A Study on Durability Parameters of Ferrocement

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Abstract. Ferrocement is formed of a thin layer of cement mortar that has been strengthened with multiple layers of wire mesh with a diameter of between 0.5 mm to 1 mm. To evaluate the durability criteria for the specimen, a series of cubes and cylinders were cast in this experiment using a mortar mix at a ratio of 1:3 and a water-cement ratio of 0.40 was selected. In this study, the ability of the ferrocement to endure water penetration, sorptivity, and resistance to sulphates were examined. The curing period was chosen to be 28, 56, and 90 days, respectively, in order to track changes in the outcome and investigate the effects of the various curing times on the ferrocement. In order to measure the rate of water absorption by capillarity rise, Sorptivity test was conducted in accordance with ASTM C1585-04. The average absorption rate at day 9 was found to be 84.87 x 10^{-7} mm/$s^{1/2}$, 93.78 x10^{-7}mm/$s^{1/2}$, and 96.34x10^{-7} mm/$s^{1/2}$ for 28, 56, and 90 days of curing respectively. The Sulphate attack test was conducted as per ASTM C 1012-2010. The mass loss was observed to be 0.28%, 0.32%, and 0.33% of the original mass, while the strength loss was 6.96%, 6.44%, and 6.33% for the curing periods of 28, 56, and 90 days respectively. According to DIN-1048, part 5, Water permeability test was conducted. Water was pressured with 500 KPa on the specimen to determine its water penetration. The average water penetration of the specimen was found to be 22.33 mm, 18.67 mm, and 14.33 mm for the corresponding curing periods of 28, 56, and 90 days. The results were within the range twaswere specified in the respective code, and they were judged acceptable in terms of the ferrocement's durability guidelines.

Keywords. Ferrocement, Durability, Reinforcement, Mesh, Corrosion, Compressive Strength, Sulphate attack test, Sorpivity test, Water penetration test.

1 Introduction

Ferrocement is a type of reinforced concrete that is made by embedding layers of small-diameter wire mesh or chicken wire in a mortar mix. Typically, Portland cement, water, and aggregate are combined to make mortar to create the matrix for ferrocement. It is a very adaptable type of reinforced concrete. For unique purposes, a mineral admixture may be mixed with the cement [1]. Joseph Louis Lambot advocated the use of ferrocement as a composite building material in 1848[15]. Due to its adaptability, environmental friendliness, accessibility of raw materials, simplicity of transportation, and lack of special construction requirements, it can be built using a variety of techniques. Due to the closely spaced internal reinforcements, ferrocement provides better qualities for controlling fractures[2]. Closely spaced steel wire mesh (SWM) or tiny diameter bars were used to define it as the principal reinforcement, while cementitious material served as the matrix. This construction material is often used to build thin, lightweight structures that are strong and durable, such as boats, roofs, water tanks, and even housing. A ferrocement compound's capacity to withstand cracking, weathering, chemical attack, abrasion, and other forms of deterioration may be considered a measure of its durability[6]. Ferrocement was first developed in the mid-20th century as a low-cost and lightweight building material that could be easily moulded into complex shapes. It has many advantages over traditional concrete, such as its high strength-to-weight ratio, flexibility, and resistance to cracking and corrosion. Like other building materials, the success of ferrocement depends on its longevity. The properties of the ferrocement can also be altered to some extent with the help of fibres, fly ash etc. thus giving different properties to the ferrocement[15]. In order to prevent corrosion of the reinforcement in ferrocement, it is typically necessary to utilise galvanised wire mesh to increase cover or dense mortar with additives like fly ash, silica fumes and blast furnace slag. Additionally, it can be made using locally available materials and can be constructed by unskilled labour with minimal equipment. The ferrocement construction process involves building a frame or skeleton using metal rods or tubes, and then applying several layers of mesh and cement mortar to create a thin, strong shell. The resulting structure can be finished with a variety of materials, such as plaster, paint, or tiles. Ferrocement is a versatile material that has been used in a variety of applications, including in earthquake-resistant structures, bridge decks, and even sculptures. Ferrocement has superior resilience to thermally induced stresses than other options like cellular concrete and hollow block, which can be utilised for secondary roofing that is required to provide heat insulation in structures[10]. Ferrocement can also be integrated with polymers and geo polymers to further increase the mechanical properties of the ferrocement[31]The strength of the ferrocement components has decreased due to the inefficiency of these suggested approaches over time. ACI-549R strongly advised conducting research to find long-term anti-corrosion methods to prevent water and salt penetration, which could cause the reinforcing wire mesh to corrode[12]. The ferrocement can be moulded and designed according to any specification with the help of systems which help in giving different properties to the ferrocement.[20]

1.1 Aim and objectives

The study aims to check the experimental investigation of the durability of the ferrocement with the following experiment:-

- To understand the durability of the ferrocement.
- To determine the water absorption rate through capillarity rise in the concrete.
- To determine the resistance to sulphates on the concrete.
- To determine the resistance of water penetration on the concrete.

2. Methodology

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Ferrocement, which may be utilised in a variety of settings and which contains a fine wire mesh inserted in a cement panel, can change the cement's varied properties. This experiment investigated the ferrocement's capacity to survive various durability factors. Three different sets of curing times—28 days, 56 days, and 90 days—were chosen. The different results for the material and for each test were noted down in order to observe the distinct changes. The sulphate attack test, in which the specimen was immersed in the sulphate solution for 28 days following the curing time, was performed on the ferrocement. The changes in mass loss and strength loss were then calculated. The second test was the Sorptivit test, which measured and recorded the rate of water absorption in the ferro-cement specimen by capillarity rise. The cube's water penetration depth was measured during the final test, which was followed by a longitudinal cube split to verify the results.

2.1 Materials

In this investigation, Ordinary Portland Cement (OPC) that is readily available and complies with BIS 1489-1991 was used locally accessible, Zone 2-compliant, well-dried sand

The mortar specimens were prepared with potable water. Inhibitor-admixed mortar and regular cement mortar with a 1:3 cement-to-sand mix ratio were the types of mortar mixes employed in this investigation. In the experiment, 2% of the cement's weight of Perma Plast superplasticizer was added. The water-to-cement ratio of the mortar mixtures was taken as 0.4. It was discovered that the inhibitor helped the mixture perform better.

The materials used to cast the ferrocement cubes were as follows:

Cement- The cubes were made using OPC 53, a common grade of Portland cement. Table 1 contains a list of the typical Portland cement's properties.

Table 1. Cement Properties

Properties	Values
Specific Gravity	3.18
Standard consistency	36%
Initial Setting time	42 mins
Compressive Strength	52.69 N/mm2

Sand- Sand that met Zone 2 Fine requirements and was readily accessible locally was used. The features of sand are listed in Table 2.

Table 2. Sand Properties

Specifications	Values
Specific Gravity	3.18
Fineness modulus	2.36mm
Zone	II

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Admixture: The mortar was made self-compacting by adding a superplasticizer called Perma Plast Super PS-34, which accounted for 2% of the cement's total volume.

Water: Fresh clean, potable tap water was used to mix and cure the specimens. Water was free from organic matter, silt, oil, and acidic materials.

Three cubes were cast for testing for the compressive strength of the ferrocement and the Table 3 indicates the strength of concrete after 3 days.

Table 3. Compressive strength of mortar at 3 days

Size	Load at failure (kN)	Compressive Strength (N/mm2)	Average compressive strength (N/mm2)
70x70	64.72	13.21	
70x70	60.43	12.33	13.69
70x70	76.12	15.53	

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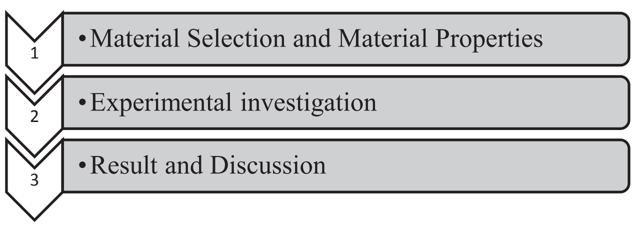

Fig. 1. Flowchart of Methodology.

2. Experimental Investigation

2.1 Sulphate Attack Test

The experiment involves casting concrete cube specimens of various mixtures with a size of 150 mm and water curing them for 28,56 and 90 days. The testing was done according to ASTM C 1012-2010. After curing, the specimens are removed from the curing tank and allowed to dry. The weights of the concrete cube specimens are then taken. Next, the sulphate attack test is conducted on the concrete cube specimens. This is done by immersing the cubes in sulphate water for 28 days, with the concentration of sulphate water being maintained throughout the period. Specifically, 5% of magnesium sulphate ($MgSO_4$) by weight of water is added to the water. After 28 days of immersion, the concrete cubes are taken out of the sulphate water. Compressive strength is then evaluated for the specimens. When concrete cubes are submerged in sulphate water, the percentage weight loss of the specimen and the percentage compressive strength loss are calculated to measure the concrete's resistance to sulphate assault. In figure no 6 the cubes after immersion in sulphates can be seen. These results will indicate the susceptibility of the concrete to sulphate attack and the extent of damage caused by the sulphate attack.

Fig. 2. specimens used for the sulphate attack test

2.2 Sorptivity test

In this test, a sample that measures 100 mm in diameter and 50 mm in height is put to the test for water absorption using the capillary rise and ASTM C1585-04 standards. In this test, the sample is first allowed to cure for 28,56 and 90 days, after which one side of it is painted with epoxy to prevent water from being absorbed from the side of the atmosphere, and it is then maintained in an oven for three days at a temperature of 50+-2°C and an RH of 80+-3%. The sample is placed in a container with supports to the bottom as it is raised and the bottom part is exposed to the surface of water as which can be seen in figure 2. The sample should be submerged, and the water level should be maintained at the bottom 2-5 mm of the sample. Before beginning the test, the sample mass should be noted to the nearest 0.01 to have an accurate measure of the absorption of water done by the sample. The sample should then be weighed at intervals of 0 seconds, 30 seconds, 60 seconds, 5 minutes, 10 minutes, 20 minutes, 30 minutes, 60 minutes, and then at a variation of 60 minutes until 6 hours. The weight should then be examined every 24 hours from the initial weight measurement or 0 seconds until 9 days with a buffer time of +- 2 hours. This test allows us to determine the specimen's water absorption capacity.

Fig. 3. Specimens used for the acid attack test

2.3 Water Penetration Test

The test that is being discussed is a permeability test done on concrete samples to figure out how far water under pressure can penetrate. The test is conducted using concrete cubes that are 28,56 and 90 days old and have dimensions of 150x150x150 mm in accordance with German standard DIN 1048- Part5. The samples are put together for the test in a test cell that can accommodate up to three cubes at once. The next step is to pressurise the cell with water for 72 hours at a pressure of 500 KPa (5 bar). e test that is being discussed is a permeability test done on concrete samples to figure out how far water under pressure can penetrate. The test is conducted using concrete cubes that are 28 days old and have dimensions of 150x150x150 mm in accordance with German standard DIN 1048-Part 5. The samples are put together for the test in a test cell that can accommodate up to three cubes at once. The next step is to pressurise the cell with water for 72 hours at a pressure of 500 KPa (5 bar). The test setup can be seen in figure 4.

The samples are divided perpendicular to the injected face after the test, and the depth of penetration is assessed visually. This test can help determine how long concrete structures will last because prolonged water infiltration can cause structural deterioration.

Fig. 4. Test Setup Used for The Water Penetration Test

3. RESULT AND DISCUSSION

3.1 Sulphate Attack test

Sulphate ions interact chemically with the constituents of hardened concrete in a series of processes known as sulphate attack. As a result of these processes, concrete structures may crack, spall, or lose strength. Tests are conducted in accordance with ASTM C1012-2010. The following averages for concrete's loss of mass and strength were discovered:

Table 4. Loss of Weight after Immersion in Sulphate and 28 Days of Curing

Weight of cube before immersion	Weight of cube after immersion in a solution	Weight Loss in Percentage	Weight Gain in Percentage
8.056	8.032	0.3%	
8.073	8.053	0.25%	0.28%
8.115	8.09	0.31	

Table 5. Loss of Weight after Immersion in Sulphate And 56 Days of Curing

Weight of cube before immersion	Weight of cube after immersion in a solution	Weight Loss in Percentage	Weight Gain in Percentage
8.103	8.077	0.32%	
8.094	8.07	0.30%	0.32%
8.052	8.025	0.34%	

Table 6. Loss of Weight after Immersion in Sulphate and 90 Days of Curing

Weight of cube before immersion	Weight of cube after immersion in a solution	Weight Loss in Percentage	Weight Gain in Percentage
8.114	8.092	0.27%	
8.048	8.019	0.36%	0.33%
8.068	8.039	0.36%	

Table 7. Loss of Strength after Immersion in Sulphate and 28 Days of Curing

Strength of cube before immersion (N/mm^2)	Strength of cube after immersion (N/mm^2)	Strength Loss in Percentage	Average Value (N/mm^2)
34.5	32.4	6.09%	
34.5	31.8	7.83%	6.96%
34.5	32.1	6.96%	

Table 8. Loss of Strength after Immersion in Sulphate and 56 Days of Curing

Strength of cube before immersion (N/mm^2)	Strength of cube after immersion (N/mm^2)	Strength Loss in Percentage	Average Value (N/mm^2)
35.2	32.7	7.10%	
35.2	33.2	5.68%	6.44%
35.2	32.9	6.53%	

Table 9. Loss of Strength after Immersion in Sulphate and 90 Days of Curing

Strength of cube before immersion (N/mm^2)	Strength of cube after immersion (N/mm^2)	Strength Loss in Percentage	Average Value (N/mm^2)
35.8	33.5	6.42%	
35.8	33.8	5.59%	6.33%
35.8	33.3	6.98%	

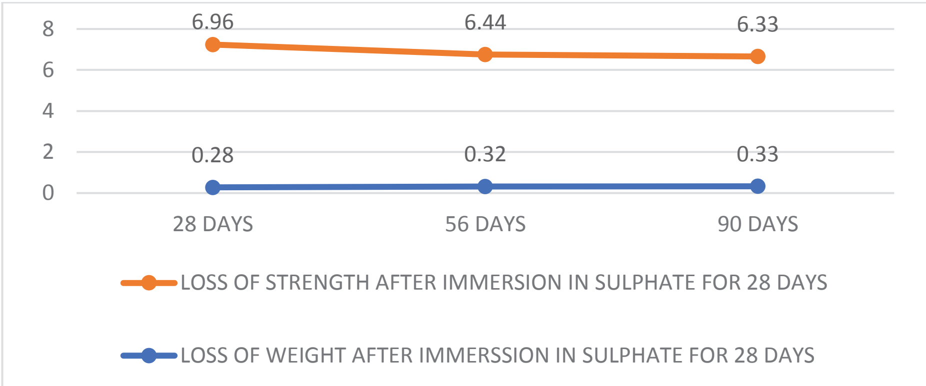

Fig. 5. Graph for sulphate attack test

3.2 Sorpivity Test

In this test, the sample's ability to absorb water through capillarity rise is evaluated for various time periods, ranging from the moment of initial weight until the ninth day of capillarity on the sample, after curing it for 28, 56, and 90 days and then drying it in an oven for three days. The result of the sample for the 9th day was noted. The result of the 28 days of curing for three samples was found to be 89.12 x10^{-7}mm/s$^{1/2}$, 68.75 x10^{-7}mm/s$^{1/2}$, 96.76 x10^{-7}mm/s$^{1/2}$ as shown in figure 6 in the graphical method. As for the curing period of 56 days, it was observed that the value of absorption were 92.94 x10^{-7}mm/s$^{1/2}$, 98.03 x10^{-7}mm/s$^{1/2}$, 90.4 x10^{-7}mm/s$^{1/2}$ as shown in figure 7 in graphical method. And figure no 8 depicts the sorptivity rate for 90 days of cured sample and the results were found to be 92.94 x10^{-7}mm/s$^{1/2}$, 95.59 x10^{-7}mm/s$^{1/2}$, and 100.5 x10^{-7}mm/s$^{1/2}$.

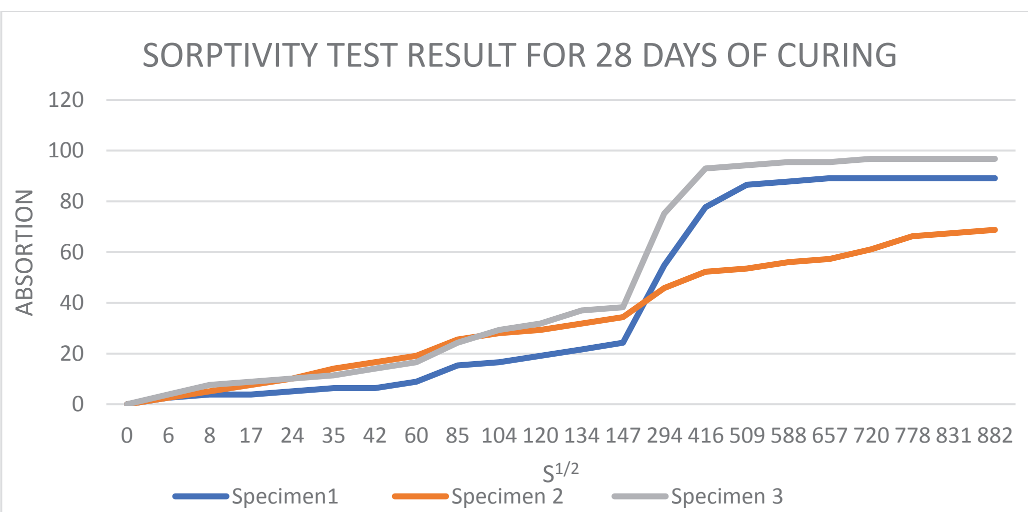

Fig. 6. Graph Sorptivity Test 56 Days Curing

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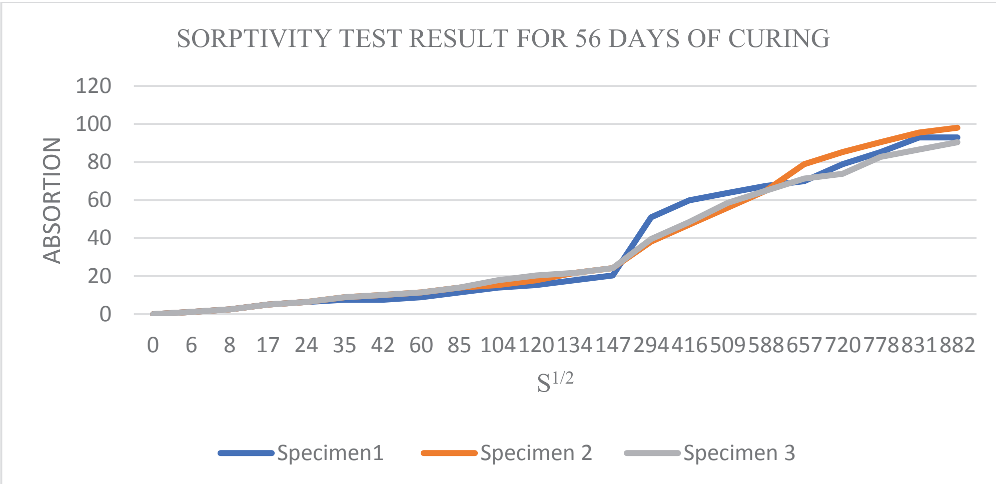

Fig. 7. Graph Sorptivity Test 56 Days Curing

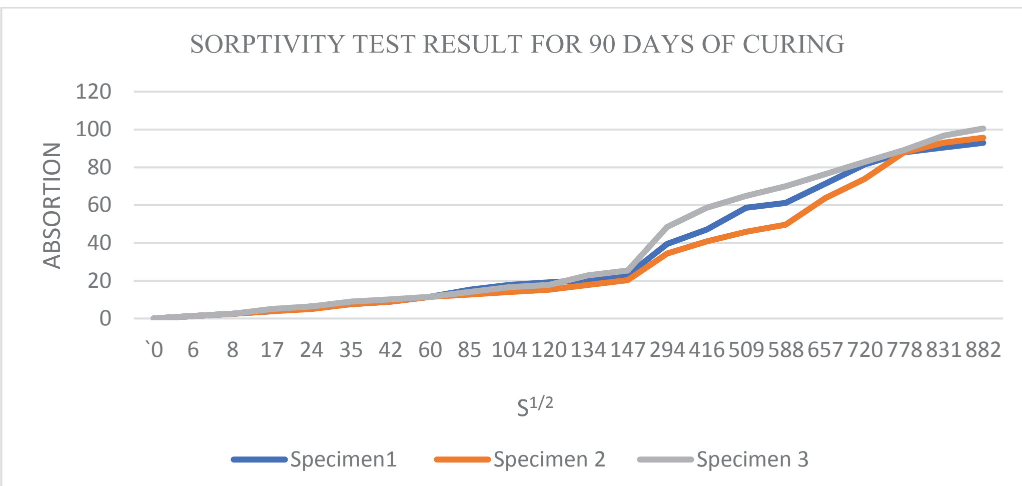

Fig. 8. Graph Sorptivity Test 90 Days Curing

3.3 Water penetration test

The specimen's resistance to water under pressure is examined in this test. The test specimens must withstand a water pressure of 5 Kpa for three days, and according to DIN 1048, the depth of penetration must be determined by dividing the specimen down the middle and measuring the angle of penetration. The testing revealed that the specimen had the following depth of penetration.

Table 13. Depth of Penetration for 28 Days of Curing

No of cubes for 28 days	Depth of penetration (mm)	Avg. Depth of penetration (mm)
1	22	
2	21	22.33
3	24	

Table 14. Depth of Penetration for 56 Days of Curing

No of cubes for 28 days	Depth of penetration (mm)	Avg. Depth of penetration (mm)
1	20	
2	19	18.67
3	17	

Table 15. Depth of Penetration for 90 Days Curing

No of cubes for 28 days	Depth of penetration (mm)	Avg. Depth of penetration (mm)
1	13	
2	14	14.33
3	16	

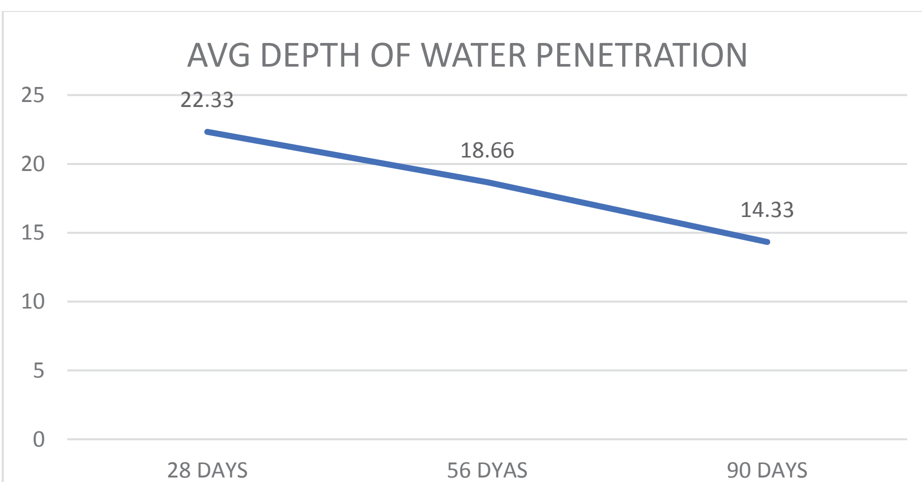

Fig. 9. Water Penetration Test

4. Observation and Conclusion

With the help of conducting tests related to parameters like the absorption of water in concrete by capillarity rise with the aid of a sorptivity test, to determine the penetration of water under pressure, so a water penetration test was conducted in accordance with DIN 1048 to determine the depth of water penetration in Ferrocement, as well as the to determine the resistance to sulphates on, an attempt was made to determine the durability parameters of the Ferrocement. For each experiment, the results were acquired after 28, 56, and 90 days of curing; the difference between each curing period's effectiveness was also observed. In the sulphate attack test, where the specimen was immersed in magnesium sulphate ($MgSO_4$) for 28 days after the curing period, it was found that the weight loss was 0.28%, 0.32%, and 0.33%, and the strength loss was 6.96%, 6.44%, and 6.33% for 28, 56, and 90 days of curing in water, respectively. These values are within the ASTM c 1012-2010 permissible limit. The absorption rate was noted down to be 84.87 x 10^{-7} mm/s$^{1/2}$, 93.78 x10^{-7}mm/s$^{1/2,}$ and 96.34x10^{-7}mm/s$^{1/2}$ for a curing period of 28, 56, and 90 days, respectively, which satisfies the criteria for ASTM C 1585-04. The mass was noted at certain intervals of time after submerging the bottom surface for about 2-5 mm in water. According to the results of the water penetrating test, the average water penetration was found to be 22.33 mm, 18.67 mm, and 14.33 mm for the curing of the specimen for 28, 56, and 90 days, respectively. These results meet the requirements of DIN 1048. As a result, it meets every need for durability-tested for.

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