

Structural Sandwich Composites

CMH-17

COMPOSITE MATERIALS HANDBOOK



WICHITA STATE
UNIVERSITY

NATIONAL INSTITUTE
FOR AVIATION RESEARCH



TABLE OF CONTENTS

	Page
FOREWORD.....	ii
CHAPTER 1 GENERAL INFORMATION	1
1.1 INTRODUCTION TO THE HANDBOOK.....	1
1.2 OVERVIEW OF HANDBOOK CONTENT.....	1
1.3 INTRODUCTION.....	2
1.4 NOMENCLATURE AND DEFINITIONS.....	3
1.4.1 Loads, geometry, and material properties.....	3
1.4.1.1 Subscripts	7
1.4.1.2 Superscripts.....	8
1.4.1.3 Assumptions and definitions.....	8
1.4.2 System of units.....	9
REFERENCES	10
CHAPTER 2 GUIDELINES FOR PROPERTY TESTING	1
2.1 INTRODUCTION.....	1
2.2 DATA REDUCTION AND PRESENTATION.....	1
2.3 EVALUATION OF CORE MATERIALS	1
2.3.1 Introduction	1
2.3.2 Mechanical properties.....	2
2.3.3 Environmental effects.....	2
2.3.4 Test methods.....	5
2.4 EVALUATION OF CORE-TO-FACE SHEET BONDS.....	6
2.4.1 Introduction	6
2.4.2 Mechanical properties.....	6
2.4.3 Environmental effects.....	6
2.4.4 Test Methods.....	6
2.5 EVALUATION OF FACE SHEET PROPERTIES	7
2.5.1 Introduction	7
2.5.2 Mechanical properties.....	7
2.5.3 Environmental effects.....	8
2.5.4 Test methods.....	8
2.6 EVALUATION OF SANDWICH PANELS	8
2.6.1 Introduction	8
2.6.2 Mechanical properties.....	9
2.6.3 Environmental effects.....	9
2.6.4 Damage resistance	9
2.6.5 Damage tolerance.....	10
2.6.6 Repair.....	10
2.6.7 Test methods.....	10
2.7 EVALUATION OF INSERTS AND FASTENERS	11
2.7.1 Introduction	11
2.7.2 Environmental effects.....	11
2.7.3 Test methods.....	11
2.7.4 Mechanical properties.....	11
2.8 EVALUATION OF OTHER FEATURES	14
2.8.1 Introduction	14
2.8.2 Mechanical properties.....	14
2.8.3 Environmental effects.....	14

2.8.4	Test methods	14
REFERENCES	16
CHAPTER 3	MATERIAL DATA	1
3.1	CORES	1
3.1.1	Description of cores	1
3.1.2	Core specifications	1
3.1.3	Honeycomb Cores	2
3.1.4	Cross-banded core.....	5
3.1.5	Corrugated core	6
3.1.6	Waffle-type core	6
3.1.7	Foam cores	6
3.1.8	Wood cores	7
3.1.9	Core properties	8
3.1.9.1	Estimation of core properties	16
3.2	FACE SHEETS	17
3.2.1	Description of face sheets.....	17
3.2.1.1	Adhesively-bonded pre-fabricated face sheets	17
3.2.1.2	Co-cured or co-bonded face sheets with adhesive	17
3.2.1.3	Self-adhesive face sheets	18
3.2.2	Face sheet properties	18
3.3	ADHESIVES.....	18
3.3.1	Description of adhesives	19
3.3.2	Adhesive specifications.....	19
3.3.3	Adhesive forms/types and uses	20
3.3.3.1	Resins from self-adhesive face sheets	20
3.3.3.2	Film adhesives	20
3.3.3.3	Paste adhesives	20
3.3.3.4	Liquid resins.....	21
3.3.3.5	Foaming adhesives	21
3.3.4	Adhesive chemistries	21
3.3.4.1	Epoxy	21
3.3.4.2	Bismaleimide	21
3.3.4.3	Phenols	22
3.3.4.4	Polyester	22
3.3.4.5	Polyimide	22
3.3.5	Adhesive properties	23
REFERENCES	24
CHAPTER 4	DESIGN AND ANALYSIS OF SANDWICH STRUCTURES	1
4.1	INTRODUCTION.....	1
4.2	DESIGN AND CERTIFICATION.....	2
4.2.1	Basic design principles	2
4.2.2	Design process	3
4.2.3	Aircraft damage tolerance	4
4.3	CERTIFICATION	8
4.3.1	Introduction to certification issues.....	8
4.3.2	Approach to certification testing.....	9
4.3.3	Analysis validation.....	9
4.3.4	Conformity oversight	9
4.3.5	Nondestructive testing (NDT).....	10
4.3.6	Documentation requirements.....	10
4.3.7	Continued airworthiness	10
4.4	SANDWICH PANEL FAILURE MODES	10

4.5	STIFFNESS AND INTERNAL LOADS	13
4.5.1	Beam stiffness analysis.....	13
4.5.2	Plate stiffness analysis.....	16
4.5.3	Combined transverse and in-plane loadings	18
4.5.4	Face sheet internal loads.....	18
4.6	LOCAL STRENGTH ANALYSIS METHODS	19
4.6.1	Face sheet failure.....	19
4.6.2	Core shear	20
4.6.3	Flatwise tension and compression.....	22
4.6.4	Flexural core crushing.....	24
4.6.5	Intracell buckling (dimpling)	24
4.6.5.1	Sandwich having cellular (honeycomb) core.....	25
4.6.5.2	Sandwich having corrugated core	26
4.6.5.3	Shear intracell buckling	40
4.6.5.4	Combined compression and shear intracell buckling	40
4.6.6	Face sheet wrinkling	40
4.6.6.1	Wrinkling of sandwich face sheets under edgewise load	40
4.6.6.2	Sandwich with core supporting face sheets continuously	41
4.6.6.3	Sandwich with honeycomb core	44
4.6.6.4	Shear face sheet wrinkling	45
4.6.6.5	Face sheet wrinkling - combined loads	45
4.6.6.6	Face sheet wrinkling - curved panels	46
4.6.7	Core shear crimping.....	49
4.6.8	Attachments and hard points	49
4.6.8.1	Design of flat circular sandwich panels loaded at an insert	49
4.7	FLAT PANEL INTERNAL LOADS AND STRESSES - PRESSURE LOADING	56
4.7.1	Design of flat rectangular sandwich panels under various normal loadings.....	56
4.7.2	Design of flat sandwich panels under uniformly distributed normal load	57
4.7.2.1	Determining face sheet thickness, core thickness, and core shear modulus for simply supported flat rectangular panels under uniform load.....	57
4.7.2.1.1	Use of design charts.....	68
4.7.2.1.2	Determining core shear stress	70
4.7.2.1.3	Checking procedures	74
4.7.2.2	Determining face sheet thickness, core thickness, and core shear modulus for simply supported flat circular panels under uniform load	86
4.7.2.2.1	Use of design charts.....	90
4.7.2.2.2	Determining core shear stress	91
4.7.2.2.3	Checking procedure	92
4.8	CURVED SANDWICH PANEL INTERNAL LOADS AND STRESSES	92
4.8.1	General equations and analysis method.....	92
4.9	FLAT PANEL STABILITY ANALYSIS METHODS	95
4.9.1	Buckling of flat rectangular sandwich columns	96
4.9.2	Design of flat rectangular sandwich panels under edgewise compression load	97
4.9.2.1	Determining face sheet thickness.....	97
4.9.2.2	Determining core thickness and core shear modulus	97
4.9.2.2.1	Determining minimum value of d	99
4.9.2.2.2	Determining actual value of d	101
4.9.2.3	Checking procedure for determining buckling stress, F_{cr}	108
4.9.3	Design of flat rectangular sandwich panels under edgewise shear load	129
4.9.3.1	Determining face sheet thickness.....	129
4.9.3.2	Determining core thickness and core shear modulus	129
4.9.3.2.1	Determining minimum value of d	131

4.9.3.2.2	Determining actual value of d	138
4.9.3.3	Checking procedure for determining buckling stress, F_{cr}	140
4.9.4	Design of sandwich strips under torsion load	149
4.9.4.1	Determining face sheet thickness, core thickness and core shear modulus for sandwich strips of trapezoidal and rectangular cross section	149
4.9.4.1.1	Determining minimum values of d and t	156
4.9.4.1.2	Determining actual values of d and t	156
4.9.4.1.3	Checking procedure for sandwich strips of trapezoidal and rectangular cross section	157
4.9.4.2	Determining face sheet thickness and core shear modulus for sandwich strips of triangular cross section.....	161
4.9.4.2.1	Determining minimum value of t	163
4.9.4.2.2	Determining actual value of t	166
4.9.4.2.3	Checking procedure for sandwich strips of triangular cross section	166
4.9.5	Design of flat rectangular sandwich panels under edgewise bending moment	168
4.9.5.1	Determining face sheet thickness.....	169
4.9.5.2	Determining core thickness and core shear modulus	171
4.9.5.2.1	Determining minimum value of d	172
4.9.5.2.2	Determining actual value of d	175
4.9.5.3	Checking procedure for determining buckling stress, F_{cr}	178
4.10	DESIGN OF FLAT RECTANGULAR SANDWICH PANELS UNDER COMBINED LOADS	183
4.10.1	Combined load buckling.....	183
4.10.1.1	Biaxial compression	183
4.10.1.2	Bending and compression	183
4.10.1.3	Compression and shear	183
4.10.1.4	Bending and shear	184
4.10.2	Combined in-plane and transverse loads	184
4.11	DESIGN OF SANDWICH CYLINDERS	184
4.11.1	Introduction	184
4.11.2	Sandwich cylinders under external radial pressure	184
4.11.2.1	Determining face sheet thickness, core thickness, and core shear modulus for sandwich cylinders under external radial pressure.....	185
4.11.2.2	Final design.....	188
4.11.3	Sandwich cylinders under torsion	193
4.11.3.1	Determining face sheet thickness for sandwich cylinders under torsion.....	193
4.11.3.2	Determining core thickness and core shear modulus for sandwich cylinders under torsion	194
4.11.3.3	Check to determine whether sideways buckling will occur.....	202
4.11.4	Sandwich cylinders under axial compression or bending	204
4.11.4.1	Determining face sheet thickness, core thickness, and core shear modulus	204
4.11.4.2	Checking procedure for determining cylinder wall buckling stress, F_{cr}	210
4.11.4.3	Check to determine whether column buckling will occur	210
4.11.5	Sandwich cylinders under combined loads.....	210
4.11.5.1	Axial compression and external lateral pressure	211
4.11.5.2	Axial compression and torsion.....	211
4.11.5.3	Torsion and lateral external or internal pressure.....	211
4.12	FINITE ELEMENT MODELING OF SANDWICH STRUCTURE	211
4.12.1	Introduction	211
4.12.2	Global models	212

4.12.3	Layered models.....	213
4.12.4	Solid models.....	214
4.12.5	Sandwich element models.....	215
4.13	OPTIMUM SANDWICH.....	215
4.13.1	Sandwich weight.....	215
4.13.2	Sandwich bending stiffness.....	216
4.13.3	Sandwich bending moment capacity.....	218
4.13.4	Sandwich panel buckling.....	220
	REFERENCES.....	222

CHAPTER 5 FABRICATION OF SANDWICH STRUCTURES (MATERIALS AND PROCESSES).... 1

5.1	INTRODUCTION.....	1
5.2	MATERIALS.....	3
5.2.1	Cores.....	3
5.2.2	Face sheets.....	4
5.2.3	Adhesives.....	6
5.2.4	Surfacing and sealing.....	7
5.3	PROCESSES.....	8
5.3.1	Core.....	8
5.3.1.1	Cleaning.....	8
5.3.1.2	Drying.....	9
5.3.1.3	Forming.....	11
5.3.1.4	Splicing.....	12
5.3.1.5	Potting.....	15
5.3.1.6	Septums.....	15
5.3.1.7	Core stabilization for machining.....	16
5.3.1.8	Machining.....	16
5.3.1.9	Tolerances.....	18
5.3.2	Face sheets - co-cure vs. pre-cure and resin pressure.....	18
5.3.3	Adhesive.....	21
5.3.3.1	Impression check.....	21
5.3.3.2	Bonding.....	23
5.3.3.3	Filleting.....	25
5.4	HONEYCOMB CORE CRUSH.....	28
5.4.1	Core crush during cure.....	28
5.4.2	Core crush - theoretical discussion.....	30
5.4.3	Core crush stabilization for cure.....	31
5.4.4	Core material characteristics and core crush.....	32
5.4.5	Prepreg and adhesive material characteristics and core crush.....	33
5.4.6	Cure cycles and core crush.....	34
5.5	QUALITY ISSUES INCLUDING NONDESTRUCTIVE EVALUATION (NDI).....	35
	REFERENCES.....	39

CHAPTER 6 QUALITY CONTROL..... 1

6.1	INTRODUCTION.....	1
6.2	MATERIAL PROCUREMENT QUALITY ASSURANCE PROCEDURES.....	1
6.2.1	Specifications and documentation.....	1
6.2.2	Receiving inspection.....	1
6.3	PART FABRICATION VERIFICATION.....	3
6.3.1	Process verification.....	3
6.3.2	Nondestructive inspection.....	3
6.3.3	Destructive tests.....	3
6.4	STATISTICAL PROCESS CONTROL.....	4
6.5	MANAGING CHANGE IN MATERIALS AND PROCESSES.....	4

REFERENCES 5

CHAPTER 7 SUPPORTABILITY 1

7.1 INTRODUCTION..... 1

7.2 DESIGN FOR SUPPORTABILITY 1

 7.2.1 In-service experience 1

 7.2.2 Inspectability 2

 7.2.3 Material selection 2

 7.2.4 Damage resistance 2

 7.2.5 Environmental compliance 3

 7.2.6 Reliability and maintainability 3

 7.2.7 Repairability 3

7.3 SUPPORT IMPLEMENTATION 5

 7.3.1 Part inspection 5

 7.3.2 Damage assessment 5

 7.3.3 Repair design criteria 6

 7.3.4 Repair of composite structures 8

 7.3.4.1 Damage removal and site preparation 8

 7.3.4.2 Bonded repairs 8

 7.3.4.3 Repair analysis 10

 7.3.4.4 Repair procedures 10

 7.3.4.5 Repair inspection 12

 7.3.4.6 Repair validation 12

7.4 LOGISTICS REQUIREMENTS 13

REFERENCES 15

Index..... 1