**JOURNAL OF ALGEBRAIC STATISTICS**
Volume 13, No. 3, 2022, p. 2889 - 2897
https://publishoa.com
ISSN: 1309-3452

# Experimental Investigation on Hybrid Fibre-Reinforced Concrete Deep Beams

**S.K.Kulkarni [1], Dr. S.A.Halkude [2]**

*[1,]Research Scholar and Assistant Professor, Civil Engg.Deptt.,Walchand Institute of Technology, Solapur, India.*
*[2] Professor in Civil Engg. & Principal, Walchand Institute of Technology, Solapur, India.*

**Email :** *[1] skkulkarni2010@gmail.com, [2] halkude60@gmail.com*

**ABSTRACT**

Researchers have established that the inclusion of steel fibres in concrete for R.C. deep beam delays crack formation, transforms the brittle behaviour of deep beams into increasingly ductile behaviour, prevents sudden shear failure and improves the shear strength of deep beam. It is also recognized that using hybrid fibre reinforced concrete (HFRC), reinforced with two or more different types of fibres, can produce better results. The hybrid fibre combination of metallic and synthetic fibres provides effective confinement and better bonding with concrete, as well as it allows for easier stress transfer from matrix to fibres. In this connection, the present study focuses on the inclusion of hooked end steel fibres and fibrillated polypropylene fibres in predefined proportions in the concrete mix to cast HFRC deep beams and study the effects. The present experimental investigation demonstrates that the inclusion of hybrid fibres improves the strength properties of concrete significantly. Moreover, it leads to a rise in first crack load, a significant increase in ultimate shear strength, and a substantial increase in reserve strength of HFRC deep beams when compared to conventional R.C. deep beams. Also, study reveals that it is possible to replace conventional shear reinforcement in deep beams with 1 per cent hooked end steel fibres and 0.3 per cent fibrillated polypropylene fibres by volume of concrete, to obtain high shear strength deep beams with increased ductility, reserve strength and lower reinforcement congestion.

**Index Terms: Deep beams, hooked end steel fibre, hybrid fibre reinforced concrete, shear strength.**

## I. INTRODUCTION

Deep beams find their applications while building structures such as transfer girders, folded plates, bunkers, silos, vertical walls of water tanks, cap beams and many more other applications. Reinforced concrete (R.C.) deep beams need to carry heavy structural loads. One of the assumptions made that plane sections before bending remains plane after bending does not hold good for R.C. deep beams. Due to their higher depth, a major portion of the load on deep beams is transferred along the diagonal joining loading points to support points resulting in the non-linear behaviour of these beams [1]-[4]. In deep beams, diagonal cracking predominates, and the brittle shear failure mode is more common than the flexural failure mode. [1] [2].

Conventional shear reinforcement in R.C. deep beams holds the concrete mass together in case of distress but cannot provide isotropic elastic properties to concrete, this results in early first crack load, poor post cracking behaviour and low shear strength [3]. Furthermore, conventional shear reinforcement is prone to induce congestion in the casting of deep beams due to narrow widths, making the casting difficult and adversely affecting the quality of concrete.

The inclusion of randomly oriented short, discrete steel and other fibres in place of conventional shear reinforcement can reduce the congestion problem considerably. Concrete with fibre reinforcement has better crack resistance and isotropic elastic characteristics [4] [5]. Fibres play an important role in arresting crack growth and propagation, by virtue of their crack arrest mechanism [6]-[9].

Hybrid fibre reinforced concrete (HFRC) is a concrete reinforced with two or more distinct types of fibres. It is recognized that better results are possible to obtain using hybrid fibre reinforced concrete [8] [9]. The hybrid fibre combination of metallic and synthetic fibres provides effective confinement and better bonding with concrete and allows easier transfer of stresses from matrix to fibres. The control of micro cracks is essential for enhancing the durability of R.C. structures [10]-[13]. The addition of steel and polypropylene fibres reduces plastic shrinkage during the curing stage [9].

The addition of fibres to concrete improves the shear strength of R.C. deep beams by changing the brittle behaviour of deep beams to a more ductile one and delaying cracking [1]-[3]. Hooked end steel fibres, as a result of better bond with matrix, improve ductility, tensile strength and shear strength of concrete. They also control the crack width in concrete. Steel fibres also improve the freeze-thaw resistance of concrete [8]. Fibrillated polypropylene fibres improve resistance to plastic shrinkage during curing and resistance to explosive spalling in case of severe fire, improving impact strength and toughness of concrete [9]. In the present work, a combination of hooked end steel fibres and fibrillated polypropylene (PP) fibres are used in predefined proportions in concrete to cast the deep beams.

## II. Objectives of the Study

The objectives of the present experimental study are,

1. To study the improvement in various concrete strength properties on account of the inclusion of hooked end steel and fibrillated polypropylene fibres to concrete.
2. To investigate the performance of HFRC deep beam in shear strength and to arrive at an appropriate steel and polypropylene fibre percentage in the concrete mix.
3. To assess the possibility of complete replacement of conventional shear reinforcement in deep beams by the inclusion of hooked end steel fibres and fibrillated polypropylene fibres and to arrive at its proper proportion.

## III. Experimental Program

### A. Materials and mix proportions:

Concrete mix M*20* and M25 were designed using *43* Gr. Ordinary Portland cement, Natural River sand and *20* mm crushed aggregates [17]. Mix proportions obtained for M20 concrete were *1:1.89:2.85* with a water-cement ratio of *0.50*. Similarly, For M25 concrete, mix proportions were 1:1.80:2.71with a water-cement ratio of *0.48*. Fe 500 steel bars were used as flexural reinforcement in both conventional & HFRC deep beams and as shear reinforcement in conventional deep beams. HFRC deep beams were cast by replacing conventional shear reinforcement with hooked end steel fibre and fibrillated polypropylene fibres [Table 1] in predefined proportions [Table 2].

### B. Study of properties of concrete:

The concrete was cast exactly as per the requirements of the concrete mix design. During mixing the balling-up of fibres were prevented by feeding the fibres into the mix in small quantities at a time. Standard cubes of size 150 x 150 x 150 mm and standard cylinders of 150 mm diameter & 300 mm in length were cast from each mix for assessing the quality of the concrete cast.

### C. Workability:

Fibre-reinforced concrete does not respond well to slump test due to stiffness rendered by metallic fibres used in it. Therefore, the compaction factor (CF) test is preferred & accordingly workability was measured in terms of compaction factor [16]. For concrete with medium workability, the minimum compaction factor required as per I.S.456-2000 is 0.85 [16]. Table No. 2 shows the properties of concrete, such as workability, compressive strength and split tensile strength, for various proportions of fibres inclusion.

It is observed that the workability of concrete decreases with increasing per cent of fibre content. It is further observed that mixes up to 1 per cent steel fibre and 0.3 per cent PP fibre (1 % SF +0.3 % PP) satisfy the medium workability limit (C.F.>0.85). Whereas, steel fibre mixes beyond 1% are found non-workable and therefore to ensure workability requirement use of super plasticizers becomes necessary (Table 2).

Reduction in workability due to addition of steel fibres beyond 1% by volume of concrete, results into harsh mixes and fibres get entangled in each other and can be used only with super plasticizers.

**Table 1: Properties of fibres used in concrete**

| Type of fibre | Length/Dia. mm/mm | Aspect ratio | Tensile strength MPa | Percent elongation per cent | Modulus of Elasticity GPa | Specific Gravity |
|---|---|---|---|---|---|---|
| Hooked end steel fibre | 60/0.75 | 80 | 1100 | 3.5 | 200 | 7.8 |
| Fibrillated polypropylene fibre | 11.5/0.05 | 230 | 453 | 25 | 3.5 | 0.9 |

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**Table 2: Workability, compressive strength and split tensile strength of concrete with inclusion of various per cent of fibres for M20 concrete**

| Type of Concrete | Per cent Steel fibre | Per cent PP fibre | Compaction Factor (C.F.) | Percent drop in C.F. | Compressive strength of cubes (MPa) | per cent increase in Comp. Strength as compared to Conventional concrete | Split tensile Strength of Concrete (MPa) | Per cent increase in Split tensile strength as compared to conventional concrete |
|---|---|---|---|---|---|---|---|---|
| Conventional | - | - | 0.96 | 0.00 | 27.11 | NA | 2.88 | NA |
| HFRC | 0.50 | 0.1 | 0.93 | 3.12 | 27.56 | 1.66 | 3.26 | 13.19 |
| | | 0.2 | 0.92 | 4.17 | 27.82 | 2.62 | 3.28 | 13.89 |
| | | 0.3 | 0.915 | 4.69 | 27.88 | 2.84 | 3.35 | 16.32 |
| | 0.75 | 0.1 | 0.89 | 7.29 | 28.10 | 3.65 | 3.50 | 21.53 |
| | | 0.2 | 0.88 | 8.33 | 28.32 | 4.46 | 3.55 | 23.26 |
| | | 0.3 | 0.875 | 8.85 | 28.56 | 5.35 | 3.65 | 26.74 |
| | 1.00 | 0.1 | 0.87 | 9.38 | 28.92 | 6.68 | 3.80 | 31.94 |
| | | 0.2 | 0.865 | 9.90 | 29.02 | 7.05 | 3.83 | 32.99 |
| | | 0.3 | 0.86 | 10.42 | 29.12 | 7.41 | 3.88 | 34.72 |
| | 1.25 | 0.1 | 0.82 | 14.58 | 29.52 | 8.89 | 4.10. | 42.36 |
| | | 0.2 | 0.81 | 15.63 | 29.62 | 9.26 | 4.16 | 44.44 |
| | | 0.3 | 0.79 | 17.71 | 29.82 | 10.00 | 4.21 | 46.18 |
| | 1.50 | 0.1 | 0.75 | 21.88 | 30.05 | 10.84 | 4.52 | 56.94 |
| | | 0.2 | 0.74 | 22.92 | 30.15 | 11.21 | 4.55 | 57.99 |
| | | 0.3 | 0.72 | 25.00 | 31.24 | 15.23 | 4.58 | 59.03 |

**D. Compressive strength:**

It is observed from Table 2 that, the compressive strength of the M20 HFRC beam increases mildly with the increasing percentage of fibre content. The maximum increase in compressive strength observed in comparison with conventional concrete is 7.41 % at a combination of 1 % SF + 0.3 % PP fibre content. Even though for a trial mix of 1.5per cent SF +0.3 per cent PP fibre, the compressive strength of HFRC is increased by 15.23% in comparison with the conventional concrete; the workability reduces drastically and C.F. is below 0.85, therefore is not acceptable from the workability consideration, making it a non-feasible combination.

**E. Split tensile strength:**

Fig. 1 shows the split tensile strength of concretefor various percentages of steel & PP fibre. It is observed that due to inclusion of fibres in concrete, significant improvement in the split tensile strength of concrete takes place. With an increasing grade of concrete, split tensile strength increases. For both the grades of concrete, increase in split tensile strength is observed to be nearly linear, initially up to 0.5 % inclusion of steel fibre, it is steep and there afterwards it becomes milder but still nearly linear for higher per cent of fibre. In comparison with conventional concrete, for M20, the split tensile strength of HFRC has increased by 34.72 %, whereas for M 25 HFRC, this enhancement is observed to be 31.94 %. However, no significant increase in split tensile strength is observed with an increasing per cent of PP fibre for a given per cent of steel fibre.

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ISSN: 1309-3452

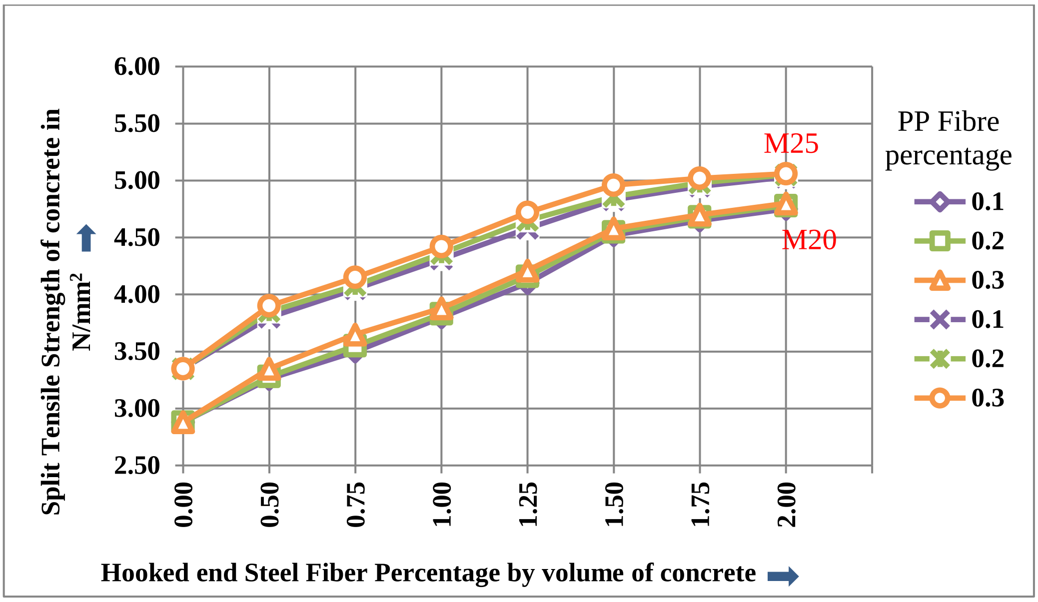


**Fig.1:Steel & PP fibre percentage Vs. Split tensile strength of M20 and M 25 concrete**

## F. Design of deep beams:

Deep beams were designed for two-point loads of 75 kN each. By applying a factor of safety of 1.5, the design stress was 2.08 MPa. Conventional R.C. deep beams were designed in accordance with I.S.456-2000[16] consisting of main and side face reinforcement as shown in Fig.2 a.

Various studies [1]-[4] report that tensile and shear strength of concrete can be improved with the inclusion of steel fibre content in the range of *0.5* to *2* per cent by volume of concrete. Also, polypropylene fibres, when used in combination with steel fibre, fibre content as low as 0.3 % by volume of concrete is adequate to improve various properties of concrete such as ductility, toughness, and impact strength. [11]-[14]. Because of this, in the present study, HFRC deep beams are cast by completely replacing conventional shear reinforcement with steel fibres 0.5 %, 0.75 %, 1.00 % along with PP fibres 0.1 %, 0.2 % and 0.3 % for each case of steel fibre content by volume of concrete (Table 3). For each of these combinations three deep beam specimens are cast.

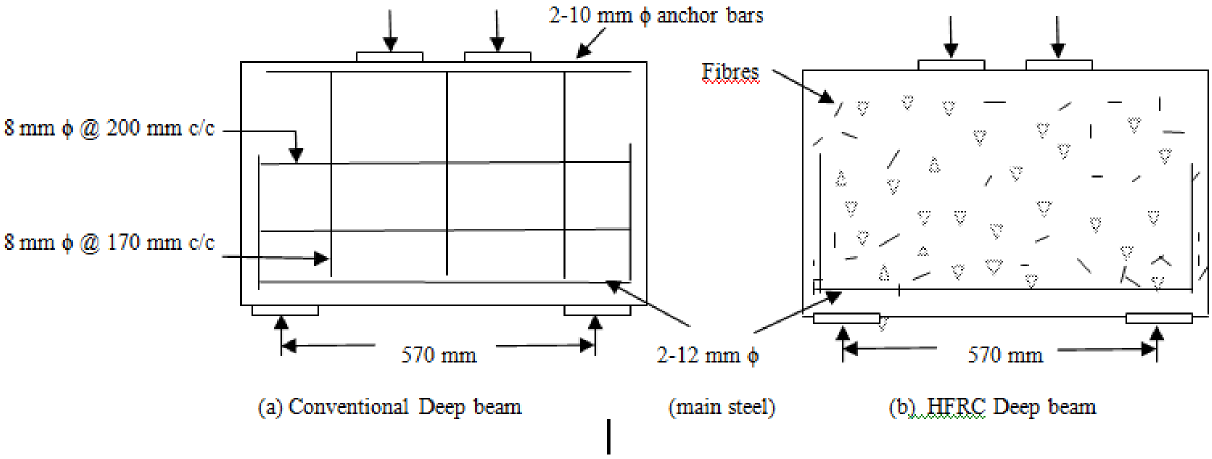


**Fig.2: Reinforcement details of deep beams.**

## G. Test Specimen, Casting and Curing Procedures:

Total *66* numbers of deep beam specimens were cast; consisting 33 number of specimen each for M*20* and M*25* grades of concrete respectively. Grade of concrete, Fibre percentages and span to depth ratios were the parameters considered for study. Each deep beam is rectangular in a cross-section, *700* mm long, *400* mm deep and *150* mm wide. After casting, specimens were kept under 90 per cent humidity for 24 hours, there after formwork was removed and specimens were water cured for 28 days.

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**H. Test procedure:**

The flexural test was performed in accordance with I.S.516 (1959) [14]**.** After 28 days of curing, beams were tested under two-point loading for three different shear span to depth (*a/d*) ratios viz.0.45, 0.50 and 0.55.Effective span to overall depth ratio was kept constant at 1.425.
The deep beams were tested under two points loading using a loading frame of capacity of 1000 kN (Fig.3). The Imetrum Video Gauge measurement system (VGMS), with a least count 1.0 micron was used to record central deflections of the beams and also to find shear strains at various points on beam specimens. To keep the bearing stress within permissible limits, M.S. bearing plates with dimensions of 150 mm length, 90 mm width, and 5 mm thickness were used at loading points and at the supports. The rate of loading was maintained constant at 4 kN/minute, in accordance with recommendations of I.S.516 [14].Load applied and resulting deformations were recorded, along with the initial crack load and maximum load for each specimen.

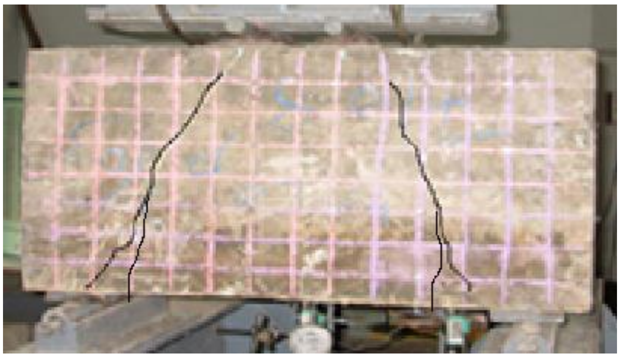

**Fig.3 a: Continuous cracks in conventional R.C. deep beams**

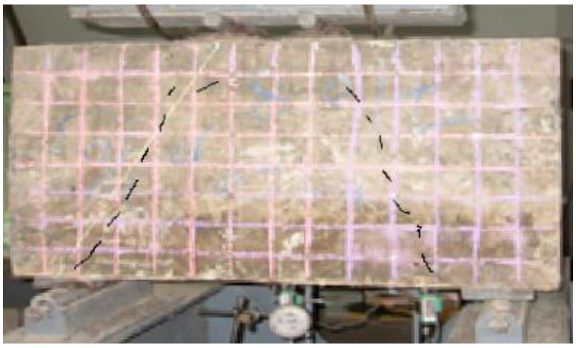

**Fig.3 b: Small discontinuous cracks in HFRC deep beams**

**Fig.3:Two point loading on deep beams and resulting crack patterns**

**I. Cracking pattern:**

In the case of conventional R.C. deep beam, cracks begin near the bottom of support of the beam and with increasing load, it progresses diagonally upwards towards the loading point (Fig.3a) and towards the centre of the shear span. Further increase in loading leads to the combining of 2-3 cracks together and these cracks become continuous and deepen further at the point of ultimate loading. The maximum crack width observed was in the range of 0.5 mm *to 1 mm*. Spalling of concrete was witnessed at some places. The brittle failure was observed.
In the case of HFRC deep beams, the first hair crack appeared was inclined & along the diagonal joining loading point to support, near mid-depth of shear span. With the increasing loading, the second crack originated in the same direction as that of the first crack but after some intermittent gap from an earlier crack. The slow rate of crack propagation demonstrated an added advantage of inclusion of fibres. At higher loads, numbers of small discontinuous cracks were observed at intermittent gap along the diagonal (Fig.3 b). The maximum crack width observed in the case of HFRC was in the range of *0.1 to 0.2* mm. This control of crack width is due to the inclusion of fibres in concrete. Also no spalling of concrete was observed as PP fibres are instrumental in preventing spalling. All the specimens failed in shear. At the same time, the enhanced ductile nature of concrete was observed due to improved post-cracking behaviour.

## IV. SHEAR STRENGTH OF DEEP BEAMS

**A. Test results and discussion:**

Two-point load tests of the deep beams specimens were carried out for three varying shear span to depth ratios, viz. 0.45, 0.50 and 0.55. However, as a representative case, the results corresponding to an *a/d* ratio of 0.45 are presented in Table 3 for M20 and M25 deep beams.

**B. First crack stress and ultimate stress:**

The first crack stress for M 20 conventional concrete deep beam observed was 2.78 MPa and which failed in shear at a stress of 4.07 MPa. The first crack stress for M 20 HFRC deep beams with 1 % SF +0.3 % PP fibre (hereafter referred to as maximum workable fibre content) was 3.38 MPa, which failed in shear at a stress of 6.76 MPa. Thus, M 20 HFRC deep beams result in 21.58 % increase in first crack stress and a 66.09 % increase in ultimate stress in comparison with conventional M 20 deep beams. The initial cracking stress for M 25 conventional concrete deep beams was 3.19 MPa, which failed in shear at maximum stress of 5.32 MPa. The initial cracking stress for M 25 HFRC deep beams with maximum workable fibre content was 3.70 MPa, which failed in shear at a stress of 8.01 MPa. Thus, M 25 HFRC deep beams result in a 15.98 % increase in first crack load and a 50.56 % increase in ultimate load over conventional M 25 deep-beams.(Table-3).

**Table 3**: **Shear strength of the M20 & M25 grade Conventional and HFRC deep beams (Shear span to depth ratio 0.45)**

| Type of Shear reinforcement | Beam Category | Per cent fibre volume fraction (*vf*) | | First crack stress MPa ($v_{fc}$) | Ultimate shear stress MPa ($v_u$) | Reserve strength (per cent) $[v_u - v_{fc}]/v_{fc}$ *100 | Per cent increase in Reserve strength w. r. t. conventional concrete deep beams | Deflection at design load *Dc* (mm) | Allowable deflection as per I.S.456:2000 |
|---|---|---|---|---|---|---|---|---|---|
| | | Steel | Polypropylene | | | | | | |
| M 20 Conv. | $F_0$ | 0 | 0 | 2.78 | 4.07 | 46.67 | -- | 1.39 | Span/325= (600/325) =1.84 mm |
| M20 HFRC | $F_{0.5}$ | 0.5 | 0.1 | 2.82 | 5.19 | 83.61 | 79.14 | 1.37 | |
| | | | 0.2 | 2.87 | 5.28 | 83.87 | 79.71 | 1.35 | |
| | | | 0.3 | 2.92 | 5.42 | 85.71 | 83.66 | 1.32 | |
| | $F_{0.75}$ | 0.75 | 0.1 | 3.06 | 5.83 | 90.91 | 94.79 | 1.29 | |
| | | | 0.2 | 3.10 | 5.93 | 91.04 | 91.88 | 1.28 | |
| | | | 0.3 | 3.15 | 6.16 | 95.59 | 104.82 | 1.27 | |
| | $F_1$ | 1.00 | 0.1 | 3.29 | 6.48 | 97.18 | 108.23 | 1.23 | |
| | | | 0.2 | 3.33 | 6.57 | 97.22 | 108.32 | 1.21 | |
| | | | 0.3 | 3.38 | 6.76 | 100.00 | 114.27 | 1.21 | |
| M25 Conv. | $F_0$ | 0 | 0 | 3.19 | 5.32 | 66.67 | 0.00 | 1.14 | |
| M25 HFRC | $F_{0.5}$ | 0.50 | 0.1 | 3.06 | 5.97 | 95.45 | 43.19 | 1.10 | |
| | | | 0.2 | 3.10 | 6.06 | 95.52 | 43.29 | 1.08 | |
| | | | 0.3 | 3.19 | 6.25 | 95.65 | 43.49 | 1.07 | |
| | $F_{0.75}$ | 0.75 | 0.1 | 3.38 | 6.76 | 100.00 | 50.01 | 1.01 | |
| | | | 0.2 | 3.43 | 6.90 | 101.35 | 52.03 | 1.00 | |
| | | | 0.3 | 3.47 | 7.04 | 102.67 | 54.01 | 0.99 | |
| | $F_1$ | 1.00 | 0.1 | 3.61 | 7.73 | 114.10 | 71.16 | 0.95 | |
| | | | 0.2 | 3.66 | 7.87 | 115.19 | 72.79 | 0.94 | |
| | | | 0.3 | 3.70 | 8.01 | 116.25 | 74.38 | 0.94 | |

Similarly, a study was carried out for shear span to depth (*a/d*) ratios of 0.50 and 0.55 and the ultimate shear stress observed was 6.16 MPa and 5.80 MPa respectively for M20 HFRC deep beams at the maximum workable fibre content. Several studies have reported that the shear strength of deep beams is inversely proportional to their *a/d* ratio [1]-[3]. The same is observed during our study. All the beams failed in shear mode.

Furthermore, at maximum workable fibre content & given *a/d* ratio for M 25 HFRC deep beam, 9.46 % increase in first crack stress and an 18.49 % increase in ultimate stress in comparison with M 20, HFRC deep beams was observed.

**C. Reserve strength:**

Reserve strength of deep beams is the percentage increase in shear stress from the first crack to the ultimate stress level, which is a measure of the post-cracking behaviour of deep beams. Hybrid fibre reinforced concrete has achieved excellent results in bridging early micro-cracks and later macro cracks [13].
PP fibres, because of their high per cent elongation and energy absorption capacity, assist steel fibres in improving concrete's post-cracking behaviour by delaying crack propagation, controlling crack width [12] [13]. The study of the crack pattern of HFRC deep beams reveals that fibres in the concrete serve as crack arrestors by applying pinching forces at the crack tips, thus delaying the appearance of cracks and creating a stage of slow crack propagation. PP fibres control the rate of propagation. Hooked end steel fibres improve flexural stiffness leading to improved reserve strength.
M 20 HFRC deep beams at maximum workable fibre content show an improvement of 114.29 % in reserve strength w.r.t. conventional M 20 deep beams. In the case of M 25 HFRC deep beams, at the same maximum workable fibre content, an improvement of 74.38 % in reserve strength in comparison with conventional M25 deep beams was observed (Table 3). Hence the use of combination of steel and PP fibre in concrete shows statistically significant improvement in the reserve strength of deep beams.

**D. Load Vs. deflection:**

Figure 4 shows central deflection of deep beam for M20 & M25 grade concrete for both conventional & HFRC beam for varying load.

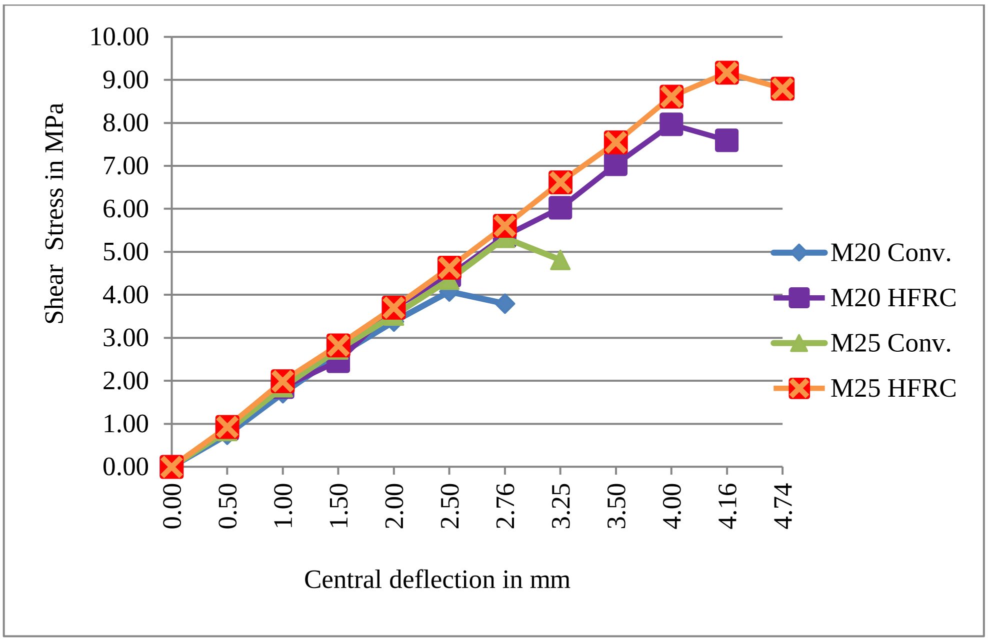


**Fig. 4: Shear stress Vs. Central deflection for conventional and HFRC deep beams with 1 per cent SF +0.3 per cent PP for *a/d* ratio 0.45**

At a design stress of 2.08 MPa, the central deflections of M 20 conventional and HFRC deep beams with maximum workable fibre content observed was 1.31 mm and 1.10 mm, respectively, indicating a 16.03 % decrease in central deflection due to the inclusion of fibres. At the same stress level, the central deflections of M 25 conventional and HFRC deep beams with maximum workable fibre content was 1.14 mm and 0.94 mm respectively, showing a per cent decrease of 17.54 % of central deflection. This is obvious as inclusion of fibres improve stiffness of beams and reduces deflection at the same stress level. M 25 HFRC deep beams show about 15 % lesser deflection, in comparison with M20 HFRC deep beams, at the same stress level indicating decreasing deflection with increasing grade of concrete. The load-carrying capacity of deep beam improves with increasing grade of concrete and fibre content. Also, it is observed that at the same stress level, HFRC deep beams exhibit improved post cracking behaviour, resulting in higher ultimate stress and lower deflection in comparison with conventional deep beams.

## V. CONCLUSION

- Based on the experimental study in which, HFRC mix with hooked end steel fibre of 1 % and polypropylene fibre 0.3 % by volume of concrete, being the maximum percentage of fibre up to which the mix is workable, the following conclusions are drawn:-
  1. The inclusion of fibre reinforcement improves the shear strength of HFRC deep beams substantially. For M20 HFRC, an average improvement of 21.58 % in first crack stress and 66.09 % in ultimate shear stress is observed at maximum workable mix when compared with M 20 conventional R.C. deep beams. However, with increasing grades of concrete, this improvement becomes milder.
  2. Improvement in reserve strength of M20 HFRC deep beams for the maximum workable mix is 114.29 % in comparison with M20 conventional deep beams. In the case of M 25 HFRC deep beams, this improvement in reserve strength is 74.38 % w.r.t conventional deep beams.
  3. It is possible to completely replace conventional shear reinforcement in R.C. deep beams by the addition of 1per cent hooked end steel fibres and 0.3 % fibrillated polypropylene fibres by volume of concrete. It results in an improvement in first crack load, ultimate shear strength, ductility, and reserve strength of deep beams while reducing reinforcement congestion.

## VI. ACKNOWLEDGMENTS

The authors express their sincere gratitude to 1. AICTE, for awarding the grant under R.P.S. 2.M/s. Bekaert Industries, Lonand, Satara for free supply of Drimex-3 Dfibres used in this study.

## VII. NOTATIONS:

*a* = *Shear span*
*a/d= Shear span to depth ratio*
*d* = *depth of beam*
*b = width of beam*
*l = span of beam*
$d_f$= *fibre diameter*
$l_f$ = *length of fibre*
$f_{ck}$= *Characteristic comp. strength of concrete, MPa*
$f_t$= *Split cylinder strength of HFRC,MPa.*
$f_{sp}$= *Basic split tensile strength of concrete (without fibres),*
$\alpha$ = *Inclination of the diagonal joining loading point to supports*
$V_f$= *Volume fraction of fibres*
$l_f/d_f$=*Fibre aspect ratio*
$v_{fc}$= *First crack stress*
$v_u$=*Ultimate shear stress*
*SF* = *Steel fibres*
*PP* = *Polypropylene fibres*

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