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Experimental Study on plastic shrinkage of polyester fiber concrete

Jessly Rajan [1], Nitin Soni [2]

[1]*Assistant Professor, Dept of Civil Engineering, DMCE, Maharashtra, India*
[2]*PG student, Dr. A.P.J. Abdul Kalam University, Indore, India*

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Abstract - *Concrete has undoubtedly been the most used material in the field of construction. Conventional concrete is prone to develop cracks right from early age due to shrinkage which may lead to the failure during the service life. However, it has been observed that the addition of the fibers in the concrete has not only reduced the shrinkage but also increased the tensile strength of the concrete. The present experimental study emphasizes on the durability characteristics of the polyester fibers in the extreme alkaline conditions (pH 14) which otherwise was claimed to degrade in the concrete having the pH of 12. The study of the workability properties of the polyester fiber concrete helped in concluding that it is virtually difficult to use the polyester fiber in the volume fraction of 0.5%. Hence the study on unrestrained and the simple plastic shrinkage test were carried out with 0.3% volume fraction. During this test, it was observed that the plastic shrinkage in the 0.3% volume fraction of polyester fiber was considerably 88.1% less than the conventional concrete. Thus, this research not only helps in optimizing the right volume fraction of polyester fiber in concrete but also helps in proving its greatest advantage in curbing plastic shrinkage.*

Key Words: Compressive strength; Split tensile strength; Plastic shrinkage; Polyester Fiber, Volume fraction.

1. INTRODUCTION

Concrete has become an invincible material in the field of infrastructure and construction due to its strength, versatility in use, durability and affordability. But concrete has its own limitations like low tensile strength, shrinkage cracks and sudden failure due to its brittle nature. Reinforcement in the form of fibers or steel bars has been used since olden times to improve these properties in concrete. Embedding steel reinforcement has increased tensile strength of concrete, but is prone to corrosion which may be initiated due to the early age cracks in concrete. Hence fiber reinforced concrete has emerged with improved tensile strength and reduced shrinkage cracks.

Plastic shrinkage or capillary shrinkage primarily depends on the environmental conditions like temperature, humidity and wind velocity. According to a report submitted by Boshoff plastic shrinkage is the loss of pore water from the concrete due to evaporation resulting in a build-up of negative capillary pressure which leads to early age cracking [1]. The very early formation of capillary tension and subsequent shrinkage appears as a skin formation at the top surface, which typically occurs in systems where the permeability is low (e.g. low w/b) relative to the evaporation rate. This may be "the driving force" for cracking in the liquid phase which may be considered as the critical stage where transportation of the deleterious material is observed to be high [2]. So, the control of plastic shrinkage is essential in order to make the concrete durable. During early days unrestrained plastic shrinkage was observed using LVDT's in the concrete specimens. The volume change is volumetric deformation, but from a practical point of view it is convenient to consider linear deformations, commonly referred to as "plastic settlement" and "plastic shrinkage". Chengqing mentioned that continuous efforts are in process in various research laboratories to find an authentic method to measure plastic shrinkage; linear beam three anchors bar restraint method was one of the oldest methods [3]. There are two ways in which shrinkage can be measured in a concrete; direct method and indirect method. However, direct methods involve in finding out the strain and potential to cracking. But not much research has been done in this method as always, the main focus of the shrinkage was the cracks developed in them. There are many indirect methods to find plastic shrinkage like finding out the rate of evaporation and measuring or quantifying the plastic shrinkage cracks. Many remedies have been suggested to reduce this early age shrinkage and one such was addition of the fibers to the concrete. Addition of fibers especially synthetic fibers in the concrete mix was found to be one of the most effective ways to make concrete almost free of plastic shrinkage. Fiber matrix in the concrete create an internal restraint against plastic shrinkage and also avoids the loss of water from the pores [4]. Aly, Sanjayan and Collins however introduced a new approach to the restrained method which is a direct method to find plastic shrinkage. They used shrinkage test rigs which were restrained at one end with a grip and the other end was connected to a LVDT. The main purpose of this test was to measure both free shrinkage strains and elastic recovery strain. It was observed that 0.5% volume fraction of fiber helped in reducing the plastic shrinkage by 26% as compared to the normal concrete [5]. Fatima used a simple direct technique to measure unrestrained strain caused due to plastic shrinkage with the help of two thumb tacks and a digital caliper for duration of 24 to 96 hours [6]. But the limitation of the results was it did not consider the main initial phase change since plastic shrinkage is predominant during the first few hours after the casting.

Ma, Tan and Wu studied the cracking patterns of polypropylene fiber added concrete on a thin restrained plate specimen. From their observations shrinkage cracking of the concrete mainly depends on the volume fraction of the polypropylene fibers. Fibers can be added in concrete either in low volume fraction (between 0.1% – 0.5%) to bridge the cracks and to reduce shrinkage or in high volume fraction (between 0.5% to 1%) to delay plastic shrinkage cracking and increase tensile strength [7]. Plastic shrinkage cracks in polypropylene fiber concrete were quantified by digital image processing, which was vividly explained by Qi, Weiss and Olek. Siva kumar and Manu Santhanam used image processing technique in high strength hybrid concrete where they observed that plastic shrinkage cracks and its crack area can be reduced by 98.80% and 99.87% by the addition of polypropylene and polyester fibers in concrete compared to concrete without fibers [8, 9]. Even though polyester fibers help in reducing the shrinkage cracks many researchers claim that polyester cannot withstand alkaline conditions. It has also been stated that polyester fibers are susceptible to slow degradation in the alkaline conditions of concrete. However, there are no significant research results regarding the degradation of polyester fibers in the concrete which has a pH of 12 to 13[10]. Hence there is a need to do some preliminary tests on the polyester fibers to ensure its durability in the concrete.

Meanwhile it is still a challenge to measure the early-age, plastic state, shrinkage of concrete and no standardized method exists to evaluate plastic shrinkage in concrete. This study is an attempt at finding the plastic shrinkage mechanism in the concrete during its initial dominant phase using a simple and direct method. The results from the study would aim at calculating free strains in the conventional concrete and fiber concrete. This also aims at creating easy yet portable method to assess plastic shrinkage as mechanism instead of quantifying it.

2. 2. MATERIALS AND EXPERIMENTAL METHODS

2.1. Materials used

Ordinary Portland Cement (OPC) of good quality and 53 grade was used as a binder. Fine aggregate consists of river sand which had a fineness modulus of 2.64 and specific gravity of 2.7. The size of the coarse aggregate used in this study was 10mm. Since synthetic fibers are microfilament in nature it was recommended to use 10 mm aggregates. During the entire study, water–cement ratio of 0.45 was maintained. The fiber used is Recron 3s polyester fiber which is monofilament in nature and was used in a volume fraction of 0.1%, 0.3% and 0.5%. Since super plasticizers are not used, the volume fraction of the polyester fibers was restricted to 0.5%.

2.2. Mixture proportioning and placing

Trial mixes were made with a water cement ratio of 0.45 to observe the strength variation of polyester fiber in various volume fractions when added in concrete after 28 days of curing. The concrete was mixed in the proportion 1:2.1:2.3:0.45 for plastic shrinkage tests with the target grade of concrete as M25.IS 10262:2009was used for conventional concrete mix design; the detailed mix proportions used in this study are given in the table 1[11]. The properties of the Recron 3s polyester fibers are given in the table 2[12]. The fine aggregates and the coarse aggregates were first dry mixed for approximately 2 minutes. Later it was mixed with the fibers that were randomly dispersed throughout the mixture and next to it cement was added and mixed thoroughly. To this mixture, water was added slowly and the concrete-fiber was mixed for approximately 4 minutes. After the thorough mixing, slump and flow ability tests were done to understand the workability of the fiber concrete. The concrete was then placed in the moulds and vibrated using the table vibrator for even compaction and smooth finish.

1.3. Experimental set up for workability tests

Slump test is considered as one of the most convenient tests in checking the workability of concrete. This test is also called as the control test to check the consistency of concrete [13]. The second test was the Vee Bee consistometer that helped in understanding the consistency of the concrete. Along with this test the V box test was conducted where the concrete would be filled in the V box and the trap door would be opened below. The time taken for the complete concrete to flow out would account for its flow ability thereby its workability [14].

2.4. Strength test methodology

Universal testing machine was used to test the strength of the cubes with and without fibers. The concrete cubes were loaded at a rate of 10mm/min gradually. The compressive strength of the concrete cubes (100mm x100mm x100 mm) was tested after 28 days of curing.

Table – 1: Trail mix - Quantities of materials in mix design

Cement (Kg/m^3)	Fine Aggregate (Kg/m^3)	Coarse Aggregate (Kg/m^3)	Water (Kg/m^3)	W/C ratio
422	897	966	190	0.45

Table - 2: Properties of polyester fibers

Dia meter (mm)	Length (mm)	Specific Gravity	Tensile Strength (MPa)	Elastic Modulus (GPa)	Aspect Ratio (l/d)
0.05	12	1.35	850-950	15	240

2.5. Experimental set-up for plastic shrinkage test

The plastic shrinkage setup used in this study mainly focused on achieving unrestrained shrinkage. The main objective of the study is to introduce a simple technique to measure the linear deformation of the concrete. However, unrestrained plastic shrinkage often depends on the type of the specimen chosen. Hence, the plastic shrinkage mould was chosen to be a slab since larger the area exposed to the environment, the larger would be the shrinkage. Thus, the plastic shrinkage mould was of the size (650mmx350mmx15) which was approximately of the same size as used by Siva Kumar and Manu Santhanam [9]. It was fabricated using plywood base and wooden walls. Plastic covers were laid beneath the concrete so that there was minimal loss of moisture. The slabs were then placed in the ambient conditions with two thumb tacks at a distance of 300mm from each other. Figure 1 below shows the experiment set up for plastic shrinkage.

Fig - 1. Experimental set up for plastic shrinkage test

The change in the distance between the two thumbtacks due to the plastic shrinkage would be measured using a digital calliper at an interval of 5 minutes. This time interval was kept constant till a constant horizontal deformation was observed for a subsequent 3 readings, after which the readings were taken at an interval of 15 minutes up to 240 minutes. The change in the length of the distance between the thumb tacks as noted by the calliper was taken as the percentage of the increases or decrease in the linear dimension is given below.

$$\Delta L = (L' - L)/L \quad (1)$$

Where ΔL = length change of specimen at any age in %

L = the gauge length (initial Length) and L' = reading of the specimen at known time interval

3. Results and discussions

3.1. Strength test on polyester fiber concrete

The claims of polyester fibers vulnerable in concrete cannot be avoided; hence a test was conducted on the fibers to understand the effect of alkalinity (pH 12 and more) on the efficiency of the fibers. This test involves adding 0.3% volume fraction of polyester fibers in 1N solution of sodium hydroxide (NaOH) having a pH of 14 for 4 days. Later these fibers were air dried and added in the concrete and test for the compressive strength after 7 days. The comparative results of the NaOH treated fiber concrete cubes to that of the normal 0.3% polyester fiber concrete after 7 days is given in the table 3.

Table - 3: Results of the NaOH subjected polyester concrete

Sample Name	Compressive Strength (7 Days and w/c 0.45) (MPa)	
	With NaOH immersed polyester fibers	Virgin polyester fibers
D1	18.2	17.5
D2	18.8	18
D3	18.6	17.8

3.2. Workability test results

Table 4 shows the results obtained by the standard slump cone test on concrete. Further the Vee Bee consistometer also helped in concluding the optimum fiber content in terms of workability characteristics. Table 5 shows the results from the Vee Bee consistometer results which helped understanding the workability of the fiber concrete. However, when the V- box test was conducted on the polyester fiber concrete, it was observed that they were obstructed by the small opening. Hence it is difficult to conduct the V box test on the fiber concrete. It was observed from the results the optimum volume fraction of polyester fiber is 0.3%.

Table - 4: Slump test result

Sr. No.	Volume fraction (%)	Slump (mm) 0.5 w/c	Slump (mm) 0.45 w/c
1.	0%	40	50
2.	0.1%	30	38
3.	0.3%	20	25
4.	0.5%	0	0

Table - 5: Vee Bee consistometer test result

Sr. No.	Volume fraction (%)	Vee Bee Time (secs) 0.5 w/c	Vee Bee Time (secs) 0.45 w/c
1.	0%	9	14
2.	0.1%	15	24
3.	0.3%	22.2	31
4.	0.5%	35	43.5

Hence it is difficult to conduct the V box test on the fiber concrete. It was observed from the results the optimum volume fraction of polyester fiber is 0.3%.

3.4 Preliminary plastic shrinkage test

A vague test was done to measure plastic shrinkage in the polyester fiber concrete to check the deformation after 24 hours. However, it is theoretically claimed that depending upon the type of cement and its setting time the duration of plastic shrinkage will change [1]. But on the whole the mechanism of plastic shrinkage is assumed to be predominant during the first three to four hours after the casting. This test was done with 0%, 0.1%, 0.3% and 0.5% volume fraction of polyester fiber concrete cubes as shown in the figure 2.

Fig 2. Plastic shrinkage cubes

The results of the test are presented in table 6. It has been observed from table 6 that when the fibers are added in a volume fraction of 0.1% - 0.3% it reduces the plastic shrinkage in the concrete considerable which has been mentioned in report by the American Concrete Institute [16]. ACI hypothetically claimed that synthetic fibers when added in the volume fraction 0.1 – 0.3% helps in reducing the plastic shrinkage to the maximum. It was observed that at 0.5% volume fraction the fibers had the tendency to ball which made it difficult to work with. This balling phenomenon would have affected its ability to reduce plastic shrinkage to a greater extent due to uneven dispersion of fibers throughout the cement paste. Hence considering the strength and preliminary plastic shrinkage test, it is suggested to use polyester fiber in 0.3% volume fraction.

Table - 6: Plastic shrinkage test for various volume fractions of polyester fibers in the concrete

Volume Fraction	Control Specimen	0.1 %	0.3%	0.5%
L (mm)	46.32	48.38	48.06	46.88
ΔL (%)	5.47	1.26	2	4.32

3.4 Unrestrained Plastic shrinkage test

The unrestrained plastic shrinkage test was done with the 0% and 0.3% volume fraction of the polyester fiber concrete specimen. Using a digital calliper, with a precision of 0.01 mm (10 micrometres), or one thousandth of an inch, the change in the length of the thumb tacks was measured. The readings were taken at an interval of 5 minutes for first 4 hours. The results of the unrestrained plastic shrinkage test to find the strain is given in the table 7.

Table 7: Unrestrained plastic shrinkage test results

Sr No	Time (mins)	Control Specimen		0.3% polyester Fiber Concrete	
		Change in length (mm)	Strain	Change in length (mm)	Strain
1	5	300	0	300	0
2	10	300	0	300	0
3	15	299.97	0.012	300	0
4	20	300	0.047	300	0.
5	25	299.8	0	299.99	0.003
6	30	299.68	0.11	299.98	0.007
7	35	299.54	0.16	299.97	0.01
8	40	299.37	0.21	299.95	0.02
9	45	299.26	0.25	299.94	0.02
10	50	299.06	0.31	299.9	0.03
11	55	298.94	0.35	299.87	0.04
12	60	298.67	0.44	299.84	0.05
13	65	298.44	0.52	299.8	0.07
14	70	298.23	0.59	299.78	0.07
15	75	297.90	0.70	299.74	0.09
16	80	297.62	0.79	299.71	0.10
17	85	297.34	0.89	299.65	0.12
18	90	297	1	299.62	0.13
19	95	296.71	1.10	299.61	0.13
20	100	296.39	1.20	299.59	0.14
21	105	296.06	1.32	299.56	0.15
22	110	295.79	1.40	299.53	0.16
23	115	295.55	1.49	299.52	0.16
24	120	295.38	1.54	299.5	0.17
25	125	295.30	1.57	299.5	0.17
26	130	295.24	1.59	299.49	0.17

27	135	295.23	1.59	299.48	0.17
28	140	295.19	1.60	299.48	0.17
29	160	295.18	1.61	299.46	0.18
30	180	295.14	1.62	299.44	0.19
31	210	295.12	1.63	299.43	0.19
32	240	295.12	1.6	299.43	0.19

It was observed that after 3 hours, significant change in the linear deformation was not observed. Hence the reading was only taken up to 4 hours. The graph in Figure 3 gives an illustrative idea of the strain in the normal concrete versus the time taken. It is a s shaped curve which shows that plastic shrinkage almost ceases after 3 hours after which the horizontal deformation remains constant and ultimately stops after 48 hours.

The graph in Figure 4 gives an illustrative idea of the strain in the 0.3% polyester fiber concrete versus the time taken to measure the readings. It is a curve which shows that plastic shrinkage starts remaining constant after 2 hours after which the horizontal deformation ceases after 48 hours.

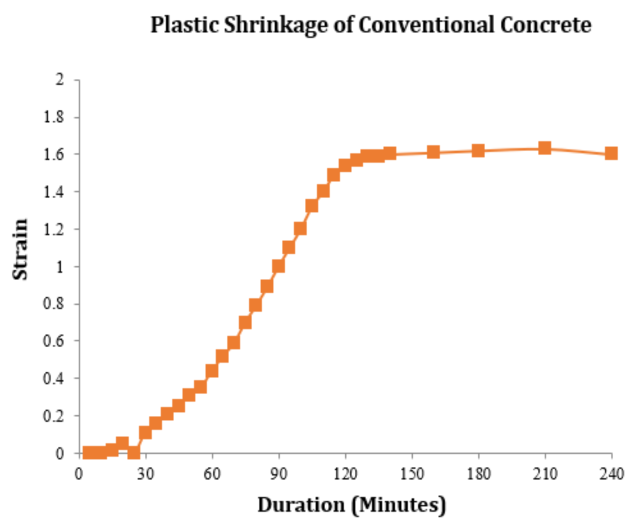

Chart – 1: Plastic shrinkage of normal concrete

S curve helps in grasping the importance of monitoring the progress of the strain in the concrete with the passage of time in minutes. It can be observed that as soon the casting is over, the strain in the concrete starts slowly but as the time gets organised the strain starts increasing. Later at a certain time interval, the rate of strain becomes constant and then decreases considerably. A standard S curve is a reliable and simple curve to observe strain relative to the time and also with some further mathematical knowledge could help in obtaining a derived equation using the least square method which could be useful to relate strain with respect to the time.

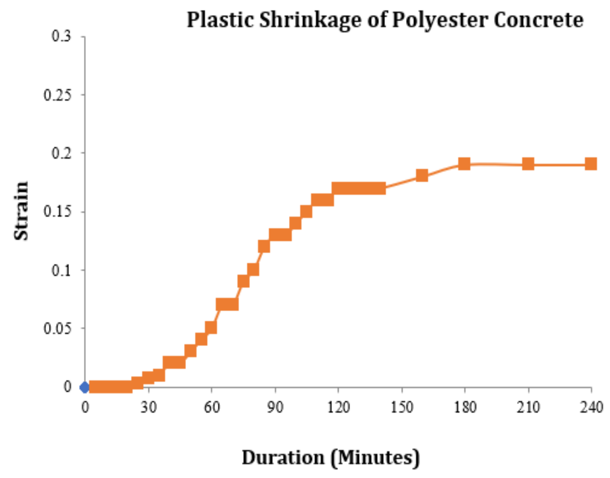

Chart – 2: Plastic shrinkage of Polyester Fiber concrete

From the table it is evident that after 4 hours, the reduction in the plastic shrinkage of polyester fiber concrete when compared to the normal concrete was 88.1%. This shows huge improvement in the reduction of shrinkage and will later on help in increasing the durability of the concrete.

4. Conclusions

This paper dealt with the study of workability, strength and plastic shrinkage properties of concrete when the polyester fibers are added to the concrete. The following points can be concluded from the above study.

1. The properties of the polyester fiber in terms of imparting strength to the concrete were not affected after subjecting it to an extreme alkalinity of 14. The strength parameter was not affected which helped in the observation that polyester fiber may withstand extreme alkaline condition which needs long-term testing.

2. The workability of concrete mainly depends on the volume fraction of polyester fibers. It can be concluded that as the volume fraction reaches the value greater than 0.5% in case of synthetic fibers the concrete shows significant reduction in the workability, recommending use of super plasticizer.

3. No significant change was observed in the compressive strength of 0.1% volume fraction of polyester fiber in concrete hence it was avoided from the further study in this paper even though it improves plastic shrinkage.

4. It was observed that addition of polyester fibers not only helps in reducing the plastic shrinkage but also helps in reducing the complete time for the mechanism of plastic shrinkage.

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