

# Synthesis and properties of lyotropic liquid crystalline copolyamides containing phthalazinone moiety and ether linkages

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## Abstract

A series of aromatic copolyamides containing phthalazinone moiety and ether linkages were prepared from 1,2-dihydro-2-(4-aminophenyl)-4-[4-(4-(aminophenoxy)phenyl)](2H)phthalazin-1-one (DHPZ-DA), *p*-phenylenediamine (PPD), 4,4'-diaminodiphenylether (DAPE) and terephthaloyl dichloride (TPC) by low temperature solution polycondensation. The copolyamides had relatively high inherent viscosities, ranging from 1.86 to 5.30 dl/g. The copolyamides showed  $T_g$  values between 297 and 351 °C. Solubility of these copolyamides was improved in NMP, DMAc, NMP (1 wt% LiCl) and DMAc (1 wt% LiCl) by introducing phthalazinone moiety and ether linkages into the main chain. And they had good thermal stability, associated with 5 and 10% weight loss temperatures in the range of 480–516 and 501–532 °C in nitrogen, respectively. WAXD measures indicated these copolyamides were semicrystalline in nature. Some of these copolyamides exhibited lyotropic liquid crystalline behavior in concentrated H<sub>2</sub>SO<sub>4</sub>, NMP (1 wt% LiCl), and even in NMP solutions, as evidenced by polarizing light microscopy.

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**Keywords:** Copolyamides; Phthalazinone; Lyotropic liquid crystalline

## 1. Introduction

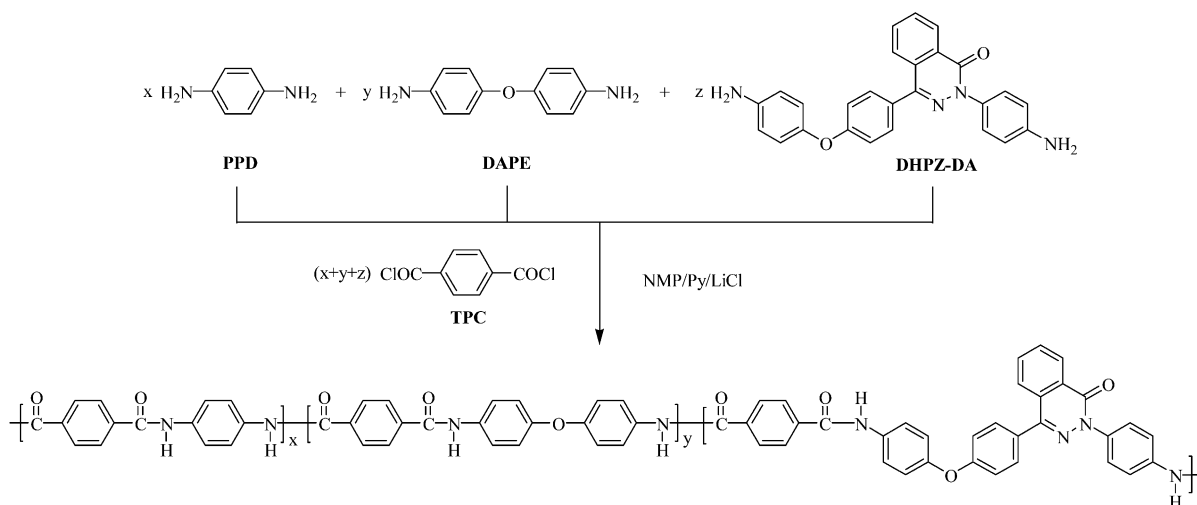
Poly(*p*-phenylene terephthalamide) (PPTA) has been noted as a kind of important polymeric material which presents a combination of outstanding properties such as high thermal stability, good chemical resistance, low flammability and excellent mechanical properties [1]. In application, lyotropic liquid crystalline property of PPTA or similar polyamides has received considerable commercial and scientific interest since it was reported and applied in the developing of Kevlar<sup>®</sup> by Kwolek, for its great advantages in the process of forming high performance fibers and films, especially the convenience in the tropism of the main chain [2,3]. Some polyamides with varied

structures have been reported, which exhibited lyotropic property in 100% sulfuric acid, a highly corrosive solvent and an acid rain generator [4]. However, the lyotropic liquid crystalline property in polar aprotic organic solvents of these aromatic polyamides as well as good organic solubility is more valuable and desirable in respect that it will be constructively helpful to reduce the cost and environmental pollution in the manufacturing process of these polyamides, by wet-spinning or extruding these polyamides or copolyamides from organic solutions and averting the use of sulfuric acid. Unfortunately, few aromatic polyamides can exhibit lyotropic liquid crystalline properties in common organic solvents, due to their limited organic solubility. The too high rigidity and too strong intermolecular hydrogen bonding in these polyamides result in their poor solubility in most organic solvents, restricting their applications [5].

Many efforts have been focused on designing new chemical structures of rigid aromatic backbones of polyamides in order to improve their solubility while

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Scheme 1. Outline of synthesis route followed for the preparation of the copolyamides.

maintaining the desired properties. These studies involved some structure modifications: introducing bulky side substituents [6,7], incorporating flexible ether linkages [8] and flexible fluorinated groups [9] into the backbone, introduction of twisted and non-coplanar structure into the main chain [10,11] and so on. Jian et al. synthesized various of aromatic polymers bearing crank and twisted non-coplanar phthalazinone moiety in the main chain, such as poly(aryl ether sulfone)s, poly(aryl ether ketone)s, polyamides and polyimides [12–17]. All these polymers containing phthalazinone moiety have good solubility as well as excellent thermal properties. Some of them have been widely applied as composite materials, membranes, insulating coating and paint [18,19]. Recent research also indicated that these polymers have a promising future in fuel cells and optical communications materials [17,20].

In our research, we attempted to prepare organic soluble lyotropic liquid crystalline aromatic copolyamides with other desired properties by incorporating the twisted and non-coplanar phthalazinone structure into the rigid main chain of PPTA for the first time. In this article, we describe the preparation of a series of aromatic copolyamides derived from 1,2-dihydro-2-(4-aminophenyl)-4-[4-(4-(aminophenoxy)phenyl)](2H)phthalazin-1-one (DHPZ-DA), *p*-phenylenediamine (PPD), 4,4'-diamino diphenylether (DAPE) and terephthaloyl dichloride (TPC) by low temperature solution polymerization. The new copolyamides thus obtained were tested of their capability to form lyotropic solutions by polarizing light microscope (PLM). The influence of the twisted and non-coplanar phthalazinone structure on the close packing of the PPTA main chains was tested by WAXD. And their other properties such as inherent viscosity, solubility, thermal properties, crystallinity of these aromatic copolyamides were also measured.

## 2. Experimental

### 2.1. Materials

1,2-Dihydro-2-(4-aminophenyl)-4-[4-(4-(aminophenoxy)phenyl)](2H)phthalazin-1-one (DHPZ-DA) was prepared according to the reported method [13]. The product was obtained as pale yellow crystals; mp: 260–261 °C; yield: 92%. *N*-Methyl-2-pyrrolidinone (NMP) was refluxed over toluene for 8 h. It was then refluxed in the presence of CaH<sub>2</sub> and freshly distilled before use. Pyridine (Py) was refluxed in an inert atmosphere in the presences of the KOH for 4 h and stored on 4 Å molecular sieves. LiCl was dried for 12 h at 120 °C under vacuum and freshly dried for 3 h at 180 °C under vacuum before use. *p*-Phenylenediamine (PPD) was purified by sublimation, and 4,4'-diaminodiphenylether (DAPE) was recrystallized from ethanol. Terephthaloyl dichloride (TPC) was distilled under vacuum and then recrystallized from *n*-hexane.

### 2.2. Polyamide synthesis

The copolyamides were synthesized in the route shown as Scheme 1. The number in the sample name indicates the molar fraction of the comonomers in the reactants. For example, P-203050 indicates that the copolyamide was synthesized from 20 mol% DHPZ-DA, 30 mol% DAPE and 50 mol% PPD. All the copolyamides were prepared in a similar procedure. Therefore, only the synthesis of the copolyamide P-203050 is described as a represent example. The copolymerization reaction was carried out in a three-neck flask equipped with a mechanical stirrer and a nitrogen inlet in a water-ice bath. The flask was charged with a mixture of DHPZ-DA (1.6 mmol), DAPE (2.4 mmol), PPD (4.0 mmol), LiCl (0.375 g), NMP (27 ml) and Py (0.72 ml). After the diamines were dissolved in the system, TPC

Table 1  
Composition and physical properties of the copolyamides

Copolymer	Copolymer composition DHPZ-DA/ DAPE/PPD	$\eta_{inh}^a$ (dl/g)	Yield (%)	Color
P-101080	10/10/80	3.19 <sup>b</sup>	99	Yellow
P-102070	10/20/70	4.05	99	Yellow
P-103060	10/30/60	5.30	99	Yellow
P-153055	15/30/55	4.15	99	Yellow
P-202060	20/20/60	3.87	99	Yellow
P-203050	20/30/50	3.63	99	Yellow
P-206020	20/60/20	1.97	98	White
P-303040	30/30/40	2.32	98	Yellow
P-400060	40/0/60	2.87	99	Yellow
P-402040	40/20/40	2.03	98	Yellow
P-404020	40/40/20	1.86	98	White

<sup>a</sup> Determined at a concentration of 0.5 g/dl in NMP (1 wt% LiCl) at 25 °C.

<sup>b</sup> Determined at a concentration of 0.5 g/dl in concentrated sulfuric acid at 25 °C.

(8 mmol) was added. The mixture was maintained under stirring in nitrogen atmosphere for 6 h at 0 °C. The resulting copolyamide was coagulated in 400 ml ethanol/water (1:1, v/v). The pale yellow massive copolymer was placed in boiling water for 3 h and dried under vacuum at 120 °C for 8 h. The yield was 99%.

### 2.3. Measurement

Inherent viscosities ( $\eta_{inh}$ ) of the copolyamides were measured by Ubbelohde capillary viscometer at a concentration of 0.5 g/dl in NMP (1 wt% LiCl) or concentrated sulfuric acid at 25 °C according to their solubility. IR absorption spectra were recorded by reflection method with a Thermo Nicolet Nexus 470 Fourier transform infrared (FTIR) spectrometer. Thermogravimetric analysis (TGA) and derivative thermogravimetric analysis (DTG) of copolyamides were performed on a Netzsch 209 thermogravimetric analysis instrument in a nitrogen atmosphere at a heating rate of 20 °C/min from 200 to 800 °C. Decomposition temperature ( $T_d$ ) was taken as the temperature of 5 and 10% weight loss. Temperature for the maximum weight loss rate ( $T_{max}$ ) in nitrogen, was also measured at a heating rate of 20 °C/min. Char yield ( $C_y$ ) were calculated as the percentage of solid residue after heating from 200 to 800 °C in flowing nitrogen. The glass transition temperature ( $T_g$ ) was determined with a Netzsch 204 differential scanning calorimetry (DSC) in flowing nitrogen at a heating rate of 10 °C/min from 50 to 450 °C. Wide-angle X-ray diffraction (WAXD) was performed at room temperature on a Rigaku D/max 2400 automatic X-ray diffractometer with Ni-filtered Cu K $\alpha$  radiation. The rotated velocity of the goniometry was 4 °/min. The mesophases of

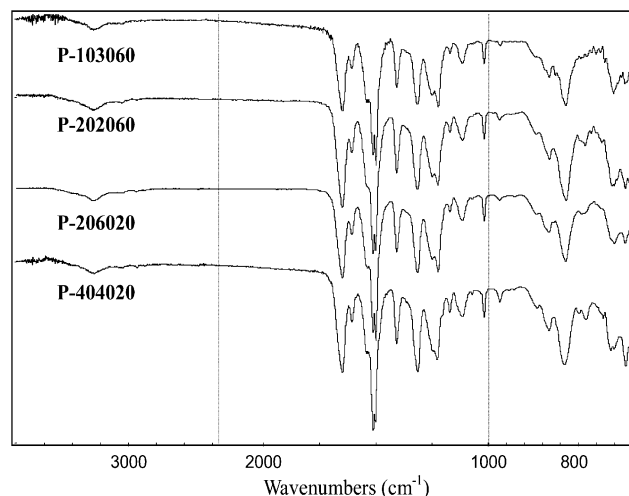


Fig. 1. FTIR spectra of copolyamides.

the copolyamides were identified with an Olympus BH-2 polarizing light microscope (PLM).

## 3. Result and discussion

### 3.1. Polymer synthesis

A one-step polycondensation of three amines and TPC was adopted in this research, as showed in Scheme 1. No oligomers were prepared before the copolymerization, comparing to the synthesis of the block copolymers using COOH-, COCl- or NH<sub>2</sub>- terminated oligomers as commoners [21–23]. Copolyamides with different comonomer ratios were prepared by the low temperature solution polymerization of dichloride and diamines in NMP. The byproduct, hydrochloride, was absorbed by pyridine. LiCl was added into the system to enhance the solubility of copolyamides. The reaction temperature was controlled well around 0 °C to avoid side reactions. Obvious rod-climbing phenomena and stir opalescence were observed during polymerization. The resultant copolyamides were massive gel and their color ranged from pale white to yellow. The inherent viscosity ( $\eta_{inh}$ ) values of these copolyamides were measured in NMP (1 wt% LiCl) or concentrated sulfuric acid according to their solubility and given in Table 1. The values ranged from 1.86 to 5.30 dl/g, indicating the high molecular weight of the resultant copolyamides.

In the copolymerization, all diamines were added into the reaction system at one time, reacting with TPC by a competition of their reaction activity. The mechanics of this polycondensation may be very complex in respect that there are many factors that may affect the reaction of the diamines and TPC. These factors may include diamine activity, the concentration and molar ratio of the diamines, reaction

Table 2  
Solubility of the copolyamides

Polymer	Solubility <sup>a</sup>				
	NMP	NMP/LiCl <sup>b</sup>	DMAc	DMAc/LiCl <sup>b</sup>	Conc. H <sub>2</sub> SO <sub>4</sub>
P-101080	–	+ –	–	+ –	+
P-102070	+ –	+ –	–	+	+
P-103060	+ –	+	+ –	+	+
P-153055	+ –	+	+ –	+	+
P-202060	+ –	+	+ –	+	+
P-203050	+ –	+	+ –	+	+
P-206020	+	+	+ –	+	+
P-303040	+ –	+	+ –	+	+
P-400060	+ –	+	+ –	+	+
P-402040	+	+	+ –	+	+
P-404020	+	+	+ –	+	+

<sup>a</sup> Tested with 0.05 g of the polymers in 1 ml of solvent: +: soluble in room temperature; + –: partially soluble; –: insoluble

<sup>b</sup> Solvent containing 1 wt% LiCl.

temperature, the quantity of acid acceptor (Py), the mass and heat transfer of the reaction system and so on. However, every diamine got its opportunity to take part in this reaction system by competing with other diamines. So it is difficult for any diamine to form a long block chain during the polycondensation from a statistical view, hence helpful to obtain a proper number average sequence length. By this measure, the extent of block copolymerization can be controlled to a desirable extent, as evidenced by the improved organic solubility and the easily available lyotropic liquid crystalline property of these copolymers. Furthermore, the one-step polycondensation may also aid the creation of random irregularities along the polymer backbone, which will be helpful to the improvement of the organic solubility. Further research will be carried out to reveal this mechanics in detail.

We also found that the presence of DAPE attributes to the high inherent viscosity of these copolyamides. This may attribute to the fact that the activity of PPD was quite higher than DHPZ-DA in a relatively low temperature (0 °C, for

example). For this reason, the rapid reaction of PPD and TPC would increase the viscosity of reaction system at a high speed and reduce the mobility of DHPZ-DA molecules, without introducing other reactants. To some extent, some DHPZ-DA molecules were ‘frozen in the highly viscous reaction body’ before reaction and then lost their opportunity to polymerize with TPC. However, we found that introducing DAPE, with a proper molar ratio, into the reaction system can adjust the reaction speed of the copolymerization and slow down the increment speed of the reaction system viscosity. It may be due to the fact that the activity of the DAPE was lower than PPD but higher than DHPZ-DA. By this means, copolyamides with higher inherent viscosity were produced indicating that the introduction of DAPE was helpful to prepare phthalazine-containing copolyamides with high molecular weight. For instance, copolyamide P-103060 had a rather higher inherent viscosity ( $\eta_{inh} = 5.30$  dl/g) than P-400060 ( $\eta_{inh} = 2.87$  dl/g), P-101080 ( $\eta_{inh} = 3.19$  dl/g) and P-102070 ( $\eta_{inh} = 4.05$  dl/g).

Table 3  
Thermal properties of the copolyamides

Copolymer	$T_g$ (°C) <sup>a</sup>	$T_{5\%}$ (°C) <sup>b</sup>	$T_{10\%}$ (°C) <sup>c</sup>	$T_{max}$ (°C) <sup>d</sup>	$C_y$ (%) <sup>e</sup>
P-101080	342	506	523	566	59
P-102070	318	516	532	565	55
P-103060	348	511	527	563	56
P-153055	323	503	518	562	58
P-202060	308	507	524	562	60
P-203050	298	503	522	570	56
P-206020	297	488	502	515, 568 <sup>f</sup>	53
P-303040	312	496	515	536, 565 <sup>f</sup>	62
P-400060	351	504	520	562	54
P-402040	321	494	514	523, 562 <sup>f</sup>	62
P-404020	309	480	502	512	55

<sup>a</sup> From DSC measurements conducted at a rate of 10 °C/min in nitrogen.

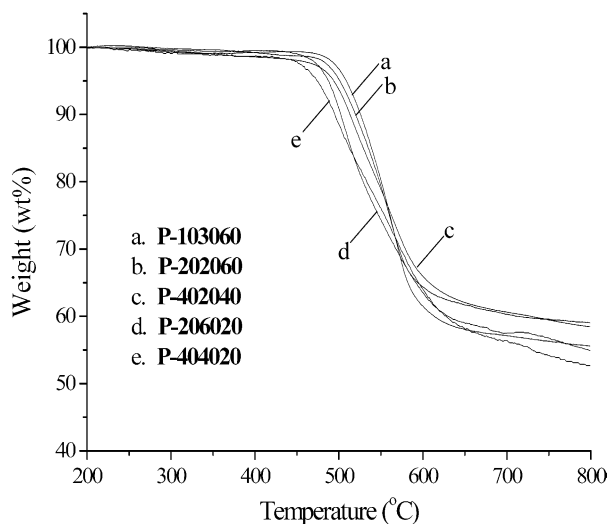
<sup>b</sup> Temperature for 5% weight loss in nitrogen, heating rate of 20 °C/min.

<sup>c</sup> Temperature for 10% weight loss in nitrogen, heating rate of 20 °C/min.

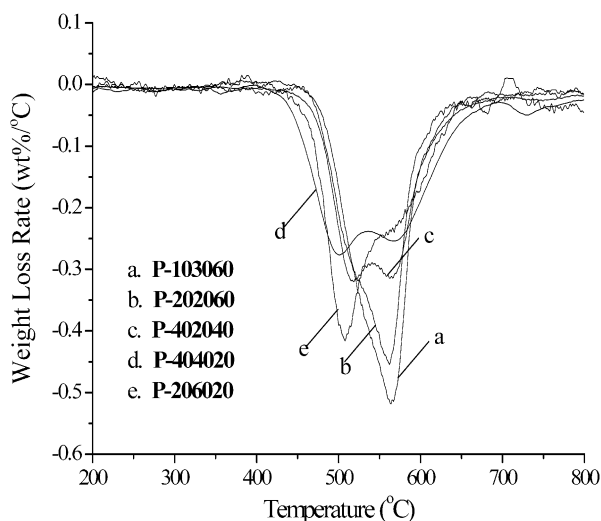
<sup>d</sup> Temperature for the maximum in nitrogen, heating rate of 20 °C/min.

<sup>e</sup> Char yield calculated as the percentage of solid residue after heating from 200 to 800 °C in nitrogen.

<sup>f</sup> Two peaks in the DTG curves.



(A)



(B)

Fig. 2. TGA and DTG curves of copolyamides: (A) TGA curves in nitrogen at a heating rate of 20 °C/min (B) DTG curves in nitrogen at a heating rate of 20 °C/min.

The structures of these resulting copolyamides were characterized with FTIR. For example, the spectra of P-103060, P-202060, P-206020 and P-404020 are shown in Fig. 1. The IR spectra of the copolyamides showed the characteristic absorption bands near 3299  $\text{cm}^{-1}$  (N–H stretching), 1649  $\text{cm}^{-1}$  (C=O stretching), 1602  $\text{cm}^{-1}$  (C=N stretching), 1516  $\text{cm}^{-1}$  (combined N–H bending and C–N stretching), 1495  $\text{cm}^{-1}$  (Ar stretching), 1219  $\text{cm}^{-1}$  (C–O–C stretching) and 1112  $\text{cm}^{-1}$  (N–N stretching). These characteristic bands in IR spectrum correlate sufficiently well with the expected structures of the copolyamides.

### 3.2. Polymer solubility

The solubility of copolyamides was determined by

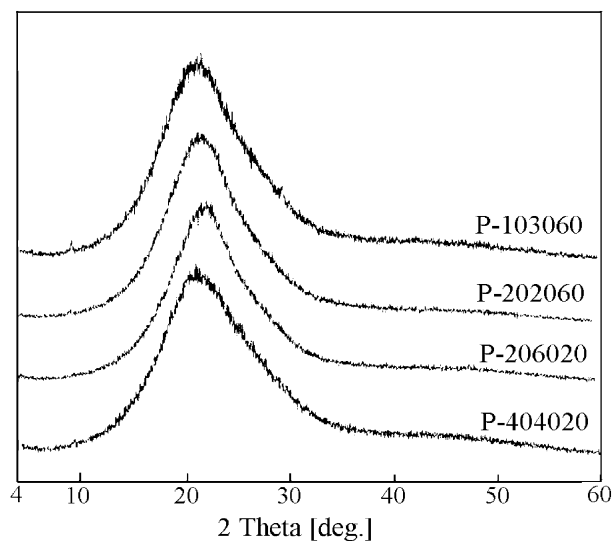


Fig. 3. WAXD diffractograms of copolyamides before annealing.

dissolving 0.05 g of polymers in 1 ml of solvent (5 w/v% of solid content) at room temperature. With the increase of the molar ratio of DHPZ-DA, the solubility of these copolyamides was improved in NMP, dimethylacetamide (DMAc), NMP (1 wt% LiCl) and DMAc (1 wt% LiCl) as shown in Table 2. For instant, copolyamides P-102070 and P-202060 were insoluble in either NMP or DMAc without the existence of LiCl, while the copolyamide P402040 was soluble in NMP even in room temperature and afforded homogeneous polymer solution within 24 h. A same tendency of solubility was also found in copolyamides P-103060, P-203050 and P-303040. The improved solubility of copolyamides could be attributed to the crank and twisted non-coplanar phthalazinone moiety and the flexible ether linkages, which help to cumber the close packing of chains and decrease the degree of crystallinity.

### 3.3. Thermal stability

The glass transition temperatures and thermal stability of these copolyamides were evaluated by DSC and TGA, respectively. Temperatures for the maximum weight loss rate ( $T_{\text{max}}$ ) in nitrogen at a heating rate of 20 °C/min were also measured by derivative thermogravimetric analysis (DTG) of these copolyamides. Experimental data obtained from TGA, DTG and DSC are listed in Table 3. The TGA and DTG curves in nitrogen of representative copolyamides are shown in Fig. 2, for example. The  $T_g$  values of the copolyamides were detected in flowing nitrogen at a heating rate of 10 °C/min from 50 to 450 °C. Their values ranged from 297 to 351 °C, indicating the phthalazinone-containing copolyamides have very high thermal resistance. The relatively high  $T_g$  values may be contributed to the introduction of the heterocyclic phthalazinone moiety in the backbone. The relatively high molecular weight may

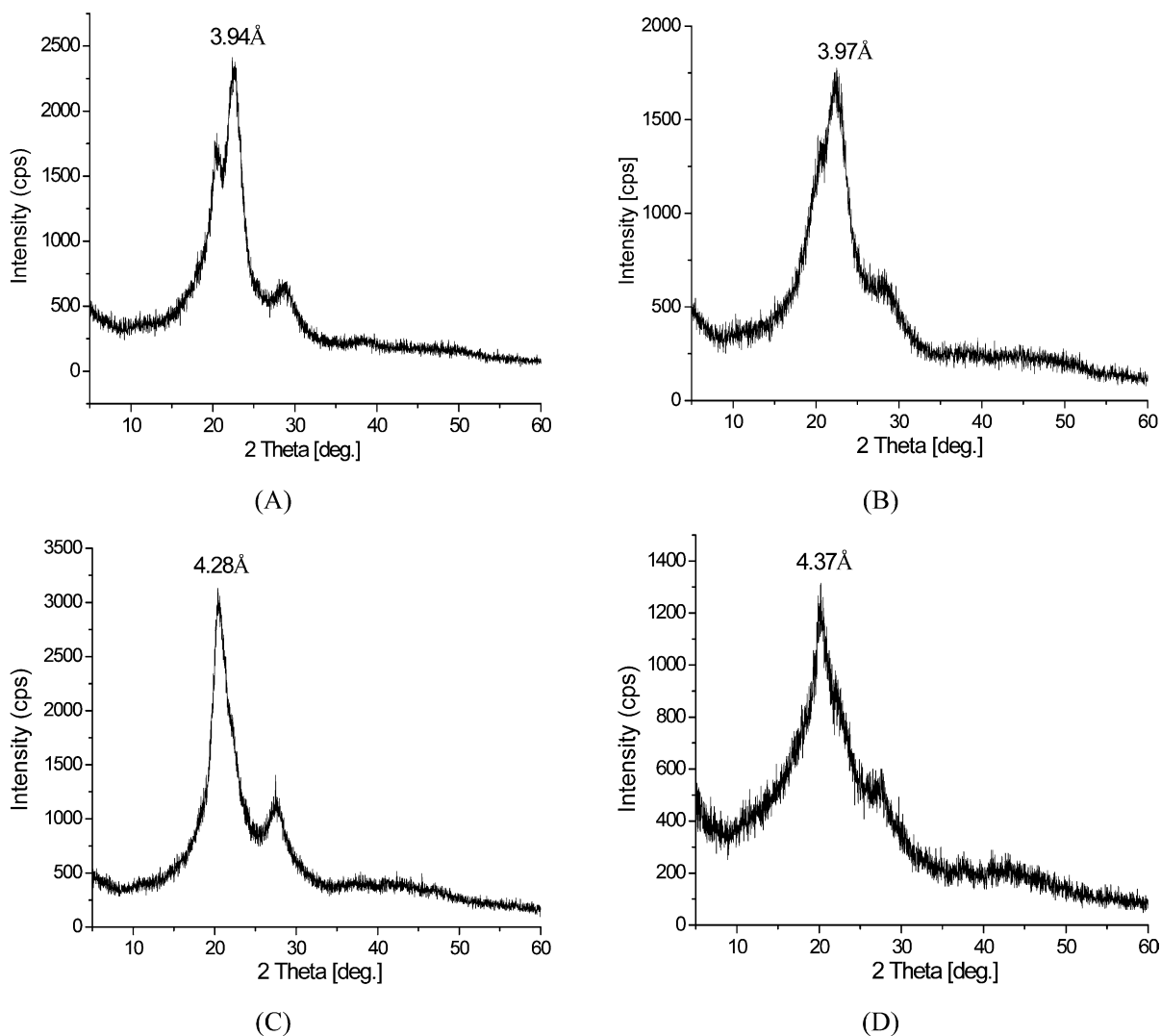


Fig. 4. WAXD diffractograms of copolyamides annealed at 360 °C for 4 h: (A) P-103060, (B) P-202060, (C) P-206020 and (D) P-404020.

also contribute to the increasing of  $T_g$  values. The weight loss temperatures ( $T_d$ ) of the copolyamides determined in nitrogen were in the range 480–516 °C (5% weight loss) and 501–532 °C (10% weight loss), compared to the initial weight loss temperature of commercial Kevlar fibre (530 °C) [24]. Temperatures for the maximum of a single step of weight loss rate ( $T_{max}$ ) in nitrogen ranged from 512 to 570 °C. The char yields ( $C_y$ ) of all copolyamides were in the range of 53–62%, conforming the high thermal stability of the phthalazinone-containing copolyamides. These resultant data suggested that copolyamides in this study possessed excellent thermal stability.

### 3.4. Polymer crystallinity

Crystallinity of these copolyamides was investigated by WAXD measures. No obvious diffraction peak appeared in their X-ray diffraction pattern when copolyamides samples were tested by WAXD measurement before being annealed.

Representative X-ray diffraction diagrams of copolyamides are shown in Fig. 3. However, after being annealed at 360 °C for 4 h, these copolyamides showed several obvious diffraction peaks in their X-ray diffraction pattern, as shown by Fig. 4. The existence of crank and twisted non-coplanar phthalazinone moiety into the main chain may reduce the regularity of the main chain, cumber the close packing of chains and hinder the movement of the main chain. When the samples were heated up to 360 °C, the polymer chains could receive enough energy to overcome the hindrance and rearrange in the regular form. Then the samples were cooled by degrees and the rearranged main chain structures were remained, which imparted the samples with the semicrystalline characteristic.

Further more, the obvious difference can be found between these copolyamides. As shown in Fig. 4, the X-ray diffraction patterns of copolyamides P-103060 and P-202060 exhibit peaks centered at  $\sim 3.9$  Å, while copolyamides P-206020 and P-404020 show sharper peaks

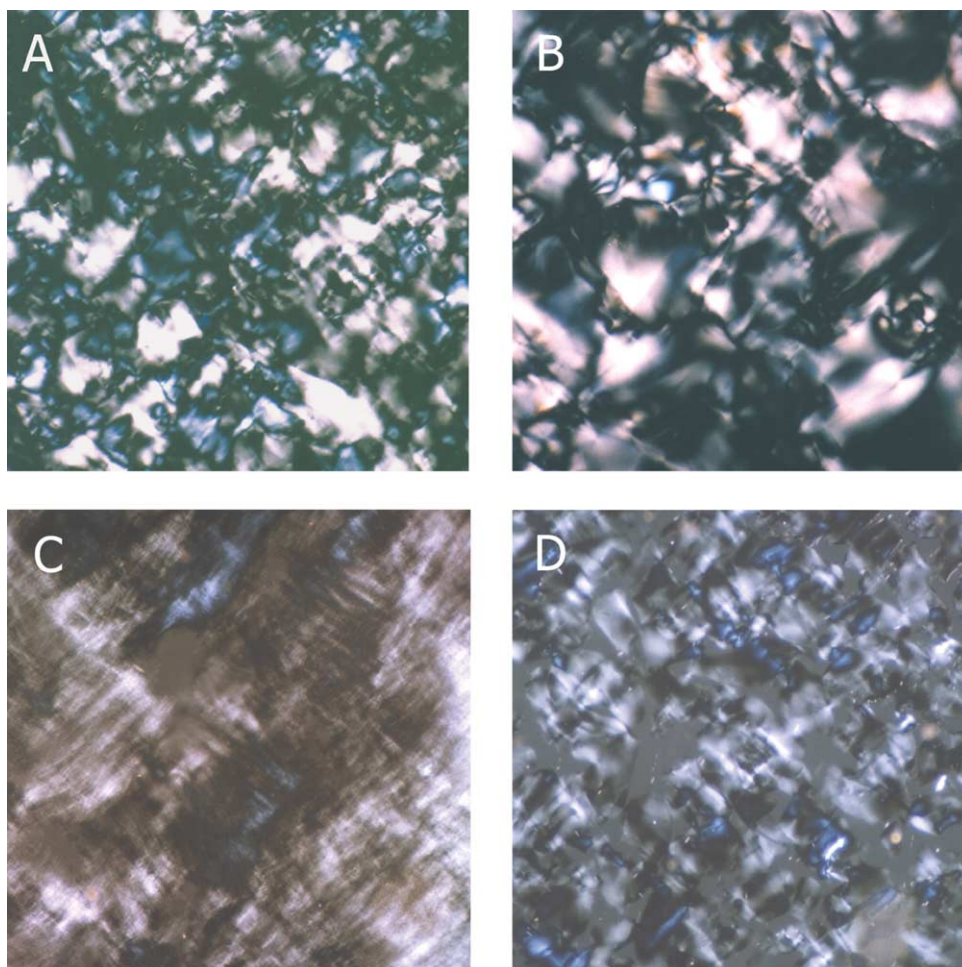


Fig. 5. Photomicrographs of copolyamides solution: (A) P-103060 in 8 wt% NMP (containing 1 wt% LiCl) solution (magnification  $25\times$ ) taken at room temperature, (B) P-202060 at 8 wt% in NMP (containing 1 wt% LiCl) (magnification  $25\times$ ) taken at room temperature, (C) P-404020 at 14 wt% in NMP (magnification  $25\times$ ) taken at room temperature, and (D) P-404020 at 18 wt% in NMP (magnification  $25\times$ ) taken at room temperature, exhibiting lyotropic solution.

centered at  $\sim 4.3$  Å, correspondingly. The introduction of bulky phthalazinone moiety and ether linkages into the backbones may encumber the close packing of polymer chain, increasing the average intermolecular distance of these copolyamides.

### 3.5. Mesophase characterization

The solution morphology of these copolyamides in different solvents according to their solubility was evaluated by visual observation on a polarizing light microscope (PLM) under crossed polarizers. All samples are dissolved in concentrated  $\text{H}_2\text{SO}_4$ , NMP (1 wt% LiCl) or pure NMP to form a series of solutions with different concentration in the range of 2–30 wt%. These viscous and homogeneous polymer solutions were pressed into thin films between two cover glasses, and shear force was applied by the upper cover slide being shifted. The critical concentration  $C^*$  values at which the mesophase appears in concentrated  $\text{H}_2\text{SO}_4$ , NMP (1 wt% LiCl) and NMP were also determined at room

temperature, respectively, as shown in Table 4. Most of these copolyamides formed anisotropic phase in their concentrated  $\text{H}_2\text{SO}_4$  and NMP (1 wt% LiCl) solution, with  $C^*$  values in the range of 21–28 wt% and 6–16 wt%, respectively. Furthermore, the solubility of P-402040, P-206020 and P-404020 was high enough to form lyotropic solutions in NMP at room temperature, with  $C^*$  values in the range of 5–14 wt%. As representative examples, three representative photomicrographs of copolyamide P-103060 at 8 wt% in NMP (1 wt% LiCl), P-202060 at 8 wt% in NMP (1 wt% LiCl), P-404020 at 14 wt% in NMP, and P-404020 at 18 wt% in NMP obtained with a PLM under crossed polarizers at room temperature were shown in Fig. 5.

The formation of the lyotropic phase in a polymer is quite complex and determined by several key requirements. The polymer usually should have a rodlike structure with high molecule weight and extended chain character to facilitate the alignment of the polymer chain along an orientated direction. The solubility needs to be sufficiently high to form a lyotropic solution. The phase behavior of a polymer

Table 4  
Lyotropic properties of the copolyamides

Copolymer	$C^*$ (wt%) <sup>a</sup>		
	Conc. H <sub>2</sub> SO <sub>4</sub>	NMP/1 wt% LiCl	NMP
P-101080	21	ND <sup>b</sup>	ND
P-102070	21	5	ND
P-103060	21	6	ND
P-153055	22	6	ND
P-202060	21	6	ND
P-203050	22	6	ND
P-206020	– <sup>c</sup>	14	12
P-303040	26	7	ND
P-400060	22	6	ND
P-402040	28	7	5
P-404020	–	16	14

<sup>a</sup> The critical concentration  $C^*$  (wt%) values at which the lyotropic phase appears at room temperature.

<sup>b</sup> Not determined for the limited solubility.

<sup>c</sup> Lyotropic phase was not available under the test condition.

is itself affected by the microstructure, molecular weight, polymer–polymer and polymer–solvent interactions, and temperature [25]. Therefore, it was observed that the presence of twisted non-coplanar phthalazinone moiety and ether linkages in each of these copolyamides might increase intermolecular freedom and polymer–polar solvent interaction significantly, resulting in the improved solubility and the prospect of formation of a lyotropic phase in polar organic solvent. In addition, copolymerization in this study seems to aid the creation of random irregularities along the polymer backbone and might also contribute to the polymer–solvent intermolecular interactions. These mesomorphic peculiarities may offer great possibility for technical application of these copolyamides.

#### 4. Conclusion

A series of aromatic copolyamides containing phthalazinone moiety and ether linkages were synthesized, with the inherent viscosity ( $\eta_{inh}$ ) values in the range of 1.86–5.30 dl/g. These resultant copolyamides possessed high  $T_g$  values and excellent thermal stability. Introducing ether linkages and crank and twisted non-coplanar phthalazinone moiety in the main chain increased the solubility in polar organic solvents. Evidence from WAXD measures also indicated that incorporating phthalazinone moiety and ether linkage into the main chain could increase the average

intermolecular distance. Evaluated their solution by visual observation on a PLM, most tested copolyamides showed lyotropic liquid crystalline peculiarities not only in concentrated H<sub>2</sub>SO<sub>4</sub> but also in NMP (1 wt% LiCl). Moreover, mesophases of P-402040, P-206020 and P-404020 at room temperature were even available in NMP, attributing to their improved solubility. The presence of twisted non-coplanar phthalazinone moiety and ether linkages in these copolyamides can significantly increase intermolecular freedom and polymer–polar solvent interaction, resulting in the improved solubility and being helpful for forming a lyotropic phase in polar organic solvent, hence the prospect of technical application of these copolyamides.

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