Three point bending flexural strength of cemented soil reinforced by PVA and Jute fiber

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Abstract. In this paper, the flexural and post-cracking performance of deep soil–cement column reinforced by Jute fiber and Polyvinyl alcohol fiber, respectively were investigated. The results indicates that both Jute and Polyvinyl alcohol fiber significantly improved the first crack flexural strength and peak flexural strength. In addition, the fiber content play a critical role for enhancing the post-cracking performance of specimens, the peak strength ratio, residual flexural strength ratio, ductility index and energy absorption capacity increased with increasing fiber content. Jute fiber group exhibited slightly better in terms of energy absorption capacity.

1. Introduction
Silty soil is a typical soil in Huanghe area of China, which has characteristics of poor cohesion and instability. In the process of foundation pit excavation, the unbraced Deep Cement Mixing (DCM) retaining wall is used for intermediate excavation. However, cement-soil mixture would have characteristics of low tensile strength and flexural strength, and brittle failure pattern, and the horizontal loads on the DCM pile can give rise to fail in tension. Randomly distributed short fibers have been utilized to modify the mechanical properties of cement-based materials, for instance, flexure strength, tensile strength, and fracture toughness. Various fiber types, including steel, polypropylene, glass, carbon fibers and natural fibers were demonstrated efficient in improving tensile and shear strengths of soil and reducing the cracking propagation process. This work focused on the flexural performance of cemented soil reinforced by Jute fiber and Polyvinyl alcohol (PVA) fiber and evaluated the effect of fiber addition, fiber types on the post cracking performance.

2. Materials and methods

2.1. Materials
The soil used in the tests was retrieved from a construction site at Taiyuan (Shanxi, China). Portland cement (42.5R) was used in this study for preparing specimens. The median grain size is 0.0196 mm, the coefficient of uniformity is 9.566 and the coefficient of curvature is 1.451. The value of liquid limit and plastic limit are 27.0%, 17.2%, respectively, the plasticity index value is 9.8. The dry density of soil is 1.3 g/cm³. Two types of fibers, including Jute fiber and Polyvinyl alcohol fiber, were opted for the fiber addition. The fiber properties of fibers are presents in Table 1.
Table 1. Fiber Properties

| Materials  | Specific gravity (g/cm^3) | Length (mm) | Aspect ratio (l/d) | Tensile strength (N/mm^2) |
|------------|--------------------------|-------------|-------------------|--------------------------|
| Jute fiber | 1.45                     | 18          | 900               | 1600                     |
| PVA fiber  | 1.3                      | 12          | 300               | 2200                     |

2.2. Methods

In this study, the silty soil was first dried and sieved by a 2 mm sieve before mixing. The mass ratio of cement was 15% by dry weight of soils. 0.25%, 0.5% and 1% weight of soils (dry weight) were then added into the mixture gradually by hand, followed by the addition of water. The water to mixture (soil and cement) ratio was 34.5%, the mixture was stirred for 2 min. Subsequently, the fiber and cemented soil mixture were finally mixed for 2 min. The fresh-mixture were then casted into the beam molds with dimensions of 400 × 100 × 100 mm, then the molds were placed onto the vibration table. After 24h of curing, the specimens were demolded and cured in curing box for 7 days with 90% relative humidity, the conditioning temperature was maintained at 20±3°C.

As Fig.1 shows, the three-point bending test was conducted on the beams under the center point load, with 400mm length, 100mm length and height, respectively. The loading speed was controlled by displacement of 0.1mm/min.

![Figure 1. Three-point bending test](image)

3. Results and discussion

3.1. Load–deflection curves

The flexural responses obtained from the three point bending test are presents in Fig. 2. The entire load-deflection curves can be classified into two types: deflection hardening and deflection softening: in the elastic deformation stage, the load increasing linearly with deflection until the first crack occurred. After the elastic deformation stage, the minor crack initiated, the first crack point was occurred at the point of nonlinearity part at the end of elastic deformation stage. Afterwards, for deflection hardening curve, the load decrease after the first crack point, which behaves brittle response, the specimen without reinforcement fractured abruptly and sudden loss of overall bearing capacity, in contrast, the load continue to increase after the first crack point, which indicates the specimen behave more ductile and toughness, the fiber reinforcement take over the bearing capacity after the sharp drop from the peak load, moreover, the inclusion of both jute and PVA fibers enhance the flexural strength with increasing fiber content. For deflection hardening curve, the load increases after the first crack point until the peak point, which is defined as the peak load point. After the peak load point, the residual flexural strength remain stable up to the ultimate failure, the increment of specimen in this stage are various with different fiber addition, for specimen with 1% fiber addition, the second peak value is higher than the first peak. The five stage is the ultimate failure stage, most of the bridging fibers which connected the crack were pulled...
out with the crack width enlarged and the residual flexural strength decrease, once all the bridging fibers were pulled out and the specimen fractured.

![Image](image_url)

**Figure 2.** Parameter calculations obtained from load–deflection curves

**Figure 3.** Load–deflection curves

### 3.2. First crack flexural strength and peak flexural strength

The flexural strength obtained from the results of three-point bending test after calculating by Eq. (1).

\[ f = \frac{pL}{bd^2} \]  

(1)

Where \( f \) is flexural strength, \( p \) is the load at any required deflection, \( L \) is the spacing between two supporting rollers, \( b \) and \( d \) refers to the width and height of the specimen. The first crack flexural strength \( (f_1) \) represents the flexural strength at the deflection of first crack point, and the peak flexural strength \( (f_p) \) represents the flexural strength at the deflection of peak strength point. The first crack flexural strength and peak flexural strength results of all specimens through the three-point bending test after calculating using Eq. (4) are presented in Fig. 4. Fig. 4 (a) shows that both fiber types have a significant effect on the first crack flexural strength. In contrast with unreinforced specimens, the first crack flexural strength increased from 0.294 MPa to 0.383 MPa, 0.487 MPa, and 0.537 MPa for J0.25, J0.5 and J1 specimens, respectively, and the increment for PVA fiber reinforced specimens were observed. In addition, the first crack flexural strength of specimens with certain fiber addition are approximately identical, which indicates both Jute and PVA fibers in the cemented soil matrix prevent the formation of crack.
Furthermore, it is also observed an increase in peak flexural strength for both fiber types, for specimens with 0.5% and 1% fiber addition, Jute fiber shows higher $f_p$ than PVA fiber.

![First peak flexural strength and peak flexural strength](image)

**Figure 4.** First peak flexural strength and peak flexural strength

### 3.3. Peak strength ratio

The peak strength ratio (PSR) is the value of the peak flexural strength divided by first peak flexural strength, which implies the degree of increment in flexural strength after the first crack point. The peak strength ratio results have been illustrated in Fig.5. The PSR value indicates the deflection hardening and deflection softening type, Fig. 5 shows the unreinforced specimens and specimens with 0.25% fiber addition show deflection softening type, the PSR value equal to 1, in contrast, the specimens with 0.5% and 1% fiber addition shows deflection hardening type. Furthermore, with increasing fiber content, the PSR value increases. Moreover, Jute and PVA fiber give the highest PSR value of 1.313 and 1.314, respectively for 1% fiber inclusion.

![Peak strength ratio](image)

**Figure 5.** Peak strength ratio

### 3.4. Residual flexural strength ratio

The residual flexural strength ratio is defined as the residual flexural strength at a certain deflection divided by the first crack flexural strength $f_1$. In this work, the residual flexural strength were obtained at the deflection of 2mm($\Delta 2$) and 4mm($\Delta 4$). Hence, besides the peak strength ratio, the residual flexural tensile strength ratio is used for evaluating the effects of fiber reinforcement of carrying the residual load since the first crack initiated. The comparative results of residual flexural tensile strength ratio of
fiber types in addition with fiber content are displayed in Fig. 6. From Fig. 6, it can be seen the unreinforced specimen were unable to carry the residual flexural tensile strength once the first crack formed. From the figure, it is noted that both Jute and PVA fiber remarkably improve the load bearing capacity after the formation of first crack, the residual flexural strength ratio for Jute and PVA fiber reinforced specimens are range from 0.88 to 1.23. At the deflection of 2mm, the minimum residual flexural strength ratio 0.906, 0.883 were provided by J0.25 and P0.25, respectively, hence even if the minimum residual flexural strength caused by 0.25% fiber addition can carry approximately as 90% as the first crack flexural strength. For H0.5 and H1, the residual flexural strength ratio were 1.135, 1.23, respectively, which implies the strain hardening response. The comparison of P0.5 and P1 with H0.5 and H1 shows that the strain hardening degree for Jute fiber reinforced specimen were higher than PVA fiber, for H1 and P1, the residual flexural strength ratio are both exceeded 1. In addition, it was observed slightly increase in residual flexural strength ratio for J0.25 and P0.25 from the deflection of 2 mm to 4 mm, however, the residual flexural strength ratio for J1 and P1 at the deflection of 2mm and 4 mm were approximately the same. Both Jute and PVA fiber provided relatively high residual flexural strength, and the residual flexural strength of fiber reinforced beams significantly increased from the first crack point up to a large deflection.

3.5. Ductility index

In this work, the ductility of composite can be calculated by equation (2): the ductility index is defined as the deflection ratio between the first crack point and peak flexural strength point, where δP is the deflection corresponding to the peak load and δ1 is the deflections corresponding to the first crack point load, hence, the ductility index (DI) can be used to evaluate the improvement of fiber reinforcement in ductility. The ductility index of unreinforced and fiber reinforced specimens are presents in Fig.7. For specimen with 0.25% addition of Jute and PVA fiber, the DI value are equal to 1, which indicates specimens with lower fiber inclusion exhibits strain softening response. Fig.7 shows that the DI values were increased with increasing fiber content, and the increment in DI value for J0.5, J1, P0.5, P1 compare with unreinforced specimen were 42.97%, 54.77%, 46.45%, 50.86% respectively.
3.6. **Toughness**

The toughness indicates the energy absorption capacity (EAC) of material during the experimental process. Energy absorption capacity implies the ability of preventing the occurrence of brittle failure. The EAC is correlated to the strength of materials with the addition of the deformation in the destruction process. The calculation method of energy absorption capacity is integrating the area under stress-strain curve, hence, the energy absorption capacity consists of two part, the first part is the energy absorption at the initial elastic deformation stage which up to the peak strength, and the residual energy absorption caused by the residual strength. In this study, the toughness is calculated at deflection of 4 mm in the test. From the figure, it can be seen the minimum toughness value was provided by unreinforced specimen which was 0.401, for J0.25 and P0.25, the value were 4.158, 4.208 respectively. Hence, the fiber reinforcement fundamentally improve the energy absorption capacity of unreinforced specimen even with the lowest fiber addition. Moreover, increasing fiber content exhibits higher bearing capacity through “fiber-bridging effect” after the first crack formed, and the “fiber-bridging effect” cease to be effective once the fiber was pulled out or ruptured. In addition, for specimen with 0.5% and 1% fiber inclusion, Jute fiber reinforced specimen exhibiter better than PVA fiber in toughness.

![Figure 7. DI index of specimens](image)

3.7. **Crack patterns**

The crack pattern of fiber reinforced specimens are displayed in Fig.9. In the three point bending test, the beams were under flexural tensile strength at the bottom, with the stress increase, the first hairline crack initiated, the unreinforced specimen ruptured instantaneously, while for fiber reinforced specimens, the tensile stress were transferred from the cemented soil to fibers, and with the crack...
propagated, the induced shear stress began to increase, and the fibers were pulled up straight, as Fig. 9 shows, and the randomly distributed fibers debonded with the matrix as the shear stress exceed the bonding strength, afterwards, the fibers were pulled out, in the pull out process, the bonding strength were replaced by the frictional resistance between fibers and matrix, finally the fibers were totally pulled out. Hence, the specimen with fiber reinforcement can carry the residual tensile strength due to the “fiber-bridging effect”.

Figure 9. Crack patterns of fiber reinforced beams

4. Conclusions

The flexural performance of Jute and PVA fiber reinforced cemented soil were investigated through the three point bending test. Based on the experimental study, the conclusions can be drawn:

1. The inclusion of Jute and PVA fibers in cemented soil significantly increases the first crack flexural strength and peak flexural strength. The fiber content of 0.5% and 1% provide the strain-hardening response.

2. The overall comparative results were investigated to evaluate the post crack performance of cemented soil reinforced by Jute and PVA fibers, the peak strength ratio, residual flexural strength ratio, energy absorption capacity, ductility index and toughness increased with increasing fiber content; Higher fiber content (≥0.5%) show a fully developed hardening response.

3. Fiber type proposed little impact on the peak strength ratio and DI index. While, for fiber content of 0.5% and 1%, the Jute fiber group exhibited slightly higher than the PVA group in terms of the toughness.

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