

# The use of paper sludge as a self-curing agent in concrete - Experimental laboratory-based comparative study.

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## Abstract

### Background

Self-curing concrete has gained attention due to limitations in conventional curing practices and increasing water scarcity. Internal curing using waste materials offers a sustainable alternative. Paper sludge, a by-product of the pulp and paper industry, has high water absorption capacity and potential as an internal curing agent.

### Methods

An experimental study was conducted using paper sludge as a self-curing agent in M20 grade concrete. Four sludge-to-water ratios (1:7, 1:9, 1:11, and 1:15) were evaluated. Specimens were subjected to two curing conditions: conventional water curing and self-curing. Mechanical properties, including compressive strength, split tensile strength, and flexural strength, were tested at 3, 7, and 28 days as per relevant Indian Standard codes.

### Results

Concrete incorporating paper sludge demonstrated improved performance compared to conventional concrete under self-curing conditions. The 1:15 ratio showed the highest strength, with compressive strength reaching 29.19 N/mm<sup>2</sup> under normal curing and 23.66 N/mm<sup>2</sup> under self-curing at 28 days. Split tensile strength and flexural strength also showed similar trends, with maximum values of 5.12 N/mm<sup>2</sup> and 8.30 N/mm<sup>2</sup>, respectively, under normal curing. Self-cured specimens showed slightly reduced but comparable strength values.

### Conclusion

Paper sludge can effectively function as an internal curing agent, improving strength characteristics and reducing dependency on external curing.

### Recommendation

Utilization of paper sludge in concrete can support sustainable construction practices and waste management. Further studies on durability and long-term performance are recommended.

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**Keywords:** Self-curing concrete, Paper sludge, Internal curing, Compressive strength, Sustainable construction

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## Introduction

Concrete is the most extensively used construction material due to its compressive strength, durability, and adaptability to different structural requirements. The performance of concrete is strongly influenced by curing, which ensures adequate hydration of cement and development of mechanical properties. Inadequate curing has been associated with reduced strength, increased permeability, and poor durability of concrete structures [1,2].

Conventional curing methods rely on external water application, which is often inconsistently practiced at construction sites due to limitations in water availability, labor constraints, and environmental conditions. Insufficient curing leads to incomplete hydration and

microstructural deficiencies, affecting long-term performance [3,4].

Internal curing has emerged as an alternative approach to address these limitations. This method involves incorporating materials capable of absorbing and gradually releasing water within the concrete matrix, thereby maintaining internal moisture levels and sustaining hydration [5,6]. Materials such as lightweight aggregates and super-absorbent polymers have been reported to improve hydration efficiency, reduce autogenous shrinkage, and enhance mechanical properties [7,8].

The growing emphasis on sustainable construction has encouraged the use of industrial by-products as alternative materials in concrete. The pulp and paper industry generates large volumes of waste, particularly paper

sludge, which presents disposal challenges. Paper sludge consists primarily of cellulose fibers, inorganic fillers, and residual chemicals and exhibits high water absorption capacity, making it suitable for internal curing applications [9,10].

Previous investigations have demonstrated that waste-derived materials can be effectively utilized in concrete to improve sustainability while maintaining or enhancing performance. Internal curing agents have been shown to improve hydration kinetics, reduce shrinkage, and enhance strength development when appropriately incorporated [11,12].

Despite these advancements, limited studies have evaluated the direct use of paper sludge as a self-curing material in conventional concrete mixes. Understanding its influence on mechanical properties under different curing conditions is essential for assessing its practical applicability.

The present study was designed to evaluate the effectiveness of paper sludge as a self-curing agent in M20 grade concrete. The investigation focuses on compressive strength, split tensile strength, and flexural strength under both normal curing and self-curing conditions [13–15].

## Materials and methods

### Study design and setting

This investigation was conducted as an experimental laboratory-based comparative study to evaluate the effectiveness of paper sludge as an internal self-curing agent in concrete.

The study was carried out in the Concrete and Materials Testing Laboratory, Department of Civil Engineering, AVS Engineering College, Salem, Tamil Nadu, India. All experimental procedures, including specimen preparation, curing, and testing, were performed under controlled laboratory conditions in accordance with relevant Indian Standard (IS) codes. The experimental procedures, including specimen casting, curing, and compressive strength testing at 3, 7, and 28 days, were carried out within a defined timeline. Specimens were cast on 17 October 2025, followed by 7-day testing on 24 October 2025 and 28-day testing on 14 November 2025.

### Materials used

Concrete was prepared using conventional constituents along with paper sludge as an internal curing agent.

### Cement

Ordinary Portland Cement (OPC) of 53 grade (Priya Cement) was used.

### Coarse aggregate

Crushed angular granite aggregate of 20 mm size was used.

### Fine aggregate

Locally available natural river sand conforming to Zone II was used.

### Paper sludge

Paper sludge obtained from the pulp and paper industry was used as a self-curing agent due to its high water absorption capacity. The material was oven-dried for 24 hours to achieve constant mass before use.

### Mix proportions and preparation

Concrete mix design was carried out as per IS 10262:1982 for M20 grade concrete.

Four different sludge-to-water ratios were adopted:

- 1:7
- 1:9
- 1:11
- 1:15

Paper sludge was incorporated by replacing mixing water in terms of water–cement ratio, based on its consistency characteristics.

### Consistency and setting time tests

Consistency, initial setting time, and final setting time were determined for each sludge ratio using standard procedures.

The sludge ratio of 1:15 exhibited consistency comparable to conventional water, while lower ratios (1:7 and 1:9) showed increased consistency and prolonged setting times.

### Specimen preparation and curing conditions

Concrete specimens were cast for each sludge ratio and subjected to two curing conditions:

1. Normal water curing
2. Self-curing (no external water supply)

Specimens were demoulded after 24 hours and tested at 3, 7, and 28 days.

### Mechanical testing procedures

#### Compressive strength

Cube specimens of size 150 × 150 × 150 mm were tested as per IS 516:1959. Load was applied axially until failure, and compressive strength was calculated using the ratio of failure load to the cross-sectional area.

#### Split Tensile Strength

Cylindrical specimens of 150 mm diameter and 300 mm height were tested as per IS 5816:1970. The load was applied diametrically until failure.

### Flexural strength

Beam specimens of size 500 × 75 × 75 mm were tested using the third-point loading method as per IS 516:1959. The span length and loading conditions were maintained according to standard recommendations.

### Quantitative variables

The primary outcome measures were:

- Compressive strength (N/mm<sup>2</sup>)
- Split tensile strength (N/mm<sup>2</sup>)
- Flexural strength (N/mm<sup>2</sup>)

For each test condition, three specimens were evaluated, and the mean values were calculated. Variability was assessed using range and standard deviation, where applicable.

Strength values were compared across different sludge ratios and between curing conditions to determine performance differences.

### Statistical analysis

Descriptive statistics were used to summarize the experimental results. Data were expressed as mean ± standard deviation (SD).

Comparative evaluation between groups was performed using:

- Mean differences between sludge ratios
- Percentage variation relative to the control mix

Where applicable, one-way analysis of variance (ANOVA) may be used to assess statistical significance among groups, with a significance level set at  $p < 0.05$ .

### Results

#### Compressive strength

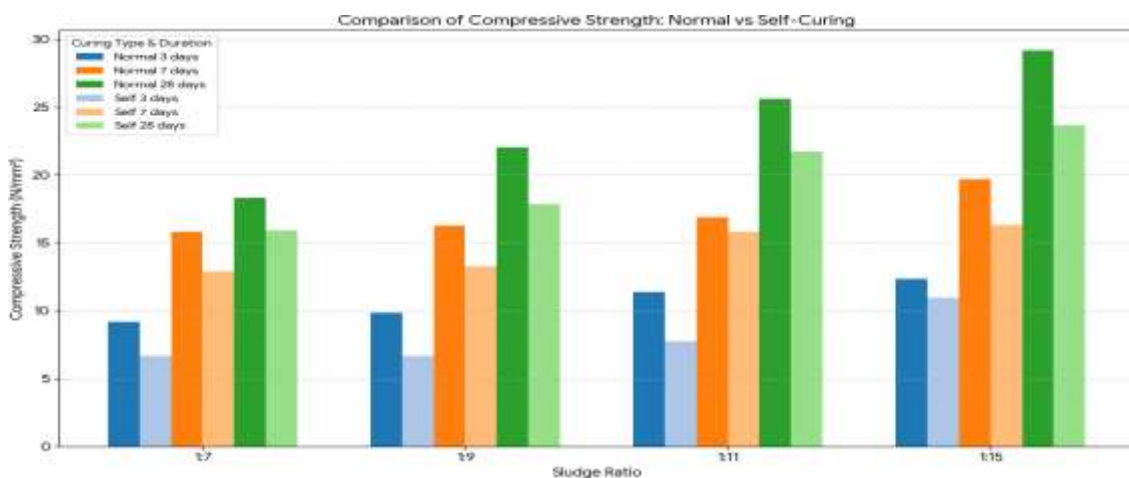
The compressive strength of concrete with paper sludge as a self-curing agent by means of normal curing and self-curing specimens was tested at the ages of 3days, 7days and 28 days. The results were shown in table 1

**Table 1: Compressive strength of concrete using paper sludge as a self-curing agent**

Sludge ratio	Compressive Strength (N/mm <sup>2</sup> )					
	Normal Curing			Self-Curing		
	3 days	7 days	28 days	3 days	7 days	28 days
1:7	9.20	15.82	18.30	6.67	12.90	15.90
1:9	9.84	16.28	22.05	6.69	13.26	17.85
1:11	11.38	16.90	25.60	7.75	15.80	21.73
1:15	12.36	19.70	29.19	10.97	16.34	23.66

The results shows that the compressive strength of 1:15 ratio concrete with paper sludge as a self-curing agent is 29.19N/mm<sup>2</sup>. It is 1.5 times that of the nominal concrete when it is in normal curing. The compressive strength of self-curing is 23.66N/mm<sup>2</sup>, which is higher than the nominal concrete. The graph in Figure 1 shows a detailed

report about the compressive strength of paper sludge concrete with the two different curing conditions, self-curing and normal curing for 3days, 7days and 28 days. As in both conditions, 1:15 ratios give higher strength than other mix ratios.



**Fig 1 Compressive strength of concrete by using paper sludge as a self-curing agent**

### Split tensile strength

The results of the split tensile strength of concrete with paper sludge as a self-curing agent, using both normal

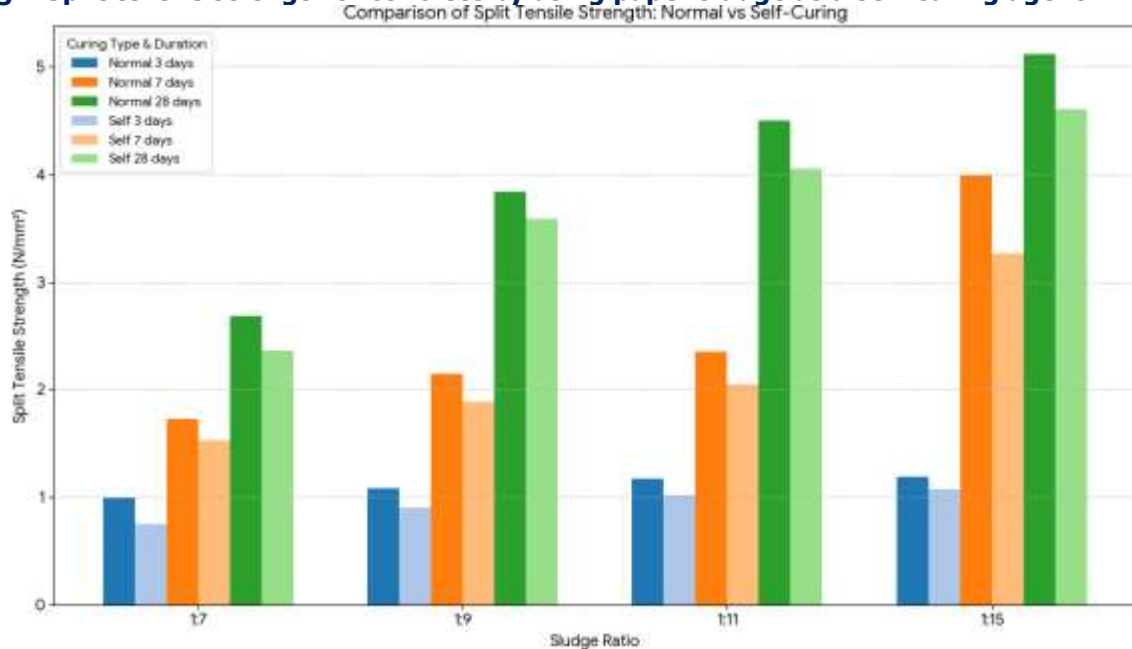
curing and self-curing specimens, were tested at ages of 3 days, 7 days, and 28 days, as shown in Table 2. The results show that the split tensile strength of 1:15 ratio concrete with paper sludge as a self-curing agent at the age of 28

days was 5.12N/mm<sup>2</sup> with full water curing and 4.61N/mm<sup>2</sup> with self-curing, which gives better results than the nominal concrete

**Table 2: Split tensile strength of concrete by using paper sludge as a self-curing agent**

Sludge ratio	Split Tensile Strength (N/mm <sup>2</sup> )					
	Normal Curing			Self-Curing		
	3 days	7 days	28 days	3 days	7 days	28 days
1:7	0.99	1.73	2.68	0.75	1.53	2.36
1:9	1.08	2.15	3.84	0.90	1.89	3.59
1:11	1.17	2.35	4.50	1.02	2.05	4.05
1:15	1.19	3.99	5.12	1.07	3.27	4.61

**Fig 2 Split tensile strength of concrete by using paper sludge as a self-curing agent**



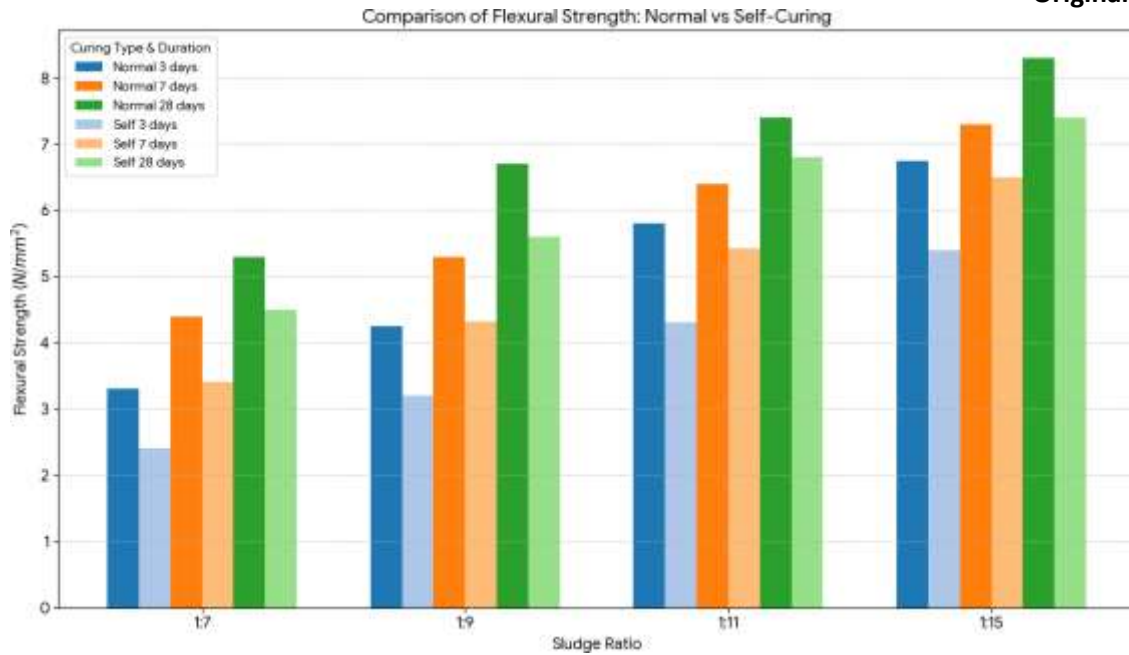
### Flexural strength

The results of flexural strength of concrete with paper sludge as a self-curing agent by means of normal curing

and self-curing specimens were tested at the ages of 3days, 7 days, and 28 days, and are shown in Table 3 and Fig 3.

**Table 3: Flexural strength of concrete using paper sludge as a self-curing agent**

Sludge ratio	Flexural Strength (N/mm <sup>2</sup> )					
	Normal Curing			Self-Curing		
	3 days	7 days	28 days	3 days	7 days	28 days
1:7	3.30	4.40	5.30	2.40	3.40	4.50
1:9	4.25	5.30	6.70	3.20	4.32	5.60
1:11	5.80	6.40	7.40	4.30	5.42	6.80
1:15	6.74	7.30	8.30	5.40	6.50	7.40



**Fig 3 Flexural strength of concrete by using paper sludge as a self-curing agent**

The results in Figure 3 show that the flexural strength of 1:15 ratio concrete with paper sludge as a self-curing agent at the age of 28 days was 8.30 N/mm<sup>2</sup> with full water curing and 7.40 N/mm<sup>2</sup> with self-curing, which

gives better results than the nominal concrete. The manufacturing process and testing process of the concrete with paper sludge as a self-curing agent are shown by means of an image format as follows,



**Fig 4 Casting of concrete cubes by using paper sludge as a self-curing agent**



**Fig 5 Casting of concrete cubes by using paper sludge as a self-curing agent**



**Fig 6 Casting of concrete cylinders & prism using paper sludge as a self-curing agent**



**Fig 7 Split Tensile testing of concrete by using paper sludge as a self-curing agent**



**Fig 8 Compressive strength testing of concrete by using paper sludge as a self- curing agent**



**Fig 9 Curing of concrete cubes for normal concrete**

### Discussion

The findings of this study demonstrate that paper sludge can function as an effective internal curing agent in concrete. Among the evaluated mix proportions, the 1:15 sludge-to-water ratio consistently exhibited superior performance across compressive, split tensile, and flexural strength tests. This improvement is attributed to the ability of paper sludge to retain water and gradually release it during hydration, thereby sustaining internal moisture levels [16,17].

Internal curing mechanisms have been extensively documented, where materials with high absorption capacity act as reservoirs of water within the cement

matrix. These materials release moisture over time, reducing self-desiccation and promoting continued hydration, which contributes to improved microstructural development and strength gain [18,19].

The observed trend of increasing strength with higher sludge ratios indicates that adequate internal water availability plays a critical role in hydration kinetics. Similar findings have been reported in studies using lightweight aggregates and other internal curing agents, where enhanced hydration led to improved strength and reduced shrinkage [20,21].

Although specimens subjected to self-curing showed slightly lower strength compared to those under conventional water curing, the differences were not

substantial. This suggests that internal curing using paper sludge can compensate, to a considerable extent, for inadequate external curing. Comparable observations have been reported in studies involving self-curing concrete, where internal water supply supported hydration even in the absence of continuous external curing [22,23]. The results also align with earlier studies, which indicate that internal curing reduces the risk of early-age cracking by minimizing autogenous shrinkage and maintaining internal relative humidity within the concrete matrix [24, 25]. This effect is particularly significant in mixes with lower water–cement ratios, where self-desiccation can adversely affect hydration.

From a sustainability perspective, the use of paper sludge contributes to waste utilization and reduces the environmental burden associated with landfill disposal. Previous research has emphasized the potential of incorporating industrial by-products in construction materials to promote sustainable development while maintaining structural performance [26,27].

Despite these advantages, certain limitations must be considered. The variability in the composition of paper sludge depending on its source may influence its performance as an internal curing agent. In addition, long-term durability characteristics, including permeability, chemical resistance, and shrinkage behavior, were not evaluated in this study [28,29].

Further investigations focusing on durability performance, microstructural analysis, and field-based validation are required to establish the broader applicability of paper sludge in concrete construction.

## Conclusion

Utilization of paper sludge as an internal curing agent results in good strength. The compressive strength of 1:11 and 1:15 was more effective than the other two ratios. The result of a 1:15 ratio gives a result for self-curing at a maximum of 23.66 N/mm<sup>2</sup> compared to the other two ratios, the consistency and initial setting time of 1:7 and 1:9 have been increased in the paper sludge concrete, and also, there is a minimum strength loss. This 1:11 ratio has comparatively higher strength than the control concrete, but the consistency, which is the water-cement ratio, is high compared to the 1:15 ratio and the control concrete. When it's cured with water, the strength of a 1:15 ratio is 29.19N/mm<sup>2</sup> at 28 days, and 1:11 gives 25.60 N/mm<sup>2</sup> at 28 days. The results of split tensile strength for 1:15 ratio paper sludge concrete at the age of 28 days were found to be 5.12N/mm<sup>2</sup> with normal curing and 4.61N/mm<sup>2</sup> with self-curing. The results of flexural strength for 1:15 ratio paper sludge concrete at the age of 28 days were found to be 8.3N/mm<sup>2</sup> with normal curing and 7.4N/mm<sup>2</sup> with self-curing. From these results, the paper sludge was used as a self-curing agent to attain the approximate strength for 1: 15 ratios. The nominal mix of M20 grade gives 20 to 23.66 N/mm<sup>2</sup> strength when it is with paper sludge as a self-curing agent. Therefore, we can also use the paper sludge as a self-curing agent in concrete.

## Limitations

- The investigation was limited to laboratory-controlled conditions, which may not fully represent field environments.
- Only M20 grade concrete was evaluated; results may vary with higher strength grades.
- The study focused primarily on mechanical properties, without assessing long-term durability parameters such as permeability, shrinkage, or chemical resistance.
- Variability in the composition of paper sludge from different sources was not considered.
- Statistical analysis was limited to descriptive methods, and advanced inferential comparisons were not performed.

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## List of abbreviations

**PSC** – Paper Sludge Concrete

**OPC** – Ordinary Portland Cement

**IS** – Indian Standard

**M20** – Grade of concrete with characteristic strength of 20 MPa

w/c ratio – Water–cement ratio

**SD** – Standard Deviation

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## Conflict of interest

The authors declare that there are no conflicts of interest related to this study.

## Authors' contributions

**Vignesh Eswaran Sivalingam:** Conceptualization, experimental work, data collection, and manuscript drafting

**Vijayanand Mathialaghan:** Study design, supervision, data validation, and critical revision of the manuscript

**Valarmathi Matheswaran:** Methodology support, data analysis, and manuscript editing

All authors have reviewed and approved the final version of the manuscript.

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## Data availability statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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