BEHAVIOR OF SMALL CONCRETE ELEMENTS REINFORCED OR REPAIRED WITH EXPANDED STEEL MESH

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ABSTRACT

The use of expanded steel mesh as concrete reinforcement is believed to give greater elasticity and cracking resistance compared to conventional reinforcement. This may be attributed to the fact that the expanded mesh is made up of relatively small elements with high surface area. In this investigation, cubes (150 x 150 x 150 mm) and cylinders (150 mm x 300 mm) were reinforced by embedding a single layer of expanded mesh shaped as a cage parallel to the long edges of the elements and placed 1 cm from the end surfaces. Alternatively, cubes of the same dimensions and prisms (100 x 100 x 300 mm) were loaded to 80% of their expected ultimate load and then wrapped by a cage of the expanded steel mesh and plastered with mortar to simulate the repair of concrete elements. The studied variables were W/C ratios and orientations of the expanded mesh with respect to the direction of loading. It was found that both W/C ratio and mesh orientation have a significant effect on the compressive strength of the elements reinforced with expanded steel mesh. However, the W/C ratio had negligible effect on the compressive strength of cracked elements repaired by the expanded mesh. The mesh orientation was the main factor affecting the strength of such elements. The compressive strength results of cylinder specimens reinforced with the mesh, were predicted with reasonable accuracy by including the effect of mesh orientation into the used theoretical equation.

INTRODUCTION

The type of thin wall reinforced concrete (R.C) constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small steel wire diameter mesh or expanded steel mesh is called ferrocement [1]. The arrangement of reinforcement in ferrocement construction is such that a composite material is formed which exhibits behavior sufficiently different from conventional R.C. in strength, deformation and potential applications. Therefore, ferrocement is classified as a separate and distinct material [2]. It has a very high tensile strength to weight ratio and superior cracking behavior compared with reinforced concrete which means that thin ferrocement structures can be made relatively light and watertight [3]. Ferrocement does not require formwork and hence it is suitable for structures with curved surfaces, such as shells, and free-form shapes [4]. It is also an attractive material for the construction of wind tunnels, tanks, and swimming pools [5]. The universal availability of the basic ingredients of ferrocement, steel wire mesh or expanded steel mesh, and concrete, created interest in the potential application of this material in developing countries for prefabricated units of low cost housing [2].

Extensive research work was devoted for the application of ferrocement to construct new structural elements or repair of existing R.C. elements such as beams, slabs and shells [6, 7 and

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8]. Experience has shown that the quality of mortar and its application to the steel mesh (i.e. plastering) is the most critical phase in constructing ferrocement structures or repair of R.C elements using steel wire mesh embedded in a mortar matrix (ferrocement jacket) [7 and 9]. In addition, it was found that the orientation of the mesh embedded in the mortar matrix has a great effect on the behavior of slabs and shells [8]. Wrapping of beams and columns by a ferrocement jacket resulted in improving flexural, shear stresses of beams and increasing load capacity of columns [5 and 10]. As expected, the confinement of circular elements is always better than that for sharp edged ones, e.g. rectangular or square elements [11]. However, the repair by ferrocement jacket does not enhance only the ductility but it increases also the load carrying capacity of strengthened elements by resisting and delaying the cracks propagation. Although several investigations have reported on ferrocement elements under axial and eccentric compression [12, 13, 14 and 15], studies on the effect of reinforcing and strengthening of different shapes of small concrete elements by expanded steel mesh or ferrocement jackets on the compressive strength of such elements are limited.

The aim of this investigation is to study the behavior of small concrete elements reinforced or repaired by expanded steel mesh. The reinforcement was either cast with the elements originally or applied as a repair jacket of ferrocement to cracked elements. The studied variables were W/C ratio, orientation of the expanded steel mesh and type of concrete element. In addition, the compressive strength results of cylinder specimens were predicted by modifying the analytical method used earlier [12 and 15] to add the effect of expanded steel mesh orientation.

EXPERIMENTAL PROGRAM

Materials And Mix Design

All concrete constituents used conformed to the relevant Egyptian Standard Specifications. Expanded steel mesh used in this investigation was expanded metal lath conforming to ACI Committee 549, 1R-88 [16]. The mesh has a diamond shape of wire diameter equals 1 mm and the yield strength was considered 2600 kg/cm^2 [16]. The mesh was used in either one of three different orientations as shown in Figure 1. Three concrete mixes were used to prepare the test specimens. The specimens had W/C ratios of either 0.4, 0.5 or 0.7. The mix proportions were as shown in Table 1.

Preparation Of The Test Specimens

The control specimens were prepared in accordance with E.S.S 1658/1991 and were cured for 28 days in water. These were either cubes (150 x 150 x 150 mm), cylinders (150 mm ϕ x 300 mm), or prisms (100 x 100 x 300 mm).

Specimens reinforced with expanded steel mesh

Cubes and cylinders were reinforced with expanded mesh by making a cage smaller than the mold dimensions by 10 mm in each direction and placing it parallel to the long axis of the cylinders and perpendicular to the casting surface of the cubes. The orientation of the expanded mesh forming the cage was varied as shown in Figure 1. It is defined by a number representing the angle in degrees between the reinforcing elements and the direction of the applied load, e.g., O-30° for the mesh with all the elements at ± 30° to the applied load. The reinforced specimens were also cured for 28 days. Table 2 shows the details of test program for cubes and cylinders reinforced with expanded steel mesh.

Specimens repaired by a ferrocement jacket

To simulate the real effect of using the expanded mesh in repair, cubes (150 x 150 x 150 mm) and prisms (100 x 100 x 300 mm) without any internal reinforcement, were water cured for 28 days. The specimens were loaded to 80% of the compressive strength of the control specimens counterparts for five minutes after which the load was released. Later, they were wrapped by a one layer of the mesh along one circumference for the cubes or around the long axis of the prisms, as shown in Figures 2 (a) and (b), and then plastered with a thin layer of mortar to form a jacket of ferrocement. The wrapped specimens were water cured for 7 days. The details of test specimens are shown in Table 3.

All expanded mesh cages, used in reinforcing or repairing concrete elements, were overlapped with sufficient splice length (approximately 4cm). For each mix, mesh orientation, specimen shape or test case two identical specimens were prepared to be tested. A total of 106 specimens were tested in this experimental program (see Tables 2 and 3).

Testing Scheme of The Concrete Specimens

A 2000 KN capacity automatic compression testing machine was used to carry out the compressive strength testing. The tests were performed in accordance with ASTM C39 for cylinders and BS 1881 : part 116 for cubes. The prisms were tested in a similar manner to the cylinders by adjusting the loading rate to suit the cross sectional area of these elements. The same test machine was also used to load the specimens before wrapping by the ferrocement jacket.

RESULTS AND DISCUSSION

Elements Reinforced with Expanded Steel mesh

Figure 3 shows the results of compressive strength for cubes and cylinders of different W/C ratios and reinforced with expanded steel mesh of different orientations. The gain of compressive strength as a result of reinforcing cube and cylinder specimens with expanded steel mesh is shown in Figure 4. For different W/C ratios, the figure shows the gain of strength as a percentage of the compressive strength of control specimens.

Effect of W/C

It can be seen from Figures 3 (a) & (b) that for all specimens, the decrease of W/C ratio results in an appreciable increase of compressive strength. For the specimens reinforced with expanded steel mesh, the effect of W/C ratio is related to the orientation of the expanded mesh. For example, the reduction of W/C ratio from 0.7 to 0.4 for control specimens led to an increase of cube and cylinder strength of approximately (210 Kg/cm^2) and (160 Kg/cm^2), respectively. On the other hand, reinforcing elements with expanded mesh of orientation (O-30°) for cube specimens and orientation (O-60°) for cylinder specimens resulted in an increase of their strengths of approximately (350 Kg/cm^2) and (255 Kg/cm^2), respectively for the same values of W/C ratio.

Effect of Expanded Steel Mesh Orientation

Figure 3(a) shows that the compressive strength results for cube elements reinforced with expanded mesh of orientation (O-30°) are close to those reinforced with expanded mesh of orientation (O-45°). It can be argued that these two orientations are almost perpendicular to the possible cracks developed in the cubes during loading. These orientations normally contribute to the increase in load carrying capacity by resisting crack propagation since the confinement mechanism for the sharp edged elements such as cubes is weak. It can be seen from Figure 3 (b) that using expanded mesh of orientation (O-60°) for reinforcing cylinders resulted in a significant raise in compressive strength compared to that of the other orientations. This might be attributed to the fact that the expanded mesh of this orientation, which is inclined with the horizontal direction by 30°, works as a spiral reinforcement confining the cylindrical elements [1].

Figures 4 (a) and (b) show that reinforcing cubes with expanded steel mesh of orientation (O-60°) and cylinders with mesh of orientation (O-30°) led to a reduction not a gain in the compressive strength of such elements for different W/C ratios. The increase of W/C ratio led to further losses in the compressive strength. It can be argued that reinforcing elements with expanded mesh of these orientations did not contribute to crack resistance for cubes or confining cylinders as mentioned earlier but perhaps they interfered with the flow of concrete during casting and reduced the homogeneity of concrete elements. Figure 4 (a) shows that reinforcement of orientations (O-45°) and (O-30°) enhanced the cube compressive strength by approximately 40-42% for W/C ratio = 0.4 and 14-25% for W/C ratio = 0.7. The cylinder specimens reinforced with expanded steel mesh behaved in a similar manner to the cube elements as shown in Figure 4 (b). For example, reinforcing cylinder specimens with expanded mesh of orientation (O-60°) resulted in a gain of strength by about 54% for W/C = 0.4 and 47% for W/C = 0.7 while orientation (O-45°) increased the strength by 19% and 6% for W/C = 0.4 and 0.7 respectively. In other words, the effect of orientation is maximum for W/C =0.4 and decreases with the increase of W/C ratio. This might be attributed to the fact that concrete at high W/C ratio (0.7) is so brittle that lateral strain could not attract passive pressure from expanded steel mesh.

The failure mode of a typical cylinder reinforced with expanded mesh of orientation (O-45°) is shown in Figure 5. It was observed that the failure took place in two stages. First, the concrete layer around the reinforcing cage was cracked and spalled as shown in Figure 5. Second, the expanded steel mesh kept confining the cylinder core till yielding of reinforcement and then the element collapsed. The major crack direction was inclined to the vertical axis with an angle of 20-30°.

Elements Repaired By Ferrocement Jackets

Cubes

Figure 6 shows the effect of mesh orientation and W/C on the compressive strength of repaired cubes. The figure shows that wrapping cubes by ferrocement jackets resulted in improving the behavior of such elements by increasing their compressive strength compared with the cubes before repair. However, the enhancement in strength depends on the mesh orientation. It can be observed that wrapping cube specimens by expanded steel mesh of orientations (O-60°) and

(O-45°) improved the compressive strengths more than those for specimens repaired by expanded mesh of orientation (O-30°). For example repairing cubes by expanded mesh of orientations (O-60°) and (O-45°) resulted in enhancing compressive strength by 40% and 26% for W/C = 0.4 while using mesh of orientation (O-30°) in repair increased the strength 12% only for the same W/C. It can be argued that the confinement using expanded mesh of orientations (O-45°) and (O-60°) is better than that of orientation (O-30°) for cracked elements since the contribution of reinforcement in such elements, which are already cracked, is mainly for confinement not for crack propagation resistance.

Prisms

Figure 7 shows the compressive strength of prisms before and after repair by ferrocement jackets for different W/C ratios. This figure shows a trend different from that of the repaired cubes shown in Figure 6. It can be seen that wrapping prisms by expanded mesh of orientation (O-30°) results in a slightly higher compressive strength than wrapping at other orientations. This might be because of the mechanical behavior of prisms which simulates short columns. Expanded steel mesh of orientation (O-30°) resists the vertical loading more than confining the prism. Therefore, repair utilizing mesh of orientation (O-30°) resulted in enhancing the compressive strength by approximately 31% for W/C = 0.4 while the use of mesh at orientation (O-45°) or (O-60°) resulted in an increase of strength by 26%,and 24%, for the same W/C ratio, respectively. This is consistent with the findings reported [1] which defined the effective area of steel as the cross sectional area of steel reinforcement multiplied by the cosine of the angle between the wire reinforcement and the direction of the applied load. It can be argued that the cosine of 30° is the highest among the studied orientations and in turn the effective area of steel will be the maximum for (O-30°).

It is interesting to note that the effect of W/C ratio was not as significant as for elements reinforced originally with expanded steel mesh (see Figure 3). This might be attributed to the fact that the cubes and/or prisms were already cracked to some extent before repair by the ferrocement jacket and the only significant factor was the orientation of the mesh in ferrocement wrapping. The failure mode of a typical prism wrapped by a ferrocement jacket is shown in Figure 8. Again, the failure mechanism is divided into two stages. Initially, the plastering around the mesh started cracking and spalled from the weak points, e.g. corners of the specimen, as shown in Figure 8. Finally, the mesh kept confining the specimen till yielding and then the prism cracks propagated till failure with major cracks inclined to the direction of loading by 5-15°. At this stage, localized buckling of the mesh was noted.

Prediction of The Experimental Results

Two methods were used earlier by Desayi and Joshi [12] and Mansur and Paramasivam [15] gave reasonably good predictions for their elements which were reinforced with traditional reinforcement beside the wire mesh. The predictions of ultimate loads, P_u, by the first method is as follows:

$$P_u = 0.67\, f_{cu}\, (A_g - A_s) + A_s\, f_y \qquad (1)$$

where;

f_{cu} = compressive strength of control cubes.
A_g = gross cross-sectional area of the concrete section.
A_s = cross-sectional area of one layer of steel mesh.
f_y = yield strength of steel mesh reinforcement as reported earlier [16].

and;

$$A_s = \eta \, V_f \, A_g \tag{2}$$

where;

η = global efficiency factor of mesh reinforcement in the loading direction (equals 0.65 for expanded steel mesh [16]).

In the second method, the contribution of the slender wires in the expanded steel mesh was ignored. The ultimate load was predicted as;

$$P_u = f_f \; f_{cu} \; A_g \tag{3}$$

where;

f_f = ratio of the cylinder compressive strength to cube compressive strength.

Mansur and Paramasivam [15] considered $f_f = 0.8$. They found that Equation (3) gave better predictions than Equation (1).

In this study, an attempt has been made to predict the ultimate strength of the cylinder specimens experimentally tested and detailed in Table 2. The effective area of expanded steel mesh was calculated from Equation (2) and it was found to be very small (wire diameter = 1 mm) compared to the gross area of concrete specimens (concrete cylinder diameter = 150 mm). Hence, the contribution of reinforcement in Equation (1) for concrete cylinder reinforced with expanded steel mesh will be minimum. Therefore, the prediction given using this equation would not be relevant. Equation (3) was modified to take the orientation of mesh reinforcement into consideration in order to predict the ultimate load. The author added the effect of mesh orientation as a confining cage and modified Equation (3) to be

$$P_u = (f_f / \cos \theta) \; f_f \; f_{cu} \; A_g \qquad [4]$$

and

$$f_{cyl} = (f_f / \cos \theta) \; f_f \; f_{cu} \qquad [5]$$

where;

f_{cyl} = compressive strength of cylinder specimens reinforced with expanded mesh.
θ = angle of orientation of expanded steel mesh (see Figure 1).

Equation (3) was applied for control specimens while Equation (5) was applied to specimens reinforced with expanded steel mesh of different orientations. The results obtained from these equations were compared with the experimental results of concrete cylinder specimens shown in Figure 3 (b) for different W/C ratios and expanded steel mesh orientations. Table 4 shows that Equations (3) and (5) give good predictions of the compressive strength. The maximum difference between the experimental and predicted results was 6.7%.

CONCLUSIONS

The following conclusions can be drawn from this study:

1. Generally, the existence of expanded steel mesh tends to increase the compressive strength of the specimens when they contribute to crack resistance or confine the element.
2. The occurrence and, indeed, extent of such increase in load carrying capacity of concrete elements depends on the orientation of the expanded mesh with respect to the loading direction and the W/C ratio of the concrete. In this investigation, it was found that the use of expanded mesh has resulted in an increase of the load carrying capacity of cubes and cylinders by approximately 42 and 54% at W/C ratio =0.4 when orientations O-30° and O-60° were used, respectively. The increase of the load carrying capacity was less for higher W/C ratios.
3. When the expanded steel mesh is used in the repair of cracked concrete elements, its effect is believed to be associated with the confining of the elements more than crack resistance.
4. The confining effect of the expanded mesh used in the repair of the elements depends mainly on the mesh orientation. Cube specimens repaired by mesh of orientation O-60° had an enhancement of strengths of 28% greater than similar specimens repaired by mesh at orientation O-30°. The difference in the load carrying capacity, of prism specimens repaired by expanded mesh of different orientations, was less than that observed with cube specimens. However, in this case, the best orientation was O-30°.
5. Compressive strengths of control cylinder specimens or those reinforced with expanded steel mesh were predicted analytically with a reasonable agreement. It was found that including the effect of mesh orientation in the calculation was very significant in the prediction.

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Table 1 The Concrete Mix Proportions

W/C	Water (kg/m^3)	Gravel (kg/m^3)	Sand (kg/m^3)
0.4	190	1200	650
0.5	190	1200	700
0.7	190	1200	750

Table 2 Number and Details of Control Specimens And Those Reinforced with Expanded Steel Mesh

W/C	Control Specimens			Reinforced Specimens		
	Shape of Specimen			Reinforcement Orientation	Shape of Specimen	
	Cylinder	Cube	Prism		Cylinder	Cube
0.4	2	2	2	O - 30° O - 45° O - 60°	2 2 2	2 2 2
0.5	2	2	2	O - 30° O - 45° O - 60°	2 2 2	2 2 2
0.7	2	2	2	O - 30° O - 45° O - 60°	2 2 2	2 2 2

Table 3 Number and Details of Specimens Repaired by Ferrocement Jackets

W/C	Specimens without a Repair Jacket		Specimens Repaired by a Ferrocement Jacket		
	Shape of Specimen		Mesh Orientation in the Jacket	Shape of Specimen	
	Prism	Cube		Prism	Cube
0.4	2	2	O - 30° O - 45° O - 60°	2 2 2	2 2 2
0.5	2	2	O - 30° O - 45° O - 60°	2 2 2	2 2 2
0.7	2	2	O - 30° O - 45° O - 60°	2 2 2	2 2 2

Table 4 Comparison of Experimental Compressive Strength With Calculated Values for Cylinder Specimens

W/C	Reinforcement Orientation	Experimental Compressive Strength Kg/cm^2	Calculated Compressive Strength Kg/cm^2	Difference (%)
0.4	Control	400	405	1.25
	O - 30°	375	374	0.3
	O - 45°	475	458	3.6
	O - 60°	610	648	6.2
0.5	Control	340	340	0.0
	O - 30°	310	314	1.3
	O - 45°	393	385	2.0
	O - 60°	510	544	6.7
0.7	Control	240	232	3.3
	O - 30°	210	214	1.9
	O - 45°	255	262	2.7
	O - 60°	350	371	6.0

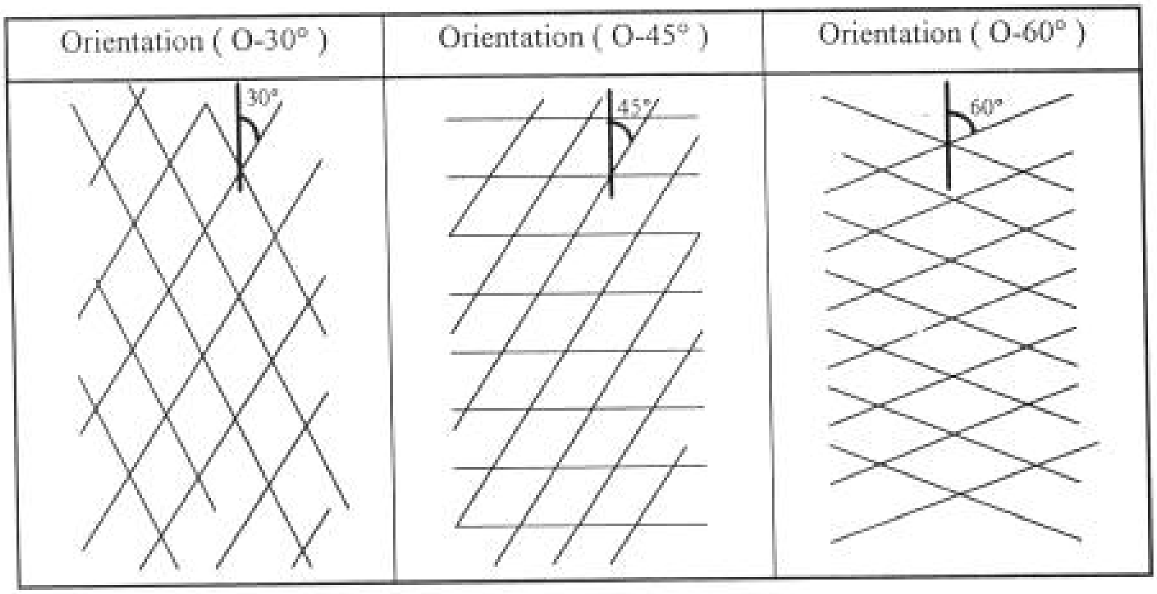
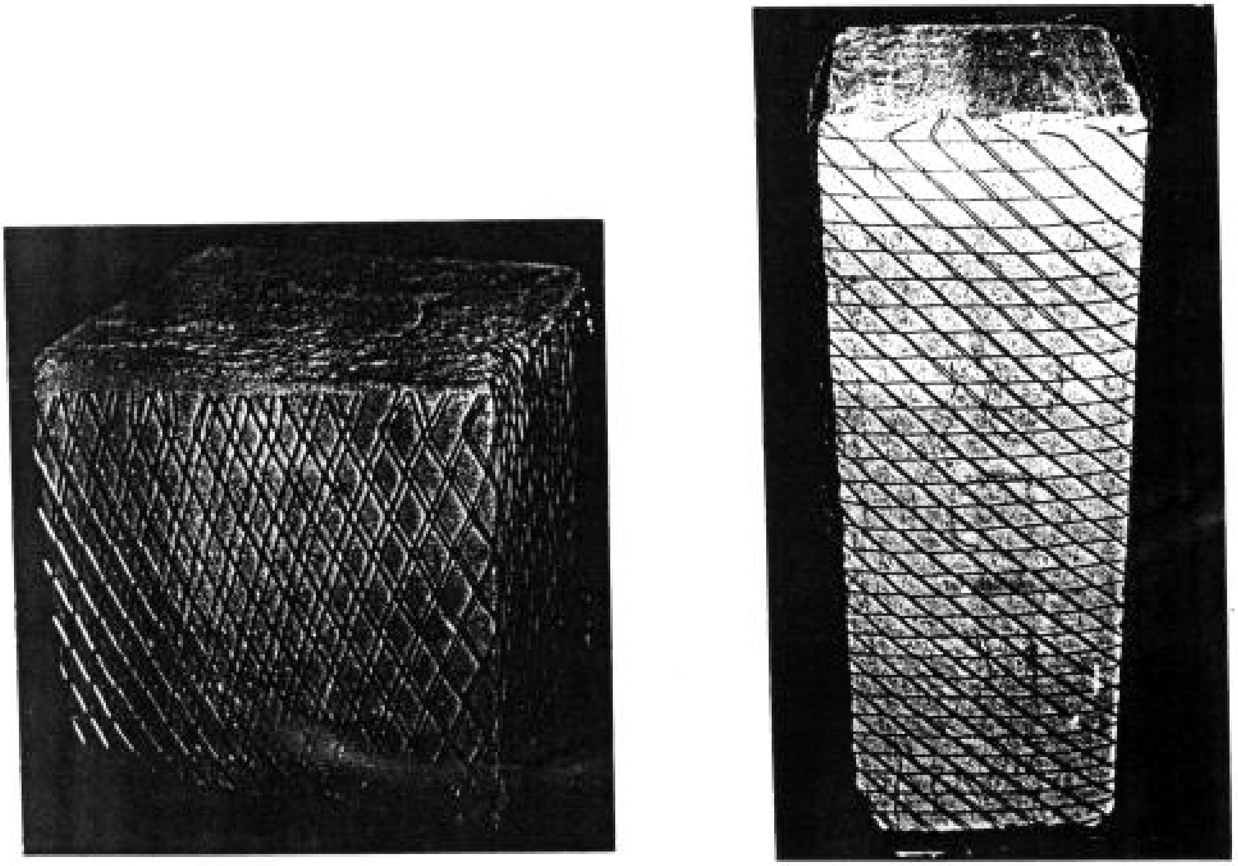


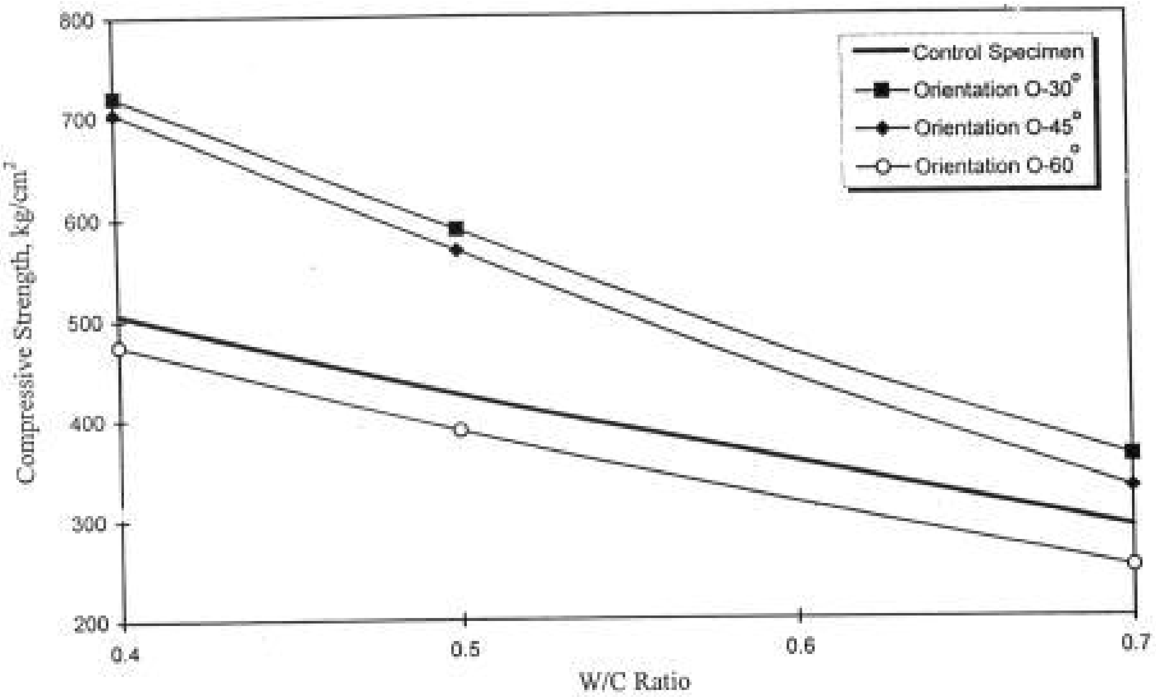
Fig. 1 Different orientations of the expanded steel wire mesh



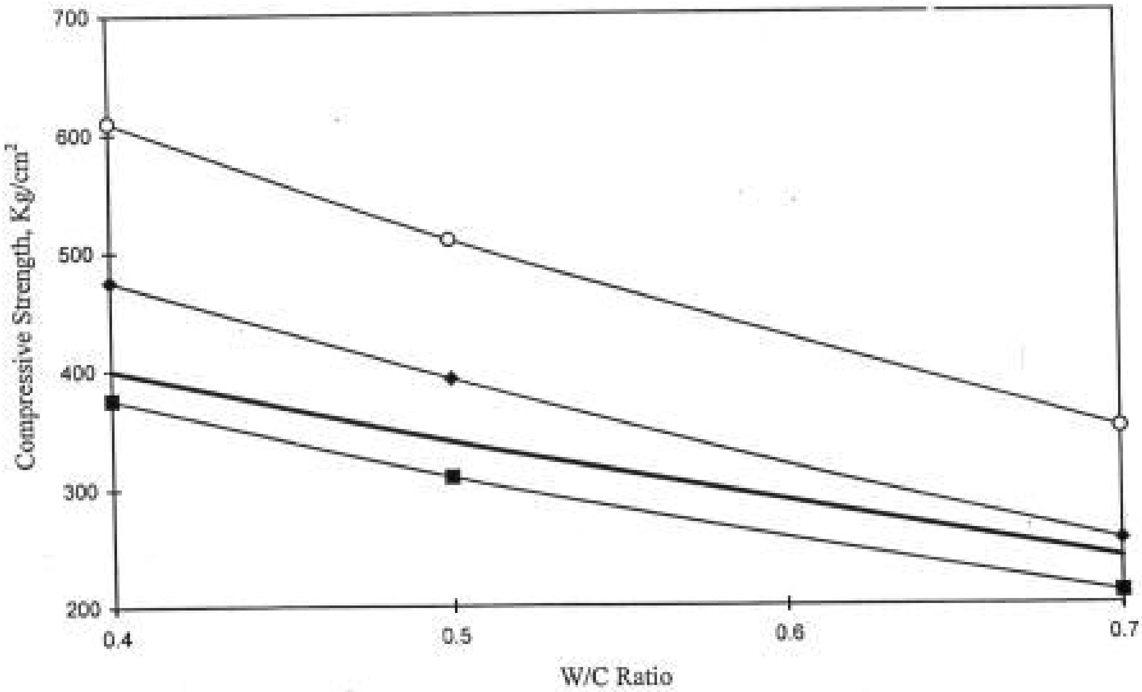
(a) Cube, (O-30°)

(b) Prism, (O-45°)

Fig. 2. Wrapping of concrete elements by expanded steel wire mesh.

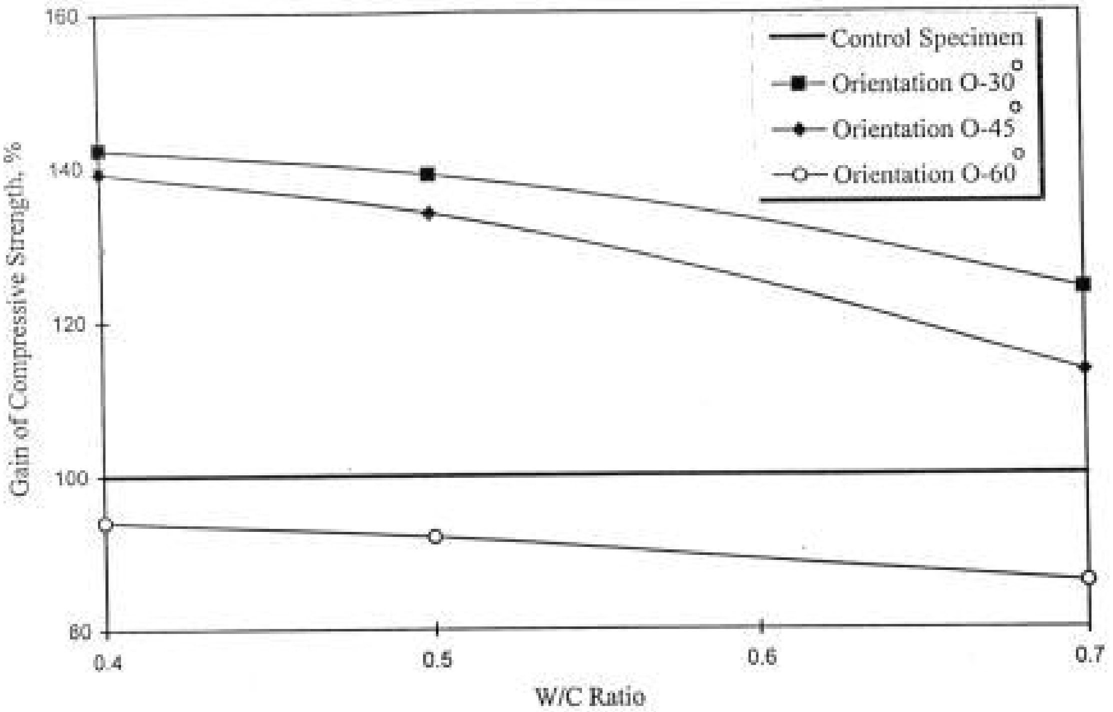


(a) Cube Specimens

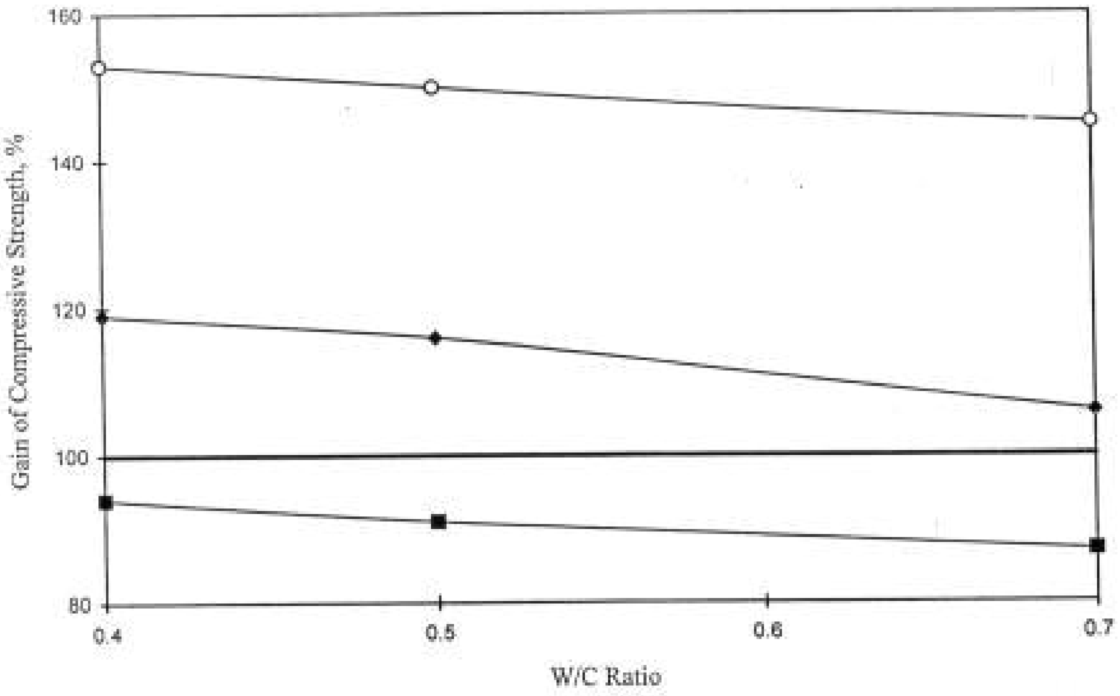


(b) Cylinder Specimens

Fig. 3 Compressive strength & W/C relationship for elements reinforced with expanded steel mesh of different orientations.



(a) Cube Specimens



(b) Cylinder Specimens

Fig. 4 Effect of expanded steel mesh orientation on the gain of compressive strength for different W/C ratios.

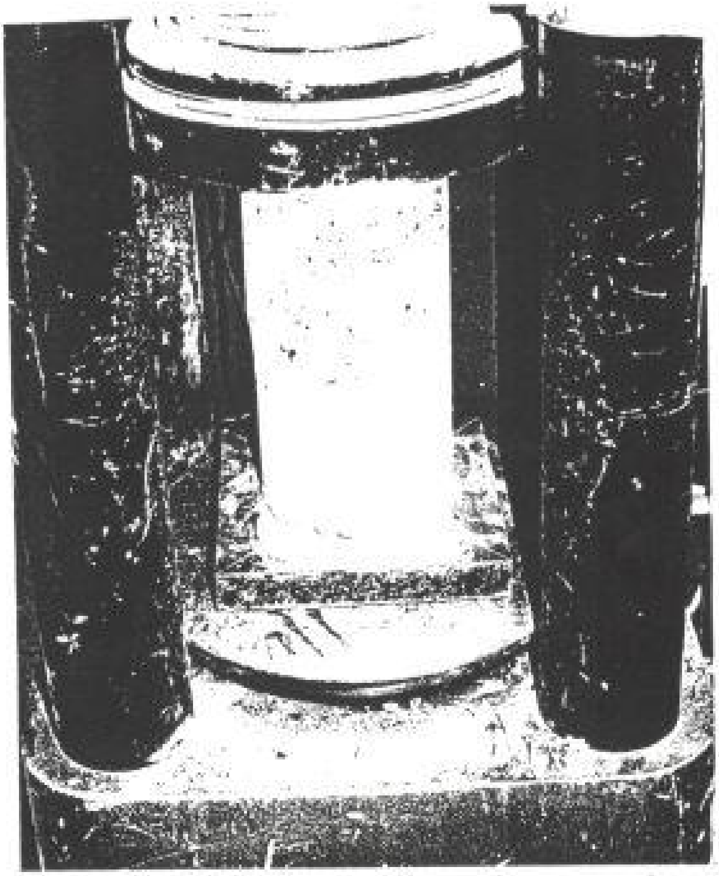


Fig. 5 Typical failure mode of a concrete cylinder reinforced with expanded steel mesh.

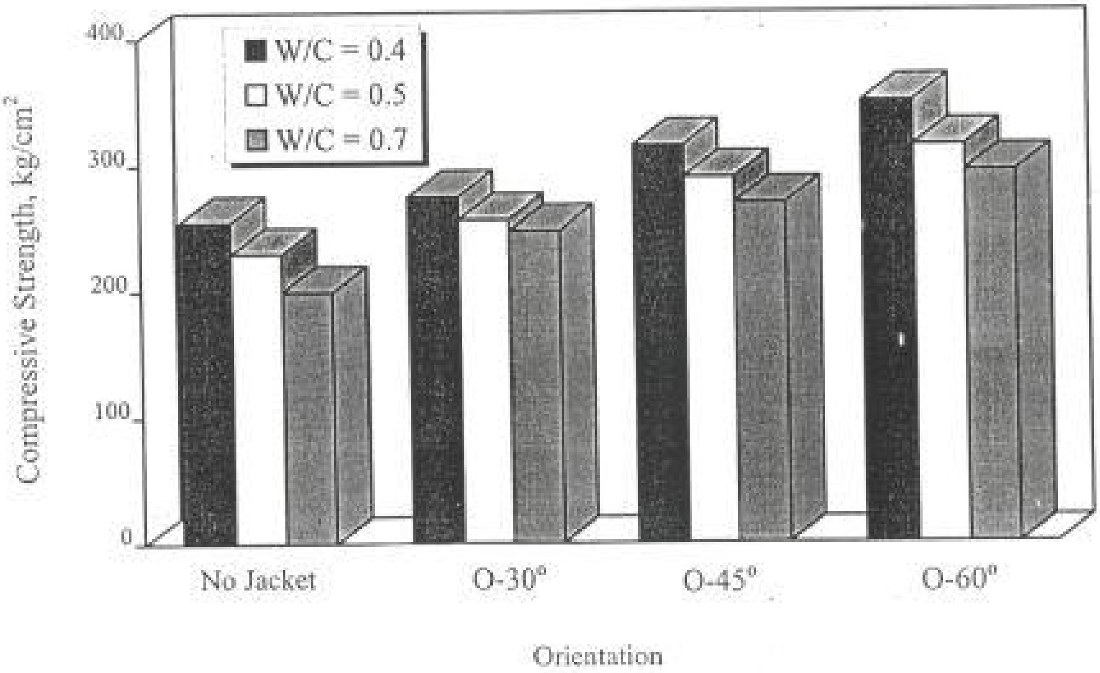


Fig. 6 Effect of reinforcement orientation and W/C on cracked cubes repaired by ferrocement jacket.

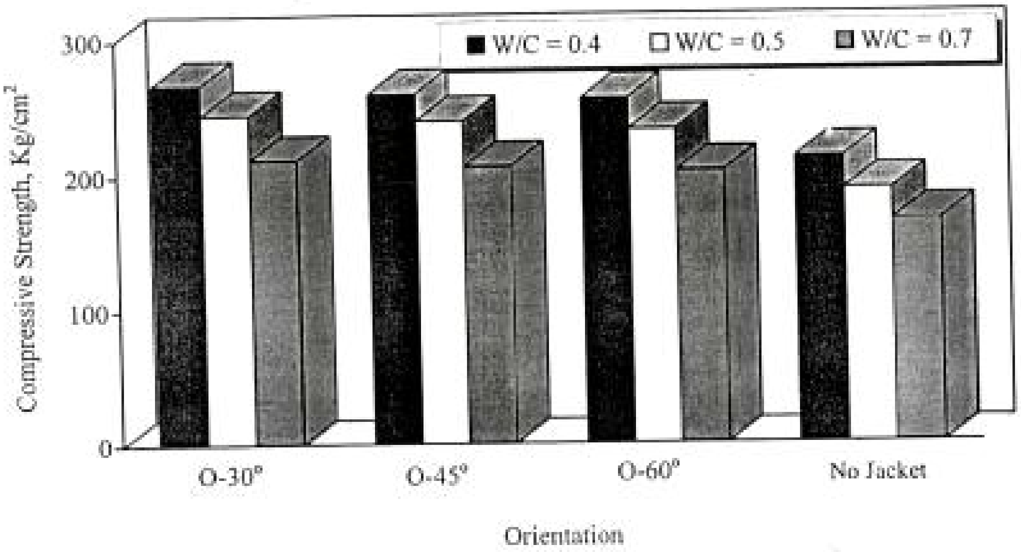


Fig. 7 Effect of reinforcement orientation and W/C ratio on cracked prisms repaired by ferrocement jackets.

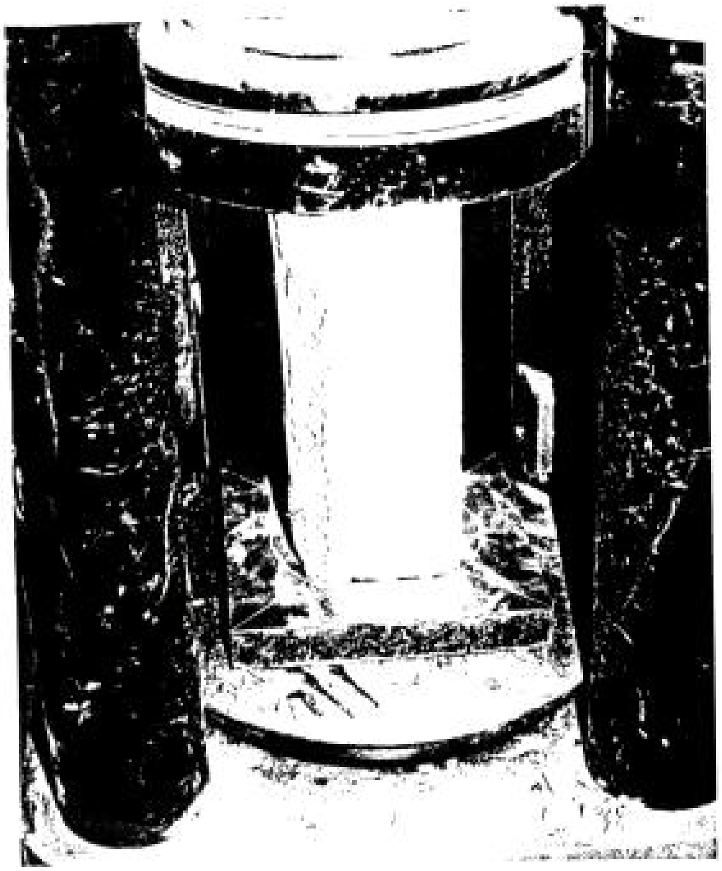


Fig. 8 Typical failure of a prism element strengthened by a ferrocement jacket.