Materials Research Proceedings **23** (2022) 362-369 https://doi.org/10.21741/9781644901953-41

Experimental Investigation on Effects of Bendable Composites on Ductility

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Keywords: Bendable Composite, Fly Ash, Polyvinyl Alcohol Fibres (PVA), Ductile

Abstract. The challenge in the structural characterization on ductile behaviour of bendable composite is to enhance the structural safety under severe loading. This paper emphasis on inclusion of a high dosage of fly ash (class F) with fly ash to cement (FA/C) in the ratio of 1.6 and an optimum amount of 2% of Polyvinyl Alcohol (PVA) fibres on the ductile behaviour of reinforced and unreinforced Bendable Composite. The absence of Coarse aggregates in this Bendable Composite reduces the crack width which increases the tensile strain capacity of Bendable Composites. The ductile behaviour of this Bendable Composite gives a high-end property in earthquake resistance applications when compared to conventional concrete.

Introduction

Bendable Composite is a fibre reinforced cementitious composite that has been enhanced through the usage of micromechanics [1]. Theses composites helps to achieve high ductility, because of incorporating fibres having high tensile strength and it helps to tighten the major crack widths. The addition of fibres to Bendable Composite is known to create more cracks, but at the same time restrain the widening of these cracks [14]. The term 'Ductility' is considered as one of the important key feature in Bendable Concrete. The materials that crack, break or shatter under stress cannot be manipulated. High degrees of ductility occur due to bond of Bendable concrete.[2,4] Enhancement of Ductility in Reinforced Concrete structures can be done by many ways One of the ways is providing Composites in critical locations. The composites are in much form. Randomly distributing and mixing small length of fibres with particular volume in concrete is the best way to performance enhancement of structures. [10]

Necessity of Ductility Determination

The philosophy of earthquake resistant design (in general) for buildings is based on the following principles in such a way that they should,

- Withstand small to minor earthquakes without damages.
- Withstand the medium to moderate earthquakes without causing structural damages, but accepting the probability of non-structural damages.
- Under average earthquake, the buildings should resist structural as well as non- structural damages without collapse. This is considered as one of the ideal condition under this average earthquake. [15]
- During major earthquake, the structural response is inelastic and the load carrying members will starts to yield and in-turn produces plastic hinges in the main load carrying members like columns and beams. During such cases, non-linear analytical procedures are not commonly used, as it might be expected one. In practice a great deal of dynamic analysis is carried out on the basis of elastic response in terms of ductility and energy absorption.

Bonding Strength of PVA fibre enhances Ductile Behaviour
Poly Vinyl Alchol fibre has one of the noticeable characteristics, is that, it produces strong bonding with cement matrix. Compared to Polypropylene fibre, the PVA has strong bonding towards its rupture [1]. It is analyzed that PVA fibre has the combination of bond strength, high tenacity and high modulus. With this property, the PVA-reinforced concrete attains substantial tensile and flexural strength. It is always assumed that Ca+ ions and OH- ions present in cement slurry are attracted by Poly Vinyl Alcohol fibre and makes the by-product calcium hydroxide Ca(OH)2 layer [5,6]. It evident that Calcium Hydroxide Ca (OH)2 layer plays a key role for bonding the strength in concrete elements. The calcium hydroxide Ca (OH)2 layer, tends to peel the surface of PVA fibre and this phenomenon is establishing a strong bonding with PVA fibre and cement matrix.

Toughness of PVA fibre Enhances Ductile Behaviour
The another important property to evaluate the energy absorption capacity is Toughness. It is the tendency of the material to absorb energy and plastically deform, without fracturing. In other words, it is also described as the total amount of energy absorbed by the material before undergoing rupture per unit volume. It is also stated, that when a material is stressed to fracture, it offers resistance towards it. The property of toughness requires a balance of both strength and ductility [8, 9]. When a material has high toughness index, up to the failure point, it absorbs the mechanical energy. The stress-strain values are plotted and the area under the stress- strain curve is considered as the toughness.

Modulus of resilience is the amount of energy absorbed by the material per unit volume, provided the restriction is given in the upper limit of integration up to the yield point. Hence, it is equally important in considering the energy absorption of a material when it deforms elastically and plastically [13].

Test Specimens
In order to validate the ductile behaviour of Bendable Concrete a 600mm long, 250mm width and 25mm thick Reinforced Bendable Concrete slab of optimum mix (FA/Cement=1.6) and 500mm long, 100mm width and 25mm thick unreinforced Bendable Concrete slab of optimum mix (FA/Cement=1.6) were casted. These two slabs were tested under the UTM (Universal testing machine) and its experimental load – mid span deflection were recorded.

Table 1 shows the mix proportioning adopted in Bendable composites. The water-to-cement ratio maintained for the all the mixes as 0.58. The percentage of SMF on average as 1.2%. The optimum fibre percentage of PVA fiber is taken as 2% based on the trail values. Figure 1 shows the Unreinforced Bendable Concrete Slab.

TABLE I Mix Proportion of Bendable Composite

Mixes	**W/C**	**Cement**	**Sand**	**Fly Ash**	**PVA Fibre**	**SMF**
Bendable Composite (BC)	0.58	1.0	0.8	1.2	2%	1.2%

Fig. 1 Photographic View of Unreinforced Bendable Concrete Slab

Fig. 2 Photographic View of Casting Reinforced Bendable Concrete Slab

Test Results and Discussion on Ductility

Unreinforced bendable concrete slab

The ductile behaviour of the test specimens of size 500mm x 100mm x 100mm beams were difficult to observe the ductile behaviour particularly for its flexural strength [8]. This is mainly due to the thickness of the specimens.

The thickness reduces the flexibility of the beam and it also restrains any noticeable amount of bending. To verify this idea, casting a 500mm long, 100mm width and 25mm thick unreinforced Bendable Composite slab of optimum mix (FA/Cement=1.6) was prepared and cured for 28 days. For measuring the deformation in the slab, a Linear Variable Differential Transformer (LVDT) was used.

Fig. 3 Photographic View of Slab Testing on Universal Testing Machine

Figure 4 gives the different plots of displacement values which are the data collected from the LVDT sensors for the test specimen of size, 500mm long, 100mm width and 25mm thick unreinforced Bendable Composite slab of optimum mix (FA/Cement=1.6). The displacement taken at the time of failure can be considered as the point at which the displacement value reaches a plateau followed by a significant increase in the rate of displacement. From this, it is evident that the slab has experienced a moderate degree of bending and it failed much soon.

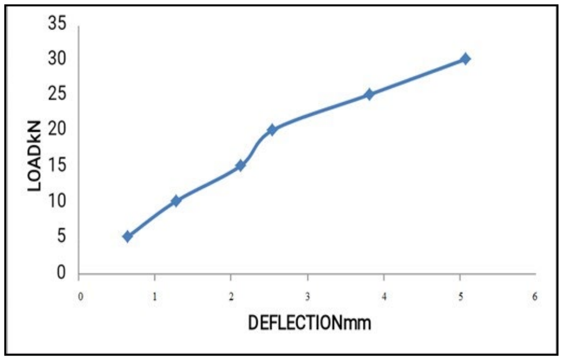

Fig. 4 A sample line graph for Load Vs Deflection in Unreinforced Bendable Composite Slab

Fig. 5 Photographic View of Slab Failure

From the test results, it is evident that, at the crack location, the fibres did not rupture. This is mainly because, the PVA fibre helps in maintaining the structural integrity of the entire slab. It also has the ability to hold the crack together without causing much rupture.

This suggests that, although the Poly Vinyl Alcohol fibres may not only prevents the formation of large cracks as they do in true ECC, but they may help in keeping the cracks closer and tighter [5]. From the graphical view it is observed that unreinforced bendable concrete slab showed a maximum displacement of 5.08mm at ultimate load of 30KN. The PVA fibre did not rupture at the crack location [11]

Reinforced bendable concrete slab

A reinforced bendable concrete slab having the dimensions of 600mm x 250mm x 25mm were casted and tested for flexural loading. The overall deflections were measured using LVDT. During loading, the first crack load and ultimate loads along with its corresponding deflections were noted. The maximum Ultimate load on RC beam, Energy absorption, Toughness Index, and ductility factor are discussed.

Conventional RC Slab:

(i) First crack Load = 20kN
Deflection at First Crack Load = 0.68mm
(ii) Yield Load = 40kN
Deflection at Yield Load = 3.98mm
(iii) Ultimate load = 60kN
Deflection at Ultimate load = 7.43mm

BC 2 mix RC Slab:
(i) First crack Load = 30kN
Deflection at First Crack Load = 1.54mm
(ii) Yield Load = 60kN
Deflection at Yield Load = 2.79mm
(iii) Ultimate load = 100kN
Deflection at Ultimate load = 11.3mm

Behaviour of BC Mix RC Slab

Ultimate load of the BC Mix RC Slab
The ultimate load is found by casting and testing the practical and typical field condition. The knowledge of the failure of the reinforced cement concrete (RCC) beam and BC mix RC slab were analysed. The ultimate load of the reinforced concrete slab has to be primarily examined. This is due to the effect of induced corrosion, since it has considerable effect on reinforcements in the concrete. For M40 grade, conventional concrete Reinforced Concrete slab and BC mix RC slab, were taken into consideration for the 28 days for Ultimate load.

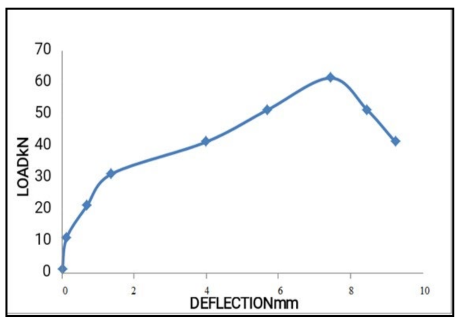

Fig. 5 Graphical View of Load vs. Deflection for reinforced Conventional concrete Slab

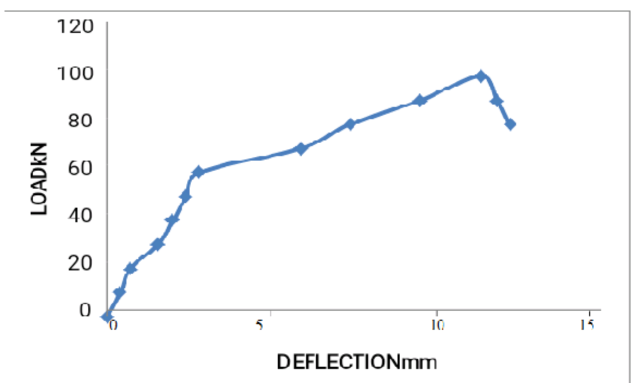

Fig. 6 Graphical View of Load vs. Deflection for reinforced Bendable Composite Slab

The above figures 6 show the load-deflection relationship for concrete slab specimens of conventional RCC slab and BC mix RC slab. Generally, it can be observed that fibre volume fraction has little effect on the load- deflection relationship but there is a relatively stiffer response at the post cracking stage for the slab specimen's BC mix in comparison with conventional RCC beam.

This may be due to the high tensile strength of PVA fibres and high bond strength between the fibres and the matrix which is achieved with the densification of Fly ash combined with suitable water-cement ratio [11, 12]. It was observed that the PVA fibres bridge the crack formed in the

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reinforced concrete member. It also makes the member capable of carrying the load well even after the development of cracks on the concrete [8]. It is also observed that the replacement of Fly ash and volume fraction of PVA fibre have little effect on load- deflection behavior [10].

Energy absorption capacity

Energy absorption capacity for all the specimens were calculated from the load-deflection curve. The maximum value of deflection is observed at the load of 98kN with the deflection of 11.38mm. The energy absorption capacity is calculated by summation of the area beneath the load= deflection curve. The total area below the load– deflection curve is considered from origin to ultimate deflection point as shown in figure 7. This Figure shows the calculated area below the load-deflection curve of BC 2 mix RC Slab specimen. Energy absorption of capacity is 342 kN mm.

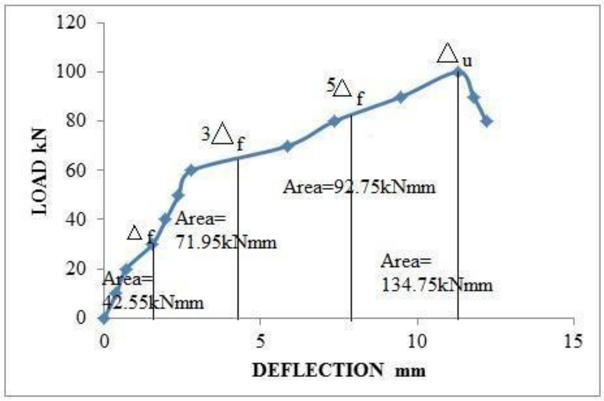

Fig. 7 Graphical View of load vs. deflection BC 2RC slab showing the area below the curve

Toughness indices

The toughness indices were calculated as per the standards given in ASTM C-1018. As like energy absorption, this index is also based on the load-deflection curve. From figure 7, it is the ratio of the area of the load-deflection curve up to deflections of 3 and 5.5 times the first crack deflection which is divided by the area of the load-deflection curve up to first crack deflection (first crack toughness). The approximate shape of the post cracking load deflection responses were taken from these indices. The figure shows the yield deflection and deflection corresponding to span/150 mm on the load- deflection curve of BC mix RC specimen.

Toughness (Energy required) as per JCI, is 294440 N mm

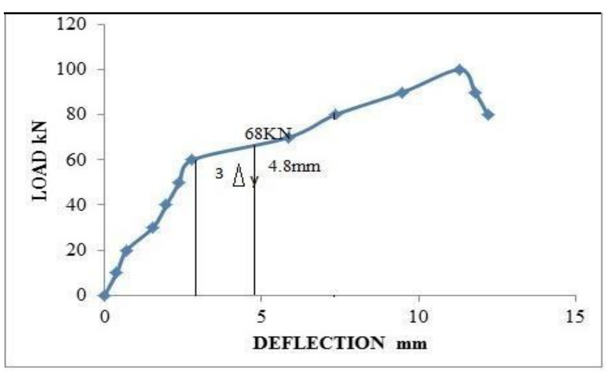

Fig. 7 Graphical View of Load Vs Deflection curve for BC mix RC Slab showing the yield deflection and deflection corresponding to span/150 mm

Ductility factor
Ductility factor is calculated from the load-deflection curve. It is the ratio between the deflection which is corresponding to its ultimate load and the deflection corresponding to its yield load [7]. Ductility factor for BC mix specimen is 4.06.

Conclusions

1. The unreinforced Bendable composite slab of mix BC mix (Fly ash/Cement=1.6) showed a maximum vertical displacement and the ductile behaviour was justified by achieving high curvature before failure.
2. The slab has experienced a moderate degree of bending and failed but the fibres did not rupture at the crack location.
3. The reinforced Bendable composite slab of mix BC mix (Fly ash/Cement=1.6) showed a maximum vertical displacement compared to conventional concrete of reinforced slab due to the ductile characteristics of Bendable Composite.
4. Percentage Increase of Fly ash content in concrete can reduce the chemical bonding effect, in meanwhile, it increases the frictional force between the matrix and the PVA fibre. The overall effect on the fibre/matrix interface is beneficial to the strain hardening behaviour of Bendable Composite, thus leads to enhanced deflection capacity.
5. The void filling Fly ash increases energy absorption capacity reduces the stiffness degradation and increases the ductility factor. Increase toughness of PVA fibre to improve the impact resistance, bending strength and brittleness of Bendable composite.
6. Tests in case of both reinforced and unreinforced Bendable composite slab did not give perfect estimation about the ductile behaviour of bendable composites. But its failure pattern gives a fairly a good ideology about the ductility of the material. [12]
7. Thus Bendable composite, an ultra-ductile fibre reinforced cementitious materials enhances structural safety under severe loading [3].

References

[1] Carl Redon (2001), 'Measuring and modifying interface properties of PVA fibres in ECC matrix' Journal of materials in civil engineering, vol. 13, no. 6, pp.399-406. https://doi.org/10.1061/(ASCE)0899-1561(2001)13:6(399)

[2] Dhawale AW, Joshi VP (2013) 'Engineered cementitious composites for structural applications' International journal of application, vol.2, no.4, pp.198-205.

[3] Dong Bingqing; Pan Jinlong; Lu Cong, "Flexural behavior of steel reinforced engineered cementitious composite beams", Journal of Southeast University, Volumn: 35 Issue: 2019 1 Page: 72-82

[4] Fukuyama, H., Matsuzaki, Y., Nakano, K. and Sato, Y. (1999), "Structural Performance of Beam Elements with PVA-ECC", Proceedings of High Performance Fiber Reinforced Cement Composites 3 (HPFRCC 3), Ed. H.W. Reinhardt and A. Naaman, RILEM Publications S.A.R.L., PRO 6, pp 531-541.

[5] Hakan Nuri Atahan, (2013) 'Behaviour of PVA fibre - reinforced cementitious composites under static and impact flexural effects' Journal of materials in civil engineering, vol.25, no.10, pp.1438-1445. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000691

[6] JIANG Shiyong, TAO Shuai,YAO Weilai,WU Shijuan, CAI Tao (2017), "Mechanical Performance and Size Effect of Engineered Cementitious Composite (ECC) Subjected to Uniaxial Compression, Materials Reports, Vol. 31 Issue (24): 161-168.

[7] Li, V.C. (1993), "From Micromechanics to Structural Engineering - The Design of Cementitious Composites for Civil Engineering Applications", Structural Engineering and Earthquake engineering, Vol. 10, No.2, Japan Society of Civil Engineers, pp 37-48 https://doi.org/10.2208/jscej.1993.471_1

[8] Liang Li, Hongwei Wang, Jun Wu, Shutao Li and Wenjie Wu (2021) "Experimental Investigation on Dynamic Tensile Behaviors of Engineered Cementitious Composites Reinforced with Steel Grid and Fibers" Materials (Basel), Nov; 14(22): 7042. https://doi.org/10.3390/ma14227042

[9] Mohamed Maalej (2005) 'Behaviour of Hybrid-Fibre engineered cementitious composites subjected to dynamic tensile loading and projectile impact' Journal of materials in civil engineering, vol.17, no.2, pp.143-152. https://doi.org/10.1061/(ASCE)0899-1561(2005)17:2(143)

[10] Mustafa Sahmaran, (2011) 'Effect of fly ash on microstructural damage and residual properties of engineered cementitious composites exposed to high temperatures' Journal of materials in civil engineering, vol.23, no.12, pp.1735-1745. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000335

[11] Peerapong Suthiwarapirak, (2004) 'Multiple cracking and fibre bridging characteristics of engineered cementitious composites under fatigue flexure' Journal of materials in civil engineering, vol.16, no.5, pp.433-443. https://doi.org/10.1061/(ASCE)0899-1561(2004)16:5(433)

[12] Shuxin Wang, Victor C Li (2007) 'Engineered cementitious composites with High-Volume Fly ash' ACI journal, vol.104, no.3, pp.233-241. https://doi.org/10.14359/18668

[13] Suleyman Bahadir Keskin, (2013) 'Effect of pre-soaked expanded perlite aggregate on the dimensional stability and mechanical properties of engineered cementitious composites' Journal of materials in civil engineering, vol.25, no.6, pp.763-771. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000553

[14] Rathod JD, Patodi SC (2009) ' Effect of cement sand ratio and fibre orientation on tensile characteristics of ECC' Indian Concrete Institute, vol.10, no.1, pp.17-23

[15] IS 1893 (Part I), 2002, Indian Standard Criteria for Earthquake Resistant Design of Structures (5th Revision).