Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 45 No. 1 (2024)

Effects of Composite Fiber on Minimizing the Plastic Shrinkage Cracking and Use of AI Tools for Image Detection in Concrete Pavement Structures

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Abstract: The use of fibers in concrete structure enhances the structural integrity and reduces its permeability. The present study is focused on the use of composite fibers in the concrete pavement structures to minimize the potential cracking during transition period. For research purpose polypropylene (PP) and steel fiber (SF) are induced as composite fibers (CF) in concrete mix to analyze its effects on potential cracking with aspect ratio, 200 and 70 respectively and effects of plastic shrinkage cracking (PSC) is evaluated. Under the program objective pavement quality concrete of M40 grade was designed with water cement ratio of 0.35% as per IRC SP: 46-2016. Cubes and slab were casted under strict lab quality control and plastic shrinkage cracking and compressive strength were evaluated with different percentages of composite fibers.The result shows that the effectiveness on compressive strength on 7 and 28 days curing from design mix proclaim that adding CF escalate the compressive strength by 15%. shrinkage cracking is reduced up to 99%by adding 0.2 and 0.5% of CF and is highly effective. The Artificial intelligence (AI) Internet of Things (IoT) based machine learning software tool was developed and used for the comparative crack analysis and to plot the results of different cracking pattern

Keywords: Plastic shrinkage cracking (PSC), composite fibers (CF), Polypropylene (PP), Steel Fiber (SF). Internet of Things (IoT), Machine learning (ML), Artificial intelligence (AI)

1. Introduction

Fibers of various kind are induced in concrete which effect various properties of concrete and enhance the performance in concrete. By stopping and bridging developed cracks, reinforcement—such as steel bars and/or fibers—is introduced to increase tensile characteristics and ductility. [2] PSC occurs when the concrete surface loses moisture rapidly and start shrinking and cracks is observed on the facet of the structures and this phenomena is most commonly seen in materials with a high surface to volume ratio, such slabs and pavements, and it happens soon after casting when the concrete is still in the plastic stage.

The literature is been thoroughly examined and the study shows that: A 3′ length of 0 - 2% steel fiber performed exceptionally well in both compression and flexural test. A 2% dosage with a 3′ fiber length can be employed for the commercial manufacturing of structural concrete, according to thorough investigation [4]. In cement-based materials, cracking and brittleness can be overcome depending on the form and kind of fibers. Plastic shrinkage cracking can be minimize by adopting certain precautionary methods including rapid drying of top surface of concrete and by acquiring good curing methods. The use of fibers are a secondary reinforcing mechanism which also support in mitigating stresses which developed during the evaporation process [8].

A total of 9 cube and slab samples were casted under strict quality control as per IRC SP:46-2013 for pavement structure after the performance on compression strength was analyzed the shrinkage analysis was done on slab with the selected percentage of composite fibers discussed in this paper.

2. Objectives:

- To find out the effect of steel fibers and polypropylene on workability and permeability of in fresh concrete.
- To analyze the effects of composite fibers on minimizing the potential cracking in concrete structures.
- To determine the use of AI tools for image detection in concrete pavement structures.

3. Data collection

3.1. Materials: Composite fiber reinforced concrete is prepared by combining cement and aggregate (course and fine) with water along with the composite fiber combinations with varying percentage of fiber is used and concrete mix is prepared as per IRC SP:46-2016.

3.2 Cement: OPC as per IS 269:2015 of grade 43 is used. About 45-50% slag, 0-4% gypsum is added. Cement's specific gravity was found to be 3.18. The properties of OPC is shown below in Table 1A and Table 1B.

3.3 Aggregate: N sand and course aggregate is used, N sand of Narmada Basin and the course aggregate of 20 mm size is taken from the Indore region of Madhya Pradesh, Indore. Physical properties of aggregate are shown (Table 3). Sieve analysis of course and fine aggregate was conducted.

3.3 Super plasticizer: Sikament-2004 NS, a high workable and retarder admixture was used. It is available commercially in liquid form and dispensed in concrete before adding water as a water reduction of upto 25% is noted by using this admixtures. The properties of admixture is given below Table 2.

Table 1A (Chemical properties of Cement)

Composition	Content %
Silica, SiO_2	13.6%
Alunima, Al_2O_3	4.6%
Iron oxide, Fe_2O_3	5.5%
Magnesia, MgO	4.1%

3.4 Fibers:

Micro and Macro fibers, metallic and non metallic (steel fibers and polypropylene) with an aspect ratio of 70 and 200 respectively is taken as per IS 16481-2016.

Image 1a [15] and Image 1b shows the classification of different steel fibers and Image 2 shows the structure and appearance of polypropylene fibers also Table 4 and Table 5 shows properties of SF.

Table 1B (Physical properties of Cement)

Physical properties	Test Results
Specific Surface area (m^2/kg)	280.5
Setting time (Vicats Apparatus) Initial setting, hrs : min	00:35
Final setting, hrs : min	09:00
Compressive strength MPa for 3 days	28.5

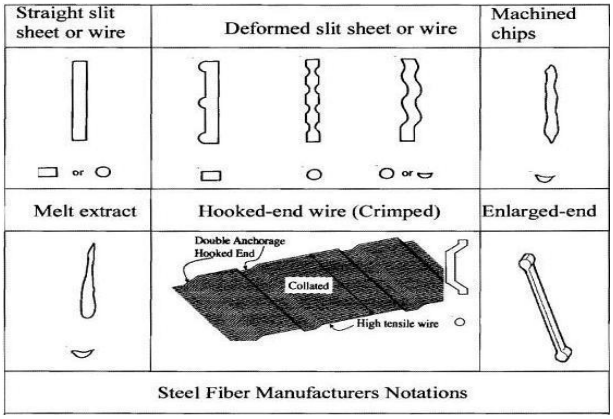


Image 1a (27) Study of Compressive Strength of SFRC with Different Grade of Concrete (2016)

Image 1b

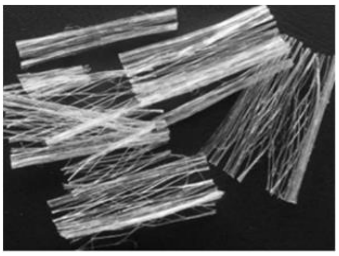


Image 2

Image 1 & 2 Steel fiber and Polypropylene Fiber

Table 2. Properties of Superplasticizers	
Chemical base	Modified Napthalene Formaldehyde Sulphonate
Packaging	275 kg/ Bulk supply
Appearance	Dark Brown Liquid
Storage Conditions	Store in dry conditions at temperatures between +10°C and +40°C. Protect from direct sunlight and frost.
Density	~1.18 kg/l at 25°C
pH-Value	≥ 6

Table 3 Properties of aggregates		
Properties	N sand	Course aggregate
Fineness modulus	2.74	6.45
Specific gravity	2.62	2.85
Silt Content	1.75%	0%

4. Data Analysis:

A highly workable and retarder admixture is taken for this study available in liquid form. The concrete mix as per IRC SP 46:2019, for targeted strength of 40MPa at 28 days with the slump value of 80-100 mm is designed and after the attending the targeted slump value and compressive strength the concrete slab is prepared for the analysis of PSC. The concrete mix was prepare as per IRC SP:46-2013.

4.1 Setting Time Test:

Vicat apparatus is used to determine initial and final setting time. The mix design was done as per IRC recommendation and fibers was added within the range of 0%-2%. Course and fine aggregate as mention in table 3, sand is as per table 1 and fibers describe in table 4 and table 5 was taken for the mix design, which was mixed for a total of 4 minutes in dry state and then superplastizer was added for free flowing of concrete mix. Slump cone test is conducted to determine the workability of concrete.

4.1.1 Initial and final setting time:

The initial and final setting time is determined by Vicat's Apparatus

Initial setting time: 35 Min

Final Setting time: 600 min

Fig 3: Vicat's apparatus

Table 4 Properties of Polypropylene Fiber		
Test	**Unit**	**Result**
Specific Gravity	-	0.91
Alkali Resistance	%wt	Alkali proof
Water Absorption	% Wt.	Nil
Equivalent diameter (Average)	mm	0.038
	Um	38.09
Aspect ratio	-	450
Tensile strength	MPa	355.31

Table 5 Properties of Steel fibers	
Tensile strength	2500 MPa
Elastic modulus	200 GPa
Length	12mm
Aspect ratio	75
Geometry	Straight
Water absorption	Nil

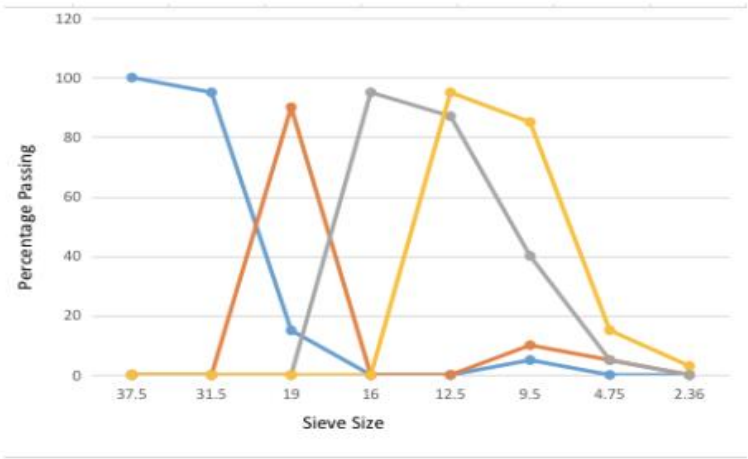
4.2 Aggregate: Crushed stone obtained from crushers is taken as coarse aggregate. The test was conducted as per IS 2386 (Part III). Graph 1.

4.3 Fine Aggregate: N-sand is used for the mix design and sieve analysis was done as per IS: 2386 (Part-I). Graph 1shows the results.

4.4 Specimen Preparation and testing methods:

Slab sample of 500mm*500mm*75mm is prepared . Image was captured at 1 hour time intervals. And using the IoT based image processing and analyzing software is used the crack observation took place within 10 hours of the freshly poured concrete and the image are taken by various percentage variation and graphs are plotted which for the total cracks appearance and reduction of cracks were observed by image processing tool. The images taken for the samples are classified and 3 images were selected for output results.

Graph:1 Sieve analysis of Aggregates



The two types of aggregates make up 65 and 35 percent of the total volume of aggregates: fine (0–4 mm and 0–8 mm) and coarse (8–20 mm) and Sikament-2004 NS were taken. A solution of SP and water was added after the aggregates, cement, and filler had been combined for a minute in a pan mixer.
Table 6 is mix design for 1 m^3 of Concrete proportion along with the material specifications and table 7 shows the fiber percentage used for mix preparation for various concrete mix proportions taken for the test.

4.5 Shrinkage testing:

Shrinkage test was observed by taking a slab of 450mm*450mm*60mm was created samples were prepared and was kept in room temperature for 24hrs, direct heat is prevented for the samples due to loss of moisture and the shrinkage cracking was observed.
Set up a controlled environment where the concrete specimens can be exposed to conditions leading to plastic shrinkage cracking. Monitor the concrete surface for the appearance and progression of cracks. Visual Inspection for determining the plastic shrinkage cracking: Regularly inspect the concrete surface for the appearance and progression of cracks.
The plastic shrinkage cracking was measure by the formation of cracks when the concrete is in green state and it start setting initially in the duration and after that the images were taken in every 2 hour the reading was taken. Record data on environmental conditions (temperature, humidity, wind speed), concrete mix proportions, and any other relevant parameters. Document the timing and characteristics of observed cracks.

The specimens were then put in the mould with regulated humidity and temperature. When water was introduced to the control concrete, around 150 minutes later, a fine fissure (hair line crack) that ran in the slab was seen. It was discovered that this little fissure, became wider after more drying.

- Fig. 4 displays samples of concrete with shrinkage cracks. These phenomena may be explained by the presence of bleed water on the upper surface, which causes delays in surface drying and potential polypropylene fibre reinforcement of the concrete. Regarding F4 concrete (Fig. 6d), there was no discernible fracture.

Table 6 - Proportion 1 m^3 of Concrete

S.No.	Item	Unit	Quantity of material	Quantity of material required for 1 bag of cement
1	Cement OPC - 43	Kg	360.00	50.00
2	Fly ash	Kg	59.00	8.00
3	Aggregate 20 mm	Kg	691.04	96.00
4	Aggregate10 mm	Kg	553.51	77.00
5	Sand	Kg	702.59	97.50
6	Water	Kg	148.80	17.75
7	Admixture (Sikament 2004 NS)	Kg	3.96	0.55
Avg. Compressive strength of M-40		7 days	35.20 MPa	As per MORTH target strength required for 28 days 42 MPa
		28 days	43.51 MPa	

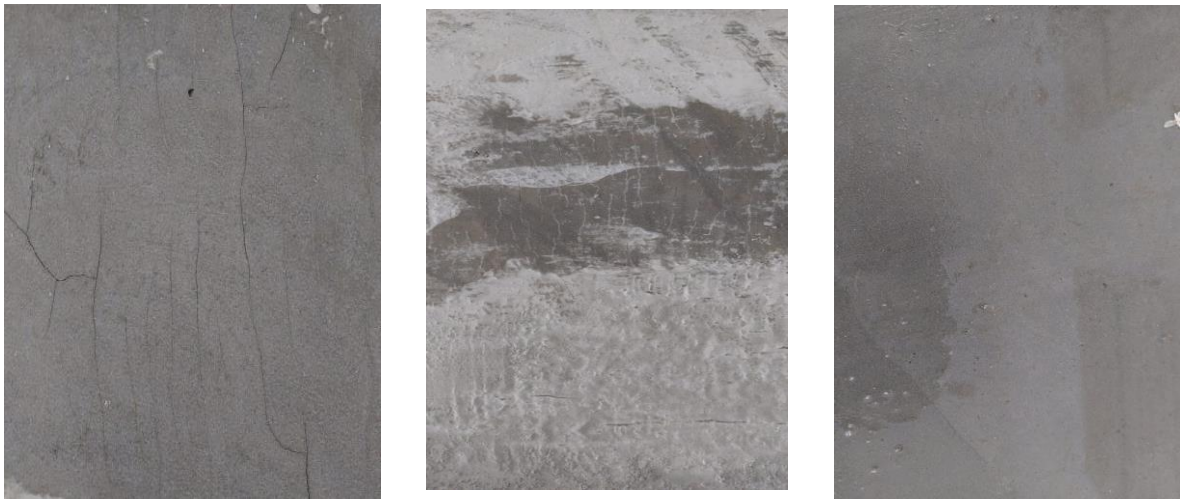
- With the use of an optical zoom camera, pictures of the fractures were taken. Later then, image analysis computational method was used to process and alter the collected photos to get a distinct crack profile.

The brightness was adjusted and thus the image processing was done. Image 5 provide the details of the image after processing.

- The analysis was done by IoT based ML tool which gives various graphs along with the number of cracks and there horizontal and vertical changes, the length analysis in pixels was also calculated which is helpful for analyzing cracks. The outcome images are shown in the Fig. 6, 7 and 8.

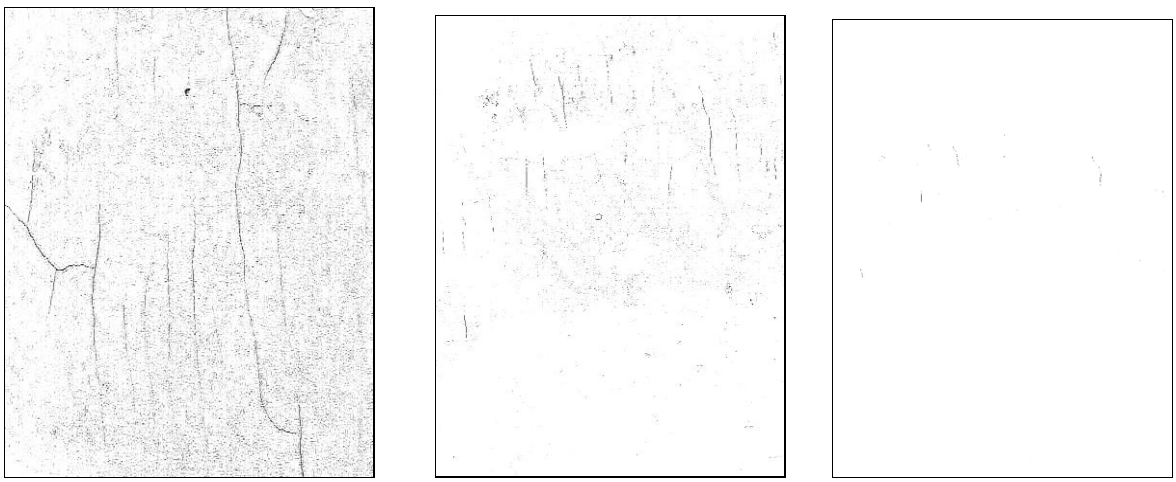
Table 7: Fiber percentage used in mix proportion

Mix	Water (kg/m^3)	Cement (kg/m^3)	Course aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Superplasticizer (kg/m^3)	Fiber content	
						SF %	PP%
F_1	148	360	1200	702	3.96	0	0
F_2	148	360	1200	702	3.96	0.25	0.1
F_3	148	360	1200	702	3.96	0.5	0.2



F_1 (0%) F_2 (0.25 & 0.1%) F_3 (0.5 & 0.2%)

Figure 4: Shrinkage Cracks in Concrete slab



F_1 (0%) F_2 (0.25 & 0.1%) F_3 (0.5 & 0.2%)

Figure 5: Processed image of Shrinkage Cracks in Concrete slab using IoT based software

- As fibre is added, the percentage of cracks reduces, as Fig.4 illustrates. Using around 0.20% polypropylene fiber and 0.5 % steel fibers (by volume), there were ZERO plastic shrinkage fractures found. When 0.10–0.25% fibres were added, the crack width was clearly constrained in comparison to the control sample (Fig. 4, F_2).
- When fibre up to 0.25% was added, the crack width decreased from 52.93% to 73%. The inclusion of fibres up to 0.2%-0.5% (polypropylene and steel fibers) the reduction of shrinkage cracking observed by 50–99%. As per the advice provided by ACI 224 (2007) the crack width caused by plastic shrinking in concrete slab should not exceed 3 mm.
- The number of cracks observed in the F_2 mix is more but the intensity i.e the size of the crack is very small, only fine lines were observed but in the F_1 mix the cracks are less in number but the area of cracks are more. Image 6 show the appearance of cracks as per there size and numbers, Image 7 describe the horizontal and vertical changes in the individual cracks occur in the samples and image 8 show the total number of cracks appeared in the samples and the regardless there size of occurrence.

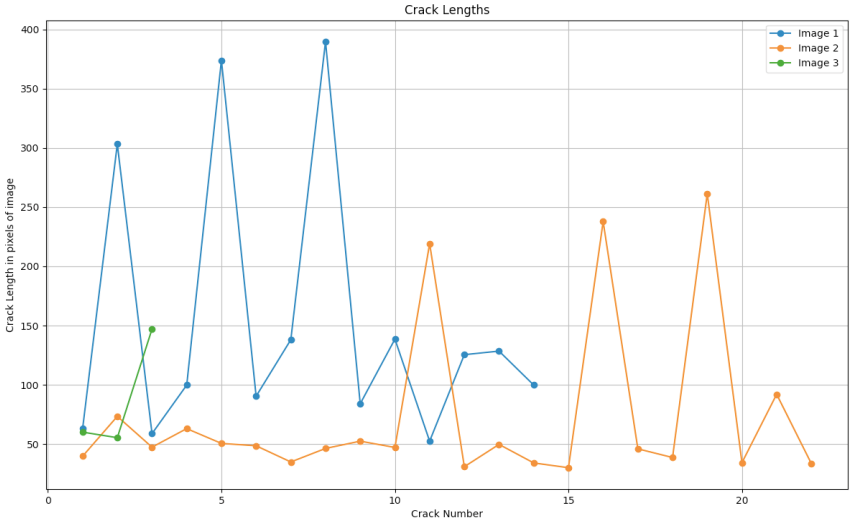


Image 6: No. of cracks and there length in pixels

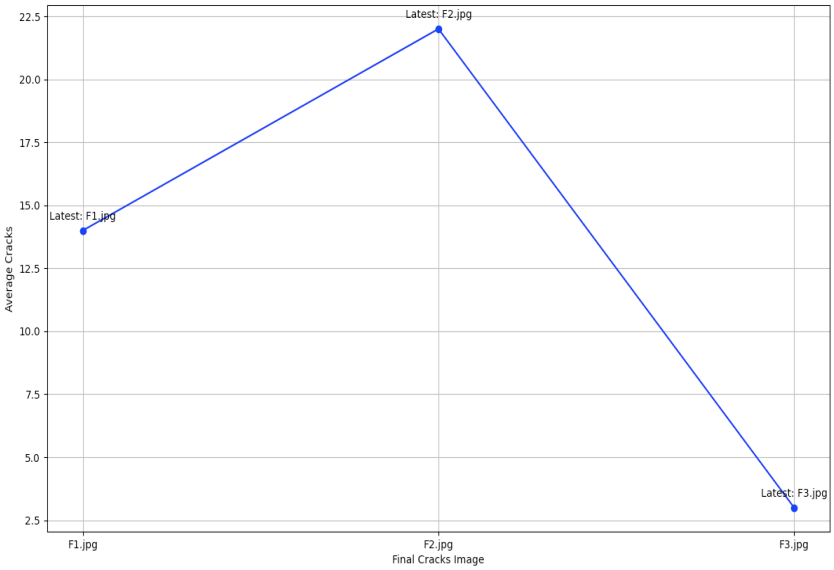


Image 7: Average no. of cracks observed in the trial mix

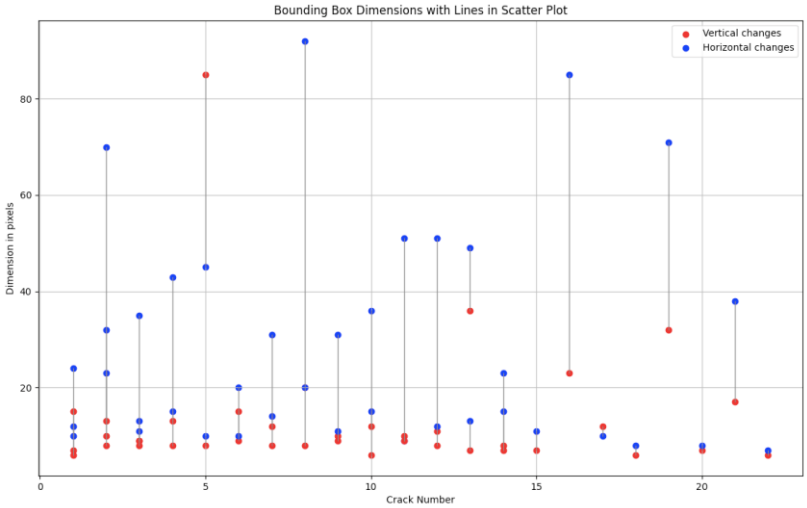


Image 8: Vertical and Horizontal changes in the dimension of individual cracks

These requirements were likewise met with the inclusion of fibre. Table 8 shows the cracks characteristics of composite fiber reinforced concrete.

Table 8: Fiber percentage used in mix proportion

Concrete mix	Total crack %	Avg crack pixels	Reduction of cracks intensity (%)	Composite fiber Steel + polypropylene fiber
F_1	15.6	153.9	-	0%
F_2	9.70	66.59	45	0.25% + 0.1%
F_3	0.30	10	99	0.5% +0.2%

5. Conclusion

The analysis of PSC by experimental research with an IoT based ML tool which shows the pixel of cracks developed in the test specimens. Following are the conclusion as per the result discussed above are observed:

1. The study shows that the effects of adding steel and polypropylene fibers in concrete mix design causes reduction in workability by 25 % and the permeability of concrete is decreased.
2. It is concluded that the use of 0.2%-0.5% (polypropylene and steel fibers) shows the reduction of plastic shrinkage cracks to upto 99% which is consider to be the most suitable composite fibers that can be used for rigid pavement structures.
3. The IoT based ML software provide the total numbers of plastic shrinkage cracks observed on the surface of the slab along with the horizontal and vertical changes in the cracks was plotted in image 8, which shows that by adding 0.1% & 0.25% of PP & SF, the numbers of cracks increases but with a very small in dimensions as compared to nominal mix also the reductions is plotted which defines the total change in cracks is decreasing when CF is added in nominal mix hence it is suggested to use the above mentioned CF percentage in the rigid pavement structure for optimum results.

- To find out the effect of steel fibers and polypropylene on workability and permeability of in fresh concrete.
- To analyze the effects of composite fibers on minimizing the potential cracking in concrete structures.
- To determine the use of AI tools for image detection in concrete pavement structures.

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