TOUGHENED PLASTICS

MATERIALS SCIENCE SERIES

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TOUGHENED PLASTICS

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PREFACE

Rubber-toughened plastics constitute a commercially important class of polymers, which are characterised by a combination of fracture resistance and stiffness. The best known members of the class are toughened polystyrene, or HIPS, and ABS, but there are also toughened grades of polypropylene, PVC, epoxy resin, and a number of other polymers. Each of these materials is a composite polymer, consisting of a rigid matrix and a disperse rubber phase. This book describes their manufacture, analysis, mechanical properties and processing characteristics. The aim is to show how structure can be controlled during manufacture, and how the properties of the product are consequently affected.

The book is divided into three main sections. The first four chapters, which are concerned broadly with the chemistry of toughening, cover phase separation and compatibility, grafting, microscopy, analytical techniques and methods of polymerisation. This section is of interest not only to physical chemists engaged in research and development, but also to all who are involved in the characterisation and quality control of rubber-toughened plastics. The second section, comprising six chapters, deals with mechanical properties, including viscoelastic properties, creep, yield, fatigue, fracture and impact strength. The effects of structure upon properties and the role of crazing and shear deformation are discussed in some detail. This section is of interest to all concerned in the manufacture and applications of rubber-toughened plastics. The third section consists of two chapters on the manufacture of finished components, covering melt rheology, thermoforming, extrusion, injection moulding and electroplating. The emphasis throughout is on the effects of adding rubber on the manufacturing technology and product properties. Topics, such as solvent crazing resistance, which are not considered to be affected significantly by the addition of rubber, have been excluded or treated only briefly.

The field of rubber toughening provides many good examples of the principles of materials science and technology applied to practical ends. For this reason, the subject is of interest not only to specialists involved in the industry, but also to advanced students of materials or polymer science. The treatment followed in this book is designed to introduce the reader to a class of materials which must surely rank amongst the principal inventions of the plastics industry.

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GLOSSARY

a	Cross-sectional area of craze (Chapter 7)
	Crack length (Chapters 9 and 10)
	Major axis of ellipse (Chapter 11)
a_T	Temperature shift factor
a_ϕ	Rubber content shift factor
a_M	Molecular weight shift factor
$\dot{a}$	Shear band velocity (Chapter 6)
	Crack speed (Chapters 9 and 10)
A	Pre-exponential factor (Chapter 6)
	Dummy variable (Chapters 5 and 10)
$A(T)$	Crazing parameter
A^*	Activation area
b	Beam thickness (Chapter 9)
	Minor axis of ellipse (Chapter 11)
B	Crack width (Chapters 9 and 10)
	Die swell ratio (Chapter 11)
$B(T)$	Crazing parameter
C	Specimen compliance (Chapters 9 and 10)
$C(t,T)$	Crazing parameter
C_p	Specific heat at constant pressure
CED	Cohesive energy density
$D(t,T)$	Crazing parameter
e_1, e_2, e_3	Extensions in the 1, 2 and 3 directions
E	Young's modulus
f	Frequency
G	Gibbs free energy (Chapter 2)
ΔG_m	Gibbs free energy of mixing
G, G_0	Shear modulus (Chapter 5)
G_1, G_2, G_i, G_m	Shear moduli of phase 1, phase 2, inclusion, matrix
$\mathcal{G}_B$	Apparent critical strain energy release rate for blunt notch specimen

$\mathcal{G}_c$, $\mathcal{G}_{IC}$	Critical strain energy release rate
h	Displacement
H	Enthalpy (Chapters 2, 6 and 8)
	Specimen height (Chapter 9)
ΔH_m	Enthalpy of mixing
ΔH_{vap}	Enthalpy of vaporisation
I	Initiator (Chapter 2)
	Impact strength (Chapter 10)
I_{ke}	Kinetic energy contribution to impact strength
I_0	Intensity of incident light
I_s	Intensity of scattered light
I_{tr}	Intensity of transmitted light
$J(t)$	Compliance at time t
J''	Loss compliance
$\mathcal{J}_{IC}$	Plastic work parameter for ductile fracture
k	Boltzmann's constant
k_d, k_i, k_p, k_{AB}, etc.	Rate coefficients
K	Bulk modulus
$\mathcal{K}$	Stress intensity factor
$\mathcal{K}_C$, $\mathcal{K}_{IC}$	Fracture toughness
L	Length of capillary
m	Integer (Chapter 2)
	Exponent (Chapter 11)
M	Monomer (Chapter 2)
	Beam constant (Chapter 9)
$\overline{M}_w$	Weight average molecular weight
n	Number of cycles (Chapter 9)
	Power law exponent (Chapters 7 and 11)
n_1, n_2	Mole fractions of 1 and 2
N	Fatigue exponent
p	Integer (Chapter 2)
	Probability (Chapter 4)
	Pressure (Chapters 6 and 11)
P	Force
P_c, P_f, P_{gy}	Force at critical stage, at fracture and at general yield
Q	Flow rate
r	Radial distance (Chapters 5, 9 and 11)
	Craze length (Chapter 7)
	Plate radius (Chapter 10)

r^*	Interparticle distance
r_1, r_2	Monomer reactivity ratios
r_0	Root radius of crack or notch
r_w	Radius of capillary or tube
$\dot{r}$	Radial migration rate
R	Gas constant (Chapter 2)
	Particle radius (Chapters 3, 5 and 11)
	Distance between rubber particles (Chapter 7)
R_y	Yield zone length
$\mathscr{R}$	Specific refraction
Re_p	Particle Reynolds number
S	Entropy (Chapter 2)
	Beam span (Chapters 9 and 10)
ΔS^*	Configurational entropy change
ΔS_m	Entropy of mixing
t	Time
T	Temperature
T_e	Effective temperature
T_g	Glass transition temperature
T_0	Reference temperature
$\mathscr{T}$	Interfacial tension
U	Internal energy (Chapters 2, 9 and 10)
ΔU_{vap}	Energy of vaporisation
U_c, U_y	Energy at critical stage and at yield
v	Velocity
	Craze volume (Chapter 7)
v_f, v_p	Velocity of fluid and of particle
V	Volume
V_{liq}	Molar volume of liquid
V_0	Original volume
V^*	Activation volume
ΔV	Volume strain
$\Delta V(0)$	Volume strain at zero time
$\Delta V(t)$	Volume strain at time t
w_1, w_2	Weight fraction of components 1 and 2
w_p	Plastic work
W	Specimen width
x	Integer (Chapter 2)
	Distance (Chapter 3)
X	Rubber content (Chapter 3)

X	Deflection (Chapter 10)
X_c	Critical deflection-to-span ratio
X_p	Deflection subsequent to general yield
y	Integer
Y	Geometrical factor in fracture mechanics
Z	Geometrical factor for impact specimens

GREEK SYMBOLS

β	Volume coefficient of thermal expansion (Chapter 5) Angle (Chapter 6)
$\Delta\beta_f$	Temperature coefficient of equilibrium free volume
γ	Shear strain (Chapter 6) Stress concentration factor (Chapter 8) Fracture surface energy (Chapter 9)
γ_p	Fracture surface energy involving limited plasticity
$\dot{\gamma}$	Shear strain rate
$\dot{\gamma}_w$	Shear strain rate at wall
δ	Solubility parameter (Chapter 2) Crack opening displacement (Chapters 9 and 10)
δ_c	Critical crack opening displacement
δ_d, δ_h, δ_p	Solubility parameter terms relating to dispersion, hydrogen bonding and dipole interaction contributions
ε	Strain
$\dot{\varepsilon}$	Strain rate
ζ	Craze initiation time
η	Viscosity
η_{21}	Viscosity of suspended phase divided by viscosity of suspending phase
θ	Angle
λ	Wavelength (Chapter 3) Natural draw ratio: current length over original length (Chapters 7 and 11)
μ	Refractive index (Chapter 3) Plasticity term (Chapter 6)
ν	Poisson's ratio
ν_1, ν_2, ν_i, ν_m	Poisson's ratio of phase 1, phase 2, inclusion, matrix
ν^*	Kinetic chain length
ξ	Frozen free volume

ρ	Density
σ	Stress
σ_{11}, σ_{12}, σ_{22}, σ_{rr}, $\sigma_{\theta\theta}$, $\sigma_{\psi\psi}$	Components of the stress tensor
σ_c	Critical stress
σ_{cy}, σ_{ty}	Yield stress in compression and in tension
σ_y	Yield stress
τ	Turbidity (Chapter 3)
	Shear stress (Chapters 6 and 11)
τ_{oct}	Octahedral shear stress
τ_w	Shear stress at wall
τ_i	Induction period
ϕ_1, ϕ_2, ϕ_i, ϕ_m	Volume fractions of phase 1, phase 2, inclusion, matrix
χ_{12}	Flory–Huggins interaction parameter
ψ	Angle