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Behaviour of High-Performance Fibre Reinforced Concrete Composite Short and Slender Columns under Uniaxial Compression

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Abstract

This paper describes the experimental studies carried out on the RC short and slender columns of bagasse ash blended HPC with influence of steel fibre (STF) and polypropylene fibre (PPF)are presented. The concrete was considered for M60 grade as recommended by P.C.Aitcin. The mix included both free steel fibre and polypropylene fibre, and furthermore the hybridization of steel fibre and polypropylene fibre at a total volume fraction of 1.0% by volume of concrete with 10% bagasse ash as a substitution of cement. Behaviour of eleven HPFRCC of each short and slender column with steel fibre, polypropylene fibre and hybrid fibres was examined. The behaviour of each column was assessed and presented with respect to load carrying capacity. The numerical studies were done using ABAQUS 6.9 to validate the experimental results.

Keywords: Fibers, Bagasse ash, High performance concrete slender column, Short column,

1. Introduction

HPFRCC, a new type of HPC, is designed with low water cement ratio and addition of pozzolanic materials. It has high tensile strength and improved durability properties. Concrete turns out to be more ductile, upgrades the control against crack growth in longitudinal direction and delays crack propagation once the fibers are added. The increased toughness of the material improves structural ductility which in turn is significant in presenting the overall performances of a structure, particularly in energy improvement and dissipation capacity of the overall structure. Steel fibre reinforced concrete is a concrete mix, which consists of discontinuous and discrete steel fibres dispersed randomly and disturbed uniformly. Ganesan *et al.*(2007)**[**1] compared the flexural members made of high performance concrete (HPC) and steel fibre reinforced high performance concrete (SFRHPC) under two point loading. A concrete grade of M60 is used to obtain the HPC mix. Steel fibres are added to the HPC to increase the flexural strength. Flexural specimens of 10 numbers of dimensions 100×150×1200 mm using HPC and SFRHPC are used for the study. The specimens are cast and tested under static loading. The results showed that the cracking behaviour significantly improved by the addition of steel fibres. The first crack load increased and the formation of finer cracks is large in specimens with steel fibres. Sivakumar *et al.* (2007) [2] has deliberated the performance of hooked steel fibres and a non-metallic fibre in high strength concrete up to 0.5 percent volume fraction. Three types of hybrid fibre combinations are developed in the form of steel and polypropylene, steel and polyester, steel and glass, and their mechanical properties are studied. The flexural properties are studied as per Japanese Concrete Institute (JCI) using beam specimens under four point bending. The fibre addition caused an increase in flexural strength as well as toughness because of the enhancement in pre-peak and post-peak region of the load deflection curve. This enhancement is due to the contribution of polypropylene fibres to small crack widths. The toughness of the steel-polypropylene concrete also reduced with increasing dosages of polypropylene fibres. This is because the proportion of steel fibres is less which is not enough to bridge the wider cracks in the system. The relative residual compressive strength of FRHPC is improved by adding hybrid fibres at high temperatures.

The steel fibre content and the type of fibres have a very high effect on the toughness parameters of FRHPC. The oxidation of steel fibres is very strong at a maximum exposure of 900°C. The failure model changes from pull-out at low temperature to tensile failure at high temperature for the steel fibres. The failure pattern changes to brittle from ductile for FRHPC beam. The ductility cannot be enhanced by PP fibres. However it reduced the effects of spalling. The steel fibres enhanced the ductility of HPC but did not mitigate the damage caused by spalling of HPC during heating. Yining Ding *et al.*(2008) [3] studied the compressive strength, flexural strength and ductility and failure pattern after exposure to various high temperatures in fibre reinforced high-performance concrete (FRHPC). It is found that the HPC without fibres showed a declination in compressive strength after 900°C. Only 10% residual compressive strength to the original strength is obtained.

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However, the negative effect of spalling in HPC is significantly reduced by the inclusion of steel fibre (SF) and polypropylene fibre (PP). But the flexural toughness of concrete mix did not show a clear effect. To the contrary, with the inclusion of macro steel fibre the HPC reinforced concrete has a higher flexural toughness and ultimate load bearing capacity before and after high exposure to temperatures. Vahid Afroughsabet & Togay Ozbakkaloglu (2015) [4] investigated the effect of hooked end-steel (STF) and polypropylene fibres (PPF) on mechanical and durability properties of silica fume blended high strength concrete. It is concluded that addition of silica fume as micro filler in high strength concrete improves the strength of concrete during later age of curing, due to enhancement of matrix-aggregate bond. Inclusion of fibres in high strength concrete also improves the mechanical properties of the concrete due to setback in the expansion time of cracks. Arunachalam &Sabapathi (2004) [5] analysed the high strength concrete (HSC) short columns subjected to axial loading. The behaviour of the columns with respect to the variation in the degree of confinement by changing the diameter of the lateral ties and their spacing are compared with normal strength concrete (NSC) columns. The ductility, load carrying capacity and energy absorption capacity are increased due to the confinement in HSC brittle columns. Chien-Hung Lin *et al.* (2004) [6] studied the behaviour of normal concrete columns and high workability columns (HWC) under concentric compression. Higher stiffness, better ductility and crack control ability are more in HWC columns when compared to normal concrete columns. The ductility of confined concrete and columns are improved effectively by a decrease in concrete strength, increase of longitudinal reinforcement, increase of transverse reinforcement strength and decrease in transverse reinforcement spacing. Marco di Prisco *et al.* (2009) [7] defined the major concepts behind the structural rules for FRC structural design. The fibre reinforcement mechanisms established by using fibres for bridging the crack surfaces has paved way for the enhanced post-cracking tensile residual strength, also known as toughness, of Fibre Reinforced Concrete (FRC) a composite material. The possibility of implementing FRC in fib Model Code, that may assist in developing structural rules for FRC elements in Euro codes or in national codes is a notable achievement. The reinforcement fibres contribute majorly in terms of the resistance offered to diffused tensile stresses and guaranteed reinforcement even in large concrete covers, required for fire resistance and durability issues, or in the corners of the structural elements. Cracking phenomena or Structural deformation can be reduced to improve the structural behaviour at service conditions by employing fibre reinforcement.

2. Experimental Programme

2.1. Materials

53 grade ordinary Portland cement was used for making high performance concrete specimens [8]. Bagasse ash varied at constant 10% by weight of cement. fine aggregates and coarse aggregate were conforming to IS 383: 1970 [9] specifications. In this study, hooked end steel fibres with length of 60 mm, diameter of 0.75 and aspect ratio of 80, and polypropylene fibres with length of 12 mm, diameter of 0.0022 and aspect ratio of 545 were employed. Polycarboxlic ether based super plasticizer is used. P.C.Aitcin method is followed for design of M60 grade of concrete.

2.2 Specimen details

The reinforcement details of HPFRCC short and slender columns are shown in Fig.1. The HPFRCC columns were supported at the base with rubber pads to provide hinged end condition. The HPFRCC column specimens were adjusted so that the centre line of the axial load coincides with column faces. Throughout the test setup, care was taken to ensure that the load was applied axial with permissible eccentricity. The plumb bob was used to keep the columns perfectly vertical, however some eccentricities unavoidable.

All the HPFRCC short columns were tested for compression and slender columns were tested for axial compression and uni-axial bending in a loading frame capacity of 1000 kN. LVDT with 50 mm range of 3 numbers were placed at top, middle, and bottom for slender columns and at middle in short columns to measure the lateral deflection of the column. The axial deformation is measured using strain gauge (mechanical) with gauge length and least count of 100 mm and 0.002 mm. The following Mix No. were used for different proportions of Steel fibre and Polypropylene fibre with 10% of bagasse ash: P1-Control specimen, P2- 10% cement replaced by BA, Q1-STF 0.25% , Q2-STF 0.50%, Q3- STF 0.75%, R1-PPF 0.15%, R2-PPF 0.30%, R3-PPF- 0.45%, S1- PPF 0.15%+STF 0.85%, S2- PPF 0.30%+STF 0.70%, S3- PPF 0.45%+STF 0.55%.

2.3 Preparation of Test Specimen

2.3.1 Short Columns

Using a hydraulic jack of 500 kN, compression load was applied to HPFRCC specimens. To measure the applied axial loads in HPFRCC specimens electronic load cell is used and load indicator is used to monitor. The load was transferred to the HPFRCC columns through steel plates. The HPFRCC column specimens were so adjusted that the centre line of the axial load coincides with column faces. HPFRCC short column specimen is shown in Fig. 2.

2.3.2 Slender Columns

The HPFRCC columns were tested under uni-axial compression after curing. Column heads are provided in all the HPFRCC columns in both top and bottom ends to make easy loading. Load cell and displacement indicator were

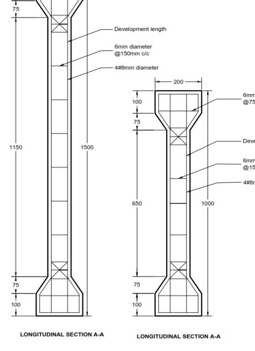


Fig.1. Schematic diagrams of Long column and short column showing reinforcement details

Fig.2. HPFRCC Short column specimen before testing

Fig.3. HPFRCC Slender column specimen before testing

used to measure loads and deflections in HPFRCC columns. Through steel plates, load was transmitted to HPFRCC columns. The HPFRCC slender column specimen before testing is shown in Fig.3.

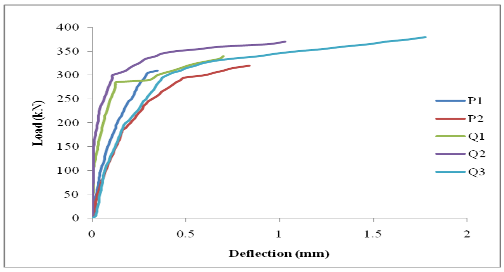
3. Results and Discussion

3.1 Behaviour of HPFRCC Short columns

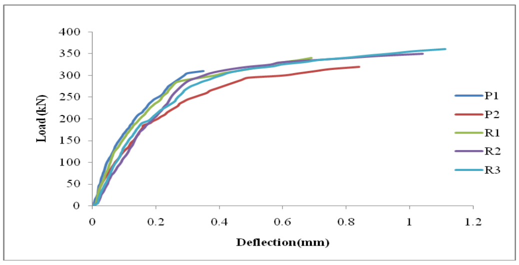
The HPFRCC short columns were cast for varying proportions of STF, PPF and Hybrid fibres with 10% of bagasse ash. The short columns are tested for axial load in loading frame of capacity of 1000 kN. The test results of HPFRCC short columns cast with w/b ratio of 0.28.

The first crack was observed at the column head for the control mix specimen P1 when the load reached 140 kN. As the load increased the cracks width increases and prolonged around the initial crack. The maximum load obtained for control mix specimen P1 was 310 kN. The short column with 10% BA (P2 mix) attains the maximum load of 320 kN, which is 1.03 times higher than the control mix specimen P1. The short column (Q1 mix) with STF of 0.25% and short column (R1 mix) with PPF of 0.15% have the ultimate load of 340 kN. The ultimate load of Q1 and R1 mix is 1.097 times higher than the control mix specimen P1. The short column (Q2 mix) with STF of 0.5% has the ultimate load of 370 kN[10]. The ultimate load of Q2 mix is 1.19 times higher than the control mix specimen P1. The short column (Q3 mix) with STF of 0.75% has the ultimate load of 380 kN. The ultimate load of Q3 mix is 1.22 times higher than the control mix specimen P1. The short column (R2 mix) with PPF of 0.30% has an ultimate strength of 350 kN. The ultimate load of R2 mix is 1.12 times higher than the control mix specimen P1. The short column (R3 mix) with PPF of 0.45% attains the ultimate load value of 360 kN. The ultimate load of R3 mix is 1.16 times higher than the control mix specimen P1. The short column (S1mix) with PPF of 0.15% and STF of 0.85% has an ultimate strength of 395 kN. The ultimate load of S1 mix is 1.27 times higher than the control mix specimen P1. The short column (S2 mix) with PPF of 0.30% and STF of 0.70% attains the maximum ultimate strength of 390 kN when compared with all other mix specimens. The ultimate load of S2 mix is 1.25 times higher than the control mix specimen P1. The short column (S3 mix) with PPF of 0.45% and STF of 0.55% has an ultimate load of 385 kN. The ultimate load of S3 mix is 1.24 times higher than the control column P1.

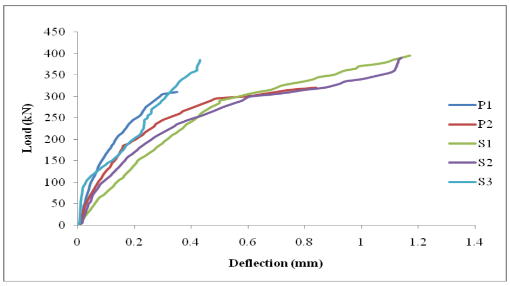
The ultimate load carrying capacity of HPFRCC specimens increased from 9.7% to 22% when compared to the control mix specimen P1, by increasing the proportions of STF in the concrete matrix. Similarly the ultimate load also increased from 9.7% to 16% when compared to the control mix specimen P1, by increasing the proportions of PPF. From these observations it can be inferred that the incorporation of STF is better than that of PPF in HPC. It is seen that the mix specimen S1 prepared with hybrid fibres of 0.15% PPF and 0.85% STF has the maximum load carrying capacity when compared to all the other mix proportions. But increasing the quantity of PPF and decreasing the quantity of ST fibres slightly decreased the load carrying capacity from 27% to 24%. From the experimental studies, it was observed that columns fail by buckling of reinforcement with concrete crushing. The comparison load - deflection curves are shown in Fig.4.



4(a) Steel fibre specimens



4(b) Polypropylene fibre specimens



4(c) Hybrid fibre specimens

Fig.4. Comparison of Load-deflection curves of (a) STF (b) PPF (c) Hybrid fibres

3.2. Behaviour of HPFRCC Slender columns

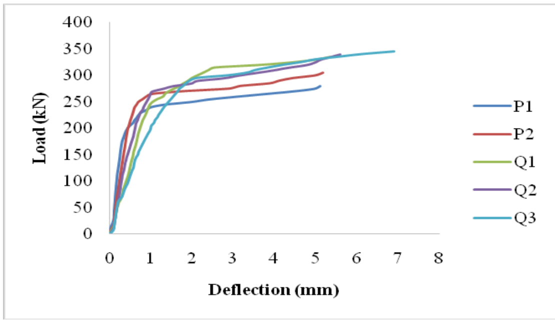
The HPFRCC slender columns were cast for various proportions of STF, PPF and hybrid fibres with 10% of bagasse ash. They are tested in a loading frame of capacity 1000 kN. The column specimens were so adjusted to give condition of loading as uniaxial compression. LVDT of 50 mm range were used to measure the deflection of the HPFRCC slender column specimens.

The first crack was observed at 110 kN for the control mix specimen P1. As the load increased the cracks width increases and prolonged around the initial crack. The maximum load obtained for control mix specimen P1 was 280 kN. The slender column with 10% bagasse ash (P2 mix) and slender column (R1 mix) with 0.15% PPF attains the maximum load of 305 kN, which is 1.09 times higher than the control specimen P1. The slender column (Q1 mix) with STF of 0.25% has a ultimate load of 335 kN. It is 1.19 times higher than the control mix specimen P1. The slender column (Q2 mix) with STF 0.50% has a ultimate load of 340 kN. It is 1.21 times higher than the control mix specimen P1. The slender column (Q3 mix) with STF .75% has a ultimate load of 345 kN. It is 1.23 times higher than that of the control mix specimen P1. The slender column (R2 mix) with 0.30% PPF has a ultimate load of 310 kN. It is 1.107 times higher than the control mix specimen P1. The slender column (R3 mix) with 0.45% PPF has a ultimate load of 315 kN. It is 1.12 times higher than the control mix specimen P1. The slender column (S1 mix) with PPF of 0.15% and STF of 0.85% has an ultimate strength of 385 kN. It is 1.37 times higher than that of the control specimen P1. The slender column (S2 mix) with PPF of 0.30% and STF of 0.70% has an ultimate strength of 372 kN. It is 1.33 times higher than that of the control specimen P1. The slender column (S3 mix) with PPF of 0.45% and STF of 0.55% has an ultimate strength of 370 kN. It is 1.32 times higher than that of the control specimen P1[11].

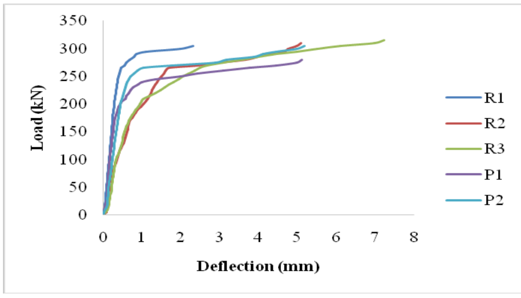
The ultimate load carrying capacities of HPFRCC specimens increased from 19% to 23% when compared to the control specimen P1, by increasing the proportions of STF in the concrete matrix. Similarly, the ultimat load also increased from 9% to 12% when compared to the control mix specimen P1, by increasing the proportions of PPF. From these observations it can be inferred that the incorporation of STF is better than PPF in HPC. It is seen that the mix specimen S1prepared with hybrid fibres of 0.15% PPF and 0.85% STF has the maximum load carrying capacity when compared to all the other mix proportions. But increasing the quantity of STF and decreasing the quantity of STF slightly decreased the load carrying capacity from 37% to 32%. From the experimental studies, it was observed that columns cast with 10% bagasse ash and fibres in HPC mixes undergo inelastic deformation. The comparison load - deflection curves are shown in Fig.5.

3.3. Analytical Modelling

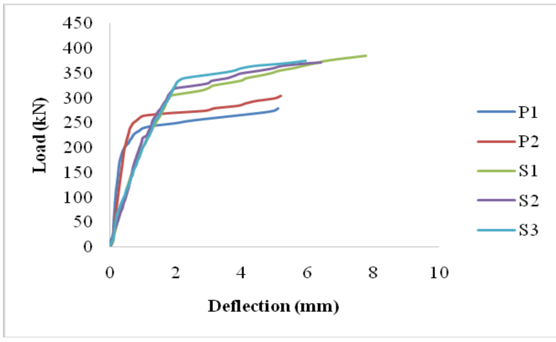
ABAQUS 6.9 is used in this study, which is a finite element tool, primarily developed to model the behavior of solids and structures under external loads. The ABAQUS modeling are in good agreement with experimental results for both load and deflection.



5(a) Steel fibre specimens



5(b) Polypropylene fibre specimens

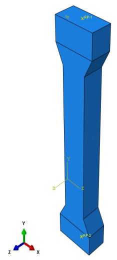


5(c) Hybrid fibre specimens

Fig.5. Comparison of Load-Deflection curves of (a) STF (b) PPF (c) Hybrid fibres

3.3.1. Short columns

The short column model with loading and support condition are shown in Fig.6. and Fig.7. P1 short column specimen demonstrate an ultimate load of 310kN, the subsequent deflection obtained during experiment (0.35 mm) and the FEA using ABAQUS (0.32 mm) varied by 8.57%. P2 short column specimen show an ultimate load of 320kN, the corresponding deflection obtained during experiment (0.84 mm) and the FEA using ABAQUS (0.78mm) varied by 7.14 %. Q1 short column specimen exhibit an ultimate load of 340 kN, the subsequent deflection obtained during experiment (0.70 mm) and the FEA using ABAQUS (0.66 mm) varied by 5.71%. Q2 short column specimen show an ultimate load of 370kN, the corresponding deflection obtained during experiment (1.03 mm) and the FEA using ABAQUS (0.98 mm) varied by 4.85%. Q3 short column specimen show an ultimate load of



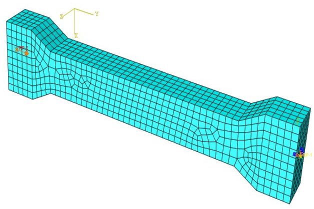
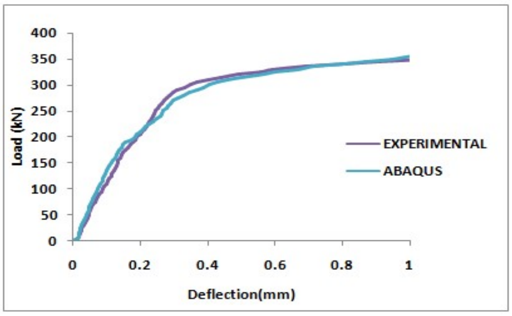
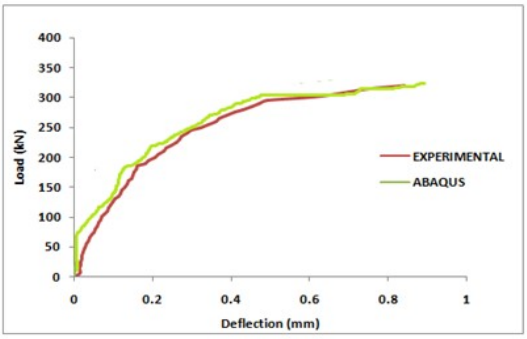


Fig.6. Short column model   Fig.7. Loading and support condition



(a) P1 specimen



(b) S1 specimen

Fig.8. Comparison of Experimental and ABAQUS Load-deflection of P1 and S1 Short column specimens

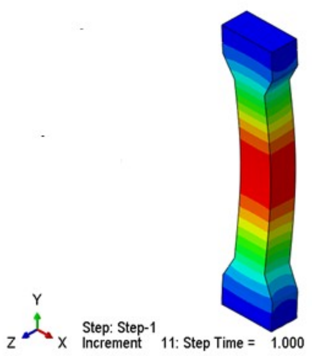
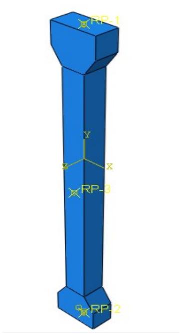


Fig.9. Displacement plot of S1 short column specimen

380kN, the corresponding deflection obtained during experiment (1.78 mm) and the FEA using ABAQUS (1.62 mm) varied by 8.98%. R1 short column specimen demonstrate an ultimate load of 340kN, the corresponding deflection obtained during experiment (0.69 mm) and the FEA using ABAQUS (0.65 mm) varied by 5.79%. R2 short column specimen exhibit an ultimate load of 350kN, the corresponding deflection obtained through experiment (1.04 mm) and the FEA using ABAQUS (0.97 mm) varied by 6.73%. R3 short column specimen show an ultimate load of 360kN, the corresponding deflection obtained through experiment (1.11 mm) and the FEA using ABAQUS (1.04 mm) varied by 6.30%. S1 short column specimen show an ultimate load of 395kN, the corresponding deflection obtained during experiment (1.17 mm) and the FEA using ABAQUS (1.11 mm) varied by 5.12%. S2 short column specimen demonstrate an ultimate load of 390kN, the subsequent deflection obtained during experiment (1.14 mm) and the FEA using ABAQUS (1.08 mm) varied by 5.26%. S3 short column specimen show an ultimate load of 385kN, the corresponding deflection obtained through experiment (0.43 mm) and the FEA using ABAQUS (0.39mm) varied by 9.30%. The load-deflection for the specimen S1 and P1 are compared in Fig.8. The displacement plot obtained for S1 specimen is shown in Fig.9.

3.3.2. Slender columns

The slender column model with loading and support condition are shown in Fig.10 and Fig.11. P1 slender column specimen demonstrate an ultimate load of 280kN, the subsequent deflection obtained during experiment (5.11 mm) and the FEA using ABAQUS (5.05 mm) varied by 1.17%. P2 slender column specimen show an ultimate load of 305kN, the corresponding deflection obtained during experiment (5.18 mm) and the FEA using ABAQUS (5.13mm) varied by 0.96%. Q1 slender column specimen exhibit an ultimate load of 335kN, the subsequent deflection obtained during experiment (5.34mm) and the FEA using ABAQUS (5.29mm) varied by 0.93%. Q2 slender column specimen show an ultimate load of 340kN, the corresponding deflection obtained during experiment (5.60 mm) and the FEA using ABAQUS (5.40 mm) varied by 3.57%. Q3 slender column specimen show an ultimate load of 345kN, the corresponding deflection obtained during experiment (6.90mm) and the FEA using ABAQUS (6.79mm) varied by 1.59%. R1 slender column specimen demonstrate an ultimate load of 305kN, the corresponding deflection obtained during experiment (2.31 mm) and the FEA using ABAQUS (2.28 mm) varied by 1.29%. R2 slender column specimen exhibit an ultimate load of 310kN,



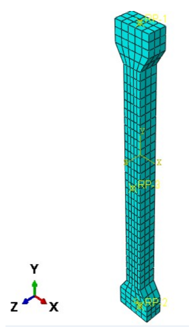
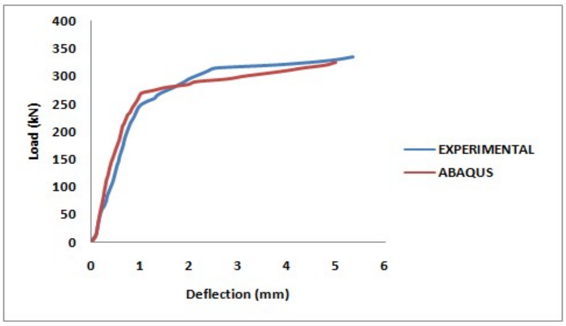
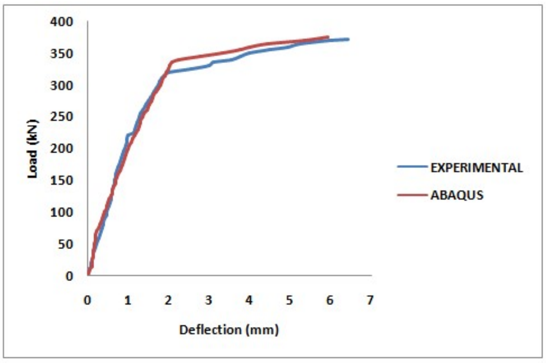


Fig.10.Slender column model   Fig.11.Loading and support condition



(a) P1 specimen



(b) S1 specimen

Fig.12. Comparison of experimental and ABAQUS Load-deflection of P1 and S1 slender column specimen

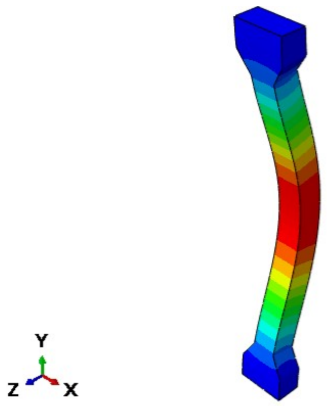


Fig.13.Displacement plot of S1 slender column specimen

the corresponding deflection obtained through experiment (5.08mm) and the FEA using ABAQUS (5.04 mm) varied by 0.78%. R3 slender column specimen show an ultimate load of 315kN, the corresponding deflection obtained through experiment (7.22mm) and the FEA using ABAQUS (7.18 mm) varied by 0.55%. S1 slender column specimen show an ultimate load of 385kN, the corresponding deflection obtained during experiment (7.76 mm) and the FEA using ABAQUS (7.71 mm) varied by 0.64%. The load-deflection for the specimen S1 and P1 are compared in Fig.12. The displacement plot obtained for S1 specimen is shown in Fig.13.

4. Conclusions

The study of bagasse ash blended high performance concrete columns with STF, PPF and hybrid fibres were carried out to understand the load carrying capacity. The following conclusions are observed:

- The utilization of higher fibre content comes out with a better performance against the distribution and minor crack width. Increase in fibre content provides additional internal confinement to concrete, which increases the amount of the crushed portion at failure.
- Both short and slender columns are performed well with bagasse ash blended high performance fibre reinforced concrete. It showed an increased load carrying capacity varies from 8.19% to 27.32% compared to control specimen for long column. Similarly for short column increase in load capacity varies from 3.12% to 21.5%.
- Using ABAQUS, the finite element models were developed. For prediction of load carrying capacity of columns the developed models can be used.
- The difference between experimental and ABAQUS in ultimate load varies from 5.12% to 8.98% and 0.98% to 1.96% for Short and slender columns.

Disclosures

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