

Original Article

# Development of Self-Healing Concrete Using Synthetic Fiber Reinforcement

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**Abstract** - Weathering of concrete happens while it is put to use, impacting its durability as well as its load-carrying capacity. In this investigation, the impact of the addition of synthetic fibers to concrete would be on the water permeability of concrete due to crack formation. In a previous investigation, it has been suggested that these fibers can control the width of cracks that form in concrete and can also close existing micro-cracks (instances of sizes between 0.1mm and 0.3mm), in addition to crack widths. A total of 24 cube samples were prepared using standard mix proportions, having an equal amount of cement content for all specimens, but varying quantities of synthetic fibers (20g, 30g, and 40g). In addition, these specimens were subjected to compressive load to obtain visible cracks after 21 days of curing time for all specimens. After an additional Seven-Day cure for the already formed specimens, they were subjected to water permeability tests to measure the ability of crack closure of specimens through measurement of the depth of water penetrated into the sample. Water permeability was found to be the least (amounting to 16mm of water penetrated in specimens containing 20g of synthetic fibers). An increase was seen in specimens containing 30g of synthetic fibers (amounting to an increase of 18mm of water penetrated). A substantial amount of water penetrated (amounting to 22mm of water penetrated), resulting from specimens having higher amounts of synthetic fibers (40g). There can be an inference drawn that an excess of synthetic fibers can reduce workability of cement paste, resulting in higher strength (harder or more brittle), yet poor ability to resist water seepage into its matrix.

**Keywords** - Synthetic fibre, Self-healing, Crack formation, Water permeability, Hydration behaviour.

## 1. Introduction

### 1.1. General

Modern construction utilizes a great deal of concrete for its affordability, ease of manufacturing, and its high compressive strength. Although these characteristics contribute to the wide use of concrete, concrete does poorly in tension, which causes cracking because of the load or temperature changes or the development of shrinkage during the curing process. Once cracks are formed, they allow water and other aggressive agents to enter the concrete. With continued exposure, these agents can reach the embedded steel reinforcement and initiate corrosion. This process accelerates material degradation and increases the need for repair and maintenance. For this reason, controlling crack formation and limiting crack propagation are essential for ensuring satisfactory long-term performance of concrete structures.

Self-healing concrete has been gaining increasing attention due to its potential to reduce the need for repairs or prolong the lifespan of the structure. In regular concrete, there is a possibility of very limited self-healing due to continued hydration reactions and the formation of calcium

carbonate. However, this is normally limited to very fine cracks, typically smaller than 0.1 mm, and tends to decrease in larger cracks, whether they are open or closed. Alternatively, due to the above limitations, many other methods have been tried to improve the self-healing process in concrete, including the incorporation of fibres, mineral materials, and bacterial media. Out of the many, polypropylene fibres have been extensively investigated, as they prevent the opening of the cracks and promote the retention of hydration products in the cracks, thus facilitating self-healing.

The effects of synthetic fibers on the mechanical properties and the width of cracks are well demonstrated, but the research on the effects of synthetic fibers on the healing process is relatively limited. This is particularly the case in relation to the measurement of the water permeability after the creation of cracks with a predetermined width. A considerable number of studies deal mainly with steel fiber materials, high-performance concretes, and bacterial or mineral healing agents. Thus, the healing properties of normal concrete and polypropylene fibers have not been researched in depth yet.



A second unexplored topic deals with the effect of fibre dosage on the fresh properties, hydration performance, and healing capabilities. When fibres are excessively incorporated, the internal flow resistance might increase, the flowability might reduce, and the microstructure of the cement matrix might be disrupted. All these factors might result in the limitation of healing capabilities and any positive effect that might be generated due to fibres. These factors highlight the importance of experimental works to explore the dosage of fibres that would help in healing while preventing any detrimental effect on the performance.

Despite the common use of polypropylene fibres for shrinkage crack mitigation, their direct role in healing in normal-strength concrete, especially when evaluated through permeability measurements after generating cracks within a specific range, remains insufficiently documented. Much of the literature prioritises strength recovery or focuses on materials with very high fibre contents that exceed levels typically used in practice.

Only a limited number of studies have examined how realistic, commercially standard polypropylene fibre dosages influence the healing of cracks between 0.1 mm and 0.3 mm in conventional concrete mixes without significantly altering the fundamental mixture proportions.

The following contributions are made by this study to close these gaps:

- Instead of using specialised high-performance materials, three realistic polypropylene fibre dosages (20 g, 30 g, and 40 g) were evaluated in a typical normal-strength concrete mix.
- To reflect typical service-level crack widths, controlled cracks with a range of 0.1–0.3 mm are introduced.
- Instead of depending just on strength recovery, water permeability is used as the main indicator of healing, providing a direct assessment of resistance to moisture penetration.
- Finding a fibre composition that effectively seals cracks without sacrificing the qualities of fresh or hardened concrete.
- Including a control mix of plain concrete to make it easy to see how the fibres affect healing behaviour.

### **1.2. Problem Statement (Importance of the Study)**

Over the course of its service life, concrete will eventually develop cracks due to loading and environmental changes. The aperture starts to function as a pathway for moisture and hostile substances once the breadth surpasses 0.1 mm. The issue gets more serious when fractures reach a size of about 0.3 mm because regular concrete's natural self-sealing mechanisms are typically insufficient to repair such gaps. Identifying solutions that could aid in healing in this range is critical to performance improvement, given that these appointments could cause acceleration of deterioration, along with a risk of a possible repair job.

Polypropylene fibres, which are often used in the reduction of crack widths and in shrinkage, through the conservation of tighter and more stable apertures, have emerged as a means that could effectively support the healing process.

The effect of various dosages of fibres on the healing properties of concrete is still unknown. The current research addresses this issue. Water permeability tests, which provide an unambiguous indication of the regained resistance to water penetration, characterised by the initial breaking state, are employed.

### **1.3. Aim**

Through the use of self-healing processes, which are improved by the incorporation of synthetic fibers such as Weberad Fibre M, it is hoped that the lifespan of reinforced concrete can be improved by resisting crack formation.

### **1.4. Objective**

To determine the self-healing characteristics of concrete reinforced with Weberad Fibre M synthetic fibers and reduce water permeability.

### **1.5. Scope of Work**

The experimental project was carried out in the university laboratory with a well-organised workflow. The initial step in the project, in attempts to describe the experimental methodology and the testing procedures to be followed, was the review of relevant literature. The next step involved the characterisation of the material, where the coarse aggregates were evaluated through bulk density and sieve analysis, and the fine aggregates through the determination of the specific gravity.

The concrete mixture proportion was established on the basis of these results. The quantities of synthetic fibers were accurately measured and then added to the mixture batches after the final mixture proportion had been established. Subsequently, general curing procedures were carried out for casting the specimens. The controlled load values were then applied to generate the desired width of the crack after the completion of the curing process. To evaluate the extent of healing, the fractured samples were subjected to water permeability tests in the final stage of the experiment.

### **1.6. Literature Review**

The reviewed literature suggests a mounting interest in developing an effective way of minimizing concrete cracking. It is often stated in particular research that microscopic, initial concrete cracks may accelerate a concrete structure's eventual destruction in the future, which may be prevented by introducing self-healing properties into a concrete mixture. Apparently, there is a study according to which some types of concrete-borne bacteria can produce calcite, which is able to form concrete minerals to close concrete cracks in a structure.

There are very few materials that can match the strength, diversity, and low cost of concrete, and this explains why it remains so dominant in the world of construction, as stated in another publication. As highlighted, what is called for is an improvement in the durability of the current infrastructure of concrete, rather than replacing it altogether, as stated in reference [1].

A different study suggests a repair approach appropriate for sites with restricted or dangerous direct human access. Similar to how bones naturally renew and seal fractures, the procedure entails injecting a specialised substance that migrates into interior fissures and seals them [2].

The literature also discusses difficulties that have been documented to exist in Japan, where many structures that were constructed approximately 50 years ago are being noticed to exhibit observable wear and tear. Consequently, there is an increasing need to embrace necessary rehabilitation processes and maintenance practices for efficiency to be achieved [3]. The same trend has also been documented to exist in countries such as Germany, where the maintenance of aging infrastructure has become too expensive. The financial struggles that result from deteriorated infrastructure are evident in the fact that, in some cases, annual expenditure directed towards its maintenance has surpassed the construction cost of new infrastructure [4].

Many publications cover the evolution of bio-modified concrete, in which microorganisms help create a self-sealing effect. Calcium carbonate can be formed by some species, including *Bacillus pasteurii*, whose calcite crystals fill in pores and micro-cracks. As a result, this concrete becomes less porous, less susceptible to water, and less permeable due to these accumulations within it [5].

It is commonly accepted that the most significant deficiency within concrete is the presence of cracking. While the cracking is taking place, substances such as water and reactive materials are able to gain entrance into the concrete and consequently affect its stability by contributing towards the erosion process. This poses the greatest danger to the durability of the concrete through the provision of direct entrance points for dangerous substances into the concrete [6].

In addition, the literature emphasizes the necessity of ensuring that the concrete possesses ample mechanical strength for long periods of service life. In any case, prevention of cracking cannot be done to a final degree with respect to practical implementation. After the occurrence of cracking, high permeability sets in with a substantial increase in the formation of channels, allowing admixture to reach the steel and decrease system durability [7].

Steel fibres are often distributed throughout cementitious matrices to enhance mechanical resistance and regulate crack behaviour. Their presence promotes stress transfer across fracture planes, strengthens toughness, and facilitates crack bridging. The degree of alignment of the fibres with respect to the applied load, the strength of the fiber–matrix connection, and the slip behaviour at the interface all affect the flexural performance of fiber-reinforced composites [8]. Even when exposed to a 10-weight-percent NaCl environment, research on Ultra-High-Performance Concrete (UHPC) has demonstrated that chloride penetration can be limited to less than 1 mm, with minimal loss of strength. The quality of the fiber–matrix interface is partly responsible for this remarkable longevity, and multiple studies verify that uncracked UHPC provides outstanding resilience to harsh conditions [9, 10].

However, there are still gaps in our knowledge of how steel fibres react over extended periods of time under different climatic conditions and how UHPC functions after it has cracked [11-13]. According to some research, UHPC with about 2% steel fibres can maintain its increased tensile strength even after the fibre surfaces start to corrode. The development of ferric oxide ( $\text{Fe}_2\text{O}_3$ ), which enhances fibre roughness and fosters better mechanical coupling between the corroded fibres and the surrounding matrix, has been connected to this enhancement [14].

According to research, the roughening of steel fibre surfaces caused by corrosion may actually improve their pullout performance. The resistance to extraction rises with the irregularity of the fibre surface, improving toughness and requiring more energy to remove the fibre. The degree of corrosion and the ensuing change in surface roughness have been directly related to these effects [15, 16]. Similar findings were found when hooked and double-hooked steel fibres (60 mm long and 0.75 mm in diameter) were added to traditional steel-fiber-reinforced concrete. Fibres that had experienced partial slide demonstrated enhanced bonding with the surrounding matrix after six months of alternating wet and dry exposure in a 7% chloride solution, each cycle lasting two days. This suggests that modest corrosion may augment mechanical anchoring [17].

Durability studies on UHPC often rely on four-point bending tests and direct tensile evaluations to understand fibre performance after cracking. Once cracks form, harmful agents can travel through the openings and interact directly with the fibres, providing crack bridging. Corrosion usually begins when variable pH levels and moisture content along the crack walls create favourable conditions for attack, eventually producing pits on the exposed fibre portions [18]. Chlorides can migrate through the matrix and, at sufficient concentrations, may combine with hydration products to form phases such as Friedel's or Kuzel's salts, influencing the microstructure of the hardened paste. Some chloride ions may also become physically bound within the C–S–H gel

[19, 20]. The UHPC mix created under the ReSHEALience program has been the subject of extensive research, which has looked at its durability, structural performance, and capacity for autonomous fracture closing [21, 22]. The pullout resistance of the inserted fibres increased with the curing of these mixes in seawater. This could be due to the presence of calcium chloride in both artificial and natural seawater, which promotes early-stage matrix hardening. Consistent with the findings of Marcos-Meson and colleagues [23, 24], a slight corrosion product buildup on the fibre surface is assumed to have been a contributory aspect for the better anchoring, mainly because of the confinement provided locally to the fibre. The specimens still exhibited a high pullout resistance and achieved the highest loading even after being stored under a 3.5% NaCl solution for a period of thirty days. On debonding, the loading showed a slipping-hardening phase for the fibres, with a significant reduction in load only beyond a displacement of 2.5mm [25].

This research not only focuses on the long-term durability problems of concrete but also highlights how synthetic polypropylene fibers can be effective in the self-repair of regular concrete. Even though synthetic polypropylene fibers are often used in concrete to prevent plastic shrinkage and reduce the generation of early-stage cracks, current studies have also demonstrated their potency in inducing autogenous healing.

The most important factor that affects their effectiveness is their ability to keep low crack widths. The fibres promote the formation of many small cracks instead of larger ones by more evenly distributing tensile forces. Moreover, this is particularly significant, since it has been found that natural healing processes such as calcium carbonate formation and steady hydration work best when crack widths are around or below 0.3 mm, according to [7]. Fibers of polypropylene help in maintaining cracks small enough to enable effective natural healing. They have very important applications in developing environments that enable autogenous healing because of their ability to control the size of the cracks.

Furthermore, these fibres also collect fine residue and unhydrated cement particles within the fractured region. The ingredients that remain would continue to react and fill up the voids created as soon as there is moisture present during the curing stage.

Calcium carbonate tends to build up advantageously where the fibers are in contact with cement paste in very narrow fissures. The fibers contribute towards enhanced workability and efficiency of fracture sealing by enhancing mineral precipitation on their surfaces as a result of their early stability on microcracks. Polypropylene fibers also influence the movement of water within the concrete despite the non-absorbable nature of the fibers. Polypropylene

fibers delay the drying process and are responsible for the creation of a humid environment because they cause the formation of minute pathways and defects. The critical self-healing mechanisms, like hydration and calcite precipitation, are enhanced by the presence of a constant humidity level within the concrete. Preserving the humidity within the interior is significantly effective in the natural self-healing mechanisms of the concrete [26].

Additionally, the fibers also prevent excessive spreading of concrete when shrinking or subjected to loading, as they act as a kind of reinforcement over the newly formed cracks. This bridging action is essential as self-healing is possible only if the pores are very small. Research studies on the interaction of microfibers in a matrix have confirmed that even though polypropylene fibers are more flexible compared to steel fibers, they can prevent the widening of the existing cracks in normal-strength concrete [27]. The polypropylene fibres influence the passage of water and the fine particles during hydration, without reacting with the cement. It affects the mixability, making it difficult if an excess amount of the fibres is used. There will be a low microstructure due to the low consolidation. This will also affect hydration. However, a low amount of mild fibres will improve the microstructure within the formed fractures and the retention of the moisture within the microstructure. Similar observations have been made by other researchers that a higher amount can result in the hydration being impeded, despite a higher amount having a more compact microstructure.

The specimens with 20 g of polypropylene fibre showed the least amount of water penetration in this investigation. This dose seems to provide the greatest balance since it prevents the compaction issues linked to higher fibre quantities, restricts fracture widening, and maintains the interior moisture conditions required for autogenous repair. More voids and a discernible decline in healing ability resulted from the fresh concrete becoming more difficult to consolidate when the amount of fibre exceeded this threshold.

It is also worth noting that synthetic fibres are rarely the focus of research on self-healing of normal-strength concrete. Much of the existing work centres on bacterial agents or steel fibres in high-performance mixes. As a result, investigations examining how polypropylene fibres influence healing in standard concrete classes such as C30–C40 remain relatively scarce, highlighting the need for further research in this area.

Previous studies offer only a limited explanation of how different amounts of polypropylene fibres influence the self-healing behaviour of concrete. The effects of high fibre dosages, such as reduced workability and hindered hydration, are not well documented, even though these factors directly affect the healing process. In addition, only

a small number of researchers have assessed healing performance through water-permeability tests, which are among the most reliable indicators of durability. Although controlled fracture widths of 0.1–0.3 mm approximate realistic service-level cracking, there is also a dearth of experimental studies on these ranges. By analysing the healing behaviour of normal-strength C35 concrete with different amounts of polypropylene fibres, this work fills these gaps. Water-permeability testing was used to assess the degree of recovery after controlled cracks within the practical healing range were introduced. This approach made it possible to determine the ideal fibre content that promotes healing without having the detrimental consequences of high fibre content. The findings add to our understanding of the cost-effective use of synthetic fibres to promote natural healing in regular structural concrete.

Common repair techniques, including epoxy injection, surface coatings, patch repairs, and stitching, are mostly reactive, despite structural cracking being acknowledged as a major durability concern. They often require skilled craftsmanship and involve direct intervention in the cracked area. These techniques may show short-term enhancements in workability, though they fail to arrest new cracking and close microscopic fractures that allow water ingress. Thus, a considerable number of constructions have periods of deterioration and restoration, which increases the maintenance cost over time.

The fiber-based method discussed here is relatively preventative in approach. When a crack occurs, the fibers work by minimizing the size of the fractures and allowing a microclimate that enables a natural sealing process. This occurs automatically after casting, and this method is most suitable for those hard-to-reach regions such as slabs, beams, foundations, and other confined structural members. The service life of concrete structures could be extended, maintenance could be reduced, and reliance on conventional healing agents could be obviated by incorporating fibers that induce the healing process. The above findings are attested by the result of this investigation, as a mix containing 20 g of fibers successfully reduced the size of the cracks and

created optimal interior conditions for mineral and hydration-based healing processes. On the other hand, excessive fiber quantities prevented the induction of moisture and hydration processes that are essentially needed for a healing process.

**1.7. Experimental Setup and Methodology**

The methodology was carried out following the sections outlined below:

- Preliminary Investigations of Raw Material
  - Fine aggregate, Coarse aggregate, Cement, Weber ad fiber M: synthetic fiber.

**1.7.1 Material Description**

Specifications of Weber. ad M synthetic fiber is presented in Table 1 and shown in Figure 1.

**Table 1. Specifications of Weber. ad M synthetic fiber**

Colour	White
S.G	0.91
Constituents	Virgin Polypropylene
Fiber thickness	18-30 micron
Melting point	> 160°
Alkali & salt resistance	High
Modulus of elasticity	500 ksi
Absorption	None

Test results of materials and mix design for C35 Grades are shown in Tables 2 and 3.



**Fig. 1 Microscopic view of Weber. ad M synthetic fibers**

**Table 2. Results of tests on raw materials**

Tested Material	Specific Gravity	Bulk Density	Fineness Modulus	Water Absorption	Water-Cement Ratio
Fine aggregate	2.7	-	3		0.47
Coarse aggregate	-	1664		20%	0.47

**Table 3. C35 grade mix design**

Water	Cement	Fine Aggregate	Coarse Aggregate
205	437	753.3	999
0.47	1	1.723	2.286

1.7.2. Mix proportions of Synthetic Fibers

The synthetic fibre used in this study is added directly to the concrete without replacing any portion of the fine or coarse aggregates. Based on the supplier’s guidance, up to 600 grams of fibre may be used per cubic metre of fresh concrete. The trial mixes for this work were prepared as follows:

- Sample 1: 20 g of synthetic fibre with 60 mL of superplasticizer
- Sample 2: 30 g of synthetic fibre with 80 mL of superplasticizer
- Sample 3: 40 g of synthetic fibre with 100 mL of superplasticizer

Table 4. Mix proportions of synthetic fibers in the samples

Batch No.	Cement kg	Fine Aggregate kg	Coarse Aggregate kg	Water kg	Synthetic Fiber gm	Plasticizer mL
Batch 1	5.9	10.17	13.5	2.8	0	0
Batch 2	5.9	10.17	13.5	2.8	20	60
Batch 3	5.9	10.17	13.5	2.8	30	80
Batch 4	5.9	10.17	13.5	2.8	40	100

2. Experimental Investigation

2.1. Preparation of Samples

Four concrete batches were prepared for the study, including one reference mix without fibres. This setup makes it possible to examine the effect of adding synthetic fibres and to see how different fibre amounts influence performance. The mixes containing fibres were prepared using:

- Sample 1: 20 g of synthetic fibres with 60 mL of superplasticizer
- Sample 2: 30 g of synthetic fibres with 80 mL of superplasticizer
- Sample 3: 40 g of synthetic fibres with 100 mL of superplasticizer.

2.2. Casting of Samples

The study originally planned to include three samples per mix, but this number was increased to enhance the dependability of the findings. A total of six cubes were produced for each mix type, the control mix, and those containing 20 g, 30 g, and 40 g of fibres, giving 24 specimens overall. All batches were cast and cured following identical procedures. Each specimen was formed in a 150 mm × 150 mm cube mould and left to set for one day. After demoulding, the cubes were placed in a curing tank and submerged for a 28-day curing period (Figure 2).



Fig. 2 Casting the samples

2.3. Crack Inducement

After curing for 15 days, the specimens were removed from the water tanks and transferred to the UTM facility. A compression testing machine was then used to introduce controlled cracks in the concrete cubes.

The setup was similar to a standard compressive strength test, but the loading was halted immediately once surface cracks became noticeable on each sample (Figure 3). Following crack formation, the specimens were returned to the curing tank for an additional 14 days before proceeding to the final phase of the study, the water-permeability assessment.



Fig. 3 Cracks formed on the samples

2.4. Crack Measurement

After the cracks were formed in the samples, their widths were measured to allow comparison later and to determine whether any reduction occurred. A crack-width gauge was used for these measurements (Figure 4). The measurement point was first selected on a straight section of the crack, ensuring proper alignment with the gauge.



Fig. 4 Crack width gauge apparatus

The gauge was then placed against the specimen surface and adjusted until its calibrated scale aligned precisely with the crack edges. Once properly positioned, the crack width was read from the scale and recorded (Figure 5).

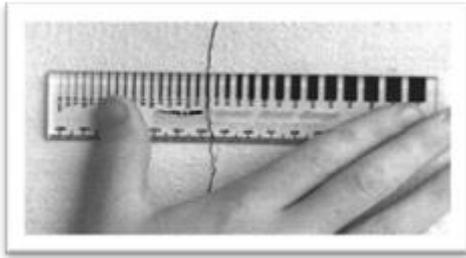


Fig. 5 Crack measurement method

Most of the cracks observed in the specimens were within the range of 0.1–0.2 mm. In a few cases, partial failure during the compressive strength test produced wider cracks measuring approximately 0.5–0.9 mm. Cracks of this magnitude fall outside the healable range and are not expected to undergo any self-healing.

### 3. Results and Discussions

#### 3.1. Testing of Hardened Concrete and Results Water Permeability Test

The water-permeability procedure is carried out on concrete cubes or cylindrical samples to assess how far pressurised water can infiltrate the material. Cube specimens are typically at least 150 mm in size. For the test, the sample is clamped tightly between two flanges fitted with circular seals, and water is applied to one surface at a

constant pressure for 72 hours. Once the exposure time ends, the specimen is split open so that the deepest point of water ingress can be measured. The volume of water that passes into the concrete can also be observed through the graduated burettes attached to the upper section of the testing setup (Figure 6).



Fig. 6 Water permeability apparatus

Batch 1: Reference mix with no synthetic fibres and no superplasticizer.

The standard mix recorded a water penetration depth of 22 mm (Table 5). This relatively high penetration reflects the absence of fibres, meaning the mix had no mechanism to restrict crack widening or promote healing, and therefore showed no ability to seal the cracks (Figure 7).

Table 5. Results of the water permeability test on batch 1

Customer Sample Ref.	01	02	03
Age at test (days)	41		
Surface treatment	Wire brush		
Moisture Condition	Saturated Surface Dry		
Density (kg/m <sup>3</sup> ) [Moist]	2470	2460	2500
Maximum water penetration (mm)	34	13	19
Mean (mm)	22		



Fig. 7 Samples cut in half to check water penetration

Batch 2: Fibre-reinforced mix containing 20 g of synthetic fibres and 60 ml of superplasticizer. This batch recorded a water penetration depth of 16 mm (Table 6).

Table 6. Results of the water permeability test on batch 2

Customer Sample Ref.	04	05
Age at test (days)	41	
Surface treatment	Wire brush	
Moisture Condition	Saturated Surface Dry	
Density (kg/m <sup>3</sup> ) [Moist]	2480	2460
Maximum water penetration (mm)	11	20
Mean (mm)	16	

Compared to the conventional mix, the 20-gram fiber-reinforced mix had an average water penetration depth of 16 mm. The presence of synthetic fibres is responsible for this decrease, suggesting that they assisted in keeping crack widths within a range where healing and crack sealing may occur (Figure 8).



Fig. 8 Penetration level in the second batch of samples

Batch 3: Fibre-reinforced mix containing 30 g of synthetic fibres and 80 ml of superplasticizer.

This batch recorded a water penetration depth of 17 mm (Table 7).

Table 7. Results of the water permeability test on batch 3

Customer Sample Ref.	06	07	08
Age at test (days)	41		
Surface treatment	Wire brush		
Moisture Condition	Saturated Surface Dry		
Density (kg/m <sup>3</sup> ) [Moist]	2530	2530	2520
Maximum water penetration (mm)	19	17	17
Mean (mm)	18		

The 30-gram fibre-reinforced samples showed an average water penetration depth of 18 mm, which is 2 mm higher than the 20-gram batch. This suggests that increasing the fibre content begins to negatively affect the mix by reducing workability and disrupting the hydration process during the curing stage. As a result, additional or wider cracks may form, falling outside the range that synthetic fibres can effectively control or support in terms of self-healing (Figure 9).



Fig. 9 Penetration level in the third batch of samples

Fibre-reinforced mix containing 40 g of synthetic fibres and 100 ml of superplasticizer. This batch recorded a water penetration depth of 22 mm (Table 8).

The 40-gram fibre mixes recorded an average water penetration of 22 mm, again showing higher values than the earlier batches. This confirms that increasing the fibre content progressively reduces the workability of the fresh concrete, and at the same time, the greater fibre dosage interferes more noticeably with the hydration process during curing (Figure 10).

Table 8. Results of the water permeability test on batch 4

Customer Sample Ref.	09	10
Age at test (days)	41	
Surface treatment	Wire brush	
Moisture Condition	Saturated Surface Dry	
Density (kg/m <sup>3</sup> ) [Moist]	2520	2460
Maximum water penetration (mm)	25	17
Mean (mm)	21	

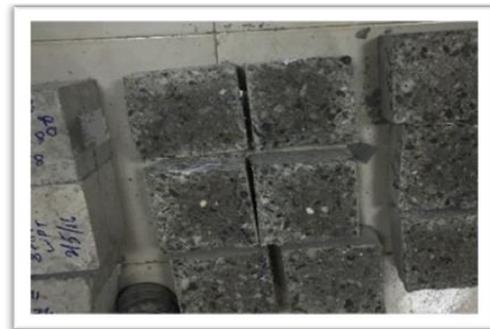


Fig. 10 Water penetration in the sample

#### 4. Conclusion

##### Summary of Key Outcomes

- The concrete containing 20 g of polypropylene fibres had the least amount of water intrusion, with a penetration depth of about 16 mm. At this dosage, the fibres effectively reduced crack widths to a range where continued hydration and other natural sealing mechanisms could still be effective. The mix also retained an adequate degree of workability and compaction.
- By increasing the amount of fibres to 30 g, the penetration depth of approximately 18mm was attained and revealed low self-healing properties. This caused difficulties in workability to the mix, resulting in the formation of minute voids and improper healing due to the easy flow of water through those voids.
- The highest penetration depths were observed for the 40 g fibre mixes, indicating that a very high proportion of fibres can prevent the healing process. At this point,

the condensation of the mixture was very difficult, even with the addition of plasticiser. In addition, clustering of fibres affected the morphology of the matrix.

- For samples with gaps larger than 0.3 mm, no healing occurred, independent of the fibrous additive. This confirms the knowledge that polypropylene fibres act nearly exclusively in the prevention of crack development; afterwards, if the crack size exceeds 0.2-0.3 mm, the fibres have no positive effect, and natural healing is no longer active.
- The importance of selecting the appropriate quantity of fibres has been highlighted by the findings of this research study. Low fibre content promotes healing by restraining the width of cracks and maintaining internal saturation, while high fibre content lowers workability and inhibits matrix development.
- Experiments revealed a certain decrease in workability as the quantity of fibre content increased. The increase in fibre content made it difficult to achieve uniform distribution; hence, it tended to clump together even when using a plasticiser. This might be the reason for the increase in water penetration in the 30g & 40g mixture.

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