Progress in Polymer Science 61 (2016) 1–28

Contents lists available at ScienceDirect

Progress in Polymer Science

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

Review of thermal conductivity in composites: Mechanisms, parameters and theory

N. Burger[a,b,*], A. Laachachi[a], M. Ferriol[b], M. Lutz[c], V. Toniazzo[a], D. Ruch[a]

[a] Luxembourg Institute of Science and Technology, 5, avenue des Hauts-Fourneaux, L-4362 Esch/Alzette, Luxembourg
[b] Université de Lorraine, LMOPS E.A 4423, Metz F-57070, France
[c] Thales Alenia Space, Mechanical & Thermal Technologies Dpt., 100 Boulevard du Midi, 06156 Cannes-La-Bocca, France

ARTICLE INFO

Article history:
Received 8 January 2015
Received in revised form
22 December 2015
Accepted 3 May 2016
Available online 12 May 2016

Keywords:
Thermal conductivity
Composites
Enhancement
Mechanisms

ABSTRACT

Thermal conductivity has become an important parameter for new technologies, especially in aerospace and aeronautics. The advanced materials used in some electronic applications tend to undergo an increase in temperature when they are used. Increasing the thermal conductivity of a material will help to diffuse heat faster to avoid substantial overheating that could lead to premature degradation of the material.

This article reviews theoretical and experimental aspects of thermal conductivity in composites, from thermal energy generation to heat transfers. The fundamental mechanism of thermal conduction, its mathematical aspects, and certain essential parameters to be considered in this study, such as crystallinity, phonon scattering, or filler/matrix interfaces are discussed in detail to examine their impact on thermal conductivity, complementing several reviews in the field.

Contents

* Corresponding author at: Luxembourg Institute of Science and Technology, 5, avenue des Hauts-Fourneaux, L-4362 Esch/Alzette, Luxembourg. Tel.: +352 42 59 91 4628.
E-mail address: nicolas.burger@list.lu (N. Burger).

http://dx.doi.org/10.1016/j.progpolymsci.2016.05.001

Nomenclature

α	thermal diffusivity
λ	wave length
$\vec{\nu}$	speed of a particle
ρ	density
σ	electrical conductivity
τ_c	thermal diffusion characteristic time
φ	heat flow rate
Ag	silver
Al	aluminum
AlN	aluminum nitride
BN	boron nitride
C	heat capacity
C_p	specific heat capacity
Cal	calorie
CB	carbon black
CNF	carbon nanofibers
CNT	carbon nanotubes
Cu	copper
E	energy of charged atomic oscillator
h	Planck constant
H_2SO_4	sulfuric acid
HNO_3	nitric acid
k	thermal conductivity parameter
k_e	electronic thermal conductivity (due to electrons)
k_p	phonic thermal conductivity (due to phonons)
l	phonon mean free path
L_c	thermal diffusion characteristic length
m	mass
MWCNT	multi-walled carbon nanotube
PCA	pyrenecarboxylic acid
Q	thermal energy
$\dot{Q}$	heat flux
S	surface area
Si	silicon
SWCNT	single-walled carbon nanotube
t	time
T	temperature
TiO_2	titanium dioxide
UV	ultraviolet light
V	volume
wt.	percent weight (in % wt.)
x	thickness

1. Introduction

In everyday life, heat and temperature are commonly used and confused but these two fundamental concepts should be distinguished from a scientific perspective: they are directly related to thermal energy. Thermal energy is defined by the microscopic vibrations of particles. The temperature, describing the state of a body, is a physical property quantifying those microscopic thermal vibrations of the particles. Heat, which is directly related to the thermal conductivity, is defined as the thermal energy transfer from a particle to its adjacent particle(s), i.e., temperature tells us how much particles are vibrating and heat evaluates how much of this energy is transferred, how fast and in what direction (Fig. 1)

These general concepts regarding heat transfer help us to introduce this review and are essential to understand what is presented next. The fundamental and theoretical mechanisms result from quantum physics and mechanics, with phenomena that are difficult to extrapolate at a macroscopic scale. This review's objective is not to present thermal conductivity mechanisms at the quantum scale but to try to extrapolate and understand those mechanisms at a macroscopic scale. It complements the reviews by Han et al.

Fig. 1. Consequence of 2nd law of thermodynamics.