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AN EXPERIMENTAL INVESTIGATION OF SELF CURING CONCRETE USING SOLID POLYETHYLENE GLYCOL (PEG-1500) AS SELF CURING AGENT

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Abstract
This research entails the experimental investigation of self-curing concrete using solid polyethylene glycol (PEG-1500) as a self-curing agent. The study aimed at proffering a solution to the challenges and inadequacies associated with the conventional methods of curing concrete. Introducing a concrete that can cure itself with the aid of a curing agent mixed with the concrete. The curing agent must be able to retain an amount of water adequate for the self-curing of concrete. An experimental research method was adopted, in which two concrete grades, C30 and C35 Types (A and B), were selected. Various dosages of PEG-1500 by weight of cement were used to mix the concrete, giving Types (A^1 and B^1). Water retention capacity of the PEG-1500 was investigated by comparing the 7,14, and 28 days cumulative weight losses of concrete cubes mixed with PEG-1500 Types (A^1 and B^1) with those of concrete cubes without PEG-1500 Types (C and D), which were both cured in air. A slump test was conducted on each concrete mix, and the compressive strengths of concrete cube specimens of Types (A^1 and B^1) cured in the air with those of Types (A and B) cured in water. Types (A^1 and B^1) specimens gave maximum weight losses of 0.17kg and 0.12kg, and Types (C and D) specimens gave maximum weight losses of 0.37kg and 0.36kg. The less weight loss of Type (A^1 and B^1) specimens indicates a good water retention capacity of PEG-1500. Workability increased for each corresponding increase in the percentage dosage of PEG-1500, and Types (A and B) concrete gave the least slump. The 28days compressive strength of Types [(A) and A^1] concrete were [(33.92N/mm^2) 32.33N/mm^2, 31.84N/mm^2 , 35.59N/mm^2, 31.32N/mm^2] corresponding to PEG dosages of [(0%), 0.5%, 1.0%, 1.5%, and 3.0%] and [(48.11N/mm^2), 45.70N/mm^2, 49.63N/mm^2, 49.93N/mm^2, 36.70N/mm^2, 38.48N/mm^2] for Types [(B) and B^1] concrete corresponding to dosages of [(0.5%) 1.0%, 1.5%, and 3.0%]. The optimum compressive strength was found at a 1.5% PEG-1500 dosage. A further increase in the dosage resulted in a decrease in the compressive strength. Solid PEG-1500 is an effective self-curing agent of concrete, and dosage of 1.5% by weight of cement is recommended.
Keywords: self-curing, concrete, polyethylene glycol, Slump-test, compressive–strength, admixtures

1. Introduction

The desire to increase the service life of civil engineering infrastructures has led to the need for keen attention to concrete curing in construction. The need for adequate curing cannot be overemphasized because it strongly influences the properties of hardened concrete, such as durability, strength, water tightness, abrasion resistance, volume stability, and resistance to freezing and thawing effects [1].

Curing of concrete is the process of maintaining satisfactory moisture content and a favorable temperature in concrete during the period immediately after the placement of concrete so that hydration of cement may continue till the desired properties are developed sufficiently to meet the requirements of service [2]. Self-curing of concrete is the process of introducing a self-curing agent into concrete during mixing to reduce moisture evaporation from concrete and hence increase the water retention capacity of concrete for effective curing [3].

Various curing methods such as ponding, sprinkling or fogging, use of plastic sheets, curing compounds, etc., are adopted in the construction industry [4]. However, in most cases, such curing methods are not feasible in vertical structures, inaccessible areas, like high-rise buildings and water-scarce areas. For such special cases, self-curing concrete has been developed to achieve proper curing of concrete. The self-curing agents (admixtures) used in concrete are pre-saturated lightweight aggregate, water-absorbent polymers like (polyethylene glycol, polyvinyl alcohol, and paraffin wax) [5], and wood-derived materials [6]. Self-curing concrete with liquid polyethylene glycol of molecular weight of 200, 400, 600 at dosages of 0.5% to 1.5% by weight of cement have been studied and the strength and durability results reported are comparable to those of concrete cured by other methods [7]. The challenges associated with concrete curing are a lack of good workmanship and inadequate water supply [8]. Also, when water is not readily available within the concrete during curing, significant autogenous deformation and early age cracking may occur [9]. In order to take care of these challenges and improve concrete performance, self-curing of concrete could be an alternative to take care of the lapses associated with other curing methods. Also, increasing the service life of concrete structures as self-curing makes it possible to cure concrete more efficiently. An increase in molecular weight and chain length of self-curing agents will enhance self-curing characteristics. At longer lengths, entwined chains should be capable of mechanically locking water molecules into their structures, thus retaining water for more effective curing [10].

2. Background of study

Inadequate attention to concrete curing could lead to the delivery of poor quality concrete, lacking the potential to pass the test of time and environmental exposures. Some of the major challenges associated with concrete curing in the construction field are lack of good workmanship and inadequate water supply for achieving adequate curing, autogenous cracking of the concrete, which usually occur if sufficient water is not available for hydration, curing of vertical concrete structures and curing of inaccessible areas in structures [11]. Studies suggest that an increase in molecular weight and molecular chain length of self-curing agent will enhance self-cure characteristics. At longer length, entwined chains should be capable of mechanically locking water molecules into their structures, thus, retaining water for more effective curing [12]. The study conducted for optimum dosage of PEG-400 (polyethylene glycol) for maximum compressive strength was 1%, strength achieved by the self-curing concrete was comparable to that of the concrete cured by the conventional method, the split tensile strength of the PEG concrete also showed a similar maximum value at 1% dosage [13]. In the research on self-curing concrete with PEG-400, using a concrete grade of M25, the percentage dosage of PEG-400 by weight of cement in the concrete mix was varied from 1% to 2%. The PEG concrete was cured in air. It was also reported that the durability characteristics of the self-curing concrete with PEG has a promising effect when they are exposed to 10% of acidic condition. An experiment was carried out to investigate self-curing concrete incorporated with polyethylene glycol as a self-curing agent and a w/c ratio of 0.5. The percentage of polyethylene glycol (PEG) by weight of cement from 0% to 2% as the dosage of the internal curing compound was fixed. The test results were studied both for M25 and M40 mixes. It was found through this experimental study that PEG 400 helps in self-curing by giving strength on par with that of the conventional curing method and also improved workability [14].

These problems can be reduced to a great extent with self (internal) curing concrete since it controls the rate and extent of moisture loss from concrete during hydration, as self-curing agents make the concrete cure itself. This study aimed at investigating the properties of self-curing concrete in comparison with concrete cured by the ponding method. Hence, higher molecular solid polyethylene glycol (PEG-1500) at dosages above 2% by weight of cement could have a better curing effect.

3. MATERIALS AND METHODS

3.1 Materials

Crushed granite sourced locally within Edo State of maximum size 20mm was used. River sand was used in both aggregate materials conforming to British standards [15]. Ordinary Portland cement of strength class 42.5 conforming to British standard [16] was obtained from the open market. Portable water free from impurities was used. The concrete grades of C30, Type A, and C35, Type B were selected based on the Nigerian General Specification for Roads and Bridges (NGSRB). They were designed using the Building Research Establishment (BRE) method, in conformity with the British Standard (BS) code. The concrete was machine mixed, and cubes of 150mm x 150mm x 150mm were also made in accordance with the requirements of British standards [17].

3.2 Self-Curing Agent (Polyethylene glycol-1500)

The self-curing agent was a non-toxic, odorless, neutral, lubricating, non-volatile and non-irritating chemical used in various pharmaceuticals. In concrete works, it serves as a shrinkage-reducing admixture. PEG is soluble in water. It has a general formula $H(OCH_2CH_2)nOH$. It mainly forms hydrogen bonds with water molecules when added to the concrete mix. In concrete, it reduces the chemical potential of the molecules of water which in turn reduces the vapour pressure, thus reducing the rate of evaporation from the concrete surface. Its density ranges from 1.1 to1.2 and increases as the molecular weight increases.

3.3 Nomenclature of Specimens

The specimens were designated according to concrete characteristic strength and percentage of polyethylene glycol (PEG) dosages. Type A represents control concrete sample of characteristic strength of 30N/mm^{2}with 0% polyethylene glycol for conventional/water curing, Type A^1(A_1, A_2, A_3 A_4) represent specimens of characteristic strength of 30N/mm^2 with (0.5%, 1%, 1.5%, 3%) dosages of polyethylene glycol respectively, by weight of cement, for air curing. While Type B represents concrete specimens of characteristic strength of 35N/mm^{2}with 0% polyethylene glycol for conventional/water curing, Type B^1(B_1, B_2, B_3, B_4)represent control specimens of characteristic strength of 35N/mm^2 with (0.5%, 1%, 1.5%, 3%) dosages of polyethylene glycol respectively, by weight of cement, for air curing. Type C represents control specimens of 30N/mm^2 with 0%PEGfor air curing, and Type D represents control specimens of 35N/mm^2 with 0%PEGfor air curing.

3.4 Mixing and Casting

Mixing of concrete was done using a laboratory concrete mixer. All the dry constituents were placed in the mixer and mixed for 2 min to ensure uniformity of the mix. The mixing water was added gradually during mixing. For the concrete batches for air curing, the curing agent was first dissolved in the mixing water before adding the water to ensure a uniform mix of the curing agent. Mixing of all ingredients continued for another 2minutes. After mixing, the mixture was cast into 150 × 150 × 150 mm cubic molds, which were vibrated by a mechanical vibrator machine. After vibration, the surface of the concrete in the moulds was leveled, the top surface was leveled with a trowel, the tag number and the date of casting were inscribed on the top surface of the cubes. For easy de-molding and to achieve smooth cube surfaces, the moulds were cleaned and oiled on all contact surfaces before casting. After casting, the cubes were kept in the laboratory for 24 hours, after which the cubes were demolded and placed for curing.

3.5 Water Retention Test

The retention of water in concrete was monitored by weighing the concrete cubes at 7days, 14 days, and 28days intervals. The initial weight of each specimen type was taken as the reference value using an electronic balance. The weight loss concerning time was calculated as the difference between the weight at curing age 7, 14, and 28 days and that of the initial weight. The final weight loss of all the specimens after 28 days is recorded, as shown in Table 4.6. This is plotted concerning the percentage PEG dosages.

4. RESULTS AND DISCUSSION

The results obtained from the laboratory experiments on test specimens and the materials used for the experiments are presented, and analyses are made on the results.

4.1 Compressive Strength Results

Table 1: 7 days Average Compressive Strength of Concrete Cubes for all Specimen Types (A, A^1, B, B^1, C, and D)

Cube No	Age (days)	Average weight Before curing (Kg)	Average weight After curing (Kg)	Average Density Before curing (kg/m^3)	Average Density After curing (kg/m^3)	Average Compressive strength (N/mm^2)
A	7	8.440	8.560	2500	2536	30.67
A_1	7	8.460	8.180	2506	2523	31.71
A_2	7	8.420	8.350	2494	2474	33.16
A_3	7	8.090	8.390	2397	2485	31.19
A_4	7	8.280	8.250	2453	2444	30.81
B	7	8.260	8.350	2447	2474	44.30
B_1	7	8.500	8.450	2518	2503	43.48
B_2	7	8.380	8.350	2482	2474	45.78
B_3	7	8.350	8.320	2474	2465	44.45
B_4	7	8.330	8.330	2468	2468	35.56
C	7	8.480	8.410	2512	2491	26.37
D	7	8.320	8.260	2465	2447	36.86

Table 2: 14 Days Average Compressive Strength of Concrete Cubes for all Specimen Types (A, A[1], B, B[1], C, and D)

Cube No.	Age (days)	Average weight Before curing (kg)	Average weight After curing (kg)	Average Density Before curing (kg/m^3)	Average Density After curing (kg/m^3)	Average Compressive Strength (N/mm^2)
A	14	8.460	8.590	2506	2545	33.78
A_1	14	8.240	8.170	2441	2420	31.95
A_2	14	8.420	8.350	2429	2474	33.88
A_3	14	8.300	8.240	2468	2441	34.07
A_4	14	8.200	8.150	2441	2414	30.95
B	14	8.330	8.430	2468	2497	47.26
B_1	14	8.400	8.350	2488	2474	45.33
B_2	14	8.310	8.280	2462	2453	46.82
B_3	14	8.280	8.250	2453	2444	45.85
B_4	14	8.280	8.250	2453	2444	35.75
C	14	8.370	8.260	2480	2447	26.94
D	14	8.300	8.210	2468	2432	38.17

Table 3: 28 days Average Compressive Strength of Concrete Cubes for all Specimen Types (A, A[1], B, B[1], C, and D)

Cube No.	Age (days)	Average weight Before curing (kg)	Average weight After curing (kg)	Average Density Before curing (kg/m^3)	Average Density After curing (kg/m^3)	Average Compressive Strength (N/mm^2)
A	28	8.400	8.500	2488	2474	33.92
A_1	28	8.240	8.130	2441	2408	32.33
A_2	28	8.460	8.350	2506	2474	31.84
A_3	28	8.200	8.130	2429	2408	35.59
A_4	28	8.200	8.140	2429	2411	31.32
B	28	8.220	8.300	2435	2459	48.11
B_1	28	8.430	8.350	2497	2474	45.70
B_2	28	8.410	8.350	2491	2474	49.63
B_3	28	8.310	8.250	2462	2444	49.93
B_4	28	8.300	8.240	2459	2441	36.70
C	28	8.410	8.260	2491	2447	27.19
D	28	8.510	8.300	2521	2459	38.48

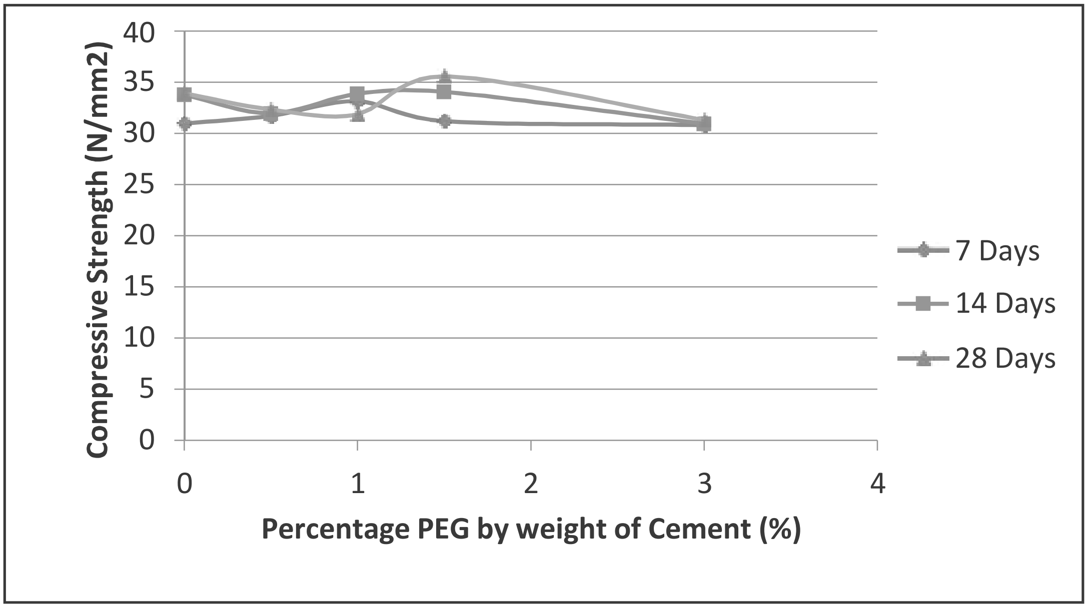

Fig 1: Compressive Strength of Type A concrete with varied percentage of PEG

From Fig 1, it is observed that 1.5%PEG concrete specimen cured in the air gave an optimum performance, resulting in a strength increase of 1.6N/mm^2, 4.9% compared to the strength of the control sample of 0% PEG dosage cured in water. Judging by the 28days compressive strength, solid PEG-1500 concrete cube specimens cured in the air without immersing in water gave a higher compressive strength of 35.59N/mm^{2}at 1.5% PEG dosage and 49.93N/mm^2 at 1.5% PEG dosage for grade C30 and C35 concrete, respectively. A rapid strength gain is seen in the first 7days of curing for the PEG concrete, attaining the compressive design strength before 28 days. Both concrete specimens cured in water by the ponding method and those cured in the air by self-curing method attained the design strength. It is carefully observed that a further increase in PEG dosage at 3% resulted in a decrease in compressive strength, which is against the speculation that higher content of the self-curing agent in concrete could serve to retain more water for more effective hydration and self-curing, hence, producing a better strength.

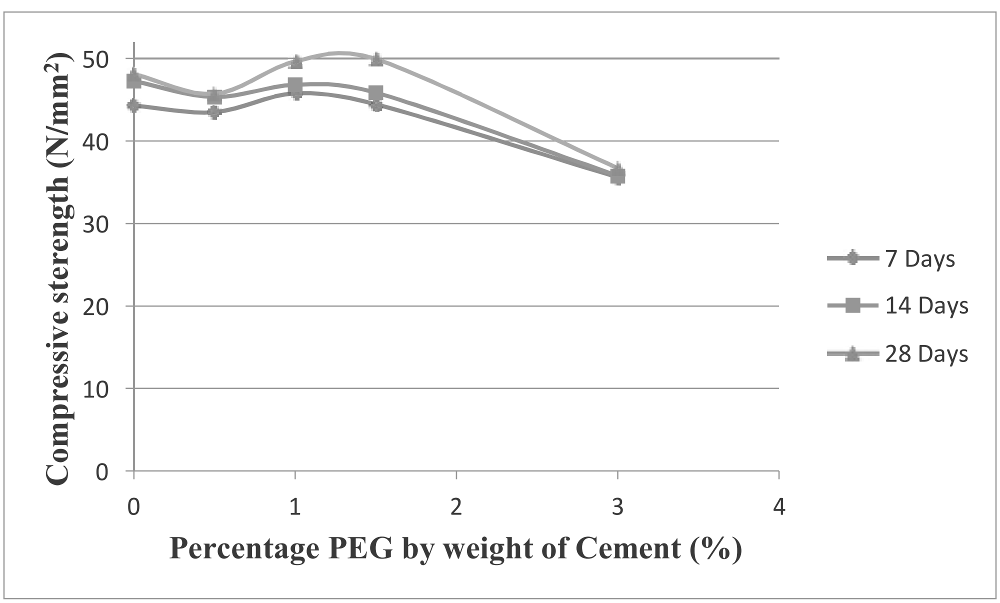

Fig 2: Compressive Strength of Type B concrete with varied percentage PEG

It is observed again in Fig 2 that 1.5%PEG dosage concrete specimen at 28 days produced an optimum performance in effecting self-curing by attaining a compressive strength increase of 1.8N/mm^2, 8.2% compared to the 28 days compressive strength of the control specimen, and the same order of rapid strength gain is observed for both grades of concrete. However, the results obtained from the grade B^1 samples tend to show that solid PEG-1500 is more effective in self-curing concrete at a lower w/c ratio, judging by the higher strength increase produced by the grade B^1 samples.

4.2 Weight Loss Results

Table 4: 28 Days Weight Loss (kg) of concrete cube Types (A, A^1, B, B^1, C, and D) Specimens

	C	**D**	**A_1**	**A_2**	**A_3**	**A_4**	**B_1**	**B_2**	**B_3**	**B_4**
	0.11	0.06	0.05	0.07	0.07	0.06	0.05	0.03	0.03	0.03
	0.11	0.09	0.07	0.07	0.06	0.05	0.05	0.03	0.03	0.03
	0.15	0.11	0.11	0.11	0.07	0.06	0.08	0.06	0.06	0.06
Average Wt. Loss(kg)	0.37	0.36	0.23	0.25	0.2	0.17	0.18	0.12	0.12	0.12

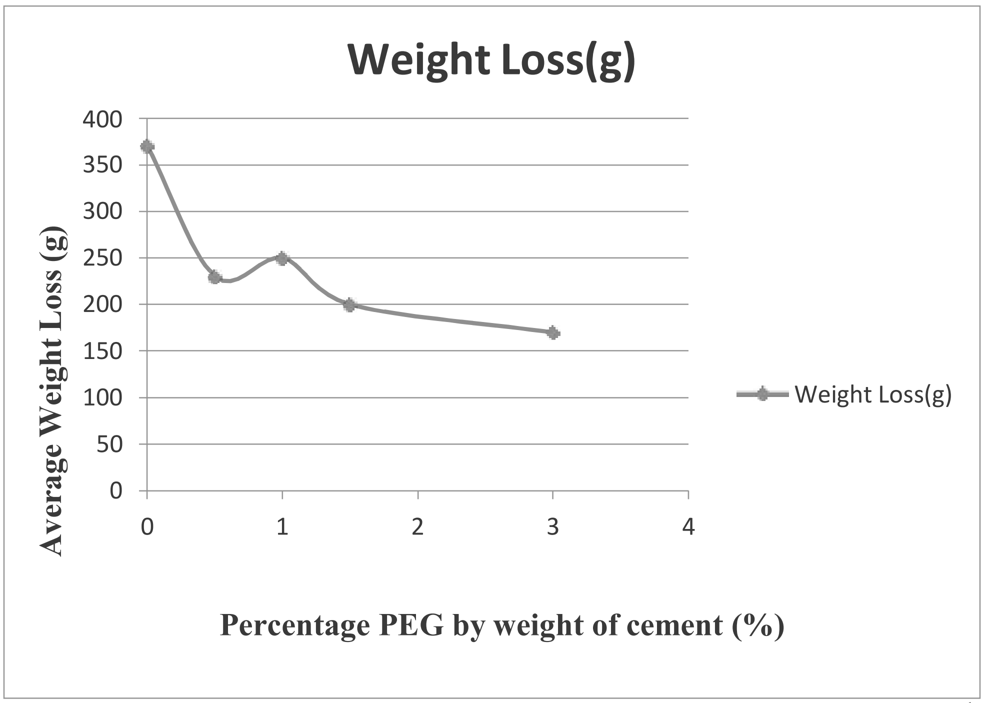

Fig 3: 28Days Average Weight Loss of Air cured Type C and Air cured Type A^1 concrete

The magnitude of weight losses in Type A^1 concrete specimens is more than that of Type B^1 specimens, as shown in Fig 3 and Fig 4. While the range of average weight losses for all the Type A^1 specimens is between 0.05kg and 0.07kg for age 7, 14, and 28 days, those of Type $B^1$are between 0.03kg and 0.05kg. This shows a better solid PEG500 in Type B^1 than Type A^1 in terms of water retention.

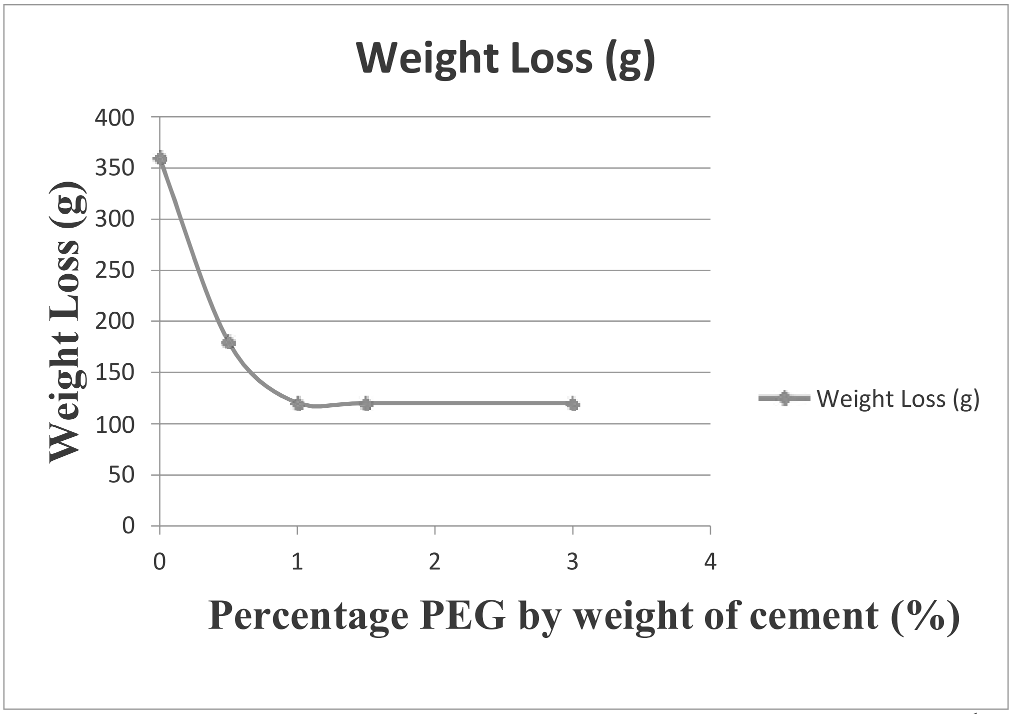

Fig 4: 28Days Average weight loss in Air cured Type D and Air cured Type B[1]concrete

From the results of the weight loss obtained for Type B[1]concrete, as shown in Fig 4, it can be observed that the capacity of the specimens to retain water increases with a corresponding increase in the percentage of the curing agent. Precisely, a specimen with 1% PEG to 3% PEG retain water in the same order, except for 0.5%PEG specimens, which retained less water as its average loss was 0.05kg and others 0.03kg at the curing age of 7days. The exact order of weight loss was observed at ages 14 and 28 days. The average weight loss is of equal amount for age 7 and 14 days at the rate of 0.05kg for 0.5% PEG specimens and 0.03kg for other specimens with a higher percentage of PEG per 7days, except the 28day weight for 0.5%PEG specimen, which had a less loss of 0.03kg. This observation does not correspond to the previous findings that the rate of weight loss decreased with age, indicating water retention, making it possible for continuous hydration process within the concrete as suggested in the literature [18] that curing agents with larger molecular weight and long chains should be capable of mechanically locking water molecules into their structures for more effective curing. On this premise, solid PEG was expected to be more efficient in retaining water better than liquid PEG of less molecular weight, such that the weight loss of self-curing concrete would decrease with time. However, from the result obtained in this study, the weight loss of the self-curing concrete specimen was virtually in the same order from age 7 to 28 days. It can hence be inferred that solid and liquid PEG have equal capacity in retaining water for self-curing, undermining their molecular weight.

Looking at Fig 5, air-cured concrete specimens with 0% PEG (Type C) could not reach the design strength of $30N/mm^2$ at 28 days. This can be attributed to the premature drying of the concrete and a drop of relative humidity below 80%, which hindered the formation of calcium silicate hydrate (CHS). Whereas air-cured PEG specimens reached their design strength because the curing agent reduced moisture evaporation from the concrete, maintaining a good curing condition within the concrete. This comparison is to appreciate the performance of the curing agent in concrete curing.

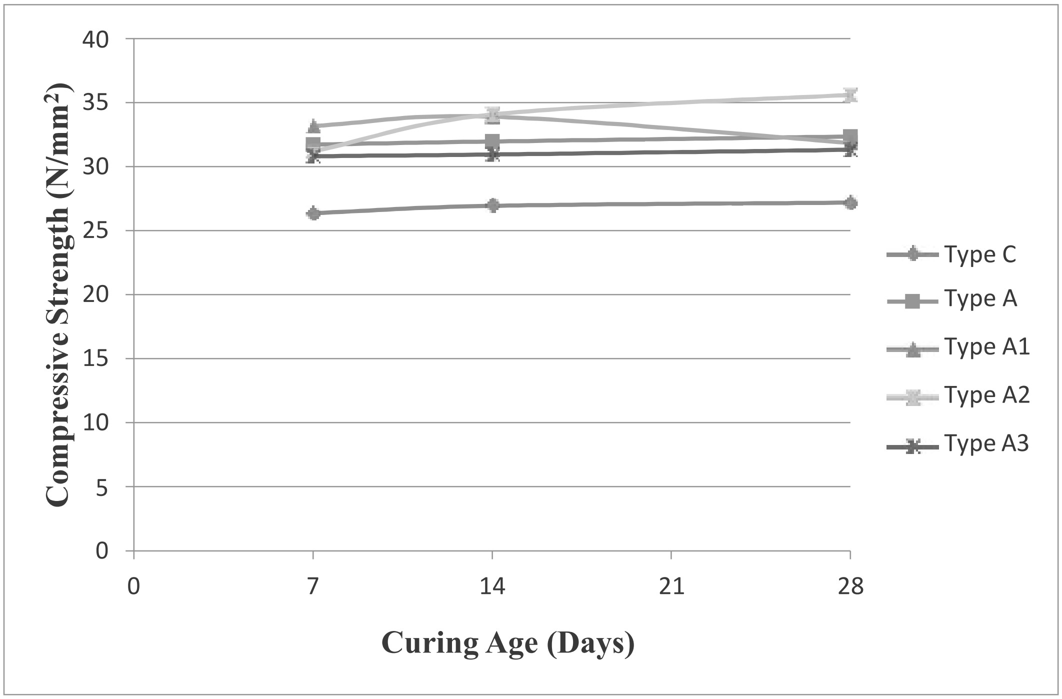

Fig 5: Compressive Strength of Air cured Type C and Air cured Type A[1]concrete

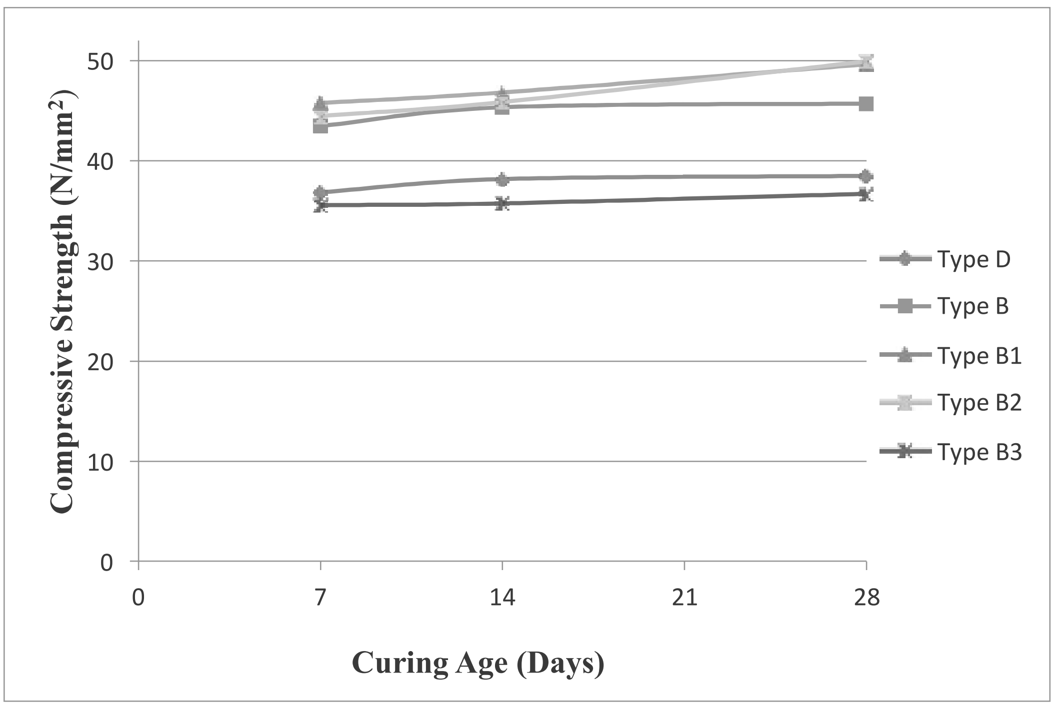

Fig 6: Compressive Strength of Air cured Type D and air-cured B[1] concrete

From Fig. 6, an appreciable difference in the 28 days compressive strengths of Type D (0% PEG) specimens and Type B[1] specimens of varied PEG dosages. Though Type D gained Strength rapidly, attaining a higher strength above its design strength of 35N/mm^2 at 28 days, a more rapid strength gain is observed with Type B[1]. The effect of the curing agent is yet observed with Specimens B[1] because the curing agent functioned to retain water for effective curing.

5. Conclusion

The following are the conclusion from the outcome of the experimental investigation:

(a) The workability tests found that self-curing concrete has maximum workability at 3.0% application of PEG. As a percentage of PEG-1500 increased, slump values increased for both C30 and C35 grades of concrete. However, it will be irrelevant to fully rely on the self-curing agent to improve workability by increasing the PEG dosage since a corresponding strength increase was not achieved.

(b) The effectiveness of self-curing concrete was affected by the w/c ratio, the grade of concrete, and percentage dosages of the self-curing agent. The water retention of solid polyethylene glycol (1500) concrete specimens cured in the air was higher compared to air-cured specimens without the curing agent.

(c) There was a significant relationship between the compressive strength of concrete and the water retention capacity of the self-curing agent. The compressive strength of the PEG (1500) concrete mix cured in the air increased by 4.9% and 8.2% for grades C30 (w/c 0.47) and C35 (w/c 0.35) at a dosage of 1.5% PEG1500 compared to the concrete cured by the ponding method. The optimum dosage of PEG1500 for maximum compressive strengths was found to be 1.5% by weight of cement.

(d) The performance of solid polyethylene glycol (1500) in self-curing concrete did not differ much compared to the report in literature [19] on self-curing concrete with liquid PEG-400.

(e) Comparing the results of this research according to the British Standard with results of previous researchers [20], using the Indian Standard on the subject of self-curing of concrete with polyethylene glycol, self-curing gave higher compressive strengths than conventional curing in both standards. The percentage difference in strength gain between conventional and self-curing in the Indian Standard, as reported by some researchers [21] is higher than the ones obtained in this research by the British Standard (BS).

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