Ferrocement – A Review

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Abstract

Ferrocement has been proved as a reliable, cheap strengthening component for reinforced concrete structure in construction industry. Ferrocement element can be used as a plate or walling units or as a fire resisting unit. Though there has been many experiments done on the strength (basically Flexural, compressive) by taking different section of ferrocement plates as well as beams, this paper has given an importance on the shear behavior of ferrocement elements. Since there is no codal provisions has been made for calculating the shear strength of ferrocement elements, this paper has been emphasized to form different empirical formula to calculate the shear strength of ferrocement element. The shear strength of ferrocement element varies due to different layer of mesh used and the shear span(a) to depth(d) ratio(a/d). It is observed that stress intensity as well as cracking shear strength of plate depends upon volumetric fraction (Vf) of wires.

1. Introduction

Ferrocement is a composite construction material where closely spaced wire mesh is embedded with mortar. The ACI committee 549[1] has defined ferrocement a “thin wall reinforced concrete commonly constructed of hydraulic cement mortar reinforced with closely spaced small diameter wire mesh”. The mix is generally of cement and sand mortar, where the wire mesh having wide openings which makes adequate bonding of mixture. This steel wire mesh is responsible for ferrocement structure having very high tensile and flexibility strength which is not found in ordinary concrete structures. Ferrocement is also ideally used as an alternative strengthening component for rehabilitation of R.C element. The ultimate tensile resistance of ferrocement is only due to the reinforcement in the direction of loading and the compressive strength is equal to that of a unreinforced mortar. But in the case of flexure and shear, the analysis and design of ferrocement is complex thus the principle as for the R.C.C is taken into consideration. There are very few reports available on the calculation of the shear strength of ferrocement element.

2. Literature Review

Till today there is no codal provisions being made for the calculating the shear strength of the ferrocement element empirically. Thus the codal empirical formula for R.C.C has been extended for the ferrocement element. In various studies the experimental values has been compared with the empirically solved results obtained from ACI and BS code procedures for reinforced concrete. This paper includes some of the empirical solution and their comparative experimental solution for determining the shear strength of ferrocement element. Different paper solution has taken into consideration to compare the semi empirical solution.
3. Factors Affecting Shear Strength Of Ferrocement Element

From the different experimental studies on ferrocement it has been found that the strength of ferrocement element in shear affects due to the shear span \((a)\) to depth \((d)\) ratio \((a/d)\) and volumetric fraction \((V_f)\) of mesh reinforcement.

![Diagram showing factors affecting shear strength](image)

Now the cracking shear strength of the can be calculated analytically [3]. The following equation has been derived to predict the shear capacity of ferrocement plate.

**Cracking shear strength \((\vartheta_{cr})\):**

\[
\vartheta_{cr} = (0.27 + V_f^{0.65}) \times (F_{cu} \times (d/a))^{0.65}
\]

Where,

- \(V_f\) = volume fraction of mesh depending upon size of opening
- \(F_{cu}\) = Mortar compressive strength
- \(a\) = shear span
- \(d\) = Overall depth of plate.

4. Different proposed Empirical Solution for calculating the shear capacity Of Ferrocement element

4.1. Method 1 - Calculation of cracking shear strength of ferrocement plates [2]

According to the reference no.2 the increase in the volume fraction \((V_f)\) of the wire mesh layer subsequently increase in the shear carrying capacity of the ferrocement plate. It is observed that stress intensity as well as cracking shear strength of plates depends upon volume fraction [2]. The experiment has been carried out by taking a section of \([490 \times 230 \times 20\text{ mm}]\) and the test result is being verified by using the FEM (Ansys) [4].

From the above experiment it has been found that Hexagonal mesh improves the shear capacity than that of Diamond and Square mesh because higher straight length [3]. From these results it has been found that strength depends upon volume fraction \((V_f)\). The volumetric function all type of mesh can be calculated by using formula.

For square mesh:-

\[
V_f = \left(\frac{N}{4}\right) \frac{\pi d w^2}{h} \left[\left(\frac{1}{D_l}\right) + \left(\frac{1}{D_t}\right)\right]
\]

Where \(N=\text{No. of mesh layer}, \pi = 3.14,\)

\(d_w=\text{Diameter of wire mesh}\)

\(D_l=\text{distance center to center between longitudinal wires}\)

\(D_t=\text{distance center to center between transverse wires}\)

\(h=\text{thickness of ferrocement plate}\)

In this section [6] a rectangular section of size \([600 \times 150 \times 25 \text{ mm}]\) has been tested experimentally and the value is being compared with the empirical formula based on Australian code (AS 3600-1994) and American code (ACI Committee 318-95). It has been proved from this section that the number of increase in mesh improves the shear capacity of the member. Another result shows that beyond \((a/d)=3\) the flexural behavior is predominant and design of the member based on flexure is enough but \((a/d)<3\) the shear behavior is predominant. The member is being put under a two point load testing machine and load was applied by means of proving ring. Different shear span to depth ratio as well as the number of layers of mesh has taken into consideration. Different properties of member having same sizes has put under the same testing procedure and the ultimate shear force \((V_u)\) and the cracking shear load is measured. Then the test result was compared with the empirical formula suggested for R.C.C in Australian code (AS 3600-1994) and American code (ACI Committee 318-95). After comparison it has been observed that the formula for R.C.C can be extended for ferrocement. Thus a separate formula is being generated for predicting the shear capacity of ferrocement element. Shear resistance of ferrocement member is mainly depends upon mortar and longitudinal reinforcement.
i) Thus Shear resistance due to mortar can be expressed as 

\[
\frac{V_u}{bd} = k \frac{\sqrt{F_{cu}}}{a/d}
\]

Where \(V_u\) = Shear capacity \\
\(F_{cu}\) = Compressive strength of mortar \\
k = constant, which can be calculated from the graph drawn between shear capacity vs. \(F_{cu}/(a/h)\).

ii) Shear resistance of ferrocement member can be expressed as the sum of shear resistance due to mortar and the wire mesh. Thus the expression derived from the experimental data is due to the shear to be contributed by mesh only is-

\[
\frac{V_u - V_m}{bd} = y \times V_f \times \frac{F_y}{a/d}
\]

Where, \(V_m\) = ultimate shear load of mortar element \\
\(V_f\) = volumetric fraction \\
\(F_y\) = yield strength of the wire mesh \\
b = width of plate

\[y=\text{constant which can be found from the graph plotted [ (V_u-V_m)/bd ] vs. [(V_f\times F_y)/(a/d)]}.\]

Thus from the combination of (1) & (2) will give the shear resistance of ferrocement element. Finally the empirical equation can be written as:-

\[
\frac{V_u}{bd} = \frac{\sqrt{F_{cu}}}{a/d} \left( k + y \frac{V_f \times F_y}{\sqrt{F_{cu}}} \right)
\]

(3)

4.3. Method-3-Empirical formula derived by Desayi\cite{7} for Different Cases Of Shear Formula

According to reference no. 7 there may be formation of flexure-shear crack and web shear crack, and the failure due to flexure-shear and web-shear may occurred. Thus the analytical expressions has been derived to predict the shear force at cracking and failure. The equations has been developed by comparing the different experimental results. These empirical formula has been derived from the ACI and BS code procedures applicable for reinforced concrete and compared. Most of the empirical procedure currently available to predict the shear behavior of ferrocement element are probably less than satisfactory. As it has been found that there are two possible types of inclined cracks, namely flexure-shear and web-shear cracks and correspondingly two different modes of failure in ferrocement member\cite{8,9}. In this study\cite{7} two layouts of meshes have been proposed and they (1) distributed throughout the thickness and (2) lumped near the extreme fibers of the specimen. Small diameter of steel called skeletal steel are placed at the middle of the specimen. The proposed empirical solutions are derived as in [Ref no. 7] was compared with experimentally obtained data [Ref no. 8 & 9] and the best fit equation s are proposed for evaluating the different characteristics strength. These equations can be used for design purpose.

The following table-1 shows the best fit equations proposed for shear force at cracking and failure and ratio of the experimental and empirical solution. The above empirical solution has been proposed after the experimental results being compared with the procedure followed to calculate the shear strength by ACI:318\cite{10} and BS:8110\cite{11}.Where ‘d’ has been taken as overall depth of ferrocement element instead of effective depth.
6. NOTATIONS USED

\( a \) = shear span  \\
\( b \) = width of the section  \\
\( d \) = overall depth of the section  \\
\( P \) = Load applied  \\
\( Vt \) = volumetric fraction of wire mesh  \\
\( \sigma_c \) = cracking shear strength  \\
\( V_u \) = ultimate shear load  \\
\( F_{cu} \) = compressive strength of mortar  \\
\( F_y \) = yield strength of wire mesh  \\
\( V_u \) = Shear force at flexure-shear failure  \\
\( V_{cf} \) = Shear force at flexure-shear crack  \\
\( V_{uw} \) = Shear force at web-shear failure  \\
\( V_{cw} \) = Shear force at web-shear crack \\
\( P_m \) = Volume fraction of wire mesh used in longitudinal direction  \\
\( P_{bt} \) = Volume fraction of skeletal steel bars in longitudinal direction  \\
\( \Theta \) = Inclination of the crack with the longitudinal axis of the specimen, \( \tan^{-1}(d/a) \) \\

7. References

[1] ACI committee 549 report, Guide for design, construction and repair on ferrocement. ACI 549.1R-93, 1993  
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[7]. A Semi-Empirical Approach to Predict Shear Strength of Ferrocement, P. Desayi & N. Nandakumar, Cement & Concrete Composites II(199.5) 207-218


[10]. ACI Committee 318, Building Code Requirements for Reinforced Concrete (ACI 3 18-89). American Concrete Institute, Detroit, 1989, pp. 351.