1

PREFACE

ACKNOWLEDGMENTS

Chapter	1 INTRODUCTION TO FERROCEMENT
1.1	Ferrocement: Definition and Historical Background 1 1.1.1 Introduction 1 1.1.2 Definition by ACI Committee 540.
	1.1.2 Definition by ACI Committee 549 91.1.3 Suggested Revised Definition 9
1.2	
	1.2.1 Marine Applications 9
	1.2.2 Terrestrial Applications 10
	1.2.3 Repair and Rehabilitation 11
1.3	Constituent Materials of Ferrocement 15
	1.3.1 Cement Based Matrix: Composition and Compressive Strength 151.3.2 Skeletal Steel 17
	1.3.3 Mesh Reinforcement 17
1.4	Distinct Characteristics of Ferrocement versus Reinforced Concrete 22
	1.4.1 Physical <i>22</i>
	1.4.2 Mechanical <i>22</i>
	1.4.3 Processing / Manufacturing / Maintenance / Repair 24
1.5	Similarities Between Ferrocement and Reinforced Concrete 24
1.6	The state of the s
	1.6.1 Square or Rectangular Meshes 25
	1.6.1.1 Example: Square Mesh 26
	1.6.2 Any Mesh Type 27
	1.6.2.1 Example: Expanded Metal Mesh 27 1.6.3 FRP Meshes 28
	1.6.3.1 Example: FRP Mesh 29
1.7	1
	1.7.1 Example: Reinforced Concrete versus Ferrocement 30
1.8	Distinctive Behavior of Ferrocement In Tension 31
	1.8.1 Cracking and Multiple Cracking Behavior 31
	1.8.2 Maximum Elongation at Failure 33
	1.8.3 Stress at First Cracking 33
	1.8.4 Influence of Specific Surface of Reinforcement 33
1.9	1.8.5 Apparent Modulus of the Mesh System 37 Ferrocement: a Composite and a Member of the Structural Concrete Family 38
1.10	Ferrocement: a Composite and a Member of the Structural Concrete Family 38 Ferrocement versus Fiber Reinforced Polymeric Composites 40
1.11	Ferrocement as a Laminated Composite 41
1.12	Advantages of Ferrocement as a Construction Material 42

Chapter 2 MECHANICAL PROPERTIES OF FERROCEMENT 45 AS OBSERVED FROM TESTS

- 2.1 Introduction 45
- 2.2 Tensile Properties 46

	2.3	First Cracking 50	
	2.4		
		2.4.1. Uncracked Member 51	
		2.4.2. Cracked Member 52	
	2.5		
		2.5.1 Typical Behavior <i>53</i>	
	0.6	2.5.2 Observations and Conclusions 58	
	2.0	Fatigue under Bending 60	
	2.7	- · · · · · · · · · · · · · · · · · · ·	
		2.7.1. Design for Shear 62	
	2.8	Compression 64	
	2.9	Impact – Impermeability 65	
	2.10	Leakage 67	
	2.11	Fire Resistance 69	
		Durability 69	
		Criteria for Selection and Use of Ferrocement 70	
	2.10	Ontena for Selection and Ose of Perfocement 70	
Chapte	er 3	MODELING THE TENSILE RESPONSE OF FERROCEMENT AND OTHER BRITTLE MATRIX COMPOSITES WITH CONTINUOUS FIBERS	73
	3.1	General Assumptions and Notation 73	
		Upprocked Teneile Members Decis Machanisms and Machalisms 70	
	3.2	Uncracked Tensile Member: Basic Mechanisms and Modeling 76	
		3.2.1 Stresses in Fiber and Matrix within Transition Length 76	
		3.2.2 Distance at which Equal Strains Occur: Transfer Distance 78	
		3.2.3 Stresses in Matrix and Reinforcement beyond the Transfer Distance 8	0
		3.2.4 Load and Stresses at First Matrix Cracking 80	
		3.2.5 Minimum Volume Fraction of Reinforcement 81	
	3.3	Example: Uncracked Tensile Member 82	
		3.3.1 SI System 82	
		3.3.2 US System <i>84</i>	
	3.4		
	- • •	3.4.1 Stresses in Matrix and Reinforcement at a Cracked Section 86	
		3.4.2 Stresses Between Two Cracks 88	
		3.4.3 Stresses at Yield and Ultimate 88	
		3.4.4 Minimum, Maximum, and Average Crack Spacing 88	
		3.4.5 Average Stress in Reinforcement and Matrix 91	
		3.4.6. Average Crack Width 93	
	3.5	Example: Cracked Ferrocement Tensile Member 95	
		3.5.1 SI System <i>95</i>	
		3.5.2 US System <i>97</i>	
	3.6	Experimental Observations Supporting Cracking Theory 99	
	3.7		03
		3.7.1 US System 106	00
		3.7.2 SI System 107	
	2 0	3.7.3 Example: Crack Width Using ACI Recommended Method 107	
	3.8	Elastic Modulus: Cracked and Uncracked Member 108	
		3.8.1 Uncracked Member - Upper Bound Solution 108	
		3.8.2 Cracked Member: Absolute Lower Bound Solution 109	
		3.8.3 Cracked Member: Suggested Approximate General Solution 110	
;	3.9	Example: Prediction of Composite Stress-Strain Response 111	
		3.9.1 SI System 111	
		3.9.2 US System 115	
:	3.10	Basic Properties as Random Variables 117	
	3.11	Particular Remarks for Ferrocement 119	
· ·	1	. Sinssial Fieldand for Fellocenicit. 113	

4.1 Notation 121

IN BENDING

Chapter 4 ANALYSIS AND DESIGN OF FERROCEMENT

121

4.2	Differenc	es in the Analysis/Design of Ferrocement with Conventional roed Concrete 122	
4.3		d Remedies 122	
4.4		Area of Reinforcement 123	
4.5		Moment-Curvature Response 125	
4.6	Analysis	Methods for Bending under Service Loads 126	
		Flexure Formula: Uncracked Section 126	
	4.6.2	Transformed Area Method for the Cracked Section 128	
	4.6.3 4.6.4	Equilibrium and Compatibility Method for the Cracked Section 130 Moment versus Deflection Curve 130	
4.7			
	4 7 1	Cracked Section by the Transformed Area Method <i>(SI System)</i> 130 Welded Wire Mesh Reinforcement 130	
	4.7.2	Expanded Steel Mesh Reinforcement 133	
4.8	–	Cracked Section by the Transformed Area Method (US System) 134	
	4.8.1	Welded Wire Mesh Reinforcement 134	
	4.8.2	Expanded Steel Mesh Reinforcement 136	
4.9		Methods for Nominal Bending Resistance 137	
	4.9.1	Compatibility Method Similar to Reinforced Concrete Columns 137	
		4.9.1.1 Example: M_n by the Compatibility Method (SI System) 139)
	4.9.2	Simplified Method Based on All Tensile Reinforcement Yielding 140)
		4.9.2.1 Example: M_n Assuming All Tensile Reinforcement Yielding	
	400	(SI System). 141	
	4.9.3	Simplified Method Using Plastic Moment 142	
	404	4.9.3.1 Example: M _n Using Plastic Moment (SI System) 143	
	4.9.4	Simplified Method Using Design Chart or Prediction Equation 144	
	405	4.9.4.1 Example: M _n Using Prediction Equation (SI System) 145	
4 10	4.9.5	Remarks on the Use of Simplified Methods 145 I Examples of Nominal Bending Resistance Using the Simplified	
7.10	Method	is (SI System) 146	
	4.10.1	Using the Plastic Moment Approach 147	
		Using the Design Chart or Prediction Equation Approach 147	
	4.10.3	Using the All Tensile Reinforcement Yields Approach 147	
4.11		ns of Crack Widths in Bending 148	
		Static or Monotonic Loading 148	
		Cyclic Fatigue Loading 149	
4 1 E		Example: Crack Width in Bending 150	
7.1 🗅	Strengt	Elastic Bending Strength (MOR) and Correlation with Tensile th 151	
	4.12.1	Modulus of Rupture (MOR) 151	
			52
	4.12.2	MOR versus Tensile Strength 153	-
		4.12.2.1 Example: Ratio of Bending to Tensile Strength 154	
4.13		tion of Deflections 154	
	4.13.1	Deflection of Simply Supported Uncracked and Cracked Beams 154	
111		Moment Deflection Relation 156 ng Remarks 156	
7.14	Concludit	iy nemarka 100	
ter 5	PRAC	TICAL DESIGN GUIDELINES	1
_			•

Chapt

159

5.1	Design Philosophy 159
5.2	General Design Approaches 160
	5.2.1 USD, LSD, or LRFD <i>161</i>
	5.2.2 WSD or ASD 162
5.3	Design Approaches Applied to Ferrocement 164
5.4	Practical Design Guidelines to Insure Good Serviceability 165
	5.4.1 Allowable Stresses under Maximum Service Load 165
	5.4.2 Maximum Crack Width 166
	5.4.3 Fatigue Life 166
	5.4.4 Durability and Corrosion 166
	5.4.5 Deflection Limitations 166
5.5	Practical Design Parameters for Ferrocoment 166

	5.6 5.7 5.8 5.9	Design Example: Bending Element - Floor Sandwich Panel 172	
Chapt	er	6 CONSTRUCTION - FABRICATION OF FERROCEMENT	181
	6.1 6.2 6.3	Mortar Placement 182	
	6.4 6.5 6.6 6.7	6.3.4 Open Mold Method 190 Special Manufacturing Techniques 191 Ferrocement Element versus Structure 198 Protective Surface Treatments 198	
Chapt	er	7 TESTING FOR REINFORCEMENT AND COMPOSITE PROPERTIES	205
	7.1 7.2		
	7.3	Efficiency Factor of Reinforcement 212 7.3.1 η_O from Direct Tensile Tests 213 7.3.2 η_O from Bending Tests with One Layer of Mesh 213 7.3.3 η_O from Bending Tests with Several Layers of Mesh 214 7.3.4 Discussion Related to σ_{IY} and E_I 216	
	7.4	7.3.5 Test Sequence 217 Recommended Values for η_{o} , σ_{ry} and E_{r} 217	
	7.5	Example of Computation of E_{I} , η_{L} , and σ_{IU} from a Tensile Test 217	
	7.6	Example of Computation of Mesh Yield Strength, σ_{ry} 219 7.6.1 Using a Composite Tensile Test 219 7.6.2 Using a Composite Bending Test 220	
	7.7		
Chapt	ter	8 COST ESTIMATES OF TYPICAL FERROCEMENT COMPOSITES	225
	8.1 8.2 8.3 8.4	Introduction 225 Description of Cost Survey 225 Comparative Cost Results 230 Building and Construction Cost Indexes 234 8.4.1 Definition 234 8.4.2 Cost Correlation to the Present 236 8.4.3 Relative Importance of Labor and Materials Costs 237	
	8.5 8.6	Examples of Gross Cost Estimates Based on Past Experience 238	

Chapter	9 FERROCEMENT IN HOUSING AND RELATED APPLICATIONS	245
9.1 9.2 9.3	3 Total Control of	
9.4 9.5 9.6 9.7 9.8 9.9	9.3.6 Moment Type Joint 263 Ferrocement Sandwich Panels 267 Manufactured Housing: Engineering Vision and Consumer's Dream 272 Monolithic Ferrocement Auditorium 273 Ferrocement Water Tanks 273 Sunscreens 276	
Chapter	10 ADVANCED MATERIALS AND CONCEPTS	281
10.2	Advanced or High Performance Materials 281 Fiber Reinforced Polymeric Meshes 282 10.2.1 Introduction - Significance 282 10.2.2 Advantages and Drawbacks 283 10.2.3 Type and Availability 283 10.2.4 Cost Considerations 283 10.2.5 Examples of FRP Meshes Tested 286 10.2.6 Test Parameters of Experimental Investigation 288 10.2.7 Typical Results 290 10.2.7.1 Influence of Number of Mesh Layers or V _r 290 10.2.7.2 Loading-Unloading Response 291 10.2.7.3 Effect of Production Process 294 10.2.7.4 Effect of Using Meshes with Low Elastic Modulus 294 10.2.7.5 Effect of Using a Fiber Mat 294 10.2.8 Conclusions on the Use of FRP Meshes with Conventional Cement Mortar Matrices 296 Hybrid Composites 297 10.3.1 Justification 297 10.3.2 Experimental Results 299 10.3.2.1 Effect of Adding Discontinuous Fibers with PVA Mesh 28 10.3.2.2 Effect of Adding Discontinuous Fibers with Kevlar and	99 300
10.4	Spectra Meshes 302 10.3.3 Conclusions on Using Hybrid Composites 304 Three-Dimensional (3-D) Meshes 305	
10.5	Advanced Matrices 307 10.5.1 Inorganic Matrices 307	
10.6	10.5.2 Concrete Polymer Composites 308 Self-Stressing Composites 309 10.6.1 Motivation 309 10.6.2 Methods of Prestressing and Self-Stressing 309 10.6.3 Definition of Deformation Controlled Recovery Property (DCRP) 310 10.6.4 Why Self-Stressing Cementitious Composites and What Can Be Expect 10.6.5 Advantages of Self-Stressing 311 10.6.6 Analytical Formulation 312 10.6.7 Typical Analytical Results 315	ed?
10.7	10.6.8 Experimental Results to Demonstrate the Concept 317 Concluding Remarks 319	

APPLICATIONS, AND TECHNOLOGY	, 020
11.1 Research Trends in Construction Materials 32311.2 Prospects for Ferrocement Materials, Applications and Technology 32	23
Appendix A: NOTATION	329
Appendix B: UNIT CONVERSIONS	335
Appendix C: REFERENCES	337
Appendix D: STANDARD MESHES, WIRES AND BARS	355
Appendix E: COMMON FORMULAS FOR BEAMS	359
INDEX	367