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Deformation and Fracture Behaviour of Polymer Materials

Springer

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Preface

The growing demands on the reliability, safety and lifetime of machines, equipment and components made of polymers and composites make it necessary to develop meaningful test methods for the assessment of fracture properties. For this purpose, polymer-specific evaluation methods and concepts of the field of technical fracture mechanics and polymer diagnostics/polymer testing are used. Within polymer sciences, these areas of research have emerged as separate disciplines over recent years, evidenced by curricula of polymer engineering programmes at universities and universities of applied sciences.

The present status report on the current state of knowledge of technical fracture mechanics of polymers and composites with polymer matrix has been supplemented by revised presentations from the 14th discussion conference on "Deformation and Fracture Behaviour of Polymers" and by contributions describing our own research. By including additional contributions dealing with the investigation into the toughness of polymers with time-dependent fracture mechanical characteristics and the use of crack resistance concepts for polymers and elastomers, we aim to provide a comprehensive overview of the current state of knowledge.

The discussion conference on "Deformation and Fracture Behaviour of Polymers" has been taking place every two years in Merseburg for more than 30 years and has become a recognised scientific conference.

The 2014 conference was held jointly with the international scientific congress "PolyMerTec 2014", which was organised by the Merseburg University of Applied Sciences and focused on engineering topics for the first time.

The conferences aim at showcasing the progress in fundamental research and applied research in this scientific discipline. This is accomplished by means of plenary talks, short contributions and lively discussions among the large number of expert colleagues.

Essential topics are as follows:

– Polymer testing, damage analysis and polymer diagnostics of components
– Toughness characterisation of polymers with fracture mechanics concept

– Hybrid methods for polymer testing and diagnostics
– Non-destructive polymer testing (ultrasound)
– Long-term static behaviour and ageing

The conference programme also includes exhibitions of equipment used for non-destructive and destructive material testing, polymer analytics and elastomer and film testing.

This book follows the status reports that have already been published by Springer:

- Deformation und Bruchverhalten von Kunststoffen
  Hrsg: W. Grellmann und S. Seidler
  1998, ISBN 3-540-63671-4
- Deformation and Fracture Behaviour of Polymers
  Eds.: W. Grellmann and S. Seidler
  2001, ISBN 3-540-41247-6

A comprehensive compilation of mechanical and fracture mechanical properties from the literature and own research is documented in the following encyclopaedia:

- Mechanical and Thermomechanical Properties of Polymers
  Group VIII Advanced Materials and Technologies Volume VIII/6A3
  Eds.: W. Grellmann and S. Seidler
  2014, ISBN 978-3-642-55165-9

In addition to the aforementioned books on the deformation and fracture behaviour of polymers, the Merseburg School edited the textbooks *Polymer Testing* for students at universities and universities of applied sciences. These textbooks were published by Hanser in German (2005, 2011, 2015) and English (2007, 2013). A Russian translation appeared in 2010.

These textbooks on polymer testing and diagnostics and on technical fracture mechanics of polymers and composites with polymer matrix also form the basis of an online encyclopaedia on "polymer testing and diagnostics". This online encyclopaedia follows the wiki system known from Wikipedia and is available for free at http://wiki.polymerservice-merseburg.de in Version 4.0 (2014).

With the edition of this status report, we hope to contribute to an enhanced understanding of specific problems of the discipline among colleagues from different research institutes and the polymer industry.

The editors would like to express their special thanks to Dr.-Ing. Ralf Lach, Polymer Service GmbH Merseburg, Associate Institute of the Merseburg University of Applied Sciences, for his comprehensive support and critical advice.

Halle and Merseburg, Germany — Wolfgang Grellmann
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Abbreviations

2NCT	Double Notch Creep Test
3D-FAC	Fluorescence adsorption contrast method
ABS	Acrylonitrile–butadiene–styrene
ACN	Acrylonitrile
ACT	Accelerated Creep Test
AE	Acoustic emission
AFM	Atomic force microscopy
aFNCT	Accelerated Full Notch Creep Test
ALE	Arbitrary Lagrangian Eulerian
ATBN	Amine-terminated butadiene–acrylonitrile copolymer
BET	Brunauer–Emmett–Teller
BIIR	Brominated poly(isobutylene-co-isoprene)
BOPET	Biaxial oriented poly(ethylene terephthalate)
BR	Butadiene rubber
BSE	Backscattered electrons
C(T)OD	Crack-(tip)-opening displacement
CA	Coupling agent
CB	Carbon black
CCG	Creep crack growth
CD	Particle distance
CEG	Cation exchange capacity
CF	Coniferous trees
CIP	Carbonyl iron powder
CNT	Carbon nanotubes
CRB specimen	Cracked round bar specimen
CRB test	Crack Round Bar Test
CS	Compression set
CSEM	Conventional scanning electron microscopy
CT specimen	Compact tension specimen
CT	Computed tomography

CTOA	Crack-tip-opening angle
DCP	Dicumyl peroxide
DENT specimen	Double-edge-notched tension specimen
DGEBA	Diglycidyl ether of bisphenol-A
DI	Macro dispersion index
DIC	Digital image correlation
DIE	Digital image elaboration
DMA	Dynamic-mechanical-analysis
DMTA	Dynamic-mechanical-thermal analysis
DSC	Differential scanning calorimetry
EB	Electron beam
EDS	Energy-dispersive X-ray Spectrometry
EDZ	State of plane strain
EFTEM	Energy-filtered transmission electron microscopy
ENR	Epoxidised natural rubber
EPDM	Ethylene–propylene–diene rubber
EPFM	Elastic–plastic fracture mechanics
EPR	Ethylene–propylene rubber
ESEM	Environmental scanning electron microscopy
ETD	Everhart-Thornley detector
EVA	Ethylene(vinyl acetate)
FBA	Formerly bonded area
FCG	Fatigue crack growth
FCP	Fatigue crack propagation
FE	Finite element
FEA	Finite element analysis
FEG	Field-emission gun
FEM	Finite element method
FKM	Fluorocarbon rubber
FNCT	Full Notch Creep Test
FSBR	Styrene–butadiene–butylacrylate mix polymer
FTIR	Fourier transform infrared spectroscopy
FT-model	Folgar-Tucker model
FW	Impact falling weight
GF	Short glass fibre-reinforced
GPC	Gel permeation chromatography
HNBR	Hydrogenated nitrile butadiene rubber
ICIT	Instrumented Charpy impact test
IR	cis-1,4-polyisoprene; synthetic rubber
IRHD	International rubber hardness degree
LEFM	Linear elastic fracture mechanics
LFT	Long fibre-reinforced thermoplastics
LVSEM	Low-voltage scanning electron microscopy
MAH	Maleic anhydride
micro-CT	Microcomputer tomography

MR	Magnetorheological
MRE	Magnetorheological elastomer
MTS criterion	Maximum tangential stress criterion
nanoG	Nano-graphite
NBR	Nitrile–butadiene rubber
NCTL Test	Notched Constant Tensile Load Test
NIS	Notched impact strength
NPT	Notch Pipe Test
NR	cis-1,4-polyisoprene; natural rubber
PA	Polyamide
PA6	Polyamide 6
PA66	Polyamide 66
PB-1	Polybutene-1
PC	Polycarbonate
PDMS	Polydimethylsiloxane
PE	Polyethylene
PE-HD	High-density polyethylene
PE-LD	Low-density polyethylene
PE-LLD	Linear low-density polyethylene
PE-MD	Medium-density polyethylene
PENT Test	Pennsylvania Edge Notch Tensile Test
PES	Polyethersulfone
PET	Poly(ethylene terephthalate)
PLT	Point Load Test
PMMA	Poly(methyl methacrylate)
PNR	Polynorbornene
PP	Polypropylene
PPA	Polyphthalamide
PS specimen	Pure-shear specimen
PVC	Poly(vinyl chloride)
PXRD	Powder X-ray Diffraction
R-curve	Crack resistance curve
RH	Relative humidity
RSC model	Modified model of Wang and Jin
SBEM	Serial block face scanning electron microscopy
SBR	Styrene–butadiene rubber
SCG	Slow crack growth
SE	Secondary electrons
SEM	Scanning electron microscopy
SENB specimen	Single-edge-notched bending specimen
SENT specimen	Single-edge-notched tension specimen
SF	Single fibre
SFRP	Short fibre-reinforced polymers
SHT	Strain Hardening Test
SIM	Stepped Isothermal Method

SMART	Small accelerated reliable test
SZH	Stretch zone height
SZW	Stretch zone width
TEM	Transmission electron microscopy
TGA	Thermogravimetric analysis
THF	Tetrahydrofuran
TMT	Thermomechanical treatment
TOR	Polyoctenamer
TPE	Thermoplastic elastomer
TPU	Thermoplastic polyurethane
TTSP	Time–temperature superposition principle
UD	Unidirectional
VPSEM	Variable pressure scanning electron microscopy
WF	Wood flour
WLF	Williams-Landel-Ferry
WOL	Wedged open loading
WT	Wavelet transform
X-CT	X-ray computed tomography