

A fractal Cantor set based description of interlaminar contact evolution during thermoplastic composites processing

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Fusion bonding is the principal phenomenon governing the fabrication of layered thermoplastic-matrix composites using techniques such as tow placement and tape laying. An important step in fusion bonding is the *intimate contact* process, which refers to the development of interfacial contact area between thermoplastic plies, caused by the spreading of the surface asperities. The contacted areas, in turn, form sites for molecular interdiffusion which leads to interfacial bonding. The geometric complexity of the surface asperity profiles presents a fundamental challenge to an effective description of the intimate contact process. Toward addressing the challenge, this paper presents a model for interfacial contact area development utilizing the fractal properties of thermoplastic ply surfaces. Using a Cantor set representation of the surfaces, and a squeeze flow model to describe their spreading during the processing, the interfacial contact area evolution is related to the process parameters and the geometric parameters in the fractal surface description. The model predictions are shown to compare well with experimental data for several thermoplastic materials. © 2001 Kluwer Academic Publishers

Nomenclature

a	height of a generic rectangular asperity at time t [m]
$a_{n,0}$	initial height of (n)th generation asperity [m]
$a_{n,f}$	final height of (n)th generation asperity [m]
b	width of a generic rectangular asperity at time t [m]
$b_{n,0}$	initial width of (n)th generation asperity [m]
$b_{n,f}$	final width of (n)th generation asperity [m]
D	fractal dimension of rough surfaces
D_{ic}	degree of intimate contact
f	scaling ratio between two adjacent generations of asperities in the Cantor set
\hat{F}	force applied to an asperity of unit depth [N/m]
h_0	recess depth of the first generation asperities [m]
h_n	recess depth of the ($n - 1$)th generation asperities [m]
L_0	total horizontal length of the Cantor set block [m]
L_n	total horizontal length of the (n)th generation asperities [m]
L_i	linear contact area of the fractal surface with a plane [m]
p	pressure inside a generic asperity at location ξ and time t [N/m ²]
p_0	ambient pressure [N/m ²]

p_{app}	applied consolidation pressure [N/m ²]
s	number of asperities on a repeating segment of the Cantor set block
$S(\omega)$	power spectrum [m ³]
t	time [s]
u	displacement of the contact plane from its initial position [m]
u_n	cumulative displacement of the flattening of asperities of generation $\geq n$ [m]
v_ξ	average velocity of the squeeze flow inside an asperity [m/s]

Greek symbols

μ	viscosity of the thermoplastic material [Ns/m ²]
σ	standard deviation of rough surface profile [m]
ω	frequency on the power spectrum [m ⁻¹]
ξ	coordinate along the interface [m]

1. Introduction

Fabrication of layered thermoplastics and thermoplastic-matrix composites using processes such as tow placement, tape laying, resistance welding, and autoclave forming is fundamentally based on the principle of fusion bonding, which involves applying heat and pressure to two contacting thermoplastic surfaces. The applied

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