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Effect of Aspect Ratio of Fiber in HDPE Reinforced Concrete

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***Abstract*:- In recent years, with the development of industrial technology, a series of reactions take place between HDPE plastic fibres and relate materials to form mixtures for different functions. Polymer reinforced concrete made up of HDPE fibres is known to increase the energy absorption, free shrinkage and post cracking strength. These effects are not quantified and the purpose of this paper is to show the impact of using HDPE fibres on important concrete characteristics. Basic tests on concrete like the test for workability, compressive strength test, beam flexure test and Plastic shrinkage tests are carried out to compare various characteristics of the HDPE polymer reinforced concrete with different fibre contents (i.e., 0.67% and 0.45% volume fraction over M40 and M25 grades of concretes respectively) by varying fibre aspect ratios (75 and 125) and are compared to the characteristics of plain concrete in order to evaluate the effect of the aspect ratios in HDPE Reinforced Concrete. Aspect ratio of fibre played a key role in effective enhancement in mechanical properties and plastic shrinkage properties of both M40 and M25 grade HDPE Fibre Reinforced Concrete over plain concrete. Least aspect ratio of FRC (i.e., 30mm length of HDPE fibres) shown better performance than the higher aspect ratio of FRC (i.e., 50mm length HDPE fibre).**

Keywords*: *HDPE fibre; aspect ratio; plastic shrinkage.

1. INTRODUCTION

Polymers are being used for various purposes and are virtually irreplaceable in the world today. Constant advancements in material and production technology has further lifted the availability of polymers and diversified their use. Research on construction has been lately experimenting on the viability of use of polymers in concrete so as to bring out the desired characteristics to suit their requirements. High Density Poly Ethylene (HDPE) is a polymer of ethylene known for its high strength to density ratio and finds its use in many daily applications in life. Concrete reinforced with HDPE polymer resins is known to reduce the permeability and control plastic shrinkage cracking and drying shrinkage cracking. Polymer reinforced concrete is known to have a superior after crack strength that prevents immediate failure of structures. Even though it is known that HDPE reinforced concrete exhibits such properties, its quantified measurement and accurate mix designs are not known or standardized to find its way into daily construction activities.

HDPE reinforced concrete shows different characteristics based on the type of material used and the design mix that is being implemented. Different sizes of fibres and different compositions have to be tested to arrive at a suitable mix design that satisfies the requirements. The concrete mix is designed and proportionate quantity of fibres of HDPE rope of specific size are added and tested for the characteristics. Various tests are employed to know the properties like workability [1], density, compressive strength, flexural strength and plastic shrinkage properties of concrete. These properties are compared with the properties of both ordinary concrete and HDPE Fiber Reinforced Concrete and corresponding recommendations are given.

2. LITERATURE REVIEW

J.M. Irwan et al (2013), investigated the performance of concrete containing PET fiber of 0.5%, 1.0% and 1.5% fraction volume in order to measure the strength properties of concrete in which they concluded that the strength of the concrete will be affected by fiber content and also strong fibers are desired which helps in improving strength and ductility of concrete, but in turn may lead to loss in segregation, increased porosity, and overall reduction in concrete strength. Such that the addition of high dosages of fiber will also cause workability problems because of their relatively surface area. Ninoslav Pesic et al (2016) used 0.25mm and 0.40mm diameter of HDPE fibres at a volume fraction of 0.40%, 0.75% and 1.25%. The results showed that the compressive strength and modulus of elasticity were not improved using HDPE fibers and even a small amount of added HDPE fiber showed a significant result in early reduction of plastic shrinkage cracking of concrete which decreases by more than 50% crack width realized at a volume fraction of 1.25% of 0.40mm diameter HDPE fibres**.** Sudarshan et al (2015) made an attempt to evaluate the strength properties of high density polyethylene fibre reinforced concrete with varying fiber

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content from 0 to 6% and results shown an increment of Compressive strength by 10.63% Split tensile strength by 15.76% Flexural strength by 13.9%.As the HDPE is non bio degradable waste disposable material is much useful for the concrete works in durability aspects as it improved the strength gradually by 11.25% at 7days and 10.63% increase after 28days. Shi Yin et al (2015) made effective use of virgin and recycled polypropylene fibers with 0.67% and 0.45% volume fractions in M40 and M25 grades of concrete respectively and compared the results with plain concrete [2] and concluded that there is no effect in compressive strength with the addition of these PP fibres, but a significant improvement in residual flexural strength was observed. Fernando Pelisser et al (2010) studied effect of different types of synthetic fibers on plastic shrinkage cracking in thin cement mortar slabs of size 910mm x 610mm x 20mm [3] using polypropylene, glass, PET and Nylon fibers with a volume fraction of 0.0%, 0.05% and 0.10% and performed tests in a climatized closed chamber rather than Paul kraai's (1985) basic method of exposing the slabs to wind pressure [4]. The results have shown that the polypropylene fibers has a great effect on reduction of plastic shrinkage cracks while nylon fibers showed adverse results, Glass and PET fibres shown similar betterment in cracks as compared to the conventional thin slabs. Ruben Paul Borg et al (2016) used straight and deformed fibers of length 30mm and 50mm [5] that are obtained by shredding of recycled PET bottles while Ozgur EREN (2019) used steel fibers of aspect ratios 55, 65 and 80 at a fiber volume fraction of 0.5%, 1.0% and 1.5% in concrete to evaluate the effects of fibers on cracking potential due to plastic and restrained drying shrinkage. They concluded that the larger fibers has shown significant effects than that of short fibers in restraining crack development [6] and propagation while steel fibers reduced the total area of plastic shrinkage crack and maximum crack width by about 74% and 70%, respectively, compared to raw concrete.

3. MATERIALS AND METHODOLOGY

3.1 Materials Used

Natural Godavari river sand confining to Zone II (As per IS 383 – 1970) passing through 4.75mm sieve and the crushed stone aggregates of 12mm (passing through 20mm and retained on 4.75mm sieves) size were used as fine and coarse aggregates respectively and Ordinary Portland Cement of 53 Grade Deccan Cement were used in the present study. The High Density Polyethylene (HDPE) rope of 0.4mm fiber diameter which is cut into 30mm and 50mm lengths having aspect ratios 75 and 125 are used as fibres for reinforcement. The properties of the materials are listed in Table 2.

3.2 Concrete Mix Design

Mix design for M40 Grade of concrete using 0.67% of fibres and M25 grade of concrete using 0.45% of fibres were done by following the guidelines of IS 10262: 2009. The following Table 1 gives the details of mix proportions for 1 cubic meter of M25 & M40 grades of concretes.

Table 1. Mix proportion details

	Grade	Cement	Fine aggregate	Coarse aggregate	W/C ratio	HDPE Fibers (%)
Mix Proportions	M25	1	2.04	1.85	0.50	0.45
	M40	1	1.41	2.05	0.45	0.67

Table 2. Properties of Materials

Material	Test for	Code for testing	Properties
Cement (OPC 53 Grade)	Specific gravity	IS 2386	3.15 Kg/m^3
	Fineness	IS 4031 (Part 2)	326 m^2/Kg
	Initial setting time	IS 1489 (Part 1)	75 min
	Final setting time	IS 1489 (Part 1)	242 min
Fine Aggregate	Specific gravity	IS 2386-3 (1963)	2.60 Kg/m^3
	Sieve analysis	IS 383-1970	Zone II
Coarse Aggregate	Specific gravity	IS 2386-3 (1963)	2.75 Kg/m^3
HDPE Fiber	Density		970 Kg/m^3
	Diameter		0.40mm
	Tensile strength		345-490 MPa
	Elasticity Modulus		5000 MPa
	Water absorption		Nil
	Aspect ratio (30mm, 50mm)	(l/d)	75, 125

3.3 Methodology:

The present study is concerned with the comparison of properties of M25 and M40 grades of plain concrete with 0.45% and 0.67% HDPE Fiber (both aspect ratios of 75 and 125, i.e., 30mm and 50mm length of fiber) Reinforced Concrete respectively. A set of 54 cubes, 54 prisms and 6 thin shrinkage slabs of plain and HDPE FRC samples are casted, cured and tested to compare the various properties of concrete. An attempt of evaluation of effect of aspect ratio in plastic shrinkage cracking behavior of thin cement mortar slabs has been made with reference to the works done previously.

4. RESULTS AND DISCUSSIONS

4.1 Slump Test

Slump, or measurement of the fluidity of the concrete, is also commonly specified to facilitate the placement of concrete in the formwork. The behavior of the concrete under this test is also a valuable indication of the cohesion of the mixture. A well-proportioned mixture will gradually collapse to the lowest altitude and maintain its original shape, while a mediocre mixture will collapse, separate and collapse.

The Fig: 1 shows the variations of slump in different mixes. It shows that the slump value decreases with addition of increased

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aspect ratio of HDPE fibers for both grades of concrete. As slump value is the resemblance of its workability, from the below graph we can infer that the workability of concrete decreases with the addition of HDPE fibers in the mix. The reason is that the concrete mix with fibers makes the mix less workable. But when compared by grade wise, M25 grade of concrete is more workable than M40 grade of concrete.

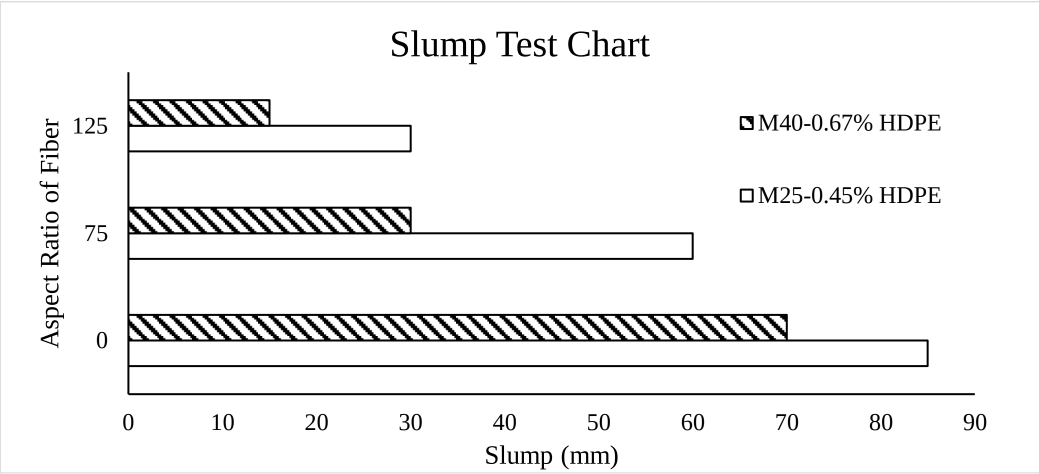

Fig: 1 Slump Test Chart

4.2. Fresh Density Test

Fresh density of concrete is the measure of unit weight of Concrete. Density of Concrete is the weight per cubic meter of concrete is calculated by dividing the weight of fully compacted concrete in the cylindrical measure by the capacity of measure in kg/cu. m. in the present study the Fresh density test is carried out in a cylindrical measure of Capacity $0.0053m^3$. It reflects the ability of concrete to function for structural support, durability and air entrainment. This helps in calculating the yield of concrete per cubic meter. Fig: 2 shows that the fresh density of concrete has decreased with the increase in aspect ratio of HDPE fibers. When both M40 and M25 grades of 30mm HDPE Fiber reinforced concretes are compared, there was no such great difference in their fresh densities. The FRC with 125 aspect ratio of fibers has least density than FRC with 75 aspect ratio and plain concretes. This is due to the formation of balling effect of fibers in the mixture due to their larger dimensions which cannot be compacted fully during tamping.

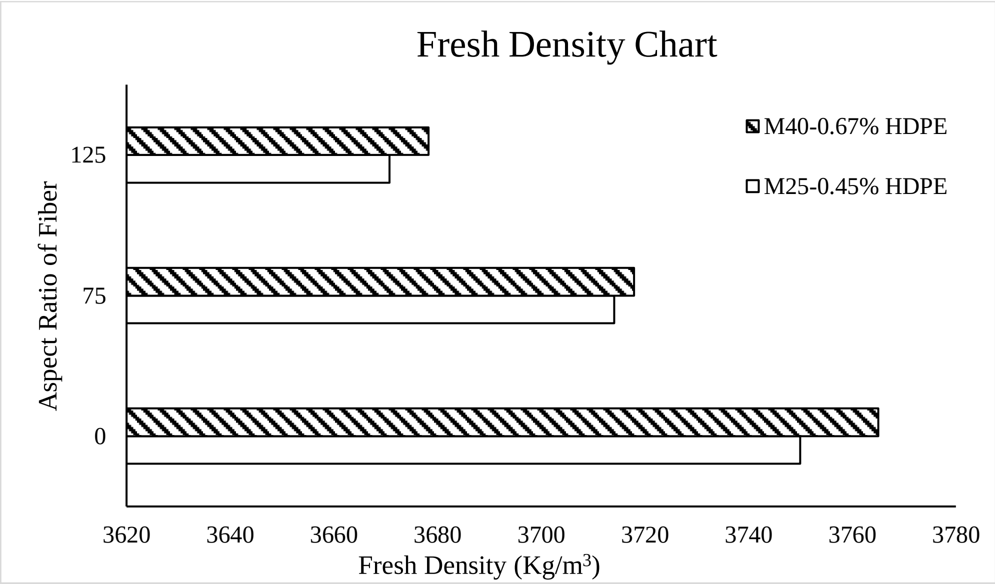

Fig: 2 Fresh density chart

4.3. Rebound Hammer Test

Rebound hammer test or Schmidt hammer test is a non-destructive test method for concrete that provides a comfortable and quick indication of the compressive strength of concrete. Fig: 3 indicates the compressive strength of concrete of M40 & M25 grades of plain and HDPE FR Concrete which are evaluated from Rebound hammer test using calibration chart.

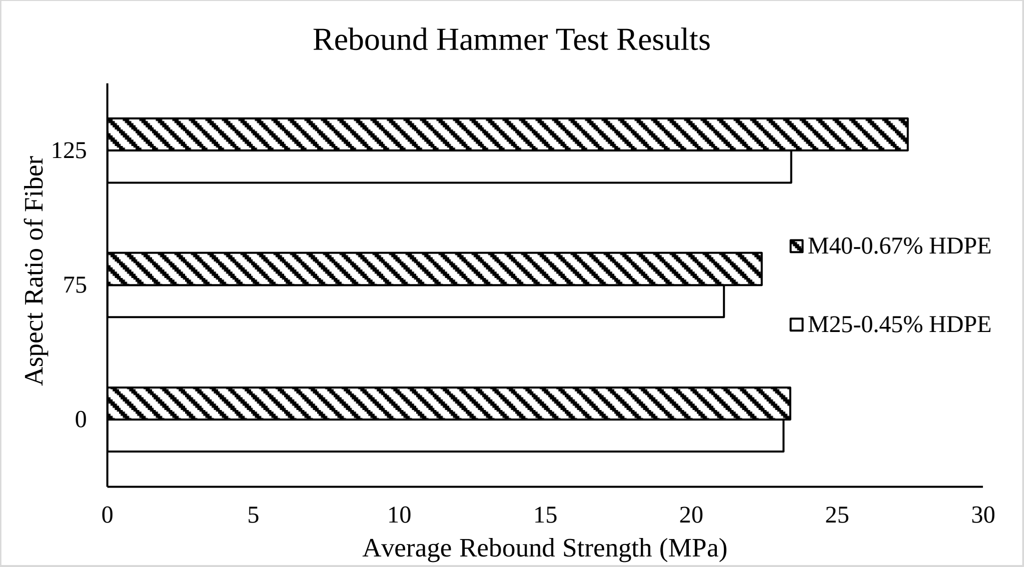

Fig: 3 Rebound Hammer Chart

4.4. Ultra Sonic Pulse Velocity Test

Ultrasonic test on concrete is used for Qualitative assessment of strength of concrete, any discontinuity in cross section like cracks, cover concrete delamination etc. and depth of surface cracks. The quality of concrete in terms of Ultrasonic Pulse Velocity can be characterized with the help of following table 3 as per IS 13311-Part 1-1992.

Table 3. Pulse velocity

Sl. No	Pulse Velocity (Km/s)	Concrete Quality Grading
1	Above 4.5	Excellent
2	3.5 to 4.5	Good
3	3.0 to 3.5	Medium
4	Below 3.0	Doubtful

From Fig: 4, since the average pulse velocities of all cube specimens of both the grades of plain and HDPE FR Concrete are greater than 4.5km/s, all the specimens are considered to be of excellent quality.

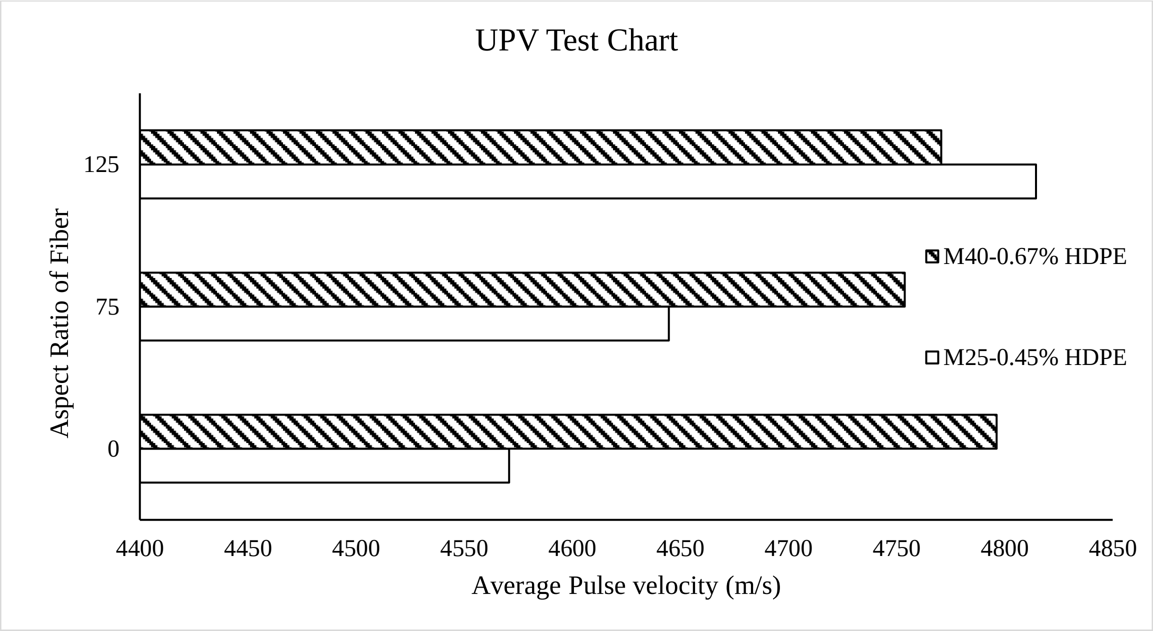

Fig: 4 UPV test chart

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4.5. Compressive Strength of Concrete

The test for compressive strength of concrete was performed according to IS 516-1959 on M40 and M25 grades of HDPE fibre reinforced and plain concretes. Concrete specimens of size 150mmx150mmx150mm were casted, cured for 28 days and tested under Compression Testing Machine (CTM) of 2000KN capacity at a rate of loading of 140kg/ Sq.cm. From the Fig: 5, when the strength regarding grades are compared, M40 grade of concrete has shown higher compressive strength than M25 grade of concrete in both plane concrete and HDPE fiber reinforced concretes at various fiber dosages and lengths. There was only an average increment of 7.61% of compressive strength from plain to 30mm FRC and a decrement of 5.4% from 30mm length HDPE FRC to 50mm length HDPE FRC which are not much noticeable. This shows that the incorporation of increased length of fibers in concrete increases its strength to a very little extent as compared to plain concrete.

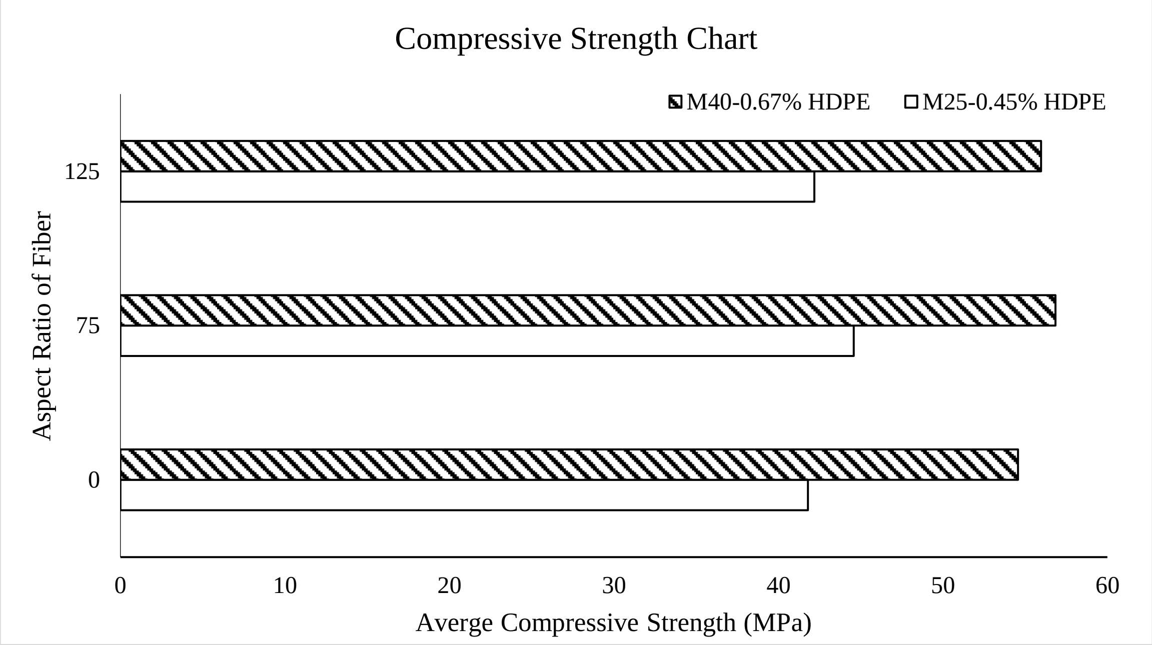

Fig: 5 Compressive Strength Chart

4.6. Beam Flexure Test:

The flexural strength test on 500mmx100mmx100mm beams was performed under Two-point loading system in which equal loads are applied at a distance one-third of the two beam supports in order to get pure bending according to IS 516:1959 at a rate of loading of 180kg/min. The Fig: 6 shows a drastic change of flexural strength between plain and 30mm HDPE reinforced concrete of designed volume fraction of both grades than with 50mm. For M40, 16% of flexural strength was increased from plain to 30mm fiber while 2.2% decreased from 30mm to 50mm fiber length. Similarly, for M25, 6.69% increment and 2.2% decrement in flexural strength was observed from plain to 30mm and 30mm to 50mm respectively. In all the above three cases, HDPE fiber reinforced concrete with the least aspect ratio has shown higher strengths than the plain and the FRC with highest aspect ratio.

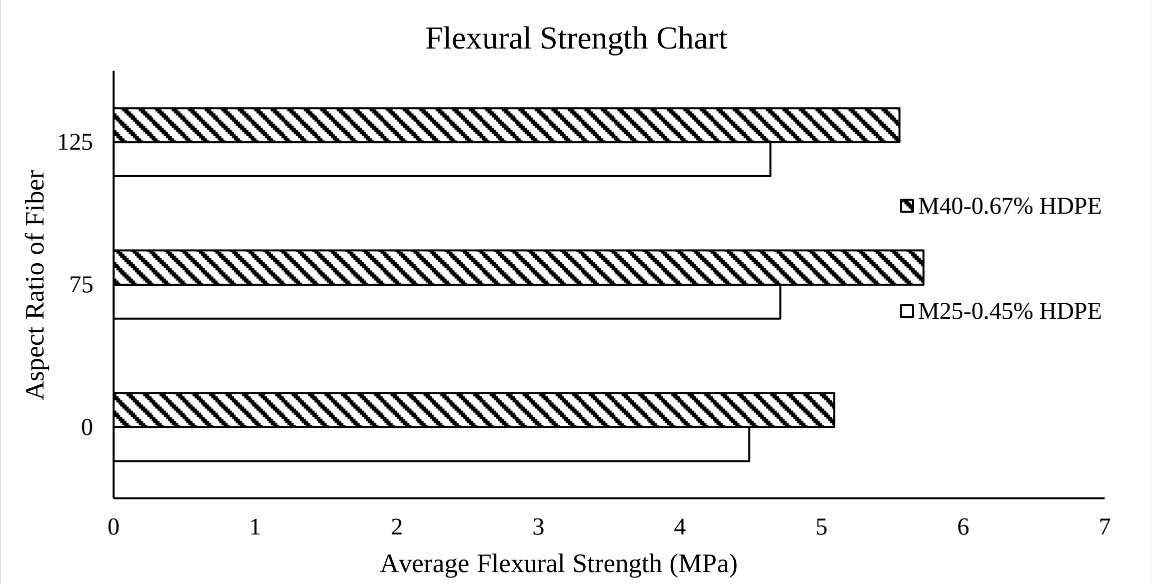

Fig: 6 Flexural Strength Chart

4.7. Plastic Shrinkage Test:

Plastic shrinkage of concrete occurs where high evaporation takes place from the fresh concrete surface that tends to dry early due to high temperatures, relatively low humidity with high velocity of wind, before it sets. These shrinkage cracks impair the strength of concrete floors and pavements, such that can allow the access of hostile particles or chemicals that affect the durability and may become the reason for the initiation of larger cracks further.

To avoid plastic shrinkage cracking, the most widely accepted method is the use of randomly distributed fibers, particularly fine synthetic fibers in the lower volume fraction. In the present study, an attempt has been made to reduce these plastic shrinkage cracks in concrete by the incorporation of HDPE fibers of 75 and 125 aspect ratios, with reference to the works done by Fernando et al [3], P. Kraai [4], and Ruben Paul Borg et al [5]. The test described here, however, is not a measure of drying shrinkage, but rather the cracking potential.

Rectangular thin slabs of 910mmx610mmx20mm size were casted with 0% (plain S1), 0.67% of 30mm (S2) and 50mm (S3) HDPE Fibres for M40 grade of concrete and 0% (plain S4), 0.45% of 30mm (S5) and 50mm (S6) HDPE fibres for M25 grade of concrete to evaluate the effect of addition of HDPE fibres in fresh concrete on plastic shrinkage cracking. The ends of the slabs are restrained by 3.5mm thick L-angles over the entire perimeter of the 19mm thick 910mmx610mm wooden plank [3]. A thick polythene sheet is to be spread on the plank before pouring the mortar for easy removal of slab after drying. Constant environmental conditions of nearly 70°C temperature and 50% relative humidity with constant wind speed are maintained by using blow hot room heater of 2000W capacity under polythene sheet coverage as shown in Fig: 7. Two rectangular boxes of size 230mmx130mmx70mm are also arranged to note the rate of evaporation of water and mortar mass losses.

The test was carried out with Mortar i.e., mixture of water, cement, fine aggregate and fibres. Coarse aggregates are avoided in this test so as to avoid the intermediate restrain of the mortar flow. A minimum of 1Kg/m²/hour of evaporation is allowed to carry out the test as per ACTM C1579-06, 2006. The readings of water loss (evaporation), temperature, humidity and mortar mass loss are taken for every hour during the test. The test was performed for 7 hours under these closed environmental conditions to allow the mortar to shrink. At the end of the test, the number of cracks developed on the surface of the slab as shown in Fig: 8 was keenly observed and lengths of the cracks were recorded with the help of sewing thread and scale. The experiments are conducted for six days with one specimen cast and test per day. The average test results of plastic shrinkage cracking for the 6 slabs casted were tabulated in the following Table 4.

Table 4: Plastic Shrinkage test results

Grade of Concrete	M25			M40		
Volume fraction of HDPE fiber added (%)	0.00	0.45		0.00	0.67	
Slab Specification	S1	S2	S3	S4	S5	S6
length of HDPE fiber (mm)	Plain	30	50	Plain	30	50
Aspect ratio (l/d)	--	75	125	--	75	125
Cracking:						
Average Crack length (mm)	320	65	35	285	40	30
Number of cracks observed	18	12	3	32	9	5
Environmental Conditions:						
Average temperature(˚C)	66	62	65	69	66	69
Relative Humidity (%)	61.10	59.60	60.40	63.00	68.30	66.90
Mixture conditions and mass loss:						
Average rate of evaporation (kg/m²/h)	1.2	1.01	0.98	1.3	1.12	1.01
Mass loss (g)	38.71	35.85	30.62	34.12	33.14	30.06

As the aim of the test is to access the control of plastic shrinkage cracking with the introduction of HDPE fibers in the cement mortar, from Fig: 9, a graph is plotted between the fiber aspect ratio and number of cracks formed during the test and another graph (Fig: 10) is plotted between the fiber volume fraction and average length of the cracks formed for M40 and M25 MPa strength concrete. Fig: 9 shown a decrement in formation of number of cracks with increased aspect ratio of fibers for both grades of concrete. In case of 40MPa strength, 72% of cracks are minimized with introduction of 0.67% 30mm HDPE fibers (aspect ratio 75) in the mortar mix while, 84.37% of cracks are minimized with the introduction of 50mm fibers (aspect ratio 125) in the same cement mortar mix. The same decrement pattern is repeated with the 25MPa strength mixture with 33.33% of decrement by addition of 30mm HDPE fibers and 83.33% of decrement by the addition of 50mm HDPE fibers of same volume fraction of 0.45. Fig 10 shows a decrement in the average plastic shrinkage crack length with the incorporation of generous amount of fibers into the cement mortar for both mix grades. On an average, with an addition of 0.47% HDPE fibers, around 81% of crack length has been decreased for M25 mortar mixture and around 86% for 0.67% M40 mixture.

There may be a quite difference in these results as they are interpreted with naked eye rather than optical zoom cameras to determine the absolute crack length. But however this helps in gaining a better knowledge in reducing plastic shrinkage cracks using various volume fractions of HDPE fibers with different aspect ratios.

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Fig: 7 Testing of Shrinkage Slab


Fig: 8 Crack assessment of shrinkage slabs

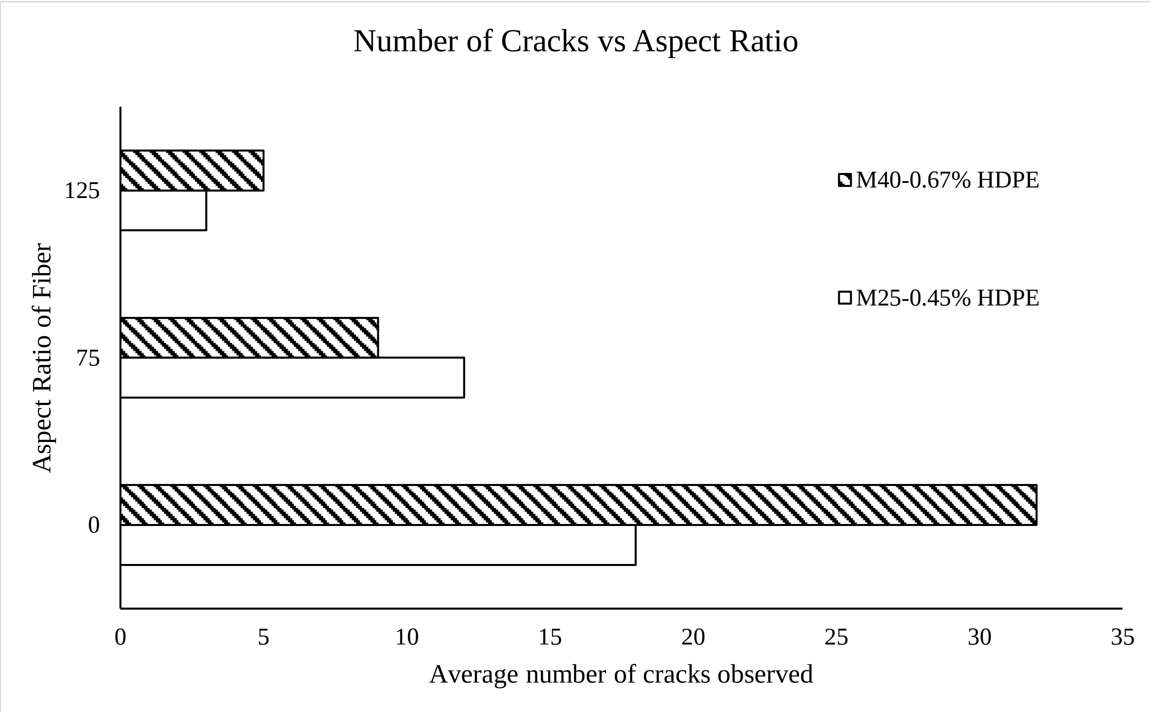

Fig: 9 Number of Cracks vs Aspect Ratio

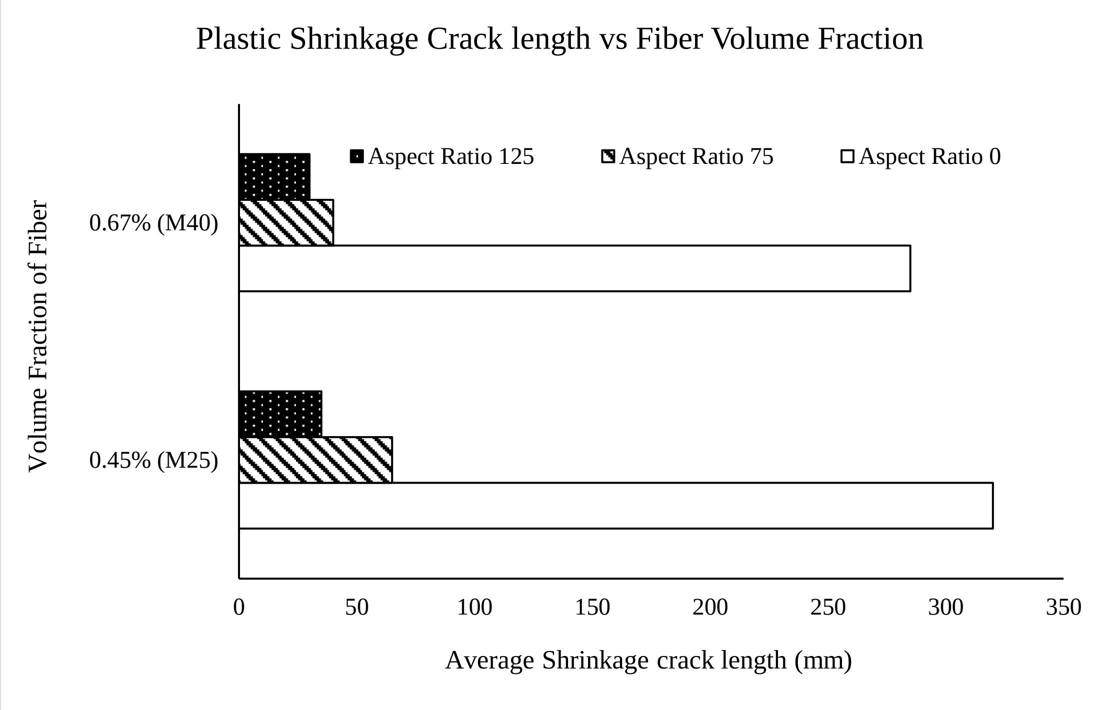

Fig: 10 Shrinkage Cracking length vs Fiber Volume Fraction

14. CONCLUSION

From the above mentioned test results, the following conclusions can be drawn.

The concrete mix with HDPE fibers made the mix less workable such that the strength of concrete increased as it is inversely proportional to the workability of concrete.

Fresh density of concrete is reduced with an increase in Water to cement ratio and increased with increase in aspect ratio i.e., HDPE fiber length.

The flexural strength and compressive strength properties of concrete with 75 aspect ratio (30mm length) HDPE FRC was found to be higher followed by 125 aspect ratio (50mm) length HDPE FRC followed by the plain concrete one for both the M40 and M25 grades of 0.45% and 0.67% volume fraction respectively.

Average shrinkage cracking length and number of cracks formed on the surface of thin slab were found to be decreased with increased fiber volume fraction and aspect ratios respectively. As these values are obtained only by the eye judgment, better results can be expected by assessing the cracks with the help of optical microscope. However, the results obtained are remarkable.

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