Preparation, Analysis, and Properties of Benzocyclobutene-Terminated Polycarbonate–Polycarbonate Thermoplastic Alloys

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ABSTRACT: Thermoplastic alloys of benzocyclobutene-terminated bisphenol A polycarbonates (BCB PC) and *t*-butylphenol-terminated PC can be prepared by double extrusion of the flake components, as follows: first, at a relatively low temperature at which the BCB PC reacts slowly; and, second, at a higher temperature to complete the BCB PC reaction. These alloys can then be injection-molded using the same conditions as used to mold the base PC. Gel permeation chromatography (GPC) and liquid chromatography (LC) analyses show that the BCB PC forms a very high-molecular-weight branched polymer, which is largely soluble in the base PC. Only minor amounts of insoluble, crosslinked BCB PC are formed under the appropriate melt processing conditions. The melt flow rate (MFR) of BCB PC–PC alloys is much lower than that of the base PC, yet the two materials can be injection-molded under identical conditions. This phenomena indicates that the melt viscosity of these alloys have high shear sensitivity. Therefore, MFR is not an accurate measure of the melt processability of BCB PC–PC alloys. The melt strength of BCB PC–PC alloys is much greater than that of linear or branched PC and is dependent on the amount and type of BCB PC and the MFR of the base PC. Transparent alloys having about a six-fold increase in melt strength over branched PC were prepared. The mechanical properties of these alloys that were examined are largely unchanged compared to standard grades of PC. Alloys retain the high toughness, heat distortion, and flexural modulus typically associated with PC. The surface gloss on injection-molded BCB PC–PC alloys is reduced compared to linear PC and appears to decrease with increasing BCB PC content in the formulation. The melt strength of BCB PC–PC alloys also imparts drip suppressant properties in burning samples. An ignition resistant alloy formulation had a 1/16 in. UL-94 V-0 rating while retaining transparency and normal PC physical properties. © 1997 John Wiley & Sons, Inc. J Appl Polym Sci **66:** 1821–1829, 1997

Key words: polycarbonate; benzocyclobutene; alloy

INTRODUCTION

Benzocyclobutene-terminated bisphenol A polycarbonates (BCB PCs; Structure I) are a class of thermally crosslinkable PCs which form thermosets having a wide range of improved properties over linear PCs, which vary according to the network crosslink density.[1] Low to moderate crosslink density BCB PCs have much improved solvent and ignition resistance over linear PC while retaining a high impact strength compared to other thermosets.[1] High crosslink density BCB PCs form highly abrasion resistant thermosets that can be used as protective coatings for PC and other thermoplastics.[2]

The objective of this study was to prepare ho-
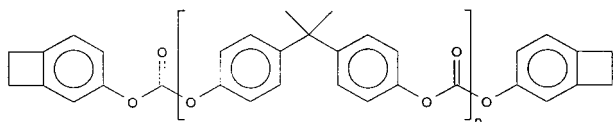
Structure I

mogeneous mixtures of small amounts of high to moderate molecular weight BCB PCs and linear PC by melt processing techniques and to examine their selected melt and glassy properties. Since the BCB end groups only react with themselves,[3] it might be expected that the products produced from such mixtures would range from a semi-interpenetrating polymer network,[4] wherein the BCB PC crosslinked, to a homogeneous mixture (solid solution or alloy) of linear PC and very high molecular weight PC, wherein the BCB PC mostly chain extended. This article describes the preparation of BCB PC–PC alloys, the nature of the products produced by the reactive BCB PC component, and some key melt and solid-state properties of these novel materials.

RESULTS AND DISCUSSION

The amount of reactive BCB end groups in BCB PCs is expressed as the moles of BCB terminator per mole of bisphenol A monomer used its preparation, termed herein as "m/m". In these studies 0.03, 0.06, and 0.10 m/m BCB PCs were used with standard grades of linear PCs having 3, 13, and 22 melt flow rates (MFR). The resultant products were characterized by gel permeation chromatog-

raphy (GPC), reversed phase liquid chromatography (LC) of alloy hydrolysates, and weight % (wt %) gel fraction. Properties evaluated include MFR, melt strength, impact strength, heat distortion temperature, flexural modulus, surface gloss, and ignition resistance.

Preparation of BCB PC–PC Alloys

BCB PC–PC alloys were prepared by two methods. In order to ensure homogeneity prior to reaction of the BCB PC component, dichloromethane solutions of BCB PC and PC were devolatilized with steam to form intimately mixed granules. These granules were then extruded, first, in a single-screw machine and, second, in a twin-screw machine to form the alloys. Alternatively, BCB PC–PC alloys were prepared by dry blending the polymer components, single-screw extrusion at a relatively low melt temperature to form a homogeneous mixture with a low extent of reaction of the BCB PC, and then a second extrusion at higher temperature to complete the reaction of the BCB PC. Due to its relative ease, the latter method was used to prepare most of the samples studied. All samples were injection-molded to fabricate test specimens. While the complex kinetics of mixing, melting, and BCB PC reaction were not studied, the best means found to accomplish the melt preparation of BCB PC–PC alloys employed PC and BCB PC granules, with the first extrusion at about 230 to 280°C and the second extrusion at about 310°C. Attempts to prepare alloys from BCB PC granules and more dense PC pellets or in a single extrusion step at the higher temperature

Table I Compositions and Percentage Gel of BCB PC–PC Alloys

Sample	BCB PC (m/m)	BCB PC in Alloy (wt %)	BCB in BCB PC (wt %)	BCB Total in Alloy (wt %)	PC Base MFR	Gel %
13 MFR PC	—	—	—	—	13.0	0.00
3 MFR PC	—	—	—	—	3.5	0.00
Branched PC	—	—	—	—	2.5	0.00
1	0.06	5.0	2.75	0.14	22.0	0.40
2	0.06	7.0	2.75	0.19	22.0	0.34
3	0.06	10.0	2.75	0.28	22.0	1.62
4	0.06	5.0	2.75	0.14	13.0	1.54
5	0.06	7.0	2.75	0.19	13.0	2.35
6	0.06	9.0	2.75	0.25	13.0	1.84
7	0.10	2.0	4.51	0.09	13.0	0.25
8	0.10	3.5	4.51	0.16	13.0	1.35
9	0.10	5.0	4.51	0.23	13.0	1.73
10	0.06	4.0	2.75	0.11	3.0	0.12

Table II   GPC and LC Analyses of BCB PC–PC Alloys

Sample	Composition[a]	Process[b]	BCB Conversion (%)	M_n	M_w	M_z
1A	5% : 0.06 : 20	sp	0	10,426	24,320	41,928
1B	5% : 0.06 : 20	sse	100	11,236	25,708	44,996
1C	5% : 0.06 : 20	tse	100	11,351	28,290	69,434
1D	5% : 0.06 : 20	im	100	11,130	28,696	76,370
2A	7% : 0.06 : 20	sp	0	10,508	23,101	37,660
2B	7% : 0.06 : 20	sse	61	11,204	27,419	56,476
2C	7% : 0.06 : 20	tse	100	11,046	31,059	106,081
2D	7% : 0.06 : 20	im	100	10,816	27,581	66,684
3A	10% : 0.06 : 20	sp	0	10,484	23,748	44,464
3B	10% : 0.06 : 20	sse	36	11,036	31,821	103,009
3C	10% : 0.06 : 20	tse	100	10,654	27,538	67,659
3D	10% : 0.06 : 20	im	100	9,934	25,982	63,322
4B	5% : 0.06 : 13	sse	47	11,042	26,924	42,118
4C	5% : 0.06 : 13	tse	100	11,383	32,106	88,960
4D	5% : 0.06 : 13	im	100	11,191	31,655	85,262
5B	7% : 0.06 : 13	sse	34	10,948	26,708	41,679
5C	7% : 0.06 : 13	tse	100	11,322	33,766	109,820
5D	7% : 0.06 : 13	im	100	11,211	30,846	74,418
6B	9% : 0.06 : 13	sse	15	10,807	26,471	42,779
6C	9% : 0.06 : 13	tse	100	11,366	31,758	90,240
6D	9% : 0.06 : 13	im	100	10,673	30,187	74,409
7B	2% : 0.10 : 13	sse	21	11,058	27,247	42,553
7C	2% : 0.10 : 13	tse	100	11,315	27,979	45,784
7D	2% : 0.10 : 13	im	100	11,446	29,080	54,914
8B	3.5% : 0.10 : 13	sse	26	10,990	26,910	42,016
8C	3.5% : 0.10 : 13	tse	100	11,256	29,584	66,383
8D	3.5% : 0.10 : 13	im	100	11,413	31,197	81,694
9B	5% : 0.10 : 13	sse	41	11,063	27,153	42,385
9C	5% : 0.10 : 13	tse	100	11,414	32,546	98,702
9D	5% : 0.10 : 13	im	100	10,834	28,453	63,490
10D	4% : 0.06 : 3	im	100	13,197	38,875	81,483

[a] Wt % BCB PC to m/m BCB PC to MFR base PC.
[b] sp = solution precipitation; sse = single-screw extrusion; tse = twin-screw extrusion; im = injection molding.

resulted in the formation of significant amounts of gelled BCB PC particles. Such gels caused strand dropping during extrusion and reduced molded part optical and impact properties.

During the second high-temperature extrusion, a significant amount of strand swelling at the die face was observed. This die swell is commonly observed during the extrusion of various types of PC formulations, such as those containing elastomers.[5]

Although the MFR of BCB PC–PC alloys are much lower than the base PC used (see below), injection molding of the alloys was done using essentially identical conditions (temperature and pressure) to that of the base resin. No difficulties were encountered in filling 3.2 mm tensile bars under normal molding conditions. All injection-molded alloys formed a hazy surface, the degree of which appeared proportional to the BCB content.

Characterization of BCB PC–PC Alloys

BCB PC–PC alloys are mostly soluble in dichloromethane, as shown by the gel analysis data in Table I. This low amount of gel formation proves that BCB PC does not form a significant amount of crosslinked polymer in the alloy and, therefore, that semi-interpenetrating networks are not formed. Table I also shows the compositions prepared in this study and the wt % of BCB PC and of BCB in each sample.

GPC of the alloy soluble fractions and LC of alloy hydrolysates were examined to follow the changes in molecular weight and BCB conversion
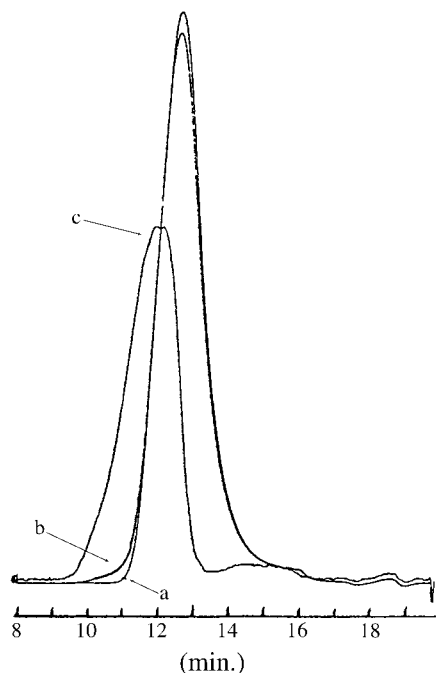
Figure 1 GPC chromatographs of (a) 3 MFR PC, (b) BCB PC–PC alloy, and (c) their difference.

with melt processing (Table II). The molecular weight of each sample increased following both of the extrusion steps, a manifestation of the reaction of the BCB PC component. The molecular weight of most of the samples decreased slightly with injection molding, but no evidence of PC chain degradation was apparent.

LC analysis of BCB PC hydrolysates can quantify unreacted 3-hydroxy-BCB and show the products produced by BCB homopolymerization.[3] Applying this analysis to the alloys showed BCB conversion ranging from 15 to 100%, mostly less than 50%, after the first extrusion. The wide range of BCB conversion found is not unexpected due to the variability of the temperature of the polymer in the various zones of the extruder.

The GPC chromatographs of BCB PC–PC alloys show the presence of a high-molecular-weight fraction formed by the BCB PC. Depicted in Figure 1 are the chromatographs of 3 MFR PC, 4% 0.06 m/m BCB PC/3 MFR PC alloy (Sample 10 in Tables I and II), and the weighted difference chromatograph of the two. The molecular weight (M_w) of the high-molecular-weight fraction of this alloy, estimated from the peak position of the difference chromatograph, is about 300,000 daltons.

As mentioned above, LC analysis of BCB PC–PC alloy hydrolysates shows the products formed by homopolymerization of BCB PC. The BCB end

groups only react with themselves to form dimers, trimers (two types), and tetramers in various numbers of isomers.[3] An expanded plot of the key region of the chromatographs of the above alloy hydrolysate (top) and 3 MFR PC hydrolysate (bottom) shows the absence of 3-hydroxy-BCB (retention time of about 19 min), the presence of BCB dimers as the predominant products, and trace amounts of the two types of BCB trimers (Fig. 2). BCB tetramers, if present, are masked by the later eluting peaks. The predominance of the BCB dimers shows that BCB PC mostly undergoes a chain extension reaction, while the small amount of trimers present are a result of small amounts of branching and crosslinking.

These gel %, GPC, and LC analyses show that BCB PC reacts during alloy melt processing to primarily form a very high-molecular-weight branched PC. On average, about 90 wt % of the BCB PC used to prepare the alloy reacts to yield a soluble, high-molecular-weight, branched PC; while the remainder forms an insoluble crosslinked PC dispersed in the thermoplastic matrix.

Properties of BCB PC–PC Alloys

Melt Flow Rate

The melt properties of BCB PC–PC alloys are radically altered compared to the base PCs, whereas the solid-state properties examined are largely unchanged. Two melt properties were examined in this study, MFR and melt strength. The MFR of these alloys are much lower than that of the corresponding base PC (Table III). For example, a 13 MFR PC-based alloy showed a MFR as low as 1.1. The decrease in MFR is proportional to both the amount and molecular weight of BCB PC used to make the alloy; but in these samples, which were prepared by extrusion, the actual amount of BCB in each alloy is uncertain. It appeared that part of the BCB PC was retained in the extruder, based on the large die swell observed during purging with linear PC, particularly in samples having larger concentrations of BCB PC.

As noted previously, BCB PC–PC alloys were injection-molded using the same conditions used to mold the base PC, in spite of the much lower MFR's measured for the alloys. It appears that the melt viscosity of these alloys is shear-rate-dependent. Therefore, MFR is not a representative measure of the melt processability of BCB PC–PC alloys.
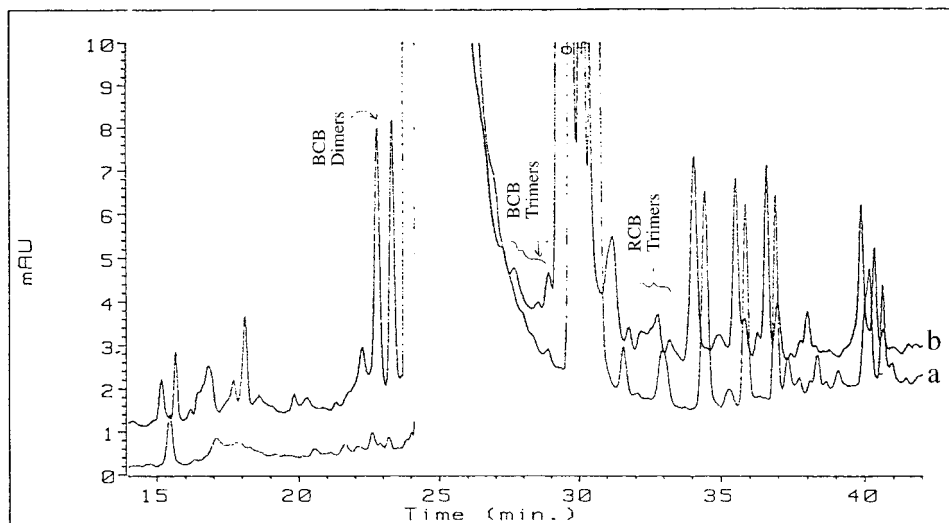
Figure 2 LC chromatographs of (a) 3 MFR PC and (b) BCB PC–PC alloy hydrolysates.

A comparison of the MFR of a series of 22 MFR PC-based alloys as a function of total wt % BCB unambiguously shows the strong effect of the initial molecular weight BCB PC (Table IV and Fig. 3). These samples were prepared on a small scale by solution blending–hot water devolatilization, followed by compression molding, a technique which eliminates any uncertainty in their compositions. Very little effect of the added BCB PC is seen in alloys having less than 0.10 wt % total BCB. At higher BCB levels, the decrease in MFR of the alloys is inversely proportional to the initial molecular weight of the BCB PC (as m/m increases, molecular weight decreases). Note that

two of these samples (MFR = 0) did not flow through the plastometer under the load and temperature used.

Melt Strength

The melt strength of BCB PC–PC alloys was measured by determining the mass that injection-molded tensile bars can hold at 200°C for 5 min.[6] The equilibrium load reported in Table III is the mass required to maintain the tensile bar at its original length. Since injection-molded materials having high melt strength tend to shrink upon heating above their T_g, the higher the equilibrium

Table III Melt Properties of BCB PC–PC Alloys

Sample	BCB PC (m/m)	BCB PC in Alloy (wt %)	BCB in BCB PC (wt %)	BCB Total in Alloy (wt %)	PC Base MFR	Alloy MFR	Eq Load (g)
13 MFR PC	—	—	—	—	13.0	—	0
3 MFR PC	—	—	—	—	3.5	—	0
Branched PC	—	—	—	—	2.5	—	36
1D	0.06	5.0	2.75	0.14	22.0	7.6	36
2D	0.06	7.0	2.75	0.19	22.0	4.4	68
3D	0.06	10.0	2.75	0.28	22.0	4.0	56
4D	0.06	5.0	2.75	0.14	13.0	4.4	56
5D	0.06	7.0	2.75	0.19	13.0	1.5	116
6D	0.06	9.0	2.75	0.25	13.0	1.1	200
7D	0.10	2.0	4.51	0.09	13.0	7.8	10
8D	0.10	3.5	4.51	0.16	13.0	4.6	50
9D	0.10	5.0	4.51	0.23	13.0	2.9	76
10D	0.06	4.0	2.75	0.11	3.0	1.9	98

Table IV MFR of BCB PC–PC Alloys

BCB (m m)	BCB (wt %)	Alloy (%)	BCB Total (%)	MFR
0.03	1.40	6.00	0.08	22.5
0.03	1.40	14.00	0.20	13.4
0.03	1.40	20.00	0.28	8.1
0.06	2.75	3.00	0.08	21.6
0.06	2.75	7.00	0.19	6.1
0.06	2.75	10.00	0.28	2.7
0.1	4.51	1.50	0.07	24.5
0.1	4.51	3.00	0.14	4.4
0.1	4.51	7.00	0.32	0
0.1	4.51	10.00	0.45	0

load, the greater the melt strength. Linear PCs have very low melt strengths and do not support even their own weight during this test.

Branched PC is manufactured specifically because of its higher melt strength. Only very small amounts of added BCB PC are needed to impart significantly higher melt strength in these alloys. A plot of the fractional length increase in this test versus weight added shows this effect (Fig. 4). Linear PC sags under its own weight, and branched PC holds about 36 g; whereas the alloy (4% of 0.06 m/m BCB PC in 3 MFR PC) holds about 98 g. Alloys having about a six-fold higher melt strength than branched PC were prepared, but this is probably not the upper limit of melt strength achievable. Comparing the alloys prepared from 13 MFR PC, it appears that those

made from 0.06 m/m BCB PC have a greater melt strength than those from 0.10 m/m BCB PC on a total wt % BCB basis.

Alloy melt strength depends on the amount of BCB PC and the MFR of the base PC (Fig. 5, wherein the lines are drawn to aid viewing). Higher melt strengths are found in alloys based on lower MFR base PCs. Within a given series of alloys, the melt strength generally increases roughly linearly with wt % BCB. The only exception to this trend is the last 0.06/22 alloy sample, which, in agreement with its melt strength, showed about the same M_w as the middle sample of that series. Alloys based on 0.06 m/m BCB PC show a greater effect in melt strength on a BCB weight basis than the 0.10 m/m analogs, which may be related to the molecular weight and/or the number of branches in the derived high-molecular-weight polymer.

A few room temperature mechanical property measurements were made on these alloys, showing that they are not significantly affected by incorporation of the reacted BCB PC (Table V). Notched Izod toughness, heat distortion temperature, and flexural modulus remain within the normal ranges for standard PCs.

Surface Gloss

Injection-molded samples of BCB PC–PC alloys have a matted surface appearance, the degree of which is proportional to the amount of BCB PC in the formulation. This surface effect does not
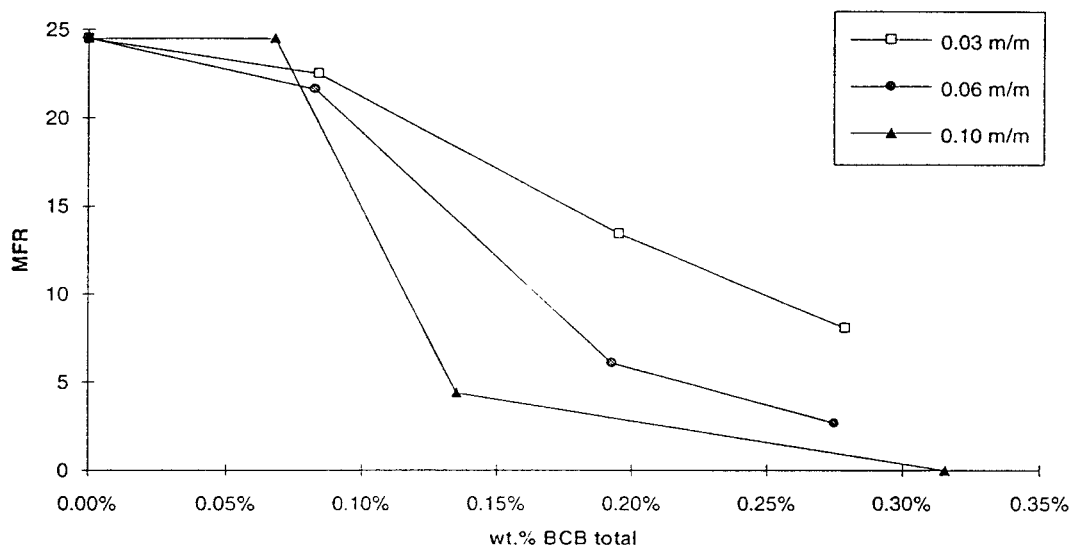

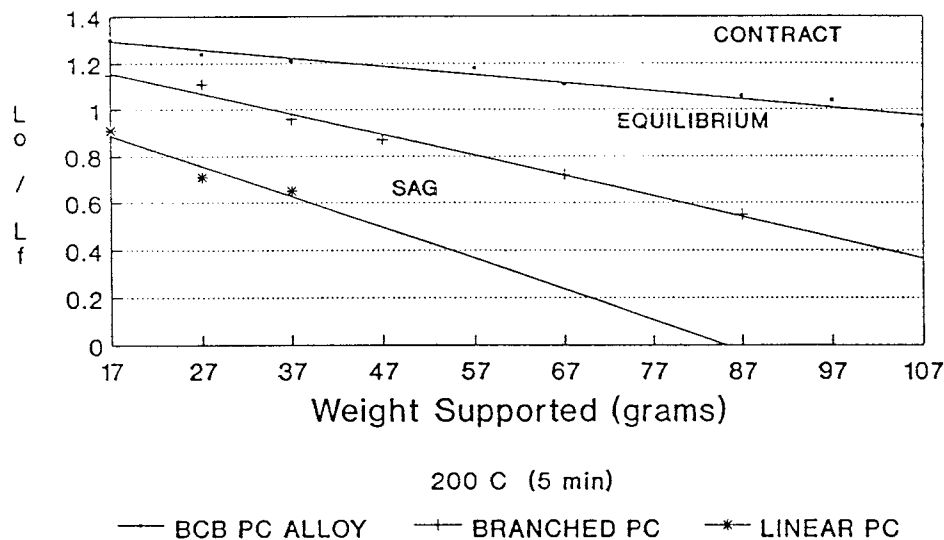**Figure 3** BCB PC/22 MFR PC alloy MFR versus wt % BCB total in alloy.

Figure 4 Melt strength of 3 MFR PC, branched PC, and BCB PC–PC alloy.

appear in compression-molded samples and is probably due to the higher low shear viscosity of the reacted BCB PC component in these materials. This phenomena can be measured as surface gloss (Table VI). Much lower gloss readings are found in alloys compared to linear PC, especially at the lower angles.

Ignition Resistance

Some ignition resistant (IR) PC products use poly(tetrafluoroethylene) (PTFE) as a drip-sup-

pressing agent in conjunction with other IR additives.[7] Problems associated with the use of PTFE in PC typically include a loss of impact and transparency and pitting of sample surfaces.[8] Preliminary results show that reacted BCB PC dispersed in PC can behave as a drip-suppressing agent in burn-test samples yet does not cause embrittlement or opacity problems. For example, a 5% 0.10 m/m BCB PC/13 MFR PC alloy was prepared from BCB PC and PC granules by extrusion at 280°C. To these extruded pellets were added IR additives, and the mixture was reextruded at
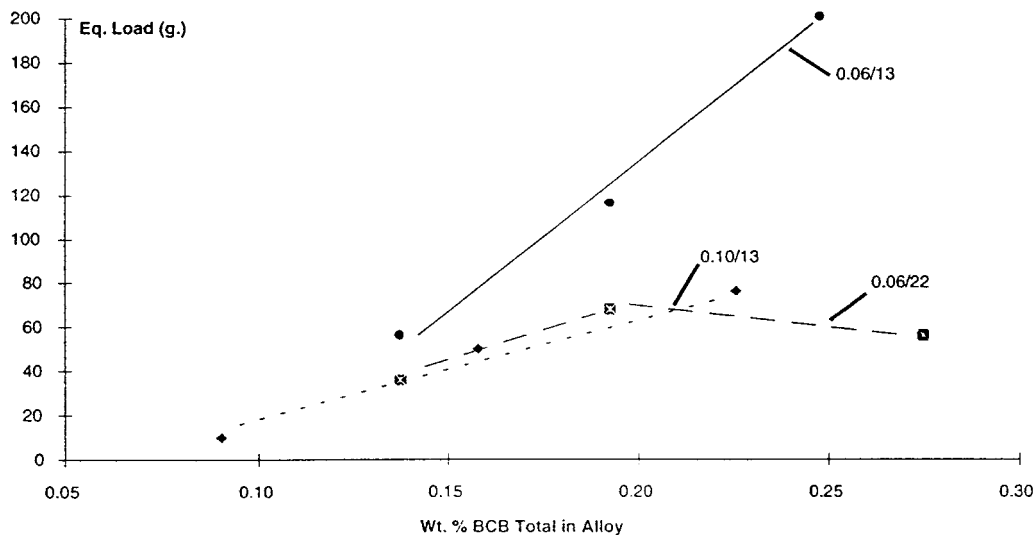

Figure 5 BCB PC–PC alloy melt strength versus wt % BCB total in alloy.

Table V Mechanical Properties of 4% 0.06/3 BCB PC–PC Alloy Compared to 3 MFR Linear and 3 MFR Branched PCs

Property	3 MFR PC	Branched PC	4% : 0.06/3 Alloy
300°C MFR	3.5	2.5	1.9
10 mil Izod (J/m)	907	854	854
DTUL (0.46 MPa; °C)	142	141	144
Flex. Mod. (MPa)	2480	2414	2345

311°C. Samples molded at 340°C showed improved ignition resistance due to the drip-suppressing action of the alloy and retention of the normal PC physical properties (Table VII).

EXPERIMENTAL

Materials

BCB PCs were prepared as previously described.[1] Linear CALIBRE™ 300-# (where # indicates the MFR) and branched CALIBRE 600-3 PCs were obtained from the Dow Chemical Co. *p*-Tolylsulfonamide (HPTSM) and its potassium salt (KPTSM) were obtained from Eastman Kodak Company, Kingsport, TN. BC-52 (tetrabromobisphenol A carbonate oligomers) was obtained from Great Lakes Chemical, West Lafayette, IN.

Melt Processing

BCB PC–PC alloys were prepared by tumble blending the two flake components, with extrusion in a Killion 2.54 cm single-screw extruder under the following conditions: 107 RPM, 270°C barrel temperature, and 5 amps. The material was flood-fed so that feed rate was controlled by the channel depth of the extruder. The extruded product exited a four hole die, quenched in a water bath, and then pelletized. The second extrusion was performed using a Werner–Pfleiderer corotating 30 mm twin-screw extruder operated at 240 RPM, 310°C barrel temperature, and 60 torque.

Table VI Surface Gloss of BCB PC–PC Alloy

Degree of Angle	3 MFR PC	5% : 0.06/13 Alloy
20	171	9
60	160	50
85	111	92

The material was quenched and pelletized as described above.

Prior to injection-molding, alloy samples were dried in a forced air oven at 125°C for at least four hours. Parts were made on an Arburg 70 ton injection-molding machine using a mold to make tensile and DTUL bars of 3.2 mm thickness. The following molding conditions were used: 315°C barrel temperature, 45 bar injection pressure, 85°C mold temperature, and 20 s cool time.

Alternatively solutions of BCB PC and PC in dichloromethane were prepared and hot-water-precipitated[1] to obtain a homogeneous mixed flake. These mixed flake materials were extruded and molded as described above, or compression-molded.[1]

Analytical

GPC[1] and melt strength[6] analyses were done as previously reported. Preparation and LC analysis of alloy hydrolysates was done as previously described,[3] except that the hydrolysate solution was not diluted with tetrahydrofuran prior to LC analysis. The following tests were done in accordance to ASTM procedures: MFR by ASTM D-1238, Izod impact strength by ASTM D-256, heat distortion (DTUL) by ASTM D-648, flexural modulus by ASTM D-790, tensile strength by ASTM D-638, and ignition resistance (UL-94) by ASTM D-4804-88. Weld line strength was measured on double-gate-molded, unnotched tensile bars, which were cut and tested according to the Izod ASTM D-256.

Gel analyses were performed on mixtures of about 0.5 g of alloy in about 30 g dichloromethane. After shaking the mixture for about 18 h, the insoluble portion was collected by vacuum on a 12.5 cm Whatman No. 1 qualitative filter. The gel was washed with excess CH_2Cl_2 and then dried in a vacuum oven at 100°C overnight. The dried sample was allowed to cool and then weighed.

Surface gloss was measured on injection-molded tensile bars using a Hunter Lab model

Table VII   Properties of BCB PC–PC Alloy Ignition-Resistant Formulation (alloy containing 0.1% HPTSM, 0.1% KPTSM, and 1.0% BC-52)

Additive	Concentration (%)	Property	Result
HPTSM	0.1	300°C MFR	2.0
KPTSM	0.1	1.53 mm UL-94	V-0
BC-52	1.0	3.2 mm Izod (J m)	811
—	—	Weldline Izod (J m)	no break
—	—	Tensile strength at peak (MPa)	61
—	—	Tensile strength at break (MPa)	63
—	—	Tensile elongation at break (%)	90
—	—	DTUL (0.46 MPa; °C)	142

LMG064 gloss meter. Readings were recorded after 5 s exposure; the average of three readings is reported.

CONCLUSIONS

Thermoplastic BCB PC–PC alloys can be prepared by double extrusion of the flake components as follows: first, at a relatively low temperature at which the BCB PC reacts slowly; and, second, at a higher temperature to complete the BCB PC reaction. Combining these separate extrusion steps into one having the appropriate temperature control would appear quite feasible. These alloys can then be injection-molded using the same conditions as used to mold the base PC.

GPC and LC analyses show that the BCB PC forms a very high-molecular-weight branched polymer, which is largely soluble in the base PC. Only minor amounts of insoluble, crosslinked BCB PC are formed under the appropriate melt processing conditions.

The MFR of BCB PC–PC alloys is much lower than that of the base PC, yet the two materials can be injection-molded under identical conditions. This phenomena indicates that the melt viscosity of these alloys has high shear sensitivity. Therefore, MFR is not an accurate measure of the melt processability of BCB PC–PC alloys. The melt strength of BCB PC–PC alloys is much greater than that of linear or branched PC and is dependent on the amount and type of BCB PC and the MFR of the base PC. Transparent alloys having about a six-fold increase in melt strength over branched PC were prepared.

The mechanical properties of these alloys that were examined are largely unchanged compared to standard grades of PC. Alloys retain the high toughness, heat distortion, and flexural modulus typically associated with PC. The surface gloss on injection-molded BCB PC–PC alloys is reduced compared to linear PC and appears to decrease with increasing BCB PC content in the formulation. The melt strength of BCB PC–PC alloys also imparts drip suppressant properties in burning samples. An IR alloy formulation had a 1/16 in. UL-94 V-0 rating while retaining transparency and normal PC physical properties.

REFERENCES

1. M. J. Marks and J. K. Sekinger, *Macromolecules,* **27,** 4106 (1994).
2. J. A. Logan and M. J. Marks, U.S. Pat. 5,318,827 (1994).
3. M. J. Marks, J. S. Erskine, and D. A. McCrery, *Macromolecules,* **27,** 4114 (1994).
4. D. Klempner and L. Berkowski in *Encyclopedia of Polymer Science and Engineering,* Vol. 8, H. F. Mark, N. M. Bikales, C. G. Overberger, G. Menges, J. I. Kroschwitz, Eds., Wiley, New York, 1987, pp. 279–341.
5. H. T. Pham, in *Proceedings of the SPE 53rd Annual Technical Conference in Boston, MA,* Vol. 16, 1995, p. 1116. B Society of Plastics Engineers, Brookfield Center, CT.
6. M. K. Laughner, U.S. Pat. 5,273,706 (1993).
7. S. A. Ogoe and T. H. Ho, U.S. Pat. 4,826,900 (1989).
8. S. A. Ogoe, U.S. Pat. 5,041,479 (1991).