

## **Index**

<i>Workflow of the thesis</i>	12
<i>Abstract</i>	13
<i>List of Acronyms</i>	15
<b>Chapter 1 Structural glass introduction</b>	<b>17</b>
1.1 Materials	21
1.1.1 Glass	22
1.1.2 Interlayer materials	27
1.1.2.1 PVB	32
1.1.2.2 SG	32
1.1.2.3 DG41	33
1.1.2.4 Other interlayer materials and multilayer interlayers	34
1.1.3 Adhesion between glass and interlayers	35
<b>Chapter 2 State-of-the-art and aim of the research</b>	<b>37</b>
2.1 Shortcomings in the regulatory framework	38
2.2 Scientific literature overview	41
2.2.1 Properties of interlayers used for LG	42
2.2.2 LG models and full-scale experimental analyses	49
2.2.3 Reinforced LG	53
2.2.4 Pre-stressed LG	56
2.2.5 Post-failure LG performance	60
2.3 Aim of the research	62
<b>Chapter 3 Mechanics</b>	<b>65</b>
3.1 Elasticity	65
3.1.1 Linear elasticity	66
3.1.2 Non-linear elasticity (hyperelasticity)	67
3.1.3 Time-dependent linear elasticity (linear viscoelasticity)	73
3.1.3.1 Creep and relaxation: the Wiechert model and Prony series	74
3.1.3.2 Methods for fitting experimental data to Prony series	79
3.1.3.3 Hereditary integrals for linear viscoelasticity	79
3.1.3.4 Dynamic tests	80
3.1.3.5 Time-Temperature superposition	82
3.2 Plasticity	83
3.2.1 Viscoplasticity	84
3.3 Adhesive bonds	86
<b>Chapter 4 Experimental Tests</b>	<b>89</b>
4.1 Short-term Tensile properties of interlayers	90
4.1.1 Design and aim of tensile tests	90

## Serviceability and post-failure behaviour of laminated glass structural elements

4.1.2	Experimental results	92
4.2	Long-term viscoelastic properties of interlayers	99
4.2.1	Aim and design of tests	99
4.2.2	Preliminary tests and highlights	103
4.2.2.1	Calibrations	105
4.2.2.2	Preparations of specimens	105
4.2.2.3	Stress distribution improvements	106
4.2.2.4	Improvements of chamber operations	106
4.2.2.5	Thermal effects on dynamometric rings	108
4.2.2.6	Anelastic lead interface settling	108
4.2.2.7	Deformation of testing devices	111
4.2.2.8	Linear drift of load readings	112
4.2.3	Performed tests	113
4.2.4	Experimental results and first data analysis	115
4.2.4.1	Load drift correction and initial displacement	116
4.2.4.2	Elastic setup deformation correction	118
4.2.4.3	Thermal effects	119
4.2.4.4	Relaxation and creep	119
4.2.4.5	Experimental Delamination	123
4.3	Progressive damage in Laminated Glass beams	124
4.3.1	Purpose of tests	124
4.3.2	Design and setup	125
4.3.3	Experimental results	134
4.3.3.1	Undamaged LG	134
4.3.3.2	Partially damaged LG	137
4.3.3.3	Fully damaged LG	143
4.3.4	Uniaxial tests on fully damaged LG specimens	147

## Chapter 5 Critical analysis and discussion 151

5.1	Interlayer properties	151
5.1.1	Short-term properties of interlayers	151
5.1.1.1	True stress-strain diagrams	152
5.1.1.2	A general model for the intrinsic response	154
5.1.1.3	Pseudo Yielding	163
5.1.2	Viscoelastic properties of interlayers in LG	166
5.1.2.1	Time-shift	167
5.1.2.2	Connection of shifted experimental branches	171
5.1.2.3	WLF regression (A proposed fitting procedure)	176
5.1.2.4	Prony series corfficients for mastercurves	180
5.1.2.5	Analytical and Tabulated results	187
5.1.2.6	Limits and reliability of results	188
5.1.3	Temperature-depentent adhesive properties	190
5.2	Post-failure properties of LG	193
5.2.1	Analysis of the tension-stiffening effect	193
5.2.2	Dynamic tests	195
5.2.3	Equivalent thermal expansion model	198

5.2.4	Fully damaged LG models	203
5.2.5	Delamination and TS effect	207
5.2.6	Synthesis of post failure LG properties	208
<b>Chapter 6</b>	<b>Applications</b>	<b>209</b>
6.1	Cold-bent glazing	209
6.1.1	Design hypotheses and material properties	211
6.1.2	Design procedure and verifications	213
6.1.3	Results, design options and interlayers comparison	217
6.2	Post-failure analysis of a LG element	219
6.2.1	Data, constraints and parameters	221
6.2.2	Validation of the numerical model	222
6.2.3	Verifications and design	224
<b>Chapter 7</b>	<b>Thesis and developments</b>	<b>229</b>
7.1	Conclusions of the research	229
7.2	Open topics for future investigations	232
<i>Appendix A</i>		241
<i>Appendix B</i>		246
<i>Appendix C</i>		250
<i>Appendix D</i>		254
<i>Appendix E</i>		255
<i>Appendix F</i>		256
<i>Appendix G</i>		257
<i>Appendix H</i>		262
<i>Appendix I</i>		264
<i>Index of figures</i>		265
<i>Index of tables</i>		273
<i>References</i>		275
<i>Acknowledgements</i>		295