based copolyester fibers are prepared by chemical structure design and crystal structure regulation. The chemical structures of poly(ethylene terephthalate-co-1,4-cyclohexanedimethylene terephthalate, (PETG)) copolyesters are first confirmed by ¹H- and ¹³C-nuclear magnetic resonance which indicates that all copolyesters are random copolyesters. Then, the crystallization and melting behavior, thermal stability, and mechanical properties of copolyesters are significantly affected by the CHDM content and CHDM cis-trans isomerism ratio, showing that trans-CHDM can effectively improve the comprehensive performance of PETG copolyesters. Besides, the influence of the CHDM monomer (amount and cis-trans isomerism ratio) and melt-spinning drawing process on the crystal structure and mechanical properties (tensile strength, elongation) is also investigated by wide-angle X-ray diffraction, small-angle X-ray scattering, and tensile testing. Especially, the resultant PETG30-trans80 copolyester fibers exhibit good mechanical properties, and the tensile strength and elongation are 113.9 MPa and 136.5%, respectively. Therefore, our work provides a promising strategy for the fabrication of copolyester fiber.

Highlights

- Bio-based PETG copolyester was obtained.
- Synergistic effects of a chemical structure and drawing process of PETG fiber were discussed.
- The influence of drawing process on crystallization, and orientation of fiber properties was studied.

KEYWORDS

1,4-cyclohexanedimethanol, copolyester, crystal structure, mechanical properties, melt-spinning

1 | INTRODUCTION

Poly(ethylene terephthalate) (PET) fiber has been widely applied in various fields, such as packaging,^{1–4} electronics,^{5–7} healthcare,^{8–10} and other fields^{11–13} due to its high tensile strength, chemical resistance, etc. However, the further application and development of PET are still limited by its shortcomings, such as slow crystallization speed, poor toughness, and long cycle time.¹⁴ Therefore, the functional modification of PET fiber has become an important issue.

Currently, the modification of PET fiber can be mainly divided into two categories physical blending^{15–19} and chemical copolymerization.^{20–23} Among these, physical blending is the more common approach to fabricating functional PET fiber by introducing different agents into the PET polymer matrix, including bio-based materials, elastomers, etc. Unfortunately, physical blend modification still has some drawbacks, such as phase separation and low compatibility, which negatively affect the performance of PET fibers.

Recently, it has been reported that the copolymerization of terephthalic acid, ethylene glycol (EG), and other functional monomers might be the effective solution to the above problems. Various kinds of functional monomers have been incorporated into PET molecular chains, including diamines,²⁴ binary acids,²⁵ and diols.²⁶ Among them, 1,4-cyclohexanedimethanol (CHDM) dibasic EG functional monomer has been receiving more and more attention due to its good transparency, corrosion resistance, and high thermal stability. Wang et al. synthesized high molecular weight copolymers using terephthalic acid, 1,4-butanediol, 1,4-cyclohexanedimethanol, and polylactic acid oligomers. The effect of the rigid hexacyclic ring of CHDM on the synthesis, mechanical properties, thermal stability, and degradation behavior of the copolymers was investigated by adjusting the molar ratio of the two diols.²⁷ Fei et al. synthesized high molecular weight copolymers using 2,5-furandicarboxylic acid, 1,4-cyclohexanedimethanol, and 1,4-butanediol. It was shown that moderate amounts of CHDM units could improve the melting temperature and crystallinity of furan-based polyesters. In recent years, scholars have focused on the relationship between the stereo configuration of CHDM and the structural properties of copolyester materials and a series of copolyester materials with very different structural properties have been prepared by simply changing the ratio of CHDM cis-trans isomers.²⁸ Wang et al. synthesized bio-based poly(1,4-cyclohexanedimethylene furandicarboxylate) (PCF) from FDCA and CHDM using different cis-CHDM/trans-CHDM ratios. The stereo-configuration of CHDM had a significant effect on its properties, and as the content of trans-CHDM increased in PCF, the T_g , T_c , and T_m as well as the rate of crystallization and enthalpy of melting

increased significantly.²⁹ From the published research results, it can be seen that CHDM monomer is increasingly emphasized and has been studied from different perspectives. However, most of the reported works of literature focus on plastic and film but seldom involve fiber material.

In this work, a series of novel poly(ethylene terephthalate-co-1,4-cyclohexanedimethylene terephthalate) (PETG) fibers were prepared by melt spinning. Firstly, PETG copolyesters were prepared by one-pot copolymerization of CHDM, EG, and terephthalic acid according to the chemical structure design. Secondly, the effects of CHDM content and CHDM cis-trans ratio on crystal and thermal properties were analyzed. Finally, the crystal structure regulation of PETG fibers under the influence of the post-drawing process was systematically investigated.

2 | EXPERIMENT

2.1 | Materials

Purified terephthalic acid (PTA) was purchased from Sinopec Yizheng Chemical Fiber Co, LTD. (Jiangsu). EG and ethyl acetate (EA) were purchased from Titan Technology Co, LTD. (Shanghai). CHDM was purchased from Aladdin Biochemical Technology Co, Ltd. (Shanghai). The catalyst was a self-made titanium catalyst with a Chinese invention patent (CN103087089A, CN103059284A).

2.2 | Purification of trans-CHDM isomers

Commercially available CHDM (trans-cis ratio 68:32) was dissolved in EA and stirred for several hours to gradually form crystals in suspension. The solid crystal product was collected by filtration and washed several times with EA. Then the high-purity trans-CHDM monomer was dried in a vacuum oven at 60°C to remove the residual EA.

2.3 | Synthesis of PETG copolyesters with different CHDM contents

The PETG copolyesters with different contents of PTA, EG, and CHDM were synthesized through the one-pot method, which was divided into two stages, esterification and polycondensation. The esterification reaction required a 2-hour hold at 245°C until the volume of condensate reached the theoretical amount. The polycondensation reaction required a vacuum of less than 0.2 mbar and was held at 275°C for 1 h. After the mechanical stirrer reached the setting power, the copolyesters were cut into pellets.

The resultant PETG copolyesters were marked as PETGXX, where XX denoted the molar percent of CHDM to the two diols.

2.4 | Synthesis of PETG copolyesters with different trans-CHDM contents

A series of PETG copolyesters with different CHDM cis-trans ratios (Figure S1) were also prepared by direct esterification melt polycondensation, denoted as PETG30-transxx, where the total CHDM molar content was uniformly 30% and transxx denoted the proportion of trans-CHDM to the total CHDM content.

2.5 | Preparation of PET and PETG30-trans80 fibers

Neat PET and PETG30-trans80 copolyesters were dried in the vacuum oven (JM-500ZDGX) before melt spinning (Jwell Chemical Fiber Machinery Co, LTD, Shanghai, China). The spinning temperatures were 245–270°C and the as-spun fibers were taken up at the speed of 1000 m/min. The temperatures of hot drawing and heat setting were 80°C and 100°C, and the total drawing ratio was 1.0–2.5.

2.6 | Characterizations

The chemical structures of PETG copolymers are investigated by ¹H and ¹³C-nuclear magnetic resonance (¹H- and ¹³C-NMR, Bruker 600 M ADCANCEIII, CF₃COOD as the solvent). Thermal behavior is measured by differential scanning calorimetry (DSC, DSC1, METTLER, Switzerland) at the temperature from 30°C to 300°C under N₂ with a heating/cooling rate of 10°C/min. The thermal stability is characterized by thermogravimetric analyses (TGA, Netzsch TG 209 F1, Germany) at the heating rate of 10°C/min under nitrogen from 30°C to 600°C.

The crystal structure is analyzed by wide-angle X-ray diffractometer (WAXD, Bruker D8 ADVANCE, Germany) and small-angle X-ray scattering (SAXS, 2θ = 0.1–5° SAXSess mc2, Austria). The interplanar spacing (*d*_{hkl}), crystal size (*D*_{hkl}), crystallinity (*X*_c), and long-period (*L*) are calculated using Equations (1–4).³⁰

$$d_{hkl} = \lambda / 2 \sin \theta_{hkl} \quad (1)$$

$$D_{hkl} = K\lambda / (\beta_{hkl} \times \cos \theta_{hkl}) \quad (2)$$

$$X_c = S_c / (S_c + S_a) \quad (3)$$

$$L = 2\Pi/q, \quad (4)$$

where λ is the wavelength of X-ray 0.154 nm, K is the Scherrer constant 0.89, β_{hkl} is the full width at half-maximum of diffraction peaks, S_c is the area of crystal peaks, S_a is the area of amorphous peaks, q is the scattering vector.

Two-dimensional WAXD (2D-WAXD, Bruker D8 Discover, Germany) is used to examine the orientation degrees of the crystal region, which can be calculated by Equation (5). Where H is the full width at half-maximum.

$$\Pi = (360^\circ - H) / 360^\circ \times 100\%. \quad (5)$$

The mechanical properties of the copolyesters and fibers are carried out using the electronic universal material testing machine (5969 Instron, USA). Here, the pre-tension is 0.05 ± 0.005 cN/dtex, the distance between the two fixtures is 500 mm, and the tensile speed is 500 mm min⁻¹. Each mechanical data is the average value after testing 20 groups of fibers to ensure accuracy and repeatability.

3 | RESULTS AND DISCUSSION

3.1 | Synthesis and chemical structure of PETG copolyesters

As shown in Figure 1A, PETG copolyesters are synthesized from PTA, EG, and CHDM via the melt polymerization method, and then the chemical structure is confirmed by ¹H- and ¹³C-NMR. PETG ¹H-NMR, (Figure 1B–E, δ , ppm): 8.2–8.3 (peak *t*, –CH of benzene ring), 4.9–5.0 (peak *a*, –CH₂– of EG), 4.25–4.55 (peak *b*_{cis} and *b*_{trans}, –CH₂–, linked to an ester group), 1.9–2.3 (peak *c*_{cis} and *c*_{trans}, –CH of CHDM) and 1.2–2.2 (peak *d*_{cis} and *d*_{trans}, –CH₂– of cyclohexane ring).³¹ The actual proportion of CHDM in the PETG copolyesters can be accurately calculated by comparing the area of the resonance absorption peak produced by hydrogen atoms on the benzene ring, –CH₂– on cyclohexane, and –CH₂– on EG at different chemical shifts. The area ratio results of *S*_b to *S*_a based on the peak area of hydrogen atoms on the benzene ring show that the actual content of CHDM is 0%, 2.5%, 14.5%, 31.0%, 51.0%, and 80.0%, as expected.

To further characterize the sequence structure of PETG copolyester, the ¹³C-NMR spectrum of PETG copolyesters and the related zone units are shown in Figure S2. The peak of *S*₁ indicated that the TPA is connected to two EG units. The peaks of *S*₃ and *S*₄ indicate that the TPA is connected to one EG unit and one CHDM

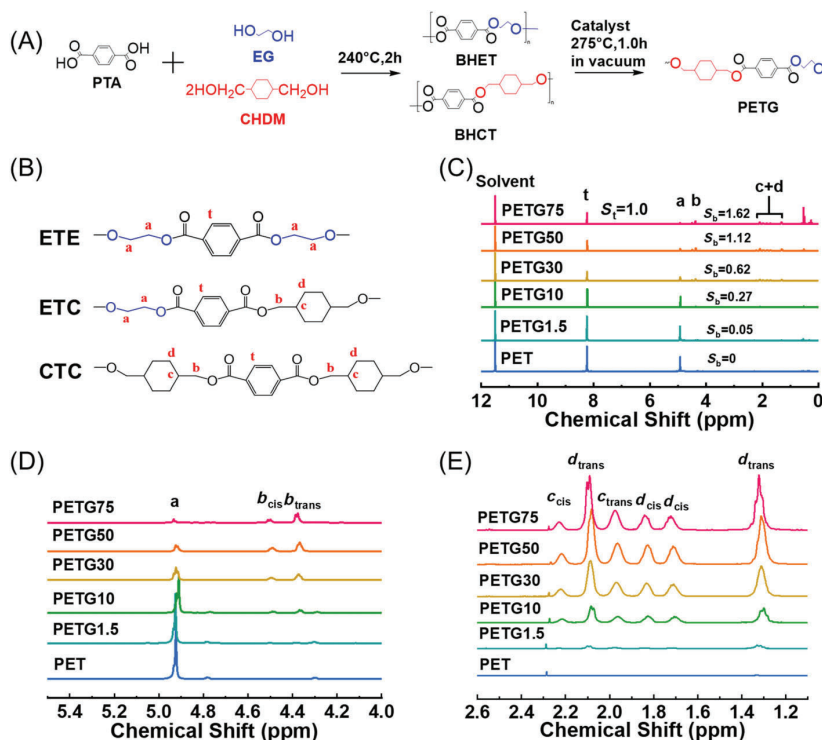


FIGURE 1 Synthesis and chemical structure of PETG copolymers.

(A) PETG copolymers polymerization route. (B) Chain structures of the PETG copolymers. (C) ^1H -NMR spectrum of PETG copolyester with different CHDM content in CF_3COOD . (D) Enlargement of chemical shifts between 4.0 and 5.5 ppm. (E) Enlargement of chemical shifts between 1.1 and 2.6 ppm.

unit, and the peak of S_2 indicates that the TPA is connected to two CHDM units. The areas of peaks S_1 , S_2 , S_3 , and S_4 are calculated by integration representing the contents of chain segments ETE, CTC, CTE, and ETC in PETG copolymers. The molar contents and average sequence lengths of ETE, CTC, and CTE + ETC can be calculated by Equations (6–10), and the degree of randomness, R , can be calculated by Equation (11).^{32,33} The results are shown in Table S1.

$$N_{\text{ETE}} = \text{Is}_1 / (\text{Is}_1 + \text{Is}_2 + \text{Is}_3 + \text{Is}_4) \quad (6)$$

$$N_{\text{ETC+CTE}} = (\text{Is}_3 + \text{Is}_4) / (\text{Is}_1 + \text{Is}_2 + \text{Is}_3 + \text{Is}_4) \quad (7)$$

$$N_{\text{CTC}} = \text{Is}_2 / (\text{Is}_1 + \text{Is}_2 + \text{Is}_3 + \text{Is}_4) \quad (8)$$

$$Y_{\text{ET}} = 1 + 2\text{Is}_1 / (\text{Is}_3 + \text{Is}_4) \quad (9)$$

$$Y_{\text{CT}} = 1 + 2\text{Is}_2 / (\text{Is}_3 + \text{Is}_4) \quad (10)$$

$$R = 1/Y_{\text{ET}} + 1/Y_{\text{CT}} \quad (11)$$

It can be found that the CTC chain segment content and sequence length increase, while the ETE chain segment content and sequence length decrease with the increasing CHDM content. Moreover, the degree of randomness of all

copolymers is close to 1, which indicates that all copolymers are random copolymers, which is in line with the experimental expectations. As shown in Table S3, the intrinsic viscosities of all PETG copolymers are consistent at around 0.7 dL/g.

The chemical structures of PETG copolymers with different trans-CHDM contents are further investigated by ^1H - and ^{13}C -NMR. From Figure 2C,D, it can be observed that the peak areas of b_{cis} , c_{cis} , and d_{cis} decrease continuously as the content of trans-CHDM increases from 68% to 98%. For PETG-trans98, the characteristic peaks of cis-CHDM are hardly observed. From the calculation of the integral area of b_{trans} peaks, it can be concluded that the actual proportion of trans-CHDM is almost the same as the theoretical feeding ratio, indicating that the high temperature and high-pressure environments do not result in cis-trans isomers transforming into each other in the whole polymerization process. As shown in Figure S3 and Table S2, with the increase of the trans-CHDM content from 68% to 98%, it is observed that the peak intensity of b_{cis} at 69.7 ppm gradually decreases, while the b_{trans} at 71.8 ppm gradually increases. Similarly, the cis-trans ratio of CHDM does not change the composition of the copolyester chain segments, the average sequence length, and the degree of randomness, as expected.

As shown in Figure 3A, except for PETG30, each copolyester sample has obvious diffraction peaks at (0 1 0), (1 1 1), (1 1 0), (1 0 0), and (1 0 1), and the detailed

FIGURE 2 Chemical structure of PETG copolyesters. (A) ^1H -NMR spectrum of PETG copolyesters with different trans-CHDM content in CF_3COOD . (B) enlargement of chemical shifts between 7.5 and 8.5 ppm. (C) enlargement of chemical shifts between 4.1 and 5.2 ppm. (D) enlargement of chemical shifts between 1.0 and 2.5 ppm.

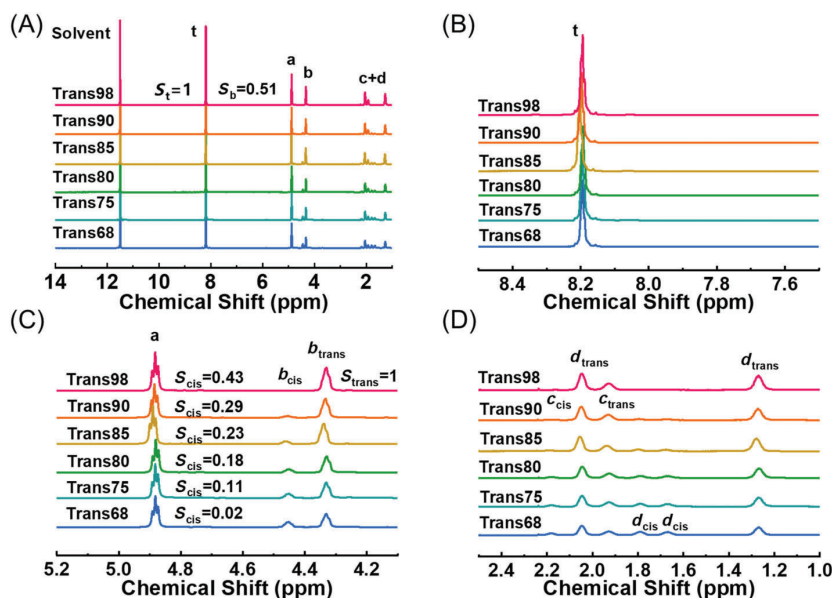


FIGURE 3 XRD curves of PETG copolyesters. (A) PETG copolyesters with different CHDM contents. (B) PETG copolyesters with different trans-CHDM contents.

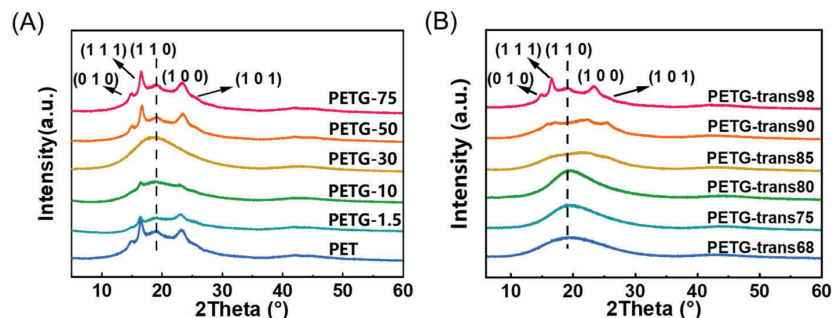


TABLE 1 XRD Crystal parameters of PETG copolyester with different CHDM content.

Samples	$d_{(010)}$ (nm)	$d_{(111)}$ (nm)	$d_{(100)}$ (nm)	$D_{(010)}$ (nm)	$D_{(111)}$ (nm)	$D_{(100)}$ (nm)	X_c (%)
PET	6.00	5.39	3.82	8.1	12.2	4.9	35.85
PETG-1.5	6.01	5.42	3.86	5.1	12.4	4.9	26.21
PETG-10	6.03	5.39	3.87	11.5	15.0	3.1	23.46
PETG-30	/	/	/	/	/	/	21.34
PETG-50	5.93	5.34	3.78	9.5	11.8	5.4	29.34
PETG-75	5.98	5.36	3.80	8.6	10.7	4.9	34.69

information of the crystal spacing and grain size are shown in Table 1. With the increasing of CHDM addition from 0% to 75%, at a CHDM content of 30%, the grain size of each crystal surface can not be tested and shows an amorphous morphology, and the reduction of grain size reduces the stress concentration and damage of large spherical crystals occurring during the fiber drawing process, which may help for improving the mechanical properties of PETG copolyesters. As shown in Figure 3B, the crystallinity of

PETG copolyesters increases from 22.0% to 40.1% (Table 2), and the crystal spacing of the (1 1 0) and (1 1 1) crystal planes decreases as the content of trans-CHDM increase, indicating that the arrangement of the grains gets more compact, which is beneficial to enhance the tensile strength and tensile modulus of the copolyesters. This might be explained by the fact that the regular chemical structure of trans-CHDM is conducive to the formation of crystal nuclei. Therefore, the crystallinity of copolyesters can be effectively

TABLE 2 Crystal parameters of PETG copolyesters with different trans-CHDM content.

Samples	$d_{(010)}$ (nm)	$d_{(111)}$ (nm)	$d_{(100)}$ (nm)	$D_{(010)}$ (nm)	$D_{(111)}$ (nm)	$D_{(100)}$ (nm)	X_c (%)
PETG-trans68	17.64	5.07	0.75	/	/	/	21.96
PETG-trans75	18.31	4.84	0.76	/	/	/	24.16
PETG-trans80	18.25	4.86	0.68	/	/	/	27.89
PETG-trans85	19.27	4.61	0.62	17.41	5.08	14.12	31.57
PETG-trans90	19.17	4.62	0.59	17.36	5.08	13.25	33.52
PETG-trans98	19.67	4.48	0.61	16.61	5.33	12.73	40.10

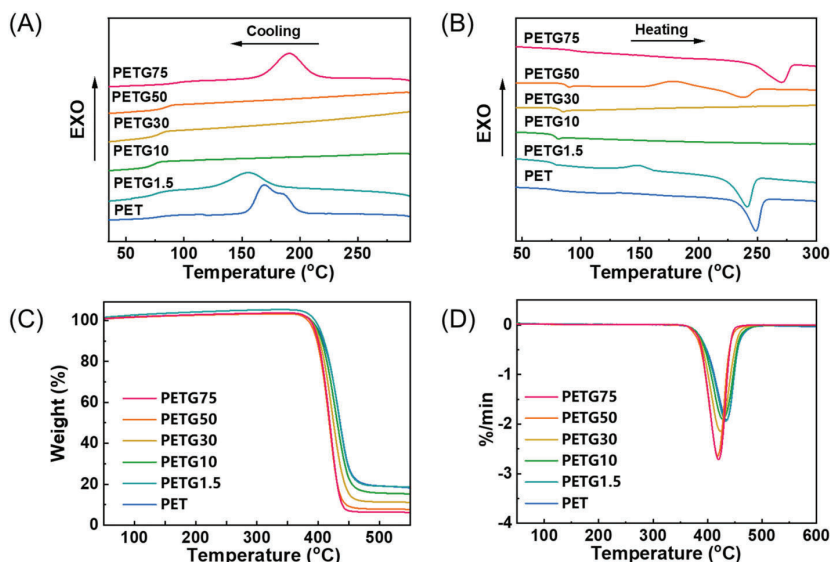


FIGURE 4 Thermal properties of PETG copolyesters. (A) DSC curves of cooling. (B) DSC curves of second heating. (C) TGA curves. (D) DTG curves.

controlled by changing the proportion of CHDM cis-trans isomers, which can further improve the thermal and mechanical properties of the copolyesters.

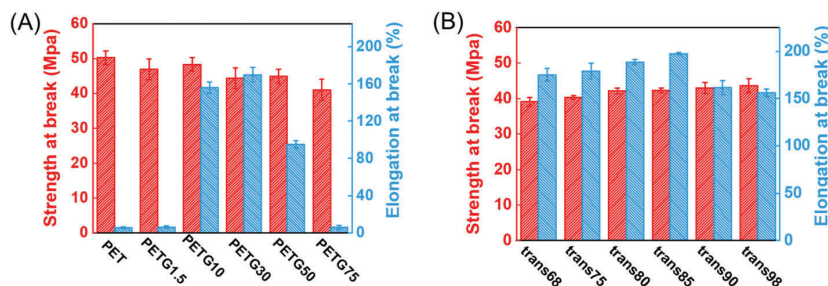
3.2 | Thermal behavior of copolyesters

The crystallization and melting behavior of copolyesters are investigated by DSC and TGA, and the corresponding data are shown in Figure 4A,B and Table S3. The glass transition temperatures (T_g) of copolyesters increase with CHDM content, suggesting that the movement of copolyester chain segments is limited by CHDM monomer, which might be caused by the steric hindrance effect of the cyclic structural unit in CHDM. When the CHDM content is lower than 50%, the crystallization ability of PETG copolyester decreases with the CHDM content due to the disruption of chain segment regularity caused by the CHDM monomer. For PETG10 and PETG30, there is no crystallization peak or melting peak appeared on the heating and cooling curves, which indicates that copolyesters are completely amorphous. When the content of CHDM is higher than 50%, the

crystallization abilities of the copolyester are recovered. For PETG50 and PETG75, the crystallization peak can be observed on the heating curve or cooling curve. It has been reported that the special six-membered ring structure of CHDM can improve the flexibility and movement of polymer chain segments, which is beneficial in enhancing the crystallization ability.³⁴ Especially, the crystallinity of PETG-75 is 34.7% (Table 1), which is similar to that of PET. Consequently, the chemical structure of PETG can be fine-tuned by adjusting the CHDM content. The amount of CHDM acts as a key regulator of the copolyester's crystallization and melting behaviors. Moreover, the six-membered ring in CHDM further disrupts crystallization, promotes amorphous formation, and consequently impacts the melting behavior.

The thermal stability of the copolyester is further confirmed by TGA. As shown in Figure 4C,D and Table S3, the initial decomposition temperature ($T_{5\%}$) and the temperature at maximum decomposition rate (T_{max}) slightly decrease with the increasing content of CHDM monomer. However, there is almost no significant weight loss until 390°C during the thermal decomposition, and the maximum thermal decomposition temperature occurred around 430°C, which

FIGURE 5 Mechanical properties of PET and PETG resins. (A) PET and PETG with different CHDM contents. (B) PETG30 with different trans-CHDM contents.



indicates that all these copolyesters exhibit good thermal stability and can completely meet the temperature requirement of melt spinning (245–270°C).

3.3 | Mechanical properties of PET and PETG copolyesters

As shown in Figure 5A, with the gradual increase of CHDM content, the strength of PETG resins gradually decreases. Nevertheless, the elongation at the break of PETG resins is closely related to the change in crystallinity. When the CHDM content is 30%, the crystallinity is the lowest, with the fewest crystal zones at the (0 1 0), (1 1 1), and (1 0 0) crystal faces. Further, the elongation at break is the largest with values up to about 170%. Therefore, we choose a fixed CHDM content of 30% and then vary the cis and trans ratios of CHDM. As shown in Figure 5B, the strength of PETG resins gradually increases with the gradually increasing content of trans-CHDM. When the trans-CHDM content is less than 90%, the XRD pattern analysis has shown that the grain spacing and grain size in the crystal region are relatively small, and the elongation at the break of PETG-trans80 copolyester is about 190%. Nevertheless, when the trans-CHDM content exceeds 90%, new characteristic diffraction peaks can be gradually observed in the XRD pattern, which indicates that a new crystal structure has been generated within the copolyester, which also leads to a decrease in elongation. For example, the crystal region at the (1 1 1) crystal plane, D(111) is much larger than D(100), and the excessive grain size of the new crystal region generates stress concentration problems. Compared with PET, PETG-trans80 copolyester further improves the toughness (elongation at break) of the material based on ensuring tensile strength.

3.4 | Effect of the drawing process on the crystal structure of PETG fibers

The PETG30-trans80 and pure PET resins are chosen to further investigate the effects of a chemical structure and

melt-spinning drawing process on the crystal structure and mechanical property of fiber. As shown in Figure 6A and Table S4, each 1D-WAXD curve of PETG30-trans80 fiber with different drawing ratios demonstrates only one characteristic diffraction peak ($2\theta \approx 20^\circ$). Compared with the as-spun PETG30-trans80 fiber, the crystal surface spacing decreases from 4.60 nm to 4.43 nm, the grain size increases from 0.61 nm to 0.73 nm, and the crystallinity increases from 17.5% to 27.8%. As shown in Figure 6B and Table S5, the 1D-SAXS result suggests the long periods of PETG30-trans80 fibers increase with the drawing ratio, which increases from 27.79 nm of as-spun fiber to 29.62 nm of PETG30-trans80 fiber at $2.5\times$ drawing ratio. It can be concluded that a certain degree of drawing ratio can effectively improve the internal structure order of PETG30-trans80 fiber due to the effect of stress-induced crystallization. Furthermore, 2D-WAXD is used to better understand the relationship between crystal structure and drawing process, where PET fiber shows significant diffraction arcs with increasing drawing ratio, while PETG30-trans80 fibers keep the completed diffraction ring. It is also observed that the orientation degree of PETG30-trans80 fiber is less than that of PET fiber at the same drawing ratio.

3.5 | Mechanical Properties of PETG Fibers

As shown in Figure 7A,B and summarized in Table S6, the tensile strength of PET and PETG30-trans80 fibers increase with the drawing ratio due to enhanced crystallinity and molecular orientation induced by the drawing process. Specifically, the strength of PETG30-trans80 fiber increases from 54.9 MPa to 113.9 MPa, while elongation decreases from 178.4% to 136.5% at the drawing ratio of $2.5\times$. Figure 7C,D shows that the ET chain segments in PET fibers' crystal regions become more ordered during the drawing process, which contributes to greater fiber strength. However, the CT chain segments of PETG30-trans80 fiber are excluded from the

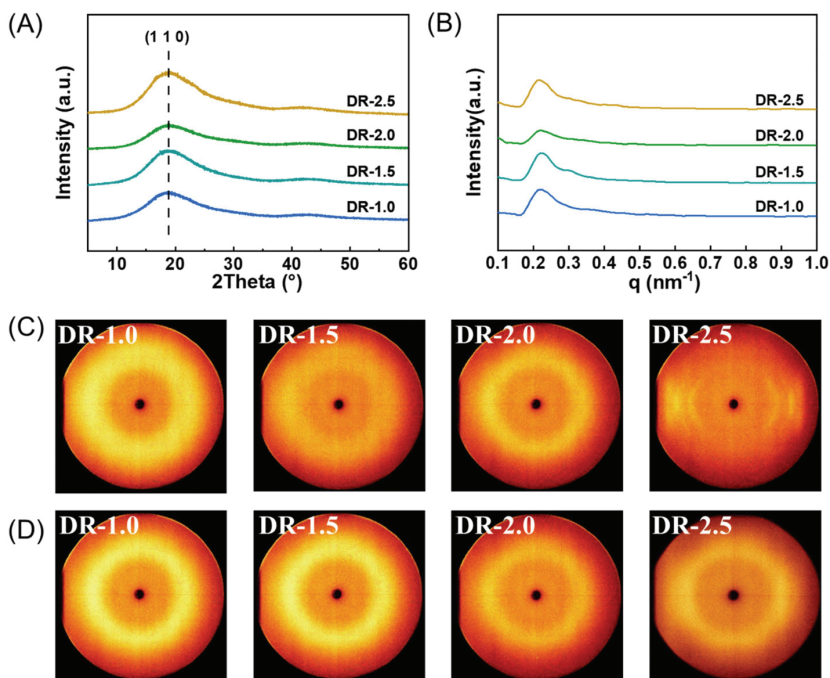


FIGURE 6 Crystal structure of PET and PETG30-trans80 fibers. (A) and (B) 1D-WAXD and 1D-SAXS curves of PETG30-trans80 fibers with different drawing ratios. (C) and (D) 2D-WAXS diagrams of PET and PETG30-trans80 fibers with different drawing ratios.

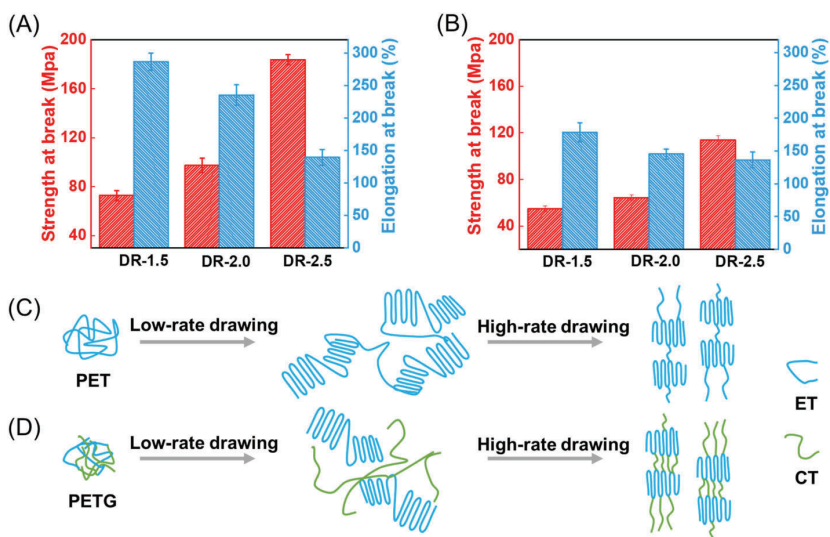


FIGURE 7 Mechanical properties and crystal packing structures of PET and PETG30-trans80 fibers. Mechanical properties of (A) PET fibers and (B) PETG30-trans80 fibers with different drawing ratios. Crystal packing structures of (C) PET fibers and (D) PETG30-trans80 fibers with different drawing ratios.

crystal zone, leading to a more amorphous structure compared to PET fibers. It can be explained by the fact that CT chain segments are relatively flexible and hard to crystallize, and the ET chain segments preferentially crystallize under the hot-drawing process. Therefore, the area of grain boundary increases with grain size, where the slip formation is hindered by disordered molecular arrangement. Besides, the slip and deformation between grain surfaces in the crystal structure becomes more difficult, which leads to a decline in mechanical properties.

4 | CONCLUSIONS

In this paper, a series of PETG copolyesters are prepared by melt polycondensation of CHDM with EG and PTA, and the PETG30-trans80 copolyester is further chosen to prepare melt-spinning fiber. The chemical structure is systematically confirmed by $^1\text{H-NMR}$ and $^{13}\text{C-NMR}$, which suggests that the PETG copolyesters are synthesized as expected and all copolyesters are random copolyesters. The crystallization, melting behavior, and thermal stability of copolyesters are investigated by WAXD, DSC, and TGA,

respectively. The glass-transition temperature, melting temperature, and crystallinity first decrease and then increase with the CHDM content. Besides, the crystallinity of PETG copolyesters increases from 22.0% to 40.1% and the crystal spacing of the (1 1 0) and (1 1 1) crystal planes decrease with the trans-CHDM content, which might be explained by the fact that the regular chemical structure of trans-CHDM is conducive to the formation of crystal nuclei, and the grain size decreases slightly and the arrangement of the grains get more compact. All the PETG copolyesters exhibit good thermal stability, which can completely meet the temperature requirement of melt-spinning. Therefore, the crystal structure of the copolyester can be effectively regulated by changing the CHDM content and the ratio of cis-trans isomers, which is conducive to improving the thermal stability and mechanical properties of the copolyester. In addition, the synthetic effects of the chemical structure and different drawing ratios on the crystal structure and mechanical properties of PETG30-trans80 fibers are analyzed by 2D-WAXD and tensile strength. The tensile strength increases from 54.9 MPa to 113.9 MPa and the crystallinity increases from 17.5% to 27.8%, which illustrates that certain drawing ratios can effectively improve the internal structure order and tensile strength due to the effect of stress-induced crystallization. In conclusion, we successfully fabricated the PETG copolyester fibers with tunable properties by the industrialized copolymerization and melt spinning way, which can be applied in the fields of medicine, construction materials, packaging materials, etc.

ACKNOWLEDGMENTS

This work was supported by the National Key R&D Program of China (2021YFB3700300), the Shandong Province Key Research and Development Project (2023CXGC010611), the Open Project Program of High-Tech Organic Fibers Key Laboratory of Sichuan Province (PLN2023-16) and the Fundamental Research Funds for the Central Universities (CUSF-DH-T-2023005).

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

Data available on request from the authors.

ORCID

Zhihao Zhang  <https://orcid.org/0009-0008-8941-8089>

Hengxue Xiang  <https://orcid.org/0000-0002-7576-9434>

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Zhang Z, Yao Z, He Y, et al. Melt-spun poly(ethylene terephthalate-co-1,4-cyclohexanedimethylene terephthalate) (PETG) copolyester fibers: Synergistic effect of chemical and crystal structure regulation. *Polym Eng Sci*. 2025;65(2):755-764. doi:10.1002/pen.27040