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STATISTICAL QUANTIFICATION OF THE EFFECTS OF CURING AGENT AND FLY ASH ON SELF-CURING CONCRETE

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Abstract : Self-curing concrete is one type of special concrete which is mitigated insufficient curing due to human negligence paucity of water in arid areas, inaccessibility of structures in difficult terrains and in areas where the presence of fluorides in water will badly affect the characteristics of concrete. The use of Polyethylene Glycol (PEG600) in conventional concrete as an admixture helps better hydration and hence the strength of concrete. The Project aim is to determine the significance of polyethylene glycol and fly ash in self-curing concrete for given mix and its moisture transport in self-curing concrete. This experimental study is carried out on the two mixes, conventional concrete and replacement of cement by fly ash up to 40%, self-curing agent in concrete with PEG-600. The chemical agent PEG will be used with different percentages as 0.5%, 1%, 1.5% and 2% to the weight of cement. Fly ash is replaced in cement with 15%,30%,40%. The properties such as compressive strength and durability using sorptivity test will be examined for M20 grade of concrete. The optimal proportion of fly ash to curing agent in order to attain maximal compressive strength, 0.5% curing agent without fly ash appears to have produced the highest reported average strength of 44.95 N/mm². Strength typically falls as fly ash content increases, but when 2% curing agent is added at 30% fly ash content, this trend is reversed. When evaluating the overall performance under various trial conditions, the average sorptivity values offer a convenient point of comparison.Trial 13 has the lowest average sorptivity value with 2% curing agent and 0% fly ash, whereas trial 3 has the highest average sorptivity value with 0% curing agent and 30% fly ash.

Key words- Sorptivity, Compressive strength, ANOVA, Flyash, Curing agent

1. INTRODUCTION

Internal curing concrete, also described as self-curing concrete (SCC), used to describe the process of concrete hydration in response to the availability of additional internal water which isn't part of the mixing process (Khan and Gupta 2020). Concrete's properties are primarily evaluated from the perspectives of strength and durability. Maximum impact is depended upon the primary variable which is Curing. Therefore, it's critical to reach the target intensity and cure for adequate hydration of 14 to 28 days. In order for concrete to acquire long-lasting qualities, it must be cured, which is the process of maintaining the temperature and moisture levels necessary for the normal hydration reaction (Prasad et.al. 2019). The effects of improper curing will manifest quickly. The effectiveness and longevity of concrete may soon be impacted by improper curing. Let's talk about high-performance concrete. Their tendency to crack at a young age is the main problems using concrete compositions that are so intense (Bentur et al. 2001). A concrete that has a low w/c ratio and a high percentage of cement may suffer from cracking and shrinkage, as well as drying within caused due to the concrete absorbing water through hydration, a process known as self-desiccation (Vaisakh et al. 2018). A successful cure requires the continuous the presence of interior humidity to sustain hydration process at moderate temperatures and in situations where external forces are unavailable at an early age (Dhir et al. 1994). This is accomplished following the steps of mixing, putting, and concluding with traditional curing. The most common building element is water, and as a result of the modern world's constant consumption of water supplies, the number of water shortage zones is steadily rising. Moreover, height related labour, vertical components, inclined floors, towers make continuous curing extremely challenging (Hameed et al. 2017). A chemical admixture or curing agent that has the ability to prevent water evaporation through a maintaining functionality is the basis of the self-curing method (Malathy 2017). A variety of admixtures, including Lightweight aggregates, sodium lignosulphonate (SL), poly-ethylene glycol (PEG), poly vinyl acryl (PVA), poly acrylamide (PAM), wood powder, and coco pith, are employed to produce efficient curing results for concrete that cures itself (Khan and Gupta 2020). From the existing research we can tell that adding a self-curing ingredient in regular concrete significantly increases durability, mechanical properties of self-curing concrete (Malathy 2017). By comparing self-curing concrete to regular concrete which explains properties of both types of concretes and a much deeper understanding on their applications. The review's in-depth examination will clarify the usefulness and possible future paths of employing self-curing concrete as an effective and sustainable substitute for conventional curing techniques.

Self-curing concrete, also known as internally cured concrete or self-desiccation controlled concrete, is a specialized type of concrete designed to mitigate the effects of moisture loss during the curing process. Traditional curing methods rely on external moisture application, such as water spraying or ponding, to maintain the necessary hydration conditions for proper cement hydration. However, self-curing concrete incorporates lightweight aggregates, pre-soaked polymers, or superabsorbent polymers (SAPs) within the concrete mix to provide internal reservoirs of water for hydration (Bashandy 2017).

Self-curing concrete relies on incorporating specific ingredients into the concrete mix to facilitate internal moisture retention and hydration. These ingredients act as internal reservoirs of water, ensuring continuous hydration of cement particles and mitigating the effects of moisture loss during the curing process (Sandanayake 2016).

Here are some of the common ingredients used in self-curing concrete:

a. Lightweight Aggregates:

Expanded Shale, Clay, or Perlite: Lightweight aggregates with high porosity are often used in self-curing concrete mixes. These aggregates absorb water and release it gradually during hydration, providing internal moisture reservoirs.

b. Pre-Soaked Polymers:

Polyethylene Glycol (PEG): PEG is a water-absorbent polymer that can be pre-soaked and added to the concrete mix. It absorbs water and releases it gradually over time, ensuring continuous moisture availability for cement hydration.

Polyvinyl Alcohol (PVA): PVA is another water-absorbent polymer that can be pre-soaked and incorporated into the concrete mix. Similar to PEG, it absorbs and retains water, contributing to internal curing of concrete.

c. Superabsorbent Polymers (SAPs):

Synthetic Polymers: Superabsorbent polymers, such as hydrogel-based SAPs, are capable of absorbing and retaining large amounts of water relative to their own mass. These polymers are added to the concrete mix in the form of granules or powder.

d. Water-Reducing Admixtures:

*Polycarboxylate Superplasticizers**:*** Water-reducing admixtures are often used in self-curing concrete mixes to improve workability and reduce water content without compromising hydration. Polycarboxylate superplasticizers are commonly employed for their high water-reducing efficiency and compatibility with self-curing agents.

e. Fibers:

Polypropylene or Nylon Fibers: Fibers can be added to self-curing concrete mixes to enhance internal curing and mitigate cracking. Polypropylene or nylon fibers are commonly used for their ability to absorb and retain moisture within the concrete matrix.

f. Hydration Controlling Agents:

Calcium Nitrite: Calcium nitrite can be used as a hydration controlling agent in self-curing concrete mixes. It accelerates the hydration of cementitious materials and promotes early strength development while minimizing the risk of early-age cracking.

g. Other Additives:

Crystalline Waterproofing Admixtures: Crystalline waterproofing admixtures can be added to self-curing concrete mixes to improve moisture resistance and reduce permeability. These additives react with moisture to form insoluble crystals, sealing microcracks and pores within the concrete matrix.

Self-curing concrete improves quality, efficiency, durability, and sustainability compared to traditional methods, provided there is proper mix design and dosage optimization. By ensuring uniform, complete cement hydration and maintaining consistent moisture levels, self-curing concrete enhances compressive and tensile strengths. This uniform consistency improves workability, eases placement, and minimizes drying shrinkage. Consequently, it significantly reduces risks of cracking, crazing, scaling, and surface defects, resulting in a smoother, superior finish. Eliminating external curing methods like water spraying or ponding saves substantial labor, resource, and material costs. Streamlining the construction process allows for faster formwork removal and finishing, accelerating overall project timelines. Reduced permeability and minimized microcracking block the ingress of water and harmful chemicals. This vastly improves resistance to environmental factors and freeze-thaw cycles. Furthermore, this technology promotes sustainability by conserving water resources and extending the service life of structures, which lowers long-term maintenance, repair costs, and environmental impact. Overall, self-curing concrete is a highly valuable, resource-efficient technology that effectively resolves traditional curing challenges to optimize infrastructure performance.

2. LITERATURE STUDY

The reviewed studies mainly focus on the mechanical properties and performance of self-curing concrete using different self-curing agents such as Polyethylene Glycol (PEG), Polyacrylamide (PAM), Super Absorbent Polymers (SAP), and lightweight aggregates. Proper curing is essential for concrete to achieve maximum strength and durability; however, conventional curing methods often face difficulties due to water scarcity, poor water quality, difficult terrain, and human negligence. To overcome these challenges, researchers investigated self-curing concrete as an alternative solution (Kumar 2012).

Several studies examined the effect of PEG-400 on M20, M25, and M40 grade concrete by varying the dosage from 0% to 3% by weight of cement. The results showed that PEG significantly improves compressive strength, split tensile strength, flexural strength, and modulus of rupture while also enhancing workability. Most studies reported that optimum PEG dosage lies between 1% and 2%, depending on the concrete grade. PEG acts as a shrinkage-reducing admixture by retaining internal moisture and reducing water evaporation, thereby improving hydration and minimizing shrinkage cracks. Self-curing concrete containing PEG achieved strength comparable to or higher than conventionally cured concrete (Bashandy 2017).

Research on combined chemical agents such as PEG-400 and PAM revealed that the combination performs better than the individual use of either agent. The optimum combination of 1% PEG-400 with 0.01% PAM significantly improved the mechanical properties of concrete at different curing ages. This combination was also found to be economical because PAM is inexpensive and reduces the required PEG dosage. The studies emphasized that self-curing concrete is especially beneficial in arid and water-deficient regions (Sandanayake 2016).

Other investigations focused on recycled coarse aggregate concrete using SAP as a self-curing agent. SAP reduced shrinkage cracks and improved structural performance, although recycled aggregate concrete showed lower strength than conventional aggregate concrete due to impurities present in recycled aggregates. The reduction in strength was most significant in split tensile strength and least in flexural strength (Dahyabhai & Jayeshkumar 2014).

Studies involving PEG-600 and PEG-1500 demonstrated that both admixtures considerably increase compressive strength and improve hydration. An optimum dosage of 1% was identified for M25 grade concrete, producing higher strength without affecting workability. PEG-600 and PEG-1500 increased compressive strength by approximately 37% and 33.9%, respectively, compared to conventional concrete (Ananthi et al. 2017).

Review papers on curing methods highlighted the importance of proper curing in achieving durable and high-quality concrete. Various curing techniques such as immersion curing, wet gunny bag curing, membrane curing, steam curing, and accelerated warm water curing were compared. Immersion curing generally produced the highest compressive and split tensile strengths. The studies also emphasized that self-curing techniques using PEG, PAM, PVA, SAP, and lightweight aggregates can effectively improve tensile strength, flexural strength, durability, and workability (Poovizhiselvi & Karthik 2017).

Overall, the reviewed literature confirms that self-curing concrete is an effective alternative to conventional curing methods. Chemical admixtures such as PEG and PAM enhance hydration, reduce shrinkage, improve workability, and increase mechanical strength. These findings demonstrate the suitability of self-curing concrete for sustainable construction, particularly in regions where proper external curing is difficult or water resources are limited (Viswam & Murali 2018).

By compiling a broad range of research articles, a comprehensive report was produced. Conducting a thorough analysis of the available literature revealed that Numerous studies have been conducted on the fundamental characteristics of concrete through the addition of chemical and natural admixtures that cure on their own. Despite the extensive research conducted on the mechanical properties of concrete that cures itself using moulds, no relevant studies about the durability of concrete have been conducted.

3. EXPERIMENTAL INVESTIGATION

3.1 Factors identified and its levels

To investigate the moisture transport properties of self-curing concrete, this study identifies two primary independent variables: the Internal Curing Agent and Fly Ash content. These factors were selected due to their significant influence on the microstructure and hydration kinetics of cementitious matrices.

Identification of Factors and Levels

The first factor, the **curing agent concentration**, is evaluated at four distinct levels: **0%, 0.5%, 1.0%, and 2.0%** by weight of cement. The 0% level serves as the control group (conventional concrete), while the incremental dosages allow for a phenomenological observation of how varying polymer or chemical concentrations affect internal humidity retention and capillary suction.

The second factor is the **percentage of Fly Ash**, a supplementary cementitious material (SCM), which is also tested at four levels: **0%, 15%, 30%, and 40%**. Fly ash is known to refine pore structure through pozzolanic activity; however, its interaction with self-curing agents requires precise quantification to determine the optimal balance between workability and long-term durability.

Table 1. Identified Factors and Levels

Factor-1 and its Levels Curing agent (%)	Factor-2 and its Levels Fly ash (%)
0	0
0.5	15
1.0	30
2.0	40

3.2 Experimental Design: Full Factorial Approach

A **Full Factorial Design** has been adopted for this experimental program to ensure a comprehensive mapping of the interaction effects between the curing agent and fly ash. Unlike "one-factor-at-a-time" testing, a full factorial approach considers every possible combination of the identified levels.

Given that there are two factors ($k = 2$), each with four levels ($L = 4$), the total number of experimental runs is calculated as:

$$n = L^k = 4^2 = 16$$

By employing this design, the study can statistically evaluate not only the individual influence of each material but also the **synergistic or antagonistic interactions** between them. For instance, it allows the researcher to determine if the effectiveness of a 2.0% curing agent is enhanced or inhibited by a high (40%) fly ash replacement. This rigorous framework provides the necessary data density to develop a robust phenomenological model of moisture transport across the entire parameter space.

The concrete mix design was prepared in accordance with IS 456:2000 and IS 10262:2019 guidelines. An M20 grade concrete mix was selected for the study to achieve the required strength and durability characteristics. Ordinary Portland Cement (OPC) 53 grade was used as the binding material due to its high strength and better performance. The target slump value was maintained at 100 mm to ensure adequate workability for mixing, placing, and compaction. Crushed coarse aggregate with a maximum nominal size of 20 mm was used to obtain proper strength, density, and overall concrete performance.

Table 2: Mix proportions for concrete with varying percentages of Fly ash as a replacement of cement and Poly Ethylene Glycol.

Trials	**Curing Agent (in %)**	**Fly Ash (in %)**	**Cement (in grams)**	**Fine aggregate (in grams)**	**Coarse aggregate (in grams)**	**Water (in litres)**
1	0	0	358	755	1336	197
2	0	15	335	763	1350	197
3	0	30	275	783	1369	197

4	0	40	236	812	1522	197
5	0.5	0	358	755	1336	197
6	0.5	15	335	763	1350	197
7	0.5	30	275	783	1369	197
8	0.5	40	236	812	1522	197
9	1	0	358	755	1336	197
10	1	15	335	763	1350	197
11	1	30	275	783	1369	197
12	1	40	236	812	1522	197
13	2	0	358	755	1366	197
14	2	15	335	763	1350	197
15	2	30	275	783	1369	197
16	2	40	236	812	1522	197

3.3 COMPRESSION STRENGTH TEST

The compressive strength of concrete cubes serves as a pivotal indicator of the structural integrity and quality of concrete mixes in construction projects. It represents the maximum load-bearing capacity that a concrete cube can withstand before failure occurs, typically measured in megapascals (MPa) or pounds per square inch (psi). Determining the compressive strength involves subjecting cured concrete cubes to gradually increasing axial loads using specialized compression testing machines. During testing, data such as load and deformation are meticulously recorded to monitor the behaviour of the concrete cube until failure. The compressive strength is then calculated based on the maximum load sustained by the cube and its cross-sectional area.

3.4 Sorptivity Test:

The sorptivity test of concrete is a method used to evaluate the ability of concrete to absorb water from its surroundings. This property is known as sorptivity and is an important characteristic in determining the durability and performance of concrete structures, especially in environments where they are exposed to moisture or water. The sorptivity test provides insights into the capillary suction properties of concrete, which can influence its resistance to moisture-related damages such as freeze-thaw cycles, corrosion of reinforcement, and the overall service life of the structure. The test is typically conducted in accordance with standards such as ASTM C1585 or BS EN 12390-8, which outline the procedures for measuring the rate of moisture absorption under specific conditions.

4. RESULTS AND DISCUSSIONS

4.1 Compression test results:

The results of compressive strength at 28 days are shown in the following table:

Table-3: compressive strength results

Exp No.	**Curing agent (%)**	**Fly ash(%)**	**Compressive strength (N/mm^2)**			**Average compressive strength (N/mm^2)**
			Specimen1	**Specimen2**	**Specimen3**	
1	0	0	27.12	37.32	30.81	31.75
2	0	15	30.04	26.60	19.82	25.48
3	0	30	26.12	19.71	20.60	22.14
4	0	40	34.38	26.64	26.83	29.28
5	0.5	0	44.29	38.38	52.20	44.95
6	0.5	15	38.13	29.06	30.96	32.71
7	0.5	30	39.14	48.72	36.30	41.38
8	0.5	40	38.23	35.37	31.68	35.09
9	1	0	33.22	41.29	23.49	32.66
10	1	15	39.31	32.38	34.56	35.41
11	1	30	31.44	35.36	35.30	34.03
12	1	40	28.97	26.48	25.88	27.11
13	2	0	38.56	36.98	41.95	39.16
14	2	15	31.31	32.77	35.03	33.03
15	2	30	65.69	61.90	62.20	63.26
16	2	40	23.64	27.43	24.80	25.29

The compressive strength of concrete specimens was studied by varying fly ash content from 0% to 40% under different curing agent dosages. Without curing agent, compressive strength decreased from 31.75 N/mm² to 29.28 N/mm² as fly ash content increased. With 0.5% curing agent, the highest strength of 44.95 N/mm² was achieved at 0% fly ash, though strength gradually decreased with higher fly ash percentages. Similar reductions were observed with 1% curing agent. However, with 2% curing agent, strength increased significantly to 63.26 N/mm² at 30% fly ash before sharply decreasing at 40% fly ash. Overall, fly ash and curing agents showed a complex interaction influencing compressive strength.

Analysis of variance for compression results:

Table 4: Analysis of Variance of Compression strength

source	**Adj ss**	**Adj ms**	**F-value**	**p- value**	**Percentage contribution (%)**
Fly ash	908.3	302.76	14.80	3.22×10^{-6}	18.43
Curing agent	1287.1	429.02	20.98	1.06×10^{-6}	26.1
Two-way interactions	2076.8	230.75	11.28	1.08×10^{-6}	42.15
Error	654.5	20.4520.45	-	-	13.28

The significance of fly ash, the curing agent, and their two-way interactions in terms of compression strength are thoroughly analyzed in Table 6.

Comparing the curing agent to fly ash, the F-value is even higher and the p-value is lower, suggesting that the curing agent also has a statistically significant impact on compressive strength. When compared to fly ash, the curing agent accounts for a higher percentage of the variance (26.1%).

4.2 Sorptivity test results:

Table-5 Sorptivity test results

Trail Number	Curing Agent (%)	Fly Ash (%)	Sorptivity Values			Average (mm/s^0.5) $(x10^3)$
			Specimen 1 (mm/s^0.5)	Specimen 2 (mm/s^0.5)	Specimen 3 (mm/s^0.5)	
1	0	0	0.0091	0.0095	0.0085	9.033
2	0	15	0.0093	0.0098	0.0098	0.0096333
3	0	30	0.0161	0.0162	0.0379	0.0234000
4	0	40	0.0112	0.0102	0.0158	0.0124000
5	0.5	0	0.0128	0.0176	0.0106	0.0136667
6	0.5	15	0.0155	0.0075	0.0116	0.0115333
7	0.5	30	0.0135	0.0156	0.0126	0.0139000
8	0.5	40	0.0210	0.0128	0.0177	0.0171667
9	1	0	0.0076	0.0175	0.0340	0.0197000
10	1	15	0.0142	0.0133	0.0144	0.0139667
11	1	30	0.0150	0.0200	0.0156	0.0168667
12	1	40	0.0154	0.0118	0.0159	0.0143667
13	2	0	0.0052	0.0044	0.0086	0.0060667
14	2	15	0.0080	0.0160	0.0040	0.0093333
15	2	30	0.0108	0.0136	0.0101	0.0115000
16	2	40	0.0106	0.0242	0.0185	0.0177667

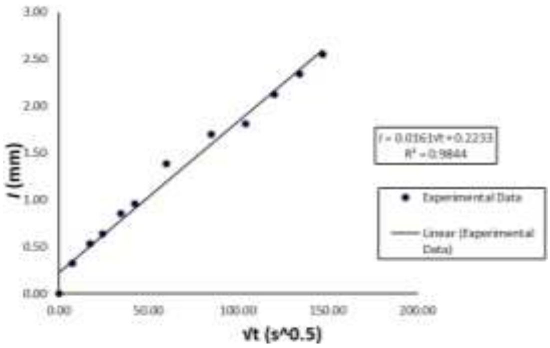

Fig .1 Trail-2 (fly ash-15%, curing agent -0%)

Analysis of variance for sorptivity results

After doing analysis of variance for the above table results some outliers are found.so after eliminating the outliers following results are achieved.

Table. 6 Analysis of variance for sorptivity results

Source	Adj SS	Adj MS	F-value	p- value	Percentage contribution (%)
Fly ash	0.000194	6.5×10^{-5}	9.86	0.00018	25.52
Curing agent	0.000100	3.3×10^{-5}	5.11	0.00681	14.16
Two-way interactions	0.000259	29×10^{-5}	4.39	0.00160	36.68
Error	0.000164	0.7×10^{-5}	-	-	23.22

Fly ash: This source has an F-value of 9.86, which is relatively high, indicating a strong influence on sorptivity results. The p-value is 0.00018, which is very low and suggests that the effect of fly ash is statistically significant. The percentage contribution of fly ash to the sorptivity results is 25.52%.

5. CONCLUSIONS

The compressive strength of concrete is a crucial property that determines its ability to withstand loads without failure. The addition of fly ash to the concrete mix tends to decrease the average compressive strength, while the incorporation of a curing agent increases it. The interaction between fly ash and the curing agent plays a significant role in determining the compressive strength of the specimens, with two-way interactions having the highest percentage contribution to the variance. Fly ash has a strong and significant influence on the sorptivity of the material being studied, while the curing agent also has a less pronounced but still significant effect. Two-way interactions contribute the most to the variability in sorptivity results, indicating that the combined effects of factors are very important in the study of sorptivity. The statistical analysis demonstrates that both fly ash and the curing agent significantly affect the compressive strength and sorptivity of the material, with fly ash having a stronger effect on sorptivity. The two-way interactions, representing the combined effects of different factors, show the highest influence on the variability of sorptivity results. In conclusion, the careful selection of fly ash and curing agent proportions is essential for optimizing the compressive strength and sorptivity of concrete. The statistical analysis supports the significance of their combined effects.

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