Experimental Study on Behavior of Engineered Cementitous Composite by Using Poly-Propylene and Glass Fibers

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***Abstract*–An Engineered Cementitious composite is a high ductile cementitious composite which possess property of high crack resistance, with a tensile strain capacity which surpasses the property of normal concrete. Engineered Cementitious Composites are similar to that of a Fiber Reinforced Concrete. But in ECC the fiber percentage is optimized to get the better performance and the absence of coarse aggregates reduces the transition zone effect thus altering the behavior of ECC and also in ECC the mineral admixtures are added to reduce the effect of the obscene of coarse aggregates which cause the decrease of volume. As the bond between the fiber and the matrix is found to play an important role in behavior of ECC. In this experiment an attempt is made to study the interaction of poly propylene and glass fibers with the matrix prepared by incorporating the different mineral admixture such as Metakaolin and fly ash.In this experiment flexural tests were carried out to study the mechanical behavior and to evaluate the behavior with different fibers with the percentage varying between 1% to 2% in the interval of 0.25% and their interaction with different mineral admixtures. It is observed that the control mixes show no deflection whereas glass fiber in Metakaolin with 1% of fibers had shown a good deflection and the same fibers in fly ash shown good deflection at fibers content of 2% whereas poly propylene fiber in Metakaolin with 1.25% of fibers had shown a good deflection and the same fibers in fly ash shown good deflection at fibers content of 1.75%.**

***IndexTerms* - Engineered Cementitious Composites, Polypropylene fiber, glass fiber, Fly*ash*, Metakaolin.**

I. INTRODUCTION

Engineered cementitious composite (ECC) represent the latest family in cement concrete industry. we already know that cement is very good in compression but is very weak in taking the tensile forces. However the innovations had been carried out to make the concrete to take up the tensile forces hence steel was introduced to take up the tensile forces but this introduction doesn't increase tensile capacity of concrete, there again resulted in the incorporation of fibers in to the concrete which are known as FRCC but however the tensile strain capacity of concrete is not improved much. This resulted in the development of ECC where the tensile strain capacity of concrete is around 3-7% compared to 0.01% of that of normal concrete. The construction of ECC is even more interesting and is mainly based on the micromechanical interaction between fiber, matrix and processing technology. The interaction between the fibers and the matrix, is governed by the fiber matrix interface has been recognized, leading to interface modification techniques to design the desired properties. Fiber breakage in ECC prevented and pulls out from the matrix enabled by using different mineral admixture, leading to improved tensile strain capacity in excess of 4% for ECC containing 2% by volume fiber. Micromechanical interaction relates the macroscopic properties to the microstructure of a composite, and forms the backbone of the ECC material design theory. Especially, it allows microstructure tailoring of ECC as well as material optimization. Microstructure based tailoring can lead to extreme composite ductility. Micromechanical models constructed on the relevance of fracture mechanics and deformation mechanisms. These parameters provide an opportunity of tailoring micromechanical parameters so as to control the failure mode, the tensile strength, and ultimate tensile strain of the composite

There are three types of tensile failure modes have been observed in cementitious composite materials they are brittle, quasi-brittle, and strain-hardening failure. The Brittle failure can be observed in hardened cement paste material. It is characterized by the linear stress-strain curve followed by a sudden drop in stress after the appearance of first cracking with the ultimate tensile strain an order of 0.01 %. Quasi-brittle failure can be observed in most of the fiber reinforced cements and concretes. It is characterized by a linear stress-strain curve then followed by softening tail after the first cracking, due to the bridging action of cement ligaments, fibers, aggregates respectively. Strain-hardening materials are characterized by their special ability to sustain an increased level of loading after first cracking while undergoing larger deformations .The ultimate strain value of strain-hardening material is of the orders of magnitude higher than the brittle or quasi-brittle material.

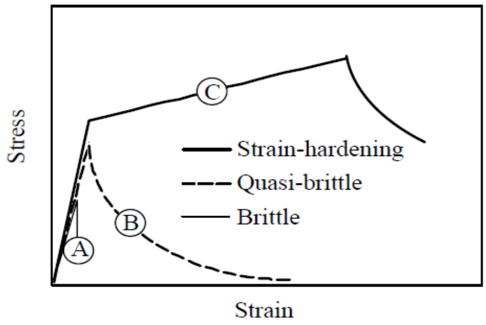

Fig. 1: Three Types of Failure Modes Observed in Cementitious Materials

One of the important conditions for the transition from state of quasi-brittle to strain-hardening failure mode is the presence of 'steady state' cracking phenomena. In fiber cementitious composites, the extension of a cementitious matrix crack is accompanied by the fiber-bridging across the crack. As the matrix crack widens, increases in bridging zone length. When the bridging stress increases with the magnitude of the applied load, the fiber-bridging across the crack maintain the constant applied stress level .This phenomena is termed as the steady state cracking stress. The crack has now gone into the process of steady state cracking mode, extending without the need of any further increase in applied load. Thus during process of steady state cracking, the tensile load is independent of the crack length. This is well known Griffith residual strength concept, which relates the decreasing tensile load to the increasing crack size. The bridging law mainly describes relationship between the averaged stress carried by the fibers which are bridging across a matrix crack and opening of the crack. For the steady state cracking to occur, the steady state cracking stress i.e.σ_{ss} must be less than the σ_0 which is maximum bridging stress in the bridging law. That is, $\boldsymbol{\sigma_{ss} \leq \sigma_0}$provide a general condition for transition from the state of quasibrittle to strain-hardening failure mode. Apart from steady state cracking condition phenomena, it is also necessary for the critical flaw size which is dependent first crack strength to be less than the maximum bridging stress or else, the bridging fibers are not capable to bear the tensile load shed by the matrix at first crack.

The ingredients of ECC are just similar to that of fiber reinforced cement concrete. Notably, ECC utilizes short, randomly distributed fibers with a moderate volume fraction (2% or less in general). The absence of coarse aggregates has resulted in the reduction of volume and this may results in high temperature stresses and this is overcome by the addition of suitable mineral admixture .With this relatively small amount of short fibers, self-consolidating ECC has been designed for use with normal construction equipment.

II. MATERIALS

The main components of ECC are ordinary Portland cement(OPC), flyash(FA),fiber, super plasticizer, sand and water. The cement used for this investigation is ordinary Portland cement (43grade) is confirmed to the requirement of BIS. The results are reported in table.

Table 1.Physical properties of OPC

Sl. No.	Particulars	Tests Conducted on	Requirement as per IS:8112-1989	Test Results found
1	Fineness of the cement	90micron sieve	<10	4%
2	Specific gravity	Sp.gr. bottle	3.15	3.1
3	Normal consistency %	Vicat apparatus	35>	31%
4	Initial setting time (min)	Vicat apparatus	Minimum of 30min	55min.
5	Final setting time (min)	Vicat apparatus	<600min	355min
6	Soundness	Le-Chatelier	≯10mm	6mm

In this work, class-F flyash and metkaolin are used as pozzolonic material in making concrete or various kinds of cement based materials. The main reason of adding the flyash in the mix is to improve the fresh state properties and also to reduce the matrix stiffness in holding the fibers. The addition of flyash also reduces the heat of hydration, which maintains the plastic properties required for pressing. Another pozzolonic material used here is the metakaolin. Metakaolin combines with the product of hydration that is calcium hydroxide which accounts for size up to 25% of the hydrated Portland cement, and calcium hydroxide does not contribute to the any gain of concrete's strength or durability. When the metakaolin combines with calcium hydroxide to produce additional cementitious compounds, the cementitious material is responsible for holding concrete together. Property of Metakaolin being very fine and highly reactive, gives the fresh concrete of creamy, non-stick texture that results in easier finishing. Generally the fiber used in ECC is PVA, one of the remarkable characteristics of this fiber is capable of strong bonding with cement matrix. The layer of Ca $(OH)_2$ called as interfacial transition zone is formed around PVA fiber and is formed as white part, and in case of PP, this layer is not observed around these. It is known fact that PVA is easy to make complex cluster with metal hydroxide of cement matrix. It is pursued that Ca^+ and OH^- ions in cement slurry are attracted by PVA and makes $Ca(OH)_2$ layer. It makes to think that Ca $(OH)_2$ layer plays important role for bonding strength between the fiber and the matrix. However there is absence of some epoxy coating around the poly propylene fibers and as well as glass fibers which are possessing high tensile strength but they are not coated with any epoxy and they are susceptible for alkali environment of matrix this makes us to do experimental study by selecting these fibers. Polypropylene fibers used in this experiment are in the range of 22 to 35 micron by 19mm long .and the glass fibers selected is also of the same order as poly propylene fibers. These fibers are differing from one another only by their density. The selected Polypropylene fibers possess the density of 1.19g/cm^3 and the Tensile strength of 500~700 MPa and the percentage of elongation is 20% .Whereas the glass fiber selected has the density of 2gm/cm^3. Tensile strength of 2200 MPa and the percentage of elongation is 0-4%. The super plasticizer used is Conplast SP-430 is based on Sulphonated Naphthalene Polymers and supplied as a dark brown liquid instantly dispersible in water. This super plasticizer has been specially formulated to give a high water reduction up to 25% without the loss of workability to produce the high quality concrete of reduced permeability. It improves the cohesion and dispersion of particles minimising the segregation and bleeding .Good river sand is used in the project, particles are angular in shape passing 250 micron and retaining on 150 micron is sieve. Sample is then washed to get free from earthy and silt content and dried over a period of 48 hrs. Water which is fit for drinking is generally considered for making concrete. Water should be free from foreign matters such as acids, oils, alkalis, and other organic Impurities.

Experimental work

Mix Proportions

There is no standard procedure for calculating the mix design for ECC. The mix design procedure was mainly based on the micromechanical modeling of composite materials. Various authors have proposed the different mix proportions of ECC based on workability criteria. The standard mix design procedure adopted by most of the scientists are the mix design proposed by Dr.Victor.c.li and is given in table 2.

Table 2.Basic mix proportion with different proportions of fibers.

	Cement	Fly Ash	Sand	Water	HRWR*	Fiber (Vol %)
Ratio	1.0	1.2	0.8	0.56	0.012	0.02
Kg/m^3	587kg/m^3	704.6 kg/m^3	469.9 kg/m^3	299.7 kg/m^3	17.31 kg/m^3	Based on density of fiber
Per cube	166gms	199gms	132.8gms	87.89ml	5ml	6.7gms for 2%ppa 11.32gms for 2% GF

Note: The metakaolin mix requires more water content(WC).This WC is varied till 0.6 to get the workable mix. Hence WC of 0.6 is adopted for metakaolin mix. Here the beam cast is custom made for size of**304.8mmx76.2mmx12.2mm**and according the volume of the cubes the quantity of materials are calculated.

Preparation and Casting of test specimens

In case of mixing for ECC, a rotary planetary type mixer was used for mixing. The cement and sand are first mixed dry upto half minute and then water is added resulting in fluid mix then the flyash is added. At the time of adding the flyash super plasticizer is also added. The mixing is done upto a minute where the fluidity of mix is obtained and at last the fibers are added. The mixing time should be less than 5 mints.

Mixing procedure for ECC

Figure.1. Dry mixing of cement and sand

Figure.2.Adding water to cement and sand to drymix

Figure.3.Adding the mineral admixtures

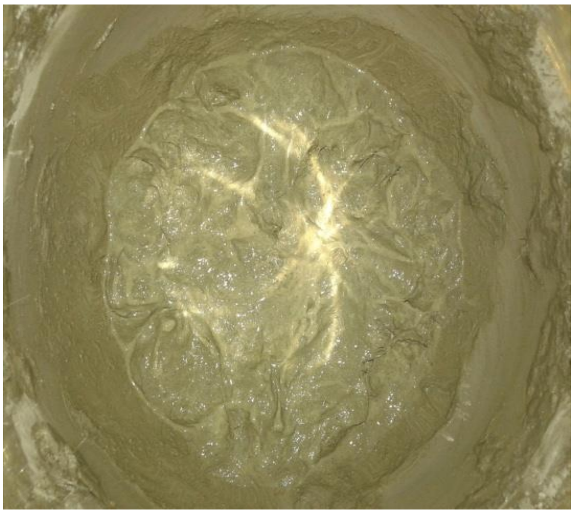

Figure.4.Adding fibers the flowable mix thus obtained

Figure.5. Planetary type rotatory mixerFigure.

Figure.6. Prepared beams are water spray cured with polyethylene sheet Covering.

Beam moulds of **304.8mmx76.2mmx12.2mm** were used to cast beam specimens. In order to remove the specimen from the mould, the moulds were greased before casting. After taking the beams out of the moulds were initially cured by polythene sheet covers and then cured by water sprayed and polythene sheet covered curing for 14,28 and 56 days for the respective flexural strength tests.

III. RESULTS AND DISCUSSIONS

Hardened cementitious composites Test Results

Control mix

The control mixes are prepared using the cement, sand and water and without the mineral admixtures and fibers. The results of control mixes are tabulated in table 3

Table 3.Control mix results

Load (kN)	Deflection in (mm)
0	0

0.1	0
0.2	0

Fly ash based mix with Poly Propylene fiber

Mixes were prepared by using cement, flyash, sand, fiber (varying percentage), water and super plasticizer,the result of the mix are shown in below table and the graph of load v/s deflection was shown in the fig. The control mixes prepared by using the cement, sand and water without the flyash and fiber shows sudden failure without any deflection. It was observed that no visible cracks are appeared till 0.5kN and sudden failure is observed at 0.6kN for 1% of fibers.For the mixes prepared with 1.25% of fibers, no visible cracks are appeared till 0.6kN of loading and mixes prepared with 1.5% of PP fibers no visible cracks are appeared till 0.7kN loading. Further for specimens with 1.75%PP fibers carried more load by giving more deflectionsand specimen with 2%of fibers has carried less load with less deflection.

Table 4. Fly ash based mix with varying percentage of Poly Propylene fiber

LOAD(kN)	Deflection in mm with varying % of PP fibers				
	1%	1.25%	1.5%	1.75%	2%
0.00	0	0	0	0	0
0.10	1	2	1	1	1
0.20	3	4	3	2	1.5
0.30	4.5	9	6	3	2
0.40	6	12.5	9	5	6
0.50	9	14	13	10	9
0.60	12	15	14	11	10
0.70		16	15	13	13
0.80			17	15	15
0.90				17	
1.00				20	

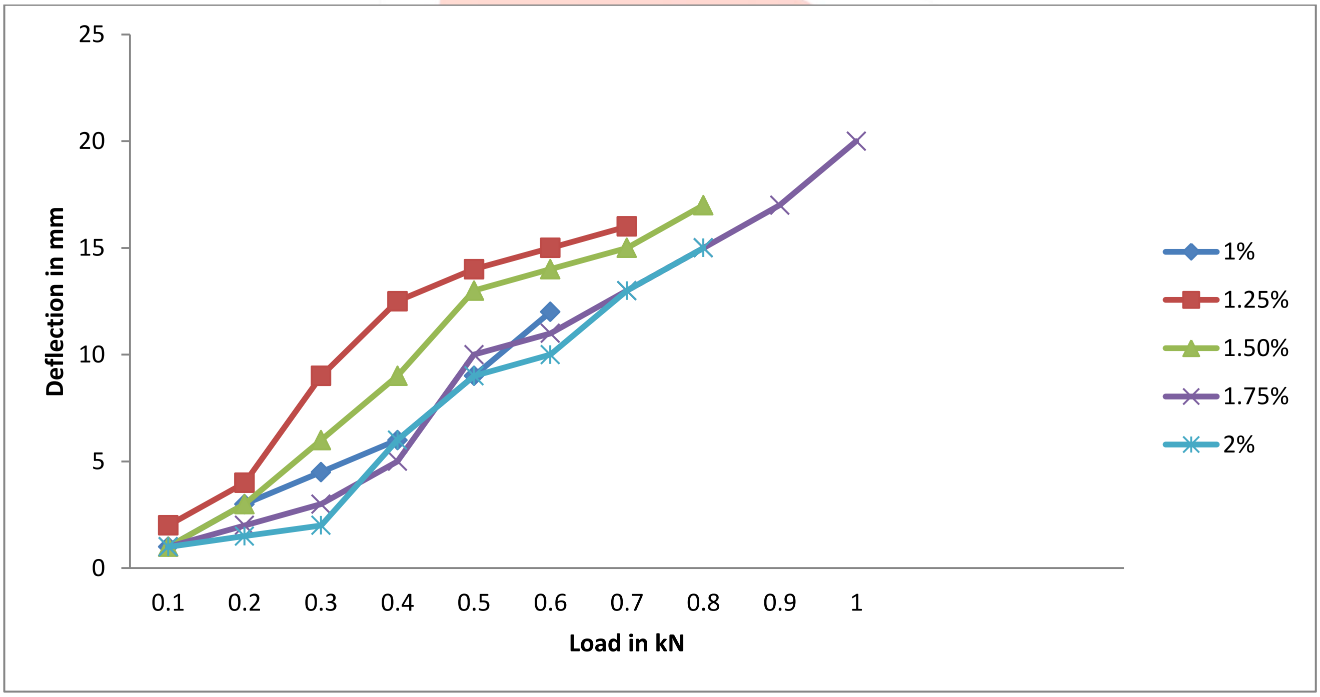

Figure.7.Load verses deflection of Fly ash based mix with varying percentage of Poly Propylene fiber

Fly ash based mix with glass fiber

Mixes were prepared by using cement, flyash, sand, fiber (varying percentage), water and super plasticizer,the result of the mix are shown in below table and the graph of load v/s deflection was shown in the fig. The control mixes prepared by using the cement, sand and water without the flyash and fiber show sudden failure without any deflection. It was observed that no visible cracks are appeared till 0.3kN and sudden failure is observed at 0.5kN for 1% of fibers .For the mixes prepared with 1.25% of fibers, no visible cracks are appeared till 0.6kN of loading and mixes prepared with 1.5% of poly propylene fibers no visible cracks are appeared till 0.7kN loading. Further for specimens with 1.75% glass fibers carried the same load as 1.5% fiber do but giving more deflections. And specimen with 2% of glass fibers carried more load by giving more deflections.

Table 5. Fly ash based mix with varying percentage of Glass fiber

LOAD(kN)	Deflection in mm with varying % of PP fibers				
	1%	1.25%	1.5%	1.75%	2%
0.00	0	0	0	0	0
0.10	1	1	1	1	1
0.20	1	2	1	2	1
0.30	2	2	2	2	2
0.40	4	3	3	3	3
0.50	6	4	4	4	4
0.60		5	5	6	5
0.70		6	6	7	6
0.80			7	8	9
0.90					10
1.00					12

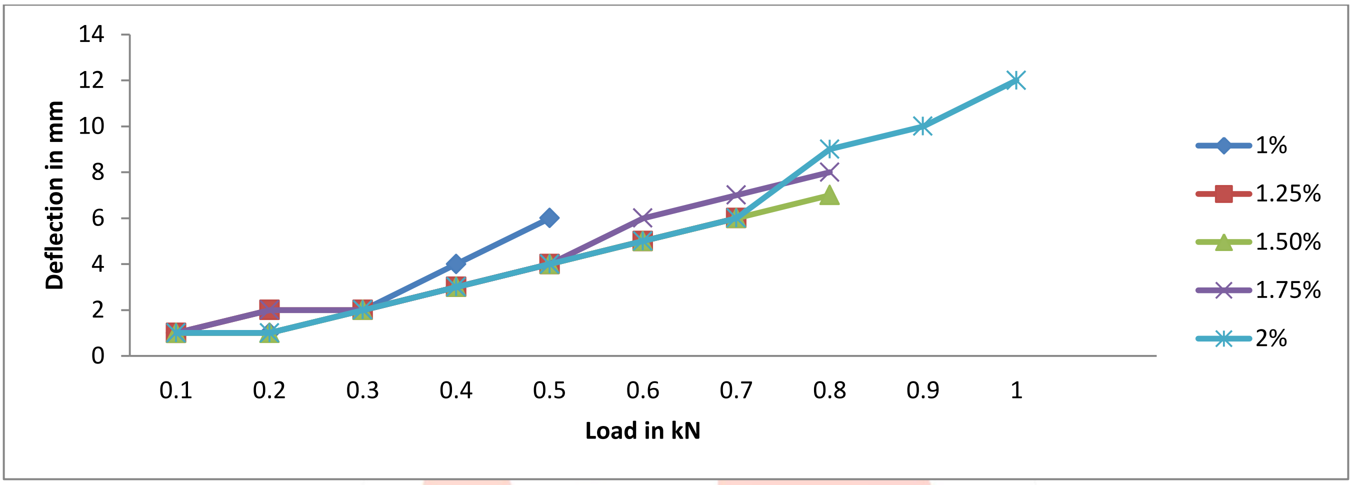

Figure.8.Load verses deflection of Fly ash based mix with varying percentage of glassfiber

Metakaolin based mix with Poly Propylene fibers

Mixes were prepared by using cement, flyash, sand, fiber (varying percentage), water and super plasticizer,the result of the mix are shown in below table and the graph of load v/s deflection was shown in the fig. The control mixes prepared by using the cement ,sand and water without the Metakaolin and fiber show sudden failure without any deflection.it was observed that the mixes prepared with metakaolin doesn't show a good yield in deflection, the brittle failure is observed in most of the specimens. The mix with 1.25% of fibers was found to be the only one which deflected more by taking comparatively more load than other mixes with metakaolin and PP fibers

Table 6.Metakaolin based mix with varying percentage of Poly Propylene fiber

LOAD(kN)	Deflection in mm with varying % of PP fibers				
	1%	1.25%	1.5%	1.75%	2%
0.00	0	0	0	0	0
0.10	1.5	0.5	0.5	0	0
0.20	2	1.5	1	0.5	0.5
0.30	3	3	1.5	1	1
0.40	3	4	2	2.5	1.5
0.50	4	6	4.5	3.5	2
0.60	4	7	6.5	4.5	3.5
0.70	5	7	7	5.5	4
0.80	6	9	7.5	7	5
0.90		10	9		
1.00		11	10		
1.10		12			

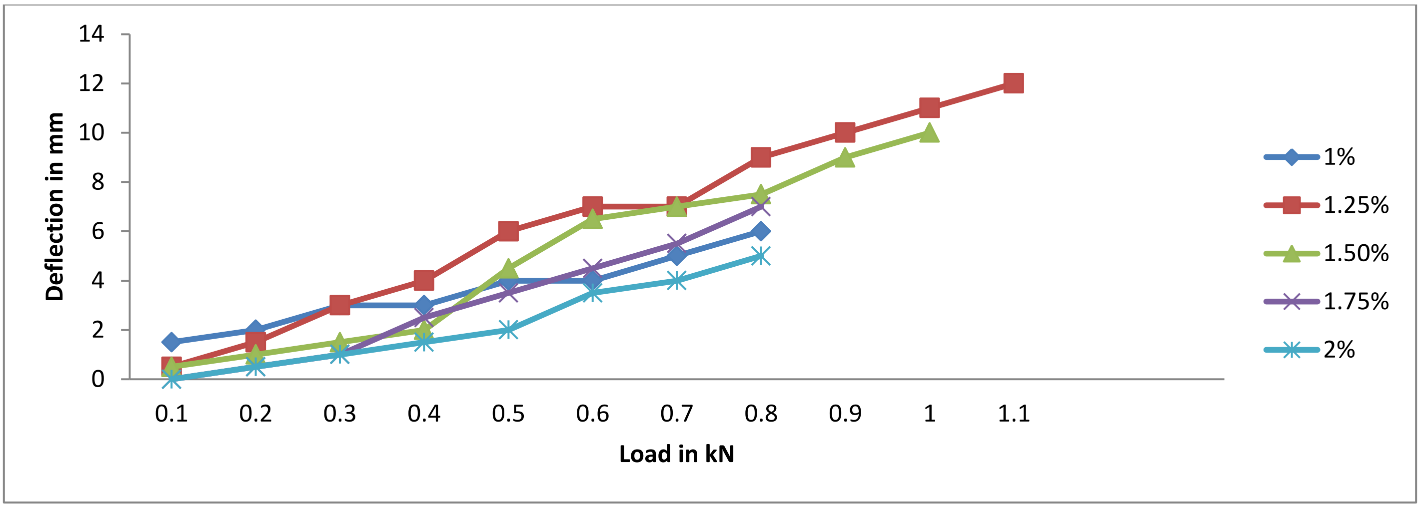

Figure.9.Load verses deflection of Metakaolin based mix with varying percentage of PolyPropylenefiber

Metakaolin based mix with glass fiber

Mixes were prepared by using cement, flyash, sand, fiber (varying percentage),water and super plasticizer,the result of the mix are shown in below table and the graph of load v/s deflection was shown in the fig. the control mixes prepared by using the cement ,sand and water without the Metakaolin and fiber show sudden failure without any deflection. It was observed that the mix prepared with metakaolin doesn't show a good yield in deflection, the brittle failure is observed in most of the specimens. The mix with 1.75% of fibers was found to be the only one which deflected more by taking comparatively more load than other mixes with metakaolin and glass fibers

Table 6. Metakaolin based mix with varying percentage of glassfiber

LOAD(kN)	Deflection in mm with varying % of PP fibers				
	1%	1.25%	1.5%	1.75%	2%
0.00	0	0	0	0	0
0.10	1	1.5	1	1	1
0.20	2	3.5	1.5	1.5	1.5
0.30	3	4.5	3	3	2.5
0.40	4.5	5	4.5	4	4.5
0.50	6	6.5	5	4.5	5.5
0.60	7.5	7	6	6	6
0.70	8	7	7.5	6	6.5
0.80	8	8.5	8.5	6	8
0.90	9	8	9	7.5	8.5
1.00			9.5	8.5	
1.10				9.5	
1.20				10	

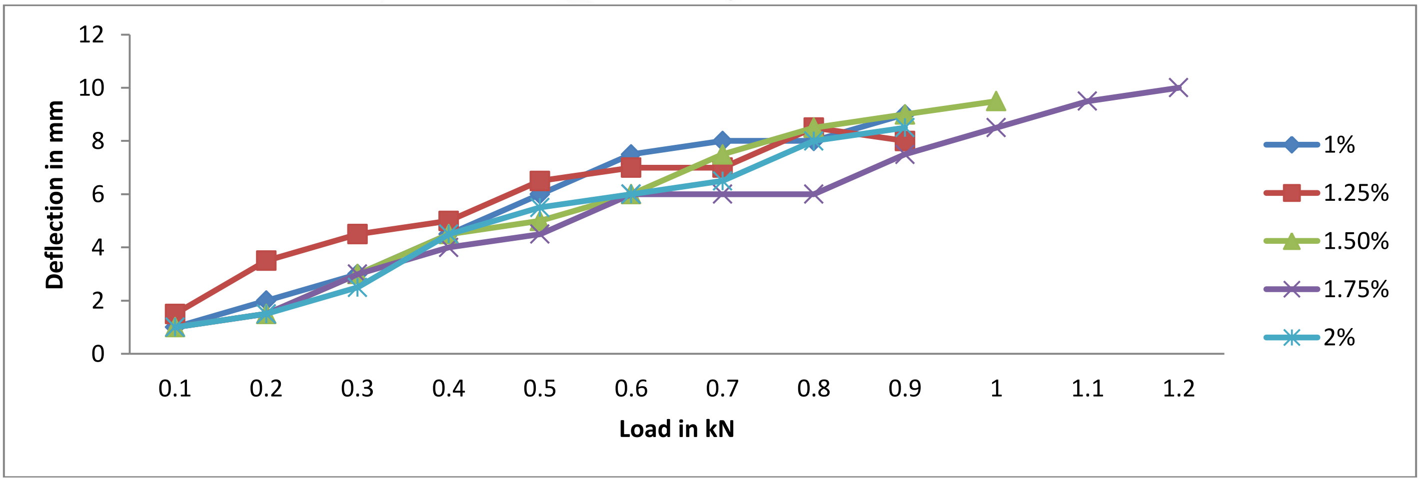

Figure.10.Load verses deflection of Metakaolin based mix with varying percentage of glassfiber

IV. CONCLUSIONS

The ECC can be prepared standard PVA and different types of fibers. The fluidity mix is obtained for flyash as a mineral admixture by adopting the standard mix proportion whereas the mix containing the metakaolin requires more water content to get the fluid mix than the standard mix proportion. It is observed that the control mixes doesn't show any deflection, Whereas glass fiber in Metakaolin with 1% of fibers had shown a good deflection and the same fibers in fly ash shown good deflection at fibers content of 2%. Also poly propylene fiber in Metakaolin with 1.25% of fibers had shown a good deflection and the same fibers in fly ash shown good deflection at fibers content of 1.75%. It is observed that the ECC mix with flyash and poly propylene fibers are performed better than any of the mix prepared in this experimental work .The interaction of fibers and the cement matrix is high enough for cement reinforcing composites and it can be used for future modification of ECC. Weathering, fatigue and fire resistance will be enhanced by using these poly propylene and Glass fiber composites. It is observed that the use of poly propylene and glass fibers can reduce the initial cost and construction time and maintains the good durability.

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