Progress in Materials Science 67 (2015) 1–94

Contents lists available at ScienceDirect

Progress in Materials Science

journal homepage: www.elsevier.com/locate/pmatsci

Nanoindentation in polymer nanocomposites

Ana M. Díez-Pascual [a,*], Marián A. Gómez-Fatou [a], Fernando Ania [b], Araceli Flores [b,*]

[a] Department of Polymer Physics, Elastomers and Energy Applications, Institute of Polymer Science and Technology (ICTP-CSIC), Juan de la Cierva 3, 28006 Madrid, Spain
[b] Department of Macromolecular Physics, Institute for Structure of Matter (IEM-CSIC), Serrano 119, 28006 Madrid, Spain

ARTICLE INFO

Article history:
Received 12 June 2014
Accepted 14 June 2014
Available online 17 July 2014

Keywords:
Nanoindentation
Polymer nanocomposites
Modulus
Hardness
Filler reinforcement

ABSTRACT

This article reviews recent literature on polymer nanocomposites using advanced indentation techniques to evaluate the surface mechanical properties down to the nanoscale level. Special emphasis is placed on nanocomposites incorporating carbon-based (nanotubes, graphene, nanodiamond) or inorganic (nanoclays, spherical nanoparticles) nanofillers. The current literature on instrumented indentation provides apparently conflicting information on the synergistic effect of polymer nanocomposites on mechanical properties. An effort has been done to gather information from different sources to offer a clear picture of the state-of-the-art in the field. Nanoindentation is a most valuable tool for the evaluation of the modulus, hardness and creep enhancements upon incorporation of the filler. It is shown that thermoset, glassy and semicrystalline matrices can exhibit distinct reinforcing mechanisms. The improvement of mechanical properties is found to mainly depend on the nature of the filler and the dispersion and interaction with the matrix. Other factors such as shape, dimensions and degree of orientation of the nanofiller, as well as matrix morphology are discussed. A comparison between nanoindentation results and macroscopic properties is offered. Finally, indentation size effects are also critically examined. Challenges and future perspectives in the application of depth-sensing instrumentation to characterize mechanical properties of polymer nanocomposite materials are suggested.

* Corresponding authors.
E-mail addresses: adiez@ictp.csic.es (A.M. Díez-Pascual), emaraceli@iem.cfmac.csic.es (A. Flores).

http://dx.doi.org/10.1016/j.pmatsci.2014.06.002
0079-6425/

Abbreviations

AAER	acrylic electrophoretic resin
AFM	atomic force microscopy
APTES	aminopropyltriethoxysilane
CB	carbon black
CCNT	coiled carbon nanotube
CEAR	cathodic electrophoretic acrylic resin
CF	carbon fibre
CNC	cellulose nanocrystals
CNF	carbon nanofibre
COF	coefficient of friction
CSH	calcium silicate hydrate
CSM	continuous stiffness measurement
CVD	chemical vapour deposition
deox-ND	decarboxylated nanodiamond
DMA	dynamic mechanical analysis
DSC	differential scanning calorimetry
DSI	depth-sensing indentation
EG	exfoliated graphite
EGO	exfoliated graphene oxide
EGS	exfoliated graphene sheets
EOGCNF	exfoliated oxidized graphitized carbon nanofibre
EPDM	ethylene-propylene-diene rubber
FP-POSS	fluoropropyl polyhedral oligomeric silsequioxane
FG	few-layer graphene
FGS	functionalized graphene sheets
GBL	gamma-butyrolactone
GF	glass fibre
Glymo	glycidoxy-propyltrimethoxysilane
GNP	graphene nanoplatelets
GO	graphene oxide
GP	graphite platelets
GPTS	glycidoxypropyltrimethoxysilane
GS	graphene sheets
HA	hydroxyapatite
HDDA	1,6-hexanediol diacrylate
HDPE	high density polyethylene
HEMA	2-hydroxyethyl methacrylate
IBMA	isobornyl methacrylate
IF	inorganic fullerene-like
ISE	indentation size effect
KF	kenaf fibre
LbL	layer-by-layer
MBZ	methylbenzoate
MDMA	monomeric dimethacrylates
MEH-PPV	poly[2-methoxy-5-2(2-ethylhexyloxy-p-phenylenevinylene)]
MEMO	(3-(trimethoxysilyl) propyl methacrylate
MMT	montmorillonite
MPTES	methacryloxypropyltriethoxysilane
MPTMS	methacryloxypropyltrimethoxysilane
MWCNT	multi-walled carbon nanotubes
NA	non available
Na-MMT	sodium montmorillonite