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DUCTILITY AND FLEXURAL BEHAVIOUR OF HYBRID FIBRE REINFORCED CONCRETE (HFRC) MADE WITH POLYPROPLYLENE FIBRE (PPF) AND ALKALI RESISTANCE GLASS FIBRE (ARGF).

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ABSTRACT

This study experimentally investigated the flexural and ductility performance of hybrid fibre reinforced concrete, using polypropylene fibres (PPF) and alkali resistance glass fibres (ARGF). The fibres were added to grade 25 concrete at different proportion of 0.5%, 1.0%, 1.5% and 2.0% by percentage volume of concrete. A total of twenty four beam samples were tested for flexural strength and ductility test. The beam samples attained their maximum flexural strength at 1.0% fibres volume with hybrid fibre ratio of 60% ARGF and 40% PPF. When compared with the plain concrete, 37.5% deflection ductility increment was attained at fibre volume of 2.0% with fibre percentage ratio of 80% ARGF and 20% PPF.

Key words: Hybrid fibre, polypropylene fibre, alkali resistance glass fibre, reinforced concrete, flexural strength, ductility, deflections.

INTRODUCTION

Due to the extensive usage of concrete, many research works have been done on the investigation of its engineering properties. Development of modern civil engineering construction have necessitated the demand for new types of concrete which are required to have improved qualities, including strength, toughness, ductility and durability. Some examples of new types of concrete include High Strength Concrete (HSC), High Performance Concrete (HPC), Ultra high performance concrete (UHPC), fibre reinforced Concrete (FRC) and Hybrid fibre reinforced concrete (HFRC). The most important contribution from the fibres is the ability to delay crack propagation in the hardened concrete. The internal stresses in the hardened concrete cause the formation of micro cracks, continuous steel reinforcing element cannot stop the development of micro cracks in concrete. Fibres are discontinuous and randomly distributed in the matrix in both tensile and compressive zone of a structural element. Fibres add to the stiffness and crack control performance by transferring the stress within the concrete microstructure and prevent the propagation and growth of the cracks. Because of this fibre characteristic, the flexural strength and resistance under impact and fatigue loading properties can be improved. It has also been observed that addition of fibre to concrete can reduce the brittleness and alter the mode of failure of the concrete structure. Fibre reinforced concrete is defined as a concrete made of hydraulic cements, fine or fine and coarse aggregates and discontinuous discrete fibres (ACI544.IR-96 2002).

A fibre is a small discrete reinforcing material produced from various materials like steel, plastic, glass, carbon and natural materials in various shapes and sizes. The combination of two or more types of fibres in the same concrete mixture can produce a composite with better engineering properties than that containing single fibre. Different types of fibres can be properly combined to produce hybrid fibre reinforced concrete.

Fibre reinforced concrete is relatively a new construction material developed through extensive research and developmental work during the last three decades. It has already found a wide range of practical applications and proved to be a reliable construction material having superior performance characteristics compared to conventional concrete. Addition of fibres in concrete can improved several properties like compressive and tensile strength, cracking resistance, ductility, durability, flexural strength, impact and wear resistance, toughness, post cracking behaviour of concrete and fatigue resistance.

Previous work on hybrid fibers reinforced concrete

Experimental investigation on ductility and flexural performance of hybrid fibre reinforced concrete using a hybrid fibre reinforced concrete specimens having different proportion of steel and polyester fibre was carried out by (Ewari 2015)].

The following conclusions were drawn from the investigation.

i. Hybrid proportion of 60-40 steel – polyester combine significantly improves the overall performance of reinforced concrete specimens.
ii. The hybrid fiber reinforced concrete specimen exhibit enhanced strength in flexure. The values of flexural strength were increased up to 45% compared to the plain concrete.
iii. The hybrid fiber reinforced concrete specimens exhibit increase deflection to the tune of 86.36% when compared to the plain concrete.
iv. The hybrid fiber reinforced concrete specimens exhibit reduced crack width at all load levels, the maximum reduction in crack width was found to be 61.30% compared to the plain concrete.

The hybrid fibre reinforcement appreciably enhanced the ductility of concrete specimens. The increase in ductility was found to be 67% and 58% in terms of energy and deflection respectively.

For a fibrillated polypropylene fibre content of 0.1% by volume, there was a slight increase in flexural strength (0.7% to 2.6%), and at 0.2 to 0.3% by volume there was a slight decrease. Others have reported that the modulus of rupture determined at 7 and 28days was slightly greater for fibrillated polypropylene fibre reinforced concrete at fibre content of 0.1% to 0.3% by volume compared to plain concrete.

The effects of polypropylene fibres on the strength properties of fly ash based concrete was investigated by (Murahari, and Rama moha Rao 2013). It was observed that the flexural strength increased with polypropylene fibre content up to 0.3% and gained more strength at 28days when compared to 56days.

A comparative study of polypropylene fibre reinforced silica fume concrete of M30

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grade with plain concrete was also investigated by (Mahendra et al 2013).

Cement was replaced by silica fume in the following proportions: 0%, 0.2%, 0.4% and 0.6% by volume fraction of concrete. It was reported that the increase in flexural strength was around 40% with the use of polypropylene fibres and silica fume in concrete

A research on performance assessment of glass fibre reinforced concrete beams was carried out by (Gudetti, and Chandana 2015). The following conclusions were made from their result:

i. Alkali resistance glass fiber in concrete gives a reduction in bleeding. A reduction in bleeding also improves the surface integrity of concrete, its homogeneity and reduces the probability of cracks occurring where there are some restrain to settlement.

ii. Increasing the percentage of alkali resistance glass fiber by volume of concrete did not show much variation in the compressive strength of concrete. The increase in percentage of compressive strength for 0.5% GF was 5.4%, for 1.0% GF was 5.47% and for 1.5% GF was 8.9%. It showed a very good variation on split tensile strength, the increase in percentage of split tensile strength for 0.5%GF was 25.0%, for 1.0%GF was 52.84% and for 1.5%GF was 72.78% but the increase in percentage of flexural strength was 16.49%, 47.64% and 87.17% respectively.

iii. The ultimate load carrying capacity of glass fibre reinforced concrete beams are more than that of the control beams (plain concrete). Ultimate load carrying capacity of SET II beams to that of SET I beams increased from 72KN to 84KN, 68KN to 94KN, and 75Kn to 86KN. The ultimate load carrying capacity of Set III beams to that of SET I increased from 72KN to 90KN, 68KN to 102KN and 75KN to 98KN.

iv. The load deflection behavior of the beams of the glass fiber reinforced concrete (GFRC), were more than that of the control beams and the number of cracks are less than the control beams.

The behaviour of hybrid fiber reinforced concrete column under axial loading was investigated by (Muthuswamyand Thirugnanam 2014). The coarse aggregates used was crushed granite stone with a specific gravity of 2.60 conforming to a well graded aggregate having maximum size of 12.5mm. Silica fume was added as partial replacement of cement at 7.5% by weight of cement in order to get high performance concrete. A super plasticizer named comp last – sp 430 was added to get the required workability. Round crimped steel fibre of 1% by volume of concrete having 0.5mm diameter, 30mm length and aspect ratio 60 was used to get SFRC. Alkaline resistant glass fibre with optimum proportion of 0.03% volume fraction of concrete having filament diameter of 4microns, 12mm length and aspect ratio 857.1 was used for the experiment in addition to steel fibre to prepare HFRC.

Base on their investigations, the following conclusion were drawn.

1. The load carrying capacity of the RC column improved significantly with the addition of hybrid fibers.

2. The ductility of HFRC column is 1.74 times greater than that of plain RC column and 1.34 times greater than that of SFRC column.

3. There is a marginal improvement in energy absorption capacity of RC column with the inclusion of hybrid fibers.

4. The toughness index of RC column is improved almost two fold with the addition of hybrid fibers.

This study investigated the ductility and flexural strength behaviour of a hybrid fibre of polypropylene and alkali resistance glass fibre. This hybrid has never been used in previous studies involving hybrid fibre reinforced concrete.

MATERIALS AND METHODS

Materials

Cement

The cement used for this study is Portland Lime Cement(PLC) produced by Dangote cement factory and conforming to (BS-EN 196-0.1996). The manufacturer specification of the cement is “Dangote 3x cement, grade 42.5N”

Fine Aggregate

The fine aggregate used for this studies was river sand with specific gravity of 2.63 and fines modulus of 3.3, passing through BS4.75mm sieve and conforming to zone 2 as per BS Aggregate(BS 8821996).

The sand which was mined from a river in Port Harcourt was properly air dried and free from deleterious minerals like clay, silt constituent and chloride contaminants.

Coarse Aggregate

The coarse aggregates used was crushed granite with specific gravity of 2.71, 52% of the aggregate was retained on BS13.2mm sieve and conforming to zone 3 as per BS Aggregate(BS 882 1996).

[8] The material was properly dried and free from deleterious materials like clay, silt content and chloride contaminants. The coarse aggregate was obtained from a quarry in Akampa cross river state Nigeria.

Water

Clean potable water which satisfy drinking standard and conforming to (BS 31481980) was used for mixing and curing of concrete samples.

Polypropylene Fibre

The PPF used in this research work was obtained from Purechem Manufacturing Company in Lagos Nigeria. The properties of the fibre as obtained from the manufacturer is as indicated in table 1, while fig. 1 is a photograph of the PPF.

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Figure 1: Polypropylene fibre

Table 1: Fibres properties as specified by the manufacturer

Type o fibre	Alkali resistance glass fiber	Polypropylene fiber
Fibre diameter	18microns	30Microns
Zirconia content	19% minimum	Nill
Chopped length	19mm	12mm
Tensile strength	1300MPa	350MPa
Specific Gravity	2723.4Kg/m^3	0.91g/cm^3
young modulus	77.30Gpa	5500-7000MPa
Density	380Kg/m^3	215Kg/m^3
Aspect ratio	1055	400
Strain	More than 1.5%	

Alkali Resistance Glass Fibre

The alkali resistance glass fibre used for this research work is ACS19PH901X, produced by Nippon Electrical Company Limited in collaboration with Kanebo Limited. It is a high quality alkali resistance glass fibre containing a high percentage of zirconia (Z_rO_2). The letter P in the product code shows that the filament diameter is 18 microns, it has the highest integrity and it is most resistance to filamentization during mixing and processing. The mechanical and physical properties of the fibre are as shown in table 1, while fig. 2 is a photograph of the ARGF.

Figure 2: Alkali resistance glass fibre

Method

Concrete Mix Design

In this experimental work, the concrete mix design was done as per British standard using the DOE (Design of Experiment) method. The method is applicable to concrete for most purpose including roads. The detail of concrete mix design is as shown in Table 2.Table 3 is the proportion and quantities of materials for 1m^3 of concrete.

Table 2: Concrete Mix Design

Concrete strength at 28 days	25MPa
Standard deviation (S)	6
K for 5% defective	1.64
Target mean strength $f_m = f_c + m = 25 + (6 * 1.64)$	34.84MPa
Type of cement	Ordinary Portland cement
Type of coarse aggregates	Crushed
Water/cement ratio	0.5
Maximum water cement ratio	0.55
Slump	100mm
Maximum size of coarse aggregate	20mm
1Water requirement	210Kg/m^3
Maximum cement content = 210/0.5	420Kg/m^3
Minimum cement content = 210/0.55	381.8Kg/m^3
density of fresh concrete mix	2400Kg/m^3
Total density of aggregates (coarse + fine)	2400 - 420 - 210 = 1770Kg/m^3
Proportion of fine aggregate	37%
Weight of fine aggregate	0.37 * 1770 = 655Kg/m^3
Weight of coarse aggregate	1770 - 655 = 1115Kg/m^3

Table 3: Proportion and quantities of materials for 1m^3 of concrete

Materials	Weight (Kg)	Ratio
Cement	420	1
Fine aggregate (sand)	655	1.6
Coarse aggregate (gravel)	1115	2.7
Water	210	0.5

Concrete Batching and Production of HFRC

The mixing of fibre reinforced concrete was done in the laboratory to (ACI544.IR-96 2002).Concrete batching was done by adopting a common mix ratio of 1:1.6:2.7 by weight of cement, sand and granite. It was design to give a compressive strength of 25MPa at twenty eight days and slump value of about 100mm. Concrete mixing was done by the use of a mechanical concrete mixer in the laboratory. The cement and the fine aggregate (sand) were first placed in the concrete mixer and allowed to rotate for about two minutes, followed by the addition of fibres and one third of water. The fibres were added by

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percentage volume of concrete in different proportion. Care was taken to avoid balling during the addition of fibre into the mix. The mixture was allowed to rotate in the mixer for two minutes before the addition of coarse aggregate and water. The mixture was allowed for another three minutes for proper mixing, care was taken to avoid bleeding of concrete. Slump test was conducted at every mix and the slump value recorded. The concrete was placed in oiled concrete moulds and compacted with a table vibrator. The concrete samples were allowed in the moulds for twenty four hours after which they were removed from the moulds and placed in a curing tank for twenty eight days.

Flexural Strength Test

The flexural strength test was performed in accordance with (BS 1881 1983). Figures 3 and 4 are the photographs of the Laboratory setting for the flexural strength tests.

Figure 3: Beam samples before flexural test

Figure 4: Flexural test experimental set up for two point loading

The ductility of a structure is the ability of it to undergo deformation beyond the initial yield deformation, while still sustaining load. During the experimental test for flexural strength, the values of deflection at yield that is for the first crack and at ultimate load were noted. The ultimate load level is the point of total collapse of the beam, ductility factor is defined as the ratio of deflection at failure to the deflection at yield or at the first crack.

Ductility factor = δu/ δy

Where, δu is deflection at the ultimate load level, δy is the deflection at yield load level

RESULTS

Flexural Strength

The flexural strength values for the tested beams are shown in table 4 and plotted in figure 5, while figure 6 shows the incremental values of the flexural strength for the various fibre volume content.

Table 4: Flexural strength test experimental result

S/No.	Specimen Identification	Yield Load (KN)	Ultimate Load (KN)	Flexural Strength (KN/m^2)	Yield deflection δy (mm)	Ultimate Deflection δu (mm)	Deflection ductility (δu/δy)	Flexural strength % increment
1	H0 - P0G0	10.04	11.3	4.52	0.28	0.32	1.14	0.00
2	H0.5 - P0G100	11.3	15.06	6.024	0.88	1.05	1.19	33.27
3	H0.5 - P20G80	11.3	16.28	6.512	0.68	0.89	1.31	**44.07**
4	H0.5 - P40G60	11.3	15.06	6.024	0.81	1.12	1.38	**33.27**
5	H1.0 - P0G100	15.06	16.28	6.512	0.89	1.08	1.21	44.07
6	H1.0 - P100G0	15.06	15.06	6.024	0.81	1	1.23	33.27
7	H1.0 - P20G80	15.06	16.32	6.528	0.98	1.3	1.33	44.42
8	H1.0 - P40G60	16.32	18.05	7.22	0.96	1.48	1.54	59.73
9	H1.5 - P20G80	12.55	15.06	6.024	0.6	0.8	1.33	33.27
10	H1.5 - P40G60	12.55	15.06	6.024	0.7	0.83	1.19	33.27
11	H2.0 - P20G80	11.3	15.06	6.024	0.7	1.1	1.57	33.27
12	H2.0 - P40G60	11.3	12.55	5.02	0.7	0.9	1.29	11.06

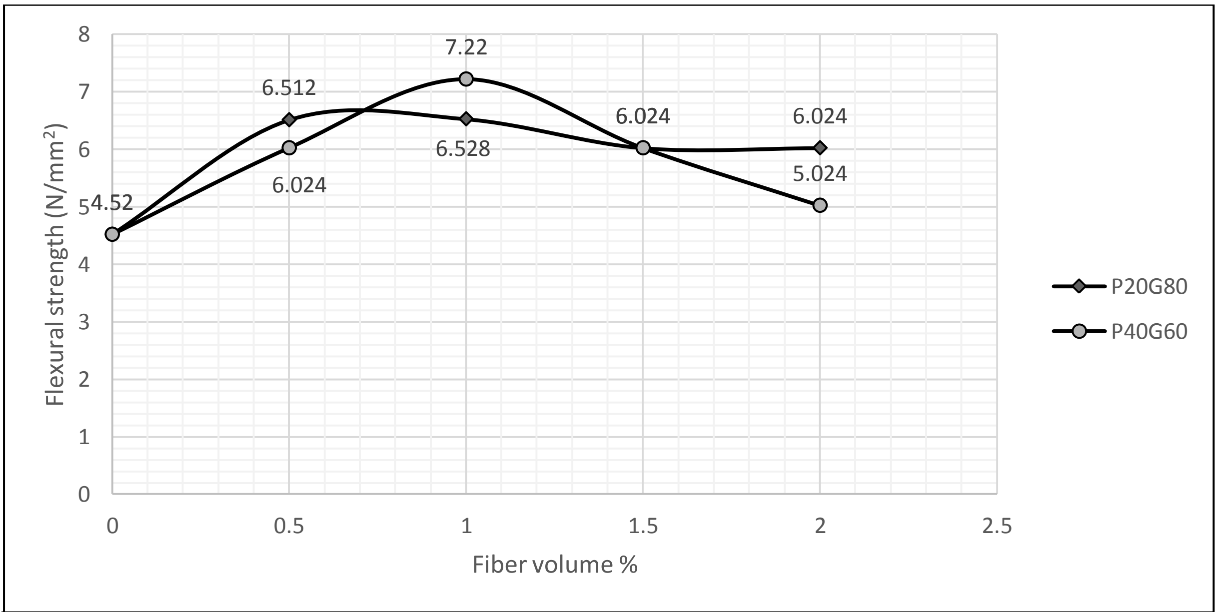

Figure 5: Plot of flexural Strength against fibre volume content

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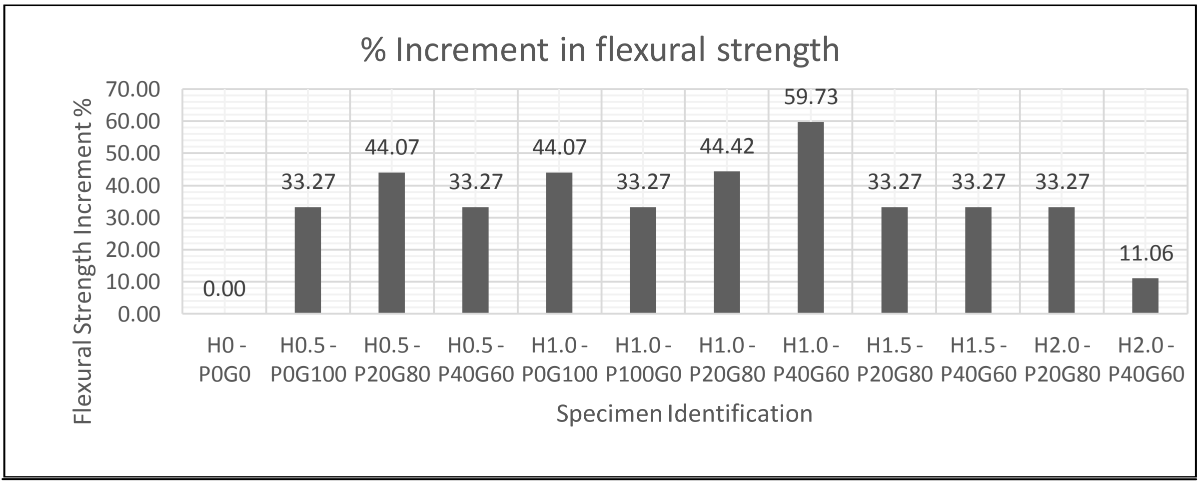

Figure 6: Plot of flexural Strength Increment against the fibre volume content

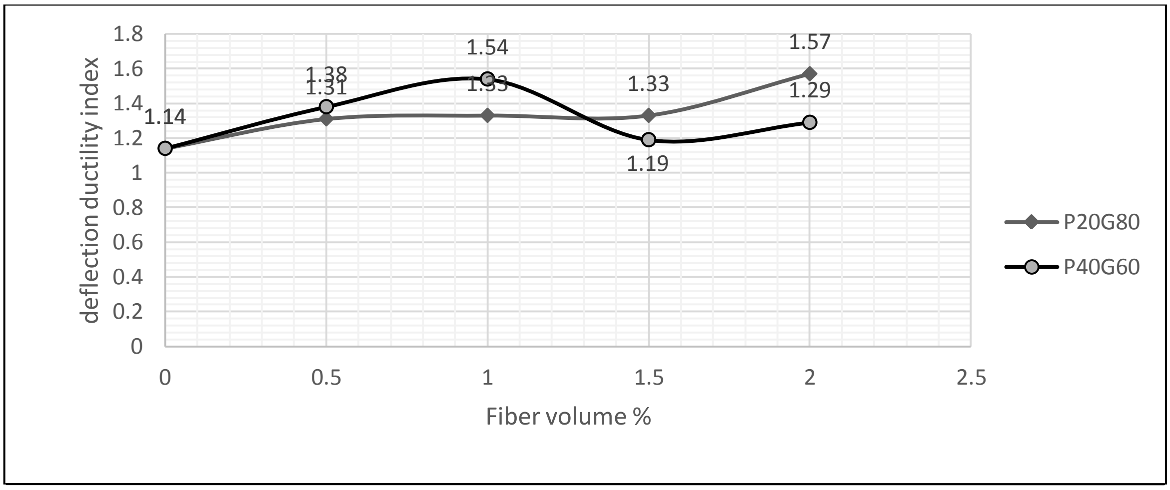

Figure 7: Plot of deflection ductility against fibre volume

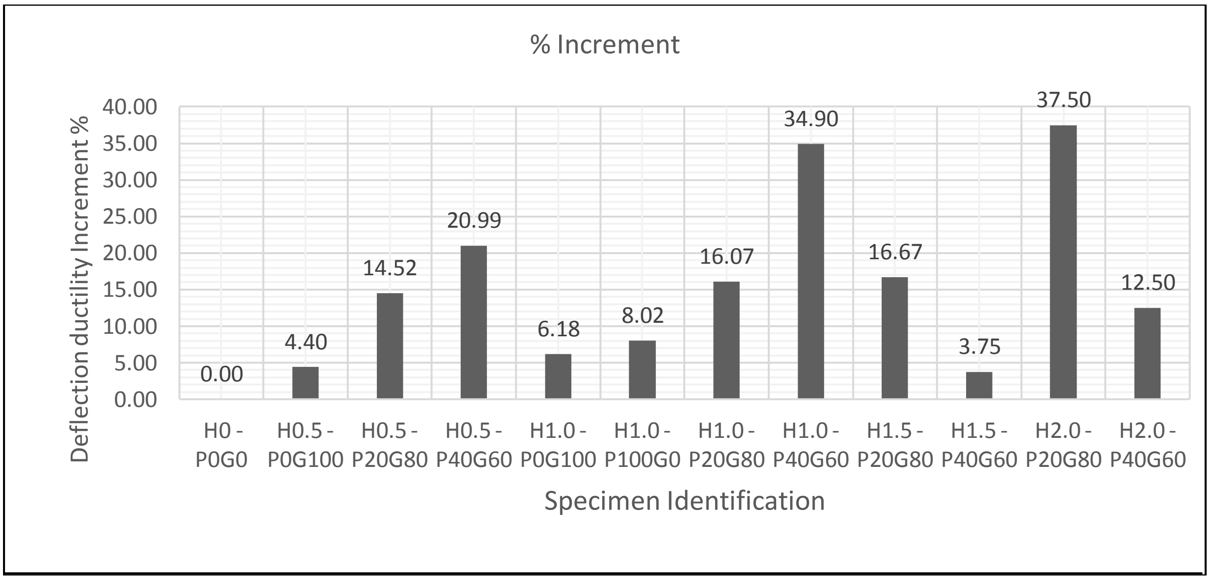

Figure 8: Plot of deflection ductility Increment against fibre volume

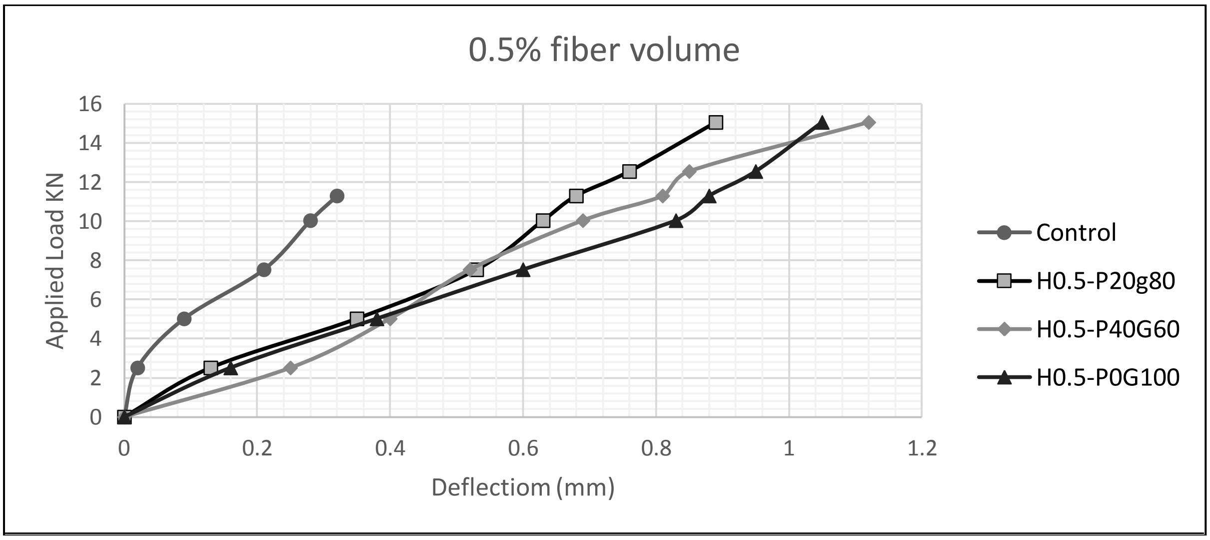

Figure 9: Plot of applied load against ductility for 0.5% fibre fraction volume

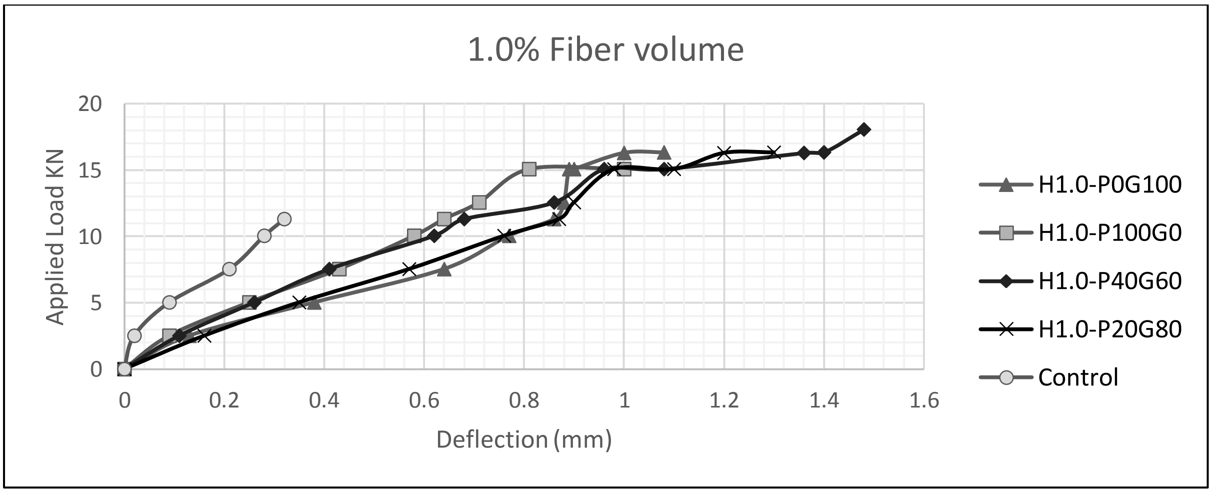

Figure 10: Plot of applied load against ductility for 1.0% fibre fraction volume

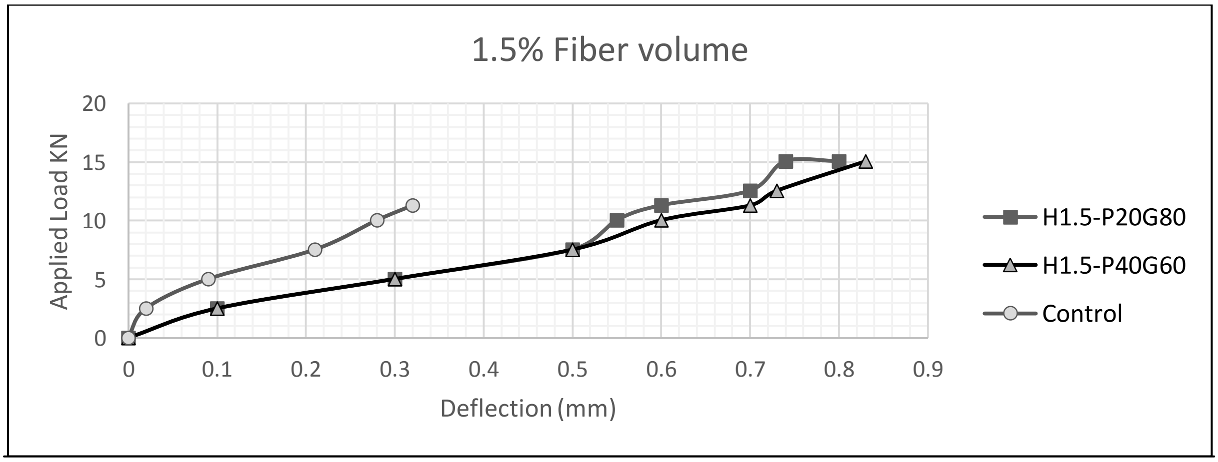

Figure 11: Plot of applied load against ductility for 1.5% fibre fraction volume

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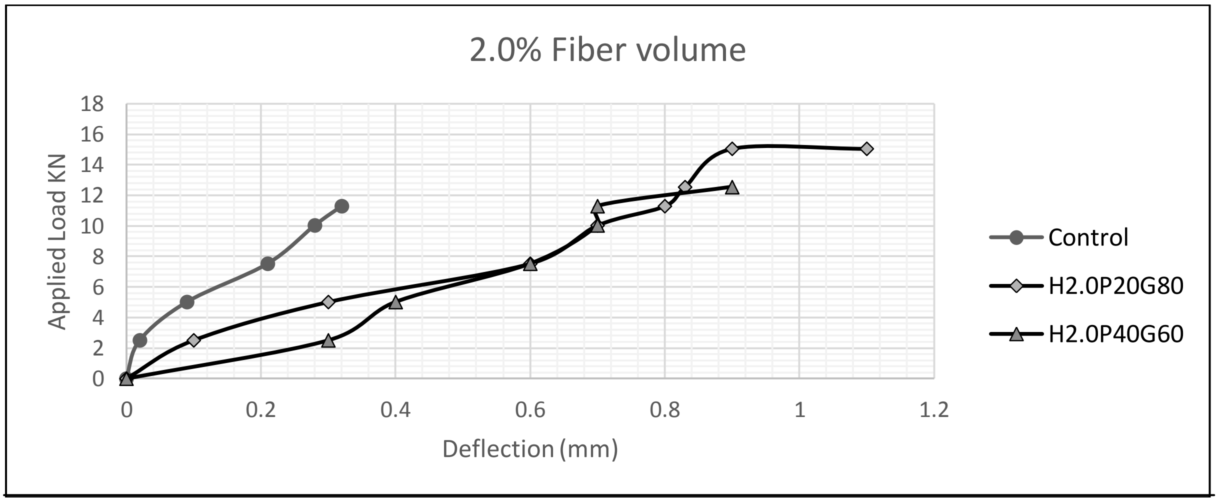

Figure 12: Plot of applied load against ductility for 2.0% fibre fraction volume

DISCUSSION

The flexural strength test result shows that the fibre combination of 40% PPF and 60% ARGF at fibre volume fraction of 1.0% attained 59.73% increment in flexural strength when compared with the control specimen g. This was the highest value of flexural strength. The ultimate load attained at that fibre content was 18.05KN. Specimen H2.0P40G60 gave the lowest flexural strength of 5.02N/mm2 at fibre volume fraction of 2.0% and had a flexural strength increment of 11.06%.

At 0.5% fibre volume fraction, the hybrid fibre specimens H0.5P20G80 with flexural strength increment of 44.07% shows better performance than the control sample. ARGF specimen at the same fibre volume fractions gave strength increment of 33.27%.with a flexural strength of 6.024N/mm^2. Specimen H0.5P0G100, H0.5P40G60, H1.0P100G0, H1.5P20G80, H1.5P40G60 and H2.0P20G80 attain the same flexural strength of 6.024N/mm^2, with strength increment of 33.27% compared to the control sample. It was observed that specimen H1.0P40G60 had the highest flexural strength with a value of 7.22N/mm^2.

Ductility

The ductility of a structure is the ability of the structure to undergo deformation beyond the initial yield deformation, while still sustaining load. During the experimental test for flexural strength, the values of deflection at yield point that is for the first crack and at ultimate load were noted. The ultimate load level is the point of collapse of the beam, ductility factor is defined as the ratio of deflection at failure to the deflection at yield or at first crack.

Ductility factor = $\delta u / \delta y$

Where δu is deflection at the ultimate load level and δy is the deflection at yield load level.

The hybrid fibre concrete specimens prove to be more ductile than the glass fibre specimens, polypropylene fibre specimen and the control specimen.

As seen in table 4 and fig.7 at 0.5% fibre volume fraction, hybrid fibre specimen H0.5P40G60 was more ductile with deflection ductility increment of 20.99% compared to the control specimen H0P0G0. At 1.0% fibre volume fraction, specimen H1.0P40G60 with deflection ductility increment of 34.9% proved to be more ductile than other specimens of the same fibre volume. Specimen H2.0P20G80 has the highest deflection ductility of 37.5% with ductility index of 1.57. It was observed the addition of fibres to concrete help to improve on the ductility properties of concrete, specimen H2.0P20G80 had the highest ductile value when compared with the twelve specimens. Figure 8 is the Plot of deflection ductility Increment against fibre volume.

Alkali resistance glass fibre is stronger and stiffer and provides reasonable first crack strength and ultimate strength, while polypropylene fibre is relatively flexible and lead to improve toughness and strain capacity in post crack. Apparently, fibre inclusion of all types and at all volume fractions prevents sudden and brittle failure of fibre specimens when compared with the plain control specimen as seen in figures 9 to 12.

Base on the results obtained from experimental investigations presented in this study, the following conclusions were made.

1. The hybrid fiber (PPF and ARGF) reinforced concrete appreciably enhances the ductility of concrete specimens. The ultimate increase in deflection ductility was found to be 37.5% at 2.0% fiber volume fraction of 80% - 20% ARGF – PPF, followed by specimen H1.0P40G60 with deflection ductility increment of 34.9% compared to the plain concrete.
2. Hybrid fiber (PPF and ARGF)reinforced concrete specimen's exhibit increase in deflection to the tune of 36.25% compared with the plain concrete.
3. The ultimate flexural strength attained for the hybrid fiber (PPF and ARGF) reinforced concrete specimens was 7.22N/mm2, with strength increment of 59.75% at 1.0% fiber volume and fiber ratio of 60% ARGF and 40% PPF.

The load carrying capacity of concrete beam samples were increased with the addition of hybrid fibers, ultimate load capacity was 18.05KN attained at 1.0% fiber volume.

LIST OF ABBREVIATIONS

ACI	:	American Concrete Institute
AFRC	:	Asbestos Fibre Reinforced concrete
ARGF	:	Alkali Resistance Glass Fibre
ARGFRC	:	Alkali Resistance Glass Fibre reinforced Concrete
ASTM	:	American Society of Testing Materials
CFRC	:	Carbon Fibre Reinforced Concrete
FRC	:	Fibre Reinforced Concrete
GF	:	Glass Fibre
GFRC	:	Glass Fibre reinforced Concrete
HFRC	:	Hybrid Fibre reinforced Concrete
PFRC	:	Polymer Fibre Reinforced Concrete
PPF	:	Polypropylene Fibre
PPFRC	:	Polypropylene Fibre Reinforced Concrete
SFRC	:	Steel Fibre Reinforced Concrete
UTM	:	Universal Testing Machine

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REFERENCES

American Concrete Institute ACI544.IR-96 State of art Report on fibre Reinforced Concrete Reported by ACI Committee 544 (2002).

BS 1881, Part 118.Testing Concrete-Method for Determination of Flexural Strength.

British StandardsInstitute, London, United Kingdom. (1983).

BS-EN 196-0. Method of Testing Cement. Determination of fineness.British Standards Institute, London, United Kingdom. (1996).

BS 3148. Methods of test for water for making concrete. British Standards Institute, London, United Kingdom. (1980).

BS 882- Specifications of aggregates from natural sources for concrete. British Standards Institute, London, United Kingdom. (1996).

Eswari, S. Experimental Investigation on Flexural Performance of Hybrid Fibre Reinforced Concrete International Research Journal of Engineering and Technology (IRJET) 2(3) 1772-1775 (2015).

Gudetti, J.R.; and Chandana, P.S. Performance assessment of glass fiber reinforced concrete beams. International Journal and Magazine of Engineering, Technology, Management and Research. 2(10) 1090-1096 (2015).

Mahendra, P., Chandak, R. and Grover, R.A comparative study of propylene fiber reinforced silica fume concrete with plain cement concrete. International Journal Of Engineering Research, Science and Technology. 2(4) 127-136(2013).

Murahari, K. and Rama moha Rao, P.Effects of polypropylene fibres on the strength properties of fly ash based concrete. International Journal of Engineering Science Invention. 2(5) 13-19(2013).

Muthuswamy, K. K.; and Thirugnanam G. S. Experimental investigation on the behaviour of hybrid fiber reinforced concrete column under axial loading.Asian Journal of Civil Engineering .15(2) (2014).