

Ferrocement Structures

12.1 SCOPE

This chapter covers selection, standards and testing of ferrocement materials, design criteria and approaches, construction methods, and maintenance and repair procedures of ferrocement structures. The provisions of this chapter are consistent with those of Chapter 6, except for the special requirements of ferrocement, such as reinforcement cover and limits on deflection.

12.2 TERMINOLOGY

12.2.1 Reinforcement Parameters

For the purpose of this chapter, the following parameters characterizing the reinforcement in ferrocement shall have the definitions given:

VOLUME FRACTION OF REINFORCEMENT (V_f): Volume fraction of reinforcement is the total volume of reinforcement divided by the volume of composite (reinforcement and matrix). For a composite reinforced with meshes with square openings, V_f shall be equally divided into V_{fl} and V_{ft} for the longitudinal and transverse directions, respectively. For other types of reinforcement, such as expanded metal, V_{fl} and V_{ft} may be unequal. Procedures for computation of V_f are shown in Appendix 6.12.A.

SPECIFIC SURFACE OF REINFORCEMENT (S_r): S_r is the total bonded area of reinforcement (interface area or area of the steel that comes in contact with the mortar) divided by the volume of the composite.

For a ferrocement plate of width b and depth h , the specific surface of reinforcement can be computed from

$$S_r = \frac{\Sigma o}{bh} \quad (12.2.1)$$

in which Σo is the total surface area of bonded reinforcement per unit length.

The relation between S_r and V_f when square grid wire meshes are used is

$$S_r = \frac{4V_f}{d_b} \quad (12.2.2)$$

where d_b is the diameter of the wire. For other types of reinforcement, such as expanded metal, S_{rl} and S_{rt} may be unequal.

EFFECTIVE MODULUS OF THE REINFORCEMENT: For welded steel meshes, effective modulus of the reinforcing system, E_r shall be taken equal to the elastic modulus of the steel wires. For other meshes, E_r shall be determined from tensile tests on the ferrocement composite as specified in Sec 12.8.

12.2.2 Notation

A_c	=	cross-sectional area of ferrocement composite
A_s	=	total effective cross-sectional area of reinforcement in the direction considered
$A_s = \sum_{i=1}^N A_{si}$		
A_{si}	=	effective cross-sectional area of reinforcement of mesh layer i in the direction considered
b	=	width of ferrocement section
c	=	distance from extreme compression fibre to neutral axis

C_c	=	resultant of the compressive stress block in ferrocement
C_{si}	=	compressive force in ferrocement layer i
d_c	=	clear cover of mortar over first layer of mesh
d_b	=	diameter or equivalent diameter of reinforcement used
d_i	=	distance from extreme compression fibre to centroid of reinforcing layer i
E_c	=	elastic modulus of mortar matrix
E_r	=	effective modulus of the reinforcing system
f'_c	=	specified compressive strength of ferrocement mortar
f_y	=	yield strength of mesh reinforcement or reinforcing bars
h	=	thickness of ferrocement section
M_n	=	nominal moment strength
N_n	=	nominal tensile strength
N	=	number of layers of mesh; nominal resistance
n_r	=	modular ratio of reinforcement
s	=	mesh opening or size
S_r	=	specific surface of reinforcement
S_{rl}	=	specific surface of reinforcement in the longitudinal direction
S_{rt}	=	specific surface of reinforcement in the transverse direction
T_{si}	=	tensile force in the ferrocement layer i
V_f	=	volume fraction of reinforcement
U	=	minimum required design strength
V_{fi}	=	volume fraction of reinforcement for mesh layer i
V_{fl}	=	volume fraction of reinforcement in the longitudinal direction
V_{ft}	=	volume fraction of reinforcement in the transverse direction
β_1	=	factor defining depth of rectangular stress block
η	=	global efficiency factor of embedded reinforcement in resisting tension or tensile bending loads
η_l	=	value of η when the load or stress is applied along the longitudinal direction of the mesh system or rod reinforcement
η_t	=	value of η when the load or stress is applied along the transverse direction of the mesh reinforcement system or rod reinforcement
η_θ	=	value of η when the load or stress is applied along a direction forming an angle with the longitudinal direction
ϵ_{si}	=	strain of mesh reinforcement at layer i
ϵ_y	=	nominal yield strain of mesh reinforcement = $\frac{f_y}{E_r}$
Σ_o	=	total surface area of bonded reinforcement per unit length
ϕ	=	strength reduction factor.

12.2.3 Definitions

ARMATURE: The total reinforcement system or skeletal reinforcement and mesh for a ferrocement element.

LONGITUDINAL DIRECTION: The roll direction (longer direction) of the mesh as produced in plant (see Fig 12.2.1).

SKELETAL REINFORCEMENT: A planar framework or widely spaced tied steel bars that provides shape and support for layers of mesh or fabric attached to either side.

SPRITZING: Spraying or squirting a mortar onto a surface.

TRANSVERSE DIRECTION: Direction of mesh normal to its longitudinal direction; also width direction of mesh as produced in plant (see Fig 12.2.1)

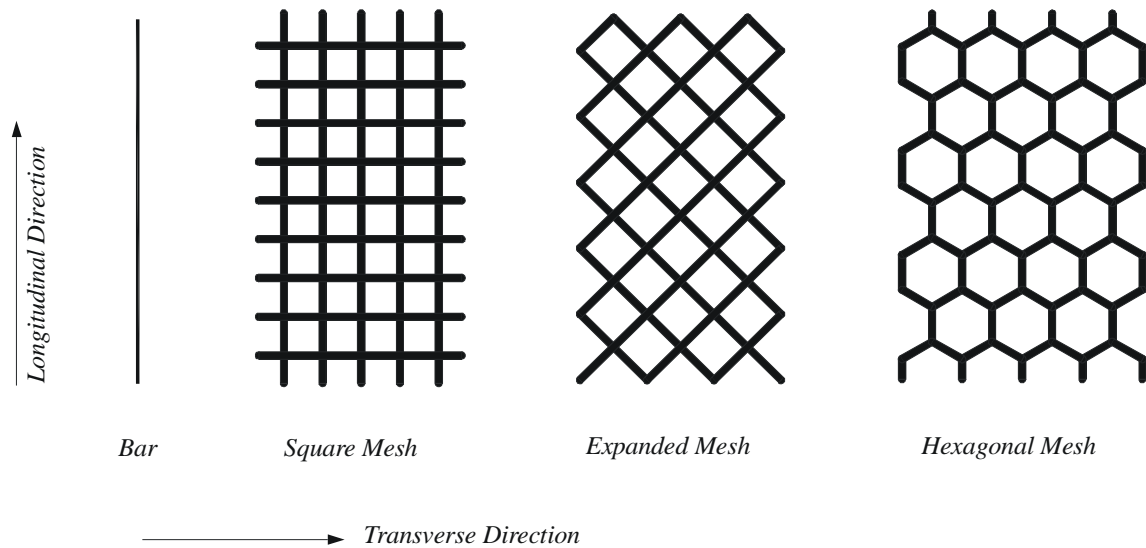


Fig. 12.2.1 Assumed Longitudinal and Transverse Directions of Reinforcement

12.3 MATERIALS

The material used in ferrocement consists primarily of mortar made with Portland cement, water and aggregate and the reinforcing mesh.

12.3.1 Cement

The cement shall comply with ASTM C150-85a, ASTM C595-85, or an equivalent standard. The cement shall be fresh, of uniform consistency, and free of lumps and foreign matter. It shall be stored under dry conditions for as short a duration as possible.

The choice of a particular cement shall depend on the service conditions. Service conditions can be classified as electrochemically passive or active. Land based structures such as ferrocement silos, bins, and water tanks can be considered as passive structures, except when in contact with sulphate bearing soils, in which case the use of sulphate resistant cement, such as ASTM Type II or Type V, may be necessary.

Blended hydraulic cement conforming to ASTM C595-85 Type 1 (PM), IS, 1 (SM), IS-A, IP, or IP-A can also be used.

Mineral admixtures, such as fly ash, silica fumes, or blast furnace slag, may be used to maintain a high volume fraction of fine filler material. When used, mineral admixtures shall comply with ASTM C618-85 and C989-85a. In addition to the possible improvement of flow ability, these materials also benefit long term strength gain, lower mortar permeability, and in some cases improved resistance to sulphates and chlorides.

12.3.2 Aggregates

Aggregate used in ferrocement shall be normal weight fine aggregate (sand). It shall comply with ASTM C33-86 requirements (for fine aggregate) or an equivalent standard. It shall be clean, inert, free of organic matter and deleterious substances, and relatively free of silt and clay.

The grading of fine aggregate shall be in accordance with the guidelines of Table 12.3.1. However, the maximum particle size shall be controlled by construction constraints such as mesh size and distance between layers. A maximum particle size passing sieve No. 16 (1.18 mm) may be considered appropriate in most applications. The sand shall be uniformly graded unless trial testing of mortar workability permits the use of a gap graded sand.

Aggregates that react with the alkalis in cement shall be avoided. When aggregates may be reactive, they shall be tested in accordance with ASTM C227-81. If proven reactive, the use of a pozzolan to suppress the reactivity shall be considered and evaluated in accordance with ASTM C441-81.

Table 12.3.1 Guidelines for Grading of Sand

Sieve Size	Per cent Passing by Weight
U.S. Standard Square Mesh	
No. 8 (2.36 mm)	80 - 100
No. 16 (1.18 mm)	50 - 85
No. 30 (0.60 mm)	25 - 60
No. 50 (0.30 mm)	10 - 30
No. 100 (0.15 mm)	2 - 10

12.3.3 Water

The mixing water shall be fresh, clean, and potable. The water shall be relatively free from organic matter, silt, oil, sugar, chloride, and acidic material. It shall have a pH ≥ 7 to minimize the reduction in pH of the mortar slurry. Salt water is not acceptable, but chlorinated drinking water can be used.

12.3.4 Admixtures

Conventional and high range water reducing admixtures (super plasticizers) shall conform to ASTM C494-86. Water reducing admixtures may be used to achieve an increase in sand content for the same design strength or a decrease in water content for the same workability. Decreases in water content result in lower shrinkage and less surface crazing. Retarders may be used in large time consuming plastering projects, especially in hot weather conditions.

If water tightness is important, such as in water or liquid retaining structures, special precautions shall be taken. To achieve water tightness, the water cement ratio shall preferably be kept below 0.4, crack widths limited (see Sec 12.4) and, if necessary, waterproofing coatings applied (see Sec 12.6.3).

Mineral admixtures such as fly ash (ASTM C618-85) can be added to the cement to increase workability and durability. Normally, 15 per cent of the cement can be replaced with mineral admixtures without appreciably reducing the strength. Pozzolanic admixtures may be added to replace part of the fine aggregates to improve plasticity. The tendency for some natural pozzolans to absorb water and thus adversely affect hydration of the cement phase shall be checked by measuring the water of absorption.

A quality matrix can be obtained without using any admixtures if experience has shown its applicability. Admixtures not covered in ASTM standards shall not be used.

12.3.5 Mix Proportioning

The ranges of mix proportions for common ferrocement applications shall be sand cement ratio by weight, 1.5 to 2.5, and water cement ratio by weight, 0.35 to 0.5. The higher the sand content, the higher the required water content to maintain the same workability. Fineness modulus of the sand, water cement ratio, and sand cement ratio shall be determined from trial batches to ensure a mix that can infiltrate (encapsulate) the mesh and develop a strong and dense matrix.

The moisture content of the aggregate shall be considered in the calculation of required water. Quantities of materials shall preferably be determined by weight.

The mix shall be as stiff as possible, provided it does not prevent full penetration of the mesh. Normally the slump of fresh mortar shall not exceed 50 mm. For most applications, the 28 day compressive strength of 75 by 150 mm moist cured cylinders shall not be less than 35 N/mm².

12.3.6 Reinforcement

The reinforcement shall be clean and free from deleterious materials such as dust, loose rust, coating of paint, oil, or similar substances.

Wire mesh with closely spaced wires is the most commonly used reinforcement in ferrocement. Expanded metal, welded wire fabric, wires or rods, prestressing tendons, and discontinuous fibers may also be used in special applications or for reasons of performance or economy.

12.3.6.1 **Wire Mesh:**

Reinforcing meshes for use in ferrocement shall be evaluated for their susceptibility to take and hold shape as well as for their strength performance in the composite system. Common types and sizes of steel meshes that may be used in ferrocement are provided in Appendix 6.12.B.

12.3.6.2 **Welded Wire Fabric:**

Welded wire fabric may be used in combination with wire mesh to minimize the cost of reinforcement. The fabric shall conform to ASTM A496-85 and A497-86. The minimum yield strength of the wire measured at a strain of 0.035 shall be 410 N/mm². Welded wire fabric normally contains larger diameter wires (2 mm or more) spaced at 25 mm or more.

12.3.6.3 **Expanded Metal Mesh Reinforcement:**

Expanded mesh reinforcement (metal lath), formed by slitting thin gauge steel sheets and expanding them in a direction perpendicular to the slits, may be used in ferrocement. Punched or otherwise perforated sheet products may also be used. Expanded mesh is suitable for tanks if proper construction procedures are adopted.

12.3.6.4 **Bars, Wires and Prestressing Strands:**

Reinforcing bars and prestressing wires or strands may be used in combination with wire meshes in relatively thick ferrocement elements or in the ribs of ribbed or T-shaped elements.

Reinforcing bars shall conform to ASTM A615-86, A616-86 or A617-84. Reinforcing bars shall be steel with a minimum yield strength of 410 N/mm² and a tensile strength of about 615 N/mm². Prestressing wires and strands, whether prestressed or not shall conform to ASTM A421-80 and A416-86, respectively.

12.3.6.5 **Discontinuous Fibres and Nonmetallic Reinforcement:**

Fibre reinforcement consisting of irregularly arranged continuous filaments of synthetic or natural organic fibres such as jute and bamboo may be used in ferrocement. If organic materials are used, care shall be taken to conduct appropriate investigations to ensure the strength and durability of the finished ferrocement product.

12.4 DESIGN

12.4.1 General Principles and Requirements

12.4.1.1 The analysis of a ferrocement cross-section subject to either bending, or to bending and axial load, whether based on strength or working stresses, is similar to the analysis of a reinforced concrete beam or column having several layers of steel (Fig 12.4.1).

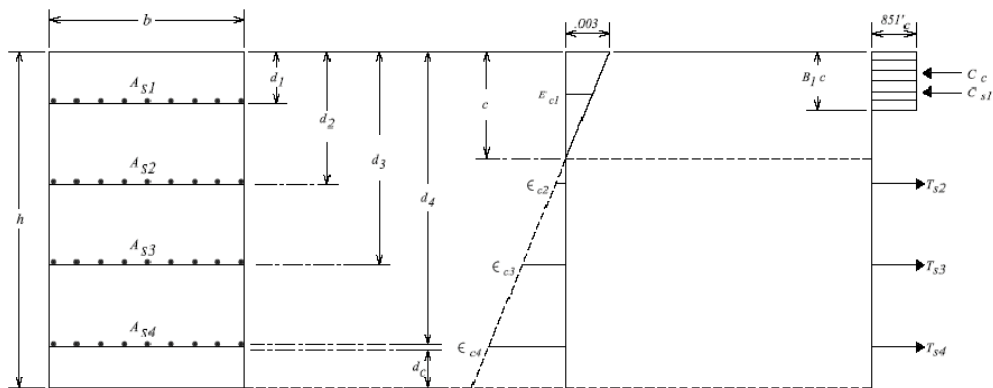


Fig. 12.4.1 Strain and Force Distribution at Ultimate in a Ferrocement Section Under Bending

12.4.1.2 In the design of ferrocement structures, members shall be proportioned for adequate strength in accordance with the provisions of this chapter using load factors and strength reduction factors specified in Chapter 6.

12.4.1.3 Ferrocement members may alternatively be designed using service loads and permissible service load stresses in accordance with the provisions of Sec 12.4.3.

12.4.1.4 All members shall also be designed to satisfy serviceability criteria in accordance with the provisions of Sec 12.4.4.

12.4.2 Strength Requirements

Ferrocement structures and structural members shall have a design strength at all sections at least equal to the required strengths for the factored load and load combinations stipulated in Chapter 1, General Design Requirements. Required strength U to resist dead load D and live load L shall be determined in accordance with Chapter 2, Sec 2.7.5.1.

Design strength provided by a member or cross-section in terms of axial load, bending moment, shear force, or stress shall be taken as the nominal strength calculated in accordance with requirements and assumptions of Chapter 6, Sec 6.1.4 multiplied by the strength reduction factor ϕ to satisfy the general relationship.

$$U \leq \phi N \quad (12.4.1)$$

where U is the factored load (equal to the minimum required design strength), N is the nominal resistance, and ϕ is a strength reduction factor defined in Sec 6.2.3.1.

Design strength for the mesh reinforcement shall be based on the yield strength f_y of the reinforcement but shall not exceed 690 N/mm^2 . Design yield strengths of various mesh reinforcement shall be in accordance with Table 12.4.1. These shall be used for design only when test data are not available. When tests for determination of yield strength are needed, they shall be conducted in accordance with Sec 12.8.2.3 and 12.8.2.4.

Table 12.4.1 Minimum Values of Yield Strength and Effective Modulus for Steel Meshes and Bars Recommended for Design

		Woven Square Mesh	Welded Square Mesh	Hexa- Gonal Mesh	Expanded Metal Mesh	Longitu- dinal Bars
Yield Strength	f_y N/mm ²	450	450	310	310	410
Effective Modulus	$(E_r)_{\text{long}}$ (N/mm ²)	138000	200000	104000	138000	200000
	$(E_r)_{\text{tran}}$ (N/mm ²)	165000	200000	69000	69000	-

12.4.2.1 Flexure:

The strain distribution at nominal moment resistance shall be assumed to be linear, and a rectangular stress block shall be used in computing the resultant compressive force acting on the concrete.

- a) Assumptions - Strength design of ferrocement members for flexure and axial loads shall be based on the following assumptions and on satisfaction of equilibrium and compatibility of strains.
 - i) Strain in reinforcement and mortar (concrete) shall be assumed directly proportional to the distance from the neutral axis.
 - ii) Maximum strain at extreme mortar (concrete) compression fibre shall be assumed equal to 0.003.
 - iii) Stress in reinforcement below specified yield strength f_y shall be taken as E_r times steel strain. For strains greater than that corresponding to f_y , stress in reinforcement shall be considered independent of strain and equal to f_y .

- iv) Tensile strength of mortar (concrete) shall be neglected in flexural strength calculations.
- v) Relationship between mortar (concrete) compressive stress distribution and mortar (concrete) strain may be considered satisfied by the use of the equivalent rectangular concrete stress distribution.
- b) Effective area of reinforcement - The area of reinforcement per layer of mesh considered effective to resist tensile stresses in a cracked ferrocement section shall be determined as follows:

$$A_{si} = \eta V_{fi} A_c \tag{12.4.2}$$

where

- A_{si} = effective area of reinforcement for mesh layer i
- η = global efficiency factor of mesh reinforcement in the loading direction considered
- V_{fi} = volume fraction of reinforcement for mesh layer i
- A_c = gross cross-sectional area of mortar (concrete) section.

The global efficiency factor η when multiplied by the volume fraction of reinforcement, gives the equivalent volume fraction (or equivalent reinforcement ratio) in the loading direction considered. In effect, it leads to an equivalent (effective) area of reinforcement per layer of mesh in that loading direction. For square meshes, $\eta = 0.5$ when loading is applied in one of the principal directions. For a reinforcing bar loaded along its axis, $\eta = 1.0$.

In the absence of values derived from tests for a particular mesh system, the values of η given in Table 12.4.2 for common types of mesh and loading direction may be used. The global efficiency factor shall apply whether the reinforcement is in the tension zone or in the compression zone.

The value of $\eta = 0.2$ for expanded metal mesh (Table 12.4.2) may not always be conservative, particularly in thicker sections in flexure with the mesh oriented in the short way diamond. The values in Table 12.4.2 shall be used for sections 50 mm or less in thickness, and tests conducted for global efficiency values for sections more than 50 mm in thickness.

Table 12.4.2 Recommended Design Values of the Global Efficiency Factor of Reinforcement for a Member in Uniaxial Tension or Bending

		Woven Square Mesh	Welded Square Mesh	Hexagonal Mesh	Expanded Metal Mesh	Longitudinal Bars
Global efficiency factor	Longitudinal, η_l	0.50	0.50	0.45	0.65	1
	Transverse η_t	0.50	0.50	0.30	0.20	0
	At 45° $\eta_{\theta=45}$	0.35	0.35	0.30	0.30	0.70

12.4.2.2 Tension:

The nominal resistance of cracked ferrocement elements subject to pure tensile loading shall be approximated by the load carrying capacity of the mesh reinforcement alone in the direction of loading by the following equation:

$$N_n = A_s f_y \tag{12.4.3}$$

where

- N_n = nominal tensile load resistance in direction considered
- A_s = effective cross-sectional area of reinforcement in direction considered
- f_y = yield stress of mesh reinforcement

The value of A_s is given by

$$A_s = \sum_{i=1}^N A_{si} \tag{12.4.4}$$

where

N = number of mesh layers

A_{si} = effective area of reinforcement for mesh layer i (Eq 12.4.2)

12.4.2.3 Compression:

As a first approximation, the nominal resistance of ferrocement sections subject to uniaxial compression shall be derived from the load carrying capacity of the unreinforced mortar (concrete) matrix assuming a uniform stress distribution of $0.85f'_c$ where f'_c is the design compressive strength of the mortar matrix. However, the transverse component of the reinforcement can contribute additional strength when square or rectangular wire meshes are used. Expanded mesh contributes virtually no strengthening beyond that achieved by the mortar alone. Slenderness effects of thin sections, which can reduce the load carrying capacity below that based on the design compressive strength shall be considered.

12.4.3 Service Load Design

12.4.3.1 Flexure:

For investigation of stresses at service loads, straight line theory (for flexure) shall be used with the following assumptions.

- Strains vary linearly with distance from the neutral axis.
- Stress strain relationships of mortar (concrete) and reinforcement are linear for stresses less than or equal to permissible service load stresses.
- Mortar (concrete) resists no tension.
- Perfect bond exists between steel and mortar (concrete).

To compute stresses and strains for a given loading, the cracked transformed section shall be used. The effective area of each layer of mesh reinforcement shall be determined from Eq (12.4.2). The same value of modular ratio $n_r = E_r/E_c$ may be used for both tensile and compressive reinforcement. Recommended design values of E_r are given in Table 12.4.1. Once the neutral axis is determined, the analysis shall proceed as for reinforced concrete beams or columns having several layers of steel and subject to pure bending.

12.4.3.2 Allowable Tensile Stress:

The allowable tensile stress in the mesh reinforcement under service conditions shall be taken as $0.60 f_y$ where f_y is the yield strength. For liquid retaining and sanitary structures, the allowable tensile stress shall be limited to 200 N/mm^2 . Consideration shall be given to increase the allowable tensile stresses if crack width measurements on a model test indicate that a higher stress will not impair performance.

12.4.3.3 Allowable Compressive Stress:

The allowable compressive stress in either the mortar (concrete) or the ferrocement composite shall be taken as where f'_c is the specified compressive strength of the mortar. Measurements of the mortar compressive strength shall be obtained from tests on 75 mm x 150 mm cylinders.

12.4.4 Serviceability Requirements

Ferrocement structures shall generally satisfy the intent of the serviceability requirements of Chapter 6 except for the concrete cover.

12.4.4.1 Crack Width Limitations:

The maximum value of crack width under service load conditions shall be less than 0.10 mm for noncorrosive environments and 0.05 mm for corrosive environments and/or water retaining structures.

12.4.4.2 Fatigue Stress Range:

For ferrocement structures to sustain a minimum fatigue life of two million cycles, the stress range in the reinforcement shall be limited to 200 N/mm^2 . A stress range of 350 N/mm^2 shall be used for one million cycles. Higher values may be considered if justified by tests.

12.4.4.3 Corrosion Durability:

Particular care shall be taken to ensure a durable mortar matrix and optimize the parameters that reduce the risk of corrosion.

12.4.4.4 Deflection Limitation:

Since ferrocement in thin sections is very flexible and its design is very likely to be controlled by criteria other than deflection, no particular deflection limitation is recommended.

12.4.5 Particular Design Parameters

12.4.5.1 The cover of the reinforcement shall be about twice the diameter of the mesh wire or thickness of other reinforcement used. A smaller cover is acceptable provided the reinforcement is not susceptible to rapid corrosion, the surface is protected by an appropriate coating, and the crack width is limited to 0.05 mm. For ferrocement elements of thickness less than 25 mm, a cover of the order of 2 mm shall be provided.

12.4.5.2 For a given ferrocement cross-section of total thickness h , the mesh opening shall not be larger than h .

12.4.5.3 For nonprestressed water retaining structures the total volume fraction of reinforcement shall not be less than 3.5 per cent and the total specific surface of reinforcement shall not be less than $0.16 \text{ mm}^2/\text{mm}^3$.

12.4.5.4 In computing the specific surface of the reinforcement, the contribution of fibres added to the matrix shall be considered, while the fibre contribution may be ignored in computing the volume fraction of reinforcement.

12.4.5.5 If skeletal reinforcement is used, the skeletal reinforcement shall not occupy more than 50 per cent of the thickness of the ferrocement composite.

12.4.5.6 For a given volume fraction of reinforcement, better performance in terms of crack widths, water tightness, and ductility may be achieved by uniform distribution of the reinforcement throughout the thickness and by increasing its specific surface. A minimum of two layers of mesh shall be acceptable, but more than two layers of reinforcement are preferable.

12.4.6 Design Aids

The following nondimensional equation can be used to predict the nominal moment strength of ferrocement beams subjected to pure bending:

$$\frac{M_n}{f'_c b h^2 \eta} = 0.005 + 0.422 \left(V_f f_y / f'_c \right) - 0.0772 \left(V_f f_y / f'_c \right)^2 \quad (12.4.5)$$

A design graph representing Eq (12.4.5) is given in Fig 12.4.2.

12.5 FABRICATION**12.5.1 General Requirements**

This section specifies the requirements for the mixing, placing, and handling of materials used in ferrocement construction.

12.5.1.1 Planning:

Plastering for fabrication with ferrocement shall be continuous through the completion of the job. This requires a large number of workers involved in plastering and in maintaining a constant supply of materials during work,

most often in confined work spaces. Adequate bond at cold joints may be achieved through surface roughness or treatment with bonding agents. Retarders may be useful in large time consuming plastering projects, especially in hot weather conditions. Planning for the job shall take into account all these requirements.

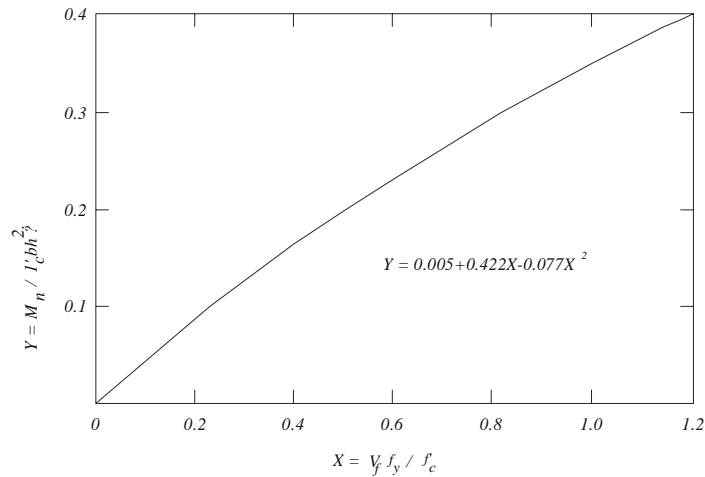


Fig. 12.4.2 Chart for Strength Design of Ferrocement in Bending

12.5.1.2 Mixing:

Any method, including hand mixing, which assures a homogeneous mixture of ingredients shall be satisfactory. Mixing may be accomplished in a mortar mixer with a spiral blade or paddles inside a stationary drum or in a pan type mixer. The use of rotating drum mixers with fins affixed to the sides shall not be permitted. Mix ingredients shall be carefully batched by weight, including the water, and added or charged in the mixer so that there is no caking. Mix water shall be accurately weighed so that the water cement ratio is controlled. The water cement ratio shall be as low as possible but the sand cement ratio shall be adjusted to provide a fluid mix for initial penetration of the armature followed by a stiffer more heavily sanded mix at the finish. Mortar shall be mixed in batches so that mortar is plastered within an hour after mixing. Retempering of the mortar shall be prohibited.

12.5.1.3 Mortar Placement:

Mortar shall generally be placed by hand plastering. In this process, the mortar is forced through the mesh. Alternatively, the mortar may be shot through a spray gun device.

12.5.1.4 Finishing:

Surfaces shall be finished to assure proper cover to the last mesh layer. The surface finish shall be slightly roughened if a surface coating is to be bonded later.

Surfaces that are too smooth shall be mechanically abraded by sandblasting or other means of mechanical abrasion. Alternatively, such surfaces may be etched with phosphoric acid, provided the residue left by it will not interfere with specified finishes. Mild solutions of muriatic acid may be applied with proper attention to corrosion potential. Additional care shall be taken when plastering around openings.

12.5.1.5 Curing:

Moist or wet curing is essential for ferrocement concrete construction. The low water cement ratio and high cement factors create a demand for large quantities of free water in the hydration process, and the amount permitted to evaporate into the air shall be kept to an absolute minimum. The use of fogging devices under a moisture retaining enclosure is desirable. A double layer of soaked burlap covered with polyethylene or a soaker hose may also be used. Continuous wetting of the surface or of wet burlap or the like shall be maintained to avoid dry spots. Curing shall start within a reasonable time after application of the finishing layer.

12.5.2 Construction Methods

All methods shall have high level quality control criteria to achieve the complete encapsulation of several layers of reinforcing mesh by a well compacted mortar or concrete matrix with a minimum of entrapped air. The most

appropriate fabrication technique shall be decided on the basis of the nature of the particular ferrocement application, the availability of mixing, handling, and placing machinery, and the skill and cost of available labour. Several recommended construction methods are outlined in the following subsections.

12.5.2.1 Armature System :

The armature system is a framework of tied reinforcing bars (skeletal steel) to which layers of reinforcing mesh are attached on each side. Mortar is then applied from one side and forced through the mesh layers towards the other side, as shown in Fig 12.5.1.

The skeletal steel can assume any shape. Diameter of the steel bars depends on the size of the structure. Skeletal steel shall be cut to specified lengths, bent to the proper profile, and tied in proper sequence. Sufficient embedment lengths shall be provided to ensure continuity. For bar sizes 6 mm or less, lap lengths from 230 to 300 mm may be sufficient. The required number of layers of mesh shall be tied to each side of the skeletal steel frame.

12.5.2.2 Closed-mould System :

The mortar is applied from one side through several layers of mesh or mesh and rod combinations that have been stapled or otherwise held in position against the surface of a closed mould, i.e. a male mould or a female mould. The mould may remain as a permanent part of the finished ferrocement structure. If removed, treatment with release agents may be needed. The use of the closed mould system represented in Fig 12.5.2 tends to eliminate the use of rods or bars, thus permitting an essentially all mesh reinforcement. It requires that plastering be done from one side only.

12.5.2.3 Integral-mould System:

An integral mould is first constructed by application of mortar from one or two sides onto a semi-rigid framework made with a minimum number of mesh layers. This forms, after mortar setting, a rigid but low quality ferrocement mould onto which further layer of reinforcing mesh and mortar shall be applied on both sides. Alternatively, the integral mould may be formed using rigid insulation materials, such as polystyrene or polyurethane, as the core. A schematic description of this system is given in Fig 12.5.3.

12.5.2.4 Open-mould System:

In the open-mould system, mortar is applied from one side through layers of mesh or mesh and rods attached to an open mould made of a lattice of wood strips. The form, shown in Fig 12.5.4, is coated with a release agent or entirely covered with polyethylene sheeting (thereby forming a closed but nonrigid and transparent mould) to facilitate mould removal and to permit observation and/or repair during the mortar application process.

This system is similar to the closed-mould system in which the mortar is applied from one side, at least until the mould can be removed. It enables at least part of the underside of the mould to be viewed and repaired, where necessary, to ensure complete and thorough impregnation of the mesh.

12.6 MAINTENANCE

12.6.1 General

Terrestrial structures are susceptible to deterioration from pollutants in ground water and those that precipitate from the air (acid rain). Environmental temperature and humidity variations also affect ferrocement durability and maintenance procedures.

Maintenance shall involve detecting and filling voids, replacing spalled cover, providing protective coatings, and cosmetic treatment of surface blemishes. Due to the thin cover in ferrocement, muriatic acid (hydrochloric acid) shall be used with extreme caution. Phosphoric acid and other nonchloride cleaners shall be the specified alternative (see Sec 12.5.1.4).

Repairs not involving large quantities of materials shall be accomplished by hand. Emphasis shall be placed on the ability of the repair material to penetrate the mesh cage, to fully coat the reinforcing to inhibit corrosion, and to bond to the substrate. Rapid set and strength gain shall be the overriding considerations for emergency repairs. Protective coatings shall bond well and be alkali tolerant, thermally compatible, and resistant to environmental pollutants and ultraviolet radiation, if exposed.

12.6.2 Blemish and Stain Removal

12.6.2.1 General:

Since ferrocement is usually less porous than conventional concrete, stains do not penetrate very deep in the mortar matrix. Care shall be taken when preparing the surface not to diminish the thin cover of mortar over ferrocement reinforcement.

12.6.2.2 Construction Blemishes:

Construction blemishes are often caused by improper selection or use of materials, faulty workmanship, uneven evaporation, and uneven curing. Care shall be exercised to minimize these and the following causes of blemishes in ferrocement.

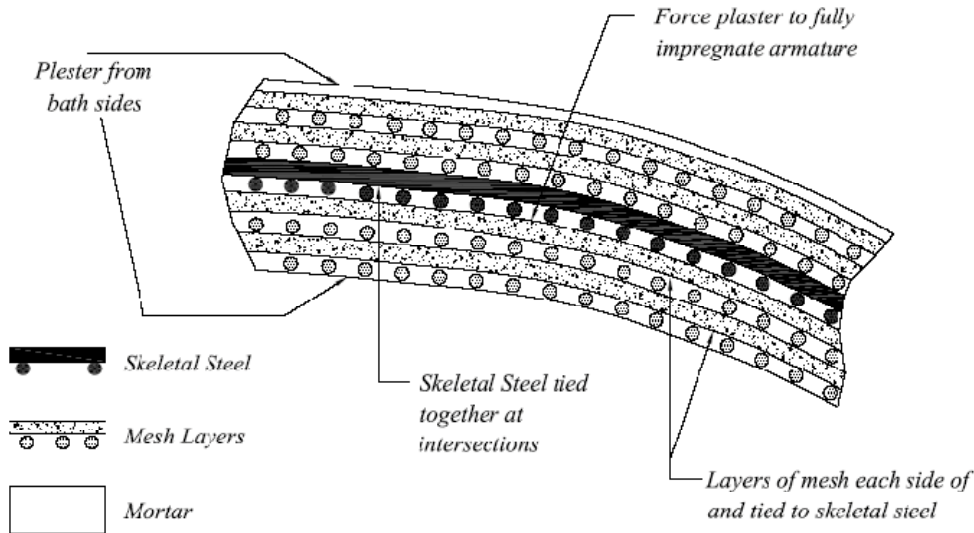


Fig. 12.5.1 Armature System

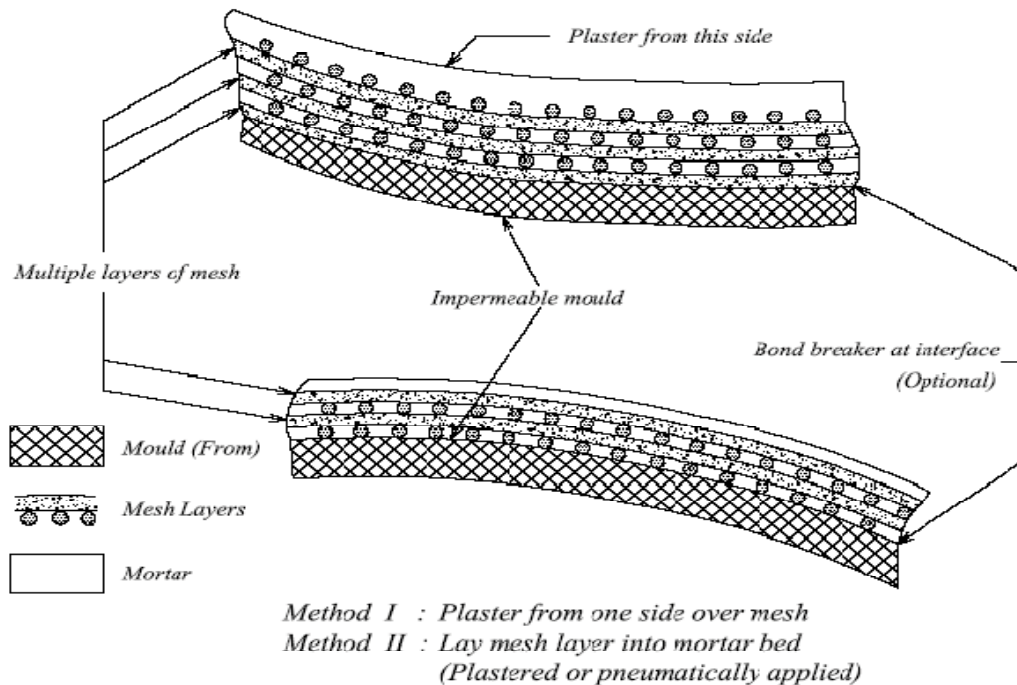


Fig. 12.5.2 Closed-mould System

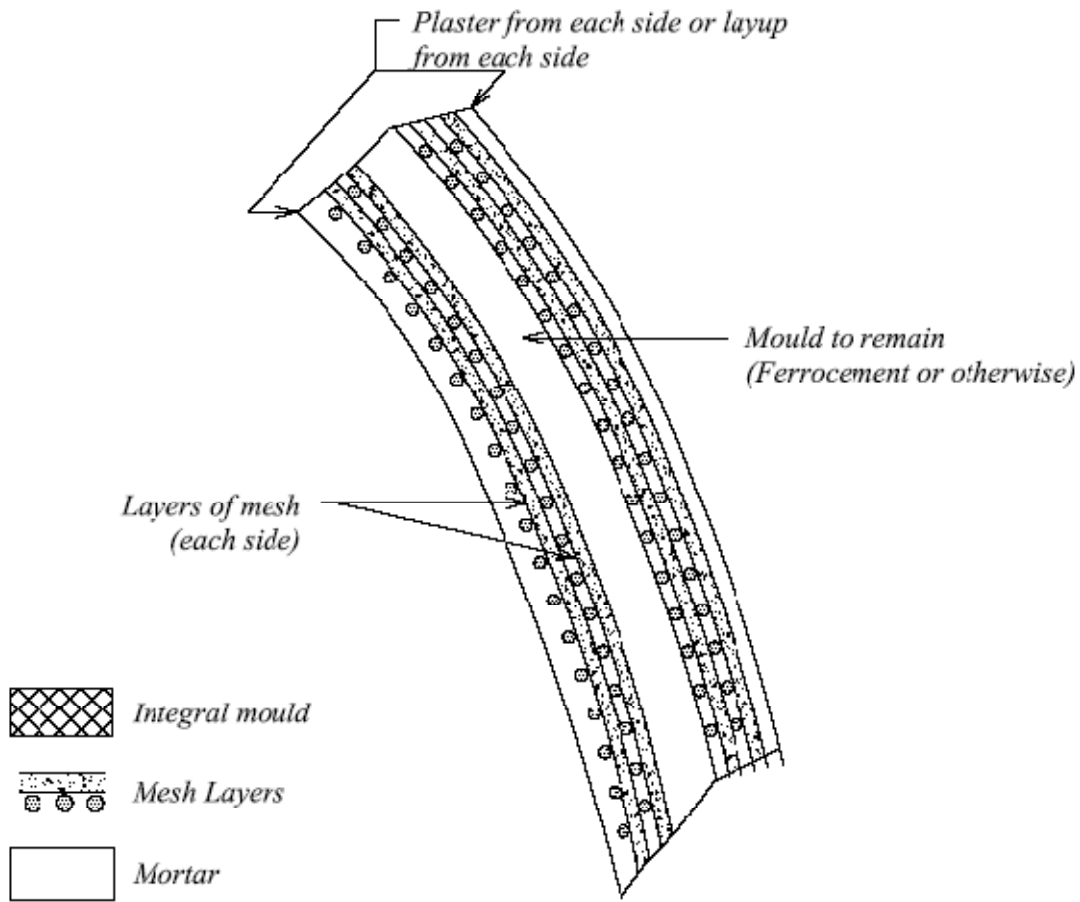


Fig. 12.5.3 Integral-mould System

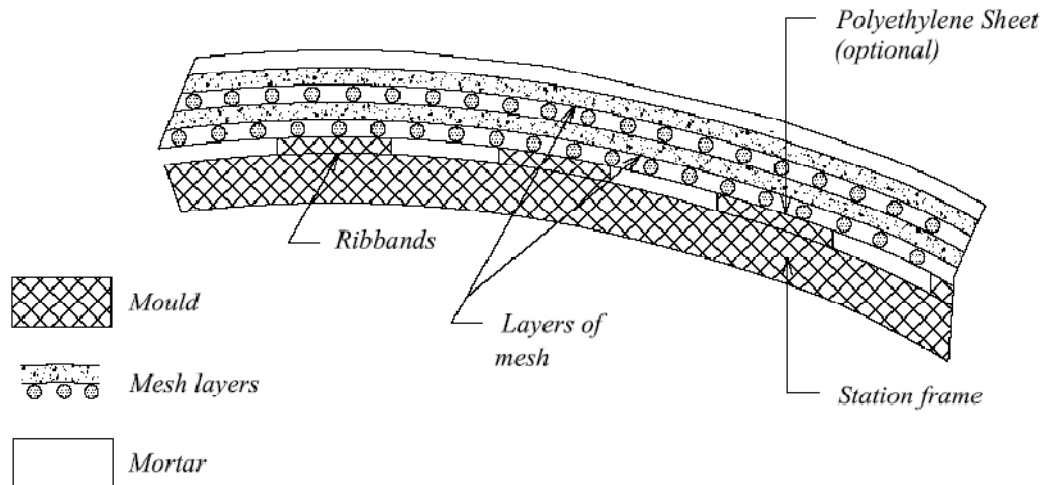


Fig. 12.5.4 Open-mould System

- a) Cement from different mills will cause colour variation, although most of the colour in mortar is due to the sand component. Where appearance is critical, care shall be taken to obtain sand from a single source and have it thoroughly washed.
- b) Mottling results from the use of calcium chloride or high alkali cement combined with uneven curing.
- c) The use of polyethylene sheet material to cover surfaces promotes uneven curing.

- d) The water cement ratio affects tone and surface appearance. Low water cement ratio will result in a darker appearance.
- e) Hard steel toweling densifies the surface, causing more rapid drying and also leaving a darkened surface.

12.6.2.3 Stain Removal:

Treatment of stains shall be done promptly after discoloration appears. Thorough flushing and brushing with a stiff bristle brush and detergent is the first approach. If this is ineffective, a dilute (about three per cent) solution of phosphoric or acetic acid shall be applied. Another chemical treatment that may be considered safe and effective is a 20 to 30 per cent solution of di-ammonium citrate, a mild acid that attacks calcium carbonates and calcium hydroxides. This treatment makes the surface more porous and promotes hydration.

When a stain has penetrated too deeply to be removed by surface chemical application and scrubbing, a poultice or a bandage may be needed. A poultice is intended to dissolve the stain and absorb it into the poultice. The poultice is made by mixing one or more chemicals such as a solution of phosphoric acid with a fine inert powder such as talc, whiting, hydrated lime, or diatomaceous earth to form a paste. The paste is spread in a thick layer over the stain and allowed to dry. A bandage may consist of a few layers of cloth or paper toweling soaked in a chemical solution. More than one application of a poultice or bandage may be needed for stubborn stains.

Caution:

Most of the chemicals used to remove stains are toxic and require safeguards against skin contact and inhalation. Whenever acids are used, surfaces shall first be saturated with water or the dissolved stain material may migrate deeper into the concrete and reappear at a later date as efflorescence.

12.6.2.4 Efflorescence:

Efflorescence is caused by deposition of salts on the surface due to the evaporation of migrating water bearing salts from within ferrocement; it is typically associated with a porous ferrocement. Water cement ratio shall be limited to within 0.4 and the mortar well compacted to minimize efflorescence. Voids, if present, may be treated by breaking into with a hammer and replastering. Alternatively, voids may be drilled into with a masonry bit and repaired by injecting a non shrinking cement grout.

12.6.3 Protective Surface Treatments

12.6.3.1 General:

Good quality mortar has excellent resistance to weathering. The application of protective surface treatments can improve the performance of ferrocement and extend its useful service life. Surface treatments shall be used to improve appearance, harden the surface, and reduce permeability, thus guarding against the corrosive action of acids, alkaline salts, and organic substances.

12.6.3.2 Hardeners:

Hardeners may be used to protect the ferrocement surface or to seal and prepare it for application of paints. When a sodium silicate hardener is used, it shall be diluted with water. The actual proportion of water to be used shall depend on the manufacturer's recommendation. The hardener shall be applied in multiple coats with the first coat being more dilute than the subsequent ones. Each coat must be completely dry before the next coat is applied.

Other hardeners that seal and prepare the surface for application of oil base paints are magnesium fluorosilicate and zinc fluorosilicate. The treatment shall consist of two or more applications. A solution containing about 1 kg of fluorosilicate crystals per 10 litres of water shall be used for the first application; and a solution containing 2.4 kg per 10 litres of water shall be used for subsequent applications. After the last application has dried, the surface shall be brushed and washed with water to remove any crystals that may have formed.

12.6.3.3 Coatings :

When resistance to abrasion is desired, ferrocement surfaces may be coated with polyurethanes, especially those furnished in two part mixtures. Coatings formulated from acrylics may be used to provide resistance to sunlight and weathering. Water based acrylic latex house paints may be used for application to damp surfaces.

For any surface opposite a surface sealed with an impermeable coating, an acrylic coating formulated to allow the escape of water vapour shall be specified.

12.7 DAMAGE REPAIR

12.7.1 Common Types of Damage

Ferrocement structures shall be inspected, as part of a regular maintenance programme, to detect any of the following types of damage. Appropriate repair measures shall then be taken.

12.7.1.1 Delaminations :

Delaminations occur when ferrocement splits between layers in laminated constructions due to springing back or bridging of the mesh during construction. Delamination sometimes occurs at or near the neutral axis under impact or flexure when there are many voids in the interior layers. Such areas give off a hollow sound when tapped with a hammer or stroked with a steel bar.

12.7.1.2 Spalls:

A spall is defined as a depression resulting when a fragment is detached from a larger mass by a blow, by the action of weather, by pressure, or by expansion within the mass. Spalls shall be considered large when their size exceeds approximately 20 mm in depth or 150 mm in any dimension, and shall be repaired by replastering.

Spalls are usually caused by corrosion of steel, which causes an expansive pressure within the ferrocement. Chlorides in the concrete greatly increase the potential for corrosion of the steel. Under such conditions, continued spalling is likely and the repair of local spall areas may even promote the deterioration of the concrete because of the presence of dissimilar materials.

An area of steel corrosion and chloride contaminated concrete may be considerably larger than the area of spalled concrete, and the full area of contamination rather than the spall itself shall be broken and replastered.

12.7.1.3 Fire Damage:

Ferrocement may be more susceptible to fire damage than conventional concrete because of the thin cover.

If the fire were intense enough to release the amount of chemically bound water in the cement, destroy the bond between the cement and the aggregate, or oxidize the reinforcement, the surface would be charred and spalled so that the damage could be easily identified. Full scale removal and repair shall then be required.

12.7.1.4 Cracks and Local Fractures:

Hairline cracks and crazing due to temperature changes or drying shrinkage in the cover coat do not require repair. Continuous wet curing will cause autogenous healing, and a flexible coating will conceal the crack from view. If cracks are caused by continuing overloads or are due to structural settlement and the cause cannot be removed, replacement or a structural overlay shall be required. Cracks due to occasional impact or overload may be repaired. Local fractures are cracks in which displacement of the section has occurred as a result of impact.

12.7.2 Evaluation of Damage

12.7.2.1 Evaluation of damage shall take into consideration its extent, cause, and likelihood of the cause still being active. The method of repair shall be dictated by the type of damage, the availability of special equipment and repair materials, and the level of skill of the workers employed. Economic factors may influence the decision as to whether the repair shall be extensive and permanent, or limited in scope in response to an immediate problem.

12.7.2.2 Repair materials shall bond to the original structure, resist pollutants in the surrounding soil, water or air, and respond the same way to changes in temperature, moisture, and loads. Removal of deteriorated or chloride contaminated mortar trapped within the reinforcing mesh requires a large amount of hand labour, so it may be economical (and better for long term durability) to reconstruct or

replace an entire area using the original structure as a form that can be left in place or removed after the overlaid structure has cured. Complete reconstruction shall be undertaken when chloride contamination, mesh corrosion, and deterioration of the mortar are extensive.

12.7.2.3 Testing for damage in ferrocement may be done by tapping with a hammer to break into any voids under the surface, or by drawing a metal bar over the surface and listening for sounds indicating voids or the presence of deteriorated concrete. A high quality ferrocement should produce a bell like sound and resist moderately severe hammer blows without damage.

12.7.3 Surface Preparation for Repair of Damage

12.7.3.1 General :

The primary objective is to remove any deteriorated mortar or mortar contaminated with corrosive agents and to provide a surface to which the repair materials can be bonded properly. The rougher the surface, the greater is the area available for bonding.

12.7.3.2 Removal of Deteriorated Concrete:

As a first step in any repair all disintegrated, unsound, and contaminated mortar shall be removed. Saws and chipping hammers used for conventional concrete shall not be used for ferrocement unless large sections are to be completely removed.

Small areas shall be prepared by hand hammering just hard enough to pulverize deteriorated or cracked mortar, but not to the point of damaging the reinforcing mesh.

A pneumatic needle gun may be used for cleaning out broken ferrocement, opening out cracks, and roughening the surface.

Particles of sound mortar embedded in the mesh need not be removed provided they are small enough not to interfere with the penetration of new mortar and they will not project from the finished surface.

12.7.3.3 Reinforcement:

Any loose, scaly corrosion revealed on cleaning out the mortar shall be removed by sandblasting, water jet, air blasting, or vacuum methods.

An alternative method for removing rust is to brush naval jelly or spray dilute phosphoric acid over the repair area and flush thoroughly.

Where the mesh cage has been displaced but is still intact, it may be pushed or jacked back in place and supported securely to withstand the pressure of applying the repair material. Where the reinforcement has been torn, the old mesh shall be laced back to close the opening.

When rods supporting the mesh cage are torn they shall be spliced by a 15 diameter overlap of the partner rod or anchored by hooks.

12.7.3.4 Cleaning:

Loose particles and dust residue from hammering or sandblasting shall be air jetted or vacuum cleaned if epoxy or methymethacrylate (MMA) is the repair material. Water jetting may be used if the repair is to be made with hydraulic cement or latex modified mortar.

If an air jet is used, the compressor shall be equipped with an oil trap to prevent contamination of the surface. Surface oil or dirt shall be removed by trisodium phosphate or other strong detergents.

12.7.3.5 Cracks:

Cracks may be cleaned by hammering out the mortar on each side of the crack and replastered with latex mortar.

If opening the crack is not feasible, epoxy or MMA injection systems shall be attempted in accordance with the product directions. The crack shall be cleaned first with oil free compressed air, and small (about 2 to 3 mm) drill holes shall be made at the highest and lowest points in the crack. The surface between the holes shall be sealed with strong coatings or a pressure pad. Catalyzed epoxy or MMA shall be injected at the lower hole until it comes out at the upper hole.

Where latex cement grout is to be used, the interior of the crack shall be thoroughly saturated with water and allowed to drain.

12.7.4 Repair Materials

12.7.4.1 Portland Cement and Sand:

Portland cement used for repair shall conform to the requirements of Sec 12.3.1.

Sand which matches that used in the original construction may be used unless the need for the repair arose because of reactive or contaminated sand. Neat Portland or blended cement paste shall be used to fill small cracks, and a mortar with fine sand shall be used to fill larger cracks or voids. Both shall be used in combination with latex for thin patches and overlays. Larger cracks shall be coated with neat cement slurry, and then dry packed with a very low water cement ratio mortar.

The addition of latex to Portland cement mortar markedly improves bond to the substrate and the tensile strength of the patch. Of the synthetic latexes, polyvinyl acetate and polyvinylidene are unsuitable for wet environments. Acrylics may be used as admixtures to improve bonding and as curing compounds. Acrylic latex in concentrated form shall be diluted to 10 to 20 per cent solids and then used as the mixing water for the mortar. Latex mortars may be applied to a damp surface, but the patch shall be allowed to dry thoroughly before being immersed in water.

12.7.4.2 Polymer Mortars:

Nonlatex polymer mortars shall require the use of surface dried and, preferably, oven dried sand. The monomers have very low viscosity and so shall be mixed with thickening agents to be placed in any area that cannot be sealed tightly. Epoxy resins that are moisture tolerant may be used on damp surfaces.

Care shall be exercised in applying polymers or the promoters and hardeners used with them which are toxic.

12.7.4.3 Admixture:

Accelerators may be employed where cement alone is the repair material. Since chloride compounds may promote corrosion, nonchloride accelerators shall be preferred for all ferrocement. Emergency repairs of small areas below the waterline with hot plug, which is neat cement moistened to a putty consistency with a concentrated solution of calcium chloride may be permitted. The hot plug may be carried in the hand or in a plastic bag to the site of the leak, pressed into the hole, and held a few minutes until set. Permanent repair shall be accomplished as soon as possible using materials without chlorides.

12.7.5 Repair Procedure

12.7.5.1 Mixing :

Small quantities of materials required for ferrocement repairs may be hand mixed on flat surface or in a tray using premixed dry ingredients. For large quantities, a plaster or pan mixer rather than a rotating drum type mixer shall be used. For machine mixing water shall be put in first; then the cement, to form slurry; then the pozzolan, if used; and finally, enough sand to bring the mortar to the desired degree of workability.

The consistency of the mortar shall be selected according to the nature of the repair. A slurry of cream consistency shall be used first to paint the moistened edges of the repair area, fill cracks or small voids, and thoroughly coat all the interior mesh and rods. After this, more sand shall be added until the mortar is stiff enough to hold its shape when brought out flush with the finished surface.

To avoid excessive amounts of entrained air, mortars containing acrylics or epoxies shall not be mixed longer than two minutes. They shall be applied within thirty minutes of mixing.

12.7.5.2 Full Depth Repair:

When both faces are accessible, a fluid mortar shall be pushed through the mesh cage from one side until an excess appears on the opposite face. This excess shall then be pushed back and finished flush. A vibrating float or trowel may be used to place and finish a very stiff mortar. Pencil type vibrators shall not be used.

12.7.5.3 Partial Depth Patches:

The area to be patched shall first be saturated with water, then air blown or blotted free of standing water until only surface-moist. Cement slurry of not more than 0.4 water cement ratio and of paint like consistency shall be brushed over the whole area and into any openings in the mesh. This shall be immediately followed by a heavily sanded mortar of the same water cement ratio, which shall be vibrated or tamped into the patch and finished flush.

12.7.5.4 **Overlays:**

The substrate shall be prepared in the manner prescribed in Sec 12.7.5.3 for patches. The old surface shall be thoroughly cleaned or scarified by mechanical means and the repair materials shall match the thermal characteristics of the substrate.

Chemical etching shall be followed by mechanical abrasion, unless the surface is flushed with high pressure water jet equipment.

For thin overlays, velocity placement such as spritzing or casting by hand, and shotcreting, shall be used.

12.7.5.5 **Shotcrete:**

Shotcrete may be used in ferrocement repair when a large area is involved. Small, low cost portable plaster pumps operating on the Moyno progressive cavity principle with a rotor inside a stator tube shall be adequate for both original ferrocement construction and repair.

Shotcrete or plastering equipment may be used for large overlays incorporating additional layers of reinforcing mesh by laminating techniques. Existing surfaces shall be scarified or sandblasted, then saturated with water and allowed to damp dry just before the shotcrete or mortar spray is applied. An initial application of cement slurry is not needed with shotcrete but a latex or wet to dry epoxy bonding compound may be used to advantage with repairs made with plastering equipment.

12.7.5.6 **Curing :**

All Portland cement patches and overlays shall be thoroughly cured unless latex compounds are used to seal the surface and furnish water for hydration. Curing shall be instituted immediately for thin patches and overlays. Several layers of paper or cloth soaked in water and covered with a plastic sheet that is well secured at the edges may be used on patches. A full plastic film covering overlays may be used but it may produce discoloration where it touches the surface.

12.8 **TESTING**

12.8.1 **Test Requirement**

Tests and observations that are commonly made during the design, construction, and subsequent service life of concrete structures shall also be applicable to ferrocement structures. The test programme shall include

- a) tests on physical, chemical and mechanical properties of the ferrocement ingredients, such as water purity, sieve analysis, mesh strength etc.,
- b) control tests for fresh mortar mix, such as slump, air content etc.,
- c) tests on the mechanical properties of the hardened ferrocement, such as bending, cracking and fatigue strengths, permeability etc., and
- d) in-service condition tests, such as potential for corrosion, cracking, durability etc.

For predicting the mechanical properties of ferrocement, the tests specified in Sec 12.8.2.1 through 12.8.2.4 shall be conducted.

12.8.2 **Test Methods**

12.8.2.1 **Compressive Strength and Static Modulus of Elasticity of Mortar :**

The compressive strength and static modulus of elasticity of the mortar used for the fabrication of ferrocement shall be determined from 75 mm x 150 mm cylinders tested in accordance with ASTM C39-86 and C469-83, respectively.

12.8.2.2 **Flexural Strength of Ferrocement:**

Ferrocement specimens shall be tested as a simply supported beam with third point loading. The span to depth ratio of the beam specimen shall not be less than 20 and its width shall not be less than six times the mesh opening or wire spacing measured at right angles to the span direction.

12.8.2.3 Tensile Properties of the Mesh Reinforcement:

Square or rectangular meshes may be tested directly in tension; hexagonal meshes and expanded metal meshes shall be tested only while encapsulated in mortar. In the latter case the tensile test shall be performed on the ferrocement material as described in Sec 12.8.2.4 below.

For square and rectangular meshes, the yield strength, elastic modulus, and ultimate tensile strength shall be obtained from direct tensile tests on samples of wires or flat coupons cut from the mesh. The test shall be in accordance with the following guidelines (see also Fig 12.8.1).

1. The test specimen shall be prepared by embedding both ends of a rectangular coupon of mesh in mortar over a length at least equal to the width of the sample. The mortar embedded ends shall serve as pads for gripping. The free (not embedded) portion of the mesh shall represent the test sample.
2. The width of the test sample shall be not less than six times the mesh opening or wire spacing measured at right angles to the loading direction.
3. The length of the test sample shall be not less than three times its width or 150 mm, whichever is larger.
4. Measurements of elongations (from which strains are to be computed) shall be recorded over half the length of the mesh sample.
5. Yield strain of mesh reinforcement shall be taken as the strain at the intersection of the best straight line fit of the initial portion of the stress strain curve and the best straight line fit of the yielded portion of the stress strain curve, as shown in Fig 12.8.1. The yield stress shall be taken as the stress point on the original stress strain curve at the yield strain found above. The procedure is demonstrated in Fig 12.8.1.

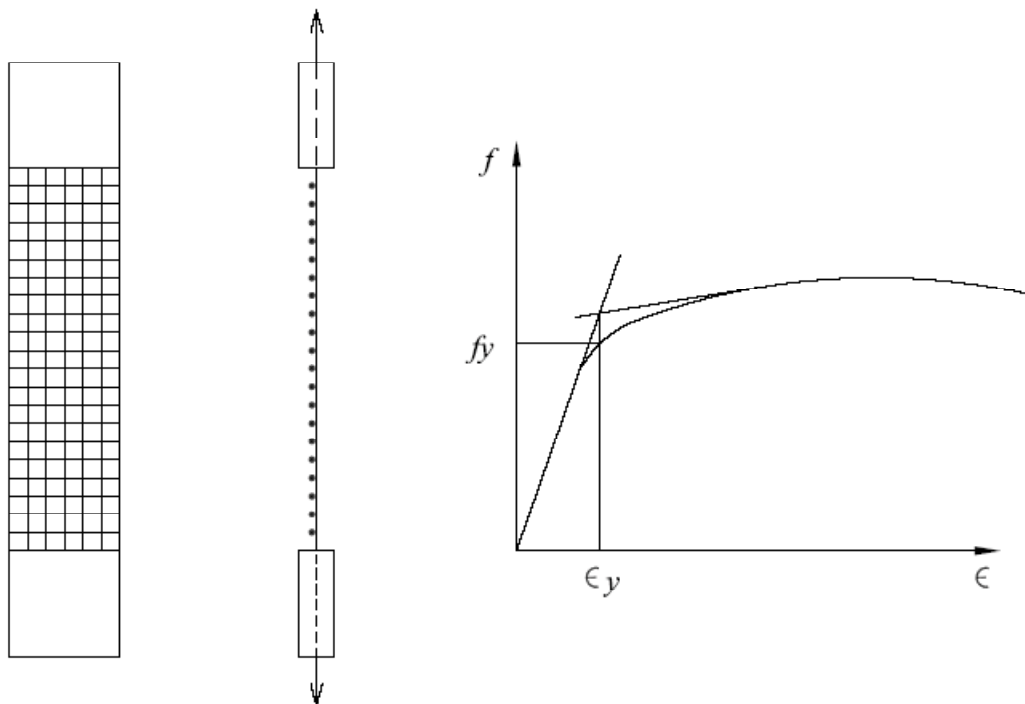


Fig. 12.8.1 Schematic Description of Mesh Tensile Test Sample and Corresponding Stress-Strain Curve

12.8.2.4 Tensile Test of Ferrocement:

Direct tensile tests of ferrocement elements shall be made using rectangular specimens satisfying the same minimum size requirement as those set in Sec 12.8.2.3 for the mesh reinforcement. The test specimens shall be additionally reinforced at their ends for gripping. The middle half of the nongripped (free) portion of the test specimen shall be instrumented to record elongations. A plot of the load elongation curve up to failure shall be

used to estimate the effective modulus of the mesh system as well as its yield strength, ultimate strength, and efficiency factor. The yield strain and corresponding stress shall be determined in accordance with the procedure described in Sec 12.8.2.3.

Related Appendices

Appendix 6.12.A Calculation of Volume Fraction of Reinforcement

Appendix 6.12.B Common Types and Sizes of Steel Meshes Used in Ferrocement