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EXPERIMENTAL INVESTIGATION OF ADVANCED SMART CONCRETE CURING BY APPLICATION OF INTERNET OF THINGS (IOT) TECHNOLOGY

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ABSTRACT
The major issue today is a lack of fresh water. For the combination and curative of concrete in production, drinkable water is necessary. It takes 28 days to complete the curing process. So there is a huge need for water in the construction industry for curing purposes. Potable water is becoming less and less available every day for a number of reasons. Therefore, a substantial sum of money must be spent on the purchase of water. Advanced technology must be used to utilize water in a forbidden way in order to reduce the amount of water wasted throughout the healing process. A moisture sensor is used to design the smart concrete curing system, which would automatically water supply for curing based on the amount of moisture present in the concrete and the ambient temperature. Utilizing Wi-Fi, the scheme will be linked to the internet. The concrete building's present level of dampness content and the status of the pumps will be uploaded to the cloud. This data will be accessed via a mobile app in the cloud. In order is to monitor the curing process for jute bags, IOT devices & water. Results have demonstrated that the strength of the cube after 7, 14, and 28 days with a SCC is greater than the cube strength after curative use of an IOT device.

Keywords: Concrete, IoT, Compressive strength, water

INTRODUCTION
Concrete's versatility, strength, durability, and flexibility make it a popular building material. Since the hydration result among water moreover cement occurs during the concrete hardening process, effective concrete curing is necessary to achieve its optimal performance. The temperature during hardening and the moisture level of the concrete are two important factors affecting the concrete's quality. Temperature controls the rate of the reaction, while moisture content indicates how well-hydrated all cement particles are during the setting phase.

It is crucial to continuously regulate the moisture, temperature, & environmental factors of the air around hardening concrete (HC) in order to keep the required levels of dampness content and temperature. It is important to prevent water disappearance, which is closely related to wind speed, humidity, and dryness. Curing is the process of keeping freshly put concrete at a constant temperature and moisture level. Concrete that has just been poured down could have less moisture in it thanks to evaporation. The ACI monograph can be used to assess the rate of evaporative water loss. No matter where the evaporation takes place, the projected evaporation rate is appropriate to both the evaporation of water that drips & the disappearance from a moist or soaking hardening concrete exterior. The rate of hydration increases with increasing temperature. High temperatures can speed up the hydration process, but because the hydration procedure doesn't fully develop at first, the near the beginning final strength of concrete is low down. There are currently available concrete curing techniques that, besides other things, including immersion, ponding, sprinkle, & wet cloth covering, preserve the concrete's dampness content with warmth at appropriate levels. The challenges in monitoring and managing the necessary ambient moisture and temperature conditions are these classical curing processes' limits, though. The construction team typically keeps daily records of the environmental data and the actions necessary to cure freshly put concrete. Given how a great deal activity and record-keeping are constantly needed on a normal edifice site, obtaining a precise master dataset in this way be able to be difficult in addition to time-consuming.

The project effort presents IoT healing, as stated in the abstract. Water is becoming more and more necessary in today's world, and old techniques of curing now require more and more water. When improved concrete curing is used, less water is needed to cure the concrete. Less time is needed for Internet of Things device healing, and a real-time tracking mechanism is offered. As a result, we must adopt cube casting and strength finding as an advanced cure method, using less water than usual at 7, 14, and 28 days for cube cure and strength finding.

LITERATURE REVIEW

King-Chi Lo, (2021) According to a study, there is a lot of dissimilarity in the curing regimes that an assortment of concrete pours experience, which makes it difficult to manage the curing environment and provide regular monitoring, reducing the efficiency of the CC curing procedure on site. This study investigated a sensor-based Internet of Things concrete curing control system to check and control the dampness content of HC to levels appropriate for high-quality HC. Based on on-site research, the effectiveness of this IoT technology was in contrast to the efficacy of conventional therapeutic techniques. In terms of how well concrete cures and how much time is needed for supervision, the technique created performs better than the traditional approach (P. 1-13) [1].

According to Natt Makul, (2020) concrete is the instant most inspired substance in the world subsequent to water. It is also the generally used building substance. However, a number of environmental disadvantages outweigh its benefits as a result of how it is produced, transported, or used. Because of its inherent fragility, concrete has poor tensile strength, strain characteristics, and crack resistance. Recent research has concentrated on enhancing the qualities of concrete using cutting-edge approaches including fibres, admixtures, and additional cementitious elements. Components with better mechanical and durability strength are required for modern building infrastructure (P. 1-25) [3].

For Sri Rama Chand Madduru, (2020) recent years have seen an upsurge in study on interior curative in concrete to allow for high water preservation ability. Concrete's strength and durability are directly impacted by the critical process of curing. The result of hydrophilic with hydrophobic compounds as self-curing chemicals in HCC is evaluated in the current research. It was found that, compared to a non-cured instance both curing chemicals worked improved at both curing warmth settings. According to the research's conclusions, liquid paraffin wax and polyethylene glycol should be present in cement at optimal amounts of 1.0% and 0.1%, respectively (P. 1-7) [5].

The author of this work has provided a wide range of structural health monitoring alternatives that are now under investigation to lecture to the consistency of concrete infrastructures at a diversity of stages of their repair life. Recent developments in the field of sensors designed to check the health of concrete infrastructure are described in this overview. In this article, Shima Taheri, (2019), looks into sensors that are designed to measure things like temperature, humidity pH rate of corrosion, along with stress or strain. The sensors are specifically made using wireless, Bragggrating, the piezoelectric electrochemical & self-sensing technologies. The numerous advantages and disadvantages of created concrete monitoring sensors, as well as unresolved research issues, will be covered in this presentation. These examples range from laboratory concepts to commercial devices (492-509) [13].

A new embedded sensor apparatus for tracking concrete curing is designed, built, and tested by Joaqun Cabezas and Trinidad Sánchez-Rodrguez (2018). A unique measure has been put in place to resist the hostile environment without changing the variables being measured. A real-time monitoring programmed is also part of the system, and it is controlled by a remote computer in the centre. The testing process is divided into two stages: the first is carried out in the laboratory to verify the actual need of the device, and the second is carried out at the actual construction site to evaluate the functionality of the device, such as range durability and flexibility. A cheap, incredibly reliable, compact, non-destructive solution was created after the devices were successfully used (P. 1-17) [15].

RESEARCH GAP

Annually, 4.4 billion tonnes of concrete are produced worldwide. Curing huge quantities is an important task in various weather and temperature conditions as they change so rapidly. Also, the relationship between materials (concrete) and the environment is not intuitive. However, no tool is specific enough to derive the perfect curing practises on-site. Hence, there is a need to invent a site-specific tool that can be used during construction for exact curing. An advanced curing device using sensors that can monitor curing at the site with real-time data availability is the need of the hour. Further, the difficulties of traditional curing, i.e., supervising and controlling, can be erased.

OBJECTIVES

1. Water –The need for fresh water is rising day by day and we have limited resources. The IoT device will detect moisture at the concrete surface and help quantify the presence of moisture at the surface of the concrete during the hydration process.
2. To use an IoT device to show the concrete's enhanced rate of growth in compressive strength (CS) at 7, 14, and 28 days.
3. To get real-time data about the concrete for initial stages such as moisture on the surface and temperature.
4. To overcome the constraints of typical concrete curing systems & monetary benefit by saving water on site and reuse of the device

PROBLEM STATEMENT

Concrete can only be made strong and durable by properly curing it. Throughout the hydration process, it is crucial to preserve the appropriate humidity level in the concrete. Cracks that compromise the strength and longevity of the concrete are lessened by curing. Thus, curing is a crucial step in the construction of concrete structures. Since water is scarce, it is very important to protect water and use it as management infrastructure.

METHODOLOGY

In this study, we have learned the first conventional methods of concrete curing. Concrete curing is one of the most important parts of construction. So, concrete curing should be done properly. As we saw in the problem statement, the use of water should be controlled, and that's what we are going to do in this study. In this study, a new technique is to be used for concrete curing.

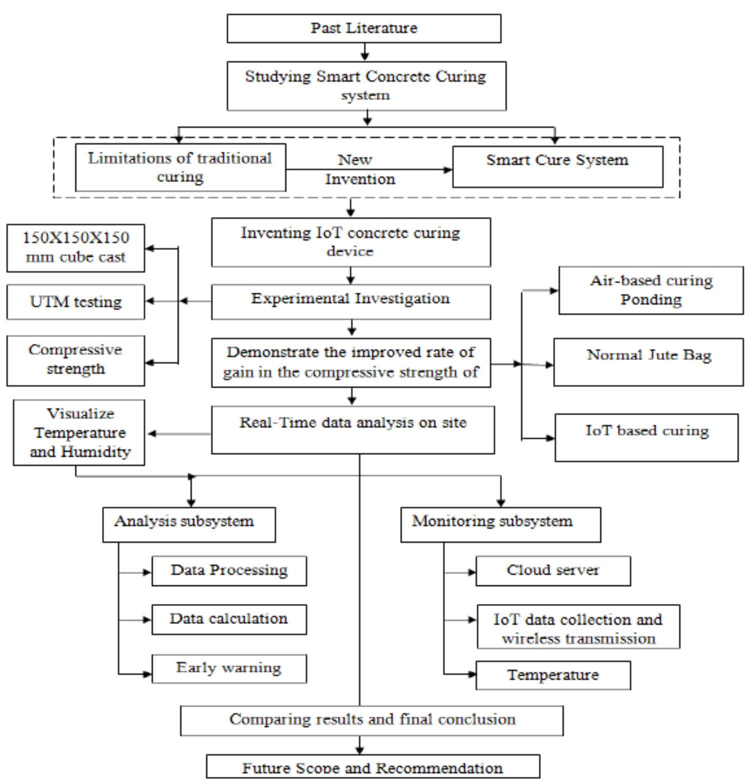

Figure 1: Flowchart of Methodology

I. Experimental Process

M20-grade concrete is used for laboratory experiments, and 150X150X150 mm cubes were produced. The various tests would be conducted for designed concrete mixes, thereby studying the smart concrete on various properties such as slump cone test, compressive strength, and wet sieve analysis (IS 1727).

There were three methods used for curing. One is sharp stone curing and the other is soaking cure using jute bags. To cure the cubes, soak them in a bucket of water for 7-14 days.

Table No. 1 Experimental Work Methodology

Sr. No	Experiment Steps
1	Arrange three sets of straight brand new concrete cubes (0.15m width, 0.15 m height, and 0.15m deepness).
2	Cure three sets of concrete with ponding, jute bags, and an IoT device.
3	Casting of an M20 concrete cube and calculating compressive strength in 7, 14, and 28 days
4	Determine and keep track of the initial concrete temperature and surface moisture while using an IoT device for curing..
5	The concrete surface's first look should be noted.
6	Compute the temperature plus exterior dampness while custody an look at on the concrete's lose blood water every 10min until it reaches the final set..
7	As the final set of samples from the first three sets are about to be placed, measure the temperature and surface wetness of each set (real-time data analysis).
8	Both manually and automatically gauge the temperature of the concrete and the amount of surface moisture immediately following the addition of water.
9	Measure the water used for both manual and IoT-based cures.
10	Compare & discuss the results.

II. M20 Mix Design according to Is 10262-2009

1 Stipulations for Proportioning

M20 concrete, ordinary Portland cement 53 grade, 20 size of aggregate, IS 456:2000 table 5 WC ratio = 0.52, 120 mm slump, mild exposure condition, Maximum nominal size of aggregate : 20mm, Specific gravity of cement : 3.16, CA : 2.85, FA: 2.71,

a) **Target Strength For Mix Proportioning**

$$f'ck = fck + 1.65xs$$

From Table I of IS 10262:2009, Standard Deviation, s = 4 N/mm^2.

Table No. 2 Target Average Compressive Strength At 28 Days

fck	S	Target Strength (f'ck) N/mm^2
20	4	26.60

2 WC Ratio

Adopt maximum WC ratio = 0.52 From the Table 5 of IS 456 for maximum WC Ratio is 0.50

Adopt water content = 0.52 Hence ok.

3 Water Content

IS 10262:2009 Table 2, maximum moisture content for 20 mm aggregate = 186 liters (also applicable for 25 to 50 mm slump range) Estimated moisture content for 120 mm slump is given in the message below

Table No. 3 Estimated Water Content For 100 mm Slump

Max. Water Content 20mm agg. (25 to 50 mm slump)	100 mm Slump	Water Content (litre)
186	6	191.58

4 Calculation of Cement Content and Fly Ash

WC ratio = 0.52. Minimum cement content 300kg/m3 in "hard" condition as per IS 456 Table 5

Cementations material content = 191.58/0.40 = 368.42 kg/m^3

368.42 kg/ m^3 > 300 kg/m^3 Hence ok

Table No. 4 Calculation Of Cement Content

Water Content in litre.	Water Cement Ratio	Cement Content in kg/m3
138	0.40	368.42

5 Proportion of Vol^m of Coarse Aggregate And Fine Aggregate Content

(IS 10262: 2009) From Table 3, when the water-cement ratio is 0.50 = 0.60, the coarse aggregate volume corresponds to 20 mm of coarse aggregate and fine aggregate (Zone II).

In this example, the water-cement ratio is 0.50. Therefore, in order to reduce the amount of fine aggregate, it is necessary to increase the amount of coarse aggregate. Because the water-cement ratio is lower than 0.10. The volume fraction of coarse aggregate increased by 0.02 (each ± 0.05 change in water-cement ratio increased by -/+ 0.01). Therefore, the water-cement ratio is set as coarse aggregate volume ratio 0.52 = 0.62.

Table No. 5 Volume Of Course Aggregate Considering Concrete

Vol^m Of Course Aggregate Increased By 0.02		Volume Of Course Aggregate
0.60	0.01	0.59

Vol^m of fine aggregate content calculated as below

Table No. 6 Volume Of Fine Aggregate

Total Vol^m	Vol^m Of C.A	Vol^m Of F.A
1	0.59	0.41

6 Mix Calculations

a) The mixture composition per unit volume is calculated as follows:

b) Vol^m of concrete = 1 m^3

c) Vol^m of cement = $= \frac{\text{□□□□ □□ □□□□□□□}}{\text{□□.□□.□□ □□□□□□□}} x \frac{1}{1000}$

Table No. 7 Calculate Volume of Cement

Mass of Cement	S. G. of Cement	Mass of Cement/S. G. of Cement	Volume of Cement (m^3)
368	3.15	116.82	0.117

d) Vol^m of water $= \frac{\text{□□□□ □□ □□□□□□}}{\text{□□.□□.□□ □□□□□□}} x \frac{1}{1000}$

Table No. 8 Calculate volume of Cement

Mass of Water	S. G. of Water	Mass of Water/Specific Gravity of Water	Volume of Water
191.58	1.00	191.58	0.192

e) Vol^{m} of all in aggregate $= [a - (b + c)]$

$= 0.691\ m3$

f) Mass of coarse aggregate

= ex□□□□□□ □□ □□□□□□□□□. □□. □□ □□□□□□ □□□□□□□□□x10000

Table No. 9 Calculate Mass of Coarse Aggregate

Vol^{m} of all in Aggregate	Volume of C.A	S.G. of C.A	Mass of C.A (kg/m^3)
0.691	0.56	2.80	1162.69

g) Mass of Fine Aggregate

= □□□□□□□□ □□ F.A.□□. □□ □□□□ □□□□□□□□□x1000

Table No. 10 Calculate Mass of Fine aggregate

Vol^{m} of Aggregate	Vol^{m} of F.A	S.G. of F.A	Mass of F.A (kg/m^3)
0.691	0.44	2.70	768.28

7 Mix Proportions

Description		Quantity	Unit	By weight		Volumetric Mix	
Cement		368	Kg/m^3	50.00	Kg	1.00	Bag
FA	Crush sand	768.28	Kg/m^3	104.27	Kg	65.99	Litre
CA	Metal I	465.08	Kg/m^3	63.12	Kg	42.94	Litre
	Metal II	697.61	Kg/m^3	94.68	Kg	66.67	Litre
Water		191.58	Kg/m^3	26.00	Litre	26.00	Litre

RESULTS

1. Compressive Strength

The moisture levels are graphed on the mobile app during the Smart Concrete curing process, as shown in the table, and the values are also displayed on the screen of a laptop that is linked to the system, as shown in the table. The strength of the cube is measured after this technique has been carried out for 7, 14, and 28 days.

Formula

$$\frac{Load}{Area} = \frac{266.9x1000}{150x150}$$

$$Strength = 11.86\ N/mm^2$$

Table No. 11 Compressive Strength by Curing in Ponding

Description	Weight	Load	Strength	Percentage
	Kg	KN	N/mm^2	%
7 days	8.263	266.9	11.86	59.3
14 days	8.216	312.6	13.89	69.45
28 days	8.349	497.1	22.09	110.45

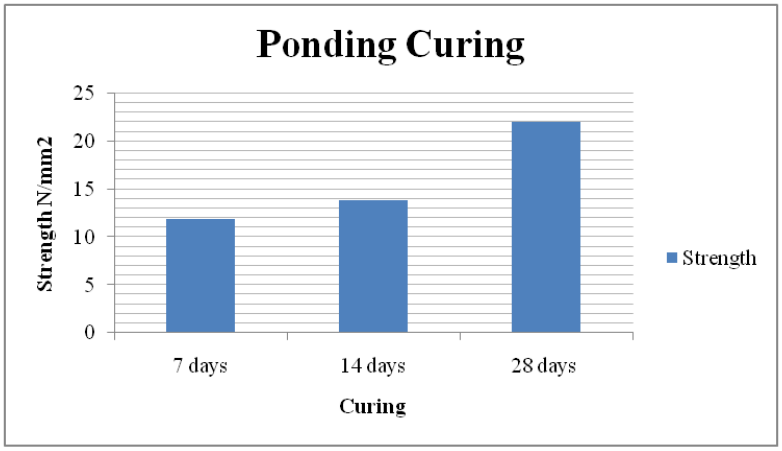

Figure 2: Ponding Curing

The figure shows the compressive strength on days 7, 14 and 28 for ponding water treatment. In order for structures to be built, the compressive strength of concrete must meet certain requirements. It describes how well the structure's support system can carry the structure's weight without buckling or cracking. In order to test concrete cube specimens for compressive strength in the laboratory, a universal testing machine (UTM) is typically employed. The CS of the concrete cube test reveals all of the properties of concrete. Concrete gets stronger after it has been in existence for a while. In the first seven days, the % of strength gained was 65%; in the second seven days, the % of strength gained was 90%; and in the third seven days, the % of strength gained was 99%. In our results, 7 days of strength (59.3%), 14 days of strength (69.45%), and 28 days of strength (110.45%) achieved good results.

Table No. 12 Compressive Strength by Curing in Jute Bag

Description	Weight	Load	Strength	Percentage
	Kg	KN	N/mm^2	%
7 days	8.247	195.7	8.69	43.45
14 days	8.280	305.9	13.59	67.95
28 days	8.429	438.5	19.48	97.4

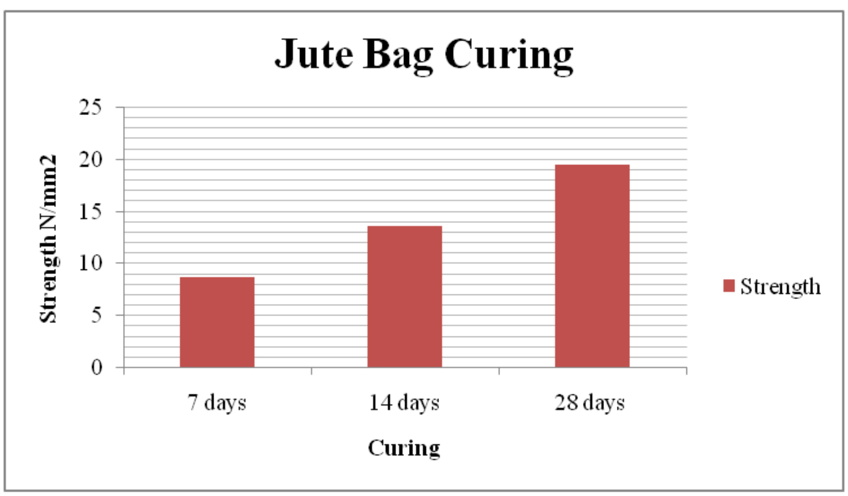

Figure 3: Jute Bag Curing

Figure shows compressive strengths at 7, 14, and 28 days in the jute bag curing method. The CS of the concrete is an important factor in accordance with the requirements for structural design. It refers to the ability of the structural elements to carry the structure's mass without buckling or deflection. Concrete cube samples are normally tested in a laboratory using a UTM to determine their compressive strength. The CS of concrete as measured by the concrete cube test gives an insight of all the qualities of concrete. As concrete ages, its compressive strength rises. The percentage of strength acquired during the first seven days was 65%; the percentage over the following 14 days was 90%; and the percentage over the following 28 days was 99%. In our results, 7 days of strength (43.45%), 14 days of strength (67.95%), and 28 days of strength (97.4%) achieved is not good results.

Table No. 13 Compressive Strength by Curing in Device

Description	Weight	Load	Strength	Percentage
	Kg	KN	N/mm^2	%
7 days	8.062	218.1	9.69	48.45
14 days	8.324	364.6	16.2	81.00
28 days	8.4	466.7	20.74	103.7

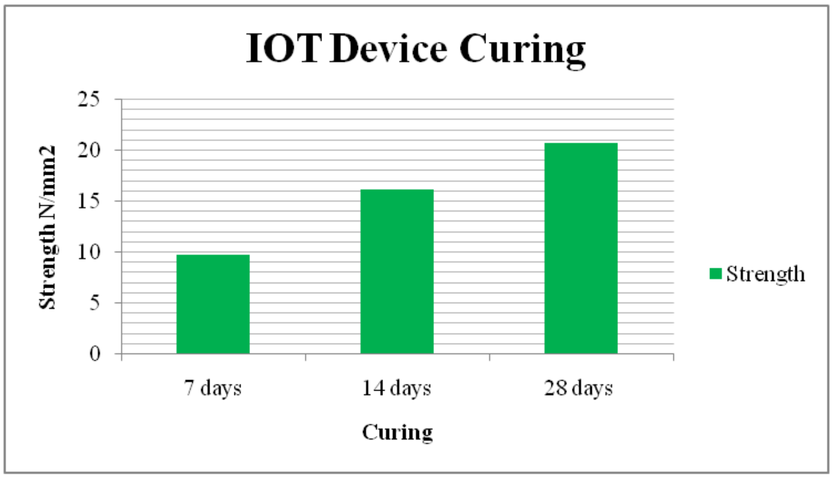

Figure 4: IOT Device Curing

The IoT device curing procedure is depicted in the figure with compressive strengths at 7, 14, and 28 days. The CS of the concrete is an important factor in accordance with the requirements for the design of the structures. It refers to the ability of the structural elements to carry the structure's weight without buckling or deflection. Concrete cube samples are normally tested in a laboratory using a UTM to determine their ability to compress. The concrete cube test's compressive strength gives a general overview of all of concrete's properties. Concrete gets stronger under compression as it ages. The percentage of strength acquired for the first seven days was 65%; for the following fourteen days, it was 90%; and for the final 28 days, it was 99%. In terms of outcomes, 7 days of strength (48.45%), 14 days of strength (81.00%), and 28 days of strength (103.7%) all outperformed.

2. Comparison of Compressive Strength

Table No. 14 Comparison of Compressive strength

Description	Crushing Load (KN) in days			Compressive Strength (N/mm^2) in days		
	7	14	28	7	14	28
Ponding	266.9	312.6	497.1	11.86	13.39	22.09
Jute Bag	195.7	305.91	438.5	8.7	13.59	19.48
Device	218.1	364.6	466.7	9.69	16.18	20.74

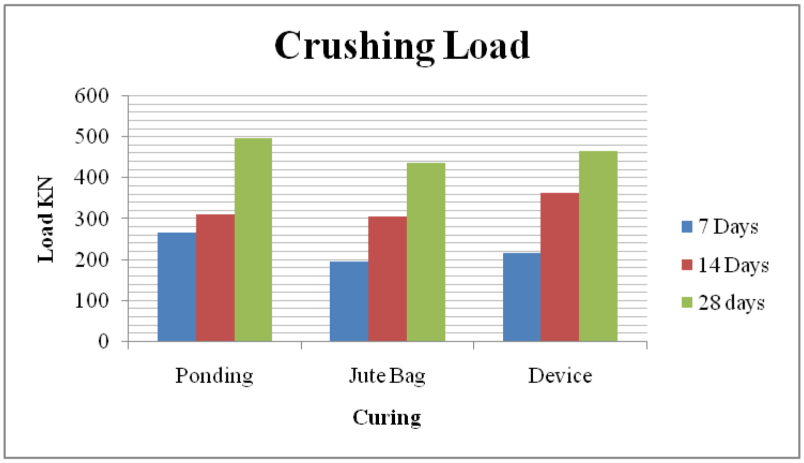

Figure 5: Comparison of Curing System in Load

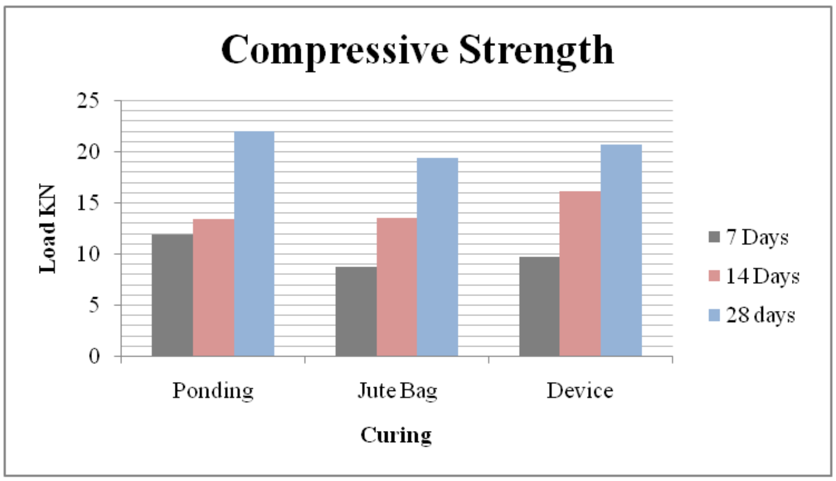

Figure 6: Comparison of Curing System

The average compressive strength vs. curing age for the various curing techniques employed in the experiment has been graphically shown to show the CS results. The CS of concrete is seen to increase with age under the aforementioned curing procedures. The process of water ponding curing produced the maximum compressive strength across all ages. The greatest compressive strength after 28 days of ponding is 22.09N/mm^2, and the device strength is 20.74N/mm^2.

3. Real Time Data Analysis

Analyzing each message as it is received, real-time analytics process data acquired through a feed. For data transformation, geofencing, and incident detection, real-time analytics are very useful. Utilizing autonomous data recording and concrete curing techniques, the Internet of Things device reduces work and production time. The device can be used to measure temperature, humidity, wind speed, moisture content and air temperature by using and connecting three sensors. IoT devices collect all sensor data and then transmit it to connected computers for continuous, real-time monitoring and decision-making. Using the IoT platform, data can be sent to remote networks.

The sensor continuously logs the internal temperature of the concrete and transmits the information to the Wi-Fi microcontroller. Using a code written in the C programming language that is supplied into the microcontroller, the microcontroller determines the early age compressive strength base on the strength versus maturity relationship established for the relevant concrete mix. The ESP8266 microcontroller is programmed in the C programming speech by means of the Arduino Integrated Development Environment. Three additional fields' temperature, maturity index, and compressive strength were added to a Thingspeak.com channel. In the C programming loaded into the ESP8266 microcontroller, the address of the ThingSpeak channel and the Wi-Fi login information should be specified. The data is shown on the Organic Light-Emitting Diode (OLED) display by the ESP8266 microcontroller before being sent in real time to the cloud platform, which is accessible from any distant location. The concrete strength at the site can be manually recorded using a maturity meter, a common tool for doing so by measuring the interior temperature. Due to the manual nature of this equipment, it is difficult to forecast compressive strength in real time without frequent internal temperature recording.

Figure 7: Temperature Module 1*(https://ubidots.com/stem)*

Figure 8: Humidity Module 1*(https://ubidots.com/stem)*

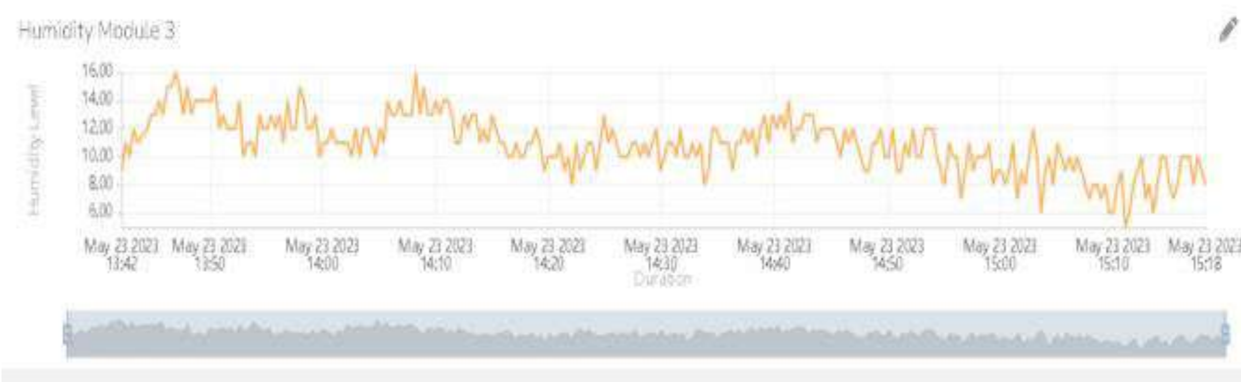

Figure 9: Humidity Module 3 *(https://ubidots.com/stem)*

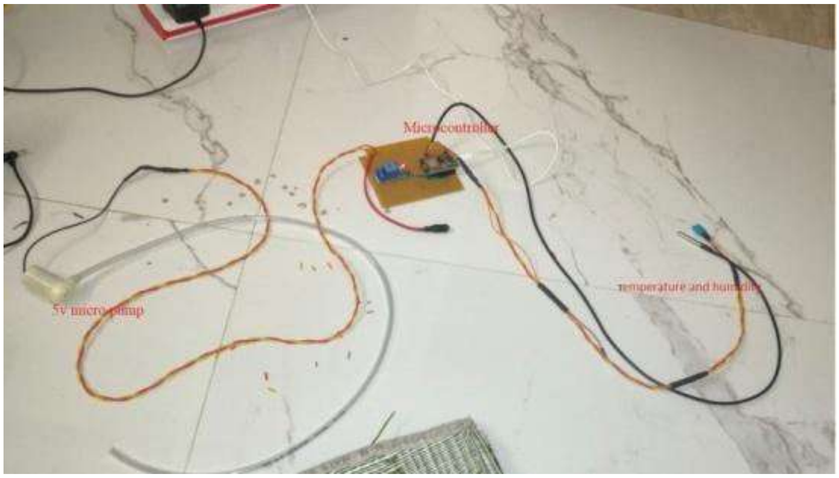

Figure 10: Internet of Things devices *(Photograph)*

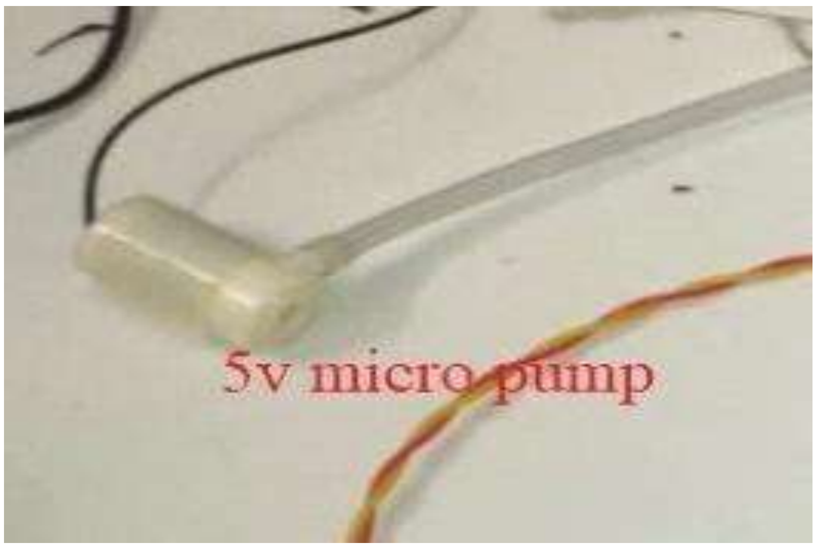

Figure 11: 5VWater Pump *(Photograph)*

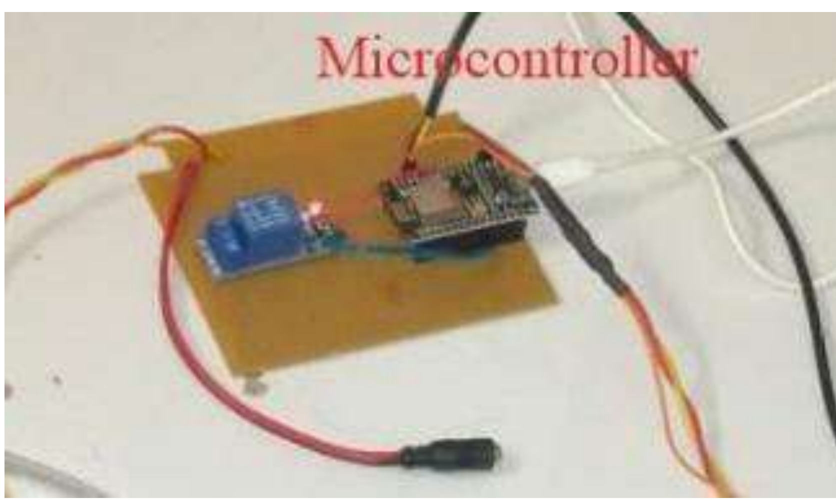

Figure 12: Microcontroller *(Photograph)*

Figure 13: Temperature and Humidity *(Photograph)*

Figure 14: Assembly Of Module *(Photograph*

4. Comparison of Curing Methods

Table No. 15 Comparison of Curing Methods

Description	Method of Curing		
	Ponding Curing	**Jute Bag Curing**	**Iot Curing**
Usages	Gives long-term continuous storage in a climate with significant moisture and steady temperatures.	Allows for prolonged, uninterrupted submersion in water while maintaining a consistent water temperature	Applying water when necessary to keep the amount of fluid in the ground constant over time
Advantages	Dependable overall environmental manage	A fixed water temperature and 100% rh; a less	Full-scale on-site concrete can be replaced with a flexible,

	for concrete test sampling	expensive alternative to specimen environmental control	feasible substitute. Integrated monitoring and analysis function to determine the water spray's intensity
	Ponding, as one of the concrete curing methods, is particularly useful for large, flat surfaces such as floors or pavements made from concrete slab because It aids in maintaining a constant level of moisture throughout days across the entire surface.	This is a common technique for curing, especially for structural concrete. As a result, concrete surfaces that are left exposed are kept from drying out by being covered with hessian, canvas, or empty cement bags.	Real-time asset And less water is needed
	Evaporation rate is high	To prevent concrete surface from drying in vertical member	End-to-end, remote monitoring and management of assets/resources
Disadvantages	Constant monitoring is needed	Constant monitoring is not needed	Constant monitoring is needed
	Excess water is needed	More water is needed	
			As radiation effects are not permitted, specimens being monitored shouldn't be exposed to direct sunlight.
Photo			
Compressive strength	22.09 N/mm^2	19.48 N/mm^2	20.74 N/mm^2

5. The Proposed IoT Device for Curing Concrete Has Some Limitations

Direct sunlight has an impact on cure accuracy because the existing IoT device does not account for the influence of radiation. It is recommended that a radiation sensor be included so that its impact on water evaporation can be calculated using the combination formula provided below. However, Penman's calculation necessitates that the air and water temperatures be equal:

$$Total\ Evaporation = \left(\frac{Q_n\ x\ \Delta\ x\ \gamma\ x\ E_a}{(\Delta +\ \gamma)}\right)$$

Where

E – Evaporation

$Q_n = Solar\ Radiation$

$E_a = Evaporation\ from\ aerodynamic\ formulas$

$$\Delta - slope\ of\ saturation\ curve = 4098\ x\ e_s/(237.3 + T)^2$$

$$e_s = 0.61\ e^{\frac{(17.3T)}{(237+T)}}$$

$$\gamma = Psychrometric\ constant = 0.066kPa/C$$

(Incorporated into the currently planned gadget is a water loss computation).

CONCLUSION

The following conclusions are listed in study:

According to this study's findings, IoT gadgets may enhance concrete curing's precision and effectiveness. Real-time monitoring of the ambient circumstances & water loss from the curing concrete is done by the suggested Internet of Things device here. Because the amount of extra water sprayed on the concrete surface is determined in line with the ambient circumstances, the already hydrated and extremely susceptible paste cement matrix will no longer be at risk of extreme water load infiltration. Both the environmental and drinking water processes can be shut down. The experimental results conclude that the highest compressive strength is 22.09 N/mm^2 and the highest load is 497.1 KN by ponding curing. The IOT device curing result reaches approximately the nearest ponding curing as strength is 20.74 N/mm^2.

The necessary moisture content could be maintained throughout the curing process thanks to intelligent concrete curing devices. By maintaining the requisite moisture level, cubes outperformed immersion curing in terms of compressive strength. It has been determined that intelligent concrete curing is a successful way for obtaining the necessary strength and long-lasting structure. Utilizing this method also decreased the need for human labour and water waste.

FUTURE SCOPE

By including strength-detecting sensors, this project can be expanded so that the curing process can be stopped once it reaches the necessary strength. Additionally, a mobile request can be created to get notifications regarding the structure's power with curing procedure, reducing construction time and costs.

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