

Joining of Ceramic Matrix Composite Materials for Aerospace Applications



Thesis submitted in partial fulfillment
for the award of degree

Doctor of Philosophy

by

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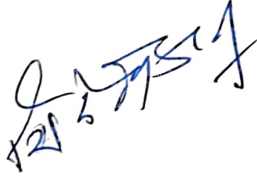
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Nomenclature

W_a	Work of adhesion
γ_{lv}	liquid-vapour interfacial energy
(s,s)	Solid solution
γ_{sl}	solid-liquid interfacial energy
γ_{sv}	solid-vapour interfacial energy
\bar{d}_p	Average particle size
ΔT	Difference in room-to-reaction temperature
$\Delta\alpha$	Difference in CTE
C_0	Constant
CR	Cooling rate
d	Desirability
E	Activation energy of diffusion
E_c	Ceramic Young's modulus
E_m	Metal Young's modulus
E_{mp}	Linear strain hardening coefficient
P_c	Capillary pressure
r	Effective pore radius
R	Universal gas constant
S	Spreading coefficient
T	Temperature
t	time
T_m	Melting temperature
w	Width
w	Weighted factor
$\beta_i, \beta_{ii},$ and	regression coefficients
ΔG	Gibbs free energy
σ	Surface tension
σ_c	Residual stresses
σ_y	Metal yield strength

Greek symbols

α	Hexagonal
β	Cubic
θ	Angle, hexagonal
ε	Error, hexagonal
δ	Orthorhombic
ζ	Orthorhombic

Abbreviations

A4PB	Asymmetric 4-point bending
ABA	Active brazing alloy
ACC	Advanced carbon/carbon
ANOVA	Analysis of variance
BN	Boron nitride

CCD	Central composite design
CFRP	Carbon fibre-reinforced polymers
CMCs	Ceramic matrix composites
CNT	Carbon nanotube
CTE	Coefficient of thermal expansion
CVD	Chemical vapour deposition
CVI	Chemical vapour infiltration
DB	Diffusion bonding
DLO	Double lap offset
DN	Double-notch
DSC	Differential scanning calorimetry
EBSD	Electron backscatter diffraction
EDS	Energy dispersive spectrometer
ESA	European Space Agency
FCC	Face-centred cubic
FE-SEM	field emission scanning electron microscope
HCP	Hexagonal closed packing
HM	High modulus
HS	High strength
HT	High temperature
IPA	Isopropyl alcohol
IRZ	Interfacial reaction zone
LS	Low strength
LSS	Lap shear strength
LST	Low service temperature
MMC	Metallic matrix composites
MMS	Monomethylsilane
MTS	Methyl trichlorosilane
MWCNTs	Multiwall carbon nanotubes
NDT	Non-destructive test
PAN	Polyacrylonitrile
PCS	Polycarbosilane
PDC	Polymer derived ceramics
PIP	Polymer infiltration pyrolysis
PLS	Pressureless-sintered
PSZ	Polysilazane
PyC	Pyrolytic carbon
RB-SiC	Reaction bonded SiC
RLV	Reusable launch vehicles
RMI	Reactive melt infiltration
RSM	Response surface methodology
RT	Room temperature
SEM	Scanning electron microscope
SiCNT	Silicon carbide nanotube
SL	Single lap
SLO	Single lap offset
SPS	Spark plasma sintering
SPS-DB	Spark plasma sintering-diffusion bonding technique
SSTO	Single stage to orbit

TC	Torsion cylinder
THG	Torsion hourglass
TLPB	Transient liquid phase diffusion bonding
TPS	Thermal protection systems
TRS	Thermal residual stress
TS	Torsion square
TSTO	Two stage to orbit
TT	Torsion tube
UAB	Ultrasonic-assisted brazed
UTM	Universal testing machine
V-PMS	Polymethylsilane
XRD	X-Ray diffraction