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STATIC AND CYCLIC BEHAVIOUR OF HIGH PERFORMANCE CONCRETE BEAMS USING METAKAOLIN AND PARTIAL REPLACEMENT WITH QUARRY DUST

G.R.VIJAY SHANKAR* AND D. SUJI**

*Department of Civil Engineering , Karpagam University, Coimbatore 641 021, Tamilnadu, India
** Department of Civil Engineering, R.V.S. College of Engineering and Technology
Coimbatore 641 402, Tamilnadu, India

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ABSTRACT

This paper presents an investigation on the flexural behaviour of High Performance concrete beams produced from metakaolin and quarry dust. The quarry dust be an economic alternative to the river sand. In this investigations Metakaolin as partial cement replacement and Quarry dust as partial fine aggregate replacement. A total of 8 specimens were considered and there reinforcement ratios are uniform (0.75%) were fabricated and tested under both static and cyclic loading. It was observed that the deflection characteristics, crack Patten, ductility indices, compressive strain, tensile strain, ultimate load carrying, moment wise curvature of the beam the results were compared with Conventional Concrete beams.

INTRODUCTION

Concrete is basically a mixture of cement, fine and coarse aggregates. High-performance concrete (HPC) conforms to a set of standards above those of the most common applications, but not limited to strength. Some of the standards are ease of placement, compaction without segregation, early age strength, permeability etc. River sand (Fine aggregate), which is one of the constituents used in the production of concrete, has become expensive and scarce. So there is large demand for alternative materials. In India Quarries and aggregate crushers are basic requisites for construction industry and quarry dust is a by product of rubble crusher units. Geotechnical and mineralogical characterization of quarry dust and its interaction behavior with soils can lead to viable solutions for its large-scale utilization and disposal of quarry dust as shown in Fig 1. Metakaolin is a cement substitute often used in concrete countertop mixes to boost the physical properties of the concrete. It is a manufactured pozzolanic mineral admixture made by calcining

*** Corresponding author's email:** girivijayshankar@gmail.com; sujimohan2002@gmail.com

(thermally activating) purified kaolin clay. chemically altered by heat, it reacts very aggressively with calcium hydroxide, a normal cement hydration byproduct, to form additional Cementitious compounds. as shown in Fig. 2. Therefore this paper presents the results of an experimental investigation on the flexural behaviour of High Performance Concrete (HPC) beams. The beams were loaded incrementally until failure and their strength, cracking deformation and ductility behaviour were examined. and the results were compared with Conventional Concrete beams.

Fig. 1 Quarry Dust

Fig. 2 Metakaolin

Experimental Programme
Materials Used

The materials used include Ordinary Portland Cement (43 Grade), metakaolin, super plasticizers, quarry-dust, river sand, coarse aggregate and water. The tested for their physical characteristics as per the relevant standards. The results are presented in Table 1.

Compressive Strength

The compressive strength of concrete was determined at 7, 14, 28, 56,90 and 120 days of curing. Tests were carried out on 150mm x 150mm x 150mm size cubes. A 2000 Kn capacity standard compression testing machine was used to conduct the test. The results are presented in Table 2.

Split Tensile Strength

Split tensile strength was determined for 28, and 56 days. The test was carried out on cylindrical specimens of 150mm diameter and length 300 mm using 2000kN capacity compression testing machine The results are presented in Table 3

Details of Test Specimen

A total of 8 reinforced concrete (RC) beams were cast for flexural test. All the beams were rectangular in cross section and designed as under-reinforced beams. Four beams were Conventional Concrete (denoted with “CC”) and the remaining four were High Performance Concrete which archived in cube test result (10% of cement with Metakaolin and 30% of sand with Quarry Dust) (denote with “MQ”) the beam dimensions were also sufficiently large to simulate a real structural element. The beam details are shown in Table 4 and Fig. 3. The yield strength Fy for tension steel bars were 417.5 N/mm N/mm2 for 8 mm,10mm &12mm bar respectively. sufficient shear lateral ties were also provided along the beams expect at the pure bending region of 600mm.

Description of the form Work

To cast the specimen, one steel moulds were fabricated. The size of the beam was 150 mm×200 mm×1500 mm shown in the Figure 4. The moulds were weld in order to keep the alignment accurately.

Casting and Curing

All the beams concrete was placed in the form work in layers, vibrated thoroughly and finished at top neatly to have uniform top surface. The reinforcement cages were placed in the moulds and cover between cage and form provided was 15 mm. Cement mortar block pieces were used as cover blocks. The concrete contents such as cement, sand, aggregate, Metakaolin, quarry dust, super plasticizer and water were weighed accurately and mixed. The mixing was done till

Table 1. Physical Characteristics of Cement, Metakaolin, Super Plasticizers, Fine Aggregate, Quarry dust and Coarse Aggregate.

Characteristics	Cement	Metakaolin	Super Plasti-cizers	River Sand	Quarry Dust	Coarse Aggregate (20 mm)
Specific gravity	3.15	2.5	4.0 – 7.5 Ph	2.67	2.36	2.87
Standard Consistency (%)	31.5	******	Max. 1000 cPS Viscosity (25°C)	Zone II	******	Zone II
Initial/ final Setting Time (mins)	140/480	******	******			
Fineness (%)	4	3	******			
Average particle size(µ m)	1.25	1.5	******			
Pozzolan Reactivity (mg Ca(OH)2/g)	nil	1050	nil			
Bulk density (kg/m3)	3110	300 ± 30	1.10 – 1.20 mg/L			
Brightness	grey	Off-white	brown			
Physical Form	Powder	Powder	liquid			
Usage	morter or conceret	*****	High-range water reducing type super plasticizer			

Table 2. 7Days, 14Days, 28Days, 56 Days, 90 Days & 120 Days Compressive Strength of Metakaolin with 30% of Quarry Dust in Concrete Cubes

S.No.	ID	% Replacement		Compressive strength (N/mm²)					
		Meta-kaolin	Quarry dust	7 days	14days	28days	56days	90days	120days
1.	CC-0	0	0	17.56	21.11	45.67	52.11	53.44	54.32
2.	CQ-20	0	30	17.33	22.89	36.44	43.11	44.77	45.57
3.	MQ-21	2.5	30	18.44	23.56	41.56	48	48.89	49.27
4.	MQ-22	5	30	22.67	27.11	45.11	50.89	51.22	52.43
5.	MQ-23	7.5	30	25.33	30.22	48.89	52.89	53.81	54.21
6.	MQ-24	10	30	27.56	33.78	51.34	56.67	57.12	57.23
7.	MQ-25	12.5	30	24.44	28.89	47.12	52.67	52.87	53.01
8.	MQ-26	15	30	19.56	24	39.11	49.78	50.88	51.42

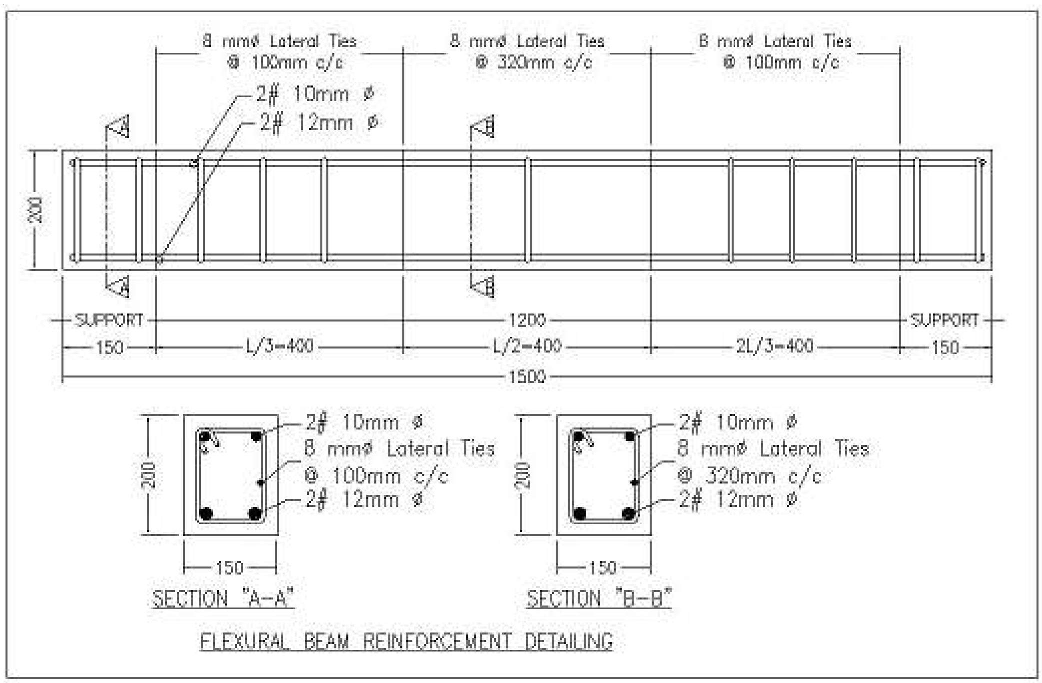
Table 3. Split tensile strength of Cylinders for 28 Days and 56 Days

S.No.	Dia of Cylinder (mm)	Height of Cylinder (mm)	%of meta-kaolin	%of quarry dust	Peak Load in (kN)	28 days Strength (Mpa)	Peak Load in (kN)	56 days Strength in (Mpa)
C1	150	300	0	30	124	1.75	150	2.12
C2	150	300	2.5	30	136	1.92	170	2.41
C3	150	300	5	30	155	2.19	190	2.69
C4	150	300	7.5	30	165	2.33	211	2.98
C5	150	300	10	30	174	2.46	230	3.25
C6	150	300	12.5	30	152	2.15	207	2.93
C7	150	300	15	30	133	1.88	185	2.62
C8	150	300	17.5	30	122	1.73	162	2.29

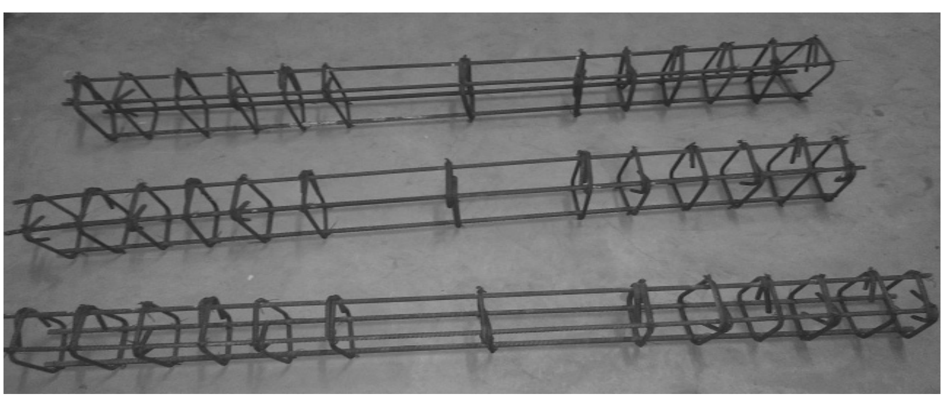
uniform mix was obtained. The concrete was placed into the mould immediately after mixing and well compacted..The test specimens were demoulded at the end of 24 hours of casting. They were marked identifications and specimen was cured with wet gunny bags for 28 , and 56 days. As shown in Fig. 5.

Table 4. Test Specimen Details

S.No.	Specimens ID		Description of test specimens	No of beams	Curing
1.	CC-1	Conventional		1 no	28 days
		(under Concrete	Top reinforcement details-		
2.	CC-2	Static loading)	2 nos 10 mm dia	1 no	56 days
3.	CC-3	Conventional	Bottom reinforcement details-	1 no	28 days
4.	CC-4	Concrete (under	2 nos12 mm dia	1 no	56days
		Static Cyclic loading)	Lateral ties-8 mm dia		
5.	MQ-1	High Performance	Þ= As/ bd %=0.75	1 no	56 days
6.	MQ-2	Concrete	Beam size B X D= 150 x 200mm	1 no	28 days
		(under Static loading)	Area of tensile steel = 226 mm2		
7.	MQ-3	High Performance		1 no	28 days
8.	MQ-4	Concrete (under		1 no	56 days
		Static Cyclic loading)			



A) Typical Reinforcement detailing for the test Beams



B) Reinforcement detailing for flexural Beams

Fig. 3 Reinforcement detailing of Beam

Fig. 4 Form work of the test specimens

Fig. 5 Test specimens Flexure beam under Curing

Experimental and Testing

The beam was loaded under two point loading in order to keep the BM constant and predominating at the middle one third regions. Two steel columns were erected over a girder placed on rigid footing. The column head placed with an arrangement on one side is roller and another side as hinge with two plates and a pin at the centre. The beam was placed on those supports with exactly 1200mm distance from the centre of roller to centre of pin. At 1/3 points two round bars of dia 30mm were placed over them. Exactly at the centre between two round rods on the girder a hydraulic jack was placed. The top of the hydraulic jack was fixed with a proving ring with dial gauge of capacity of 50t. the load was applied manually through hydraulic jack. The increment of loading was kept as 2 divisions of dial gauge (2KN) in the proving ring. To record the load precisely a proving ring was used. The load is applied measured for every 2 Kn. The deflection of the beam at the point of loading during test was measured such as 2Kn, 4Kn, and 6Kn respectively. The test setup as shown in Figure 6 and test set up of all the specimen is show in Figure 6.

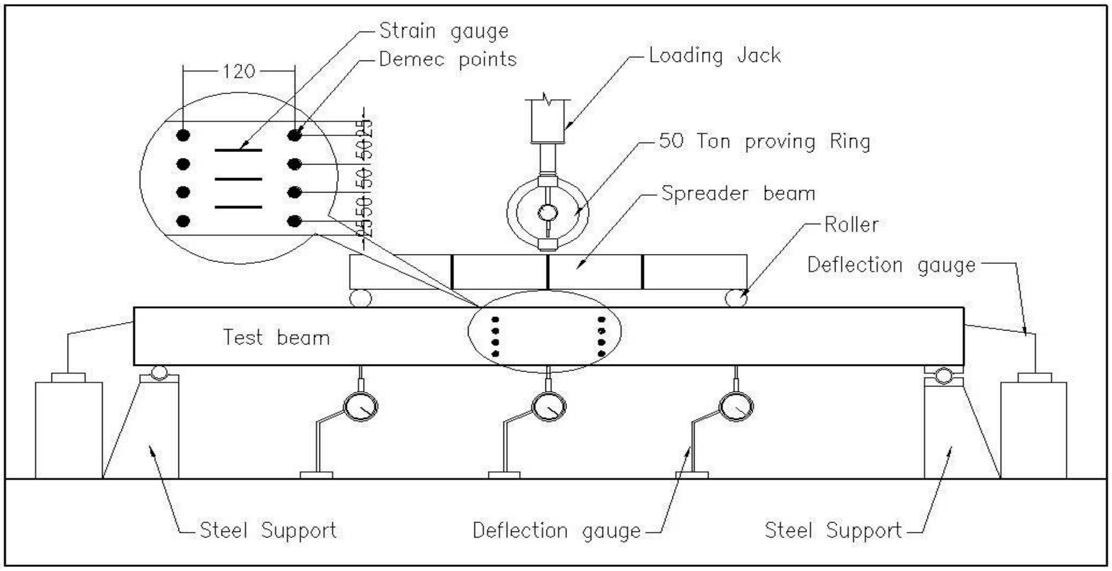
Loading History for Static Cyclic loading

The beam specimen was subjected to cyclic loading. The displacement sequence consists of 2 mm, 4 mm, 6 mm, and 16 mm. Each displacement level is indicated in dial gauge and corresponding loads are noted from proving ring. In the first cycle, beam was loaded gradually up to 2 mm deflection and then unloaded. beam was loaded gradually up to 10 mm and then unloaded and then unloaded similarly each cycle of load is applied.

RESULTS AND DISCUSSION

General observations

All the beams showed typical flexure behavior. No horizontal cracking were observed at level of reinforcement. since all beams were under-reinforced yielding of the tensile reinforcements occurred before



(a) Experimental set-up for the beam specimens

(b) Original Test set up

Fig. 6 Testing set-up for the beam specimens

crushing of the concrete cover in the pure bending zone.

Failure Pattern

All the beams exhibit a reasonably ductile performance as shown in Figure7and 8. Its failure results from the yielding of HPC followed by the crushing of concrete. At about 33% of the ultimate load, well flexural cracks appeared at the bottom of the specimen. With further increase in the load, regularly spaced vertical cracks were observed and they extended from the bottom of the specimen towards the top fiber. The failure occurs in the tensile zone following the appearance of one macro crack in pure bending region. The load was increased up to ultimate stage. After the attainment of ultimate load, the load was maintained till failure due to the confinement effect provided by HPC

Load-Deflection

Conventional concrete beam specimen and High Performance Concrete (10% metakaolin + 30% quarry dust) which was tested for their flexural behaviors and the average result are plot in to the graph are shown in Figure 9 and 14 .

Moment Curvature Curves

The set of Moment curvature curves does not show

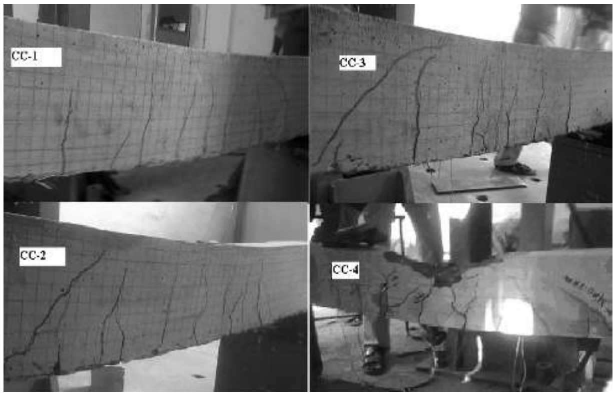


Fig. 7 Flexure Failure pattern of Conventional Concrete beams.

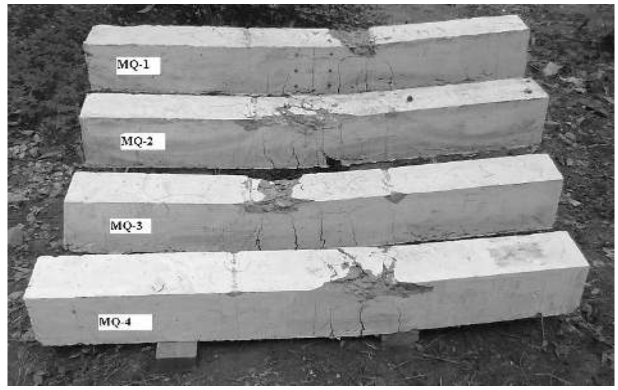


Fig. 8 Flexure Failure pattern of High Performance Concrete beams.

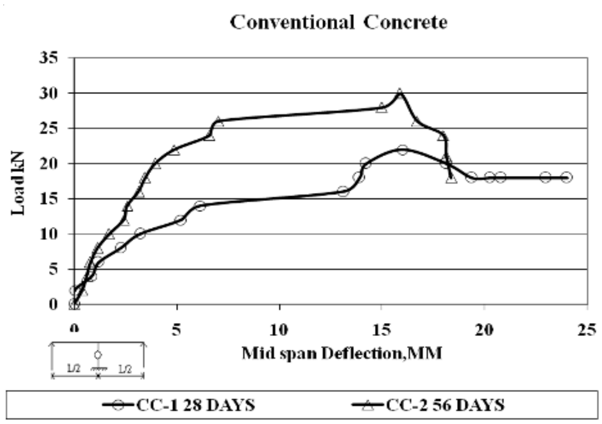


Fig. 9 Experimental Load-Deflection curve for Conventional concrete (under Static loading)

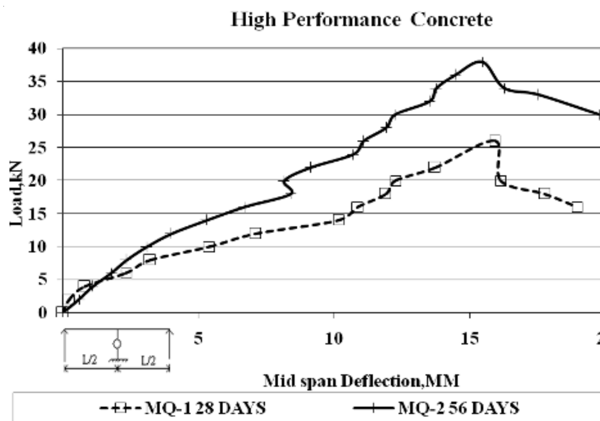


Fig. 10 Experimental Load-Deflection curve for High performance concrete (under Static loading)

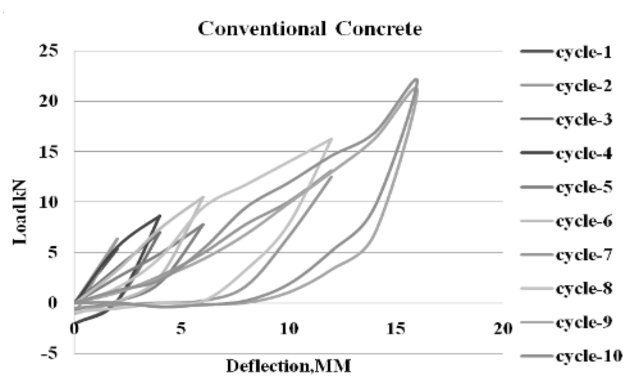


Fig. 11 Experimental Load-Deflection curve for Conventional concrete (under Static cycle loading) CC-3 28 Days

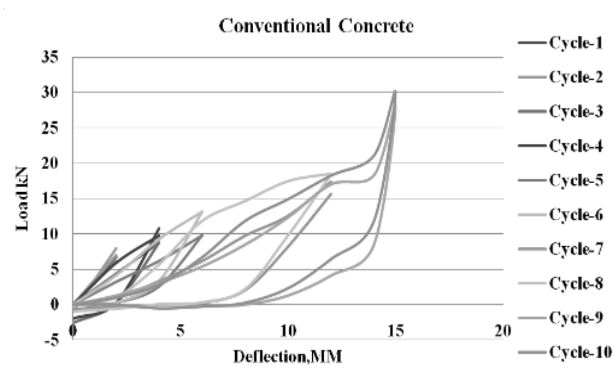


Fig. 12 Experimental Load-Deflection curve for Conventional concrete (under Static cycle loading) CC-4 56 Days

significant differences during the loading. The applied load upon the structure increases until failure. The first stage corresponds to the elastic behaviour without any cracks. In the second stage the cracking decreases the moment of inertia and therefore the bending stiffness of the beam. The last stage of the curves corresponds to the yielding of HPC. Typical moment – curvature curves HPC beams are shown in Figure 17 and 18.

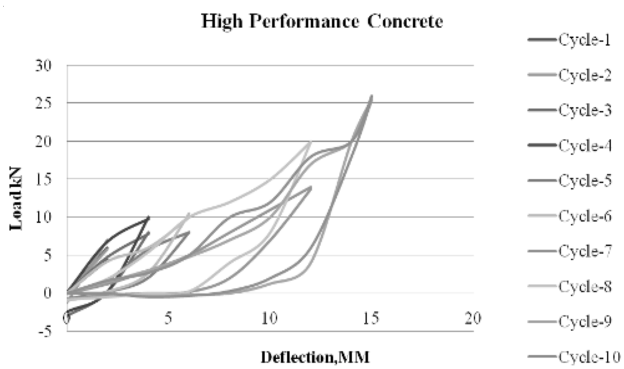


Fig. 13 Experimental Load-Deflection curve for High Performance concrete (under Static cycle loading) MQ-3 28 Days

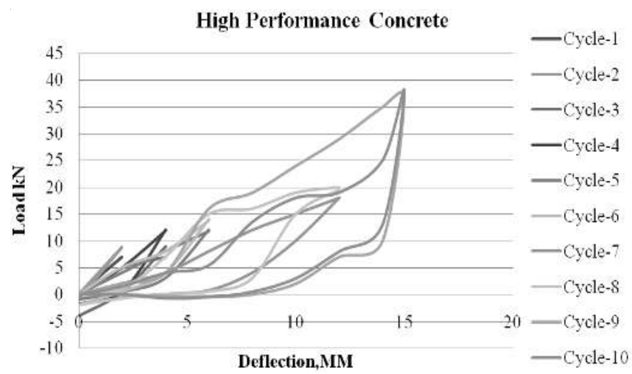


Fig. 14 Experimental Load-Deflection curve for High Performance concrete (under Static cycle loading) MQ-4 56 Days

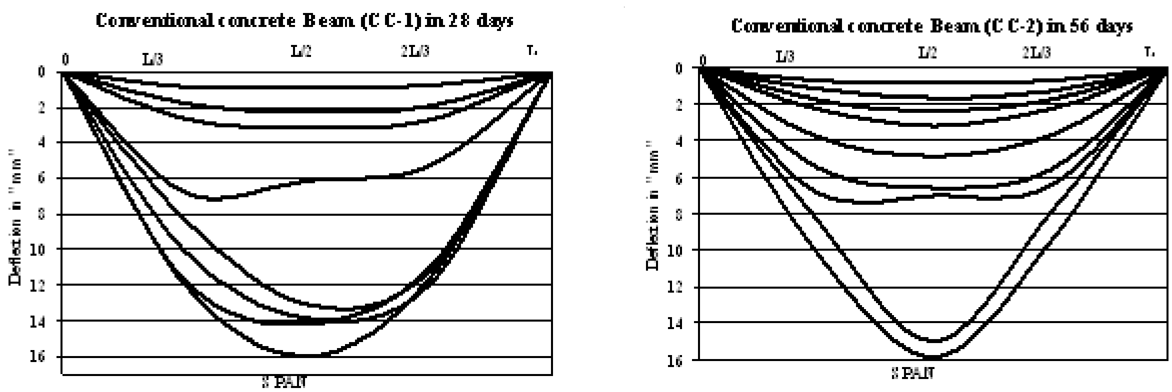


Fig. 15 Deflection profile of Conventional concrete Beam

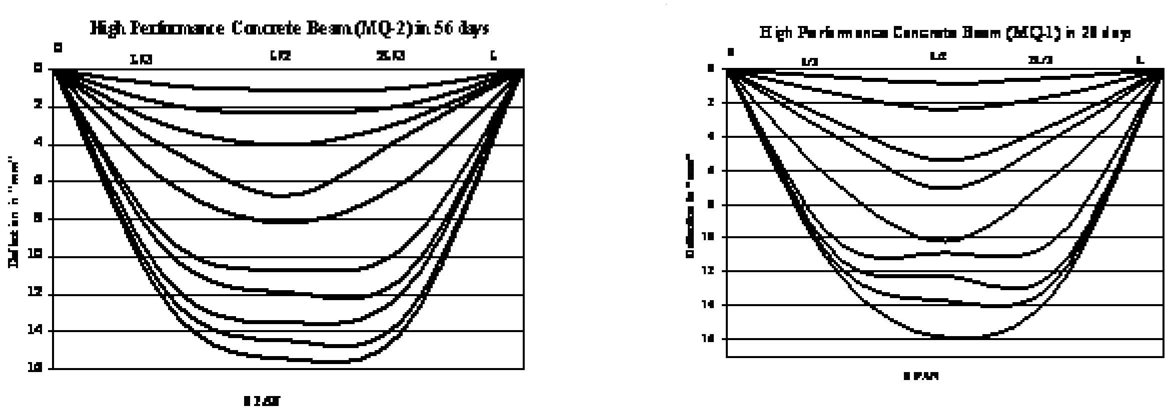


Fig. 16 Deflection profile of High Performance concrete Beam

Load – Strain Response

The load - strain curves as indicated in Figure 19 and 20 , illustrate the behaviour per unit length until the failure of concrete and steel. For all the Beams the stress - strain response shows a strain hardening behaviour. This allows an increase in the moment supported by the beam.

Energy Absorption Capacity

Ductility can be quantitatively measured in terms of

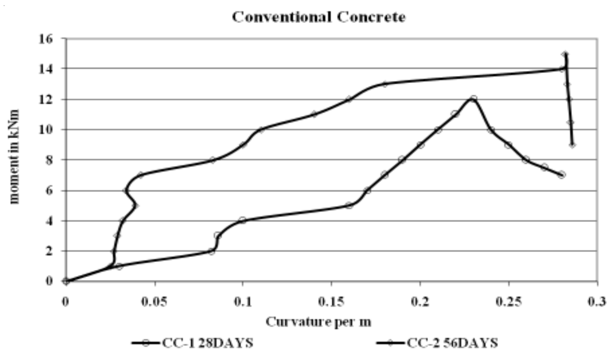


Fig. 17 Moment Curvature Curves for Conventional concrete Beam

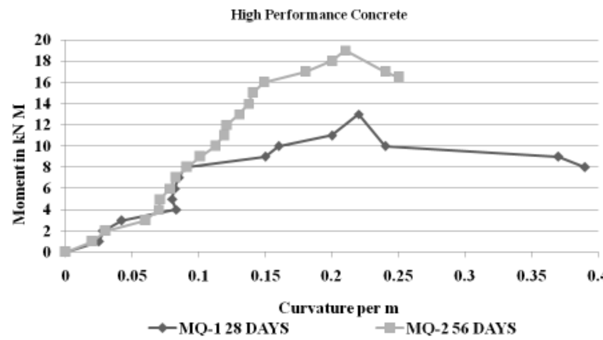


Fig. 18 Moment Curvature Curves for High Performance Concrete Beam

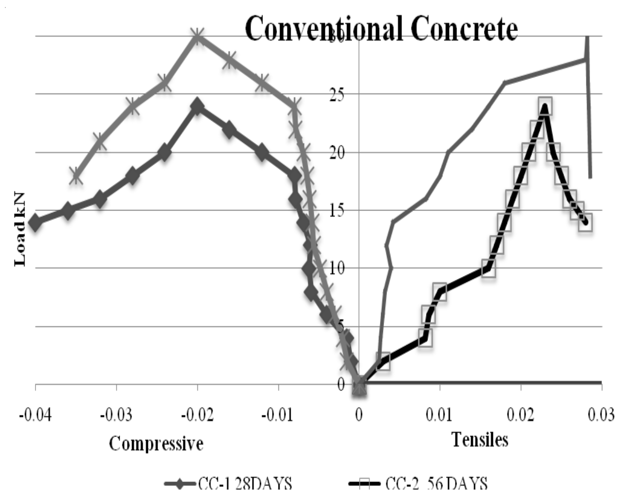


Fig. 19 Strain distribution for Conventional concrete Beam

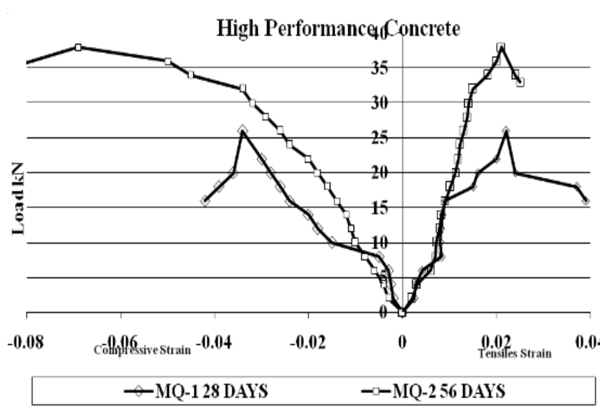


Fig. 20 Strain distribution for High Performance Concrete Beam

the energy absorption capacity. Energy absorption capacity of the members can be approximated as the area enclosed by the load deflection curve. The ability of a structural member to absorb energy is an important factor in the overall performance of structural elements. At cracking, yielding of tension steel and at ultimate stage, HPC beams exhibited a substantial increase in the energy absorption capabilities thereby indicating improved ductile characteristics.

CONCLUSION

The tests on beams carried out in this study describe the possibility of using High performance concrete using (10% of cement with Metakaolin and 30% of sand with Quarry Dust) . From the results of the experimental study reported herein, the following conclusions can be drawn

1. Partial replacement of cement by Metakaolin and Quarry Dust by sand in concrete mixes would, not only lead to considerable savings in consumption of cement and natural sand
2. The ultimateload carrying capacity of High performance concrete beam using (10% Metakaolin and 30% Quarry Dust) is found to be 26kN, and 38 kN, at the age of 28,and 56 days of curing . This shows that there is increase in load carrying capacity by 8.33 %,and 26.67 %,of Conventional concrete Beam.
3. HPC beams show good ductility due to the confinement of the compression zone. The displacement ductility factor varies from 1.23 to 1.31. The results reveal that more ductile performance.
4. The Conventional concrete Beam. show the nor-

EXPERIMENTAL OBSERVATIONS ON DUCTILITY

Sr. No.	Specimens ID	At assumed serviced		At yielding				At Ultimate		$\mu\Delta = \Delta_\mu/\Delta_y$	$\mu\Phi = \Phi_u/\Phi y$
		Load Ps (Kn)	Deflection Δ_s(mm)	Load P_y (Kn)	Deflection μ_y(mm)	(10^{-3} per m)	Fy	Load P_u (Kn)	Deflection $\Delta\mu$(mm)	Φ_u (per m)	
1.	CC-1	14.67	2.87	18.33	5.89	0.13	22	16	0.23	2.72	1.77
2.	CC-2	20	3.95	25	6.82	0.198	30	15.88	0.282	2.33	1.42
3.	CC-3	14	2.88	19.45	5.47	0.12	21	15.25	0.21	2.79	1.75
4.	CC-4	14.67	3.66	24.55	6.12	0.2	30	16	0.3	2.61	1.50
5.	MQ-1	17.33	9.75	21.65	12.87	0.14	26	15.9	0.21	1.24	1.50
6.	MQ-2	25.33	10.7	31.65	12.5	0.16	38	15.44	0.22	1.24	1.38
7.	MQ-3	17.33	9.75	21.65	12.78	0.15	26	14.99	0.205	1.17	1.37
8.	MQ-4	23.33	10.15	30.89	12.5	0.17	35	15.24	0.23	1.22	1.35

+ Assumed service load is taken as ultimate load/1.5

mal behaviour and the energy absorption is normal

5. The advantages of introducing HPC (10% of cement with Metakaolin and 30% of sand with Quarry Dust) included of the slowing down of appearance of first crack and the presence of smaller deflection, compared with Conventional concrete Beam

6. As the age of concrete increases, the compressive strength as well as tensile strength also increases

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