AN INVESTIGATION ON THE PROPERTIES OF FERROCEMENT CONTAINING DIFFERENT LAYERS OF WIRE MESH

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ABSTRACT

Ferrocement, a thin wall cement mortar reinforced with wire mesh and now considered to be a very innovative construction material, was known to be used over hundred years ago. Ferrocement is the most effective route to impart outstanding crack control to the concrete matrix and through this crack control, develop excellent mechanical properties, energy absorption characteristics, toughness and impact resistance. The principle of ferrocement is to understand it mechanism whereby the reinforcement and matrix interact to distribute strains, improve first crack strength and control the size and spacing of cracks. Numerous theoretical and experimental studies have been undertaken all over the world in recent years to investigate the properties of ferrocement and explore its potential field of applications. It is obviously unrealistic to talk about ferrocement replacing reinforced concrete for all the purposes, but it is undeniable that there are many situations where the use of the ferrocement concept can be more cost effective in terms of construction costs and its service life span. It is now clear that ferrocement, a versatile construction material, has a bright prospect and will definitely find better utilization in the future.

ABSTRAK

Ferrocement merupakan sejenis komposit campuran simen mortar dengan lapisan jejaring wayar yang dianggap sebagai bahan pembinaan yang inovatif pada masa kini dan ia telah diperkenalkan sejak ratusan tahun dahulu. Ferrocement adalah cara yang paling berkesan untuk mengawal retakan, melalui kawalan retakan, ia akan membina sifat mekanik yang lebih baik dari segi sifat kebolehresapan tenaga, kekukuhan dan ketahanlasakan terhadap impak. Prinsip bagi ferrocement ialah untuk memahami sifat mekanikal dimana hubungan jejaring wayar dan mortar adalah untuk mengagihkan daya terikan, memperbaiki kekuatan retakan pertama dan mengawal saiz dan jarak retakan. Banyak teori dan experimen telah dijalankan di seluruh dunia untuk menyiasat sifat-sifat ferrocement dan mengembangkan potensinya dalam pelbagai bidang pengunaannya. Adalah tidak realistik jika mengatakan bahawa ferrocement berupaya menggantikan konkrit bertetulang dalam semua penggunaannya, namun tidak boleh dinafikan bahawa penggunaan ferrocement adalah lebih kos efektif dari segi kos pembinaan dan kos jangka hayat perkhidmatan. Ferrocement merupakan bahan pembinaan yang mempunyai pelbagai fungsi, masa depan yang cerah dan kebolehgunaan yang lebih baik pada masa akan datang.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Ferrocement is defined as a composite made with mortar and a fine diameter continuous mesh as reinforcement. The continuous mesh has higher bond due to its smaller size and larger surface area per unit volume of mortar. Ferrocement has gained widespread use and acceptance, particular in developing countries such as for housing, sanitation, water resources, water transportation, repair and strengthening of older structures and others.

Ferrocement has relatively better mechanical properties and durability than ordinary reinforced concrete. Within a certain limits, it behaves as a homogenous elastic material and these limits are wider than normal concrete. The uniform distribution and high surface area to volume ratio of its reinforced results in better crack arrest mechanism.

Certain characteristics of ferrocement as a composite are

a. Since the wire mesh is much stronger in tension compared to mortar, the role of the mortar is to hold properly the mesh in place, to give a proper protection and to transfer stresses by means of adequate bond.
b. Compressive strength of this composite is generally a function of mortar compressive strength, while the tensile strength is a function of mesh content and its property.

c. Stress-strain relationship of ferrocement in tension may show either complete elastic behavior (up to fracture of reinforcement mesh) or some inelasticity depending upon the yielding properties of the mesh.

d. Since the properties of this composite are very much a function of orientation of the reinforcement, the material is generally anisotropic and may be treated as such in theoretical analysis.

1.2 OBJECTIVE

Ferrocement behaves differently compared to conventional concrete in some mechanical properties. The main objective of this research is to analyze the effect of the wire mesh layers on ferrocement properties. The main properties of ferrocement that need to be investigated are cracking behaviors, compressive strength and ultimate load. This study on the engineering properties and practical applications of ferrocement are important to develop standards for ferrocement construction.

1.3 SCOPE OF ANALYSIS

Two types of tests will be carried out to determine the behaviors of the material (mortar) and the structure (ferrocement). Four main properties of ferrocement behaviors have been analyzed for this experiment which are:

- First Initial Cracking Load, F_{cr}
- Ultimate Load, F_u
- Crack patterns
- Cracks width

Tests on materials need to be conducted to ensure the materials used are in well conditions. The tests on materials are

- Slump test
- Water absorption test
- Compression test

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Ferrocement is the first invention of reinforced concrete, the most popular construction material in the world. It is a thin composite made with a cement based mortar reinforced with spaced layers of wire mesh. The mesh may be made of metallic or fiber reinforced polymeric materials. This material which is special form of reinforced concrete, exhibits a behavior so different from conventional reinforced concrete in performance, strength and potential application that it must be classed as a separate material. Applications of ferrocement include marine and terrestrial structures such as boats, fishing vessels, water tanks, silos, and prefabricated housing structures.

Properties of resulting ferrocement product can be expected to be affected by filament size or gage, strength, ductility, manufacture and treatment in varying degrees. There is a wide variety of mesh dimensions as well as the amounts, sizes and properties of material used. Some mesh are galvanically coated or impregnated with sizing before or during assembly of the mesh. The concrete mortar consists of ordinary Portland cement, water and finely grained aggregate (natural sand). Portland cement as the binder material in ferrocement yields a composite in which the binder is considered to have some tensile strength. This results from a composite behavior between the mortar and the reinforcement (*Paul and Pama, 1978).*

2.2 MATERIALS USED IN FERROCEMENT CONSTRUCTION

1.1 2.2.1 WIRE MESH

The ideal mesh is a 13 x 13 mm x 19 gauges (1 mm) welded mesh in BS 4482. Although meshes of 18-22 gauges can be used, 19 gauges will prove to be the best from a practical point of view. In colder and less humid climates, it may be used ungalvanised. In semi-tropical or tropical, it will need to be galvanized.

A specification for welded mesh: Initially rod used in the manufacture of welded wire mesh is a low carbon content (0.15% max by weight) rimming steel with the carbon concentrated in the centre. The rod used in the manufacture of the wire mesh is hard-drawn from 'X' size down to 19 gauges (1 mm), hot rolled (perhaps copper washed) and then welded. It then passed through the galvanizing process (*Paul and Pama, 1978).*

Reinforcement of ferrocement is restricted to layers of continuous mesh formed by welding, twisting or weaving. Specific mesh types are stated as below:

i) Woven or interlocking mesh which filaments are interwoven and their intersections are not rigidly connected.
ii) Welded mesh in which a rectangular pattern formed by perpendicular intersecting filament elements are welded or cemented together at their intersections. Woven patterns include diagonal elements woven through the rectangular mesh pattern.
iii) The most commonly used is hexagonal wire mesh because it is cheaper and easier to handle. This mesh is commonly known as chicken wire mesh and is fabricated from cold drawn wire which is generally woven into hexagonal pattern. The wire

mesh could be woven at site from coil straight wire, allowing the user greater opportunity to choose the mesh size and wire diameter appropriate to any given job.

iv) Expended metal mesh is formed by cutting a thin sheet expanded metal to produce diamond shape openings. The manufacturing process is less labor intensive than the method used for manufacturing hexagonal wire mesh or welded mesh. It is widely known that weight, expanded metal is not as strong as the woven mesh, but on a cost to strength ratio, expanded metal has the advantage.

Classification societies may need evidence of how the alternate meshes are used, in what direction they lay, and the combination of meshes that can or may be used (*Paul & Pama, 1978*).

2.2.2 CEMENT

In the general sense, cement is any material with adhesive properties. The term of cement is also commonly used to refer more specifically to powdered materials which develop strong adhesive qualities when combined with water. These materials are more properly known as hydraulic cements. Gypsum plaster, common lime, hydraulic limes, natural pozzolana and Portland cements are the more common hydraulic cements, with Portland cement being the most widely used in construction.

The cement to use is usually ordinary Portland. However, rapid hardening Portland cement may be used in cold climates. Sometimes a sulphate resisting Portland cement is used, either wholly or in part mixed with ordinary Portland against sulphate attack, although as most vessels are protected by marine paints and antifouling, its use is hardly necessary. If the cement is used with admixtures, care should be exercised to ensure compatibility (*Paul and Pama, 1978).*

2.2.3 SAND

Sand is a naturally occurring, finely divided rock, comprising of particles or granules ranging in size from $^1/_{16}$ to 2 millimeters. An individual particle in this range size is termed a sand grain. The importance of good, clean, well graded sand cannot be over emphasized if one is to make the high grade impervious mortar required for boat building. The sand is not to contain sulphates, pyrites, or other chemically active substances in such amounts that the mix is harmed. If sea sand is used, it is to be washed free of any saline compositions. (It is always preferable to use non-saline river sand.) The sand should not contain loose clay or clay which adheres or covers the sand grains. The sand is not to contain humic acid or organic materials in quantities that may be detrimental. Preferably, the sand should be 'sharp' and not contain non-crystalline minerals. The sand should be stored in as dry a place as possible and so that water content is evenly balanced. The sand should be protected against pollution (*Paul and Pama, 1978).*

2.2.4 WATER

Mixing water should comply with the requirements of BS 3148:1980. Water should be potable, clean, and free from harmful salts or foreign materials which may impair the strength and resistance of the mortar. BS 3148:1980 gives details of testing water for concrete by comparing the properties of concrete made with any particular sample of water with those of an otherwise similar concrete made with distilled water; therefore the tests will usually be performed in a laboratory. The mixing water should be relatively free from organic compounds. Water to cement ratios commonly used in ferrocement production varies between 0.35 and 0.55 by weight. The average value, 0.45, yields a workable mix which generally will completely penetrate and surround the mesh reinforcement and still result in acceptable levels of shrinkage and porosity (*Paul and Pama, 1978).*

2.3 MATERIALS TESTING AND PRACTICE

Material testing and practice plays a vital part to the integrity of the material and the satisfaction of all parties concerned in the production of a sound ferrocement craft.

2.3.1 COMPRESSION TEST

The compression test is carried out either on cube or cylindrical samples taken from a cross section of mixes during the casting of the ferrocement hull, and any other section of construction that is cast on a different day.

The moulds for test cubes should be made of steel or cast iron, with the inner surfaces parallel to each other and machine faced. Each mould should have a metal base plate with a true surface to support the mould and prevent leakage. It is essential to keep the mould and base plate clean and both should be oiled lightly to prevent the mortar from sticking to the sides. No undue strain should be used when the sides are fixed together.

A 100 mm cube should be filled in three layers from mortar mixes. Each layer should be rammed at least 25 times with a steel bar 600 mm long and having a ramming face of 16 mm square, the weight of which complies with the local standard. The surface of the cube should be trowel smooth. Test specimens should be cured at not less than 10°C and in the same way as the hull is cured, and for the same period. Specimens should be transferred to the testing station on the seventh and twenty-eighth days, wrapped in gunny cloth or similar (*Paul and Pama, 1978).*

2.3.2 SLUMP TEST

The slump test is a practical means of measuring the consistency of mortar mix. Since changes in the values of slump obtained could indicate material changes in the water content or proportions of the mix. It is therefore useful in controlling the quality of the mortar produced.

The inside of the mould should be clean before each test, and the mould placed on a hard flat surface. The mould should be filled in four layers, each layer rammed 25 times with the tamping rod. After the top layer has been rammed, the surface of the mortar is struck off level. Any leakage is cleaned away from the base of the mould and the mould is lifted vertically from the mortar. The slump is the difference between the height of the mix before and after removal of the mould. If any specimen shears off laterally or collapses, the test should be repeated.

By using the correct mortar mix and water-cement ratio prior to undertaking any casting, as a sample test the average slump achieved from several tests will give the range of slump acceptable when the actual casting takes place. Because the mix is a mortar mix, the slump can be exaggerated by a very little increase in the water-cement ratio. Therefore, it is a handy guide but should not be an over-riding conclusion when the practicalities of the construction and need for full impregnation of the reinforcement are of priority during casting (*Paul and Pama, 1978).*

2.3.3 SAND SIEVE ANALYSIS

The sand sieve analysis is carried out as often as is required to maintain the correct grading of sand. The grading of sand for ferrocement is found by passing a representative sample of dry sand through a series of BS sieves Nos. 7, 14, 25, 52, 100 (or local equivalent standard), starting with the largest sieve. If the sieving is done manually, each sieve is shaken separately over a clean tray for not less than two minutes. If machine sieving is applied, a nest of sieves should be shaken for at least 15 minutes. The material retained on each sieve, together with any material cleaned from the mesh is weighed and recorded. The percentage by weight passing each sieve is then calculated. Sieving will not be accurate if there is too much material left on any mesh after shaking (*Paul and Pama, 1978).*

2.3.4 WATER-CEMENT RATIO

The two essential properties of hardened mortar are durability and strength. Both of these are closely related to density. The mortar must be dense to be impervious to water and to protect the reinforcement adequately. The strength and durability of the mortar is governed by the amount of water used for mixing but the overall grading of the aggregate has an indirect effect. Fine grading requires more water than coarser grading to obtain the same degree of workability. It follows that in practice the grading of the aggregate influences the amount of water which must be added. It has been established that the strength of the mortar depends primarily on the relative proportions of water and cement. The higher the proportion of water, the weaker is the mortar. An allowance for the moisture present in the sand should always be taken into account (*Paul and Pama, 1978).*

2.4 MECHANICAL PROPERTIES

Ferrocement acts as a homogeneous material in the elastic range and stress of the composite is obtained from the laws of mixtures. When the ferrocement specimen is subjected to increasing tensile load, 3 stages of behavior are observed. These stages are classified according to the width of cracks, as observed. These stages are classified according to the width of cracks as described by Walkus, 1970 and are shown in *Table 2.1*

Table 2.1 Stresses and elongations of ferrocement under tensile load (Walkus, 1970)

Stage	**Material stage**	**Performance**	**Width of crack (µm)**	**Stresses σ_{20}, σ_{50} ,σ_{100} , psi**	**Unit elongation (x 10^{-6})**
I	Linearly elastic	Water tight	-	-	-
Ia	Quasi elastic	Water tight	0-20	470	200
Ib	Non-linearly elastic	Non-corrosive I	20-50	514	290
II	Elastic-plastic	Non-corrosive II	50-100	612	645
III	Plastic	Corrosive	>100	-	-

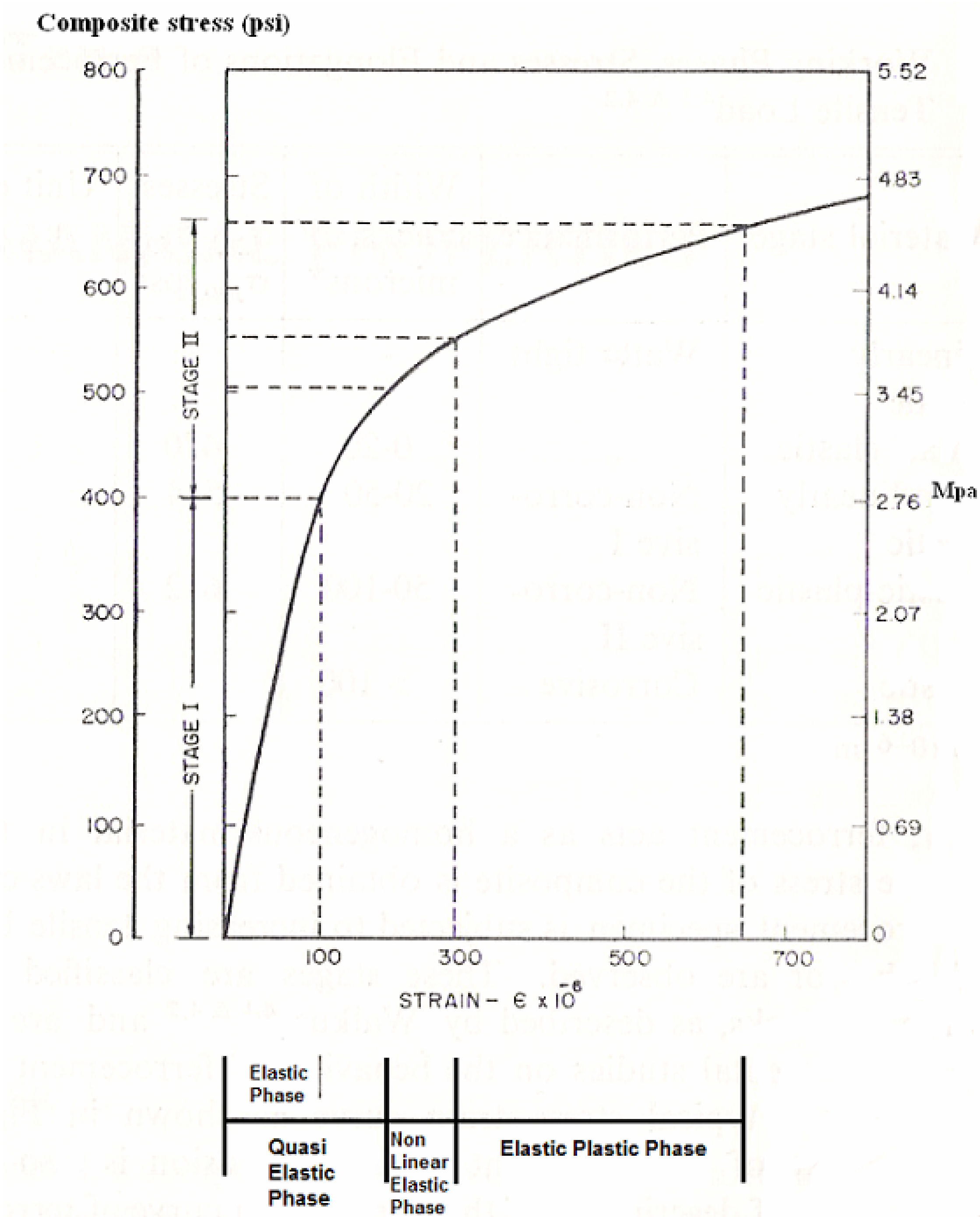

Figure 2.1 Experimental of stress-strain curves of ferrocement in tension (Walkus, 1970)

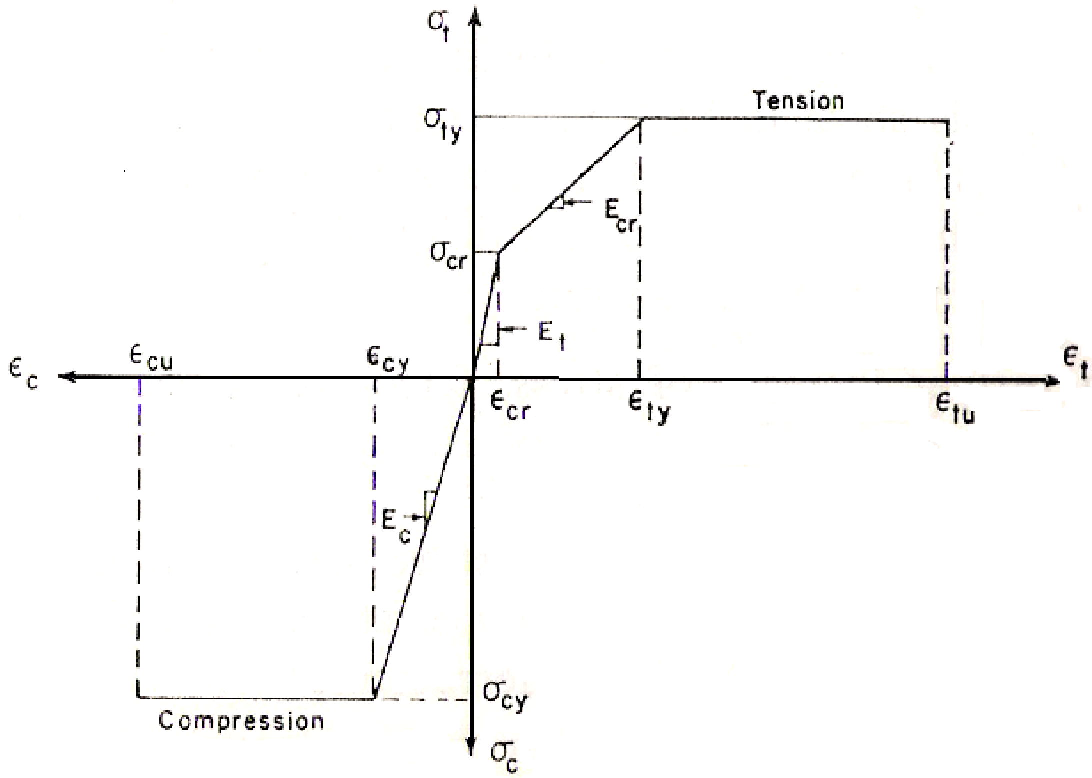

Figure 2.2 Idealized of stress-strain curve of ferrocement (Walkus, 1970)

A brief description of the stress-strain curve of ferrocement at different stress levels in *Figure 2.1 and Figure 2.2* are described as follows:

Elastic Range

Elastic deformations occur at this stage in both metal and crystalline grids as well as in colloids. There is no evidence of any crack formation even when observed with magnifications. The limit of elasticity of ferrocement is also higher than the unreinforced concrete. With a further increase of stress, ferrocement becomes quasi-elastic. The relatively small plastic strains of colloids are restrained by the elastic deformation of the metal wires. The micro cracks are invisible to the naked eye and are difficult to observe even when optical instruments are used. These two stages –the linearly elastic and quasi elastic constitute the practical elastic working range of ferrocement (*Paul and Pama, 1978).*

Cracked Range

Further increase of stress causes very definite plastic deformation of the colloids as well as the crystalline grids, which is resisted by the reinforcements. This is the time of the formation and widening of exploitation cracks. The stress-strain curve deviates from linearity and an increasing number of cracks rather than increasing stress. The cracks are very fine in this stage and have been observed to be a function of the specific surface of the reinforcement (*Paul and Pama, 1978).*

Yield range

As the load is increased the process of crack widening continues at uniform rate. The maximum numbers of cracks that are going to develop have already developed before this stage. Increasing mortar strains are caused by increasing width of cracks. Composite action between the mortar and reinforcement continues up to attainment of crack width of about 100 microns and thereafter, the reinforcement carries all the tensile forces (*Paul and Pama, 1978).*

2.5 BEHAVIOR IN CRACKED RANGE

Although ferrocement is a type of reinforced concrete and is expected a priori to behave similarly. But the cracking behavior is substantially different. This is seemed to be due to at least three major differences:

- Ferrocement comes in thin shell like element with its reinforcement distributed throughout section
- The specific surface of reinforcement is an order of magnitude higher than that of reinforcement concrete (for equal amounts of steel)
- The presence of transverse wires in the mesh reinforcement of ferrocement enhances bond transfer properties and cracking characteristics.

Naaman and Shah, 1971 observed from their experiments that the stress at the appearance of the first crack is a function of the specific surface of reinforcement. Specific surface, S_R is defined as the ratio of the total surface area of wire in contact with the mortar in the direction of load to the volume of the composite. Volume fraction of reinforcement, V_f is the ratio of volume of reinforcement per unit volume of composite. The specific surface and the volume fraction of reinforcement are related by following relationship:

$$S_R = \frac{4V_f}{\phi}$$

Where Φ is the diameter of the wire used.

The higher the specific surface and the smaller the transverse wire spacing, the larger the extent of multiple cracking stages, the larger the number of cracks developed in the same gage length, the smaller the crack spacing and the smaller the crack widths.

2.5.1 FACTORS AFFECTING THE CRACKING BEHAVIOR

Ferrocement specimens exhibit finer and more numerous cracks than conventionally reinforced concrete. Crack width in reinforced concrete can be reduced by increasing the bond between the reinforcement and concrete, by increasing the distribution of reinforcement and by reducing the thickness of cover. Specific surface and volume fraction of the reinforcement are found to play a significant role in the cracking behavior of ferrocement and their influences are described below.

i) Effect of specific surface on the first crack strength

The stress and strain at first crack increases with increasing specific surface, up to a certain point, as can be seen from *Table 2.2* and *Figure 2.3 (Bezukladovl, 1968).*

Table 2.2 Test results in axial tension (Bezukladov, 1968)

Compressive strength of mortar psi	Specific surface of reinforcement In^2/in^3	Reinforcement in the loading direction (%)	Stress at first crack, σ_{cr} Psi	Rupture stress Psi	Strain at first crack, ε_{cr} x 10^{-5}	Second modulus at first crack, $(\sigma_{cr} / \varepsilon_{cr})$ Psi x 10^6
9243	3.048	1.85	555	683	45	1.222
9243	5.283	1.80	597	683	55	1.080
9243	7.721	1.75	640	711	70	0.910
9243	4.572	2.80	839	1138	60	1.393
9243	7.924	2.70	1038	1280	100	1.038
10665	7.924	2.70	1166	1280	100	1.166
9243	11.430	2.68	711	1138	100	0.711

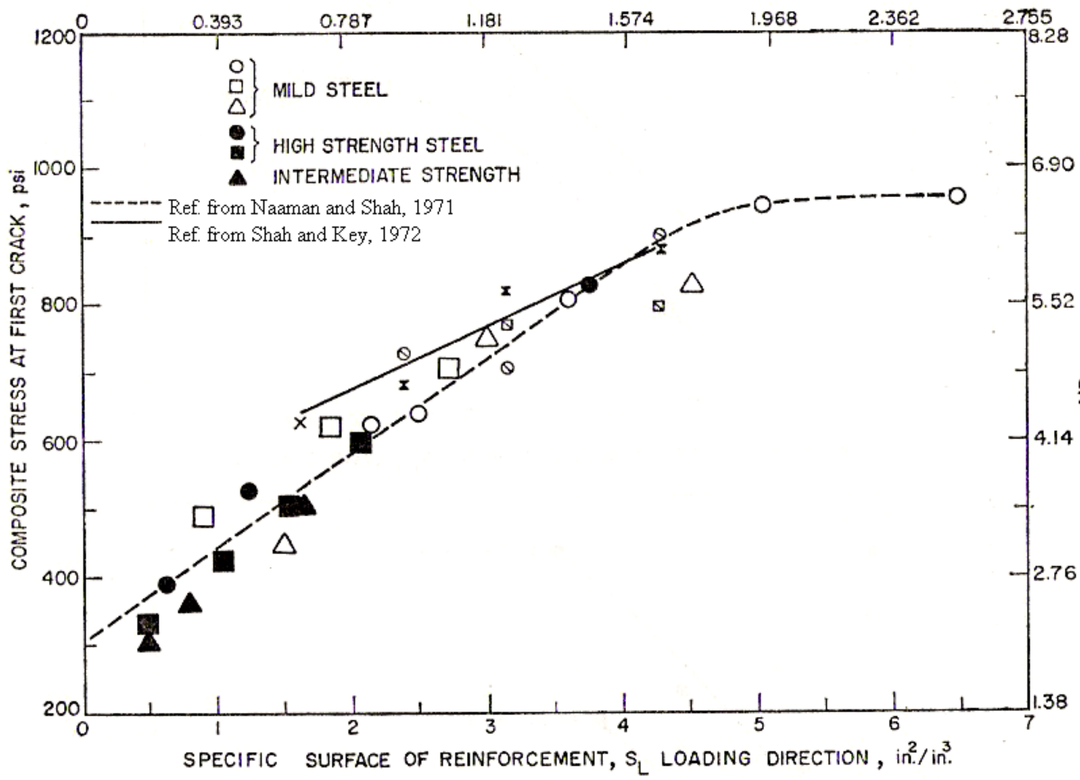

Figure 2.3 Stress at first crack versus specific surface of reinforcement (Bezukladov, 1968)

A unique relationship between specific surface ratio and composite stress at first crack was observed by *Naaman and Shah, 1971 and Shah and Key, 1972*. It is clear that the stress at the first crack increased linearly with increase in specific surface irrespective of size, type and spacing of the wire mesh. This means that the total bond forces between the steel and the mortar play an important role in influencing the cracking behavior of ferrocement. After the occurrence of the first crack, the numbers of cracks increase with increasing load. The optimum value of specific surface, considering stresses at first crack, seems to lie in between 1.4 cm^2/cm^3 to 2.0 cm^2/cm^3.

Table 2.3 Properties of meshes used in ferrocement element (*Naaman and Shah, 1971)*

Source data	Figure no.	Key	Type of mesh	Wire diam in.	Mesh size in. × in.	No. of layers	Total volume fraction of reinforcement	Tensile strength psi × 10^3
Naaman & Shah	**2.3** **2.4**	○	Woven, square	0.025	0.25 × 0.25	1,3,5,7, 9	0.90 to 8.10	51 % elong. = 5.50
		□	Woven, square	0.063	0.50 × 0.50	1,2,3	2.85 to 8.55	57 % elong. = 14.00
		△	Woven, square	0.035	1/6 × 1/6	1,2,3	2.64 to 7.92	51 % elong. = 14.80
		●	Woven, square	0.025	0.25 × 0.25	1,2,4,6	0.78 to 4.68	160 % elong. = 1.75
		■	Woven, square	0.041	0.50 × 0.50	1,2,3,4	1.05 to 4.20	140 % elong. = 1.58
		▲	Welded square	0.063 0.063 0.063	0.50 × 0.50 1.00 × 1.00 2.00 × 2.00	2 2 2	5.00 2.50 1.66	74, 2.04% 78, 3.72% 89, 2.67%
Shah & Key	**2.3**	x	Welded : gal		1.00 × 1.00	3 (inner)		58
		⊠	Woven: ungal Welded: gal		1/4 × 1/4 1.00 × 1.00	2,4,6 (outer) 2,1,0 (inner)		57 58
		⧗	Woven: gal Welded: gal		1/4 × 1/4 1.00 × 1.00	2,4,6 (outer) 2,1,0 (inner)		119 58
		θ	Woven: ungal Welded: gal		1/4 × 1/4 1.00 × 1.00	2,4,6 (outer) 2,1,0 (inner)		161 58

ii) Effect of volume fraction on first crack strength

Experimental investigations by Shah, 1971 showed that increasing volume of reinforcement increases the stress at first crack. However, this increase is different for each size of mesh employed is shown in *Figure 2.4*. In addition, it did not always appear that the smaller the dimension of the mesh that is the smaller the spacing between the longitudinal wires, the higher the first crack stress for the same volume.

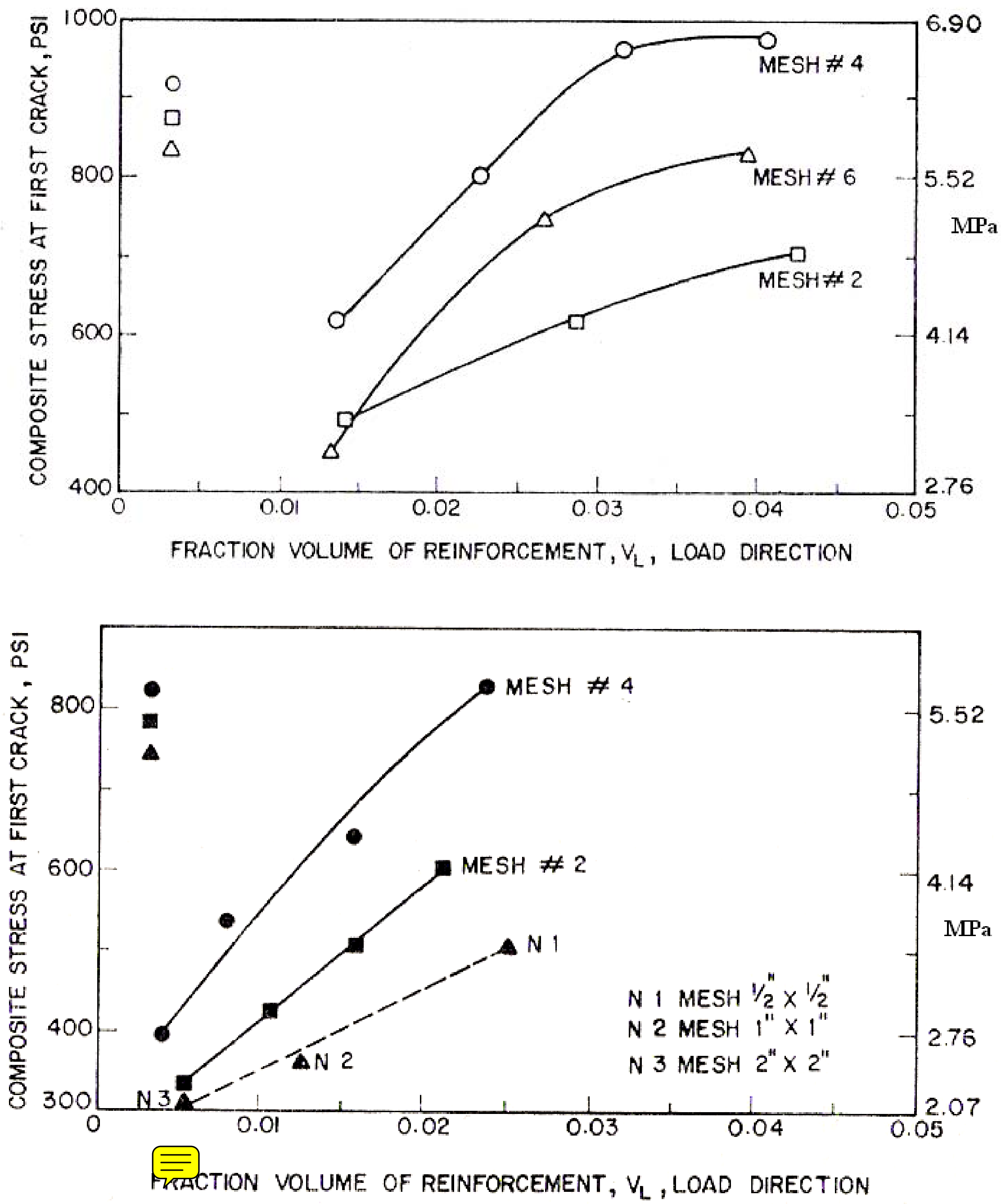

Figure 2.4 Stress at first crack versus fraction volume of reinforcement (Shah, 1972)

2.5.2 CRACK WIDTH

Crack width is an important parameter to be considered in the serviceability of a structure and many reinforced concrete codes limits its value depending on the type of structure and environmental conditions. In ferrocement elements, cracks also exist although the width of cracks appears to be very small. In fact under normal conditions cracking under working load is inevitable in non-prestressed elements irrespective of the quality of reinforcements used and unless new type of cement is developed, cracking must be accepted. Therefore, the aim of the design is not the avoidance of cracks but the limitation of their width in order to maintain the serviceability of the structure. Therefore, a good prediction of crack width is of considerable importance in design *(Shah, 1972).*

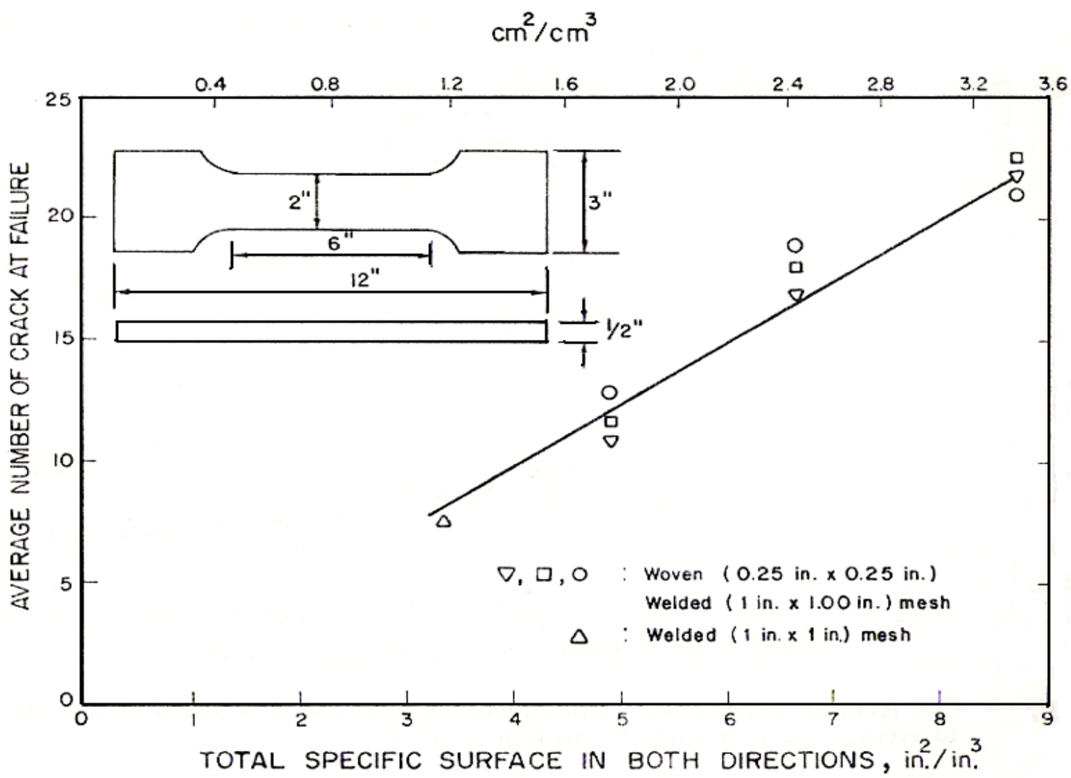

Figure 2.5 Effect of specific surface on number of cracks (Shah, 1972)

The relationship given in *Figure 2.5* between the specific surface and crack width is primarily valid up to elastic-plastic (second stage) behavior. Additional stress does not increase the number of cracks but increase the width of cracks. The crack width at failure also depends on the yielding characteristics of steel. This can be visualized from *Figure 2.6*, where width of specimens tested to failure is plotted against the tensile strength of wire mesh. The more ductile the wire meshes, the lower its yield strength, the wider the cracks become *(Shah, 1972).*

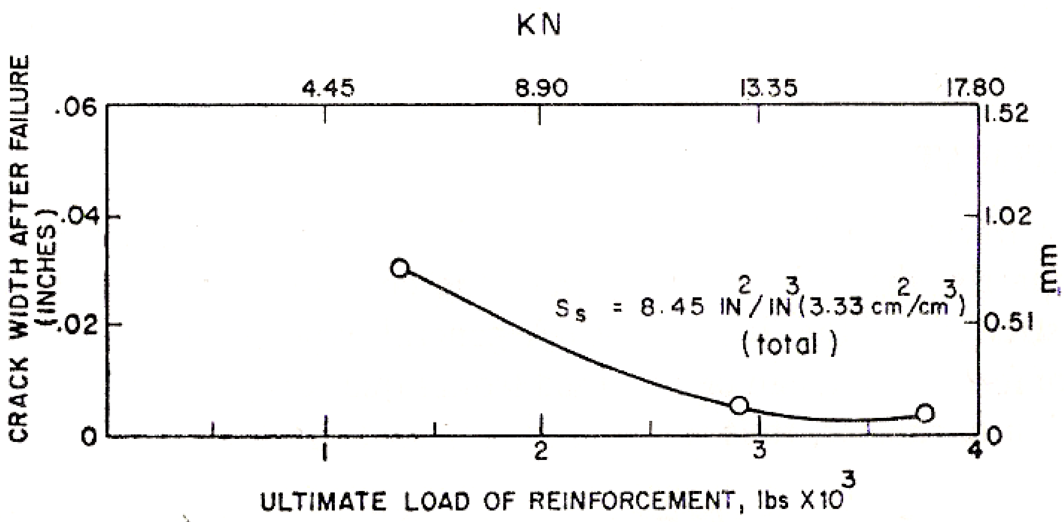

Figure 2.6 Effect of ductility on width of cracks (Shah, 1972)

2.6 FUTURE OF FERROCEMENT

The potential range of application of ferrocement is indeed broad and represents design challenge. The ability to design thin element that possess strength and ductility opens up concrete design to applications previously reserved for metals and plastics.

Not only are there exciting opportunities in the creation of new structural uses for this material, but construction and manufacturing procedures are equally challenging. The placing of layers of steel mesh and subsequently impregnating them with mortar is inherently a labor intensive process and the future ferrocement will be directly related to the extent that the process is automated or otherwise made more efficient.

The future of ferrocement will depend as much upon design creativity as it will depend upon a long and laborious research effort. It is important to recognize that ferrocement, like fiber reinforced concrete, enables us to design for a range of tensile stresses and strains far beyond that previously permitted. This feature, combined with the absence of thick cover requirement over the reinforcing, provides great flexibility in designing roofs, walls, liquid containers and precast architectural forms that could provide factory finish surfaces for members that are cast in the field (*Paul and Pama, 1978).*

CHAPTER 3

METHODOLOGY

3.1 MATERIAL USED FOR FERROCEMENT

A brief description of the materials used for ferrocement is given as below.

3.1.1 WIRE MESH

One of the essential components in ferrocement is wire mesh. The function of wire mesh in the first instance is to act as a lath providing the form and to support the mortar. 19 gauge wires spaced ½ inch apart of rectangular welded wire mesh are used in these ferrocement specimens. This type of mesh can be molded easily conforming to the desired curved of the structure, producing much fairer lines. However, welded wire mesh has the possibility of weak spots at intersections resulting from inadequate welding during the manufacture of the mesh.

3.1.2 CEMENT

Cement is the material with cohesive properties that makes it capable of bonding mineral fragments into compact mass. The binding material in ferrocement is known as mortar. The properties of the mortar are governed by the type and quality of the constituent materials, the proportion in which they are combined and their condition of preparation. Cement that used in this experimental program is ordinary Portland cement. The cement brand is Blue Lion and is produced by the CIMA Company. Chemical compositions of cements are given in *Table 3.1*.