

# Experimental Investigation on Steel Fibre Reinforced Fly Ash (Class-C) Based Alkali Activated Geo-Polymer Concrete

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## Abstract

Geo-polymer concrete (GPC) are representing the most promising green and eco-friendly alternative to Ordinary Portland cement (OPC). This paper presents the results of an experimental program on the mechanical properties of steel fibres reinforced geo-polymer concrete (SFRGPC) such as Compressive strength, Split tensile strength, Flexural strength, Water absorption, Alkali attack, Acid attack and Abrasion resistance. SFRPGPC contains Fly ash (Class- C), alkaline liquids, fine aggregate, coarse aggregate and steel fibres. Alkaline liquid to fly ash ratio was fixed as 0.45 with 100% replacement of OPC. For alkaline liquid combination ratio of sodium silicate to sodium hydroxide solution was fixed as 2.5. Steel fibres was added to the mix in volume fractions of 0%, 0.25%, and 0.5% by volume of geo-polymer concrete. Specimens were subjected to air curing at room temperature. Based on the test results Compressive strength, Split tensile strength and Flexural strength showed maximum values for 0.5% dosage of steel fibre. Hence, it is concluded that the addition of 0.5% steel fibres dosage increase the strength of geo-polymer concrete which is due to the hooked end shape of steel fibres, which provide better adhesion between fibre and concrete and can be used in the marine environment.

**Keywords:** fly ash (Class C), steel fibre, flexural strength, compressive strength, split tensile test

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## 1. Introduction

In order to make construction industry greener/eco-friendly, there is a need to develop an alternate binding material which is comparable or even superior to cement. There is a demand to develop more eco-friendly new technology that utilizes new bonding materials to replace Ordinary Portland cement (OPC). Many Lignite industries produce huge amount of post process waste which are dumped in the environment, which leads to serious problems related to pollution of soil and water. This can be solved by using this waste for the production of new, eco-friendly materials. One such development is the production of geo-polymer concrete using Class -C fly ash from NLC Neyveli as the base for construction material. This reduces energy consumption in the manufacturing process. The findings of this study (Faiz et al, 2013), showed that the mechanical properties of short fibre reinforced geo-polymer composites. Geo-polymer concrete exhibits brittle behaviour due to its low tensile strength. Addition of fibres changes its brittleness to ductility with significant improvement in tensile strength, tensile strain, toughness and energy absorption capacities. The findings of this study (Mark et.al, 2014) showed that the properties of fibre reinforced geo-polymer concrete with ambient curing for in-situ applications. It was evident from the results that the addition of polypropylene fibres enhanced the compressive strength and the ductility of geo-polymer concrete. The findings of this study (Lembo et.al,2014), showed that the structural performance of geo-polymer concrete with FRP confinement and concluded that the ductility of geo-polymer concrete can be increased by fibre reinforced polymer (FRP) confinement. The findings of this study (Motohiro et al, 2014) showed that the feasibility of strain hardening fibre reinforced fly ash based geo-polymer composites. Crack width distributions were investigated by the Digital Image Correlation technique. The analysis indicated that the maximum and average crack widths are 117  $\mu\text{m}$  and 45  $\mu\text{m}$ , respectively, even at a high imposed strain level of 4.5%. Therefore, the feasibility of strain-hardening ductile geo-polymer composites was established. The findings of this study (Kinga Korniejenko et.al, 2015), showed that the properties of fly ash based fibre-reinforced geo-polymer composites as an environmental friendly alternative to cementitious materials. Results show that the appropriate addition of polypropylene fibres can improve the mechanical properties of geo-polymer composites.

## 2. Materials and methods

The materials used are Fly ash (Class-C), Fine aggregates, Coarse aggregate, Steel fibre and Alkaline solutions (NaOH and  $\text{Na}_2\text{SiO}_3$ ).

*2.1 Fly ash (Class-C)* The low calcium fly ash (class C) collected from Neyveli Lignite Corporation Limited, Tamil Nadu, India, was used as the source material for the preparation of geo-polymer concrete. The specific gravity of fly ash is 2.52. (Table 1) shows the properties of fly ash.

Table 1 Properties of Fly Ash Class - C

Properties	Fly Ash Class C
Silicon dioxide (SiO <sub>2</sub> ), aluminium oxide (Al <sub>2</sub> O <sub>3</sub> ) and iron oxide (Fe <sub>2</sub> O <sub>3</sub> ), min, %	50.0
Sulphur trioxide (SO <sub>3</sub> ), max, %	5.0
Moisture Content, max, %	3.0
Loss on ignition, max, %	6.0

**2.2 Fine aggregate:** Fine aggregate is defined as those materials that passes through 4.75mm sieve and will for the most part, be retained on a 75 $\mu$  sieve. In this work, India river sand is used as fine aggregate. The sand was washed and screened at site to remove deleterious materials.

**2.3 Coarse aggregate:** Coarse aggregate consists of river gravel, crushed stone or manufacturing aggregate with particle size equal to or greater than 4.75mm. In this research coarse aggregates of maximum size 10-12 mm were used and the specific gravity is 2.71.

**2.4 Steel Fibre:** Hooked end steel fibres were added to geo-polymer concrete to increase the crack resistance, flexibility, ductility and toughness of the concrete. It results in high tensile strength, improves load bearing capacity etc., The ending shapes of the fibre i.e., hooked end steel fibre are very important to grant adhesion between fibre and concrete. The length and diameter of steel fibres used is 30mm and 0.60mm. The aspect ratio is 50.

**2.5 Alkaline solution:** Sodium hydroxide solution mixed with Sodium silicate solution was used as an alkaline activator for geo-polymerization. The commercially available sodium hydroxide in the form of flakes was used in this study. Sodium silicate is in liquid form.

**2.6 X-ray diffraction:** X-Ray Diffraction (XRD) qualitatively identifies the crystalline phases of the fly ash sample. Electrons hit a solid sample and x-rays are emitted. When the x-rays hit a crystal structure, some x-rays diffract based on this crystal structure but other x-rays penetrate further into the sample until colliding into a crystal. The machine reads all of the angles of diffracted, scattered x-rays and their intensities to create a pattern. These patterns are plotted, creating a diffractogram, relating diffracted intensity to diffraction angle. The X-Ray Diffraction for Fly ash Class-C is represented in the form of graph in( Figure1)

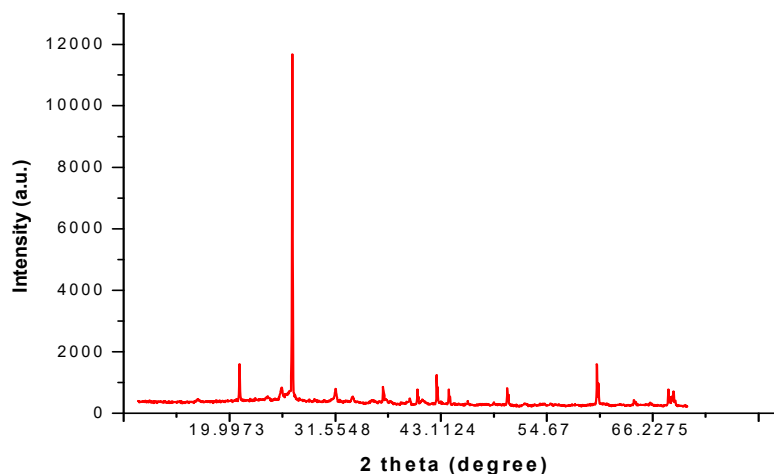


Figure 1 X-Ray Diffraction pattern for Class-C

X-Ray Diffraction studies were carried out for C-Class fly ash and the pattern confirms the presence of Al<sub>2</sub>O<sub>3</sub> and SiO<sub>2</sub> as predominant materials. The XRD pattern for C-Class fly ash illustrates that the main crystalline phases are quartz (JCPDS No. 89 - 1668) and mullite (JCPDS No. 88 - 0107) and the other crystalline phases present are hematite (Fe<sub>2</sub>O<sub>3</sub>) and calcium oxide (CaO). These patterns were matched with (JCPDS No. 89 - 7746) and (JCPDS No. 82 - 1690) respectively. These patterns were similar to the C-Class fly ash values recorded earlier. Very high intensity of calcium oxide in XRD pattern validates significant presence of calcium in C-Class fly ash. According to ACI (American Concrete Institute), the presence of quartz, hematite and calcium oxide increases strength and improves the durability of concrete.

### 3. Mix proportions

The following (Table 2) shows the mix proportions of geo-polymer concrete using fly ash (class-c) for one paver block.

Table 2 Mix proportions for one paver block

Mix	Fly ash [kg]	NaOH [kg]	Na <sub>2</sub> SiO <sub>3</sub> [kg]	Fine aggregate [kg]	Coarse aggregate [kg]	Water [kg]
M1 (0% Steel Fibre)	1.212	0.122 (8M)	0.307	1.65	3.868	0.67
M2 (0.25% Steel Fibre)	1.212	0.122 (8M)	0.307	1.65	3.868	0.67
M3 (0.50% Steel Fibre)	1.212	0.122 (8M)	0.307	1.65	3.868	0.67

**3.1 Specimen details:** Totally 96 blocks were casted and cured in room temperature for testing. The moulds were divided into three groups, M-1, M-2, and M-3 based on the dosage of steel fibres. Each mix consists of 32 moulds with different dosage of steel fibres. The paver block is in hexagonal shape of side 120 mm, area 37440 mm<sup>2</sup>, and thickness 80 mm. In addition to this, 2 cubes of each mix measuring 7cm x 7cm x 7 cm, are casted for abrasion test.

Measurements of one paver block:

Length (L/a) = 120mm

Height (h) = 80mm

Volume (v) = 0.00299 m<sup>3</sup>

Area (A) = 37440 mm<sup>2</sup>

**3.2 Preparation of alkaline solution:** The weighed quantity (480 g) of Sodium Hydroxide (NaOH) in the form of flakes to suit 8 Molarity (8M) is allowed to dissolve in distilled water and made up to one litre. By trial and error, 300 gms of NaOH solution can be obtained when 120 gms of NaOH flakes are mixed in a makeup jar of 250 ml.

**3.3 Casting the specimen:** First, the dry materials used for preparing geo-polymer concrete were mixed. Then alkaline solution and the required extra water were mixed. Machine oil was tarnished and the freshly mixed geo-polymer concrete was placed into the paver mould. Each mould was then vibrated for 15 seconds using a mechanical vibrator. After the top surface was leveled the moulds were left at room temperature for ambient curing. (Figure 2) shows the casted specimens. (Table 3) shows the number of specimen cast.

Table 3 Number of specimen casted for specified test

Name of the test	Mix 1	Mix 2	Mix 3
Compression strength	12	12	12
Split tensile strength	6	6	6
Flexural strength	6	6	6
Acid attack (Sulphuric acid 5%)	2	2	2
Alkali attack (Sodium hydroxide 4%)	2	2	2
Water absorption	3	3	3
Abrasion (7 cm X 7cm X 7cm cube)	2	2	2
Total number of blocks casted	32	32	32



**Figure 3 Casted specimen**

#### **4. Testing of specimens**

As per the IS 15658:2006 the following tests were performed to determine its strength.

*4.1 Compressive strength test:* For each mix proportions, nine paver blocks were tested, using compression testing machine of 3000kN capacity as per IS 15658:2006 code.

*4.2 Split tensile strength test:* The test was carried out along the longest splitting section of the specimen, parallel and symmetrical to the edges, in such a way that the distance of the splitting section to any side face was at least 0.5 times the thickness of the specimen over at least 75 percent of splitting section area. Since the section of the specimen is hexagonal in plan, the splitting section was chosen in such a way that it was the shortest length passing through the centre of the plan area.



**Figure 4 Failure blocks of compressive strength test, Split tensile test, Flexural strength test respectively**

*4.3 Flexural strength test:* As per IS 15658:2006 the load was applied from the top of the specimen in the form of a simple beam loading through a roller of diameter of 25mm placed midway between the supporting rollers. The load was applied without shock and increased at a uniform rate of 6 kN/min. (Figure 4) shows the failure block of compressive strength, Split tensile strength, Flexural strength test respectively.

*4.4 Water absorption test:* The specimen was weighed initially and was completely immersed in water at room temperature for 28 days. Then the specimen was removed from water and dried in room temperature for 24 hours. The dried specimen was weighed and with this noted weights water absorption percentage was calculated. (Figure 5) shows the water absorption test.

*4.5 Alkali attack test:* Initially weight of the specimen was noted. Alkaline solution is prepared in a container by dissolving 4% of sodium hydroxide in water. The specimen was completely immersed in alkaline solution and the whole setup was kept in room temperature for 28 days, after which the specimen was removed from the solution and dried in room temperature for 24 hours. The dried specimen was weighed and using this noted weights alkali attack percentage was calculated.

*4.6 Acid attack test:* Initially the weight of the specimen was noted. Acid solution was prepared in a container by mixing 5% of concentrated sulphuric acid in water. The test specimen was completely immersed in acid solution and the whole setup was kept in room temperature for 28 days. Then the specimen was removed from the solution and dried in room temperature for 24 hours. The dried specimen was weighed and using this noted weights acid attack percentage was calculated. (Figure 6) shows the alkali attack test, acid attack test.



Figure 5 Water absorption test

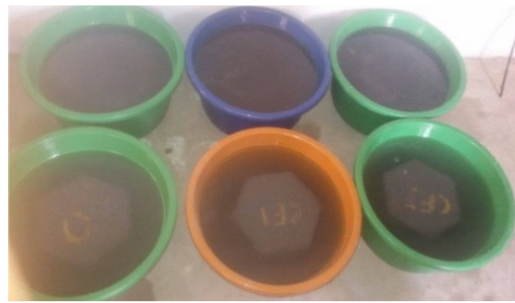


Figure 6 alkali attack and acid attack test

**4.7 Abrasion test:** Two cubes of 7cm x 7cm x 7cm were cast in each mix and cured in room temperature for 28 days. The initial dry weight was noted. The weighed, dry specimen was placed on the specimen carrier with the surface to be tested facing the nozzle tip. The nozzle tip was at the middle of the half side of the cube. Then the number of rotations of the cradle was set as 25 and the machine was started. After 25 rotations the sample was removed, cleaned and weighed to determine the loss of mass in grams of the sample. (Figure 7) shows the failure block after abrasion test.



Figure 7 Failure block after Abrasion test

## 5. TEST RESULTS

The results obtained by conducting various experiments are presented here.

### 5.1 Compressive strength, Split tensile strength and Flexural strength

The casted paver blocks have been tested for compression, split tension and flexure. The results of compressive strength test, split tensile strength test and flexural strength test are tabulated in (Table 4) and represented as bar chart in Figures ( 8, 9 & 10) respectively.

Table 4 Compressive strength, Split tensile strength and Flexural strength in N/mm<sup>2</sup>

	Compressive Strength			Split Tensile Strength			Flexural Strength		
	0% steel Fibre	0.25% steel Fibre	0.5% steel Fibre	0% steel Fibre	0.25% steel Fibre	0.5% steel Fibre	0% steel Fibre	0.25% steel Fibre	0.5% steel Fibre
<b>Specimen Designation</b>	M-1	M-2	<b>M-3</b>	M-1	M-2	<b>M-3</b>	M-1	M-2	<b>M-3</b>
<b>7<sup>th</sup> Day</b>	18.41	19.72	<b>21.65</b>	-	-	-	-	-	-
<b>14<sup>th</sup> Day</b>	20.08	22.15	<b>24.61</b>	0.40	0.54	<b>0.74</b>	2.63	2.92	<b>3.03</b>
<b>28<sup>th</sup> Day</b>	21.42	23.44	<b>26.20</b>	0.56	0.80	<b>0.90</b>	3.17	3.33	<b>3.81</b>

The Compression Strength test for paver block has been carried out. From the above result it is absorbed that compressive strength is maximum when 0.5% steel fibre is used. This indicates that compressive strength increases with addition of steel fibres. As the maximum compressive strength is 26.20 N/mm<sup>2</sup>, this geo-polymer concrete can be used where M<sub>20</sub> grade concrete.

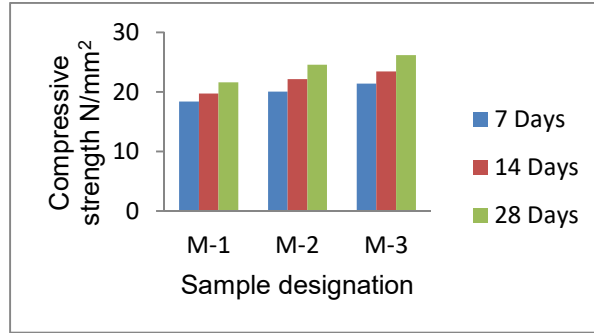


Figure 8 Compressive Strength

The Split Tensile test has been carried out for paver block in shortest length passing through center area. From the above result it is absorbed that the split tensile strength is maximum when 0.5% steel Fibre is used. This indicates that split tensile strength increases with addition of steel Fibres. From the above result, the maximum split tensile strength obtained is 0.90 N/mm<sup>2</sup>.

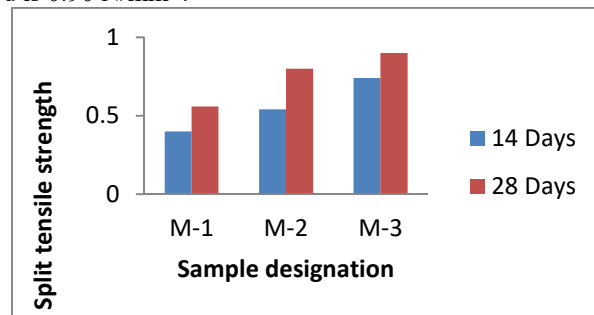


Figure 9 Split tensile Strength

The Flexural strength test for paver block has been carried out. From the above result it is absorbed that the Flexural strength is maximum when 0.5% steel Fibre is used. This indicates that Flexural strength increases with addition of steel Fibres. From the above result, the maximum Flexural strength obtained is 3.81 N/mm<sup>2</sup>.

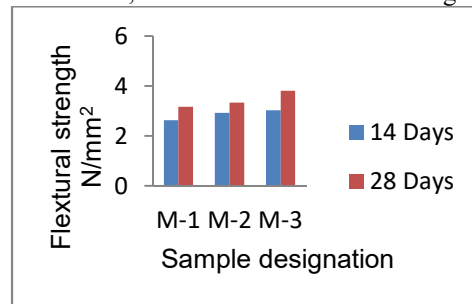


Figure 10 Flexural strength Comparison chart

5.2 *Water absorption percentage*: The water absorption test for paver block has been carried out and the results are tabulated in Table 5 and represented graphically in (Figure 11). The overall average of water absorption percentage is= 1.29%. As the overall water absorption percentage is less than 10%. This geo-polymer concrete can be used for construction.

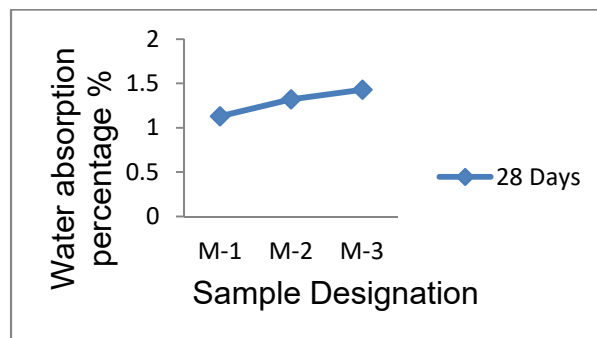


Figure 11 Water absorption

**5.3 Alkali attack percentage:** The alkali attack test for paver block has been carried out and the results are tabulated in (Table 5) and represented graphically in (Figure 12). The overall average of alkali attack percentage is = 2.57 %.As the overall alkali attack percentage is less than 10 %. This geo-polymer concrete can be used for construction

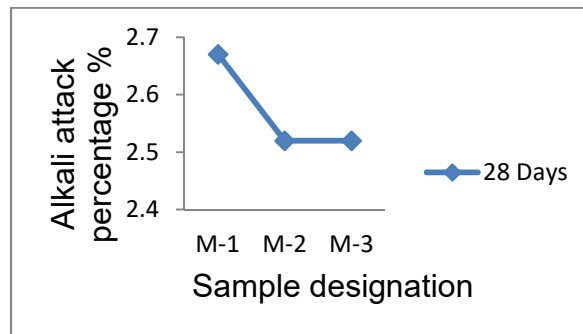


Figure 12 Alkali absorption

Table 5 % of Water absorption, % of Alkali attack and % of Acid attack

	% of Water Absorption			% of Alkali Attack			% of Acid Attack		
	0% steel Fibre	0.25% steel Fibre	0.5% steel Fibre	0% steel Fibre	0.25% steel Fibre	0.5% steel Fibre	0% steel Fibre	0.25% steel Fibre	0.5% steel Fibre
<b>Specimen Designation</b>	M-1	M-2	M-3	M-1	M-2	M-3	M-1	M-2	M-3
<b>Initial Weight (kg)</b>	5.727	6.004	5.818	5.811	5.881	5.709	5.743	6.064	5.934
<b>Final Weight after 28 days (kg)</b>	5.792	6.083	5.901	5.966	6.029	5.853	5.498	5.821	5.697
<b>% of Water Absorption</b>	1.13	1.32	1.43	2.67	2.52	2.52	4.27	4.01	3.99

**5.4 Acid attack percentage:** The acid attack test for paver block has been carried out and the results are tabulated in (Table 5)and represented graphically in (Figure 13). The overall average of acid attack percentage is = 4.09 %. As the overall acid attack percentage is less than 10 % This geo-polymer concrete can be used for construction.

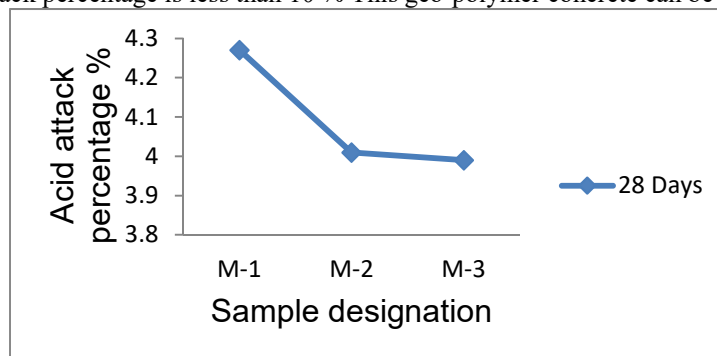


Figure 13 Acid absorption

**5.5 Abrasion loss percentage:** The abrasion test for cube specimen has been carried out and the results are tabulated in (Table 5) and represented graphically in (Figure 14).The overall average of abrasion loss percentage is = 0.413 %. As the overall abrasion loss percentage is less than 10 %. This geo-polymer concrete can be used for construction.

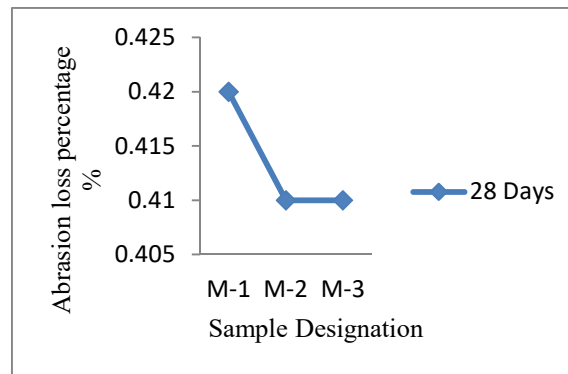


Figure 14 Abrasion loss percentage graph

Table 6 Abrasion loss in percentage

Fibre dosage	0% steel Fibre	0.25% steel Fibre	0.5% steel Fibre
Sample designation	M-1	M-2	M-3
Initial Weight Before testing(kg)	0.594	0.610	0.606
Final Weight after testing(kg)	0.592	0.608	0.604
% of Abrasion loss (%)	0.42	0.41	0.41

## 6. CONCLUSION

The addition of steel fibre dosage increases the strength of geo-polymer concrete which is due to the hooked end shape of steel fibre, which provides better adhesion between fibre and concrete. The addition of 0.5 % of steel fibre dosage gave maximum compressive strength of 26.2 N/mm<sup>2</sup>. Hence it is concluded that this geo-polymer concrete can be used where M20 grade concrete is used.

Also split tensile and flexural strength results showed maximum values for the same dosage of steel fibre. Since the overall water absorption percentage, alkali attack percentage and acid attack percentage values are less than 10% it is concluded that this geo-polymer can be used for construction purpose.

Hence, from the results obtained the author concludes that this geo-polymer concrete with steel fibre reinforcement containing Class-‘C’ fly ash can be used for normal construction purpose and thereby we can reduce the carbon-di-oxide (CO<sub>2</sub>) emission during the usage of conventional concrete.

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