

Table of contents

Analysis of the mechanical response of impact loaded composite sandwich structures with focus on foam core shear failure

Preface	III
Abstract	V
Kurzfassung	VII
Table of contents	IX
Catalogue of symbols	XIII
1 Introduction	1
1.1 Motivation	2
1.2 Objective	2
1.3 Thesis structure	4
2 State of the art of composite sandwich technology	5
2.1 Application of composite sandwich structures	5
2.2 Materials and manufacturing	7
2.3 Fundamentals of composite sandwich theory	12
2.3.1 Localized loads on sandwich beams	14
2.3.2 Failure modes of sandwich beams	17
2.3.3 Failure mode maps	20
2.4 Chapter summary	25
3 Impact response of composite sandwich structures	27
3.1 Definitions	27
3.2 Literature review	29
3.3 Classification of the structural impact response	33
3.4 Contact behavior and indentation of sandwich panels	41
3.5 Sandwich failure modes during impact	47
3.6 Chapter summary	49
4 Experimental investigation of the impact response	51
4.1 Test matrix and setup	51

4.2	Test results at room temperature.....	54
4.3	Test results at low temperatures	65
4.4	Classification of damage types.....	72
4.5	Comparison with analytical model.....	74
4.6	Chapter summary	75
5	Numerical simulation of impact on CFRP foam core sandwich structures	77
5.1	General aspects	77
5.1.1	Basic equations and explicit time integration scheme.....	77
5.1.2	Modeling approach	80
5.1.3	Thermal effects	82
5.2	Modeling of the CFRP face sheets	83
5.2.1	Mechanical behavior of CFRP.....	84
5.2.2	Material properties and strain rate sensitivity.....	94
5.2.3	Experiments.....	97
5.2.4	Simulation with one element across the thickness.....	100
5.2.5	Simulation with one element per ply	104
5.3	Modeling of the foam core	112
5.3.1	Mechanical behavior and applied material model	112
5.3.2	Experiments.....	115
5.4	Modeling of the sandwich structure	119
5.4.1	Interface crack growth.....	119
5.4.2	Static indentation of sandwich panels.....	122
5.4.3	Thermal loads and strain rates	125
5.5	Simulation of low velocity impact.....	128
5.5.1	Impact response	129
5.5.2	Damage size and impact failure mode.....	134
5.6	Chapter summary	136
6	Sandwich failure mode parameters	139
6.1	Approach.....	139
6.2	Thermal loads	141
6.3	Boundary conditions	143
6.4	Impactor geometry and velocity.....	147
6.5	Material properties of face sheet and core.....	151
6.6	Chapter summary	157
7	Concluding remarks	159
7.1	Summary of performed work.....	159
7.2	Limitations and implications.....	161
7.3	Future work.....	163
	References	165

A	Appendix: Sandwich theory	179
A.1	Sandwich beam theory	179
A.2	Sandwich plate theory	184
A.3	Alternative notation for sandwich plate theory	188
A.4	Effective properties of orthotropic sandwich plates.....	190
A.5	Foundation modulus K_z	191
A.6	Non-dimensional sandwich properties	192
B	Appendix: Material properties and failure criteria	193
B.1	Fiber properties	193
B.2	Matrix properties.....	193
B.3	Laminate properties	193
B.4	MAT262: Constitutive law with damage.....	194
B.5	Properties of the Rohacell RIST PMI foam	197
B.6	Invariant failure criterion for PMI foams.....	198
B.7	Rate sensitive material properties.....	199
B.8	Properties of the sandwich interface	199
C	Appendix: Test results	200
C.1	RT impact tests	200
C.2	Frost (-55°C) impact tests	206
D	Appendix: Simulation models	208
D.1	Simulation of CFRP tests	208
D.2	Simulation of PMI foam tests.....	211
D.3	Simulation of sandwich tests	212
E	Appendix: Author, publications and student theses	216
E.1	Curriculum vitae	216
E.2	Publications of the author	217
E.3	Student theses	217