Commercial Aircraft Composite Technology

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Preface

The contents of this book are based on my lectures “Commercial Aircraft Composite Technology” (*Verbundwerkstoffe im Flugzeugbau*) given to master’s students at the Faculty of Mechanical Engineering, Technical University of Kaiserslautern, Germany, who wish to broaden their specific knowledge about composite material properties and manufacturing-optimised light weight design. The topic is very extensive and comprehensive textbooks only exist for certain areas. I have tried to focus on the central theme of societies’ overall aircraft requirements to specific material requirements and to highlight the most important advantages and challenges of carbon fibre-reinforced plastics (CFRP) compared to conventional materials. During the product development process, it is fundamental to decide on “the right material at the right place” early on. It is, therefore, basic to understand the main activities and milestones of the development and certification process and the systematic defining of clear requirements. The process of material qualification—verifying material requirements—is explained in detail. All state-of-the-art manufacturing technologies are described, including future perspectives. Especially for composites it is key to understand the interaction of the design scheme, manufacturing technology and resulting material properties. Here I have tried to highlight some key aspects of advanced CFRP design for primary load carrying airframe structures along with selected examples. I have also included a short chapter on testing as part of the certification process—and repair.

As more and more high-performance composites such as CFRP are also used in other sectors—especially automotive, manufacturing systems engineering, wind power, architecture, sports and leisure and medical engineering—the textbook can also be useful for students and engineers engaged in these areas.

The book closes with an outlook on some of the latest developments for future aircraft that we presently pursue at the Institut für Verbundwerkstoffe (IVW). This last chapter was supported by my assistant researchers Tim Krooß (PPS—PES blends, enabling a material performance close to PEEK at lower cost), Benedikt Hannemann (carbon metal fibre hybrid materials, enabling electrical conductivity

and improved failure behaviour) and Moritz Hübler (morphing structures by shape memory alloy integration into fibre-reinforced polymer structures).

I would like to thank all my old colleagues and friends for their thorough proofreading and their precious hints for improvements to this text.

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Ulf Breuer

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Abbreviations

A/B	Air brakes
A/C	Aircraft
acc.	According
ACD	Aircraft certification documents
ADL	Allowable damage limit
A _F	Austenite finish temperature
AFP	Automated fibre placement
Aft	Rear, back
AITM	Airbus industries test method
Al	Aluminium
ALI	Airworthiness limitation items
AMC	Acceptable means of compliance
AMM	Aircraft maintenance manual
approx.	Approximately
Ar	Argon
A _S	Austenite start temperature
ATA	Air Transport Association
ATL	Automated tape laying
Au	Aurum (gold)
bbl	Barrel of oil (359 l)
BBL	Body buttock line (fuselage width-wise position)
BS	Body station (fuselage lengthwise position)
BVID	Barely visible impact damage
BWL	Body water line (fuselage height-wise position)
C	Carbon
CAD	Computer-aided design
CAGR	Compound annual growth rate
CAI	Compression after impact
CB	Cross beam
CF	Carbon fibre

CF/EP	Carbon fibre/epoxy
CFRP	Carbon fibre-reinforced plastic
CMR	Certification maintenance requirements
Conf.	Configuration
cont.	Continued
cpt	Cured ply thickness
CRC	Corporate research centre
CRI	Certification review items
CTE	Coefficient of thermal expansion
Cu	Copper
CWB	Centre wing box
DEA	Dielectrical analysis
DMTA	Dynamic mechanical thermal analysis
DOC	Direct operating cost
DSC	Differential scanning calorimetry
DSG	Design service goal
EADS	European Aeronautic Defense and Space Company
EAS	Equivalent air speed
EASA	European Aviation Safety Agency
EIS	Entry into service
EKDF	Environment knock-down factor
EP	Epoxy
ERF	Electrorheological fluid
ESG	Extended service goal
ESN	Electrical structural network
F/S	Front spar
FAA	Federal Aviation Administration
FAL	Final assembly line
FAR	Federal aviation regulations
FAW	Fibre areal weight
FC	Flight cycle
FE	Finite element
FEA	Finite element analysis
FEM	Finite element method
FH	Flight hour
FHC	Filled hole compression (strength)
FHT	Filled hole tension
FML	Fibre metal laminate
FRP	Fibre-reinforced plastic
FST	Fire (or flammability) smoke toxicity
FSW	Friction stir welding
FT, F/T	Flap track
FTF	Flap track faring
FTI	Flight test installation

FTIR	Fourier transform infrared spectroscopy
FWD	Forward
GF	Glass fibre
GFRP	Glass fibre-reinforced plastic
GLARE	Glass laminate aluminium-reinforced epoxy
GSE	Ground support equipment
H/S	High speed
H/W	Hot/wet (condition)
HT	High tensile strength
HFEC	High frequency eddy current
HM	High modulus
HMS	High modulus/high strength
HST	High failure strain
HTP	Horizontal tail plane
ICAO	International Civil Aviation Organization
IE	Impulse echo
ILSS	Interlaminar shear strength
IM	Intermediate modulus
IPS	Individual product specification
IR	Infrared
ISO	International Organization of Standardization
IVW	Institut für Verbundwerkstoffe
JAA	Joint aviation authorities
JAR	Joint aviation requirements
JIT	Just in time
L	Longitudinal
L/S	Low speed
LBW	Laser beam welding
LDC	Large damage tolerance
LEF	Load elevation factor
Li	Lithium
LL	Limit load
LM	Low modulus
LSP	Lightning strike protection
LT	Longitudinal transversal
MAC	Mean aerodynamic chord
MCFRP	Metal-carbon-fibre-reinforced polymer
MCS	Multifunctional control surfaces
MEK	Methyl ethyl ketone (cleaning agent)
MF	Metal fibre
Mg	Magnesium
MG	Master geometry
Mini-TED	Mini-trailing edge device
MLG	Main landing gear

MoC	Means of compliance
MP	Maintenance programme
MPD	Maintenance planning document
MRO	Maintenance, repair and overhaul
MS	Material specification
MTOW	Maximum take-off weight
MVI	Modified vacuum infusion process
MWE	Manufacturing weight empty
MWNT	Multi-walled nanotubes
MZFW	Maximum zero fuel weight
NC	Numerical control
NCF	Non-crimp fabric
NDT	Non-destructive testing
NGA	Next generation aircraft
NLG	Nose landing gear
NRC	Non-recurring cost
OC	Operating COST
OHC	Open hole compression
OHT	Open hole tension
PAN	Polyacrylnitrile
Pax	Passengers
PB	Plumbum (lead)
PEEK	Polyetheretherketon
PES	Polyethersulfone
PLB	Pin loaded bearing (strength)
PLB ult.	Pin loaded bearing ultimate (strength)
PLC	Plain loaded compression
PLT	Plain loaded tension
PPS	Polyphenylene sulfide
ProHMS	Prozesskette Hochauftrieb mit multifunktionalen Steuerflächen
PZT	Lead zirconate titanate
QA	Quality assurance
R curve	Residual strength curve
R&D	Research and development
R/S	Rear spar
RC	Recurring cost
RF	Reserve factor
RFI	Resin film infusion
RI	Resin infusion
RI	Repeated interval
RPB	Rear pressure bulkhead
RPK	Revenue passenger kilometres
RT	Room temperature
RTM	Resin transfer moulding

RTM6	Special HexFlow [®] Hexcel Resin (Epoxy) for resin transfer moulding
SAM	Space allocation model
Sc	Scandium
SEM	Scanning electron microscopy
SF	Safety factor
SFRP	Steel fibre-reinforced plastic
SHM	Structural health monitoring
Si	Silicium
SMA	Shape memory alloy
SRM	Structural repair manual
SW	Sandwich
T	Transversal
T/C	Ratio air foil thickness to chord ratio
T/E	Trailing edge
tbd	To be determined (or: to be defined)
TC	Type certification
TEM	Scanning tunnelling electron microscopy
tex	Unit of measure for the mass per length of rovings or yarns, 1 tex = 1 g/1000 m
Ti	Titanium
T-L	Transversal-longitudinal
TP	Thermoplastic
TS	Technical specification
TTU	Through transmission ultrasound
UAV	Unmanned air vehicle
UD	Unidirectional
UL	Ultimate load
UN	United Nations
US	United States
UV	Ultraviolet radiation
V&V	Verification and validation
VAP [®]	Vacuum assisted process
VDI	Verein Deutscher Ingenieure
VID	Visible impact damage
Vol.	Volume
VSDI	Visual special detailed inspection
VTP	Vertical tail plane
XPS	X-ray photoelectron spectroscopy
Zn	Zinc

Symbols

A	Area
a	Crack length
b_F	Specific fuel burn
c_D	Coefficient of drag
c_L	Coefficient of lift
d	Diameter
da/dN	Crack growth rate
ε	Strain
E	Elastic modulus
F, f	Force
F_{tu}	Force tensile ultimate
F_{ty}	Force tensile yield
G	Gravity force
g	Earth acceleration
G_{ic}	Fracture toughness
k	Stress intensity factor
κ	Specific electrical conductivity
L	Lift force
M	Momentum
m	Mass
m_F	Fibre mass content
N, n	Number
n_Z	Load factor (number to multiply with g, earth acceleration)
p	Pressure
Δp	Delta pressure
R	Range
R	Residual strength
S	Electrical conductivity
ρ	Density
σ	Stress

τ	Shear stress
T	Temperature
t	Thickness
T_g, T_G	Glass transition temperature
V	Volume
v	Velocity
v_c	Velocity during cruise
v_D	Diving velocity
v_F	Fibre volume fraction
v_f	Velocity flaps
v_{fe}	Velocity flaps fully extended
w	Width