Performance of Cement Mortar Composites Reinforced with Polyvinyl Alcohol Fibers

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Abstract. This research studied the hybridization influence of polyvinyl alcohol (PVA), in the first stage as solution and the second added fibers with PVA solution. Performance under flexural loads of cement mortar composite was studied on this basis, PVA concentration in solution used was 1% of cement weight with three PVA fiber volume fraction (1%, 2% and 3%) which were considered as the variables for constant PVA solution to cement ratio (P/C) and w/c ratio as 1.6% and 30% respectively. This paper is specially concentrating on the impact of fiber volume fraction contents and their metis to deform composite. The specimens were tested under one-point load test next two days wet curing and 26 days dry curing. The tests exhibited both ductility and flexural strength of cement matrix increased when the fiber volume fraction content increased. Combination only PVA fibers with the cement mortar composite showed softening in strain behaviors, whereas its performance is brittle for PVA solution-containing specimens, but mixture of PVA fiber with PVA solution to the cement mortar composites showed strain hardening performance. PVA fibers and solution in both surface properties (hydrophilic and/or hydrophobic nature) and chemical composition improved area under the curve of the reinforced cement mortar composites at 2% volume friction of PVA fiber with PVA solution about 197%, 29% and 9.6% compare with 1%, 3% volume friction of PVA with PVA solution and 2% without solution respectively. The addition 2% of PVA fibers increased about 44% flexural strength compare to the control specimens at flow diameter 190mm and 63% compare with 3% at flow diameter 130mm. It is given away that a uniform spreading of fibers through the bulk of the composite material is vital to its outstanding workability. Finally, it was observed fraction of PVA fibers plays as a result a significant role for refining ductility of cement mortar composites.

1. Introduction
Cementitious materials have characteristically brittle performance, several pains have departed into effort to develop the ductility of composite materials[1]. Supplement of that short, at random dispersed fibers have established lone of the chief approaches [2][3][4]. Binary chief sets of fibers composites which show dissimilar performance next the first cracking seemed repeatedly[5]. The chief any presented the softening strain performance by the enhanced ductility, which the loads decline next the first cracking. The additional one and only has the hardening strain conduct complemented in number of cracks which is caused in greater tensile ductility and strength. These sorts of "cementitious composites" are typically named "engineered cementitious composites" (ECC), "strain-hardening cementitious composite" (SHCC) or else "ultrahigh toughness cementitious composite" (UHTCC)[6].

ECC in the strength at ultimate is greater than strength at the first crack, remained lately advanced[7]. The strain-hardening performance may be reached through great modulus fiber is used for example PVA using a reasonable fibers volume fraction usually 2%[8]. PVA be found for produce around 90 year previously such as the principal artificial colloids and it has- been applied in place of several uses as now[9]. Unique of the important uses of PVA fibers have appropriate features such as reinforcement used for cement composite materials for example fibers have elastic modulus and high strength
paralleled to further type of fibers (i.e., polyethylene, nylon, polypropylene fibers, and others types.) this is usually utilized for cement mortar reinforcement [10]. Commonly, the mechanical conduct of the cement mortar composite will be affected through dissimilar causes for instance, the type of fiber, orientations, volume of friction of fibers in the mortar(matrix), geometry and distribution [11]. The characteristic factors such as young’s modulus, tensile strength, density and fiber elongation of PVA fiber range from 25–40 GPa, 880–1600 MPa, 1.30-1.6g/cm³ and 6–10% respectively[10]. The use of PVA fiber into cement composite rely significantly in fiber kind[10].

Usually, finer sort of PVA fibers have been utilized in place of fibers such as asbestos standby in cement roofing[10]. Incase thicker PVA fibers, it have been extensively utilized in construction requests which involves concerning roadbed overlays, industrial of floors, tunnel lining and many types of shotcrete[10]. Also, PVA fibers may be utilized to prepare ECC, which it is a sort of UHTCC, categorized through in height ductility, narrow crack size controller and comparatively little fibers volume friction [12]. PVA fibers have as well as been importantly applied for making in height interpretation fibers reinforced cement composite[13].Second application PVA uses as a water soluble manmade of polymer which goes and forms of water soluble nonionic polymer has being a(vinyl group)[14][15]. PVA is harmless , accordingly luxury not risky to handle and comparatively environmentally friendly[16]. Earlier investigation presented which the possessions of cement paste may be enhanced by the totaling PVA[17][18]. PVA with degree of solution (87–89%) is usually used in adjusted cement composite material [19][17][20][18].Singh and Rai[21] described with a view to there was an enhancement strength of compressive owing to the decrease porosity what time PVA uses by way of rice husk ash mixed cement. Development strength can be qualified to the chemical interface concerning the PVA and cement constituent part, therefore, refining the link in among the cement grains or making specific compounds that block the pore in the cement paste [21]. Allahverdi et al. [19] pointed so as to the quantity of P/C ratio with w/c can be used in the mix has significantly affected the actions from flexural strength. By a lesser w/c percentage, the cement mortar modified with PVA found not demonstration some enhancement in the flexural strength through the rise P/C percentage, on the other hand in its place had a marginal decline flexural strength rate[19].

Conversely, cement paste modified with PVA by w/c equal to 30% also lesser P/C percentage had been flexural strength twice greater than that of unmodified cement paste [19]. This consequence determine w/c ratio shows a significant part on the success of the polymer modified mortar. Though, dissimilar conclusion was stated by Kim et al. [9]. The investigators pointed that the compressive strength of PVA modified mortar reduced abstemiously, on the other hand its flexural strength was stated to need no important variations by PVA content [9]. The target of this study is to explain the influence of cross breeding on the flexural actions of cement materials composite. The mixture 1% of PVA from cement weight with three volume fractions of fiber 1%, 2% and 3% was combined to the cement materials composite then undergo to flexural test.

2. Test methods and Materials

2.1 Materials
A- Polyvinyl Alcohol (PVA):- two types of PVA were used:-
1-Polyvinyl alcohol (PVA) powder, 88% nominal hydrolysis was used without further purification. It has molecular weight about 125000. The polymer given as percentage of cement weight. To prepare PVA as solution, approximately 10.0gm of PVA powder boiled in 300 ml water up to polymer entirely melted. PVA solution was reserved overnight in an open-air atmosphere to reduce its volume to an exact value of 100 ml.
2- PVA fiber with hydrophilic characteristics, the features of fibers utilized in research are obtainable in Table 1. Fiber has circular cross-sectional form and is indissoluble in water. Figure 1 demonstrations the fiber and powder PVA.
Table 1. Mechanical and physical Properties of fiber*.

| Fibers | Diameters µm | Length mm | Young’s modulus GPa | Tensile strength MPa | Density Kg/m³ |
|--------|--------------|-----------|---------------------|----------------------|--------------|
| PVA    | 30           | 12.7      | 25-40               | 880-1600             | 1300         |

*from manufacture

Figure 1.A. Polyvinyl alcohol powder and Polyvinyl alcohol fiber. Powder PVA

Figure 1.B. Polyvinyl alcohol powder and Polyvinyl alcohol fiber, PVA fibers

B-Ordinary Portland cement:
Type I Portland cement was used in the study, it compliances with the requirements of Iraq Standard No.5 (IQS5:1984)[22]. The chemical characteristics of the cement are obtainable in Table 2.

Table 2: The chemical characteristics of the cement.

| Composition | CaO  | SiO₂ | Al₂O₃ | Fe₂O₃ | MgO  | SO₃  | K₂O  | L.O.I |
|-------------|------|------|-------|-------|------|------|------|-------|
| Cement (%)  | 61.53| 20.16| 4.95  | 3.86  | 1.62 | 2.62 | 0.58 | 1.63  |
| Compound Composition according to Bouge's equations | C₃S | C₅S | C₃A | C₄AF |
| Cement (%)  | 51.03| 19.30| 6.59  | 11.75 |

The type of fine aggregate was natural sand has maximum size of 600micron Results indicate that fine aggregate grading is within the requirements of IQS 45/1984[22] zone four as shown in Figure 2. The sand was disseminated out and left to dry in air before use.
D- **Superplasticizer (SP).**
Modified poly carboxylates was applied as super plasticizer (SP) to control the excellent flowability properties of fresh mortar ASTM C494-14[23].

2.2 **Tests**
A- **Flow test**
To estimate the influence of PVA polymer solution and fibers on mortar workability, spread diameter was according to ASTM C230-10[24] testing method.
B- **Flexural test:**
The test was specified by a one-point load test. The specimen has dimensions 40mmx40mmx160mm. The flexural strength (FS) of the samples was taken in agreement with ASTM C 348-98,[25] and using the equation 1.

\[
FS = \frac{3PL}{2bd^2}
\]  

(1)

In this equation, \(P\) (kN) is ultimate applied loads, \(L\): is the span length, \(b\) (mm): is the average prisms width, and \(d\) (mm): is the prisms depth.

2.3 **Mixing, casting, and curing procedures.**
Mixing procedure started with mixing cement, sand, then water with SP were principal mixed according the ASTM C305-10[26] process. The solution of PVA is blended with the prewetted ingredients of composites. Following mixing process was followed; The dry ingredients were placed into a container and dry mixed for 30–60s up until the mixture improves homogeneous using a spiral hand mixer; water was added and SP then PVA solution the mixing continued; The fibers were added and mixing continued until dispersion was apparent[27], as shown in figure 3.
This was then vibrated for 2 min to remove large air voids. The specimens were demolded approximately 48 hours after casting and then moist cured for two days at 20°C and more than 95% relative humidity, and then 26 days dry curing at 20°C and 50-60% relative humidity. The mix ratios of the cement mortar are specified in Table 3, and specimens after demolded was shown in Figure 4.

| Mix No. | Cement gm/m³ | Sand gm/m³ | Water ml/m³ | SP ml/m³ | PVA solution ml/m³ | PVA Fiber (vol.%) |
|---------|---------------|------------|-------------|----------|--------------------|-------------------|
| Mix₅₇  | 1000          | 500        | 450         | 0        | 0                  | 0                 |
| Mix₁   | 1000          | 500        | 300         | 5        | 16                 | 0                 |
| Mix₂   | 1000          | 500        | 300         | 5        | 16                 | 1%                |
| Mix₃   | 1000          | 500        | 300         | 5        | 16                 | 2%                |
| Mix₄   | 1000          | 500        | 300         | 5        | 16                 | 3%                |
| Mix₅   | 1000          | 500        | 300         | 10       | 0                  | 2%                |
3. Results and Discussions

PVA solution increases the cement mortar composite workability, as shown in Figure 5. The effect is detected up to the specified limits and at any specified w / c ratio. The relatively larger values of friction volume of PVA fibers work poorly and result in low workability. The optimistic effect of PVA on cement mortar composite workability is chiefly understood in terms of enhanced consistency owing to both the ball bearing act and the separating effect of polymer. Moderately high P/C-ratios, yet, decrease the cement mortar composite workability because rises in cement mortar composite viscosity.

The w/c-ratio of cement mortar composite at a given consistency (flow or slump) can therefore be obviously declined by modifying it with an appropriate amount of PVA. Moreover, viscosity modifying by PVA solution plays a significant role in the diffusion of the fibers in cement mortar composite. It is found that a uniform spreading of fibers through cement mortar composite is vital to its outstanding workability. Reduced fiber dispersion may reduction the workability of cement mortar composite significantly.

![Figure 5](image_url)

**Figure 5.** Spread diameter of cement pastes modified by polyvinyl alcohol at different PVA fibers volume friction.

3.1 Flexural Results

The typical flexural behavior of cement mortar prisms without any additives is shown figure 6, and results shown in Figure 7. In addition, the results of cement mortar composite prisms having PVA solution without PVA fiber is shown in Figure 8. The performance in fracture for cement mortar
composite with PVA solution was improvement due to adequate polymer film formation and smooth surface microstructure. The load-deflection behavior of cement mortar composite prisms unmodified and modified with PVA solution is shown in figure 9.

![Figure 6. Left: flexural set up under test](image1)

![Figure 7. Right: during the failure](image2)

![Figure 8. Flexural strength of cement pastes modified by polyvinyl alcohol at different PVA fibers volume friction.](image3)

![Figure 9. The load-deflection behavior of cement mortar composite prisms unmodified and modified with PVA solution.](image4)
Figure 10 indicate the performance of cement mortar composites prisms contain PVA fiber without PVA solution. The strain-softening performance owing drop of the load when reach a peak point was clear. The low bond of fiber and increase surface roughness and porosity to the cement mortar composite led to the decrease of its biaxial flexural strength. Flexural load of cement mortar composites reduced when first crack occurs. Effects showed post cracking is increased with PVA solution and the volume fraction of fiber. Also, area below the curve is greater to cement mortar composite has 2% of fibers volume friction. The volume friction of PVA fibers Effected on the load-deflection behavior of cement mortar composite is demonstrated in figure 11. It apparent that the load composites of flexural having PVA fibers augmented next first crack and indications the hardening strain manners principally with 2% fibers volume of specimens.

Figure 10. The load-deflection of cement pastes modified by polyvinyl alcohol at different PVA fibers volume friction with and without PVA solution.

Figure 11. Area under the curve (J) of cement pastes modified by polyvinyl alcohol at different PVA fibers volume friction with and without PVA solution.
These actions are referred to the greater fibers attachment strength to cement mortar composite because its best modulus of elasticity and hydrophilic nature. Therefore, the PVA fibers with PVA solution could withstand the additional load of flexural next the first-cracking and thus abrupt drop by the load happened to increase in the deflection. Results showed that combination of PVA solution and PVA fiber by 2% and 3% of volume fraction improved the flexural strength of cement mortar composite up and about 44% and 63% one-to-one compared with addition 1% fiber volume friction at 0.5% superplasticizer. Combination of PVA fibers with PVA solution to the cement mortar composites showed strain hardening manners. The load-deflection behaviors of hybrid cement mortar composites with greater volume of the firmer fiber makes available sensible first-cracking strength [25]. In area of post cracking polymer film form by PVA solution will be arrested the macro-cracks and will noticeably develop the ductility of the cement mortar composite see Figure 10. The good spreading and strong reaction among PVA fiber and cement mortar compounds. The fibers in the mortar with energy absorption capacity is best. As shown in figure 10 the fiber exhibited a ductile rupture and improved bending modulus and the flexural strength with 2% PVA fiber 1.6% PVA The fracture zone was presented in Figure 12 which indicate good distribution of PVA fibers.

Figure 12. The fracture region of metis composite with volume fraction (2%).

3.2 Microstructure Properties
Fracture surfaces are sometimes employed for specimens to be examined by secondary electron imaging as a result of the high degree of resolution and depth of field obtained with this imaging technique. Figure 13 (A and B) describes the SEM photographs of the fractured surfaces of cement mortar composite. Actually, cement mortar composite without PVA solution retained contain crack and the surface turn into coarse and a number of short fibrils shaped, which may be credited by interfaces among the PVA fibers and the mortar Figure (13-A). Though, the connections were not robust sufficient, thus the fiber inclined for effortlessly rupture relatively than pullout. Conversely, cement mortar composite with PVA. Solution fibers were practically divide to the bundles of prolonged fibrils. Figure 14 representing greater reactions among PVA fiber and hydrated compounds of cement. Through the SEM image we note that the solution of PVA improves the dispersed of the fibers in cement mortar which means that each fiber gives a perfect bond to the cement paste.
Figure 13a. SEM photographs of the distribution of PVA fiber in cement mortar: sample (A) without PVA solution

Figure 13b. SEM photographs of the distribution of PVA fiber in cement mortar: sample with 1.6 PVA solution

Figure 14a. Fibers is Pullout on the surfaces of fracture to sample on flexural test (A) without PVA solution

Figure 14b. Fibers is Pullout on the surfaces of fracture to sample on flexural test with 1.6 PVA solution

Through figure 14(a and b) appearances the surface of fibers comes to be rough and several tiny of PVA shaped and bonded on surface of fiber can be referred to strong connections among the PVA fiber and mortar. On the other hand, the fibers tend to fracture pull out incase unmodified mortar with PVA solution due to interaction was not strong enough, compare with modified mortar with PVA was practically split the mortar around the fiber (Figure 14b), for signifying the greater bonds concerning cement mortar and fibers. The strong interfaces between PVA fiber and cement mortar lead to the decent dispersion and able the fiber in the mortar with greater energy absorption ability. The fibers exhibited enhanced flexural strength area under the curve and ductile fracture.

By results of flexural strength and SEM test the consequences apply with the evidence given to Li et al.[28] and[29] et al. used polymer agent with PVA fibers to adapt the interfacial properties between matrix and fibers, thus obtaining a composite with a hardening strain act.

4. Conclusion
The results above have been resolved to the flexural test of cement mortar composites.

1- PVA fibers and solution in both surface properties (hydrophilic and/ or hydrophobic nature) and chemical composition enhanced flexural toughness (area under the curve) of the reinforced cement mortar composites at 2% volume friction of PVA fiber with PVA solution about 197%,
29% and 9.6% compare with 1%, 3% volume friction of PVA with PVA solution and 2% without solution respectively.

2- Low percentage of PVA fiber incorporates to the cement mortar composites showed strain softening performance, whereas the performance is more brittle for PVA solution-containing specimens, but PVA fiber incorporates with PVA solution to the cement mortar composites showed strain hardening performance.

3- The addition 2% of PVA fibers enhanced about 44% flexural strength compare to the control specimens at flow diameter 190mm and 63% compare with 3% at flow diameter130 mm. It is given away that a uniform spreading of fibers through the bulk of the composite material is vital to its outstanding workability.

4- Lowly fiber dispersion may decline the workability of cement mortar composite considerably. fiber dispersion may decline the workability of cement mortar composite considerably.

5- The deflection of specimens was enhanced significantly in cooperation fiber-and PVA solution together.

6- The optimum volume fiber friction about 2% at1.6%PVA solution but it is increased lead to decrease fiber distribution cases void and crack at interface with fibers.

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