Appendices: Commercial cyanate ester monomers, prepolymers, formulated systems and manufacturers' details

I. HAMERTON

Introduction

The first cyanate ester (CE) resin became commercially available to the consumer in 1976 as a laminating resin (in the form of Mobay Chemical's ill-fated 'Triazine A'). In the intervening time the market has expanded considerably to include a variety of cyanate ester forms. In an attempt to rationalize the following list of commercial materials, the cyanate esters resins have been classified in terms of molecular weight or solution formulation, blend or application area, etc. However, it must be appreciated that, despite having been developed for a specific use, a cyanate ester resin may often be suitable for a number of applications and so this may make the issue less clear cut. In view of their relatively recent development, some of these commercial materials have had relatively short lives in the market-place and the data available may be somewhat limited. The lists of commercially available cyanate ester resins presented in Appendices 3–9 are intended to familiarize the reader with representative examples of the various forms, rather than provide a detailed, comprehensive summary. Details of the resin systems have been obtained directly from discussions with manufacturers (and/or from their technical data sheets – for which the Editor was extremely grateful) and the author takes no responsibility for the verisimilitude of these claims. In some cases (e.g. cyanate ester monomers) latter day research and development has suggested the benefits of the use of prepolymers for their improved processing characteristics (see chapters 6 and 9 covering, respectively, processing and composite properties). Further information on any particular material can, of course, be obtained from the suppliers, details of whom are given (and who are denoted by a source number after each product). Every possible attempt has been made to ensure the accuracy of these addresses, but it is inevitable that in a rapidly changing industry some may change.

A.1 Contact addresses for manufacturers and suppliers

1. Allied Signal Incorporated Engineered Materials-PRIMASET-PT Resins, P.O. Box 2332, Morristown, New Jersey 07962-2332, USA.
2. Amoco Performance Products, Inc., 4500 McGinnis Ferry Road, Alpharetta, Georgia 30202-3944, USA.
3. Arlon, Electronic Substrates Division, 9433 Hyssop Drive, Rancho Cucamonga, California 91730, USA.
4. BASF Structural Materials, Inc., 1440 N. Kraemer Boulevard, Anaheim, California 92806, USA.
5. Bryte Technologies, Inc., 1840 Houret Ct. Milpitas, California 95035, USA.
6. Ciba-Geigy Speciality Resins Division, Technical Center, 9800 Bluegrass Parkway, P.O. Box 99038, Jeffersontown, Kentucky 40269, USA.
7. Resins Product Research and Development, Dow USA, The Dow Chemical Company, 2301 N. Brazosport Boulevard, Freeport, Texas 77541-3257, USA.
8. W.L. Gore and Associates, Inc., Electronic Products Division, Composites Group, 1320 Appleton Road, P.O. Box 809, Elkton, Maryland 21922-0809, USA.
9. Hexcel, 5794 West Las Positas Boulevard, P.O. Box 8181, Pleasanton, California 94588-8781, USA.
10. ICI Advanced Materials-Fiberite Composite Materials, 2055 East Technology Circle, Tempe, Arizona 85284-1800, USA.
11. Mitsubishi Gas Chemical Company, Inc., Electronics Materials Division, 5-2, Marunouchi 2-Chome, Chiyoda-Ku, Tokyo, Japan.
12. Nelco Hitec, Neltec Inc., 1420 W. 12th Place, Tempe, Arizona 85281-5214, USA.
13. BP Chemicals (Hitco) Inc., Fibres and Materials, 700 East Dyer Road, Santa Ana, California 92705, USA.
14. YLA, Inc., Advanced Composite Materials, 2970 Bay Vista Court, Benecia, California 94510, USA.

A.2 Key to a selection of suggested applications

1 Adhesives
2 Aircraft, primary and secondary structures
3 Bearing materials
4 Composites
5 Cryogenic tanks
6 Electronic circuitry
7 Encapsulants
8 High char-yielding materials
9 Honeycomb sandwich constructions
10 Insulating materials
11 Missiles and rockets
12 Moulding materials
13 Powder paints
14 Radomes and antennae
15 Satellite and space structures
16 Stealth and low observables

A.3 Commercial cyanate ester monomers and typical properties

Tradename	Purity/ state	Melting point (°C)	Density at 25°C (g/cm^3)	Viscosity, (cP at °C)	OCN equiva- lent weight	Refractive index
AroCy B-10	> 99%/cryst.[d]	79	1.259	< 50 (> 80)	139	1.5395[e]
AroCy M-10	> 99%/cryst[d]	106	1.197	< 20 (> 110)	153	1.5252[e]
REX-371	Liquid/semi- solid	–	1.250	500 (82)	127[f]	1.5695[e]
AroCy T-10[h]	> 99%/Solid	94	1.395	–	118	–
AroCy F-10	> 99%/Solid	86	1.497	< 50 (> 90)	193	1.4760[g]
AroCy L-10	Liquid	–	1.180	140 (25)	132[f]	1.5340[g]
RTX-366	Liquid/semi- solid	–	1.14	8000 (25)	198	1.5450[g]
Skylex CA200	Solid	79	1.240	< 50 (80)	138	1.5400

Monomers are typically soluble in acetone, MEK, THF, butylacetate, NMP, glycol ether and acetates. Applications refer to Appendix 2.

[a] Measured by DMA (depends on extent of postcure).
[b] After saturation at 100°C.
[c] Measured at 25°C and 1 MHz.
[d] Crystalline
[e] Measured at 90°C.
[f] Theoretical value.
[g] Measured at 110°C.
[h] No longer available commercially.

Fully-cured homopolymer properties							
Dry T_g[a] (°C)	Moisture absorption (%bw)[b]	Loss tangent (D_f)[c]	Dielectric constant (D_k)[c]	Fracture toughness (G_{IC}) (J/m^2)	Strain at break (%)	Application	Source
270	2.5	0.003	2.91	140	7.7	2, 6, 14, 16	6
255	1.4	0.003	2.75	175	6.6	2, 6, 14, 16	6
290	3.8	0.007	3.08	60	–	2, 6, 14, 16	6
273	1.5	0.003	3.11	158	5.4	2, 6, 14, 16	6
270	1.8	0.005	2.66	140	4.6	2, 6, 14, 16	6
258	2.4	0.005	2.98	190	8.0	2, 6, 14, 16	6
192	0.6	0.001	2.64–2.8	210	4.6	2, 6, 14, 16	6
255	1.0–3.0	0.003–0.007	3.0–3.3	–	–	2, 6, 14, 16	11

A.4 Commercial cyanate ester prepolymers and typical properties

Tradename	Purity/state/ toughener	Density at 25°C (g/cm^3)	Viscosity (cP at 82°C)	OCN equiv-alent weight	M_n/M_w	Refractive index (110°C)
AroCy B-30	Semisolid	1.221	450	200	560/1310	1.558
AroCy M-20	Semisolid	1.172	375	188	500/1200	1.550
AroCy M-30	Semisolid	1.167	3100	218	490/2300	1.5495
AroCy T-30	Semisolid	1.368	16700	240	690/2800	1.6340[d]
REX-378	Semisolid	1.140	500	–	575/825	1.5535
XU71787.02	Semisolid	1.190	1000	190	–	–
XU71787.07	10% bw coreshell rubber	1.180	1500	209	–	–
XU71787.09L[e]	T-plastics	–	–	–	–	–

Prepolymers are typically soluble in ketones, esters, NMP, chlorinated hydrocarbons and glycol ether and acetates. Applications refer to Appendix A.2.
[a] Measured by DMA (depends on extent of postcure).
[b] Moisture absorption after saturation at 100°C.
[c] Measured at 25°C and 1 MHz.
[d] Measured at 100°C.
[e] No longer available commercially.

A.5 Commercial cyanate ester prepolymers and laminating resins

Tradename	Purity/state	Density at 25°C (g/cm^3)	Viscosity (cP at °C)	OCN equiv-alent weight	M_n/M_w
Primaset PT 30	Viscous liquid	1.250	250,000 (25)	103	1.49
Primaset PT 60	Semisolid	1.240	3500 (104)	103	1.80
Primaset PT 90	Solid	1.260	–	103	2.79
Skylex CA260	Solid	1.240	170 (100)	–	400/1500
Skylex CA270	Solid	1.240	1500 (125)	–	600/3000
Hard resins					
AroCy B-50	Non-sintering	1.237	3600 (150)	278	1100/ 12000
AroCy M-50	Non-sintering	1.171	700 (150)	262	920/5500
Solutions					
AroCy B40-S	75% NV in MEK	1.089	250 (25)	235	750/2650
AroCy M40-S	65% NV in MEK	1.030	80 (25)	243	660/2870
AroCy F40-S	75% NV in MEK	1.248	210 (25)	284	840/2100
REX 379	75% NV in MEK	1.058	400 (25)	376	900/2800
Skylex CA210	70% NV	1.070	–	–	600/3000

Prepolymers are typically soluble in acetone, CH_2Cl_2, MEK, THF, NMP, dioxane, cyclohexanone, diglyme, glycol ether and acetates. Applications refer to Appendix A.2.
[a] Measured by DMA (depends on extent of postcure).
[b] Moisture absorption after saturation at 100°C.
[c] Measured at 25°C and 1 MHz.
[d] Moisture absorption after 72 h at 100°C.

Composite homopolymer properties					Applications	Source
Dry T_g (°C)[a]	Moisture absorption (%bw)[b]	Loss tangent (D_f)[c]	Dielectric constant (D_k)[c]	Fracture toughness (G_{IC}) (J/m^2)		
270	2.2	0.005	2.91	140	2, 6, 14, 16	6
255	1.3	0.002	2.80	–	2, 6, 14, 16	6
270	1.3	0.002	2.75	175	2, 6, 14, 16	6
270	1.2	0.003	3.11	158	2, 6, 14, 16	6
125–180	0.6	0.001	2.80–2.64	–	2, 6, 14, 16	6
265	1.2	0.002	2.8	70	2, 6, 14, 16	7
254	1.2	0.002	2.9	491	2, 6, 14, 16	7
220–250	0.6	0.002	3.1	–	–	7

Refractive index (110°C)	Dry T_g (°C)[a]	Moisture absorption (% bw)[b]	Loss tangent (D_f)[c]	Dielectric constant (D_k)[c]	Applications	Source
–	≤400	2.8[d]	0.007	3.10	1, 2, 3, 6, 8, 12, 16	1
–	–	–	–	–	1, 2, 3, 6, 8, 12, 16	1
–	–	–	–	–	1, 2, 3, 6, 8, 12, 16	1
–	255	1.0–3.0	0.003–0.007	3.0–3.3	1, 2, 4, 9, 10, 14	11
–	255	0.1–0.3	0.003–0.007	3.0–3.3	1, 2, 4, 10, 12, 14	11
1.580	270	2.2	0.005	2.91	6, 7	6
1.5572	255	1.3	0.002	2.75	1, 6, 12, 13	6
–	290	2.2	0.005	2.91	6, 7	6
–	252	1.3	0.002	2.81	6, 7	6
–	260	1.8	0.005	2.66	6, 7	6
–	125–192	0.6	0.001	2.64–2.80	6, 7	6
–	255	1.0–3.0	0.003–0.007	3.0–3.3	6, 10, 14	11

A.6 Commerical cyanate ester blends

Tradename	Component (2) (% bw)[a]	Melting point (°C)	Density g/cm^3 (at 20°C)	M_w	T_g (°C)[b]
BT2100	10	70–80	1.24	290	230–260
BT2160	10	30–80	1.24	1300	230–260
BT2170	10	50–80	1.24	3000	230–260
BT2300	30	110–120	1.26	310	240–270
BT2400[e]	40	110–120	1.27	320	250–280
BT2480	40	60–80	1.27	2300	250–280
BT2580[e]	50	30–130	1.28	1300	230–260
BT2562F[e]	50	60–120	1.29	2300	260–290
BT2670[e]	60	50–120	1.29	2300	260–290
BT2680	60	60–120	1.20	1000	230–260
F495[f]	–	–	1.25	–	180
HX1553[f]	–	–	1.26	–	175
BT3109	10	Liquid	1.20	1000	230–260
BT3209	20	Liquid	1.20	1000	240–270
BT3309T	30	Liquid	1.20	1000	240–270
E-905L[f]	50	Liquid	1.24	–	195
BT2110	10	Solution	–	3000	230–260
BT2060BJ	5	Solution	–	3000	220–250

BT resins are typically soluble in DMF, DMAc, MEK, NMP, dioxane, THF and acetone.
Applications refer to Appendix A.2

[a] Second component is BMI in blends prefixed BT.
[b] Measured by DMA (depends on extent of postcure)
[c] Moisture absorption after saturation at 100°C.
[d] Measured at 25°C and 1 MHz.
[e] No longer commercially available.
[f] Second component is an epoxy resin.

Moisture absorption (% bw)[c]	Loss tangent (D_f)[d]	Dielectric constant (D_k)[d]	Application	Source
1.0–3.0	0.003–0.007	3.0–3.3	10	11
1.0–3.0	0.003–0.007	3.0–3.3	1,2,4,10	11
1.0–3.0	0.003–0.007	3.0–3.3	1,2,4,10,13	11
1.0–3.0	0.003–0.007	3.0–3.3	8,10	11
1.0–3.0	0.004–0.008	4.1–4.3	10	11
1.0–3.0	0.003–0.007	3.0–3.3	3,7,10	11
1.0–3.0	0.004–0.008	4.1–4.3	7,12	11
1.0–3.0	0.004–0.008	4.1–4.3	4	11
1.0–3.0	0.004–0.008	4.1–4.3	12	11
1.0–3.0	0.003–0.007	3.0–3.3	3,7,12	11
1.26	–	–	?	13
2.0	–	–	2,5,14,15	9
1.0–3.0	0.003–0.007	3.0–3.3	10	11
1.0–3.0	0.003–0.007	3.0–3.3	10	11
1.0–3.0	0.003–0.007	3.0–3.3	10	11
–	–	–	12	13
1.0–3.0	0.003–0.007	3.0–3.3	6,10	11
1.0–3.0	0.0011–0.0014	2.8–3.0	6	11

A.7 Commercial cyanate ester prepreg systems

Tradename	Toughening agent[a]	T_g (°C)[b]	Moisture absorption (%bw)[c]	Loss tangent (D_f)[b]
63N	T	240	–	0.007–0.010
N8305	–	250	< 0.5	0.009
Speedboard C	–	190–200	–	0.003–0.004
ERL-1939-3	T	240	1.60	0.004
ERL-1999	U	187–236/202 w	1.00[i]	0.005
5575-2	T	190–260[j]	1.00[k]	0.002[e]–0.007[f]
X6555	S	250	–	0.005
X6555-1	S	250	–	0.005
BTCy-1	U	270	1.00	0.003[e]–0.006[f]
BTCy-2	U	190	0.60	0.0004[e]–0.002[f]
BTCy-3	U	166[j]	0.60	0.0006[m]–0.002[f]
EX-1515	P	–	0.04[o]	0.004[f]
EX-1505	U	315[j]	1.4	0.008[f]
EX-1509	U	335	1.5	0.006
954-2A	T	215–249	1.28	–
954-3	E	258	0.96	–
HX 1566	T	240	0.5	0.005
HX 1584-3	U	210	0.3	0.004
RS-3	U	254	1.45[q]	0.005
RS-12	T	152	1.4	–
RS-9	U	370	1.78[r]	0.0076[s]
SF-5	S	–	3.5[k]	0.004[t]
E-509L	–	195/165w	–	–
MR54-4	P	260	1.3	–

Applications refer to Appendix A.2.
[a] Toughening agent (T, thermoplastic; U untoughened system; P, proprietary; S, syntactic form).
[b] Dry T_g unless denoted (w, wet) (depends on extent of postcure).
[c] Moisture absorption after saturation at 100°C.
[d] Measured at 25°C and 1 MHz (depends on resin content).
[e] Neat resin.
[f] Measured on 7781 E-glass reinforcement.
[g] Measured on S2-glass reinforcement.
[h] Measured on non-woven expanded fluoropolymer reinforcement.
[i] After 14 days immersion at 71°C.
[j] After postcure.
[k] Measured after 30 days immersion at 71°C and 95% RH.
[l] Measured on Astroquartz®4581 reinforcement (36% resin content).
[m] Measured on Spectra®951 PT reinforcement.
[n] Measured on quartz reinforcement.
[o] Measured on Amoco P-75 reinforcement (saturation at 27°C).
[p] Measured at 10 GHz.
[q] Measured after 14 days immersion at 71°C and 95% RH.
[r] Measured after 72 h immersion in water at 100°C.
[s] Measured at 1 kHz.
[t] Measured at 18 GHz.

Dielectric constant (D_k)[d]	Fracture toughness (G_{IC}) (J/m^2)[e]	Applications	Source
2.8[e]–3.7[f]	–	6	2
3.5[g]–3.8[f]	–	6	12
2.6[h]–3.7[f]	–	14	8
3.04	–	15	2
3.25	–	15	2
3.25[f]	–	2,6,14,15	4
1.9	–	2,6,14,15	4
1.6	–	2,6,14,15	4
2.7[e]–4.3[f]	210	6,2,14–16	5
2.6[e]–4.4[f]	245	2,6,14,15	5
2.5[n]–2.7[e]	245	2,6,14,15	5
2.8[p]	–	15	5
2.77[p]	–	2,6,8,11,14,16	5
2.7	–	2,8,11,14,16	5
–	250	2,5,6	10
–	450	2,15	10
2.74	–	2,5,14,15	9
2.74	–	2,5,14,15	9
2.6	–	2,5,11,14,15	14
–	–	2,5,11,14,15	14
3.42[e]	–	2,5,11,14,15	14
1.70[r]	–	2,5,11,14,15	14
–	–	12	13
–	–	2,11	2

A.8 Commercial cyanate ester adhesive systems

Tradename	Type of adhesive system	T_g (°C)[a]	Moisture absorption (%bw)[b]	Loss tangent (D_f)[c]
Meltbond M2555	Film	232	1.3	0.002
BTCy-1A	Toughened film	260	0.6–0.7	0.005
EX-1516	Toughened film	124	0.6–0.7	0.005–0.006
EX-1502-1	Toughened paste	–	0.8	0.003
EX-1537	Toughened paste	–	1.1	0.005

Applications refer to Appendix A.2.
[a] Dry T_g (depends on extent of postcure).
[b] Moisture absorption after saturation at 100°C.
[c] Measured at 25°C and 10 GHz (depends on resin content).
[d] Measured at 25°C and 1 MHz (depends on resin content).
[e] Lap shear: metal/metal (2024T3 FPL Etch) at 0.06 lb/Ft wt (25°C/232°C).
[f] Lap shear: metal/metal (2024T3 FPL Etch phosphoric acid anodize) at 0.06 lb/Ft wt (25°C/232°C).
[g] Lap shear (6061 T-G aluminium) at 25°C on non-woven fibreglass supported film (lb/in^2).
[h] T-Peel (6061 T-G Aluminium) at 25°C on non-woven fibreglass supported film (lb/in width).
[i] Flatwise tension (unsupported, 0.002″ thickness) at 25°C/121°C (lb/in^2).
[j] Lap shear (6061 T-G Aluminium) at 25°C (lb/in^2).

Dielectric constant (D_k)[d]	Selected adhesive properties	Applications	Source
2.8[c]	2700/2500[e] 3000/3300[f]	2,6,9,14	4
2.6–2.7	4311[g]	1,2,4–6.9,14–16	5
2.6–2.7[c]	4311[g] 23.6[h] 2800/1700[i]	1,2,4–6,9,14–16	5
2.8[c]	6000[j]	1.2,4–6,7,11,14–16	5
2.8[c]	5800[j]	1,2,4–6,7,11,14–16	5

A.9 Commercial cyanate ester coating and filament winding systems

Tradename	System type	Recommended processing temperature (°C)	Features	Application	Source
EX-1530	2-Part, processable matrix	43–49	Pot life, 8h	2,14	5
EX-1532	2-Part, processable matrix	54–60	Pot life, 4h	2,8,11,14	5
EX-1510	RTM/filament winding matrix	25	Low viscosity	2,8,11,12	5
E-905L	2-Part epoxy/ cyanate ester, matrix	82–93 (RT pourable)	Components stable for >24 h at 82°C Viscosity constant for 1 h at 93°C	12	13
RS-14	RTM resin	159 cure (not postcured)	Viscosity 1000 cP (at 66°C) Minimum 100 cP	12	14
RS-16	RTM resin	265 cure	Viscosity 1000 cP (at 66°C) Minimum 100 cP	12	14

Applications refer to Appendix A.2.

General subject index

ablation resistance 41, 223, 325
activation energy
  of physical aging 100–101
  of polymerization 63, 64, 78, 290, 291
active hydrogen compounds 11, 20, 113–128, 157, 158, 234, 246, 261, 303
additives and modifiers 37, 85, 112–150, 205
adhesion 220, 221, 300–303, 321
adhesive bond—fibre/matrix *see also* interfacial adhesion 262, 263, 301, 303
adhesives 9, 87, 220–225, 294, 300–301, 318, 319
adiabatic calorimetry 26–28
aerospace 1–2, 112, 151, 193, 258–260, 274–278, 305–317
aging *see also* physical aging 87, 89, 91, 223
aliphatic carborane cyanates 30
alkylated phenols *see also* co-catalysts 289, 290
alkyl bromides 11
alkyl cyanates 8, 13, 17, 18, 22, 29, 30, 32
O-alkyl-*N*-hydroxythiocarbamates 10
alkyl silicon cyanates 30
O-alkyl thiocarbamates 10
annealing *see also* physical aging 89, 318
anodic filament growth *see also* cathodic filament growth; electrical properties, electrochemical corrosion 253, 255
antenna coatings *see also* radomes; missile nose cones 4, 53, 230, 231, 234, 247, 250–252, 255, 278, 289, 312–314, 317
antioxidants 167, 173, 177, 202, 203, 302, 303
applications for cyanate esters resins
  electronics 247–250
  microwave communication and tracking 250–252
  potential applications 325–326
  radomes 4, 9, 53, 186, 230, 231, 236, 238–240, 247, 250–252, 255, 260, 277, 278, 289, 297, 305, 312–314
  space structures 259, 273–275
  structural composites 275–277
  suggested applications 331
aramid fibres 4, 113, 179, 216, 217, 235, 249, 308
atomic oxygen resistance 273, 274, 317
autocatalysis of cyclotrimerization 34, 61, 62, 113–116, 179
autoclave cure cycle 183, 184
average degree of polymerization 65

basicity 30–32
Beer–Lambert law 66
binary-phase diagrams 139
biodegradable polymer 326
bismaleimides 2, 3, 85, 151, 226, 234, 251, 258, 276, 290, 311
blends 36, 45, 95, 112, 113, 146, 151, 168, 170, 172–173, 178, 203, 214–216
branching density of polycyanurate network 58, 69–71, 75, 77–80, 82, 99
branching theory *see also* cascade theory 58, 69
bulk effects 61

capillary viscometry (VISC) *see also* viscometry 84
carbon fibre composites *see* composites
carboxylate salts of transition metal ions 155–160
cascade theory 58, 60, 61, 64, 65, 68, 70, 74, 77–80, 82, 83
castings 172, 174, 176, 246, 306
catalysts *see under individual compounds in index of compounds* 9, 16, 31, 41, 45, 61–64, 85, 87, 89–91, 97, 113, 117–119, 121–126, 129, 131–133, 143, 155–160, 261
  effect of
    concentration 162, 163, 171
    conversion 157, 158, 162, 289
    cure rheology 171
    cure temperature 325
    dielectric loss properties 245–247
    gel time 156–159, 290, 320, 321
    impurities 18–20, 26, 45, 61–63, 115–119, 121–123, 246
    mechanical properties 157–159, 162, 174
    moisture absorption 156, 164, 165, 218, 308
    reactivity 157–160, 290, 291
    storage stability 156–159, 180, 187, 290, 291
cathodic filament growth (CAF) *see also* anodic filament growth; electrical properties, electrochemical corrosion 255, 256
char formation 34, 37, 199–202, 206–208

chemical resistance 175, 223–227, 298, 300, 304, 311, 312
circuit board 8, 87, 230, 234, 236, 247–256, 295–302, 317, 319–323
cloud point 139–146
coatings 87, 342
co-catalysts 121–125, 155–166, 180, 246, 247, 261, 289, 290
colorimetry 25, 28–29
combinatorial model of network formation 65, 75
commercial cyanate ester monomers 14, 34–38, 332, 333
communication satellites *see also* space structures 250, 306, 315–317, 322
complex formation 31, 32, 46
composites 1, 2, 8, 9, 39, 41, 53, 87, 89, 259, 293, 297, 298, 301–317, 325
  fabrication 179–190, 262–266
  properties 186, 258–281, 316, 338, 339
compression moulding 183
conductive adhesives *see also* microelectronics packaging 318
conversion
  determination 66–69, 88, 97
  effect of
    composition 71, 72
    cure temperature 61, 64, 91, 92
    internal standard 66, 67
    monomer structure 39
    monomer weight fraction 68
  effect on
    density 95, 107
    dielectric loss properties 236–238
    equilibrium moisture content 95, 97, 109
    fracture toughness 213, 214, 266, 283, 290
    gel fraction 72, 80, 81
    gelpoint 58, 65
    glass transition temperature 82, 91–94, 97, 98, 106–109, 266, 285
    isothermal free volume 98
    isothermal glassy-state modulus 99, 109
    isothermal physical aging rate 95, 99–108
    isothermal relative rigidity (modulus) 95–99, 106–108
    phase separation 144–148
    specific volume 95–98
    thermal stability 199–202
conversion–temperature–property (T_gTP) diagram 106–109
conversion to polycyanurates
  monitoring 23, 25, 27, 63, 88
co-polycyclotrimerization 71, 72
copolymerization 45, 60
core-shell rubbers 113, 139, 141, 177, 267, 294, 316
corrosion, electrochemical 253, 255, 256, 285, 311, 312, 318
crack propagation 273
crazing 223
critical
  conversion *see also* gelpoint 65, 66, 69, 71, 75, 80, 82
  exponents 60, 82
crosslink density
  effect of
    carbamate formation 120
    cyanate ester–epoxy co-reaction 129–131
    monomer structure 37, 40, 201
    phenol incorporation 124, 125
    reactive diluents 43, 137, 201, 202
  effect on
    cured resin properties 41, 95
    free volume 98
crosslinking 27, 99
crosstalk 248, 256, 295, 320
crystallinity 3, 23–26, 37, 66, 87, 94, 117, 170
cure
  atmosphere, effect on polycyclotrimerization 113–116, 129
  catalysis 155–160
  conversion, factors affecting 61, 64, 90, 160–167
  cycles 112, 163, 171–178, 262–265, 289–290
  exotherm 9, 25, 67
  kinetic analysis 58–86
  rheology 155, 168–171
  schedules 151, 262–265, 318
  shrinkage 179, 180
  temperatures 44, 90, 92, 95, 98, 161, 162, 166, 262–265
cured neat resin properties 208–216, 274, 278–280, 289
  effect of conversion 90, 160–167
curing agents *see under individual compounds in index of compounds*
cyanate esters *see under individual compounds in index of compounds*
  alkyl 8, 13, 17, 18, 22, 29, 30, 32
  blends 36, 45, 112, 113, 146, 151, 168–173, 178, 203, 214–216
  characterization 7, 20–24, 34, 36, 37, 87
  cost 4, 34, 36, 37, 112, 282, 325
  cure exotherm 15, 16
  epoxy networks
    dielectric properties 234–236
    difunctional compound studies 131–137, 141, 159, 160

—influence of catalysts 131–133, 174, 175
—influence of epoxy prepolymer concentration 135–136, 166, 167, 174, 303–305, 211, 312
—influence of epoxy prepolymer structure 133–135, 173–175, 224–226
monofunctional compound studies 128–131
toughened blends 175–178
equivalence 28, 29
historical background 3, 8, 9, 324
hydrolysis 15, 30–32, 36, 46, 89, 116, 156, 159, 160, 164, 165, 175, 202, 207, 217, 218, 311
manufacturer's details 330
monomers
characterization 7, 34, 36, 37
chemical properties 25–34
colour 25, 28, 29, 173, 177
commercial 34–38
crystallinity 23–26, 37, 39, 51, 52, 87, 94, 117, 267
fusion endotherm 19, 87
physical properties of 18–25, 151–154, 284
purity 3, 9, 15–20, 26, 34–38, 53, 136, 285
—assessment of 19–20
—effect on polymerization exotherm 9, 18, 26
research 14, 35, 38–44
—bisphenylcyanate 38–40
—carborane dicyanate 41, 43, 197, 199, 200, 201, 204, 205
—cyclic bisphenylcyanate 39, 41
—fluoroaliphatic dicyanate 41, 43
—fused-ring cyanate 40, 41
—monofunctional cyanate 42–44, 46, 114
—oligomeric dicyanate 40, 42
structure–property relationships
—effect of structure on crystal packing 50–52
—effect of structure on melting point 25, 35, 38–44, 50, 52, 151, 152
—effect of structure on melt viscosity 25, 35, 40, 142, 285–288
—effect of structure on polymerization reactivity and enthalpy 45, 46
—effect of symmetry 50–52, 287
synthesis 9–18, 53
volatility 32, 37, 38, 43, 89, 153, 223
oligomers 36, 40–42, 58–60, 68, 153, 199–202
prepolymers
analysis 20, 28
commercial 3, 8, 36
conversion 66–68, 159, 287
effect on
—cured polymer properties 133–136, 288
—processibility 153, 168, 261, 262, 267, 287, 288
—reaction mechanism 77, 80
—reactivity 115, 261, 262
—rheology 168, 171
reaction with dephenols 74–78
reaction with epoxies 60, 78–82
reaction with monofunctional cyanate esters 69–72, 74, 75, 83
reaction with monophenols 60–63, 73–78, 80, 82, 83, 122–125
reactivity of 16, 18–21, 31, 37, 38, 40, 41, 45–50, 68, 71
rheology 85, 168–171
solvent resistance 37
sterically hindered 32
storage stability 12, 15, 16, 38, 154, 159, 180
toxicity and handling precautions 32–34, 38
cyanogen halides 9–16, 325
cyanurates 21, 22, 30, 131

damage tolerance *see also* toughness 273–277, 293, 306–308
decomposition 16, 17, 31, 32, 116, 117, 197–199
degradation mechanism *see also* thermal stability 202–205
degree of polymerization 65
delamination (of composites) 31, 308, 309, 321
density 23, 66, 95, 107
developmental cyanate ester monomers *see also* cyanate esters, monomers, research 35, 38–44
Di Benedetto equation 118
dicyanate esters *see* cyanate esters
die-attach adhesives 317, 318
dielectric constant (D_k) 36, 44, 165, 230–252, 255, 256, 284, 285, 295, 296, 303, 304, 312–316
dielectric loss 4, 39, 53, 230, 231, 233, 248, 255, 256, 283, 295, 297, 314, 315, 319
comparisons with other polymers 234–235
definitions 231
factors affecting 236–237
catalyst effects 245–247, 290, 291, 308
conversion 165, 166, 237, 238, 285, 287–290, 298, 299, 303

dielectric loss *contd*
frequency (Hz) 233, 238–242, 246, 247, 250, 255, 256, 312, 313
moisture 3, 236, 241, 243–245, 250–255, 277, 280, 284, 295–297, 300, 304, 308, 309, 321
structure 36, 44, 136, 231–234
temperature 230, 239–242, 250, 253–256, 277, 280, 284, 299, 301–305, 311, 314, 321
dielectric permittivity *see also* loss tangent 53, 230, 231, 237, 239–241, 296
rule-of-mixture calculations for composites 235, 236
dielectric strength 230, 253–256
dielectric thermal analysis (DETA) 239, 241
Diels–Alder addition 137, 139
differential scanning calorimetry (DSC)
polymerization enthalpy 26–28, 34, 36, 37, 89
use of in assessment of monomer purity 18, 19, 87
use of in assessment of monomer reactivity 45, 46, 114–118, 125, 127, 131–133
use of in assessment of T_g 82, 88, 94, 109, 119
diffusion control–cure reactions 60, 64, 66, 69, 115, 120
digital logic systems 238, 256, 282, 319
dilatometry 24, 34, 37, 298, 299
dimensional stability 274, 275, 282, 290, 298–300, 315–317, 323
dimer formation 22–27, 114, 129, 163
dipolar strength 231, 232, 234, 236, 237, 243, 255, 258, 285, 287, 295, 324
discotic phase formation *see also* liquid crystalline polymers 44
dispersed phase
effect of cure temperature 138, 146
effect of viscosity 139, 146
particle size 138, 139, 146, 147, 177, 266–269
volume fraction (V_D) 138
dissipation factor (D_f) *see also* loss tangent 36, 230–242, 244–248, 250, 251, 255, 277, 295–297, 312, 313, 321
dissociation constant (pK_a) 75, 76
Doppler radar 305, 313, 314
dynamic light scattering (DLS) *see also* light scattering 84
dynamic mechanical thermal analysis (DMA or DMTA) 89, 90, 109, 133, 137, 215, 216, 279, 293
dynamic melt rheology 160, 168–170

economics of cyanate ester manufacture 14, 282, 325
elastic modulus (G') 133, 160, 161
elastomers 14, 41, 85
electrical/electronic applications 230–257
electrical properties 252–255
electrochemical corrosion 253, 255, 256, 285, 311, 312, 318
resistivity and dielectric strength 253–255
electromagnetic fields 230, 251, 255, 282, 324
electromagnetic transmission 53
elimination reactions 29
emulsion polymerization 139
encapsulants *see also* microelectronics packaging 189, 246, 318–319
ene reaction 137, 139
enthalpy of polymerization 26–28, 41, 45–47, 61, 67, 117, 118
epoxy resins 1, 2, 61, 95, 97–99, 103, 107, 109, 112, 113, 138, 140, 151, 234–240, 243–246, 249–251, 253, 255, 258, 267–273, 275, 276, 290, 292, 320, 321
copolymers with cyanate esters 34, 36, 60, 128–137, 159, 160, 166, 167, 170, 171, 173–176, 214, 215, 238, 295, 303–305, 309, 311, 312, 323, 325
equilibrium moisture content *see also* water absorption 95, 216–220, 243–245, 315
European fighter aircraft (EFA) 4, 305, 306
exotherm 15, 16, 18, 26, 34, 38, 115, 116, 125, 179, 184

fabric prepregs 184
Fermi resonance 22, 48–51
fibre impregnation 169, 179–190, 260, 309, 310
fibres 4, 89, 113, 116, 179, 186, 189, 235, 237, 248, 249, 251, 261–263, 289, 315–317, 320
Fickian behaviour 243
filament winding 112, 151, 189, 282, 288, 305
fillers 112, 174, 175, 179, 182, 189, 207, 249, 315, 318–320
film prepregging 180, 306
fire resistance 44, 53, 173
flammability 53, 174, 195, 201, 205–208
flame retardants 36, 37, 173, 182, 206–208, 320, 321, 325
flexibilizers 196, 319
flexural modulus 134, 165, 208–210
flexural strength 164–166, 263
effect of conversion 165, 166
effect of water absorption 164

Flory equal reactivity principle 64
Flory–Stockmayer theory 58
fracture behaviour 146, 293
fracture toughness 141, 147, 176–178, 185, 266, 272–274, 293–295, 306–308, 322
free volume 95, 98, 99, 103, 133, 164, 243, 265
functionality 36, 37

galvanic corrosion *see also* electrical properties, electrochemical corrosion 304, 311–312
gaseous decomposition products 31, 32, 116, 117, 197, 200
gelation
  definition 143
  effect of
    active hydrogen additives 120, 121
    chemical control 113, 114
    cyanate ester/epoxy blends 159
    cyanate ester prepolymers 159
    monofunctional cyanate 71, 128
    phase separation 139
    phenol pK_a 75, 76
    temperature 144–147, 161
  effect on
    glass transitions 92–99, 106–108
    viscosity 169
  modelling 60, 79
  threshold 60, 66, 82–84
gel fraction 65, 68–72, 75, 80, 81, 120
gel permeation chromatography *see also* size exclusion chromatography 34, 37
gelpoint 58, 65, 66, 68–71, 75, 80, 82, 83, 97, 123, 136
gel time 78, 80, 120, 134, 156–158
glass transition/glass boundary 95, 96, 98, 99, 103
glass transition/rubber boundary 98
glass transition temperature, T_g
  effect of
    branching (crosslink) density 75, 82, 98, 137, 213–215, 266, 283, 285
    chemical composition 77, 80, 82, 207, 215, 216
    conversion 75, 90–103, 118–120, 145, 162–167, 286, 289
    cure catalysts 158, 163, 289
    cure temperature 44, 94, 112, 162–167, 263
    molecular weight 98, 133, 134
    monomer structure 37, 39, 41, 43, 53, 133, 134, 160, 173, 193, 195, 258, 272, 276, 283–285, 287
    postcure 163, 164
    rubber modification 178
    thermoplastic modification 272
    water absorption 118–120, 276
  effect on
    toughness and flexibility 5, 290–292
  physical aging 95–106
    T_gTP diagram 106–109
    WLF equation 133, 136
glassy state free volume 95, 98
glassy state modulus 95, 97, 99
global positioning 250, 322
'glob-top' encapsulants 318, 319

heat capacity 27, 67, 91
heat deflection (or distortion) temperature (HDT)
  effect of catalyst 156, 158
  effect of conversion 162, 165–167
  effect of moisture absorption 210, 219, 220
  effect of postcure 158, 162
  effect of stoichiometry 136, 166, 172, 303, 304
heat of combustion 27, 28
heat resistance *see also* thermal stability 196
high performance liquid chromatography (HPLC) 19, 20, 34, 67, 68, 128, 129
high performance polymers 1
high speed civil transport (HSCT) 4, 280, 301, 302, 305, 311
high temperature polymers 1, 39, 53, 151
homopolycyclotrimerization 61–72
hot-melt prepregging 180–185, 260, 261
hot-wet performance 2, 156, 164, 264, 267, 275–277, 297, 302, 307
hydrogen bonding 31–32, 46, 48, 153, 231, 232
hydrolysis 15, 30–32, 36, 46, 89, 116, 156, 159, 160, 164, 175, 202, 207, 217, 218, 311
hydrophobicity 44, 173, 258, 259, 311

impedance (Z_0) 247–250, 315
impurities 12, 16, 18–21, 26, 45, 53, 61, 63, 85, 115, 121, 122, 126, 154, 285, 318, 319
inductive stabilization 30, 41
infrared spectroscopy
  characteristic band frequencies of cyanates and related species 20–24, 48–51, 66, 67, 81, 117, 131
  use of in assessment of cyanate ester conversion 63, 66–69, 80, 81, 127, 128, 131, 136, 160
  use of in assessment of hydrogen-bond acceptor strength 31, 32, 46–48
  use of in assessment of monomer purity 19–22, 34, 37, 117
injection moulding 267, 306, 310
inorganic cyanate esters 28, 53

interfacial adhesion 41, 262, 301, 303
  effect of size 262
interlaminar toughening 177, 182, 185, 273, 276, 308
intermolecular forces 22–27, 50–52
interpenetrating polymer network (IPN) 212–213
intramolecular cyclization 28, 60, 64, 66, 94, 97, 114, 115
isomerization
  of alkylcyanates to isocyanates 8, 13, 17, 29, 30, 129, 326
  of alkyl-substituted triazines to isocyanates 78, 79
  of substituted bicyclic cyanates to isocyanates 29
isothermal calorimetry 26–28
isotope effects 22

kinetic models of network formation 58
kinetics 60–65, 71, 77–80, 85, 121, 124, 127
  of co-polycyclotrimerization reaction 71, 72
  of co-polymerization with epoxies 79, 80
  of co-polymerization with phenols 78, 122–123
  of homopolycyclotrimerization reaction 61–64, 118

laminates *see also* composites
  delaminating 31, 164, 165, 300, 309, 321
  fabrication 179–190, 262–265
laminating resins 3, 53, 322
latent cure catalysts 156–159, 290, 310
lattice simulation 58
lay-up 183, 262, 264, 308
Lewis acids 13, 29, 117, 159
light scattering 83
linked interpenetrating networks (LIPN) 137
liquid crystalline polymers 39, 44, 53
liquid–liquid relaxation (T_{ll}) *see also* liquid–liquid transition 92–94
liquid–liquid transition (T_{ll}) 91–94, 107–108
liquid moulding 186–189
liquid state 95
loss modulus (G'') 87, 90, 108
loss tangent *see also* dissipation factor 53, 231, 239, 240, 251, 252, 296, 312
lower critical solubility temperature (LCST) 140, 142, 144
low-loss resins 39, 53, 247–252, 323
low-observable composites *see also* stealth application 255, 256, 314–315

macroscopic gelation 92, 94, 96, 97, 107
mass fraction 70
mean field theory 60, 66, 69, 71, 82, 113, 115
mechanical loss (G'') 90, 93, 94, 133
mechanical properties
  effect of catalyst 131–133
  effect of conversion 90–94, 160, 165
  effect of cure temperature 92, 166
  fibre-reinforced laminates 186, 258–281, 316, 338, 339
  unreinforced (neat) resins 208–221, 278–280
mechanism of polymerization 61, 62
melting point 25, 35, 38–44, 50, 87, 92, 151, 152, 168
melt viscosity 40, 43, 151, 152, 168, 285–288
mesogens *see also* liquid crystalline polymers 53
α-methylene fluoroalkyl dicyanate esters 13
microcrack resistance 90, 93, 177, 259, 273–275, 294, 298, 306, 315, 317, 322
microelectronics packaging 87, 151, 317–319
microwave communication and tracking 250–252
microwave electromagnetic transmission 53, 306, 312, 313
microwave windows 230, 247, 250, 306, 312
miscibility 125, 137–149, 174, 178
missile nose cones 278, 305, 311–314
models of network formation 58, 61
modification of polycyanurate networks 125–128
modifiers 125–128, 211–216
modulus 90–93, 95–99, 103, 297
  effect of conversion 92–98, 108
  effect of crosslink density 95–97
  effect of molecular weight 95, 96
  effect of temperature 92, 93, 95, 96, 103
moisture absorption of cyanate esters *see* water absorption
  effect of
    catalyst selection 156, 164, 165, 217, 218, 308
    degree of cure 95, 97, 164
    monomer structure 36, 37, 46, 304
  effect on
    dielectic loss properties 241–246, 259, 279, 280, 295–297
    glass transition temperature 118–120
    mechanical properties 97, 101–103, 109, 156, 164, 216–221, 279
    polymerization kinetics 118
    polymerization mechanism 114, 116–121

reactivity 3, 115, 116–121
storage stability 182
thermo-oxidative stability 156, 197, 202–204, 216–220
molar fraction 70
molar mass
between crosslinks (M_C) 141
distribution 65
molecular asymmetry 284–287
molecular gelation 92, 94
molecular weight 36, 65, 83, 95–98, 107, 272
average 60, 68
distribution (MWD) 37, 97
Monte Carlo simulation *see also* kinetic models of network formation 58, 60, 65
morphology 52, 125, 137–149, 167, 176–178, 185, 214, 215, 266–273, 276, 291–294
moulding compounds 189, 318, 319
multilayer chip modules (MCMs) 186, 230, 248, 253, 256, 295, 297, 317, 319–323
multilayer circuit boards 4, 186, 230, 300, 317, 319–324
mutagenicity 32, 33

neat resin formulations 171–178
network formation 58–85, 94, 99, 120, 131
non-cyanurate polymers 53, 54
non-uniform heating *see also* exotherm 34
nuclear magnetic resonance spectroscopy
characteristic chemical shifts of cyanates and related species 20–22, 34, 36, 37, 131, 215
use of in assessment of cyanate ester conversion 67, 131
use of in assessment of hydrogen-bond acceptor strength 31, 32, 46–49
number fraction 81

oligomers 36, 40–42, 58–60, 68, 125, 127, 137, 153, 199–202
optical waveguides 323
optoelectronics 323, 324
organosilicon cyanates 30, 31
out-life (or time) 180–183, 276
oxidation 89

packing
coefficients 50–52
efficiency 50, 97, 99, 152
peel strength 4, 223, 224, 300, 301
pentamethine oxonol dye 28, 29
percolation theory 60, 82, 83
phase
diagrams 139, 144–147
separation 137–149, 176, 213, 214, 266–274, 291–293, 322
transfer 15
phenol(s) 8, 11, 18, 20, 26, 45, 53, 121–122
incorporation in polycyanurate networks 123–125
photodefinable cyanate ester 248, 319, 320
physical aging 87, 89, 90, 99–108, 325
plasticization 218–221, 290, 297, 302
poling *see also* liquid crystalline polymers 53, 324
polycyanurates 58–60, 66, 67, 80, 83, 84, 87, 90, 91, 97, 98, 196
polyimides 1, 2
polymerization
enthalpy 26–28, 38, 45, 88, 89
mechanisms 61, 62
rates 45
solvent effects 22, 23, 28, 61
post cure 158, 163–167, 262–265, 310
potential applications of cyanate esters 325–326
pot life *see also* storage stability 157, 169, 170, 290
precursors *see* cyanate esters
melting points 151–152
physical state 151–154
solubility 154
storage stability 154
prepolymers *see also* cyanate ester prepolymers 3, 8, 20, 28, 36, 66, 67, 78, 80, 115, 133, 134, 153, 159, 168, 170, 261, 267, 287
prepreg flow number (PFN) 181, 182, 185
prepregging 40, 112, 116, 151, 179–186, 260–262
printed circuit boards 3, 8, 9, 53, 112, 193, 216, 230, 247–249, 255, 256, 295–300, 302
printed wiring boards 3, 224
probability 65
processability 2, 53, 137, 267, 286
processing 25, 112, 151, 178, 179, 260, 285–288
of composites 179–190, 260–262, 309–311, 320–322
pultrusion 186, 189, 282, 288
purification 13
purity of monomers 16, 18–20

radar absorbing materials/structures(RAM/RAS) 250–252, 256, 314, 315
radar tracking 238, 250, 256, 306, 322
radiation resistance 306, 315–317
radiowave electromagnetic transmission 53
radomes 4, 9, 53, 186, 230, 231, 236, 238–240, 247, 250–252, 255, 260, 277, 278, 289, 297, 305, 311–314

rate constants 45, 62, 63
reaction injection moulding (RIM) 267, 306, 310
reactive diluents 25, 36, 43, 113, 137, 142, 168–178, 169, 285–288
reactivity of cyanate groups 16, 18–21, 31, 37, 38–41, 45–50, 68, 71, 114, 115
reactivity ratio (R_H) 75, 76
recrystallization 38
recursive approach *see also* statistical models of network formation 58
reflectors 289, 290, 298, 306, 317
refractive index 323, 324
  use of in assessment of cyanate ester conversion 68, 159
  use of in assessment of monomer purity 19, 20
reinforced cyanate ester resin properties 186, 258–281, 316, 338, 339
reinforcing materials 53
relative hydrogen bond acceptor strength (RAS) 46, 48, 231, 232
relative mechanical loss ($\pi kG''$) 90–93, 103–106
relative rigidity (kG') *see also* modulus 90–108
β-relaxation (T_β) *see also* β-transition 90–94, 132, 133
γ-relaxation 133
relaxations 90–94, 98, 106
resin flow 177, 181, 187
resin transfer moulding (RTM) 112, 151, 177, 186–189, 282, 288, 305, 309–311, 314, 319, 325
resistivity and dielectric strength 253–255
rheology 85, 155, 160, 168–174, 288
rubber modification 112, 113, 125–128, 137–149, 167, 177, 178, 185, 266, 267, 293–295, 315
rubber modulus 132
rubbery state 95, 98

sandwich construction 171, 177, 184, 221, 222, 263, 265, 277, 308–309
scaling
  exponents 60, 83, 84
scanning electron microscopy (SEM) 146, 148, 262, 263, 268–271, 273, 293
sealants 190
segmental motion *see also* glass transition temperature, T_g 91, 101, 285
semi-interpenetrating polymer network (semi-IPN) 213, 214, 269
shear modulus (G') 90, 107
sheet moulding compounds 151, 189, 190
shrinkage 298–300, 319
side reactions *see also* von Braun reaction 73, 89
signal propagation 247, 248, 256, 318, 320
simulation *see also* models of network formation 60
size exclusion chromatography (SEC) *see also* gel permeation chromatography 37, 67, 68, 114, 128
  coupled with low-angle laser light scattering (SEC/LALLS) 84
  coupled with low-angle laser light scattering and viscometry (SEC/LALLS/VISC) 84
sizing 262
small angle neutron scattering (SANS) 84
small angle X-ray scattering (SAXS) *see also* X-ray analysis 84
smoke emission 34, 205–208, 325
sol fraction 45, 68, 71, 96
solidification 106
solubility 15, 16, 23, 37, 45, 67, 68, 71, 83, 97, 128, 140, 142, 145, 154, 267, 283, 290
solution prepregging 40, 180–185, 260, 261, 267
solvent effects 22, 23, 28, 61
solvent resistance *see also* chemical resistance 37, 165
solvents 12, 66, 97, 120, 154, 180, 184, 260, 268
space structures 4, 259, 274, 275, 278, 298, 300, 311
specific properties
  commercial cyanate ester adhesives 340, 341
  commercial cyanate ester blends 336, 337
  commercial cyanate ester coating and filament winding systems 342
  commercial cyanate ester laminating resins 334, 335
  commercial cyanate ester monomers 332, 333
  commercial cyanate ester prepreg systems 338, 339
specific volume 95, 97, 98, 179
spin coating 323
static light scattering (SLS) *see also* light scattering 84
statistical models of network formation *see also* Flory–Stockmayer theory 58, 65
stealth application *see also* low-observable composites 250–252, 255, 256, 306, 314, 315
step-growth 58, 137, 139, 246
steric effects 32, 39, 46, 49, 60, 71, 98, 99, 233, 234
storage modulus 87, 90, 100

storage stability 12, 15, 16, 87, 154, 159, 180
structural composites *see also* composites
structural foam core 308, 309, 313
structure–property relationships 38, 39, 44–52, 58, 284–288
substituent electronic effects 8, 21, 22, 30, 46–49, 71, 75, 226
substitution reactions (S_N1, S_N2) 29
sub-T_g transitions 91–99, 132
surface coatings *see also* coatings
swelling 164, 165, 223, 224, 226, 243, 265, 295–300, 308
synthesis of cyanate ester monomers 7, 9, 13–18

tape-automated-bonding (TAB) 317
telecommunication 282
temperature resistance *see also* thermal stability 39
tensile modulus 37, 210, 211, 223
tensile strength 37, 223
T_g *see also* glass transition temperature
thermal analysis *see* dynamic mechanical thermal analysis; differential scanning calorimetry; torsional braid analysis
thermal conductivity 89, 315, 317, 318
thermal cycling 1, 94, 301, 317
thermal degradation *see also* thermal stability 91, 94, 195, 265
thermal endurance 301–303
thermal history 91, 99
thermal (uncatalysed) polymerization 45, 62, 63, 87, 89, 90, 115, 118
thermal spiking 301
thermal stability *see also* degradation 18, 39, 193–205, 301–303, 314
  factors affecting 194–205
    bridging link molecular weight 199–202
    chemical nature of the bridging group 196–199
thermo-oxidative degradation 196
  mechanism 202–205, 265, 308
    model compound studies 202
    polycyanurates 202–204
thermo-oxidative stability
  effect of molecular weight 199–202
  effect of stoichiometry 173
  effect of substituents 172, 173
thermoplastics 2, 39, 85, 107, 113
  miscibility 125, 137–149, 266, 267, 269, 291, 292, 306
  molecular weight 269, 272, 276, 306, 310
  reactive end groups 272, 276, 291–293, 306–308, 319
  solubility 34, 36, 176, 268, 291
  toughening of cyanate esters 9, 40, 112, 124, 125, 137–149, 160, 167, 175–178, 184, 185, 212–214, 262, 266–277, 288, 306
thermosets 2, 39, 44, 50–53, 87, 91, 95, 99, 106, 107, 112, 137, 151, 179, 212, 213, 266
thixotropic encapsulants *see also* 'glob-top' encapsulants 318, 319
time–temperature–transformation (TTT) diagram 106
titrimetry 25, 28, 29, 128
tooling compounds 290, 301, 325
torsional braid analysis (TBA) 87, 89–94, 97, 109
toughening agents 124, 137, 141, 151, 167, 171, 266–276, 282, 290–295, 305–308, 315, 317, 322
toughness 37, 40, 112, 141, 167, 273, 283, 290, 292
toxic gas evolution 205–208
  of cyanogen halides 11–13, 325
  testing of cyanate ester monomers 32–34, 38, 179, 283, 326
β-transition (T_β) *see also* β-relaxation 91–94, 99, 106–109
transition metal chelates 155–160, 163, 290
transition metal ions 62, 155–160, 290
transition temperatures 87, 89–91
  effect of cure 90–94, 143, 144
transmission electron microscopy (TEM) 269–271, 273
trialkyl ammonium phenolate 15, 16
s-triazines 2, 7, 61, 62, 64, 65, 69, 73–79, 81, 116, 122, 129, 131, 136, 155, 193, 194, 196, 258, 283
trimerization 14, 26–29, 41, 45, 46, 53, 61, 62, 78, 113–115, 127, 129, 130, 139, 155, 193, 232, 234, 283

ultraviolet spectroscopy 31, 32
unidirectional (UD) fibre-reinforced laminates 182, 183, 260–262, 311, 316, 325
upper critical solubility temperature (UCST) 140–144
ureas, *N*-substituted 159, 160

vapour exposure 38
versatile curing 289, 290
versatile processing 285–288
viscoelastic properties 132–135
viscometry *see also* capillary viscometry 84
viscosity 36
  effect of
    cure 127, 139, 168, 310
    diluents 25, 43, 169–173

viscosity, effect of *contd*
monomer structure 36, 142, 151–153, 168
temperature 168–170
effect on
diffusion-controlled cure 114
fibre impregnation 169, 180–182, 187, 261, 309, 310
WLF equation 133, 136
vitrification 88, 90, 95, 97, 98, 106–108, 120, 121, 124, 139, 144, 145, 147
definition 143
void formation 11, 18, 117, 309
volatile decomposition products 31, 32, 116–118, 164, 165, 197, 202–204, 265, 275, 315
volatility of cyanate ester monomers 32, 37, 38, 43, 89, 118, 153, 223volume fraction 23–25
of additive (Φ_a) 138–145
volume resistivity 252–254
von Braun reaction 10–12, 14

water absorption *see* moisture absorption
weight average molecular weight 83
weight fraction 68, 76
weight loss 117, 118, 197–205
Williams–Landel–Ferry (WLF)
coefficients 133, 136
equation 133
wireless communication 319, 322

X-ray analysis 23–26, 50–52

Index of compounds

o-allylphenyl cyanate 44
alumina 13
alumina trihydrate, $Al_2O_3.3H_2O$ (ATH) 174, 207
aluminium chloride 41
aniline 122, 123
anthraquinone 40
Ardel D100 267, 268, 292, 294
Arlon 63-N 338
AroCy B-10 *see also* BADCy; 2,2′-*bis*(4-cyanatophenyl)isopropylidene; 2,2′-*bis*(4-cyanatophenyl)propane; bisphenol A dicyanate; DCBA 33–35, 131, 152, 165, 166, 168, 170, 187, 195, 203, 204, 207–211, 217–220, 224, 226, 227, 233–236, 238, 239, 243–245, 253–255, 261, 267, 268, 284, 288, 292, 294, 299, 300, 302–306, 308, 312, 332
AroCy B-30 34, 115, 141, 167–169, 171, 173, 189, 221, 223, 261–264, 267–269, 273, 286, 288, 297, 301, 310, 334
AroCy B-40 310
AroCy B-40S 34, 288, 321, 334
AroCy B-50 34, 115, 169, 286, 288, 310, 334
AroCy F-10 *see also* 6F-bisphenol A dicyanate; 2,2′-*bis*(4-cyanatophenyl)-1,1,1,3,3,3-hexafluoroisopropylidene 34–36, 152, 173, 195, 207–209, 224, 226, 227, 233–235, 239, 244, 245, 261, 284, 299, 302, 304, 320, 323, 332
AroCy F-40 169, 286
AroCy F-40S 321, 334
AroCy L-10 *see also bis*(4-cyanatophenyl)-1,1′-ethane; 1,1′-*bis*(4-cyanatophenyl)ethane; 4,4′-dicyanato-1,1-diphenylethane; DPEDC; ESR-310 33, 35, 36, 143, 152, 153, 157, 158, 161, 165, 166, 168–170, 173, 176, 183, 187–190, 195, 209, 211, 233, 235, 239, 261, 262, 268, 273, 284–287, 290, 306, 307, 310, 319, 332
AroCy M-10 *see also bis*(4-cyanato-3,5-dimethylphenyl)methane; METHYLCy 35, 36, 46, 152, 195, 202–204, 207–211, 213, 214, 217–220, 224, 226, 232–239, 244, 245, 250, 253–255, 261, 284, 297, 299, 302–304, 309, 311, 312, 332
AroCy M-20 160, 182, 294, 295, 297, 308, 334
AroCy M-30 169, 173, 221, 286, 334
AroCy M-40 162
AroCyM-40S 227, 244, 245, 321, 334
AroCy T-10 *see also bis*(4-cyanatophenyl)thioether; ESR-193; THIOCy 35, 37, 152, 173, 195, 203, 207–211, 214, 217–220, 224, 245, 302, 332
AroCy T-30 334
Arylsilicon cyanates 30
Atrazine 325

BADCy *see also* AroCy B; 2,2′-*bis*(4-cyanatophenyl)isopropylidene; 2,2′-*bis*(4-cyanatophenyl)propane; bisphenol A dicyanate; DCBA 152, 153, 156, 157, 160, 161, 166, 169, 172–177, 261
BADGE (bisphenol A diglycidyl ether) *see also* 2,2′-*bis*(4-glycidyloxyphenyl)propane 80, 81, 113, 131–136, 142, 143, 166, 170, 174–176, 236, 246, 286, 290, 300, 301, 303, 305
BASF 5575-2 186, 338
benzonitrile 31, 32
2,2′-*bis*(3-allyl-4-cyanatophenyl)isopropylidene 215, 216
2,2′-*bis*(3-allyl-4-hydroxyphenyl)isopropylidene (DAB) *see also* diallylbisphenol A 194
bisbenzocyclobutene 171, 178
bis(4-cyanatobenzyl)aniline 324
*bis*94-cyanato-3,5-dimethylphenyl)methane *see also* AroCy M; METHYLCy 36, 50, 203, 321
1,2-*bis*(4-cyanatophenyl)carborane 205
1,1′-*bis*(4-cyanatophenyl)ethane *see also* AroCy L-10; *bis*(4-cyanatophenyl)-1,1′-ethane; 4,4′-dicyanato-1,1-diphenylethane; DPEDC; ESR-310 36
bis(4-cyanatophenyl)-1,1′-ethane *see also* AroCy L-10; 1,1′-*bis*(4-cyanatophenyl)ethane; 4,4′-dicyanato-1,1-diphenylethane; DPEDC; ESR-310 20, 25, 36
bis(4-cyanatophenyl)ether *see also* REX-288 37, 50, 211
9,9′-*bis*(4-cyanatophenyl)fluorene 197
2,2′-*bis*(4-cyanatophenyl)-1,1,1,3,3,3-hexafluoroisopropylidene *see also* AroCy F-10; 6F-bisphenol A dicyanate 34, 201, 207

2,2′-*bis*(4-cyanatophenyl)isopropylidene *see also* AroCy B-10; BADCy; 2,2′-*bis*(4-cyanatophenyl)propane; bisphenol A dicyanate; DCBA 34, 89, 197, 201, 203, 205, 212, 213, 216
1,3-*bis*(4-cyanatophenyl-1-(1-methylethylidene)benzene *see also* 4,4′-[1,3-phenylene *bis*(1-methylethylidene)]bisphenol dicyanate; RTX-366 36
2,2′-*bis*(4-cyanatophenyl)propane *see also* AroCy B-10; BADCy; 2,2′-*bis*(4-cyanatophenyl)isopropylidene; bisphenol A dicyanate; DCBA 61
bis(4-cyanatophenyl)thioether *see also* AroCy T; ESR-193; THIOCy 37, 50
2,2′-*bis*(4-glycidyloxyphenyl)propane *see also* BADGE 80
bismaleimide–triazine (BT) resin systems
BT-2060BJ 336
BT-2100 336
BT-2110 336
BT-2160 160, 336
BT-2170 336
BT-2300 336
BT-2400 336
BT-2480 336
BT-2580 336
BT-2562F 336
BT-2670 336
BT-2680 336
BT-3109 336
BT-3209 336
BT-3309T 336
bismaleimide–triazine (BT) resins 3, 9, 44, 113, 137–139, 171, 178, 215, 216
bis(4-maleimidophenyl)methane 215, 216
bisphenol A 77, 180, 268, 325, 326
bisphenol A dicyanate *see also* AroCy B-10; BADCy: 2,2′-*bis*(4-cyanatophenyl)isopropylidene; 2,2′-*bis*(4-cyanatophenyl)propane; DCBA 8, 11, 19–21, 23–28, 34, 37, 45, 50, 53, 89, 203, 213, 214, 231, 232, 234, 236, 246, 254, 255, 283, 287, 288, 293, 297–299, 302, 304, 306, 307, 311, 321, 323, 325, 326
6F-bisphenol A dicyanate *see also* AroCy F-10; 2,2′-*bis*(4-cyanatophenyl)-1,1,1,3,3,3-hexafluoroisopropylidene) 45, 46
bis-α,α-trifluoromethyl dicyanate ester 14
BMI–DAB (2,2′-*bis*(3-allyl-4-hydroxyphenyl)isopropylidene-toughened BMI resin) 194, 203, 208, 210, 211, 217–219, 243, 287, 297
BMI–MDA (methylene dianiline-toughened BMI resin) 195, 203, 208, 210, 211, 217–220, 224, 227, 243–245, 298, 300, 302, 311, 312
brominated epoxy resin *see also* tetrabromobisphenol A diglycidyl ether, DGETBBPA) 169, 207, 236, 246, 286, 305
BTCy-1 338
BTCy-1A 340
BTCy-2 338
BTCy-3 338
BTCy-3A 314
butadiene–acrylonitrile (AN) rubber 141, 167

carbamates 3, 8, 12, 18, 20–22, 30–32, 116–121, 154, 159, 164, 308, 318
carbodiimides 30, 31
3-chlorophenol 76
4-chlorophenol 76
4-chlorophenyl cyanate (Cl.PCy) 128
3-(4-chlorophenyl)-1,1-dimethylurea 160
chromium(II) acetylacetonate 62
cobalt(II) acetylacetonate 157, 158, 245, 261, 290, 291
cobalt(III) acetylacetonate 157, 158, 160, 161, 171, 187, 246, 261, 290, 307, 310
cobalt(III) naphthenate 245, 246
cobalt(III) octoate 158
copper(II) acetylacetonate 129, 131, 132, 157, 158, 167, 171, 175, 176, 225, 261, 289, 290, 291
copper(II) naphthenate 89, 157, 175, 246
4-cumylphenol 75, 76, 77, 82, 83
p-cumylphenyl cyanate (CPCy, CPC) *see also* 4-cumylphenyl cyanate; 2-(4-cyanatophenyl)-2-phenyl-propane; 2-phenyl-2-(4-cyanatophenyl)-isopropylidene) 50
4-cumylphenyl cyanate (CPCy, CPC) *see also p*-cumylphenyl cyanate; 2-(4-cyanatophenyl)-2-phenyl-propane; 2-phenyl-2-(4-cyanatophenyl)-isopropylidene) 71, 83, 128, 129, 137
cyanated novolac *see also* Primaset PT resins; REX-371 36
cyanated phenol-dicyclopentadiene adduct *see also* XU71787 36
2-(4-cyanatophenyl)-2-phenyl-propane (CPC, CPCy) *see also* 4-cumylphenyl cyanate; *p*-cumylphenyl cyanate; 2-phenyl-2-(4-cyanatophenyl)isopropylidene) 71
cyanic acid 9, 202
cyanogen bromide 10–14, 44
cyanogen chloride 8–12, 14–16, 325

DCBA *see also* AroCy B; 2,2′-*bis*(4-cyanatophenyl)isopropylidene; 2,2′-*bis*(4-cyanatophenyl)propane; bisphenol A

dicyanate 61, 63, 64, 66–69, 71, 75–77, 80–83, 112, 114–121, 128, 131–137, 146
DEN-431 160
DER-332 (BADGE) 131, 136, 142, 143
DGETBBPA (diglycidylether of tetrabromobisphenol A) 174, 175, 305
diallylbisphenol A *see also* 2,2′-*bis*(3-allyl-4-cyanatophenyl)isopropylidene) 297
4,4′-diamino-3,3′-dimethyldiyclohexyl methane (3DCM) 136
4,4′-diaminodiphenylsulphone (DDS) 194, 241, 243, 301
2,6-di-*t*-butylphenyl cyanate 32
4,4′-*p*-dichlorodiphenyl sulphone 272
1,4-dicyanatobicyclo[2.2.2]octane 13
4,4′-dicyanatobiphenyl 197
dicyanatodiphenylcarborane 197
4,4′-dicyanato-1,1-diphenylethane *see also bis*(4-cyanatophenyl)-1,1′-ethane; DPEDC; ESR-310 89, 124–128, 142–148
4,4′-dicyanatodiphenylether (OXOCy) *see also bis*(4-cyanatophenyl)ether; REX-288 290, 301, 303
dicyandiamide 234, 238
dicyclopentadiene 36
diethylcyanamide 11, 12, 14, 18–20, 53
4,4′-*p*-dihydroxydiphenyl sulphone 272
N,*N*′-dimethylaniline 129
N,*N*′-dimethylbenzylamine 129
1,1-dimethyl-3-phenylurea 160
dinonylphenol 246, 247
dinonylphenyl cyanate 137, 201
diphenylcyanurate 202
diphenyliminocarbonate 122
DPEDC *see also* AroCy L-10; *bis*(4-cyanatophenyl)-1,1′-ethane; 1,1′-*bis*(4-cyanatophenyl)ethane; 4,4′-dicyanato-1,1-diphenylethane; ESR-310 142–148

E-905L 175, 186, 189, 311, 336, 338, 342
EpiCure-841 174, 175
Epi-Rez 509 (BADGE) 175, 221
Epi-Rez SU-8 194
ERL-422 174
ESR-193 *see also* AroCy T-10; *bis*(4-cyanatophenyl)thioether; THIOCy 37
ESR-255 *see also* 1,1,1-*tris*(4-cyanatophenyl)ethane 35, 37, 152, 173
ESR-288 *see also bis*(4-cyanatophenyl)ether 35, 37
ESR-310 *see also* AroCy L-10; *bis*(4-cyanatophenyl)-1,1′-ethane; 1,1′*bis*(4-cyanatophenyl)ethane; 4,4′-dicyanato-1,1-diphenylethane; DPEDC 261
ethoxythiatriazole 17
ethoxythiocarbonyl hydrazine 17
ethylcyanate 17, 21
ethylhexanoic acid 261
2-ethyl-4-methylimidazole (EMI) 131–134
ethyl xanthate 17
EX-1502-1 340
EX-1505 338
EX-1509 338
EX-1510 188, 342
EX-1515 316, 338
EX-1516 340
EX-1530 188, 189, 342
EX-1532 188, 189, 342
EX-1537 340

Fiberite-934 274, 275
Fiberite-954-2 306, 338
Fiberite-954-2A 163, 165, 182, 209, 270, 276–280, 338
Fiberite-954-3 209, 274, 275, 277, 278, 280, 316, 338
Fiberite-977-3 277
fluoroalkyl cyanate esters 13, 30–32, 41
p-fluorophenol 31, 32
FR-4 Epoxy 224, 226, 235, 239, 247, 249, 250, 255, 298–300, 302, 320–322

G-10 Epoxy 208

hexafluoroacetone 41
Hexcel 561-66 306
Hexcel F-495 336
Hexcel HX-1553 336
Hexcel HX-1562 (X3050) 307
Hexcel HX-1566 338
Hexcel HX-1584-3 338
Hycar ATBN-8 126, 127, 141, 142, 146–148
Hycar ATBN-31 142, 146–148
Hycar CTBN 141
Hycar ETBN 1300X40 125, 167, 177, 267, 294
Hycar HTBN 1300X17 125, 167, 177, 294, 295
hydrogen cyanide 32, 208
hydroquinone dicyanate 17, 32
hydroquinones 38

imidazoles 155, 159
imidocarbonates 8–10, 16, 21, 22
iminocarbonate 61, 73, 114–117, 122, 123, 125
isocyanates 9, 17, 22, 28, 29, 41, 133, 175
isocyanurates 29, 78, 79, 81, 131, 132, 136
iso-oxazolines 77
isourea 28, 29, 114, 122, 123, 125–127

JM-7000 318

K1352U 316
Kerimid-601 321
Kevlar-49 182
Kevlar-149 182

manganese(II) octoate 165, 245
Matrimide-5218 292, 308
Meltbond M2555 340
4-methoxyphenol 76
N-methylaniline 202, 302
METHYLCy *see also* AroCy M; *bis*(4-cyanato-3,5-dimethylphenyl)methane 152, 153, 169, 172, 173, 176, 261
methylcyanate 17
methylene dianiline (MDA) 194, 301
methyltetrahydrophthalic anhydride (MTHPA) 174, 175
MR54-4 338

NelTec N-8305 338
naphthalene 40
naphthenic acid 261
4-nitrophenol 76
nonylphenol 89, 121, 125, 132, 155–163, 166, 167, 172, 175, 180, 189, 225, 246, 247, 289, 310
4-nonylphenyl cyanate 45
Nylon-6 185, 308

oxazolidinones 54, 78–80, 81, 129–136, 141
oxazolines 77, 159, 160

PES 4100P 124, 145
PES 4800P 292
PES 5003P 124, 143–145, 148, 267, 268, 292–294
phenol 11, 16–18, 20, 26, 53, 122, 123
phenolphthalein dicyanate 212
phenoxythiatriazole 17
phenyl chlorothioformate 17
phenyl cyanate 10, 13, 17, 18, 21, 32, 122, 123, 212
2-phenyl-2-(4-cyanatophenyl)isopropylidene (CPCy, CPC) *see also p*-cumylphenyl cyanate; 4-cumylphenyl cyanate; 2-(4-cyanatophenyl)-2-phenyl-propane 37, 201
phenyl glycidyl ether (PGE) 128, 129
4-phenylphenyl cyanate 45
phenylthiatriazole 17
m-phenylene diamine (*m*-PDA) 300, 301, 303
4,4′-[1,3-phenylene *bis*(1-methylethylidene)]bisphenol dicyanate *see also* 1,3-*bis*(4-cyanatophenyl-1-(1-methylethylidene))benzene; RTX-366 87
phloroglucinol 38
PMR-15 polyimide 151, 184, 189
Polamine-650 125–128
polycarbonate 100, 177, 213, 214, 292, 326
poly(ester carbonate) 176, 177
polyesters 140, 213, 214
poly(ether ether ketone) (PEEK) 266, 293
polyetherimide 176, 306
polyethersulphone (PES) 124, 126, 140–142, 147, 176, 182, 214, 272, 306, 307, 309
poly(ethylene glycol) 15
poly(ethylene terephthalate) 213, 214
polyimides 107, 140
poly(imidocarbamate) 54
poly(iminocarbonate) 54
polymethacrylamide (PMI) 190, 309
poly-*p*-phenylene 196
polyphenylene oxide (PPO) 292
polysiloxanes 141
polysulphone (PS) 140, 176, 182, 185, 214, 306, 307
poly(vinyl chloride) (PVC) 190, 309
Primaset PT resins *see also* cyanated novolac; REX-371 36, 153, 154, 158, 162–164, 170, 183, 184, 188–190, 201, 208, 209, 233, 284
Primaset PT30 164, 169, 334
Primaset PT60 164, 334
Primaset PT90 334
pyridine 28, 29

resorcinol dicyanate *see also* ResorCy; REX-370 16, 32, 37, 38, 50, 209, 212, 223, 225
resorcinols 38
REX-288 *see also bis*(4-cyanatophenyl)ether 211
REX-370 35, 37
REX-371 *see also* cyanated novolac 35–37, 233, 284, 332
REX-379 334
REX-378 *see also* RTX-366 294, 295, 334
RS-3 316, 338
RS-9 338
RS-12 338
RS-14 342
RS-16 342
RTX-366 *see also* 1,3-*bis*(4-cyanatophenyl-1-(1-methylethylidene)benzene; 4,4′-[1,3-phenylene *bis*(1-

methylethylidene)]bisphenol dicyanate 33, 35, 36, 152, 153, 161, 162, 165, 166, 168, 170, 177, 179, 180, 184, 187, 209, 219, 232–235, 238–240, 243–247, 284, 285, 287, 289, 294, 300, 311, 312, 319, 332

SF-5 338
silicon tetracyanate 30, 53
siloxane cyanate ester oligomers 178
Skylex CA200 332
Skylex CA210 334
Skylex CA260 334
Skylex CA270 334
sodium azide 17
sodium cyanide 16
sodium hydride 14
Speedboard C 338

Tegomer HSi6420 125–127
tetrabromobisphenol A 77
tetrabromobisphenol A diglycidyl ether (brominated epoxy resin, DGETBBPA) 133, 169, 174, 321
N,N,N′,N′-tetraglycidyl diamino-4,4′-diphenylmethane (TGDDM) 113
tetraglycidylmethylene dianiline (TGMDA) 194, 300
TGMDA-DDS 195, 203, 210, 211, 217–221, 235, 243–245, 297, 301
thiatriazoles 8, 10, 17, 18
THIOCy *see also* AroCy T-10; *bis*(4-cyanatophenyl)thioether; ESR-193 152–154, 176
thiocyanates 10, 28
thiophosgene 17
Thornel ERL 1939-3 186, 338
Thornel ERL 1999 162, 163, 338
Thornel ERL-4221 159, 174
titanate chelate catalysts 129, 131, 166
Triazine A 3, 8, 14, 255, 302–304, 329
triethylamine 10, 13–16, 18, 20, 45, 122–124
α,α-trifluoromethyl cyanate 41
N,N,O-triglycidylamino-4-phenol (TGAP) 113
triphenylisocyanurate 202
triphenyl-*s*-triazine 202
tris(4-cumylphenoxy)-1,3,5-triazine 215
tris(4-cumylphenyl cyanurate) 129
1,1,1-tris(4-cyanatophenyl)ethane *see also* ESR-255 37, 50

Udel P1800 160, 267, 268, 292–294
Ultem-1000 147, 185, 267, 292, 294, 307
Unilink-4200 125–127

Vitel PE307 292, 294

WPE-183 *see also* BADGE 305
WPE-650 *see also* DGETBBPA 305

X6555 338
X6555-1 338
XU71787 *see also* cyanated phenol-dicyclopentadiene adduct 9, 35, 36, 53, 195, 207, 208, 211, 219, 224, 233, 239, 242, 244, 245, 284, 294, 295, 302, 321
XU71787.02 153, 154, 158, 160, 168–171, 183–185, 209, 261, 334
XU71787.07 171, 178, 334
XU71787.09L 334

zinc(II) acetylacetonate 157, 261
zinc(II) chloride 62, 173
zinc(II)naphthenate 157, 158, 161, 166, 172, 189, 246, 247
zinc(II) octoate 129, 165, 173, 175, 246
zinc(II) stearate 246