Contents

Preface ix	C
------------	---

1	Introduction 1
2	Viscoelasticity 5
2.1	Introduction 5
2.2	Concept of Viscoelastic Behavior 5
2.3	Concept of Time–Temperature Superposition Principle (TTSP) 7
2.4	Master Curve of Creep Compliance of Matrix Resin 8
2.5	Generalization of TTSP for Nondestructive Deformation Properties to
	Static, Creep, and Fatigue Strengths of FRPs 9
2.6	Master Curve of Static Strength of FRP 11
2.7	Master Curve of Creep Strength of FRP 12
2.8	Master Curve of Fatigue Strength of FRP 13
2.9	Conclusion 15
	Reference 15
3	Master Curves of Viscoelastic Coefficients of Matrix Resin 17
3.1	Introduction 17
3.2	Master Curve of Creep Compliance Based on Modified TTSP 17
3.2.1	Experimental Procedures 19
3.2.2	Reliable Long-Term Creep Compliance of Matrix Resin 20
3.3	Simplified Determination of Long-Term Viscoelastic Behavior 22
3.3.1	Relation between Storage Modulus and Creep Compliance 24
3.3.2	Formulation of Master Curves of Creep Compliance 24
3.3.3	TTSP Automatic Shifting Procedure 26
3.3.4	Experimental Procedures 26
3.3.5	Master Curve of Storage Modulus by DMA 26
3.3.6	Comparison of Master Curves of Creep Compliance 29
3.4	Conclusion 30
	References 32



/i	Contents

4	Nondestructive Mechanical Properties of FRP 33
4.1	Introduction 33
4.2	Role of Mixture 33
4.3	Mechanical and Thermal Properties of Unidirectional CFRPs, Fibers,
	and Matrix Resin 35
4.4	Master Curves of Creep Compliance of Matrix Resin 35
4.5	
4.5	
	References 37
_	Chatiana de Caracida (EDD 00
5	Static and Fatigue Strengths of FRP 39
5.1	Introduction 39
5.2	Experimental Procedures 39
5.2.1	Preparation of Specimens 39
5.2.2	Test Procedures 40
5.3	Results and Discussion 42
5.3.1	Master Curve of Static Strength 42
5.3.2	Master Curve of Fatigue Strength 44
5.3.3	Characterization of Fatigue Strength for Loading Directions of Three
0.0.0	Kinds 45
5.4	Applicability of TTSP 51
5.5	Conclusion 52
5.5	
	References 53
6	Formulation of Static Strength of FRP 55
6.1	Introduction 55
6.2	
	Formulation of Static Strength 55
6.3	Application of Formulation 57
6.3.1	Experimental Procedures 57
6.3.2	Preparation of Specimens 57
6.3.3	Test Procedures 58
6.4	Results and Discussion 60
6.4.1	Master Curve of Creep Compliance for Matrix Resin 60
6.4.2	Master Curve of Tensile Static Strength for Matrix Resin 62
6.4.3	Master Curves of Three Kinds of Static Strengths of Unidirectional
	CFRP 64
6.5	Conclusion 69
0.0	References 69
7	Formulation of Fatigue Strength of FRP 71
7.1	Introduction 71
7.2	Formulation 71
7.3	Application of Formulation 72
7.3.1	Specimens and Test Methods 72
7.3.2	Creep Compliance of Matrix Resin 73
7.3.3	Master Curves of Static and Fatigue Strengths for Unidirectional
7.3.3	6 6
7.4	CFRP 74
7.4	Conclusion 81
	References 82

8	Formulation of Creep Strength of FRP 83
8.1	Introduction 83
8.2	Formulation 83
8.3	Application of Formulation 85
8.3.1	Specimens and Test Methods 86
8.3.2	Creep Compliance of Matrix Resin and Static Strength of CFRP
	Strand 86
8.3.3	Creep Failure Time of CFRP Strand 88
8.4	Conclusion 90
	References 90
9	Application 1: Static Strengths in Various Load Directions of
	Unidirectional CFRP Under Water Absorption Condition 91
9.1	Introduction 91
9.2	Experimental Procedures 91
9.3	Viscoelastic Behavior of Matrix Resin 92
9.4	Master Curves of Static Strengths for Unidirectional CFRP 96
9.5	Relation between Static Strengths and Viscoelasticity of Matrix
	Resin 99
9.6	Conclusion 100
	References 100
10	Application 2. Static and Fatigue Flavoural Street who of Various
10	Application 2: Static and Fatigue Flexural Strengths of Various FRP Laminates Under Water Absorption Condition 101
10.1	Introduction 101
10.2	Specimen Preparation 101
10.3	Experimental Procedures 104
10.4	Creep Compliance 105
10.5	Flexural Static Strength 107
10.6	Flexural Fatigue Strength 109
10.7	Conclusion 121
	References 122
	A Process of the Composition of
11	Application 3: Life Prediction of CFRP/Metal Bolted Joint 123
11.1	Introduction 123
11.2	Experimental Procedures 123 Proposition of CERP/Matal Rolled Leister 123
11.2.1	Preparation of CFRP/Metal Bolted Joints 123
11.2.2	Tensile Static and Fatigue Tests 125
11.3 11.3.1	Results and Discussion 126 Master Correspond Compliance for Transports Direction of
11.5.1	Master Curves of Creep Compliance for Transverse Direction of Unidirectional CFRP Laminates 126
11.3.2	Load—Elongation Curves at Tensile Static Tests for CFRP/Metal Bolted
11.0.4	Joint 128
11.3.3	Master Curves of Static Failure Load for CFRP/Metal Bolted
	Joint 130
11.3.4	Master Curves of Fatigue Failure Load for CFRP/Metal Bolted
	Joint 131
	,

11.3.5	Fracture Appearance of CFRP/Metal Bolted Joints Under Static and Fatigue Loadings 135
11.4	Conclusion 138
11.7	References 139
	Netericity 107
12	Application 4: Life Prediction of CFRP Structures Based on
	MMF/ATM Method 141
12.1	Introduction 141
12.2	Procedure of MMF/ATM Method 142
12.3	Determination of MMF/ATM Critical Parameters 143
12.3.1	Long-Term Static and Fatigue Strengths of Unidirectional CFRP 14
12.3.2	MMF/ATM Critical Parameters of Unidirectional CFRP 144
12.4	Life Determination of CFRP Structures Based on MMF/ATM
	Method 144
12.5	Experimental Confirmation for OHC Static and Fatigue Strengths of
	CFRP QIL 148
12.6	Conclusion 151
	References 151
Α	Effect of Physical Aging on the Creep Deformation of an Epoxy
^	Effect of Finysical Aging off the creep Deformation of an Epoxy
A 1	Resin 153
A.1 A 2	Resin 153 Introduction 153
A.2	Resin 153 Introduction 153 Creep Deformation for Aged Polymers 153
	Resin 153 Introduction 153
A.2 A.3	Resin 153 Introduction 153 Creep Deformation for Aged Polymers 153 Experimental Procedure 156 Results and Discussion 157
A.2 A.3 A.4	Resin 153 Introduction 153 Creep Deformation for Aged Polymers 153 Experimental Procedure 156 Results and Discussion 157 Creep Compliance 157
A.2 A.3 A.4 A.4.1	Resin 153 Introduction 153 Creep Deformation for Aged Polymers 153 Experimental Procedure 156 Results and Discussion 157 Creep Compliance 157
A.2 A.3 A.4 A.4.1 A.4.2	Resin 153 Introduction 153 Creep Deformation for Aged Polymers 153 Experimental Procedure 156 Results and Discussion 157 Creep Compliance 157 Effect of Physical Aging on Creep Compliance 159
A.2 A.3 A.4 A.4.1 A.4.2	Resin 153 Introduction 153 Creep Deformation for Aged Polymers 153 Experimental Procedure 156 Results and Discussion 157 Creep Compliance 157 Effect of Physical Aging on Creep Compliance 159 Conclusions 162 References 162
A.2 A.3 A.4 A.4.1 A.4.2	Resin 153 Introduction 153 Creep Deformation for Aged Polymers 153 Experimental Procedure 156 Results and Discussion 157 Creep Compliance 157 Effect of Physical Aging on Creep Compliance 159 Conclusions 162 References 162 Reliable Test Method for Tensile Strength in Longitudinal
A.2 A.3 A.4 A.4.1 A.4.2 A.5	Resin 153 Introduction 153 Creep Deformation for Aged Polymers 153 Experimental Procedure 156 Results and Discussion 157 Creep Compliance 157 Effect of Physical Aging on Creep Compliance 159 Conclusions 162 References 162 Reliable Test Method for Tensile Strength in Longitudinal Direction of Unidirectional CFRP 165
A.2 A.3 A.4 A.4.1 A.4.2 A.5	Resin 153 Introduction 153 Creep Deformation for Aged Polymers 153 Experimental Procedure 156 Results and Discussion 157 Creep Compliance 157 Effect of Physical Aging on Creep Compliance 159 Conclusions 162 References 162 Reliable Test Method for Tensile Strength in Longitudinal Direction of Unidirectional CFRP 165 Introduction 165
A.2 A.3 A.4 A.4.1 A.4.2 A.5	Resin 153 Introduction 153 Creep Deformation for Aged Polymers 153 Experimental Procedure 156 Results and Discussion 157 Creep Compliance 157 Effect of Physical Aging on Creep Compliance 159 Conclusions 162 References 162 Reliable Test Method for Tensile Strength in Longitudinal Direction of Unidirectional CFRP 165 Introduction 165 Evaluation of Tensile Strength Using Post-Bonded CFRP Strand
A.2 A.3 A.4 A.4.1 A.4.2 A.5 B B.1 B.2	Resin 153 Introduction 153 Creep Deformation for Aged Polymers 153 Experimental Procedure 156 Results and Discussion 157 Creep Compliance 157 Effect of Physical Aging on Creep Compliance 159 Conclusions 162 References 162 Reliable Test Method for Tensile Strength in Longitudinal Direction of Unidirectional CFRP 165 Introduction 165 Evaluation of Tensile Strength Using Post-Bonded CFRP Strand Specimen 166
A.2 A.3 A.4 A.4.1 A.4.2 A.5 B B.1 B.2 B.3	Resin 153 Introduction 153 Creep Deformation for Aged Polymers 153 Experimental Procedure 156 Results and Discussion 157 Creep Compliance 157 Effect of Physical Aging on Creep Compliance 159 Conclusions 162 References 162 Reliable Test Method for Tensile Strength in Longitudinal Direction of Unidirectional CFRP 165 Introduction 165 Evaluation of Tensile Strength Using Post-Bonded CFRP Strand Specimen 166 Development of Co-Cured CFRP Strand Specimen 169
A.2 A.3 A.4 A.4.1 A.4.2 A.5 B B.1 B.2 B.3 B.3.1	Resin 153 Introduction 153 Creep Deformation for Aged Polymers 153 Experimental Procedure 156 Results and Discussion 157 Creep Compliance 157 Effect of Physical Aging on Creep Compliance 159 Conclusions 162 References 162 Reliable Test Method for Tensile Strength in Longitudinal Direction of Unidirectional CFRP 165 Introduction 165 Evaluation of Tensile Strength Using Post-Bonded CFRP Strand Specimen 166 Development of Co-Cured CFRP Strand Specimen 169 Molding of Co-Cured CFRP Strand Specimen 169
A.2 A.3 A.4 A.4.1 A.4.2 A.5 B B.1 B.2 B.3 B.3.1 B.3.2	Resin 153 Introduction 153 Creep Deformation for Aged Polymers 153 Experimental Procedure 156 Results and Discussion 157 Creep Compliance 157 Effect of Physical Aging on Creep Compliance 159 Conclusions 162 References 162 Reliable Test Method for Tensile Strength in Longitudinal Direction of Unidirectional CFRP 165 Introduction 165 Evaluation of Tensile Strength Using Post-Bonded CFRP Strand Specimen 166 Development of Co-Cured CFRP Strand Specimen 169 Molding of Co-Cured CFRP Strand Specimen 169 Improvement of Co-Cured CFRP Strand Specimen 169
A.2 A.3 A.4 A.4.1 A.4.2 A.5 B B.1 B.2 B.3 B.3.1	Resin 153 Introduction 153 Creep Deformation for Aged Polymers 153 Experimental Procedure 156 Results and Discussion 157 Creep Compliance 157 Effect of Physical Aging on Creep Compliance 159 Conclusions 162 References 162 Reliable Test Method for Tensile Strength in Longitudinal Direction of Unidirectional CFRP 165 Introduction 165 Evaluation of Tensile Strength Using Post-Bonded CFRP Strand Specimen 166 Development of Co-Cured CFRP Strand Specimen 169 Molding of Co-Cured CFRP Strand Specimen 169

Index *177*