EXPERIMENTAL INVESTIGATION ON THE FLEXURAL BEHAVIOUR OF OLYOLEFIN MACRO-MONOFILAMENT FIBRE REINFORCED HIGH PERFORMANCE CONCRETE BEAMS

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***Abstract*: The behavior of polyolefin macro-monofilament (PMM) fibre reinforced high performance concrete (PMMFRHPC) flexural members has been studied. The ordinaryPortland cement was partially replaced with 10% each of the mineral admixtures suchas Metakaolin and fly ash. The PMM fibre of various dosages such as 0.1, 0.2 and 0.3%by the volume fraction of concrete and randomly dispersed were adopted in the high performance concrete (HPC) mixes. The flexural beams were cast and tested less than twopoints loading. The performance of PMMFRHPC beams were compared based on the load-deflection, toughness index, energy absorption capacity and ductility factor. In addition, an analytical investigation was carried out using ANSYS software**

Keywords: Polyolefin Macro-Monofilament Fibre; Flexural Members; Deflection.

INTRODUCTION

One of the recent developments in concrete technology is the HPC. It is designed to give optimized performance characteristics for the given set of materials, usage and exposure conditions, consistent with the requirement of cost, service life and durability. Addition of fibres in cement or cement concrete may be of current interest, but this is not a new idea or concept. Fibres of any material and form play an important role in improving the strength anddeformation characteristics of the cement matrix in which they are incorporated. The advantages of incorporating fibres in concrete improve the fracture toughness, fatigue resistance, impact resistance and flexural strength. The magnitude of the improvement dependsupon the amount and type of fibres used. The PMMFRHPC is a composite material consistingof cement, fly ash, metakaolin, fine aggregate, coarse aggregate, water and fibres. In this composite material, fibres were randomly distributed throughout the concrete mass. Fibre reinforced high performance concrete represents a potential alternative for providing a cost effective ductile material for structures. In this paper the behavior of PMMFRHPC beam- columns were studied based on numbers of parameters. Excellent mechanical performance anddurability is achieved using high-strength concrete and this result in initial and long term cost reduction [1].

Mix Proportioning

The detailed mix proportions were carried out based on ACI 211.4R-08 [8] "Guide for selectingproportions for high strength concrete with Portland cement and other cementitious materials."Control mix is designated as CM and high performance concrete mix without fibre is designatedas HPC00, while HPC mixes with fibre dosage such as 0.1, 0.2 and 0.3 volume fractions are designates as HPC01, HPC02 and HPC03 respectively. The details of the mix proportions areshown in Table 1.

Table 1 Mix proportions of concrete

Mix	OPC kg/m^3	Fly Ash kg/m^3	Metakaolin kg/m^3	Fibre kg/m^3	Fine Aggregate kg/m^3	Coarse aggregate kg/m^3	Water kg/m^3	Super plasticizer Lit/m^3
CM	610	-	-	-	519	1107	183	4.8
HPC00	488	61	61	-	484	1107	183	4.8
HPC01	488	61	61	0.91	482	1107	183	4.8
HPC02	488	61	61	1.82	479	1107	183	4.8
HPC03	488	61	61	2.73	476	1107	183	4.8

LITERATURE REVIEW

JuliaBlazy and RafałBlazy: Fiber reinforced concrete is a cementitious composite material with a dispersed reinforcement in a form of fibers. Polypropylene fibers can be divided into microfibers and macrofibers depending on their length and the function that they perform in the concrete. An overview of selected polypropylene fibers available on the market was presented. Moreover, the influence of polypropylene fibers on physical and mechanical properties of concrete such as workability; elasticity modulus; compressive, flexural, and tensile strength; toughness; impact, spalling, freeze-thaw, abrasion resistance; water absorption; porosity; permeability; durability, and eco-friendly and economic properties were discussed. Additionally, certain restrictions while designing fiber reinforced concrete mixture were mentioned. The article proved that public spaces are a promising field of polypropylene fiber reinforced concrete application. Since they are subjected to e.g. unfavorable environmental conditions, impact damages, surface abrasion, and vandalism, the use of concrete with enhanced propertied will be undeniably beneficial.

M. G. Alberti: Fibre-reinforced concrete (FRC) allows reduction in, or substitution of, steel-bars to reinforce concrete and led to the commonly named structural FRC, with steel fibres being the most widespread. Macro-polymer fibres are an alternative to steel fibres, being the main benefits: chemical stability and lower weight for analogous residual strengths of polyolefin-fibre-reinforced concrete (PFRC). Furthermore, polyolefin fibres offer additional advantages such as safe-handling, low pump-wear, light weight in transport and storage, and an absence of corrosion. Other studies have also revealed environmental benefits. After 30 years of research and practice, there remains a need to review the opportunities that such a type of fibre may provide for structural FRC. This study seeks to show the advances and future challenges of use of these polyolefin fibres and summarise the main properties obtained in both fresh and hardened states of PFRC, focusing on the residual strengths obtained from flexural tensile tests.

DESIGN ASPECTS OF BEAMS

The beams were designed as under reinforced beams with cross section as 100 mm x 200 mmand an effective span of 1500 mm, by using Whitney's theory. A clear cover of 15 mm was adopted for all the beams.

Grade of concrete and steel :	M60 and Fe 415
Beam size :	100 mm x 200 mm x 1700 mm
Effective span :	1500 mm
Loading method :	Two point load (third point)
End condition :	Simply supported

Each beam was designated using alpha numerals. The letters CB refers to the control beamcontaining cement alone and B0 refers to the beam with admixtures and without fibres. B1, B2and B3 refer to the beams with admixtures and fibre dosages of 0.1, 0.2, and 0.3 percentages by the volume fraction. Two numbers of 10 mm diameter bars were provided in tension zone and two numbers of 8 mm diameter bars were used as stirrup holders at the top in compressionzone. Two legged stirrups of 8 mm diameter at a center-to-center distance of 135 mm were provided throughout the beam to resist shear. Typical reinforcement arrangement and geometry of the beam are shown in Figure 1.

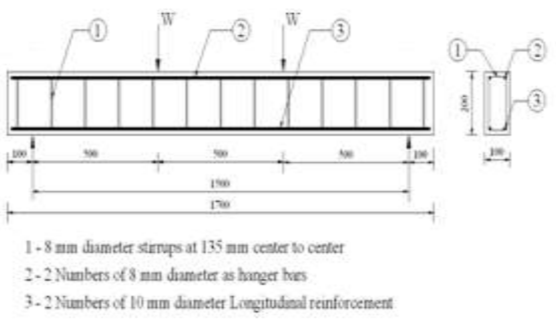


Figure 1 Reinforcement Details

Casting and Curing

All the beams were cast in steel moulds sufficiently stiffened with angles, so as to maintain thedimensions of the beam as 100 mm x 200 mm x 1700 mm. A sufficient mixing time was allowed to produce a uniform and homogenous concrete with fibres dispersed randomly. The prepared mix was poured into the moulds as layers and compacted well. After 24 hours of casting, the form work was removed and the specimens were allowed to cure for 27 days by providing wet gunny bags. Beam designation and its details are shown in Table 3. Along withthe beam specimen, auxiliary specimens to test the mechanical properties of HPC mixes were also similarly cured. The details of the auxiliary specimen are shown in the Table 2.

Table 2 Auxiliary Specimen Details

Type of Specimen	Properties	No. of Specimens	Test Age in days	Size in mm
Cube	Compressive strength	45	28, 56, & 90	100 x 100 x100
Cylinder	Splitting tensile strength	15	28	150 x 300
Prism	Modulus of rupture	15	28	100 x 100 x 500
Cylinder	Modulus of elasticity	15	28	150 x 300
Cylinder	Poisson's Ratio	15	28	150 x 300

Table 3 Details of Beam Specimen

Mix	Beam Designation	Size in mm	No. of test specimens
CM	CB	100 x 200 x 1700	1
HPC00	B0	100 x 200 x 1700	1
HPC01	B1	100 x 200 x 1700	1
HPC02	B2	100 x 200 x 1700	1
HPC03	B3	100 x 200 x 1700	1

Testing Procedure

Five simply supported PMMFRHPC beams were tested under two point loading. The beam specimens were white washed before testing and the location of the supports and linear variabledifferential transducers (LVDTs) points were marked. A loading frame of 1000 kN capacity was used for testing. Two symmetrical point loads were applied vertically using a well stiffenedsteel beam [9]. The load was applied by a hydraulic jack and measured using a load cell. The deflections were measured under the loading point. At the mid-span using LVDTs and the curvature of the beam specimen was measured using strain gauge.
The appearance of the initialcrack, development and propagation of further cracks due to the increase of loading were alsorecorded. The schematic diagram of test setup and the photograph showing the experimental test setup are given in the Figures 2 and 3.

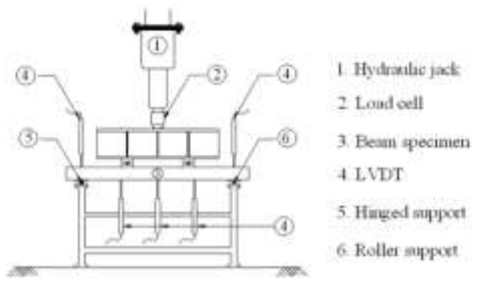


Figure 2 Schematic diagram of Test Setup

Figure 3 Loading test setup and failure pattern of tested beam

RESULTS AND DISCUSSION

Mechanical Properties

Mechanical properties such as compressive strength, splitting tensile strength, modulus of rupture and modulus of elasticity of the auxiliary specimens were tested at the same testing ageof beams. The compressive loading test on concrete was carried out on a Compression TestingMachine of capacity 2000 kN. For the compressive strength test, a loading rate of 2.5 kN/s wasapplied as per IS: 516-1959 [10]. The Universal Testing Machine (UTM) of 400 kN capacity was used for the application of the load in the splitting tensile strength test. The load was applied without shock and increased continuously to produce an approximate splitting tensile stress of 14 to 21 kg/cm^2/minute until resistance of specimen to increasing load breaks down and no greater load can be sustained. The UTM was used for the application of the load to studythe modulus of rupture. The bed of the testing machine was provided with two steel rollers, 38mm in diameter, on which the specimen was supported, and these rollers shall be so mounted that the distance from center to center was 500 mm for the 100 mm specimen. The load was applied through two similar rollers mounted at the third points of the supporting span, spaced at 133 mm center to center. The rate of loading was 4 kN/min. The UTM was used for the application of the compressive load, and the compressometer was used to record the longitudinal strain of concrete to evaluate the modulus of elasticity of concrete. The cylinder was placed with the compress meter fixed, on the plate of the compression testing machine and the rate of loading was 14 N/mm^2/min. Poisson's ratio is the ratio of transverse contractionstrain to longitudinal extension strain in the direction of stretching force. The linear strain wascalculated from the initial tangent modulus of longitudinal stress-strain curve and the lateral strain was obtained from the lateral stress-strain curve. The test results are shown in Table 4.

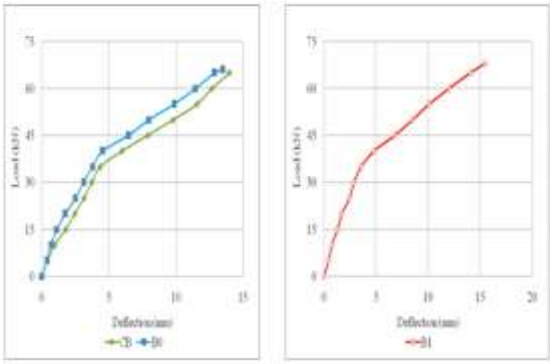
Table 4 Mechanical Properties of Concrete mixes

Mix	Fibre Dosage (%)	Compressive Strength (MPa)	Splitting Tensile Strength (MPa)	Modulus of Rupture (MPa)	Modulus of Elasticity (MPa)	Poisson's ratio
		28 days	28 days	28 days	28 days	28 days
CM	-	66.3	5.48	4.833	37735	0.169
HPC00	-	66.8	5.65	5.166	38461	0.173
HPC01	0.1	69.6	5.98	6.425	38961	0.181
HPC02	0.2	71.1	6.43	7.06	39215	0.189
HPC03	0.3	73.3	6.86	7.63	39473	0.194

Behavior of Beams

Deflection of beams

The deflections were measured in beam specimens subjected to two symmetrical concentratedloads of monotonic loading. The measured central deflections were found to decrease with theincreasing ultimate load. The load versus deflection curves for the test specimens are shown inthe Figure 4.



(b)**Figure 4** (a) load-deflection curve of beam CB and B0, (b) load-deflection curve of beam B1 It is

Table 5 Central deflection for Cracking Loads

Beam Designation	**Pre-cracking load (kN)**	**Central deflection δ (mm)**		**δex / δth**
		Theoretical	**Experimental**	
CB	30	2.25	3.72	1.65
B0	32	2.36	3.38	1.43
B1	34	2.42	3.42	1.38
B2	35.5	2.57	3.47	1.35
B3	36	2.59	3.43	1.32
Mean				1.42
Coefficient of Variation				9.15 %

Table Energy Absorption Capacity and Toughness Index

Beam Designation	Energy Absorption Capacity (kN mm)		Toughness Index	
	Absolute	Relative	Absolute	Relative
B0	576.30	1.00	6.94	1.00
B1	690.77	1.19	7.92	1.14
B2	712.92	1.23	8.47	1.22
B3	730.32	1.26	7.84	1.12

Displacement Ductility Factor

Ductility may be defined, as the ability of a structure to undergo inelastic deformations beyondthe initial yield deformation with no decrease in the load resistance. The ductility of a membercan be measured using load versus deformation response. The deformation may be strain / rotation / curvature / deflection and the ratio of ultimate deformation to the deformation at thefirst yield is defined as ductility factor. Ductility factor is an important parameter considered inthe design of structures subjected to large deformation. Generally it is defined in the case of members subjected to flexure as

It has been observed from the Table 7 that the ductility has improved nearly 1.14 times forthe beam containing 0.1 and 0.2 % volume fraction of fibre. This is due to the fibre arresting the crack propagation by bridging across the cracks. Due to this, the cracks could not propagatein the same plane and had to take a deviated path resulting in the higher energy demand for further propagation. This in turn increases the load carrying capacity at ultimate load.

Table 7 Displacement Ductility Factor

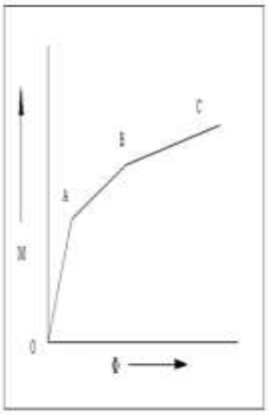
Beam Designation	**Ultimate Deformation δu (mm)**	**First Yield Deformation δy (mm)**	**Displacement Ductility (δu ⁄ δy)**	
			Absolute	**Relative**
B0	13.48	3.38	3.98	1
B1	15.46	3.42	4.52	1.136
B2	15.70	3.47	4.52	1.136
B3	15.48	3.43	4.51	1.133

THEORETICAL ANALYSIS

Experimental Flexural Rigidity

The moment curvature curve can be explained with respect to the idealized moment curvaturecurve shown in Figure 8. The first part OA of the curve is the zone of loading in the initial stageup to cracking, characterized by a steep slope and hence a high value of flexural rigidity (EI_g).The second part AB represents the zone of loading after cracking in which the flexural cracks are predominant with the formation of shear cracks. This part is characterized by a lesser slope.This is due to the reduction in the effective area of cross section caused by the formation of tension cracks resulting in the lesser value of flexural rigidity (EI_{cr}).

The third part BC is the zone of loading just prior to the ultimate load is the limit of useful strain in the concrete.



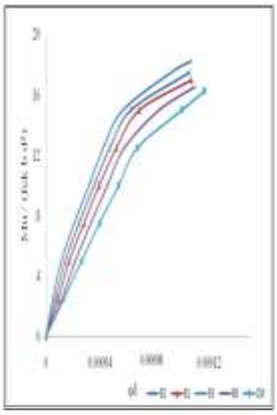


Figure 8 Idealized Moment Curvature Curve

Figure 9 Normalised Moment Curvature plot

The slope of the M- Φ curve gives the flexural rigidity (EI) of the beam section. Slope of the initial linear portion (OA) of the M- Φ curve represents the flexural rigidity of the uncrackedsection (EI_g).Slope of the next portion (AB) represents the flexural rigidity of the cracked section (EI_{cr}). Using the above procedure, flexural rigidity of the uncracked section (EI_g) and the cracked section (EI_{cr}) have been found out for the specimens using the normalized M- Φ plot shown in Figure 9.

Table 8 Experimental Flexural Rigidity

Beam Designation	Flexural Rigidity (x 10^{12} Nmm^2)	
	Before cracking	**After cracking**
CB	1.95	1.40
B0	2.34	1.51
B1	2.80	1.58
B2	3.58	1.65
B3	3.92	1.70

From the Table 8, it is clear that there is not much variation in the stiffness of the beams before cracking. The post cracking stiffness has improved by the addition of fibres. The actionof fibres came into picture only after the first crack has appeared.

Load Factor

As per Indian Standards IS 456: 2000 [6], in the limit state design of reinforced concrete structures, the design should satisfy both the safety and serviceability criteria. As far as safetyis concerned, the member subjected to bending should be safe against limit state of collapse against flexure and shear. The load factor considered in the case of limit state of collapse againstflexure and shear is 1.5. Regarding the serviceability, limit state of deflection and cracking areimportant. An attempt was made to obtain the load factor with respect to the limit state of deflection in the case of PMMFRHPC beams.
Load factor with respect to the limit state of deflection was calculated to understand whetherthe load factor with respect to strength or with respect to deflection governs the design. The following procedure was adopted to calculate the load factor with respect to limit state of deflection. For serviceability conditions, the allowable total deflection δ_t is limited to span/250.The total deflection is the sum of short term and long term deflections. The deflection obtainedfrom the experiment is short time or immediate deflection δ_i. Long term deflection, δ_l is calculated as

Table 9 Load factor with respect to deflection

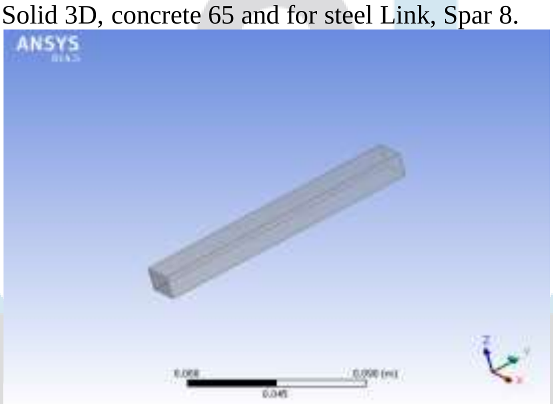
Beam Designation	Load Pδ (kN)at δi =2.70 mm	Ultimateload Pu (kN)	Load FactorPu / Pδ
CB	22.50	65	2.80
B0	26.78	66	2.46
B1	35.00	68	1.95
B2	37.50	70	1.87
B3	40.00	73	1.83

FINITE ELEMENT MODELLING OF BEAMS

The use of finite element packages are efficient and better analyses can be made to fully understand the response of individual structural components and their contribution to astructure as a whole. The investigation is based on the behaviour of PMMFRHPC Structural Elements using Finite Element Analysis. The Finite Element Method is a good choice for solving partial differential equations over complicated domains.

Material Properties

All the material properties of concrete and reinforcement based on experimental studies are adopted to develop a model in ANSYS. Type of elements used for concrete are Solid 3D, concrete 65 and for steel Link, Spar 8.



Bounding Box	
Length X	15.825 mm
Length Y	150. mm
Length Z	15.053 mm
Properties	
Volume	35732 mm³
Mass	8.2183e-002 kg
Scale Factor Value	1.
Statistics	
Bodies	1
Active Bodies	1
Nodes	849
Elements	120
Mesh Metric	None

TOTAL DEFORMATION

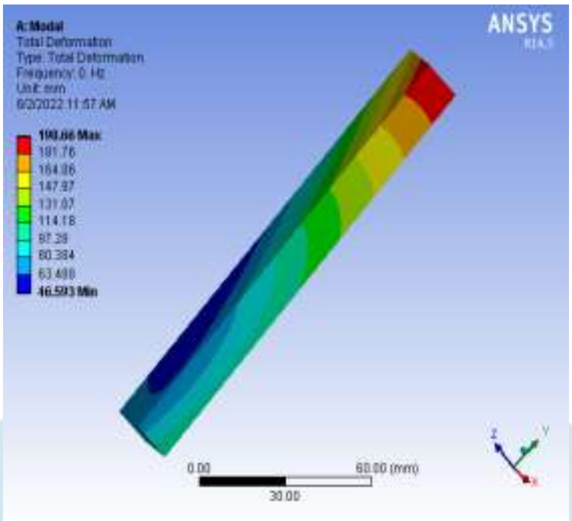


TABLE 13
Model (A4) > Modal (A5) > Solution (A6) > Total Deformation

<table>
<tr><th>Mode</th><th>Frequency [Hz]</th></tr>
<tr><td>1.</td><td rowspan="3">0.</td></tr>
<tr><td>2.</td></tr>
<tr><td>3.</td></tr>
<tr><td>4.</td><td>6.0824e-004</td></tr>
<tr><td>5.</td><td>8.721e-004</td></tr>
<tr><td>6.</td><td>2.1027e-003</td></tr>
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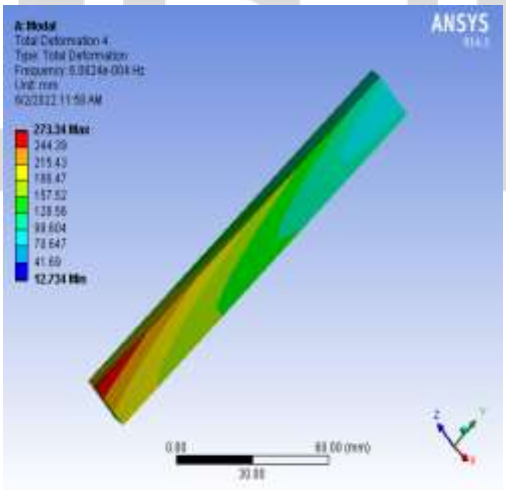
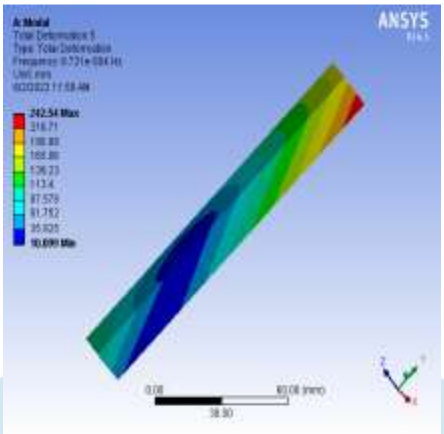
TOTAL DEFORMATION



TOTAL DEFORMATION



Definition					
Type	Total Deformation				
Mode	1.	2.	3.	4.	5.
Identifier					
Suppressed	No				
Results					
Minimum	46.593 mm	18.734 mm	53.314 mm	12.734 mm	10.099 mm
Maximum	198.66 mm	226.47 mm	210.39 mm	273.34 mm	242.54 mm
Information					
Frequency	0. Hz			6.0824e-004 Hz	8.721e-004 Hz

CONCLUSIONS

The following conclusions may be drawn from the experimental investigation results:

1. The mid span deflection was calculated for all the beams, for cracking load by making use of the conjugate beam method. It is found that the average value of the ratio of experimental deflection and the theoretical deflection is found as 1.42 with a standard deviation of 0.13 and coefficient of variation of 9.15%.
2. Cracking load increased by 6.67, 13.33 and 16.67 % for beams having fibre content of 0.1, 0.2and 0.3% respectively, when compared to beam without fibres. It was found that the addition of PMM fibres bridges the cracking effects and delayed the formation of first crack.
3. The ultimate load carrying capacity increases by 3% to 11%, when compared to beam withoutfibres and in the case of deflection the increase was found to be 13% to 17%, when compared to beam without fibres.
4. The energy absorption capacity of PMM fibre beams increases by 19, 23 and 26 % for fibre content of 0.1, 0.2 and 0.3% respectively and toughness index of beams with PMM fibre beamsincreases by 14, 22 and 12 % respectively, when compared to beam without fibres.
5. It can be seen that the ductility have improved nearly 1.14 times for the beam containing fibrescompared to beam without fibres.
6. It is clear that there is not much variation in the stiffness of the beams before cracking. The postcracking stiffness has been improved by the addition of fibres. The action of fibres came into picture only after the first crack has appeared.
7. The beam specimens are found to have load factor of more than 1.5, which is normally considered as strength factor. Load factor with respect to limit state of deflection, controls the design of PMMFRHPC beams when compared to that of the strength criterion. The experimental load versus deflection values fairly agrees with the results of finite element analysis using ANSYS software.

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