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A STUDY ON THE SHRINKAGE, CRACKING AND STRENGTH OF CONCRETE USING SYNTHETIC FIBERS

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Abstract: Shrinkage cracking remains a significant concern in concrete structures, compromising their durability and serviceability. This paper offers a comprehensive examination of shrinkage cracking mechanisms in concrete structures reinforced with synthetic fibers, aiming to provide insights into effective mitigation strategies. The introduction outlines the detrimental effects of shrinkage-induced cracking on concrete structures, including reduced durability, aesthetic concerns, and potential structural vulnerabilities. The need for innovative solutions to address this issue is emphasized, setting the stage for the exploration of synthetic fiber reinforcement. The paper reviews various types of synthetic fibers commonly used in concrete reinforcement, including polypropylene, polyethylene, and nylon fibers, among others. Each fiber type's mechanical properties, such as tensile strength, modulus of elasticity, and aspect ratio, are discussed in relation to their effectiveness in mitigating shrinkage cracking. The mechanisms by which synthetic fibers influence the shrinkage behavior of concrete are elucidated, encompassing aspects such as fiber-matrix interactions, crack bridging, and residual stress redistribution. Experimental studies and field applications are analyzed to assess the effectiveness of synthetic fibers in controlling shrinkage cracking under different environmental and loading conditions. Furthermore, the paper examines key factors influencing the performance of synthetic fibers in mitigating shrinkage cracking, including fiber dosage, aspect ratio, distribution, and compatibility with concrete mixtures. Practical recommendations for optimizing fiber-reinforced concrete mix designs are provided based on empirical data and best practices.

I. INTRODUCTION

Concrete is a composite material, comprising a matrix of aggregate and a binder, which holds the matrix together. Many types of concrete are available, determined by the formulations of binders and the types of aggregate used to suit the application for the material. Concrete is strong in compression, as the aggregate efficiently carries the compression load. However, it is weak in tension as the cement holding the aggregate in place can crack, allowing the structure to fail. Reinforced concrete adds either steel reinforcing bars, steel fibers , synthetic fibers , glass fibers , or plastic fibers to carry tensile loads. Fiber-reinforced concrete (FRC) is concrete containing fibrous material which increases its structural integrity. It contains short discrete fibers that are uniformly distributed and randomly oriented. Fibers include steel fibers, glass fibers, synthetic fibers and natural fibers – each of which lend varying properties to the concrete. In addition, the character of fiber- reinforced concrete changes with varying concretes, fiber materials, geometries, distribution, orientation, and densities.

Shrinkage of concrete

Shrinkage of concrete is the time-dependent strain measured in an unloaded and unrestrained specimen at a constant temperature. Concrete is subjected to changes in volume either autogenously or induced. Volume change is one of the most detrimental properties of concrete, which affects the long-term strength and durability. To the practical engineer, the aspect of volume change in concrete is important from the point of view that it causes unsightly cracks in concrete. Volume change in fresh concrete occurs primarily due to rapid loss of surface bleed water on evaporation. In addition, the cracks allow water and other chemical agents to penetrate into concrete and get in touch with steel reinforcements, leading to reinforcement corrosion, even to breakage.

All this leads to shrinking of cement paste. The resultant restraint offered by aggregates leads to cracking on the surface of the fresh concrete. Fresh concrete is susceptible to shrinkage cracking especially during hot, windy and dry weather conditions. When the evaporation rate is higher than bleeding rate, it can cause high tensile stresses that may be sufficient to exceed the tensile strength of concrete. If the surface cracks that develop as a result of shrinkage remain unnoticed, they become channels for external deteriorating agents and reduce long-term durability.

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Recent studies have shown that the early loss of moisture from fresh concrete can produce large tensile stresses in the concrete at a very early age. Early-age cracking can occur when volumetric changes caused by temperature reduction, chemical reaction and moisture loss are prevented. The reduction of volume reduction results in the development of tensile stress in concrete. If these tensile stresses exceed the tensile strength of concrete, a visible crack can be expected to occur. In addition to free shrinkage and tensile strength, several other factors can also influence the potential for early-age cracking including the magnitude and rate of shrinkage, the degree of restraint, stress relaxation, time-dependent material property development, and the –geometry of the structure and fracture resistance of material. Early-age cracking is problematic because it is responsible for the increase in the water penetration, de- icing chemicals, sulphates, and other corrosive or aggressive agents into concrete, thereby accelerating the corrosion of reinforcing steel. The structures that are particularly sensitive to the above-described phenomenon include pavements, industrial floors, bridge decks, walls and tunnel linings. The above is due to the low volume/surface ratio and to the fact that such structures typically have a high rate of shrinkage and, moreover, they are frequently exposed to high concentrations of corrosive agents. Due to the high impact associated with the repair of a damaged structure, significant interest exists for the improvement of the durability of the structural elements given that concrete restoration is expensive. The durability improving has typically resulted in the use of higher strength and lower permeability that may be more susceptible to early-age cracking, especially if they are insufficiently cured. In order to better control cracking and its adverse effects on durability, specifications have been developed to limit early-age cracking. At present, there are no standard testing methods to characterise plastic shrinkage cracking in plain and fiber reinforced concretes. Various specimen geometries have been used in the past to simulate a realistic condition of plastic shrinkage cracking.

II. LITERATURE SURVEY

Test method for evaluation of plastic shrinkage cracking in fiber reinforced cementations materials. - N. Banthia and R. Gupta (2007). The author performed a test method on a rectangular box specimen. A layer of fresh concrete is placed directly into a specimen mould which is a fully hardened substrate. This substrate enhances its roughness and imposes uniform restraint on shrinking overlay. The whole assembly is then subjected to an accelerated drying environment to induced cracking in the overlay. Plastic or early age shrinkage cracking remains a critical concern for cement-based repairs and overlays. There are several reasons for this concern, first, for a better bond, cement-based repair materials generally carry a large amount of cement which increases the overall shrinkage. Second, the substrate offers a high level of restraint, thereby increasing the possibility of developing tensile stresses sufficient to cause tensile cracking in the overlays. Reinforcement of cementations materials with fibers of various types is gaining popularity. In the context of shrinkage, fibers mitigate cracking in two ways: First, they reduce the overall shrinkage strains and lower the possibility of tensile stresses exceeding the tensile strength, and second, if the cracks do occur, fibers bridge them effectively and prevent them from growing in both longitudinal and transverse directions.

Evaluation of the early age shrinkage of fiber reinforced concrete using image analysis methods – Alida Mazzoli, Saveria Monosi, Eleonora Stella Plescia (2015). Cracking is a common problem in concrete mainly influencing and reducing durability and lifetime. Cracks allow water and other chemical agents to penetrate into concrete and get in touch with steel reinforcement leading to corrosion. The present paper focuses on early age shrinkage cracking to reduce shrinkage phenomena through the addition of synthetic fibers within cement matrix. An easy methodology based on image analysis has been developed. Cracking of concrete due to early-age shrinkage is a common problem that generally leads to several problems experienced by concrete structures, mainly influencing and reducing durability and lifetime. This is of particular relevance in the case of slabs type structures such as pavements, industrial floors, bridge decks, tunnel lining and precast elements, that show much larger surface areas compared with other kinds of structural components, such as beams and columns. In addition, the cracks allow water and other chemical agents to penetrate into concrete and get in touch with steel reinforcements, leading to reinforcement corrosion, even to breakage. Consequently, curing is the unique traditional method to avoid such problems. However, in certain applications, due to the severe environmental conditions and/or due to the actual dimensions of structural elements, curing does not fit the purpose in the prevention of cracks.

A quantitative study on the plastic shrinkage cracking in high strength hybrid fiber reinforced concrete. – A. Sivakumar, Manu Santhanam (2006). The author stated that the volume change occurs due to rapid loss of surface bleed water. This leads to shrinking of concrete. Shrinkage typically occurs in a thin concrete element with high surface area. When evaporation rate higher than bleeding rate, it can cause high tensile stresses. Precautions against early age shrinkage of concrete include preventing rapid drying of the surface of concrete and adopting good curing practice. The addition of synthetic fibers is reported to reduce drying shrinkage crack width of concrete. The addition of metallic fibers has been reported to provide adequate tensile strength to concrete in addition to controlling shrinkage crack. Moreover, the addition of non- metallic fibers such as polypropylene, glass, polyethylene, etc. is reported to reduce drying shrinkage crack widths of concrete.

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Plastic shrinkage and cracking risk of recycled aggregates concrete, - Ahmed Z. Bendimerad, Emmanuel Rozière, Ahmed Loukili. This paper presents the results of experimental research on recycled concrete at early age. The influence of recycled gravel and sand (RG and RS) and initial water saturation of RG on plastic shrinkage and cracking sensitivity was investigated. Four initial water saturations were studied: 30%, 70%, 100% and 120% of saturated surface dried (SSD). The total water was kept constant for all the mixtures, so the added water was adjusted to take into account the absorption of the aggregates during the mixing process. Other concrete mixtures were designed using 30% and 100% of recycled gravel, and 30% of recycled sand. The gravel/sand ratios were adjusted to keep the maximum paste thickness (MPT) constant. To understand the evolution of early age parameters, a timeline was established and the analyses showed correlations between the evolution of plastic shrinkage and other properties at early age. The aim of the present experimental study is to quantify the cracking sensitivity of recycled concrete at early age, based on the monitoring of plastic shrinkage and mechanical properties. The experimental approach described in this paper is applied to concrete mixtures with different initial water saturation of recycled aggregates and different rates of substitution of natural aggregates by recycled gravel and sand. The water absorption and the saturation rates of the recycled aggregates used in this study were determined by combining experimental methods.

III. METHODOLOGY

3.1 Materials used and Mix Proportion –

Ordinary Portland cement was used for the concrete mixtures. Natural sand with a specific gravity of 2.55 was used as the fine aggregate, while crushed granite of specific gravity 2.65 was used as coarse aggregate. The fibers used in the study were Polypropylene and AR-glass, obtained from manufacturers. Two trial mixtures were prepared to obtain target strength of40MPa at 28 days. Concrete was mixed by Hand mixing. The coarse aggregate, fine aggregate and cement were first mixed dry for a period of 2 -3 min. and then mixed thoroughly by the addition of water in a specified mixing proportion.

Name of fibers	Types of Fibers	Relative Density (kN/m^2)	Dia. (µm)	Tensile strength MPa	Modulus of elasticity MPa	Strain at Failure (%)
Glass fibers	AR-Glass	2.70	12-20	1500-3700	80,000	2.5-3.6
Poly-propylene Fibers	-	0.90	20-200	450-700	5,200	6-15

3.2 MATERIAL TESTING

3.2.1 TESTS ON CEMENT:

1. DETERMINE FINENESS OF CEMENT BY SIEVE ANALYSIS.

PRACTICAL SIGNIFICANCE:

In Civil Engineering construction, properties of Cement play an imp role. Fineness is an imp property of Cement. The fineness of Cement has an imp bearing on the rate of hydration and thereby on its strength. This practical will enable us to select the relevant type of cement based on hydration, amount of water required for slump and its strength in concrete.

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OBSERVATIONS AND CALCULATIONS:

TABLE NO.6. Fineness Of Cement.

SR.NO	PARTICULARS	Quantity
1.	Weight of cement (W)gm	100gm
2.	Weight of cement retained (W1) gm	7gm
3.	% weight of cement retained on sieve	7%

SAMPLE CALCULATION:
% of Weight Retained= WI/W= 7/100 = 0.07

Results:
Fineness Of Cement= 7% Which is below the IS value (10%) and hence cement is in Good Condition

Fig. Fineness of Cement

2. DETERMINE STANDARD CONSISTENCY, INITIAL AND FINAL SETTING TIMES OF OPC 53.

PRACTICAL SIGNIFICANCE:
Cement is inevitable ingredient used as pasting material in construction activity and therefore its properties such as Standard Consistency, Initial and Final Setting Time bears a significant impact on the strength of structure. After performing this practical, students will develop the competency of selecting the correct W/c ratio in concrete operations.

OBSERVATION AND CALCULATION:
1. Type and brand of cement= OPC
2. Grade of cement = 53
3. Quantity of cement sample = 500gm
4. Water temperature = 26

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TABLE NO 7. Standard Consistency of cement

SR.NO.	Weight of Cement W1	Volume of Water W2	%age of Water= (W2/W1) *100	Penetration of Plunger
	g	1g = 1ml	%	Mm
1	500	120	24	9
2	500	130	26	11
3	500	135	27	12

RESULT:
The range between the standard consistency of cement typically falls within 25% to 30% water by weight of dry cement therefore its SAFE.

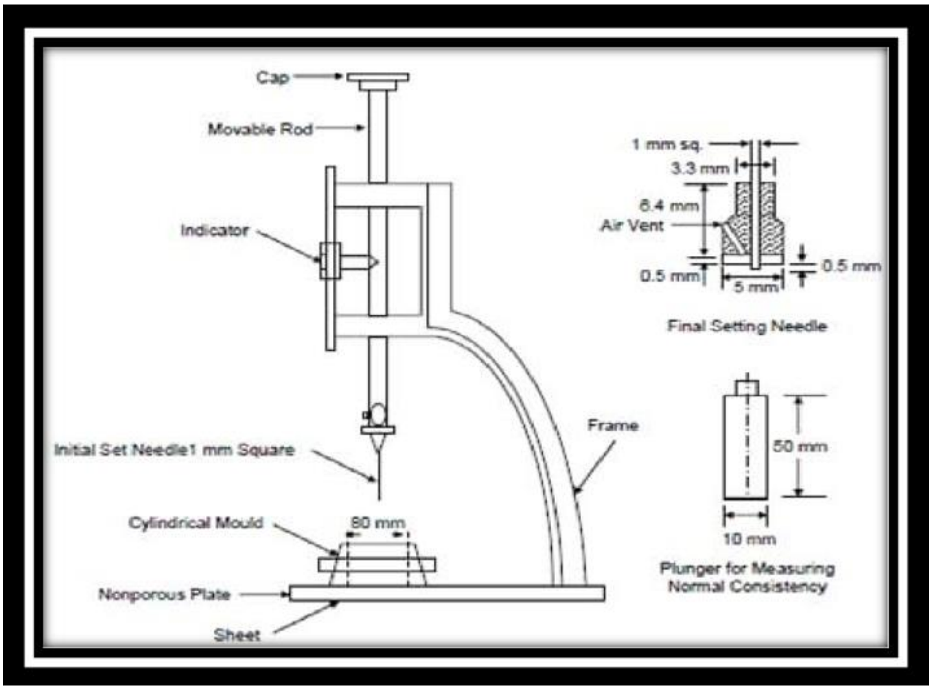

Fig. Standard Consistency of Cement

3.2.2 TEST ON SAND
Determine Bulking of Sand.
Practical Significance: While preparing concrete, quantity of aggregates must be known. Due to bulking, fine aggregate shows completely unrealistic volume. The consideration must be given to the effect of bulking in proportioning the concrete by volume. If care is not taken to the effect of bulking, in the case of volume batching, the resulting concrete may have less sand than required and concrete becomes harsh. It will also affect the yield of concrete for a given cement content.

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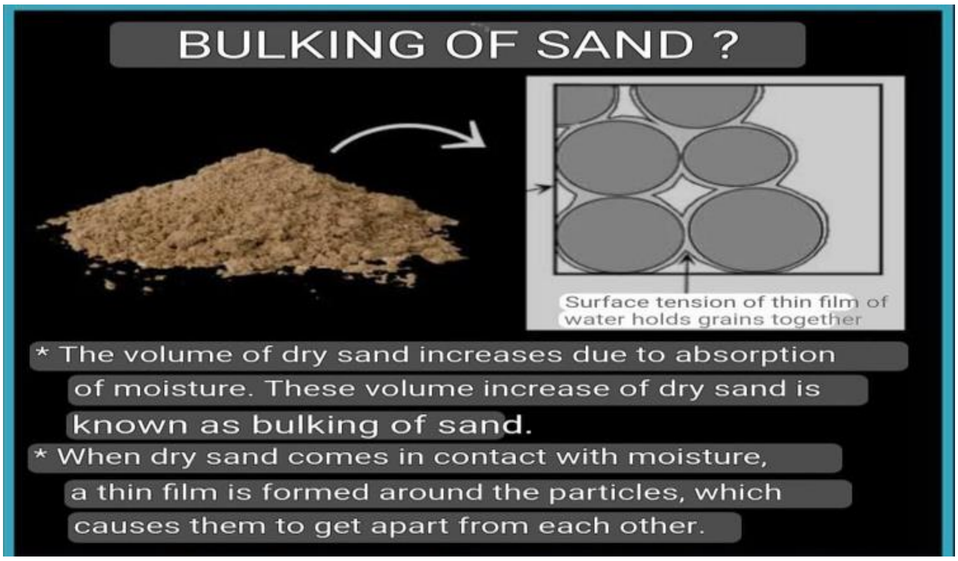
OBSERVATION SHEET

TABLE NO.8. Bulking of Sand.

S.NO.	DESCRIPTION	SAM-1	SAM-2	SAM-3
1	VOLUME OF DRY SAND	200	200	200
2	VOLUME OF SATURATED SAND	150	154	157
3	% OF BULKING OF SAND	33.33%	29.87%	27.38%

CALCULATIONS:

Average sand bulkage of above observation= (33.3+29.87+27.38)/3=30.19% The sand bulkage is between the 20-40% therefore this sand sample is OK.



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3.2.3 TEST ON FINE AGGREGATE

Determine Finess Modulus Of Fine Aggregate By Sieve Analysis.

PRACTICAL SIGNIFICANCE:

Fineness modulus is a physical property of aggregate. It is an index number which gives an idea about coarseness or fineness of aggregate. The larger the fineness modulus, the course is the aggregate. Fine aggregate affects many concrete properties, including workability and finish ability. A lower Fineness modulus results in more paste, making concrete easier to finish. For the high cement contents used in the production of high-strength concrete, coarse sand with a Fineness modulus around 3.0 produces concrete with the best workability and highest compressive strength.

CALCULATIONS:

TABLE NO.9. Finess Modulus Of Fine Aggregate.

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SIEVE SIZE	WEIGHT RETAINED	CUMULATIVE WEIGHT RETAINED	CUMULATIVE % WEIGHTRETAINED
4.75mm	0	0	0
2.36mm	100	100	10
1.18mm	250	350	35
0.6mm	350	700	70
0.3mm	200	900	90
0.15mm	100	1000	100
TOTAL			275

RESULTS:
Fineness modulus of aggregate. = (cumulative% retained)/100= (275/100) =2.75 Fine aggregates range from an FM of 2.00 to 4.00

Fig. Fineness Modulus of Fine Aggregate

3.2.4 TEST ON COARSE AGGREGATES.
DETERMINE FINESS MODULUS OF COARSE AGGREGATE BY SIEVE ANALYSIS.

Practical Significance:

The practical significance of the fineness modulus of coarse aggregate lies in its ability to assess the overall gradation and particle size distribution of the aggregate. This information is crucial in determining the workability, strength, and durability of concrete mixtures. Additionally, it helps ensure proper proportions of aggregate sizes, which can affect concrete properties such as workability, strength, and resistance to segregation and bleeding.

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OBSERVATION AND CALCULATION: Wt. of Sample = 5.00k

TABLE NO.10. Finess Modulus of Coarse Aggregate

Sieve Size	Weight Retained (kg)	Cumulative Weight Retained (kg)	Cumulative% Retained	Cumulative % Passing
80mm	0	0	0	100
40mm	0	0	0	100
20mm	1.51		30.380	69.620
10mm	3.44		99.26	0.740
4.75mm	0.037		100	0
2.36mm	0		100	0
1.18mm	0		100	0
600mic	0		100	0
300 mic	0		100	0
150 mic	0		100	0
TOTAL	**5.00**		**729.64**	

Finess of modulus = 729.64/100 = 7.30.

IV. RESULT & DISCUSSION

4.1 Compression test results
Module 1
Laboratory Test Results Module 1

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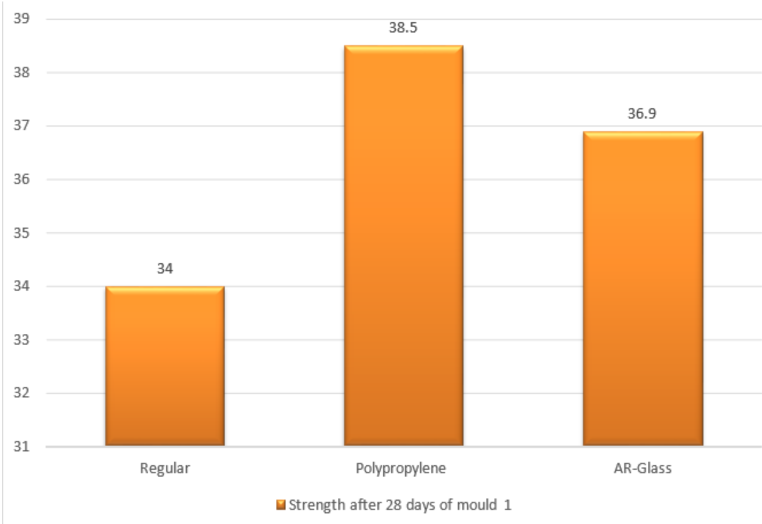

Fig. Compression Test Result Module 1

From the above module 1 graph it is observed by using polypropylene and AR- glass synthetic fibers compressive strength was increased as compare to regular concrete block.

Specimen No.	Mix	Age (Days)	Strength (MPa)
A1	Regular	28	34
A2	Polypropylene	28	38.50
A3	AR-Glass	28	36.90

Module 2
Laboratory Test Results Module 2

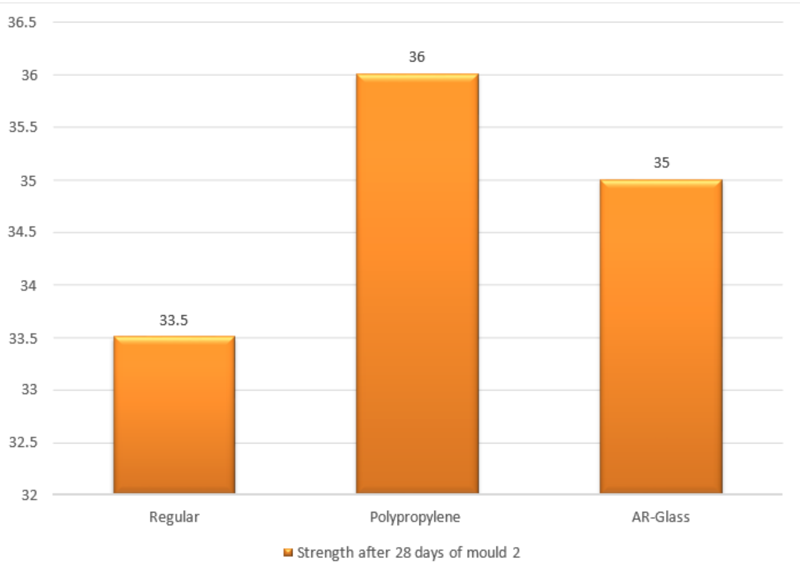

Fig. Compression Test Result Module 2

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From the above module 2 graph it is observed by using polypropylene and AR- glass synthetic fibers compressive strength was increased as compare to regular concrete block.

Specimen No.	Mix	Age (Days)	Strength (MPa)
B1	Regular	28	33.50
B2	Polypropylene	28	36
B3	AR-Glass	28	35

4.2 Crack Observations

Sr. No.	Type	Specimen 1	
		Crack Width	**Crack Length**
1	Plain Concrete	30.20 – 200.70	320.11
2	AR- Glass Fiber Reinforced	-	-
3	Polypropylene Fiber Reinforced-	-	-

Sr. No.	Type	Specimen 2	
		Crack Width	**Crack Length**
1	Plain Concrete	21.40 – 140.80	302
2	AR- Glass Fiber Reinforced	-	-
3	Polypropylene Fiber Reinforced-	-	-

- From the above crack observation, the cracking is negligible as compare to regular concrete block therefore the synthetic fibered concrete block is useful for crack reduction properties.
- The use of fibers confirmed to be very effective in the width reduction of the cracks and, even if not so significantly, in the length reduction.

V. CONCLUSION

1. The use of fibers confirmed to be very effective in the width reduction of the cracks and, even if not so significantly, in the length reduction.
2. The addition of Polypropylene and AR-Glass fibers exhibits the best performance: a certain delay in cracking formation and a wide decreasing were exhibited.
3. Results also indicate that fiber reinforcement is considerably effective in reducing shrinkage induced cracking in cementitious materials.

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4. The addition of fiber at the time of mixing of concrete, cubes become porous that means the w/c ratio has been decreased due to this type of mixing.
5. The Performance of Polypropylene fiber reinforced concrete is observed more effective than AR fiber reinforced concrete.
6. From the above module 1 graph it is observed by using polypropylene synthetic fibers compressive strength was increased by 11.69% as compare to regular concrete block.
7. From the above module 1 graph it is observed by using AR- glass synthetic fibers compressive strength was increased by 7.86% as compare to regular concrete block.
8. From the above module 2 graph it is observed by using polypropylene synthetic fibers compressive strength was increased by 6.94% as compare to regular concrete block.
9. From the above module 2 graph it is observed by using AR- glass synthetic fibers compressive strength was increased by 4.29% as compare to regular concrete block.
10. The Compressive strength of fiber reinforced concrete is greater than regular concrete.

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