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Prediction of a synergistic blend composition range based on polymer–solvent interactions*

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Solubility characteristics of bisphenol A polycarbonate, acrylonitrile-butadiene-styrene and their blends are studied in different solvents. A computer program known as 'spherical volume of solubility' is used to determine total and partial solubility parameters of the polymers and their blends. The solubility parameters calculated from group contribution techniques are compared with the computed data. Using Bagley's approach, the composition of a blend with synergy is predicted. Mechanical properties of the blends are found to be in good agreement with the predictions made from the solubility studies. © 1997 Elsevier Science Ltd.

(Keywords: *solubility characteristics; polymer–solvent interaction; mechanical properties*)

INTRODUCTION

Aromatic polycarbronates (PC) are recognized as a family of high performance polymers owing to their excellent mechanical properties such as impact strength, flexural modulus/strength, tensile strength and heat deflection temperature. However, these polymers exhibit poor chemical resistance and require high temperatures for processing (above 300°C). One approach to improve chemical resistance and ease of processability (with a marginal loss in mechanical properties) is by blending PC with ABS polymer[1–10]. The resultant blend properties are dependent on the nature of ABS, miscibility of the components, their processing conditions[6,7] and ultimate morphology of the blend.

Solubility parameter, an index of inter-molecular forces, is generally being used in selecting a suitable solvent. The Hilderbrand's approach to solubility parameter and refinements in its concepts are discussed in detail by Olabisi *et al.*[11]. The predictions of polymer–polymer miscibility, based on unfavourable physical forces, described in terms of non-hydrogen bonded solubility parameters and favourable specific interactions is presented by Coleman *et al.*[12]. These predictions are discussed in terms of critical values of interaction parameter, χ_{crit}, and the upper limits of non-hydrogen bonded solubility parameter difference, δ. A microscopic solubility parameter theory for polymer blends is developed based on liquid-state polymer reference interaction site model (PRISM) integral equation methods[13]. The microscopic solubility parameter theory predicts many novel, non-Flory–Huggins effects and their contributions to the χ-parameter. However, selection of solvents for blends based on the concept of solubility parameter is rarely found in literature.

In this paper, the Hansen's approach[14–16], applied earlier to various copolymers[17,18], is extended to PC, ABS polymers and their blends in order to calculate 'three-dimensional solubility parameter' along with its components, viz. dispersive, polar and hydrogen bonding forces. The three-dimensional solubility parameters of individual polymers and their blends are compared with values calculated from group contribution techniques[19–21]. An attempt has been made based on solvent–polymer and solvent–blend interactions to predict a suitable grade of ABS with which PC can form a blend with synergistic performance. The predictions are correlated with mechanical performance of the blend.

EXPERIMENTAL

Materials

Two different grades of polycarbonate (Lexan supplied by GE Plastics, The Netherlands) having viscosity average molecular weights ($\bar{M}_{\mathrm{V}}$) 33 243 and 14 079 are used in the investigations. Three different grades of ABS resins (Absolac supplied by ABS Plastics, India, and Polylac supplied by Polychem Ltd., India) having acrylonitrile (A) 24–27 wt%; butadiene (B) 12–20 wt%; and styrene (S) 54–64 wt% are used.

Blends preparation

In order to remove moisture, PC and ABS are dried at 120 ± 2°C for 4 h and 80 ± 2°C for 2 h, respectively. Later they are dry blended in the concentration range PC/ABS 100/0 to 0/100 wt% and then extruded in a Brabender Plasticorder with optimized temperature profile, for each blend. The extruded blends and their compositions are given in *Table 1*.

The extruded blend granules from the Brabender Plasticorder are dried at 100 ± 2°C for 2 h to remove

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Table 1 Extruded blends code and composition

Sol. No.	PC/ABS	Code	Sol. No.	PC/ABS	Code
	PC-1/ABS(A)			PC-2/ABS(A)	
1.	90/10	APC1B-1	16.	90/10	APC2B-1
2.	70/30	APC1B-2	17.	70/30	APC2B-2
3.	50/50	APC1B-3	18.	50/50	APC2B-3
4.	30/70	APC1B-4	19.	30/70	APC2B-4
5.	10/90	APC1B-5	20.	10/90	APC2B-5
	PC-1/ABS(B)			PC-2/ABS(B)	
6.	90/10	BPC1B-1	21.	90/10	BPC2B-1
7.	70/30	BPC1B-2	22.	70/30	BPC2B-2
8.	50/50	BPC1B-3	23.	50/50	BPC2B-3
9.	30/70	BPC1B-4	24.	30/70	BPC2B-4
10.	10/90	BPC1B-5	25.	10/90	BPC2B-5
	PC-1/ABS(C)			PC-2/ABS(C)	
11.	90/10	CPC1B-1	26.	90/10	CPC2B-1
12.	70/30	CPC1B-2	27.	70/30	CPC2B-2
13.	50/50	CPC1B-3	28.	50/50	CPC2B-3
14.	30/70	CPC1B-4	29.	30/70	CPC2B-4
15.	10/90	CPC1B-5	30.	10/90	CPC2B-5

Table 2 Solubility parameters of selected solvents

Sol. No.	Solvent	δ	δ_d	δ_p	δ_h
1.	Hexane	14.77	14.77	0.00	0.00
2.	Diethyl ether	15.55	14.39	2.86	5.10
3.	Cyclohexane	16.69	16.69	0.00	0.00
4.	*n*-Butyl acetate	17.27	15.65	3.67	6.66
5.	Carbon tetrachloride	17.65	17.65	0.00	0.00
6.	*p*-Xylene	17.96	17.65	1.02	3.06
7.	Ethyl acetate	18.57	15.18	5.31	9.18
8.	Benzene	18.67	18.26	1.02	2.04
9.	Chloroform	18.80	17.65	3.06	4.69
10.	Methyl ethyl ketone	18.92	15.86	8.98	5.10
11.	Tetrahydrofuran	19.43	16.77	5.71	7.96
12.	Ethylene dichloride	19.92	18.77	5.31	4.08
13.	Acetone	19.94	15.47	10.41	6.94
14.	Cyclohexanone	20.16	17.65	8.37	5.10
15.	Methylene chloride	20.27	18.18	6.33	3.26
16.	1,2-Dichlorobenzene	20.37	19.08	6.33	3.26
17.	1,4-Dioxane	20.41	18.98	1.84	7.34
18.	Diacetone alcohol	20.78	15.61	8.16	10.82
19.	Benzaldehyde	21.22	18.67	8.57	5.31
20.	*t*-Butyl alcohol	21.65	15.20	4.16	14.28
21.	Nitrobenzene	21.67	17.55	12.24	4.08
22.	Aniline	22.53	19.45	5.10	10.20
23.	*m*-Cresol	22.67	18.00	5.10	12.86
24.	N,N-Dimethylacetamide	22.76	16.75	11.47	10.18
25.	N-Methyl pyrrolidone	22.84	17.86	12.26	7.18
26.	Isopropyl alcohol	23.55	15.75	6.08	16.37
27.	N,N-Dimethyl formamide	24.78	17.39	13.67	11.22
28.	Ethyl alcohol	26.36	15.77	8.77	19.39
29.	Dimethyl sulfoxide	26.39	18.37	16.33	10.20
30.	Methyl alcohol	29.14	15.14	12.24	22.24
31.	Propylene glycol	30.20	16.82	9.39	23.26
32.	Ethylene glycol	33.27	16.84	11.02	25.92
33.	Formamide	36.33	17.14	26.12	18.98

All the values are in $(\mathrm{J\,cm^{-1}})^{0.5}$

Values for most of the solvents were taken from Hansen's work[16]

moisture. The granules of all the compositions are compression moulded into sheets (0.150 m × 0.125 m × 0.0032 m). The compression moulding of all the blends is carried out in the temperature range 460–490 K at 100 MPa pressure with a moulding cycle time of 4–8 min.

Solubility test

Thirty-three solvents having solubility parameters from 14.77 to 36.33 $(\mathrm{J\,cm^{-1}})^{1/2}$ are used in the study of solubility characteristics of the neat polymers as well as their blends. The values of total (δ) and partial (δ_d, δ_p and δ_h) solubility parameters are listed in *Table 2*.

About 0.2 g of polymer/blend is taken in each of the 33 test tubes and about 5 ml of each of the selected solvents is added individually to all the test tubes, fitted with stoppers. Then the test tubes are kept undisturbed at 25 ± 1°C, for 48 h. However, after an interval of 24 h, the solubility characteristics are observed. The solvents, with which polymer/blend has either partial or no interaction, are heated in a water-bath maintained at 50 ± 5°C and the solubility characteristics are observed again after 24 h. Based on these observations, the polymer/blend is classified as completely soluble, partially soluble or insoluble.

Testing

The test specimens of PC, ABS and their blends are cut with dimensions 0.152 m × 0.127 m × 0.0032 m from the compression moulded sheets. These specimens are tested for Izod impact strength, tensile modulus and strength properties using an impact tester and Universal Testing Machine (Instron 1195) respectively. The tensile testing of the prepared specimens is carried out with a cross-head speed 0.005 m min^{-1}, chart speed 5/1, and grip separation 0.0108 m with full scale load 200 kg.

RESULTS AND DISCUSSION

The solubility characteristics of pure polymers as well as their blends are given in *Table 3*. It is observed, that the neat polymers, PC-1, PC-2, ABS-A, ABS-B and ABS-C are soluble in polar solvents like chloroform, tetrahydrofuran, 1,2-dichlorobenzene, 1,4-dioxane, benzaldehyde and nitrobenzene etc. (A little haze is observed in all ABS solutions.) The solubility, of these polymers, in the solvents may be attributed to the presence of possible interactions such as polar (due to nitrile group) as well as hydrogen bonding (due to carbonate group and the presence of tertiary proton in PC and ABS respectively). The parent polymers and their blends are found to be insoluble in esters, ethers and aliphatic hydrocarbons like *n*-butyl acetate, diethyl ether, hexane, etc. It is observed that as the ABS concentration increases in CPC1B(1–5) and CPC2B(1–5) blends, the solubility decreases considerably in even strong polar solvents like dimethyl sulfoxide, N-methyl pyrrolidone, *m*-cresol, etc. A similar trend is observed in APC1B(1–5) and APC2B(1–5); BPC1B(1–5) and BPC2B(1–5) blends. The marked change in the solubility behaviour (from completely soluble to partially soluble/insoluble) in the highly polar solvents, may be attributed to the non-availability of resonance forces necessary between the solvent and the blend when compared to the parent polymers. By feeding the data, of δ_d, δ_p and δ_h of those solvents which had interactions with the polymer/blend leading to dissolution either completely or partially, in the computer program (the algorithm used is stated in the flow diagram shown in the Appendix), spherical volume of solubility, the co-ordinates of the centre and the radius of interaction sphere are obtained. The co-ordinates correspond to the δ'_d, δ'_p and δ'_h of polymer/blend. The computed data for PC-1/PC-2, ABS-A, ABS-B, ABS-C and their blends are shown in *Table 4*. In a similar way the total (δ') and partial solubility parameters (δ'_d, δ'_p and δ'_h) for PC-2 and its blends are

Table 3 Solubility characteristics of polymers and blends

Sol. No.[a]	PC-2	ABS			APC1B/APC2B				
		A	B	C	1/1	2/2	3/3	4/4	5/5
1.	−	−	−	−	−/−	−/−	−/−	−/−	−/−
2.	−	−	−	−	−/−	−/−	−/−	−/−	−/−
3.	−	−	−	−	−/−	−/−	−/−	−/−	−/−
4.	−	−	*	−	−/−	−/−	−/−	−/−	−/−
5.	−	−	−	−	−/−	−/−	−/−	−/−	−/−
6.	−	−	−	−	−/−	−/−	−/−	−/−	−/−
7.	−	−	−	−	−/−	−/−	−/−	−/−	−/−
8.	−	+	*	−	−/−	−/−	−/−	−/*	−/*
9.	+	+	+	+	+/+	+/+	+/+	+/+	+/+
10.	−	*	+	−	−/−	−/−	−/−	−/−	−/−
11.	+	*	+	−	−/+	−/+	−/+	*/*	+/*
12.	+	+	+	*	+/+	+/+	+/+	+/+	+/+
13.	−	−	−	−	−/−	−/−	−/−	−/−	−/−
14.	−	+	+	*	−/−	−/−	+/−	*/*	*/+
15.	+	+	+	*	+/+	+/+	+/+	+/+	+/+
16.	*	+	+	+	−/−	−/−	+/+	+/*	+/*
17.	+	*	+	+	−/+	*/+	*/*	+/*	+/*
18.	−	−	−	−	−/−	−/−	+/−	−/−	−/−
19.	*	+	+	+	−/*	−/*	+/−	+/−	+/*
20.	−	−	−	−	−/−	−/−	−/−	−/−	−/−
21.	+	+	+	+	*/*	−/*	*/*	+/+	+/+
22.	+	−	*	−	−/*	−/*	+/*	+/*	+/*
23.	+	*	*	−	−/−	−/−	+/−	+/−	−/+
24.	−	−	−	−	−/−	−/−	−/*	+/−	+/*
25.	−	*	+	−	−/−	−/−	−/−	−/−	−/*
26.	−	−	−	−	−/−	−/−	−/−	−/−	−/−
27.	−	−	*	−	−/−	−/−	*/−	*/−	*/−
28.	−	−	−	−	−/−	−/−	−/−	−/−	−/−
29.	−	*	*	−	−/−	−/−	−/−	−/−	−/−
30.	−	−	−	−	−/−	−/−	−/−	−/−	−/−
31.	−	−	−	−	−/−	−/−	−/−	−/−	−/−
32.	−	−	−	−	−/−	−/−	−/−	−/−	−/−
33.	−	−	−	−	−/−	−/−	−/−	−/−	−/−

Sol. No.	BPC1B/BPC2B					CPC1B/CPC2B				
	1/1	2/2	3/3	4/4	5/5	1/1	2/2	3/3	4/4	5/5
1.	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−
2.	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−
3.	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−
4.	−/−	−/−	−/−	−/−	*/−	−/−	−/−	−/−	−/−	−/−
5.	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−
6.	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−
7.	−/−	−/−	−/−	−/−	*/−	−/−	−/−	−/−	−/−	−/−
8.	−/−	−/−	−/−	*/−	+/+	−/−	*/−	−/−	−/−	−/−
9.	+/+	+/+	+/+	+/+	+/+	+/+	+/+	+/+	+/+	+/+
10.	−/−	−/−	−/−	−/−	−/*	−/−	−/−	−/−	−/−	−/−
11.	−/−	*/+	+/+	+/+	+/+	−/+	*/*	+/*	+/*	+/−
12.	+/+	+/+	+/+	+/+	+/+	+/+	+/+	+/+	+/+	+/+
13.	−/−	−/−	−/−	*/−	*/*	−/−	−/−	−/−	−/−	−/−
14.	−/−	−/−	+/+	+/+	+/+	−/+	−/+	−/+	*/+	*/+
15.	+/+	+/+	+/+	+/+	+/+	+/−	+/*	+/−	+/−	+/−
16.	−/−	+/*	+/+	+/+	+/+	−/*	*/−	+/−	+/+	+/+
17.	+/−	+/+	*/+	+/+	+/+	+/+	+/+	+/+	+/*	*/+
18.	−/−	−/−	−/−	+/−	−/−	−/−	−/−	−/−	−/−	−/−
19.	+/−	−/*	+/+	*/+	+/+	−/*	+/*	−/−	+/+	+/+

Table 3 (Continued)

Sol. No.	BPC1B/BPC2B 1/1	2/2	3/3	4/4	5/5	CPC1B/CPC2B 1/1	2/2	3/3	4/4	5/5
20.	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−
21.	+/−	*/*	+/+	*/+	+/+	−/+	+/+	+/−	+/+	+/+
22.	−/−	−/−	*/−	*/−	*/−	−/+	+/+	+/−	+/−	+/*
23.	−/−	−/−	*/+	+/+	+/+	−/+	−/+	−/−	−/−	−/−
24.	−/−	−/−	+/−	*/−	+/+	−/−	−/−	*/−	*/−	*/−
25.	−/−	−/−	+/−	*/−	+/+	−/−	−/−	−/−	−/−	+/−
26.	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−
27.	−/−	−/−	+/−	+/−	+/+	−/−	−/−	*/−	+/−	+/−
28.	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−
29.	−/−	−/−	−/−	*/−	+/+	−/−	−/−	−/−	−/−	*/−
30.	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−
31.	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−
32.	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−
33.	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−	−/−

[a] The solvent numbers correspond to the same solvents as mentioned in *Table 1*
+, completely soluble; *, partially soluble; −, insoluble
APC1B/APC2B 1/1 corresponds to APC1B-1/APC2B-1
2/2 corresponds to APC1B-2/APC2B-2, etc.

Table 4 Partial (δ'_d, δ'_p, δ'_h) and total (δ') solubility parameters of PC-1, ABS-A, ABS-B, ABS-C and their blends

Blend code	δ'_d	δ'_p	δ'_h	δ'
PC-1	18.27	7.04	5.71	20.39
ABS-A	18.32	8.67	6.12	21.17
ABS-B	18.06	6.64	4.61	19.79
ABS-C	17.60	7.65	4.39	19.69
APC1B-1	17.60	7.65	4.39	19.69
APC1B-2	18.58	4.08	5.31	19.75
APC1B-3	18.18	7.75	9.29	21.84
APC1B-4	18.18	7.75	9.29	21.84
APC1B-5	18.18	7.75	9.29	21.84
BPC1B-1	18.26	7.04	5.71	20.39
BPC1B-2	18.26	7.04	5.71	20.39
BPC1B-3	18.18	7.75	9.29	21.84
BPC1B-4	18.32	8.67	6.12	21.17
BPC1B-5	18.32	8.67	6.12	21.17
CPC1B-1	18.58	4.08	5.31	19.75
CPC1B-2	17.91	6.63	3.06	19.34
CPC1B-3	18.18	7.75	9.29	21.84
CPC1B-4	18.18	7.75	9.29	21.84
CPC1B-5	18.67	9.08	8.78	22.54

All values are in $(\mathrm{J\,cm^{-1}})^{0.5}$

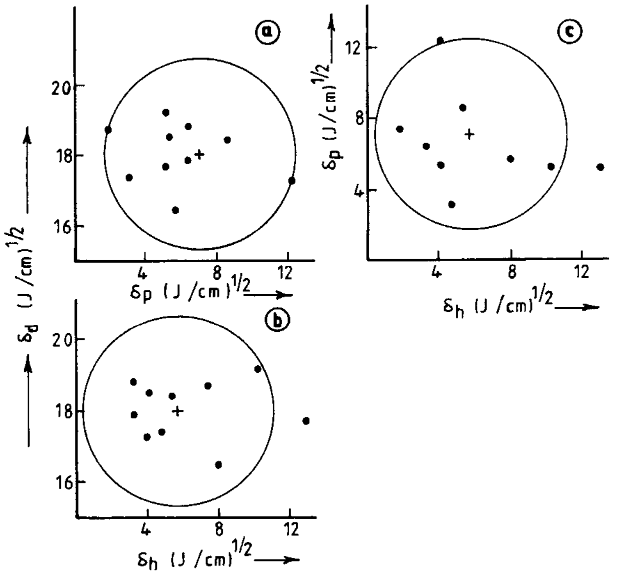

Figure 1 Typical plots of three dimensional solubility parameter in δ_d–δ_p, δ_p–δ_h and δ_d–δ_h axes for CPC2B-1 blend according to Hansen[16]

also computed. The typical plots of three-dimensional solubility parameter in δ'_d–δ'_p, δ'_p–δ'_h and δ'_d–δ'_h axes for CPC2B-1 blend are shown in *Figure 1*.

From *Table 4*, it is observed that having fulfilled the necessary and sufficient conditions for solubility to occur according to Krause[22], PC and ABS resins have not formed miscible blends, as is evident from other studies[23]. From a study of phase behaviour of PC/ABS blends Kim and Burns[24] reported that these are partially miscible. And a similar trend is also observed, earlier, by Heiss[25] with neat polycarbonate dissolution in various solvents. It is felt that the presence of active hydrogen atom, small molecular size and solubility parameter (for solvents) are to be considered but not solubility parameter alone in order to assess solvent effectiveness for solubility to occur. The solubility parameter (δ) values obtained by theoretical methods (such as group contribution techniques) according to Small[19], Van Krevelen[20] and Hoy[21] are shown in *Table 5* for PC-1/PC-2, three grades of ABS and their blends. These values are found to be in good agreement with the three-dimensional solubility parameter (δ') obtained by the computer program. 'Spherical volume of solubility'. The differences in δ' values are due to the differences in basic assumptions in the respective methods in calculating the contribution of cohesive energies of various groups that are present in the repeat units of the basic polymers. These differences have resulted in different δ values for the same polymer/blend.

As observed earlier, the contributions due to polar

Table 5 Solubility parameters of polymers and their blends obtained from different methods

Polymer/blend	Small[19] (δ)	Van Krevelen[20] (δ)	Hoy[21] (δ)	Computer program (δ')
PC-1/PC-2	20.14	21.14	21.63	20.39
ABS-A	21.82	23.51	22.02	21.17
ABS-B	22.00	23.73	22.16	19.79
ABS-C	24.73	26.67	24.98	19.69
APC1B(1–5)/APC2B(1–5)	21.33	22.53	22.51	19.67–21.84/19.75–20.39
BPC1B(1–5)/BPC2B(1–5)	20.61	21.82	21.75	20.39–21.16/18.94–21.16
CPC1B(1–5)/CPC2B(1–5)	21.16	21.59	21.57	19.35–22.55/19.75–20.39

All values are in $(\mathrm{J\,cm^{-1}})^{0.5}$
APC1B(1–5) means APC1B-1 to APC1B-5
BPC1B(1–5) means BPC1B-1 to BPC1B-5
CPC1B(1–5) means CPC1B-1 to CPC1B-5
Similarly for APC2B, BPC2B and CPC2B blends

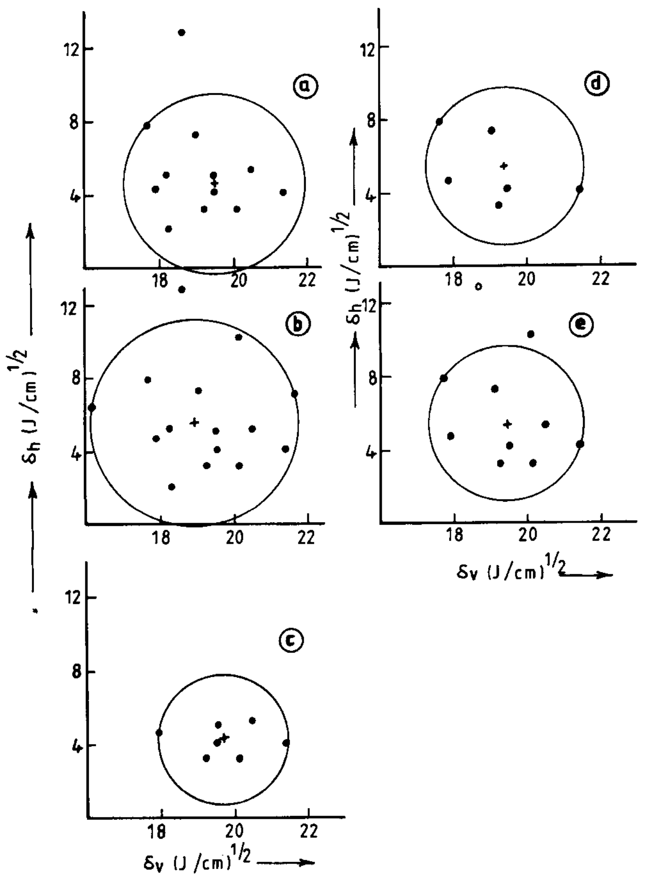

Figure 2 Plots of δ_v vs δ_h of: (a) ABS-A; (b) ABS-B; (c) ABS-C; (d) PC-1; (e) PC-2 neat polymers according to Bagley *et al.*[26]

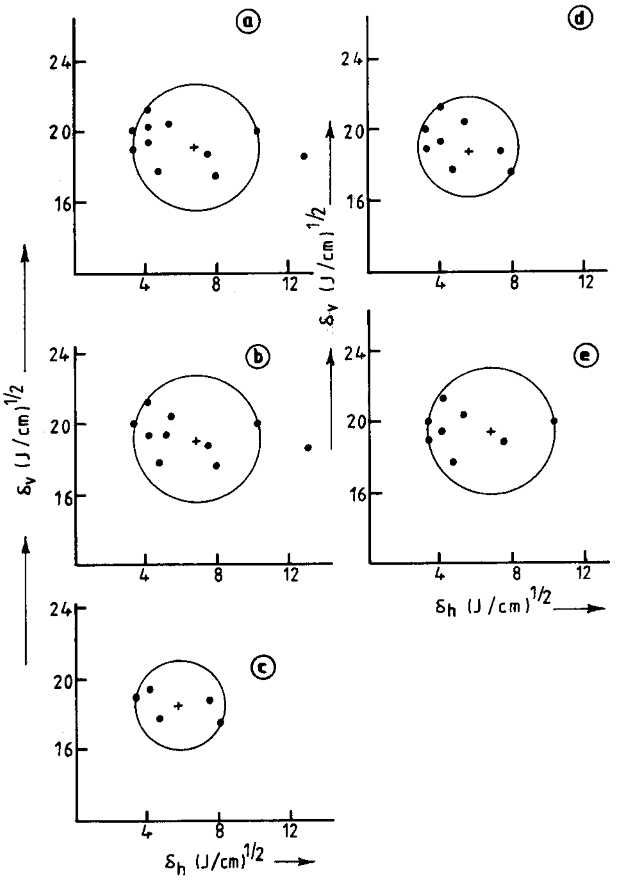

Figure 3 Plots of δ_v vs δ_h of: (a) CPC2B-1; (b) CPC2B-2; (c) CPC2B-3; (d) CPC2B-4; (e) CPC2B-5 blends according to Bagley *et al.*[26]

forces and dispersive forces, which are almost alike, but really not the same, are plotted to identify the limits of solubility following the procedure adopted by Bagley[26]. The plots are shown for pure polymers PC-1, PC-2, ABS-A, B and C in *Figure 2* and for blends CPC2B-1 to CPC2B-5 in *Figure 3*. A parameter, similar to that proposed by Bagley, δ_v $[\delta_v = \sqrt{(\delta_d^2 + \delta_p^2)}]$, is also reported by Van Arkel and Vles[27] in their multidimensional approach to solubility parameter in which the sum of the partial solubility parameters due to dipole–dipole and dispersive forces are considered. According to the Bagley concept[26], the points for good solvent have fallen in a circular region and the radius of the circle has demarcated the solubility region for polymers/blends. Using this solubility region, an appropriate solvent can be selected for a polymer or a blend for solution processing. It has been observed that the radius of circle obtained by plotting δ_v vs δ_h is significant in the selection of PC and ABS grades to result in a synergistic blend. From *Figure 2*, it is found that the radii of circles are in the following order: PC-1 ≈ PC-2 and ABS-A > ABS-B > ABS-C. A combination of ABS-C with either

PC-1 or PC-2 resulted in a better blend than with the other two grades of ABS. Further, the application of Bagley's approach to CPC2B blends, shown in *Figure 3*, has indicated a blend with minimum radius, at CPC2B-3. This blend has exhibited synergy in its mechanical properties which are discussed below. In a similar way, CPC1B blends have also shown the same pattern of behaviour in the entire composition range. These blends have also shown synergy near the composition where the radius is minimum in the plot of δ_v vs δ_h. In fact, the CPC1B-3 blend exhibits a circle with minimum radius and the synergy in its mechanical properties is also exhibited near this composition.

Mechanical properties

Mechanical properties of neat polymers and their blends are evaluated. The properties, viz. Izod impact strength, tensile modulus and tensile strength are shown for neat polymers in *Table 6*, and for all the blends in *Tables 7* and *8*. The blends of PC-2 with ABS-A; i.e. APC2B(1–5), have shown higher values of tensile modulus than PC-1 with ABS-A; i.e. APC1B(1–5) in the entire composition range, whereas APC1B(1–5) blends, except APC1B-3, exhibited a similar behaviour in their modulus values. In the case of the blends of PC-1 with ABS-B; i.e. BPC1B(1–5), have shown higher values of tensile modulus than PC-2 with ABS-B; BPC2B(1–5). It is also observed that BPC1B(1–5) blends exhibited higher modulus values compared to the corresponding neat polymers. The blends of PC-1 and PC-2 with ABS-C; i.e. CPC1B(1–5) and CPC2B(1–5), except CPC1B-2 and CPC2B-2, exhibited a similar behaviour in their values.

Table 6 Mechanical properties of PC and ABS polymers

Polymer	Izod impact strength (J m^{-1})	Tensile properties: Modulus (MPa)	Tensile properties: Strength (MPa)
PC-1	587.44	1521.88	22.51
PC-2	467.50	1609.00	20.01
ABS-A	43.64	1850.71	20.33
ABS-B	129.26	1562.88	20.10
ABS-C	291.76	1344.49	20.99

Table 7 Mechanical properties of PC-1/ABS blends

Blend code	Izod impact strength (J m^{-1})	Tensile properties: Modulus (MPa)	Tensile properties: Strength (MPa)
APC1B-1	28.73	1395.02	14.15
APC1B-2	424.94	1539.35	21.41
APC1B-3	141.71	1807.07	16.84
APC1B-4	56.39	1342.63	27.75
APC1B-5	20.89	1527.68	18.44
BPC1B-1	124.84	1861.25	20.77
BPC1B-2	18.93	1692.61	14.35
BPC1B-3	13.34	1821.52	6.58
BPC1B-4	11.28	1698.15	6.25
BPC1B-5	15.30	1644.77	27.14
CPC1B-1	247.63	1477.35	24.30
CPC1B-2	53.94	1535.75	21.67
CPC1B-3	496.73	1296.73	29.39
CPC1B-4	337.66	1304.58	27.29
CPC1B-5	339.33	1215.78	26.85

Table 8 Mechanical properties of PC-2/ABS blends

Blend code	Izod impact strength (J m^{-1})	Tensile properties: Modulus (MPa)	Tensile properties: Strength (MPa)
APC2B-1	101.01	1822.56	26.72
APC2B-2	392.58	1701.68	26.61
APC2B-3	220.66	1678.83	34.45
APC2B-4	28.93	1699.74	30.35
APC2B-5	42.66	1759.07	35.25
BPC2B-1	131.81	1567.05	14.58
BPC2B-2	58.16	1542.22	10.90
BPC2B-3	47.32	1684.32	10.90
BPC2B-4	68.65	1719.97	15.15
BPC2B-5	127.49	1584.53	17.21
CPC2B-1	278.81	1018.16	18.32
CPC2B-2	656.09	1567.00	31.31
CPC2B-3	429.26	1359.84	31.43
CPC2B-4	188.00	1418.32	25.13
CPC2B-5	364.14	1210.76	24.84

It is observed that the difference of 10 wt% of styrene content in different ABS resins did not influence the modulus behaviour of the blends significantly. The lower values of tensile strengths of APC1B(1–5) (except APC1B-4) and BPC1B(1–5) (except BAC1B-5) in comparison with CPC1B(1–5) are due to the absence of intermolecular interactions between PC and ABS resins. The present study on the blends confirms this observation. The tensile strength values of the blends of three different ABS resins with PC-2 are found to be higher than with PC-1 and are in the following order: APC2B(1–5) > CPC2B(1–5) > BPC2B(1–5). The intermolecular interactions such as dipole–dipole, hydrogen bonding, etc. are attributed to be maximum in these blends. These interactions, leading to partial miscibility, are influenced significantly by the molecular weight of polycarbonate (as observed in APC1B(1–5) and APC2B(1–5) blends shown in *Tables 7* and *8*). The interactions between PC and SAN phases of ABS are influenced by the acrylonitrile (AN) content[28]. It has been reported[7] that the adhesion has gone through a sharp maximum when the AN content is in the range of 25–27 wt%. Huang and Wang[29] have also reported a similar observation in their study on PC/SAN blends. Their study has made use of the solubility parameter approach with its three components δ_d, δ_p and δ_h. These three components are used in the estimation of optimum volume fractions of AN content in the continuous phase of ABS.

CPC1B(1–5) and CPC2B(1–5) blends have shown better impact strength than other blends. The difference in the impact behaviour in the blends with ABS-A, ABS-B and ABS-C is due to the different butadiene contents[30]. The impact strength, exhibited by these blends, is probably not only dependent on the rubber content but also on other morphological features (which are discussed below) just as in the case of other toughened plastics such as HIPS and ABS[31]. The factors influencing the impact strength, with respect to three different ABS polymers and other morphological features are being investigated in detail to understand the history of blend formation and their performance.

In toughened plastics, mechanical properties are significantly influenced by the rubber content, its nature, rubber particle size as well as the interparticulate distances[32–35]. Solubility characteristics of a blend, on the other hand, are identified based on chemical interaction between the solvent and the components of the blend but not on the physical features of the blend constituents. Thus, the solubility characteristics are apparently insensitive to the finer morphological features such as rubber particle size and inter-particulate distances in a blend. The exceptional behaviour of certain blends, mentioned above, calls for an in-depth study of such morphological features *vis-a-vis* mechanical properties which becomes a separate subject for study.

CONCLUSIONS

(1) The solubility parameters obtained through a computer program are found to be in good agreement with the theoretical values obtained from group contribution techniques, according to Small, Hoy and Van Krevelen, for polycarbonates, ABS and their blends, respectively. However, the Krause rule is found to be disobeyed in the blends formation.

(2) A salient feature observed in PC/ABS blends is that with the significance of the radius of circle in the plots of δ_v vs δ_h. The smaller the radius of a neat polymer (both PC and ABS) the greater the preference, for those polymers, for the formation of a blend with better performance. A similar behaviour is observed in the blends (e.g. CPC2B-3 radius is found to be small in the plot of δ_v vs δ_h among all the blends of CPC2B and synergy occurred near this composition).

(3) However, the computational values of δ' using Hansen's approach are found to be the basic requirement, in our PC/ABS system, in the prediction of a blend with an optimum mechanical performance.

(4) The mechanical performance of the blends is found to be in good agreement with the predictions made from the solubility studies.

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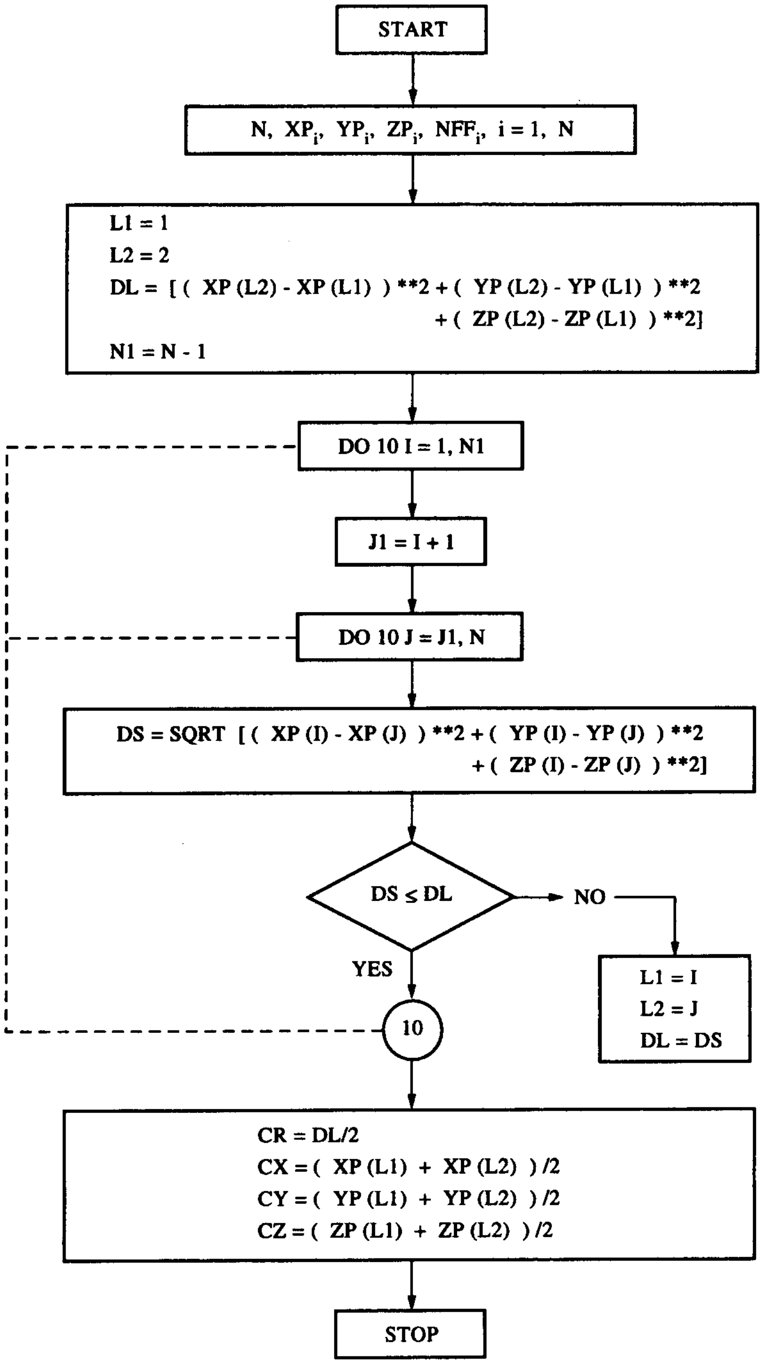
APPENDIX (*see overleaf*)

APPENDIX

Flow diagram



N = number of points, representing solvents, in the cluster.
XP$_i$, YP$_i$, ZP$_i$ = Co-ordinates of a point, representing δ_d, δ_p and δ_h of solvent, in three dimensional space.
CR = radius of sphere.
CX, CY, CZ = co-ordinates of centre of sphere.