Proceedings of the Sixth
International Symposium on Ferrocement
University of Michigan, Ann Arbor, June 7-10, 1998

Edited by
ANTOINE E. NAAMAN
Released by the International Ferrocement Society with permission from the author. www.ferrocement-ifs.com
FERROCEMENT 6
LAMBOT SYMPOSIUM

Proceedings of the Sixth
International Symposium on Ferrocement
University of Michigan, Ann Arbor, June 7-10, 1998

Sponsored by:
ACI - American Concrete Institute
RILEM - Reunion Internationale des Laboratoires
der Essais des Materiaux
ACBM: NSF Center for Advanced Cement Based Materials
IFS - International Ferrocement Society
IFIC - International Ferrocement Information Center
Ferrocement International Network
Asian Institute of Technology
University of Michigan

Edited by

ANTOINE E. NAAMAN
Department of Civil and Environmental Engineering
University of Michigan, Ann Arbor, Michigan, USA

UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN, 48109-2125, USA
Inventor of "ferciment" or ferrocement:

Joseph Louis Lambot
(Was born May 22, 1814, Montfort-sur-Argens, and died August 2, 1887, Brignoles, France)

French Patent:
(22120. 30 mars 1855.) France.
Combinaison de fer et de ciment, destine a remplacer le bois, dit ferciment succedant du bois de construction.
## Contents

**Preface**  
**Workshop**  
**Acknowledgment**

### 1. ADVANCES AND ISSUES

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>IFIC and IFS: Partners for Ferrocement Technology Development and Transfer</td>
<td>5</td>
</tr>
<tr>
<td><em>L. Robles-Austriaco and R. P. Pama</em></td>
<td></td>
</tr>
<tr>
<td>The Armature that Made History; The Boats of Joseph Louis Lambot</td>
<td>11</td>
</tr>
<tr>
<td><em>J. E. Morgan and R. Morgan</em></td>
<td></td>
</tr>
<tr>
<td>Advanced in Science and Technology of Ferrocement</td>
<td>35</td>
</tr>
<tr>
<td><em>S. P. Shah and A. Peled</em></td>
<td></td>
</tr>
<tr>
<td>Recent Research and Applications of Ferrocement in Singapore</td>
<td>53</td>
</tr>
<tr>
<td><em>P. Paramasivam</em></td>
<td></td>
</tr>
<tr>
<td>Ferrocement: Environmentally Sound Technology</td>
<td>65</td>
</tr>
<tr>
<td><em>L. Robles-Austriaco</em></td>
<td></td>
</tr>
<tr>
<td>Ferrocement: An Insight and Review - So What Is New?</td>
<td>75</td>
</tr>
<tr>
<td><em>J. M. Pemberton</em></td>
<td></td>
</tr>
<tr>
<td>The Future of Ferrocement - Some Thoughts</td>
<td>85</td>
</tr>
<tr>
<td><em>E. Z. Tatsa</em></td>
<td></td>
</tr>
</tbody>
</table>

### 2. HOUSING APPLICATIONS: PREFABRICATED AND MONOLITHIC

<table>
<thead>
<tr>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applications of Prefabricating Ferrocement Housing in Mexico</td>
<td>95</td>
</tr>
<tr>
<td><em>A. Olvera L., F. Olvera, R. Martinez, F. Almeida, A. E. Olvera, and G. Gallo</em></td>
<td></td>
</tr>
<tr>
<td>Residential Building Systems</td>
<td>109</td>
</tr>
<tr>
<td><em>E. Escobar Loret de Mola and H. Wainshtok Rivas</em></td>
<td></td>
</tr>
<tr>
<td>Technology for Prefabrication and Assembling of Light Ferrocement Panels</td>
<td>119</td>
</tr>
<tr>
<td><em>S. Marrero Osorio and H. Wainshtok Rivas</em></td>
<td></td>
</tr>
<tr>
<td>Building System for Low-Cost Ferrocement Housing</td>
<td>129</td>
</tr>
<tr>
<td><em>E. F. Machado, Jr.</em></td>
<td></td>
</tr>
<tr>
<td>Behavior of Moment Connections Between Ferrocement Half-Box Panels</td>
<td>139</td>
</tr>
<tr>
<td><em>M. A. Mansur, K. L. Tan, A. E. Naaman and P. Paramasivam</em></td>
<td></td>
</tr>
<tr>
<td>Ferrocement Bolted Shear Joints: Finite Element Analysis &amp; Stress Distribution</td>
<td>153</td>
</tr>
<tr>
<td><em>H. Hammoud and A. E. Naaman</em></td>
<td></td>
</tr>
<tr>
<td>A Monolithic Ferrocement Auditorium</td>
<td>173</td>
</tr>
<tr>
<td><em>A. Fernandez and P. Montes</em></td>
<td></td>
</tr>
</tbody>
</table>
3. MECHANICAL PROPERTIES

Improvement of Punching Shear Resistance in Ferrocement Slabs
S.F.U. Ahmed and P. Nimityongskul

Punching in Simply Supported Ferrocement Slabs
M. A. Mansur, I. Ahmad and P. Paramasivam

Experimental and Analytical Studies on Flexural Behaviour of Ferrocement Plates
M. Arif, S. K. Kaushik, and Pankaj

Flexural Behavior of Ferrocement/Concrete Composite Beams
H. H. Nassif, G. Chiravurri, and M. Sanders

Compressive Behavior of Concretes with Externally Bonded Ferrocements
A. Shirai

Some Investigations into the Behaviour of Welded Mesh and Its Effect on the Tensile and Flexural Performance of Ferrocement
M. Ranjbar, A. Nakassa, and P. J. Nedwell

High Performance Ferrocement Using Stainless Steel Mesh and High Strength Mortar
P. J. Nedwell and A. S. Nakassa

Strength of Ferrocement in Biaxial Tension Tension
C.B.K. Rao and A. K. Rao

4. DURABILITY

High Durability Ferrocement
I. G. Vickridge, A. S. Nakassa, and H. Turner

The Effect of an Aggressive Environment on the Flexural Performance of Ferrocement
I. G. Vickridge and M. M. Ranjbar

The Combined Effect of Crack, Load and Aggressive Environment on the Corrosion Rate of Ferrocement Reinforcement
I. G. Vickridge and M. M. Ranjbar

5. FIBER REINFORCED PLASTIC REINFORCEMENTS

Applications of Ferrocement Principles for the Analysis of Advanced Fiber Composites
J. Hammel, P. N. Balaguru and R. Lyon

Bending Behavior of Hybrid Ferrocement Composites Reinforced with PVA Meshes and PVA Fibers
P. Guerrero and A. E. Naaman
Tensile and Shear Response of Angle Ply Cement Based Composites  
G. J. Haupt and B. Mobahser  

Study of Shear Joints in Fiber Reinforced Plastic (FRP) Ferrocement Bolted Connections  
M. Lopez and A. E. Naaman  

Tension Tests of Mortar Reinforced with Steel Meshes and Polymeric Fibers  
M. K. El Debs and E. B. Ekane  

6. INDIGENOUS MATRICES AND FIBERS  
Cementitious Matrices Using Indigenous Materials for Ferrocement Applications  
J. Pera and J. Ambroise  

The Microstructure of the Interfacial Zone between a Portland Cement Matrix and Fique Reinforcing Fiber  
S. Delvasto, C. Ferrer, A. Carcel, and R. Mejia de Gutierrez  

Investigation of the Mechanisms of Toughness Generation in Natural Fiber Cementitious Composites  
S. Delvasto, C. Ferrer, A. Carcel, and R. Mejia de Gutierrez  

Fique Fibers: Experimental Results of Flexural Testing of Fique Fiber-Reinforced Cementitious Composites  
B. J. Hunter and A.E. Naaman  

Experimental Study on Behavior of HPSFRCC under High Velocity Impact  
Wei Sun and Xin Luo  

7. NOTABLE STRUCTURES AND INNOVATIVE APPLICATIONS  
Ferrocement Projects in Saudi Arabia  
F. Audrito, D. Angelotti, P. I. Jennings, and D. V. Russell  

A Multi-Purpose Ferrocement Element for Rural Applications  
C.B.K. Rao  

Ferrocement Sandwich Walls: Research Projects by the São Carlos Group (Brazil)  
M. K. El Debs, E. F. Machado Jr., J. B. de Hanai & T. Takeya  

Auto Prestressing Behaviour of Ferrocement under Flexural In-Service Cyclic Loading and its Practical Applications  
P. Karunakar Rao  

Strengthening and Repair of Masonry Walls with Ferrocement Coatings  
F. L. de Oliveira and J. B. de Hanai  

Recovery of Steel Tank by Using Ferrocement  
H. Wainshtok Rivas and B. Acosta Ramos
8. REGIONAL REPORTS: STATUS, PROGRESS AND PROJECT

Ferrocement in Canada and the United States
M. E. lorns and G. B. Batson

Ferrocement Research and Development: 1994-1997
R. R. Cabahug and L. Robles-Austriaco

Problems and Prospects of Ferrocement in Italy
V. Barberio and R. Muttone

Development of Ferrocement in Bolivia: Construction and Technology - National Experiences
O. Antezana M.

Regional Progress Report - Mexico
A. Fernandez

National Report - United Kingdom
P. J. Nedwell

9. FERROCEMENT MODEL CODE

Working Draft of the Ferrocement Model Code

Calibration of the New Ferrocement Model Code
H. H. Nassif

List of Participants
Author Index
Subject Index
"Ferrocement" or ferrocement is truly the first invention of reinforced concrete, the most used construction material in the world. The main difference between them relates mostly to scale. Reinforced concrete uses larger size reinforcing bars instead of wires or meshes, and a concrete binder, which, unlike cement paste and mortar, contains larger size aggregates. Ferrocement is a thin composite made with a cement based mortar matrix reinforced with closely spaced layers of relatively small wire diameter mesh. The mesh may be made of metallic or other suitable materials. The fineness of the mortar matrix is designed to allow full encapsulation of the reinforcing mesh system.

Ferrocement was invented by a Frenchman, Joseph Louis Lambot, in 1848. In spite of the fact that the rapid development of reinforced concrete stifled the development of ferrocement until the second half of the 20th century, today there is a new revival in the use of ferrocement in applications where its desirable properties cannot be matched by other materials, such as strength, toughness, water-tightness, lightness, durability, and environmental stability. An extraordinary confluence of new technologies and a large market for housing products worldwide could bring a revolution in the way ferrocement is used. Moreover, the increasing availability of advanced materials such as fiber reinforced plastic (FRP) meshes or mats, and either high performance cementitious matrices or indigenous matrices, provide new opportunities for ferrocement to expand its range of applications far beyond what has been achieved to date. Since these advances are expected to materialize in the coming century, there is a need to pause, review the state of the art, and reflect on the future.

The Sixth International Symposium on Ferrocement, is dedicated to Lambot and falls on the 150th anniversary of the invention of ferrocement. It is one of a continuous series of symposia which takes place once every four years under the sponsorship of the International Ferrocement Society based at the Asian Institute of Technology in Bangkok.

The primary objectives of this Symposium are to provide a compendium of up-to-date information on the most recent developments and research advances in the field of ferrocement and thin cement based laminates, to allow a forum of world specialists to share their knowledge of and experience in ferrocement, to foster cooperation and technical exchanges between researchers and practitioners in the field, to identify current technical gaps as well as future research needs, and to suggest directions to follow.

Particular features of the Symposium include: presentation and discussion of the first Ferrocement Model Code, which is sponsored by the International Ferrocement Society; status of ferrocement in different regions of the world and near future progress; review of recent notable structures and innovative applications of ferrocement; ferrocement prefabricated and monolithic housing or elements; the use of fiber reinforced plastic meshes; the use of indigenous matrices and fibers; durability; research advances and scientific perspective for the near future.

The organizers wish to express their deep appreciation to all those who have contributed papers to the Symposium, and to the many who have worked to make it happen.

Antoine E. Naaman
Ann Arbor, Michigan
April 1998
SYMPOSIUM ORGANIZATION

• Chair: A.E. Naaman, University of Michigan, USA
• Deputy Chair:
  - P. Nimittyongskul, Asian Institute of Technology, Thailand
  - L. Austriaco, International Ferrocement Information Center, Thailand

INTERNATIONAL COMMITTEE

• Chair:
  - S.P. Shah, Northwestern University, USA
  - R.C. Pama, SCHEMA Konsult Int. Inc., Philippines
• Deputy Chair:
  - P. Paramasivam, National University of Singapore, Singapore
  - J.B. Hanai, Sao Carlos University, Brazil
• Members
  R. Alexander, New Zealand
  O. Antezana, Bolivia
  Ding Dajun, P.R. China
  K. Chong, USA
  A. Fernandez, Mexico
  A.J. Guerra, Santo Domingo
  M.E. Iorns, USA
  P.J. Jennings, U.K.
  R. Mattone, Italy
  B.A. Mironkov, Russia
  Y. Ohama, Japan
  A.L. Olvera, Mexico
  H.W. Rivas, Cuba
  N. Swamy, UK
  D.N. Trikha, India
  G. Zhao, P.R. China

SCIENTIFIC COMMITTEE

• Chair: P. Balaguru, Rutgers University, USA
• Deputy Chair: E. Tatsa, Technion, Israel
• Members
  F. Ansari, New Jersey Institute of Technology, USA
  G. Batson, Clarkson University, USA
  M. Cheyrezy, Bouygues, France
  S. Delvasto, Universidad del Valle, Cali, Colombia
  M. El Debs, University of Sao Paulo at Sao Carlos, Brazil
  P. Gambarova, Politecnico de Milano, Italy
  W. Hansen, University of Michigan, USA
  S.K. Kauchik, University of Roorkee, India
  V.C. Li, University of Michigan, USA
  M.A. Mansur, National University of Singapore
  H. Nassif, Villanova University, USA
  P. Nedwell, University of Manchester, UK
  J. Pera, INSA de Lyon, France
  P. Rossi, LCPC, France
  M. Sandowicz, Poland
  A. Shirai, Tokyo Kasei Gakuin University, Japan
FERROCEMENT INTERNATIONAL NETWORK

National Coordinators:

Bangladesh: S.K. Sekender Ali; A.K.M. Khorshed Alam
Brazil: A. Wagner Ballarin
China: G. Zhao
Cuba: H. Wainstock Rivas; F. Delgado
India: S.K. Kaushik
Indonesia: W. Merai; P.F. Tamin; A. Djosal; U. Handayo
Malaysia: A.A. Abdullah
Mexico: J.E. Lira
Pakistan: S.H. Lodi
Philippines: E. Alabastro
Saudi Arabia: S.I. Al-Noury
Sri Lanka: N.B. Ratajuinge
Trinidad and Tobago: R. Osborne; A.K. Sharma
United Kingdom: I. Vickridge; P. Nedwell
U.S. Virgin Islands: J.H. Krishna
Vietnam: Do Toan

LOCAL ORGANIZING COMMITTEE

W. Hansen, University of Michigan
V.C. Li, University of Michigan
A.E. Naaman, University of Michigan
R. Robertson, University of Michigan
O. Tavares, Holnam Inc., Dundee, Michigan
A. Waas, University of Michigan

SPONSORSHIP

IFS - International Ferrocement Society
IFIC - International Ferrocement Information Center
FIN - Ferrocement International Network
ACI - American Concrete Institute
RILEM - Reunion Internationale des Laboratoires d'Essais des Materiaux
ACBM: NSF Center for Advanced Cement Based Materials
AIT - Asian Institute of Technology
UM - University of Michigan

SYMPOSIUM SECRETARY

Kathie Helm, University of Michigan
Acknowledgments

This Symposium was made possible by the combined efforts of a number of dedicated professionals who truly believe in the benefits, versatility, and adaptability of ferrocement to numerous construction applications. The organizers are particularly indebted to the authors and key-note speakers who have contributed their latest knowledge to the proceedings of this Symposium. A particular note of thanks is extended to Dr. R. Morgan for his research on Lambot's boat and his perspective of Lambot's invention, "ferciment." This Symposium was sponsored by the International Ferrocement Society, and CO-sponsored by the International Ferrocement Information Center, the American Concrete Institute, RILEM (Reunion Internationale des Laboratoires d'Essais des Materiaux), the NSF Center for Advanced Cement Based Materials, the Asian Institute of Technology and the University of Michigan. The support of these organizations is gratefully acknowledged. Several graduate students (P. Guerrero, M. Lopez, K. Chandrangsu, L. Pinkerton, C. Sujivorakul, Z. Xia) kindly offered their free time to help put together the proceedings for their timely completion. The help of Kathie Helm, symposium secretary, was invaluable in all aspects of the symposium preparation and is also gratefully acknowledged.