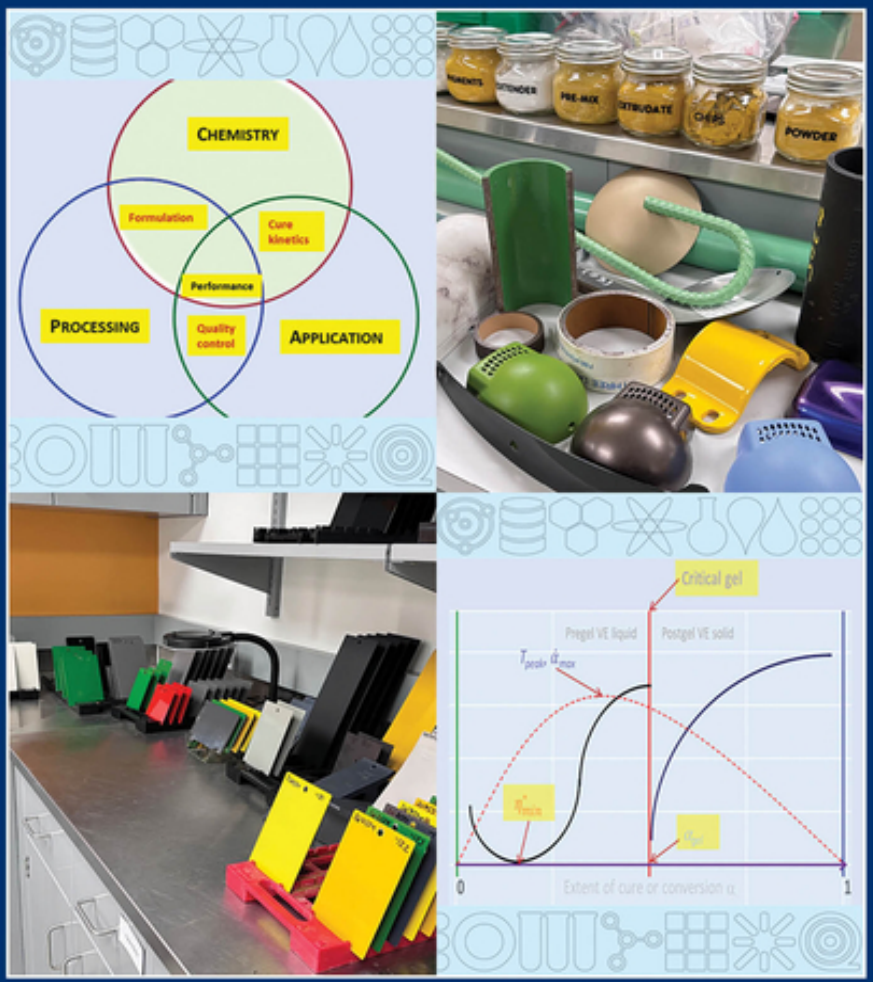
WEIH Q. LEE

APPLIED COATINGS

CHEMISTRY, FORMULATION, AND PERFORMANCE



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Chemistry, Formulation, and Performance

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Published by John Wiley & Sons, Inc., Hoboken, New Jersey.
Published simultaneously in Canada.

Library of Congress Cataloging-in-Publication Data applied for:

Hardback ISBN: 9781394211173

Cover design: Wiley
Cover images: Courtesy of Weih Q. Lee.

Set in 9.5/12.5pt STIXTwoText by Straive, Chennai, India

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Preface

This book encompasses applied (epoxy) coating chemistry, formulation, and properties. Additional technological platforms, such as phenolics and microencapsulation, are included in compliance with a broader scope of applicable thermosetting systems surrounding epoxies. As the author herein aims to offer refreshing insights from his experiences as a hands-on formulation scientist and engineer for over 20 years in the coatings industry, in-depth discussions are incorporated throughout the context, combining advanced fundamentals with related coating formulations suited for a range of intended industrial applications.

The entire narrative throughout this book is divided into parts and chapters that, in general, are self-contained and coherently organized using theoretical concepts and practical topics, both crucial to understanding and fabricating epoxy coatings, adhesives, and laminates, among other product formats. The contents presented in this monograph, including modules of in-depth debriefs and recaps in the middle or at the end of each chapter, are data-driven and exclusive in one way or the other, rejecting a similar or duplicate impression and committed to a problem-solving paradigm by sharing the most up-to-date overview of epoxy-related science and technology advancements, as the readers, particularly formulators dealing with epoxy and other chemistries, will notice. Readers are exposed to a series of real-world illustrations that explicitly apply chemical principles to formulating pragmatism (for example, crosslinker-free epoxy formulations, low-temperature cure for high-temperature service, and super high dual T_gs); readers are given access to an effective DSC (differential scanning calorimetry) exothermic analysis method for obtaining numerical approximations of kinetic parameters as disclosed in privilege; and readers would learn that a physical steric effect rather than chemical crosslinking of fluorene epoxies sometimes plays a crucial role in achieving super-elevated glass transition temperatures up to 250 °C. These are but a few exhibitions of value propositions that may both encourage and call for ingenious thoughts to develop. Additionally, these are also a few instances of insights that are probably hard to come across elsewhere. Regardless of technical proficiency, there are a wealth of fresh concepts and findings related to coatings chemistry and formulation that will keep professional readers interested and motivated.

The author and this manuscript are committed to remaining impartial, positively providing discretionary viewpoints, and assisting some readers in their professional interests and efforts to develop innovation-oriented epoxy coatings and beyond to more effectively address emerging and advanced challenges in the future. Enjoy and thank you for reading!

April 2024

Dr. Weih Q. Lee
Minneapolis, USA

Acknowledgments

For their invaluable contributions to this monograph in whatever form, the author is sincerely appreciative of peers, colleagues, and advocates who are listed at the end of each chapter where applicable. These distinguished researchers are greatly valued for their diverse skills and original ideas, which always improve and enrich discussions.

April 2024

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Abbreviations, Symbols, and Units

Symbols and abbreviations	Descriptions	Units
A	Pre-exponential factor in autocatalytic cure kinetic model Amplitude Absorbance	1/s if first-order reactions
α	Extent or degree of cure	%
$\dot{\alpha}$	Cure reaction rate (= $d\alpha/dt$)	1/s
$\dot{\alpha}_{max}$	Maximum cure reaction rate	1/s
α_c	Critical degree of cure	%
α_{gel}	Extent of cure at gelation (the gel point)	%
β	Rate of heating for cure or the heating rate	°C/min or °K/min
C_p	Heat capacity	J/°K
De#	Deborah number ($= \lambda/t = \lambda\omega$)	
D_f	Dissipation factor or dielectric loss	
D_k	Dielectric constant	
δ	Phase angle ($0° \leq \delta \leq 90°$, $\delta = 45°$ representing the gel point)	°
Tanδ or Tan(δ)	Loss tangent ($= G''/G'$)	
ΔH	Enthalpy or heat of reactions or reactivity ("−"/exo – release heat, "+"/endo – absorb heat)	Joule/g or J/g
ds	A time term in Laplace transform	second or sec or s
$\Delta\tau$	Change in stress	P_a or N
$\Delta\varepsilon$	Change in extension or elongation – solid	%
E: E′, E″	Tensile modulus: Elastic (or Young's) or storage modulus, viscous or loss modulus	P_a or MP_a or GP_a
E_a	Activation energy	J/mol
f; di-f; multi-f	Functionality or frequency; di-functional; multi-functional	

(*continued*)

Symbols and abbreviations	Descriptions	Units
$\dot{\varepsilon}$	Elongation rate (solid)	%
$\dot{\gamma}$	Strain rate (liquid)	
η	Shear viscosity	
η_B	Bingham viscosity	
η_e	Extensional viscosity	P_a-s
η*	Complex or dynamic viscosity	
η^*_{min}	Minimum dynamic viscosity	
η_B	Bingham viscosity at zero shear or strain rate ($\dot{\gamma} = 0$)	P_a-s (= 1,000 mP_a-s)
G:	Shear modulus:	P_a or MP_a or GP_a
G′, G″	Storage (elastic) modulus, Loss (viscous) modulus	
f, di-f, multi-f	Functionality, di-functional(ity), multi-functional(ity)	
G'_{min}, G'_{max}, G''_{min}, G''_{max}	Minimum storage modulus, maximum storage modulus Minimum loss modulus, maximum loss modulus	P_a or MP_a or GP_a
γ	Strain	%
$\dot{\gamma}$	Strain rate (also called shear rate) (liquid)	1/s
J*	Complex compliance	$1/P_a$
J(t)	Time-dependent creep compliance	
K	Co-efficient in Power Law	
K_{rel}	Relative rate constant	
k(T)	Arrhenius dependency = A*exp(-E_a/(RT))	
λ	Relaxation time = η/G	sec or s
	Wavelength (not wavenumber, cm^{-1} nominated for FTIR)	nm
	Thermal conductivity	W/m-°K
lnA or ln(A)	Natural logarithm of A (as a pre-exponential factor)	1/s
m, n	Reaction orders in the autocatalytic model	
n	Number of repeating units	
μ	Viscosity (kinematics)	mP_a-s or cPs
n_c	Relaxation exponent (0~1)	P_a
N_1	Normal stress	
ω	Angular frequency	rad/s (1.0 Hz = 6.28 rad/s)
R	Gas constant (= 8.314)	J/mol-°K
R-SH(s)	Thiol-alcohol(s)	
sec or s	Second	
SB (m, n)	Sestak–Berggren (m, n) kinetic model	
σ	Surface tension (liquid)	N/m or mJ/m^2 or dyne/cm
t	Time	sec or s
T	Temperature	°C or °F or °K
T_{cure}	Cure temperature	°C or °F or °K
T_{gel}	Temperature at gelation	°C or °F or °K

Symbols and abbreviations	Descriptions	Units
T_{g0} & $T_{g\infty}$	T_gs at $\alpha = 0$ & 1	°C or °F or °K
T_{onset} & T_{peak}	Onset & peak temperature on DSC exothermic curves	
τ	Shear stress	P_a
τ_y	Yield stress	
T_g, T_gs	Glass transition temperature(s)	°C or °F or °K
T_m	Melting point or melting temperature	°C or °F or °K
υ	Poisson's ratio (= 0.50 if incompressible)	
W_i	Weissenberg number = $\lambda\dot{\gamma} = \gamma_0\lambda\omega$	
1D, 2D, 3D	One-dimensional, two-dimensional, three-dimensional	
1/2/3/4K	One (1)-/two (2)-/three (3)-/four (4)-component	
1,3-PBO	1,3-Phenylene bis-oxazoline	
2E4MI	2-Ethyl-4-methyl imidazole	
2MI (or 2-MI)	2-Methyl imidazole	
2IPI	2-Isopropyl imidazole	
2PI (or 2-PI)	2-Propyl imidazole	
2MZA	2,4-Diamino-methyl-1-imidazolyl) ethyl]-triazine	
2PHZ	2-Phenyl-imidazole-4,5-diyl) di-methanol	
3-HP	3-hydroxy-propionic acid	
3M	Minnesota Mining and Manufacturing Company	
4-APDS	4-Aminophenyl disulfide	
4-PVP	Poly (4-vinyl phenol) or polyvinylphenol	
44TMDP	4,4'-trimethylenedipyridine	
C1S, C2S	Coated one side, coated two sides	
FR-4	Glass fiber-reinforced epoxy laminate materials	
HCHO	Formaldehyde	
Ph-OH	Phenyl hydroxyl functional groups	
(°/)PD	(Degree per) pipe diameter	
Type 4, 5, 7, … epoxy	Repeating unit (n) of 5, 8, and 11 … affiliated with BPA-derived epoxy resins	
AA	Adipic acid	
AzA	Azelaic acid	
AAEM	Acetoacetoxy ethyl methacrylate	
AAP	4-Amino-antipyrine	
ABS	Acrylonitrile butadiene styrene (plastic)	
AC	Acrylic **or** Acrylic coatings	
AcAc	Acetylacetonate **or** Acetoacetate	
ACE	Agricultural, construction, and earth moving	
ADH	Adipic dihydrazide	
AEP	Aminoethylpiperazine	
AFM	Atomic force microscope	

(*continued*)

Symbols and abbreviations	Descriptions	Units
AHEW	Amine hydrogen equivalent weight (= EW-NH)	g/eq or g/mol
AI	Artificial intelligence	
	Aluminum	
AlAcAc	Aluminum acetylacetonate	
AlN	Aluminum nitride	
AMEO or APTES or APTEOS	3-Aminopropyl triethoxysilane (mono-podal)	
AMFB	Fluorene-based benzoxazine monomer(s)	
AMP	Advanced modified polymer	
	Aminomethyl propanol	
AMTU	Ammonium molybdate tetrahydrate and urea (catalyst)	
ANOVA	Analysis of variance	
AP	Adhesion promoter	
APAC	Asia-Pacific regions	
APAO	Amorphous poly alpha olefin	
APEO	Alkylphenol ethoxylate	
APIs	Active pharmaceutical ingredients	
APOS	Aliphatic polols	
APP	4-Amino-antipyrine	
	Ammonium polyphosphate	
AR	Aspect ratio	
Ar	Aromatic	
ASAP	Atomerspheric solids analysis probe mass spectrometry	
ATH	Aluminum trihydrate	
ATMOS	Allyltrimethoxysilane	
ATR-IR	Attenuated total reflection - IR	
BA	t-Butyl propionate	
	Boron arsenide	
BAA (or t-BAA)	t-Butyl acetoacetate	
BAF	Bis(4-aminophenyl) fluorene	
BBL2	Berberine bridge enzyme-like 2	
BCB	Benzocyclotene	
BCF	Biscresol fluorene	
BPF	9, 9-Bis(4-hydroxy-phenyl) fluorene	
BD	Borchardt–Daniels	
BDDE	Butanediol di-glycidyl ether	
BDMA	Benzyldimethylamine	
BDO	1,4-Butanediol	
BFBCs	Bis(fluoralkyl) bis(carbonate)s	

Symbols and abbreviations	Descriptions	Units
BMIs	Bismaleimide(s)	
BOX(s)	Benzoxazine(s)	
BPA/F/S	Bisphenol-A/-F/-S	
BT (resins)	Bismaleimide triazine (resins)	
BTA	Benzotriazole (or 1H-Benzotriazole)	
BTBAC or BTBACl	Benzyl tributyl ammonium chloride (catalyst)	
BTEAC	Benzyl triethyl ammonium chloride	
BTPPC or BTPPCl	Benzyl triphenol phosphonium chloride	
BCl_3·DMOA	Boron trichloride dimethyl octylamine	
BCl_3·MEA	Boron trifluoride monoethylamine	
BCl_3·TMA	Boron trichloride trimethylamine	
C, Conc.	Concentration	meq/ml (mole) not mg/ml (mass) unless specified
C1S, C2S	Coated one side, coated two sides	
CAB	Cellulose acetate butyrate	
CAGR	Compound annual growth rate	
CAP	Citric acid-based polyester polyol	
CAPA	Corrective and preventive actions	
CASEs	Coatings, adhesives, sealants, and elastomers	
CB/CF	Coated back (C1S)/Coated front (C1S)	
CFB	Coated front and back (C2S)	
CCL(s)	Copper clad laminate(s)	
CDT(s)	Cathodic disbondment testing or test(s)	
CEs	Cyanate esters	
CFRP (GFRP)	Carbon fiber reinforced plastics (composites) (glass fiber reinforced plastics)	
CHDA	Cyclohexanedicarboxylic acid	
CHDM	1,4-Cyclohexanedimethanol	
CIE	Commission Internationale de l'Éclairage	
CNSL(s)	Cashew nutshell liquid(s)	
CNTs (SWNTs)	Carbon nanotubes (single-walled nanotubes)	
CNWs	Carbon nanowires	
COA	Certificate of analysis	
COF	Co-efficient of friction	
COPE	Co-polyester ether elastomer(s)	
CP(s)	Coated panel(s)	
	Critical point(s)	

(*continued*)

Symbols and abbreviations	Descriptions	Units
CPH	Caffeoyl-putrescine and hexenal	
CPO	Chlorinated polyolefin	
CPP	Critical packing parameter	
CRVP	Controlled rate viscosity profile	
CSR(s)	Core/shell or core-shell rubber(s)	
CTAB	Cetrimonium bromide quaternary ammonium salt	
CTBN	Carboxyl terminated butadiene acrylonitrile	
CTC	Cyclic thiolcarbonate(s)	
CTE	Co-efficient of thermal expansion	%
CTQ	Critical to quality (6σ term)	
DAAM	Diacetone acrylamide	
DABCO or TEDA	1,4-Diazabicyclo [2.2.2] octane, also known as triethylenediamine	
DAM	Diallyl maleate (inhibitor)	
DBC	Direct bond (or bonded) copper	
DBTA or DBTDA	Dibutyltin diacetate Dibutyltin dilaurate	
DBTDL (or DBTL)	1,8-Diazabicyclo [5.4.0] undec-7-ene	
DBU		
DC/AC	Direct current/Alternating current	
DCC	N', N'-dicyclohexyl carbodiimide (MW 206.3)	
DCMU	3-(3,4-Dichlorophenyl)-1,1-dimethylurea	
DCPD	Dicyclopentadiene	
DCS	DSC curve solutions (curve fitting software)	
DDBSA	Dodecylbenzenesulfonic acid	
DDDA	Dodecanedioic acid	
DDH	Dodecanedioic dihydrazide	
DDS	Diaminodiphenyl sulfone	
DEA	Dielectric analysis	
DEAP	2,2-Diethoxy Acetophenone (photo-initiator)	
DEM	Diethyl maleate	
DEMM	Diethyl methylene malonate	
DETA	Diethylenetriiamine	
DETDA	Diethyl toluenediamine	
DFT	Dry film thickness	mil or μm (1 mil = 25.4 μm = 0.0254 mm)
WFT	Wet film thickness	
DGE(s)	Do-glycidyl ether(s)	
DGEBA	Di-glycidyl ether bisphenol-A	
DGEBF	Di-glycidyl ether bisphenol-F	

Symbols and abbreviations	Descriptions	Units
DGBE	Diethylene glycol butyl ether (solvent)	
DI	Deionized	
DICY	Dicyandiamide	
DIDP	Diisodecyl phthalate	
DIOP	Diisooctyl phthalate	
Di-TMP	Trimethylolpropane tris(3-mercaptopropionate)	
DIY	Do-It-Yourself	
DMA	Dynamic mechanical analysis	
DMAA	N, N-dimethyl acrylamide	
DMAc	Dimethylacetamide (solvent)	
DMAP	4-Dimethylaminopyridine	
DMDC	Dimethyl dicykan	
DMEA	Dimethylethanolamine	
DMF	N, N-dimethylformamide (solvent)	
DMP(-30)	2,4,6-Tris(dimethylaminomethyl) phenol	
DMS	Dimethyl stearylamine (aliphatic)	
DNNSA, etc.	Dinonylnaphthalenesulfonic acid, etc.	
DOE	Department of Energy	
DOE(s)	Design of experiment(s)	
DOP	Dioctyl phthalate	
DOPA	3,4-Dihydrooxy-L-phenylalanine	
DOT	Department of Transportation	
DOTA	Dioctyltin diacetate	
DOTL (or DOTDL)	Dioctyltin dilaurate	
DPHA	Di-pentaerythritol hexa-acylate	
DPM (acetate)	Dipropylene glycol monomethyl ether (acetate)	
DSC (TMDSC or MTDSC or MDSC)	Differential scanning calorimetry (temperature-modulated DSC)	
DTM	Direct-to-metal	
ED copper foil	Electrodeposited copper foil (versus RA or rolled annealed copper foil)	
ECH	Epichlorohydrin	
ECN	Epoxy cresol novolac	
EDC or EDAC	1-Ethyl-3-(-3-dimethylaminopropyl) carbodiimide hydrochloride (MW 191.7)	
EEA	Ethylene co-ethyl-acrylate	
EEW	Epoxy equivalent weight (or WPE, i.e., weight per epoxide)	g/eq
EHD	Electrohydrodynamic	
EIS	Electrical impedance spectroscopy	

(*continued*)

Symbols and abbreviations	Descriptions	Units
EMA	Ethylene methacrylate	
(co-polymer)	Epoxy molding compounds	
EMC		
EMEAI	Europe, Middle East, Africa, and India	
EMI	Electromagnetic interference	
EPBN	6,6′6,6′-Bis(2,3-epoxypropoxy)-2,2′-binaphthyl	
EPN	Epoxy phenol novolac	
ETCH	1-Ethynylcyclohexanol (inhibitor)	
ETM	(Trimethoxy silyl) Ethyl-1,1,3,3-tetramethyldisoxane	
ETMBPS	Epoxy tetramethyl bisphenol-S	
ETPPI/ETPPB or ETPPBr	Ethyl tri-phenyl phosphonium iodide/bromide	
EW	Equivalent weight	g/eq
EW-OH	Hydroxyl equivalent weight	
EW-NCO	NCO equivalent weight	
EW-PhOH	Ph-OH equivalent weight	g/eq
EV(s)	Electric vehicle(s)	
EVA	Ethylene vinyl acetate	
FBE(s)	Fusion bonded epoxy (epoxies)	
FER(s)	Fluorinated epoxy resins(s)	
FEVE(s)	Fluoroethylene vinyl ether co-polymer(s)	
FFA	Furfuryl alcohol	
FI(s)	Formulation index(es)	
FMEA	Failure model and effects analysis	
FSR	Fluorosilicone rubber	
LSR	Liquid silicone rubber	
FTIR	Fourier transform infrared (spectroscopy)	cm^{-1} (wavenumber)
FVMQ	Fluorovinylmethylsiloxane	
GC/MS	Gas chromatography/mass spectrometry	
HS-GC/MS	Headspace-GC/MS	
GDP	Gross domestic production	
GLYEO	3-Glycidoxypropyl triethoxysilane	
GLYMO	3-Glycidoxypropyl trimethoxysilane	
GMA	Glycidyl methacrylate acid	
GMP	Good Manufacturing Practices	
G.N.F.	Generalized Newtonian fluids	
GOs, rGOs	Graphene oxides, reduced GOs	
GPC/SEC	Gel permeation chromatography/size exclusion chromatography	
GST	Bismercaptoethyl thio-propanethiol	

Symbols and abbreviations	Descriptions	Units
HAA(s)	β-Hydroxyl alkyl amide(s)	
HALS	Hindered amine light stabilizer(s)	
HCR	High-consistency silicone rubber	
HDI	Hexamethylene diisocyanate (aliphatic)	
HDO	1,6-Hexanediol	
HDT	Heat distortion temperature	
HDPE	High density polyethylene	
HDT	Heat distortion temperature	
H.E.W.	Hydroxyl equivalent weight (including aliphatic OHs, or Ph-OHs)	g/eq
HHPA	Hexahydrophthalic anhydride	
HIPC	High impact polycarbonate	
HLB	Hydrophilic-lipophilic balance	
HM(s)	Hotmelt(s)	
HMDA	Hexamethylene diamine	
HMEA	N-hydroxymethylethanol amine	
HMPSA	Hotmelt pressure sensitive adhesive	
HMMM	Hexamethoxymethylmelamine	
Homo-cure(s)	Homo-polymerization	
Co-cure(s)	Co-polymerization	
HPCs	High-performance catalysts	
HPLC	High-performance liquid chromatography	
HQ	Hydroquinone	
HS	High solids	
	Hydrostyrene	
HSD Hegman	High-speed-dispenser Hegman	
HSE	Health safety environment	
HSE, MSE, LSE	High, Medium, and Low surface energy (solid surfaces)	mN/m, mJ/m^2, dyne/cm
HTHP	High temperature and high pressure	
HUG	Hexamethylenediamine urea glyoxal	
HWA	Hot water (soak) adhesion	
IBOMA	Isobornyl methacrylate	
ICP	Intrinsically conductive polymer	
ID	Inner diameter	
IDH	Isophthalic dihydrazide	
IGBT(s)	Insulated-gate bipolar transistor(s)	
IMS (also MCPCB)	Insulated metal substrate (metal core PCB)	
IPA	Isophthalic acid (for superdurable PEs)	
	Isopropyl alcohol	

(*continued*)

Symbols and abbreviations	Descriptions	Units
IPDI	Isophorone diisocyanate (aliphatic)	
KPI	Key performance indicator	
ITX	Isopropyl thioxanthone (Type II photo-initiator)	
LAT	Low application temperature	
LC	Liquid crystalline	
LCER(s)	Liquid crystalline epoxy resin(s)	
LC/MS	Liquid chromatography/mass spectrometry	
LCP(s)	Liquid crystalline polymer(s)	
LCPU	Liquid crystalline polyurethane	
LC-UV	Liquid chromatography - ultraviolet	
LDH	Icosanedioic dihydrazide	
LDPE	Low density polyethylene	
LEDs	Light-emitting diode(s)	
LER(s)	Liquid epoxy resin(s)	
SER(s)	Solid epoxy resins(s)	
LOD	Limit of determination	
LS	Light scattering	
LVE	Linear viscoelasticity	
MAA	Methacrylic acid	
MCU	Moisture cure urethane	
MBO	2-Methyl-3-butyn-2-ol	
MBPO	Methyl-substituted benzoyl peroxide	
MCDEA	4,4′-Methylenebis(3-chloro-2,6-diethylaniline)	
MCOT	Modified cyclic olefin thermoset	
MCUs	Moisture-curable polyurethanes	
MDA	4,4′-Methylene-dianiline	
MDI	Methylene diphenyl di-isocyanate (aromatic)	
MDF(s)	Medium density fiberboard(s)	
MDPA	3,4′-(Methylene)-di-phthalic anhydride	
MEA	Mono-ethylamine	
MeAoMA	Methyl-allyloxy-methyl acrylate	
MECA	2-Methoxyethyl cyanoacrylate	
MEK	Methyl ethyl ketone (solvent)	
MF	Melamine-formaldehyde	
MFK	Model-free kinetics (E_a and E_a-α estimation)	
MgH_2	Magnesium hydride	
MMA (PMM or PMMA)	Methyl methacrylate (polyMMA)	
MMC	Metal matrix composites	

Symbols and abbreviations	Descriptions	Units
M_n	Number average MWs	g/mol
M_w	Weight average MWs	
MOCA or MBOCA	Methylene bis-ortho-chloroaniline (aromatic)	
MOFs (CP/MOF)	Metal organic frameworks (coordination polymer and MOF)	
MPD	Methyl-pentanediol	
MRO	Maintenance, repair, and operations	
MW	Molecular weight	g/mol, D_a or Dalton
MWD	Molecular weight distribution	
MXDA	Meta-xylenediamine	
MYTAB	Myristyl trimethyl ammonium bromide	
N/A	Not applicable	
NC	Nitrocellulose	
NCO	Isocyanate or Isocyanates	
ND	Not determined	
NHC	N-heterocyclic carbene	
NIR	Near infrared	
NISO	Non-isocyanate	
NIPU	Non-isocyanate polyurethane	
NLVE	Non-linear viscoelasticity	
NMA	Nadic methyl anhydride	
	N-methylolacrylamide	
NMP	N-methyl-2-pyrrolidone (solvent, e.g., for PAA or polyamic acid)	
NMR	Nuclear magnetic resonance (^{1}H-, ^{13}C, etc.)	
NPG	Neopentyl glycol	
NSF	National Sanitation Foundation	
NVM	Non-volatile mass	%
NVV	Non-volatile volume	%
OD	Outer diameter	
ODE(s)	Ordinary differential equation(s)	
OEM(s)	Original Equipment Manufacturer(s)	
OH	Hydroxyl group	
COOH	Carboxyl group	
OPSZ	Organic polysilazanes	
OPUs	Oxidizable (unsaturated) phenolic-based urethanes	
OTB	O-tolylbiguanide	
O/W or W/O	Oil-in-water or Water-in-oil	
PA	Phthalic anhydride	
	Polyamide	
	Polyaspartic	
	Phytic acid	

(*continued*)

Symbols and abbreviations	Descriptions	Units
PAA	Polyamic acid	
PAE	Polyacrylic acid	
PAI	Polyamide epichlorohydrin	
	Polyamideimide	
P/B ratio	Pigment to binder ratio (by volume or weight)	
PBD	Polybutadiene	
PBI	Polybenzimidazole	
PBO	Phenylene bis-oxazoline	
PBZ(s)	Polybenzoxazine(s)	
PC	Polycarbonate	
PCBs (MCPCBs)	Printed circuit boards (Metal-cored PCBs)	
PCBTF	Para-chlorobenzotrifluoride (super solvent, VOC exempted)	
PCI	Powder Coating Institute	
PCF	Product carbon footprint	
PCL	Polycaprolactone	
PCM(s)	Phase change material(s)	
PDA	Polydopamine	
PDI	Penta-methylene diisocyanate (aliphatic)	
PDMS(s)	Polydimethylsiloxane(s)	
PDO	1,3-Propanediol	
PE	Polyethylene	
PE(s)	Polyester(s)	
PEA	Polyetheramine	
PEDOT:PSS	Poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate)	
PEG	Polyethylene glycol	
PEI	Polyetherimide	
PEEK	Polyether ether ketone	
PEO	Poly(ethylene oxide) – epoxyphilic	
PEP	Poly(ethylene propylene) – epoxyphobic	
PES	Polyethersulfone	
PET	Polyethylene terephthalate	
PETA	Phenylethyl trimellitic anhydride	
PETMP	Pentaerythritol tetramercaptopropionate	
PFAS, PFOA	Per and polyfluoroalkyl substances, Perfluorooctanoic acid	
PF (resins)	Phenol-formaldehyde (resins)	
PFP	Passive fire protection	
PGA	Pyrogallic acid	
PGMA	Propylene glycol methyl ether acetate (solvent)	
PHPS	Perhydropolysilazanes	

Symbols and abbreviations	Descriptions	Units
phr or PHR	Per hundred resin	parts by weight
PI(s)	Polyimide(s)	
PIB	Polyisobutylene	
PLGA	Poly(lactic acid/glycolic acid)	
PM (acetate)	Propylene glycol methyl ether (acetate)	
PMA(s)	Polymethacrylate(s)	
PMC	Polymer-modified concrete	
PMDA	Pyromellitic dianhydride	
PN	Phthalonitrile	
PO	Polyolefin	
POM(s)	Polyoxometalate(s)	
POSS	Polyhedral oligomeric silsesquioxanes	
PP	Polypropylene	
	Prepolymer(s)	
PPA	Polyphthalamide	
PPE	Polyphenylene ether	
PPG	Polypropylene glycol	
PPO(s) or PPE(s)	Polyphenol oxidase(s)	
	Poly(p-phenylene oxide) (ethers)	
PPP-BP	N-phenyl phenolphthalein bisphenol	
PPS (PPSU)	Polyphenylsulfone	
PROTACS	Proteolysis targeting chimeras	
PS	Particle size	μm
	Polystyrene	
PSAs	Pressure-sensitive adhesives	
PSG DGE	Pentaspiroglycol diglycidyl ether	
PT	Phenolic triazine	
	Prout–Tompkins	
PTFE	Polytetrafluoroethylene	
PTMEG	Polytetramethylene ether glycol (or polytetrahydrofuran)	
p-TSA	p-Toluene sulfonic acid	
p-TSI	p-Toluenesulfonyl isocyanate	
PUR(s) or PU(s)	Polyurethane(s)	
	Polyurea	
PUA	Polyurethane acrylate	
PUD(s)	Polyurethane dispersion(s)	
PV(s)	Photovoltaic(s)	
PVA; PVAc	Polyvinyl alcohol; Polyvinyl acetate	
PVB	Polyvinyl butyral	

(*continued*)

Symbols and abbreviations	Descriptions	Units
PVC(s)	Pigment volume concentration(s)	
	Polyvinyl chloride	
PVDC	Polyvinylidene chloride	
PVDF	Polyvinylidene fluoride	
PXDT	1,4-Benzenedimethanethiol (thiols)	
QC	Quality control	
RAFT	Reversible addition-fragmentation chain transfer	
Redox	Reduction-oxidation (or oxidation-reduction)	
RH	Relative humidity	%
RI	Reflective index	
	Refractive index	
RT	Room temperature	
RTV	Room temperature vulcanizing (silicone, RTV-1 for 1K and RTV-2 for 2K)	
SAA	Sulfanilamide	
SAOS	Small amplitude oscillatory shear	
SB	Styrene/butadiene	
	Solvent-based (or -borne)	
SB (m, n)	Sestak–Berggren kinetic model	
SBR	Styrene/butadiene rubber	
SDS	Sodium dodecyl sulfate (anionic surfactant)	
SiC	Silicon carbide	
SiH	Silicon hydride	
SIS/SBS	Styrene-isoprene-styrene/styrene-butadiene-styrene	
SBHPP	Sumitomo Bakelite High Performance Products	
SCT	Self-contained test	
SRT	Solvent resistant test	
SDH	Sebacic dihydrazide	
SDS	Sodium dodecyl sulfate (surfactant)	
SEM	Scanning electron microscope	
SERs	Solid epoxy resins	
S.O.F.	Second Order Fluid	
SMA(s)	Styrene maleic anhydride(s)	
SMC	Sheet molding compound	
SMP(s)	Silyl-modified polymer(s) or MS-polymer(s)	
	Silicone modified polyester(s) (powder coatings)	
SPUR or STP-U	STP-urethane/polyurethane or silyl-modified PURs	
STP(s)	Silane-terminated or -modified polymer(s)	
STP-E/-U	Silane-terminated polyether/urethane (or SPUR)	
TA	Terephthalic acid (for durable PEs)	
	Thermal Analysis	

Symbols and abbreviations	Descriptions	Units
TAB	Triacetoxybenzene	
TBAH	Tetrabutylammonium hydroxide	
TBAB	Tetra butyl ammonium bromide	
TBD	To be determined	
TBT (or TnBT)	Titanium (IV) butoxide (or tetra-n-butyl titanate)	
TCF or Bimox M	4,4'-Methylenebis(2,6-di-tert-butylphenol)	
TDI	Toluene di-isocyanate (aromatic)	
TDPA	3,3'-Thiodipropionic acid	
TDP	Thiodiphenol	
TDS	Technical Data Sheet	
TEMPIC	Tris-mercaptopropionyloxy ethyl isocyanurate (thiol)	
TEOS	Tetraethoxysilane	
TMOS	Tetramethoxysilane	
TPOS	Tetrapropyl orthosilicate	
TEPIC	Tris (2,3-Epoxy propyl) Isocyanurate (epoxy-functional)	
TEVP	Thixo-elasto-visco-plastic	
TGA	Thermal gravimetric analysis	
TGIC	Triglycidyl isocyanurate (epoxy-functional)	
TGDDM	Tetraglycidyl-4,4'-diaminodiphenyl methane	
THEIC	Tris(2-hydroxyethyl) isocyanurate	
THF	Tetrahydrofuran (solvent)	
TIM(s)	Thermal interface material(s)	
TMA	Thermal mechanical analysis	
TMC	Trimellitic anhydride Trimethyl-cyclohexylidene	
TMCBDO or TMCD	2,2,4,4-tetramethyl-1,3-cyclobutanediol	
TME	Trimethylolethane (triol)	
TMP/di-TMP	Trimethylolpropane/TMP-tris(3-mercaptopropionate)	
TMPD	Trimethyl pentanediol	
TMBPF	Tetramethyl bisphenol-F	
TMPTA	Trimethylolpropane triacrylate	
DiTMPTA	Di-trimethylolpropane tetraacrylate	
TMVCTS	Tetramethylvinylcyclotetrasiloxane (inhibitor)	
TnBT	Tetra-n-butyl titanate	
TPA	Thermoplastic acrylic	
TPU	Thermoplastic PURs	
TSA	Thermosetting acrylic	
TPCP	Tetraphenoxycarbonyl pentaerythritol	

(*continued*)

Symbols and abbreviations	Descriptions	Units
TPO	Thermoplastic olefin Trimethylbenzoyldiphenyl phosphine oxide (Type I photo-initiator)	
TPOS	Tetrapropyl orthosilicate	
TPP	Triphenylphosphine	
TPPCl	Tetraphenyl phosphonium chloride	
TPPO	Triphenylphosphine oxide	
TPT (or TiPT)	Tetra-isopropyl titanate	
TPTDA	Tetraphenylthiophene diamine	
TPU	Thermoplastic polyurethane	
TTS	Time and temperature superposition	
UCM	Upper-Convective Maxwell	
UDCs	Universal dynamic crosslinking/crosllinkers	
UDH	Eicosadienedioic dihydrazide	
UL	Underwriters laboratories	
UF	Urea-formaldehyde	
UG	Urea-glyoxal	
UMF	Urea-melamine-formaldehyde	
UV	Ultra-violet	
UV/EB	Ultraviolet light/electron beam	
UV/visible	UV/visible spectroscopy	
VC-CoP	Vinylchloride co-polymers (and terpolymers)	
VDH	Valine dihydrazide	
VE (LVE, NLVE)	Viscoelastic or viscoelasticity (Linear VE, Non-linear VE)	
VOC(s)	Volatile organic compound(s)	
VTBN	Vinyl terminated polybutadiene-co-acrylonitrile	
VTMO	Vinyl-trimethoxy-silane	
WB	Water-based (or -borne)	
WLF	Boltzmann superposition (Williams-Landel-Ferry)	
WPE	Weight per epoxide (or EEW, i.e., epoxy equivalent weight)	g/eq or g/mol
WVTR	Water vapor transfer rate	g/m^2-day
XLD (or xld) or CD	Crosslinking density	
XPE	Silane-modified polyolefin	
XRF	X-ray fluorescence	
ZnAcAc or ZAA	Zinc acetylacetonate	
ZIFs	Zeolite imidazolate frameworks	
ZS	Zinc salicylate	
Zylon	Poly(p-phenylene benzobisoxazole)	