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Computational Analogies of Polyvinyl Alcohol Fibres Processed Intellgent Systems with Ferrocement Slabs

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Abstract: Ferrocement composites have distinguished characteristics when compared to other lightweight composites mainly due to its high strength to weight ratio and ductility. Ferrocement panels are being used in low cost housing units with locally available materials. These panels are generally upto 25-50mm thick. Addition of fibres as a secondary reinforcement to ferrocement mortar greatly influenced matrix failure before yielding of the steel mesh. This paper focuses on the experimental study of the flexural behaviour of ferrocement panels with Polyvinyl Alcohol (PVA) fibres.PVA fibres which finds its applications in engineered cementious composites has been selected due to its hydrophilic nature and high tensile strength. High strength cementitious mortar mix consisting of silica fumes and quartz powder at different proportions were developed for casting ferrocement slab panels. Also, polyvinyl alcohol fibres were added at different volume fractions ranging from 1% to 3% to further improve the mechanical properties of the mortar mix. The compressive strength of the optimized mix was 53.47 MPa at 2% PVA fibre. The slabs were casted by placing four layers of 1mm diameter galvanized steel welded mesh with 12mm mesh size. The dimension of the slab was 700mmx300x25mm.The slabs were tested under two point loading in universal testing machine. The comparative study between the ferrocement slab panels with and without PVA fibres on various parameters has been done. These parameters included load vs deformation, stress vs strain , crack patterns, flexural strength and toughness.

Keywords:*Ferrocement slabs, Polyvinyl Alcohol (PVA)fibres, High strength mortar ,Flexural behaviour.*

1. Introduction

Ferrocement - Ferrocement has been used as potential low cost housing material and as strengthening material.In India, ferrocement technology is gaining popularity especially for the reconstruction of houses destroyed by natural disasters due to ease of construction with less skilled labour. American Concrete Institute states that "Ferrocement is a type of thin wall reinforced concrete usually made of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small sized wire mesh, the mesh may be of metallic or other suitable materials" (ACI 2006)[1].When compared to normal reinforcing steel bar ,multiple layer of wire reinforcement increases the specific surface area , thus providing high modulus of rupture and elasticity. Moreover, ferrocement have homogeneous isotropic properties in both longitudinal and tranverse directions[2]. One of main advantage of ferrocement composites is that it can be developed at varying degree of strength and properties. Various mineral admixtures in partial replacement with cement are used to develop high strength mortar matrices. Silica fumes upto 15% by weight of cement increased the compressive strength of mortar and flexural performance of ferrocement panels[3]. High calcium wood ash(HCWA) upto 8% by weight of binder improved flexural stiffness , crack resistance and serviceability of ferrocement reinforced concrete composite slab[4].Further in a study using digital image correlation technique [5] increasing the mesh volume fraction enhanced the flexural capacity, ductility index and energy absorption. Acoustic Emission Technique has been developed to monitor the different modes of fracture development of multilayer ferrocement composite slab. Inclusion of 10% of rubber powder by weight of binder can change the failure mode from brittle to ductile[6].

Fibres as reinforcement in mortar - Many natural and synthetic fibres is added to the mortar matrix to improve its mechanical properties. Addition of synthetic fibres in short and discrete form increase the crack resistance, tensile load resistance and shear resistance of the mortar. Inclusion of 4% of steel fibre enhanced crack control and flexural capacity[2]. Macro steel fibres provided the high ultimate failure load and delayed the propagation of macro cracks[7].0.2% of polypropylene fibres and 1.2% of glass fibres with 5 layers of wire mesh led to increase in compressive strength of mortar and 58.33% increase

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in flexure strength of slab[8]. The bond strength between fibre and the mortar can be improved by stronger mortar matrix and fibre type.PVA fibre provided highest interfacial tensile bond strength and highest split tensile strength followed by basalt and glass fibre. In fibre reinforced concrete beam, PVA fibres made them more tough and ductile accompanied with better post cracking flexural behaviour[9].

Research Significance -The flexural behavior of different fibres like steel ,polypropylene , basalt fibres in ferrocement has already been studied by authors .However findings on ferrocement fabricated with PVA fibre is lacking. The present study focuses on developing ferrocement slab panels with PVA fibre.PVA fibres are used due to its hydrophilic nature , ease of dispersion in the matrix ,superior mechanical properties and delaying crack propagations. They have also been reported to be compatible with cementitious binders. Silica fumes which has been used as partial replacement with cement can reduce the problem of waste disposal. This ferrocement panels can be used in low cost modular housing, water tanks, structural retrofitting, roofing elements, permanent formwork, infilled composite wall panels etc.

Materials Used

Cement- Ordinary portland cement of grade 53 confirming to IS 12269-2013 is used in the work. The properties of the cement is given in the **Table 1.**

Sand **-** Manufactured sand confirming to Zone-II as per IS 383-1970 is used. The properties of the fine aggregate is given in the **Table 2**.

Silica Fumes- Silica fumes contains average particle of size 150nm with a specific gravity of 2.6

Quartz powder **-**Quartz powder with 200 mesh particle size was used as a filler to increase the packing density.

Table 1. Properties of cement

Properties	**Experimental outcome**
Specific gravity	3.15
Consistency(%)	32
Initial setting time(min)	35
Final setting time(min)	560
Fineness(%)	7.9

Table 2. Properties of fine aggregate

Properties	**Experimental Outcome**
Specific Gravity	2.87
Water absorption(%)	2.53
Fineness Modulus	3.32

Polyvinyl alcohol fibre **-** Polyvinyl alcohol (PVA) is a white powder obtained by polyvinyl acetate which is readily hydrolyzed by treating an alcoholic solution with aqueous acid or alkali[10]. This powder is extruded to PVA fibres.The properties of the fibres is listed in **Table 3**.

Table 3. Properties of Polyvinyl Alcohol Fibre

Property	Details
Fibre length(mm)	12
Diameter(microns)	14
Tensile strength (MPa)	1400-1600
Elastic Modulus(GPa)	39-42
Elongation (%)	7
Density(g/cm³)	1.3

Mix No.	Cement	Sand	Silicafumes	Quartzpowder	Water/cement ratio	Superplasticizer(%)
Reference mix	1	2	0	0	0.4	3
Mix 1	1	2	0.15	0	0.4	3
Mix 2	1	2	0.15	0.05	0.4	3
Mix 3	1	2	0.15	0.10	0.4	3

Table 4 Mix proportions for High strength mortar(By weight of cement)

Steel wire mesh- Welded galvanized mild steel square mesh with a wire diameter of 1mm and 12mm spacing was used.

Superplasticizer- Sulphonated Naphthalene polymer based superplasticizer confirming to IS 9103-1999 was used. The specific gravity was 1.2 with a pH value 7-9.

Water- The pH of the water shall not be less than 6 and free from suspended solids , dissolved salts and other impurities.

Development of high strength mortar - Optimum mix design for mortar mix was obtained by trial method. The mix proportions are given in the **Table 4**. After adding 75% of the mixing water, 50% of the superplasticizer, a mixture of cement, silica fume, and quartz powder, and then gradually adding sand and the remaining superplasticizer and water, the process was repeated[11][12]. 36 cubes with compressive strengths of 70.6 mm were prepared for the optimized mix. These samples were tested in accordance with IS 516-1959.

Development of high strength fibrous mortar - Polyvinyl alcohol fibres were added at different volume fractions at 1%,2% and 3% to check the increase in mechanical properties of the optimized mix. Cubes of size 70.6mmx70.6mmx70.6mm and cylinder of diameter 100mm and length 200mm were prepared and tested.

Specimen preparation - The dimensions of the ferrocement slab panels for the flexural test are 700mm x 300mm x 25mm.Wooden moulds of the same size was greased with oil on its inner surface.Weld mesh of size 1mm diameter and 12 mm mesh size was used[13]. These meshes were cut to a length of 690mm in length and 290 mm in width.Firstly, a mortar layer of 5mm thickness was placed at the bottom of the mould. Four layers of weld mesh were tied together with a binding wire. These tied meshes were placed above the mortar layer. Again, mortar was placed above the mesh layers upto required thickness of the slab , compacted and levelled at the top for smooth finish**(Fig 2).** After 24 hours of casting, the slabs were demoulded and cured for 28 days.

Flexure strength testing - After 28 days of curing the slabs, white wash was applied for clear indication of the cracks. Markings on the slab necessary for two point bending were done. The effective span of the panel was designed to be 560mm[14].Two points load are applied at one third distances from support using spreader beam. Dial guages of 0.01 mm sensitivity is used to measure the deflection of the slab. Strain value is taken by demec guage of 200 mm guage length and 0.001 mm sensitivity in the mid span of the slab[15]. There were three dial gauges used. The other two were positioned at the point loads and one at the midpoint. As the load increased, cracks were found and marked.

2. Result And Discussion

Compression strength of high strength mortar - Effect on compressive strength by partial replacement of silica fumes and quartz powder is indicated in the **Table5**.Mix 3 i.e, 15 % silica fume and 10% quartz powder gives better compressive strength**.** The compressive strength was 40.88 MPa. Silica fumes and Quartz powder densified the matrix and improved the particle packing. The filler effect reduces the porosity of the transition zone, creates a dense microstructure, and boosts the mix's strength.

Mix No.	Compressive strength(MPa)					
	7 days		14 days		28 days	
	Replicate	Avg	Replicate	Avg	Replicate	Avg
Ref mix	29.69	31.3	31.05	33.29	40.92	41.78
	39.25		38.8		401.9	
	24.96		30.02		42.53	
Mix 1	25.19	24.54	27.6	27.78	34.19	34.88
	23.5		28.16		34.5	
	24.93		27.59		35.95	
Mix 2	22.68	27.13	25.04	29.2	34.07	38.16
	26.75		30.39		37	
	31.95		32.16		43.4	
Mix 3	27.5	29.84	29.65	33.25	37.72	40.88
	31.59		33.92		40.92	
	30.42		36.17		44	

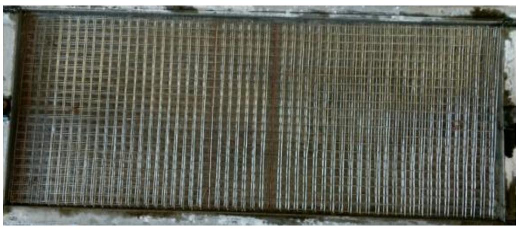
Table 5. Compressive strength of high strength mortar

S.NO	SPLIT TENSILE STRENGTH(MPa)	
	0% PVA fibre	2 % PVA fibre
1	4.2	5.94
2	4.68	5.63
3	4.53	5.47
Average	4.47	5.68

Table 6. Split tensile strength of high strength fibrous mortar

Compression strength of high strength fibrous mortar - Samples with 2% PVA fibre of total volume of composite showed highest compressive strength in comparison to 1% and 3% volume fractions(**Fig 1)**.The compressive strength obtained by adding 2% fibre was 53.47 Mpa.31% increase in compressive strength(from 40.88 to 53.47 Mpa) of the specimen was observed with 2% fibre in comparison to specimen with no fibre This is due to the fact that PVA fibers can act as numerous tiny reinforcements against shear forces by holding the shear plains together when shear forces are generated during uniaxial compression. For a fiber volume of 3%, it is observed that the compressive strength decreases.This is because higher percentage of fibre makes consolidation difficult leading to porous structure in matrix which may decrease the strength**[10].**

Fig 1. Compressive strength of strength fibrous mortar at different volume fractions



(a)

(b)

(c) **(d)**

(e) **(f)**

Fig 2. (a)Polyvinyl alcohol (PVA) fibres ,(b)Fresh mortar mix ,(c)Placing mesh over mortar layer,(d) Ferrocement slab without PVA fibre ,(e)Ferrocement slab with PVA fibre ,(f)Flexure test on slab in UTM.

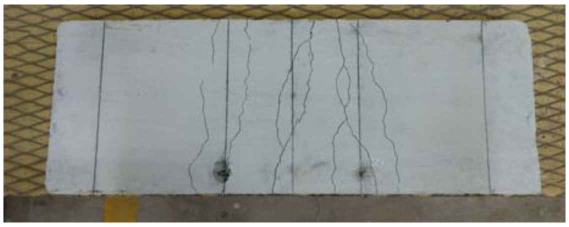
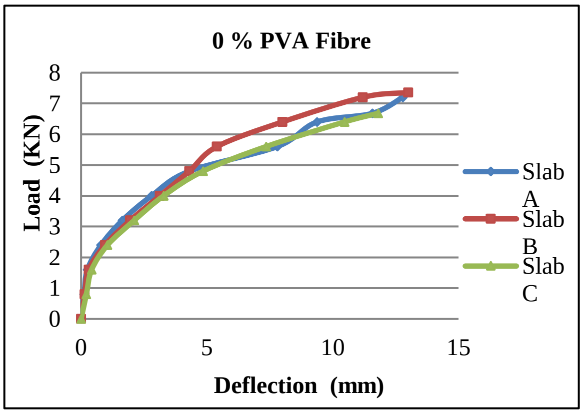


Fig 3. Crack patterns in slab panels



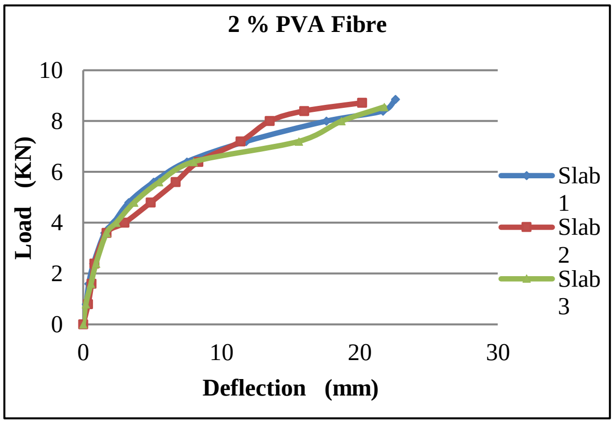


Fig 4. Load vs deflection

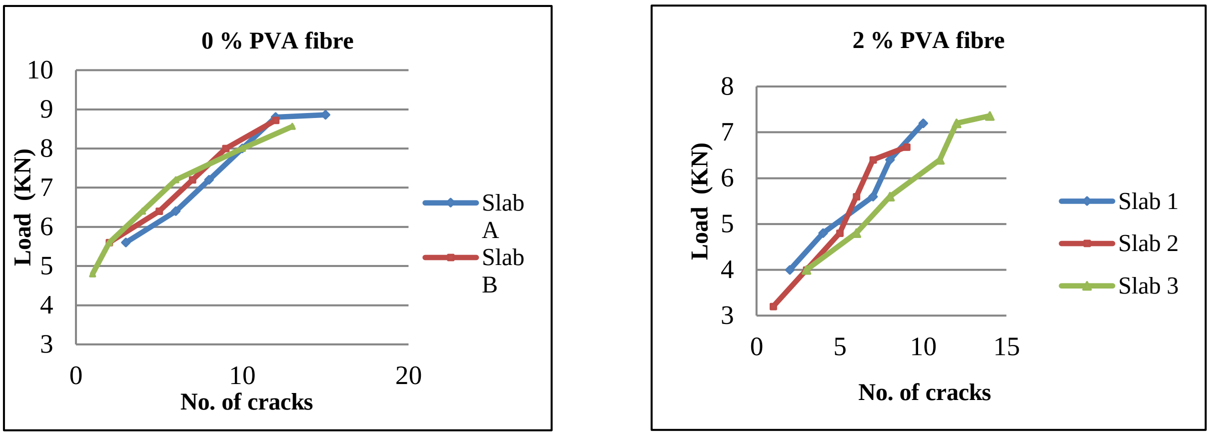


Fig 5. Stress vs Strain

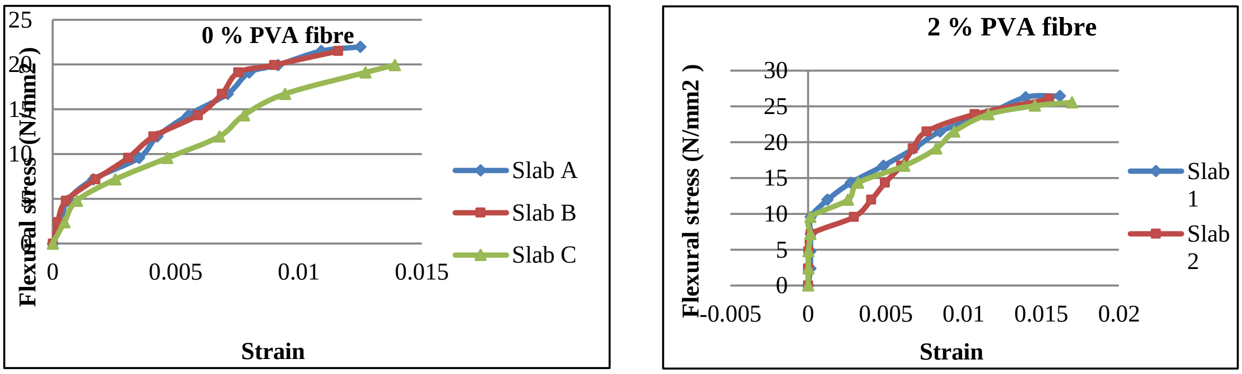


Fig 6. Load vs No.of cracks

Tensile strength of the mortar - The split tensile strength was increased to 4.47 Mpa to 5.68 Mpa(27.1%) with 2% fibre due to strong interfacial bond strength of PVA fibre (**Table 6**).

Flexural behaviour

Load vs deflection- The load vs deflection curves are plotted for allthe slabs(**Fig 4)** .These load – deflection graph depicts the flexural behaviour of slabs in a clear manner. At initial stage, linear response is observed .The linear responses are due to the elastic behaviour of the composites .The strains in the weld mesh and concrete are verysmall at this portion.Initial cracking wasobservedat loads from45to 65% of theultimate load. At a load level of approximately 60 to 73 % of the maximumappliedload,theyieldingoftheweld meshstarted.Withfurtherincrease intheload,the graph showed the non linear behaviour indicating the start of plastic range. The failure in the slab specimens can be classified as precracking stage, multiple cracking stage and failure stage. Precracking stage is the first stage of load deflection curve prior to cracking. In this stage load is mainly carried by mortar matrix. Multiple cracking stage is characterized by development of fine multiple cracksandtheirwidthincreases withincreasingload.The mechanism of transfer of loadfrommortar tothe steel wire mesh takesplace in this phase.Newcracks starts developing due to elongation of steel wire mesh. At failure stage the width of the crack starts increasing. The load is carried only through steel meshes. Large deformations with small increase in load is observed and the cracks intensifies and extends to the depth of the slab .

The complete failure of PVA fibre reinforced composites is observed at 20–22 mm deflection range. This is the consequence of the rupture of PVA fibres at high loads due to exsistence of chemical bonding between the reactive PVA fibre surface and cementitious matrix. After the peak load when deflection capacity is exceeded, the rupture of PVA fibres indirectly is determined by hearing the numerous rupturing sounds of fibres from tested composites slabs.

In most fiber-reinforced slabs, the load increases linearly with deflection, indicating an elastic region. At this point, the matrix resisted the load without cracking, so there were no cracks. A single crack appeared in the middle of the structure as the load was increased further. At this point, the fibers started acting as bridges, preventing a single crack from becoming a localized crack and instead creating a number of tiny cracks that ran along the slab. This occurred until the fibers were separated from the matrix and the beam became saturated with numerous tiny cracks.

Stressvsstrain- The strain capacities of the fiberless slabs ranged from 0.03% to 1.4%, whereas the strain capacities of the slabs that contained 2% PVA fiber ranged from 0.001% to 1.7% (see Figure 5). The final strain capacity of the PVA fibre slab increased by up to 21%. PVA fiber displayed a strain hardening property that resulted in multiple cracking. Cement-based composites reinforced with discontinuous fiber can have ductile response. Due to strain localization within a single crack, the stress–strain relationship quickly reaches its peak and displays a softening branch in the absence of fibers in the matrix. The matrix's composition and the cross-sectional flaw distribution were the primary factors that influenced the first cracking stress and strain. Multiple cracks began to form after the yield point, and the fibers that connected the cracks grew longer as a result of the axial stress they transferred. At the same time, they were gradually pulled out of the matrix at the crack locations. New cracks stopped forming and crack localization became apparent as bond strength between the fiber and the matrix, which was dependent on factors like interfacial bond strength, the tensile strength, and stiffness of the fibers.

Crack pattern and Toughness- In all the slabs multiple cracking with failure at the middle-third region of the effective span of slab was observed**(Fig 3)**. The number of cracks increased rapidly after the first crack developed**(Fig 6)**. It has been observed duringthe experimental investigation no visible cracks were obtained until 45 – 55 %of the ultimate load in the case of slab panels without fibres whereas, no visible cracks were obtained until 55 – 64 %of the ultimate load in the case of slab panels with PVA fibres. It can be inferred that the inclusion of PVA fibre has delayed the first crack load. From the results (refer **Table 7 and Table 8)** it can be interpreted that the first crack load has been delayed in the slabs with PVA fibres from 3.2 - 4 KN to 4.8 – 5.6 KN thus exhibiting higher initial cracking strength .The peak load has been also increased to an average of 7.08 to 8.71 KN , about 23 % increase .Due to increase in ultimate load, the flexural strength has also been enhanced from 21.14 MPa to 26.02 MPa, about 23.1 % increase of flexural strength. The use of PVA fibres and more layers of mesh reinforcement lead to greater flexural strength. The better bridging effect of PVA fibres after matrix cracking is more pronounced factor for higher flexural capacity.

Energy absorption capacity is typically used to describe toughness (ductility). The area beneath the load–deflection plot is used to calculate it. The area under the load–deflection curve up to the point of collapse is integrated to estimate the slab specimens' toughness. The PVA fiber-infused slab panels' relative toughness increased to an average of 2.1 times that of the fibre-less panels. This is because PVA fiber panels have a higher peak load deflection curve and a significantly pronounced strain hardening behavior. The fibers carried and transferred the load to the cement matrix as the load increased, which led to deformation and hardening and an increase in the ductility and toughness of the cement matrices. By preventing crack from localization and increasing the first cracking load, multiple crack formation improves the composite's ability to absorb energy [11].

Table 7. Flexure test result of slab with 0% PVA fibre

Slab name	First crack load (KN)	Ultimate load (KN)	Flexural strength (Mpa)	Toughness (KNmm)
Slab A	4	7.2	21.5	65.24
Slab B	4	7.36	21.98	69.93
Slab C	3.2	6.68	19.95	56.1
Average		7.08	21.14	63.76

Table 8. Flexure test result of slab with 2% PVA fibre

Slab name	First crack load (KN)	Ultimate load (KN)	Flexural strength (Mpa)	Toughness (KNmm)
Slab A	4	7.2	21.5	65.24
Slab B	4	7.36	21.98	69.93
Slab C	3.2	6.68	19.95	56.1
Average		7.08	21.14	63.76

Conclusion

A comprehensive study was carried out on the flexural behavior of ferrocement panels incorporating polyvinyl alcohol fibres in mortar matrix . Different matrices were formulated by varying silica fumes and quartz powder by weight fraction in an attempt to achieve high strength mortar. Galvanized steel welded wire mesh was used as main reinforcement for controlling the flexural response while poly-vinyl alcohol (PVA) fibers were added for resisting cracks and improving ductility in ferrocement composites. The following conclusions are drawn from the current study.

1. 2 %volume fraction of PVA fibre in mortar matrix offered the highest compressive of 53.47 MPa and tensile strength of 5.68 MPa which is used for casting the ferrocement slabs.
2. The ferrocement panels of flexural strength upto 26.02 MPa can be developed with 2% volume fraction of PVA fibre.
3. The toughness of the PVA fibre panels increased 2.1 times than that of those without fibres. Deflection hardening of PVA fibre enhanced the energy absorption.
4. PVA fibres delayed the first crack propagation in the panels.
5. More number of wire mesh layers bundled together and smaller spacing meshes influenced on flexural strength.
6. These ferrocement slabs with high strength fibrous mortar mix can be suitable for retrofitting and strengthening of structural elements.
7. Due to the lightweight of ferrocement panels, it can be used in precast roof and wall elements. Additionally, previous studies demonstrated that these components are suitable for the construction of a horizontal unit for one-way bending and can withstand significant deflections before failing.

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