



Self-reinforced polymeric materials: A review

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ARTICLE INFO

Article history:

Received 4 December 2009

Received in revised form 19 April 2010

Accepted 21 June 2010

Available online 7 August 2010

Keywords:

Polymers

Self-reinforced

Processing

Microstructure

Structure–property relationships

Semicrystalline polymers

Application

ABSTRACT

The preparation, properties and applications of self-reinforced polymeric materials (SRPMs), representing an emerging family of composite materials, are surveyed. SRPMs are classified according to their constituents (single- or multi-component), their production (in one-step (in situ) or in multi-step (ex situ) procedures) and the spatial alignment of the reinforcing phase in the matrix (in one-, two- or three-dimensions; 1D, 2D or 3D, respectively). The pros and cons of the related processes and products are introduced, and further developments with SRPMs are highlighted. The driving forces in the development of SRPMs include possibilities for recycling (i.e., reprocessing via remelting) and the fabrication of lightweight structures.

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1. Introduction

Presently, considerable research activities and accompanying commercial interest are devoted to all-polymeric materials, especially to self-reinforced versions. In all-polymeric materials, both the reinforcing and matrix phases are given by suitable polymers. In self-reinforced

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Nomenclature

$a_{c,n}$	impact strength (notched) (kJ/m^2)
$a_{c,n,L}$	longitudinal impact strength (kJ/m^2)
$a_{c,n,T}$	transversal impact strength (kJ/m^2)
D	extruder screw diameter (mm)
E_B	E -modulus (flexural) (GPa)
E_t	E -modulus (tensile) (GPa)
$E_{t,L}$	E -modulus (tensile and longitudinal) (GPa)
$E_{t,T}$	E -modulus (tensile, transversal) (GPa)
k	thermal conductivity (W/mK)
L	extruder screw length (mm)
p	processing pressure (MPa)
p_A	pressure amplitude (MPa)
T_D	drawing (stretching) temperature ($^{\circ}\text{C}$)
T_g	glass transition temperature ($^{\circ}\text{C}$)
T_{proc}	processing temperature ($^{\circ}\text{C}$)
$T_{\text{proc,opt}}$	optimal processing temperature ($^{\circ}\text{C}$)
T_m	melting temperature ($^{\circ}\text{C}$)
T_{melt}	melt temperature ($^{\circ}\text{C}$)
T_{mold}	mold temperature ($^{\circ}\text{C}$)
V	extrusion velocity (mm/min)
λ	drawing ratio
σ_B	tensile strength (MPa)
$\sigma_{B,L}$	longitudinal tensile strength (MPa)
$\sigma_{B,T}$	transversal tensile strength (MPa)
σ_F	flexural strength (MPa)
σ_Y	yield strength (MPa)
BP	based pressure for VIM (MPa)
CBT	cyclic butylene terephthalate oligomer
CM	conventional injection molding
CNF	carbon nanofiber
CP	cross-ply structure
DMA	dynamical mechanical analysis
DSC	differential scanning calorimetry
EP	ethylene-propylene copolymer
EPR	ethylene-propylene rubber
GF	glass fiber
HDPE	high-density polyethylene
hPP	polypropylene homopolymer
iPP	isotactic polypropylene
LCP	liquid crystalline polyester
MD	machine direction
MFC	microfibrillar composite
OPIM	oscillating packing injection molding
PA	polyamide
PA-12	polyamide-12
PA-6	polyamide-6
PA-6.6	polyamide-6.6
PBA	polybutyl acrylate
PCTG	polycyclohexane-terephthalate glycol
PE	polyethylene
PEEK	polyether-ether-ketone
PEN	polyethylene-naphthalate
PET	polyethylene-terephthalate
PETG	polyethylene-terephthalate glycol
PMMA	polymethyl-methacrylate
POM	polyoxymethylene or polyacetal
PP	polypropylene

PPS	polyphenylene-sulfide
PS	polystyrene
PTFE	polytetrafluoro-ethylene
PVC	polyvinyl-chloride
PVDF	polyvinylidene-fluoride
rPP	random polypropylene copolymer
SCORIM	shear-controlled orientation injection molding
SEM	scanning electron microscopy
SRPM	self-reinforced polymeric material
SRPP	self-reinforced polypropylene
TD	transverse (to machine) direction
TEM	transmission electron microscopy
TMA	thermo mechanical analysis
UD	unidirectional alignment, structure
UHMPE	ultra high modulus polyethylene
UHMWPE	ultra high molecular weight polyethylene
VF	vibration frequency (Hz)
VIM	vibration injection molding
VPA	vibration pressure amplitude (MPa)
α -PP	isotactic PP (alpha form)
α -rPP	random polypropylene copolymer (alpha form)
β -PP	isotactic PP (beta form)

polymeric materials (SRPMs), the same polymer forms both the reinforcing and matrix phases. SRPMs are also referred to as single-phase or homocomposites. Moreover, in the open literature, such polymer composites in which the reinforcement and matrix polymers are different but belong to the same family of polymers (see below) are also termed as SRPMs.

SRPMs may compete with traditional composites in various application fields based on their performance/cost balance. With respect to their performance, the ease of recycling has to be emphasized because they represent likely the best recycling option when reprocessing via remelting is targeted. Accordingly, SRPMs can be considered to be environmentally benign materials. The concepts used to produce SRPMs can also be adapted to biodegradable polymers to improve their property profiles, whereby even the degradation properties can be tailored upon request.

A further driving force for SRPMs is the possibility of manufacturing lightweight parts and structures because the density of SRPMs is well below those of traditional filled polymers. The density of the corresponding composite is usually higher than that of an SRPM because the former contain reinforcements such as glass (density: $2.5\text{--}2.9\text{ g cm}^{-3}$), carbon (density: $1.7\text{--}1.9\text{ g cm}^{-3}$), basalt (density: $2.7\text{--}3.0\text{ g cm}^{-3}$), aramid (density: $1.38\text{--}1.44\text{ g cm}^{-3}$) and/or fillers like talc (density: $2.7\text{--}2.8\text{ g cm}^{-3}$), chalk (density: $1.1\text{--}2.5\text{ g cm}^{-3}$) and silica (density: $2.1\text{--}2.6\text{ g cm}^{-3}$).

The basic concept of self-reinforcement is the creation of a one-, two- or three-dimensional alignment (1D, 2D or 3D, respectively) within the matrix to fulfill the role of matrix reinforcement. Reinforcing action requires that

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