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UTILIZATION OF PERLITE AS PARTIAL REPLACEMENT TO THE FINE AGGREGATE IN SELF-HEALING CONCRETE

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ABSTRACT

Concrete is vital in construction, but it can be compromised by factors like crack formation, shrinkage, moisture control etc. which allows harmful substances to loss its strength. To address this, a self-healing mechanism is introduced using perlite, a lightweight aggregate known for thermal insulation. This study explores how perlite can enhance self-healing by partially replacing fine aggregate and using sodium meta silicate as a crystalline healing agent in M40 grade concrete. In addition steel fibers are added to control cracking due to shrinkage. Controlled cracks are induced in cube specimens for water immersion, water contact and exposures conditions, and compressive strength is tested after 7, 14, 28, and 56 days to assess recovery rates and healing efficiency is studied.

Keywords: Self-Healing concrete, Expanded perlite, Crack formation, Sodium meta silicate solution.

1. INTRODUCTION

1.1. General

Concrete stands as a construction mainstay, celebrated for its remarkable robustness and impressive weight-bearing capabilities. The utilization of perlite as a partial replacement for fine aggregate in self-healing concrete represents a ground breaking innovation in the construction industry, driven by the pursuit of more sustainable, durable, and resilient building materials. Self-healing concrete has emerged as a promising solution to address the pervasive issue of concrete deterioration, which occurs due to factors like freeze-thaw cycles, crystalline attacks, and general wear and tear. It is engineered to autonomously repair micro cracks that inevitably develop in concrete structures over time, thereby enhancing their longevity and structural integrity. In this context, perlite, a naturally occurring volcanic glass, has garnered significant attention for its potential to revolutionize the field of self-healing concrete. When subjected to control heating, perlite expands, creating lightweight, porous particles with exceptional insulating properties. This unique attribute of perlite makes it an ideal candidate for replacing a portion of traditional fine aggregate (typically sand) in concrete mixes, thereby not only enhancing the self-healing capacity of the material but also contributing to sustainability goals by reducing the demand for natural sand resources.

The utilization of perlite in self-healing concrete holds several key advantages. Firstly, its porous nature enables it to act as a reservoir for healing agents, such as crystalline admixtures or bacteria. These agents are released from the perlite particles when cracks occur in the concrete, thereby initiating the self-repair process. This innovative approach mitigates the ingress of harmful substances into the concrete matrix, effectively preventing further deterioration and extending the service life of structures. Additionally, perlite's lightweight properties can reduce the overall density of the concrete, resulting in several benefits, including potential reductions in the dead load on structures and transportation costs. This not only enhances the environmental sustainability of construction practices but also contributes to cost-effectiveness. Furthermore, perlite is readily available and economically viable, making it an attractive choice for construction projects seeking to incorporate self-healing concrete as a viable solution for addressing infrastructure durability and resilience challenges.

1.2. Objectives of research

1. The primary objective is to replace a fraction of the conventional fine aggregate in M40 grade concrete with Perlite.
2. Another key aim is to investigate the self-healing capacity of M40 grade concrete containing Perlite under three distinct environmental conditions: Water Immersion (WI), Water Contact (WC), and Air Exposure (AE).
3. The current aim triggers and endeavors to pinpoint the most appropriate combinations of Perlite and crystalline admixtures to be integrated into the M40 grade concrete mix. This analysis is geared towards enhancing the concrete blend for superior performance and sustainability.

2. LITERATURE REVIEW

Several studies have explored the multifaceted applications of perlite in construction materials. Ibrahim Turkmen et al. [1] investigated the impact of expanded perlite aggregate and curing conditions on self-compacting concrete shrinkage. The compressive strength of EPA concrete was lower than those of NA concrete except for EPA5, EPA10 and EPA15, inair exposure condition. Sisomphon et al. [2] used sodium monofluorophosphate (Na_2PO_3F) in EC capsules 4 mm in diameter and demonstrated that sodium monofluorophosphate healed the samples and significantly improved the quality of concrete in the carbonation region. Alghamri et al. [3] used light aggregate capsules impregnated with sodium metasilicate. Cracking tests demonstrated an 80% recovery in load-bearing capacity when compared to a control sample. Capillary water absorption was also improved, indicating a reduction in cracking and an expected longer durability of the material. Ulger Bulutin [4], done an investigation was undertaken to explore the potential of perlite as a pozzolanic additive in lime mortars, with the objective of formulating cementitious materials that not only exhibit robust strength characteristics but are also impermeable to water.Vijay et al. [5] explored granulated self-healing agents to improve water leakage prevention through cracks. Granulation improved recession delay and water leakage prevention. Stuckrath et al. [6] examined various self-healing agents (chemical, biological, and combined) in mortar specimens. Chemical agents showed better healing performance, and combined agents exhibited the most effective results.. Foust et al. [7] experimented with ash replacement in concrete and tested mechanical properties. Optimal ash replacement was found to be 25%, enhancing concrete's self-healing abilities. Dr. K. Vidhya and colleagues [8] highlighted that plain concrete is brittle and requires reinforcement to withstand normal stresses and impact loads. They found that the introduction of micro cracks in concrete structures can be mitigated by adding fibers, which improve flexural and tensile strength. Their study focused on M40 grade concrete with varying steel fiber percentages and assessed compressive strength, tensile strength, and flexural behavior in concrete beams. S. Bakhtiyari [9], a comprehensive examination was conducted to investigate the efficacy of incorporating expanded perlite aggregate and zeolite powder additives as means to significantly augment fire resistance in self-compacting concrete, thus contributing to the development of concrete materials that can withstand and mitigate the impact of high-temperature environments and fire-related challenges. Atila Gurhan Celik et al. [10] explored expanded perlite as a lightweight construction material, focusing on partial replacement of fine aggregate. These studies collectively contribute to the expanding knowledge of perlite's diverse roles in construction.

3. MATERIALS AND METHODOLOGY

The blends are casted with the goal of giving concrete its maximum strength. The mix proportions of the different materials used in the concrete mixes are considered based on the IS 10262-2019 Code approach.

3.1. MATERIALS USED

3.1.1. Ordinary port land cement (grade 53)

The type of cement used in the study is OPC 53 grade from JSW cement. The individual properties of the cement were determined to ensure that they met the limits specified in the IS: 12269-1987 standard. The specific gravity of cement is obtained as 3.15.

3.1.2. Coarse aggregate

The coarse aggregates originate from a combination of naturally existing rock fragments and crushed granite. Concrete strength qualities may also be affected by the coarse aggregate form. As per IS: 383-1970, in the study coarse aggregate is used as 20 mm size aggregate. The specific gravity of the aggregate is obtained as 2.74.

3.1.3. Fine aggregate

Sand is a naturally occurring substance composed of minuscule fragments of rock and mineral. Quartz's chemical inertness and substantial hardness make it the most prevalent material that can withstand harsh weathering. In concrete, it serves as a fine aggregate. To do this task, in this study the river sand found locally is used, which was passing through a 4.75mm IS sieve and conforming to grading zone II of IS: 383. The specific gravity of fine aggregate is obtained as 2.65.

3.1.4. Perlite

Perlite is natural hydrated volcanic glass. It is also classified into two types based on the expanding property namely expanded perlite and unexpanded perlite. There are two main processes that cause hydration of perlite. Primary hydration occurs during formation of the rock before it is cooled; secondary hydration occurs after the rock has cooled. In our project unexpanded perlite from SID Pv. Ltd. Gujrat is been used. The specific gravity of perlite is obtained as 2.40.

Fig 1. Perlite

3.1.5. Steel fibers

Fibers are normally used in concrete to control cracking due to plastic shrinkage and to drying shrinkage and the Steel fibers increases durability and ductility of the concrete mix. They also reduce the permeability of concrete and for this reason minimize bleeding of water. Some types of fibers produce greater impact, abrasion, and shatter–resistance in concrete.

As concrete was weak in the tension zone the steel fibers incorporated in the concrete would nicely handle the tensile stresses. The weight of steel fibers is chosen as 2% by weight of cement. The length of fiber is 10 mm and the diameter is 0.12 mm.

3.1.6. Water

The primary ingredient in making concrete is water. Concrete was mixed and cured using drinkable water. Oils, acids, alkalis, salts, biological matter, and other pollutants that might harm concrete should not be present in the water used to mix concrete, including the free water on the aggregates.

3.1.7. Super Plasticizer

In order to make high-strength concrete, super plasticizers (SP) are added to fresh concrete to enhance its workability and enable the water content to be dropped. Conplast SP 430 DIS is the Super plasticizer utilized in this investigation. The specific gravity of super plasticizer is obtained as 1.08.

3.1.8. Sodium meta silicate

Sodium meta silicate commonly referred to as water glass, is a versatile healing agent used in self-healing concrete. When incorporated into concrete mixes, sodium meta silicate reacts with calcium ions in the presence of moisture to form calcium silicate hydrate (C-S-H) gel. This reaction effectively seals micro cracks that develop in concrete over time, enhancing the material's self-healing capabilities. Sodium meta silicate has proven effective in improving concrete durability and minimizing the ingress of harmful substances, making it a valuable component in the development of more resilient and long-lasting concrete structures. Its non-toxic nature and compatibility with existing concrete technology further contribute to its attractiveness as a healing agent in the construction industry. The specific gravity of Sodium meta silicate is obtained as 1.91.

3.2. METHODOLOGY

In this study to evaluate the effects of Perlite as partial replacement to fine aggregate four stages are given below followed.

1. Determination of compressive strength of plain concrete without crystalline admixture RM, Perlite concrete without crystalline admixture (PE5, PE10, PE15 & PE20) and plain concrete with crystalline admixture CRM, Perlite concrete with crystalline admixture (CPE5, CPE10, CPE15 & CPE20).
2. Creation of controlled damage in the specimens.
3. Simulation of the various environmental exposures needed to achieve better healing results.
4. Determination of regained compressive strength of specimens subjected to controlled cracking and self-healing agent as sodium meta silicate for 7, 14, 28 and 56 days under different exposure conditions.

Table 1. Mix proportions

Perlite as partial replacement to fine aggregate for kg/m3								
Mix	**Cement**	**Perlite**	**Fine aggregate**	**Coarse aggregate**	**Water content**	**Super plasticizer**	**Steel fibres**	**Healing agent**
RM	411	0	667	1274	148	4.11	8.22	0
PE_5	411	33.85	643.15	1274	148	4.11	8.22	0
PE_{10}	411	67.7	609.3	1274	148	4.11	8.22	0
PE_{15}	411	101.55	575.4	1274	148	4.11	8.22	0
PE_{20}	411	135.4	541.6	1274	148	4.11	8.22	0
CRM	411	0	667	1274	148	4.11	8.22	20.55
CPE_5	411	33.85	643.15	1274	148	4.11	8.22	20.55
CPE_{10}	411	67.7	609.3	1274	148	4.11	8.22	20.55
CPE_{15}	411	101.55	575.4	1274	148	4.11	8.22	20.55
CPE_{20}	411	135.4	541.6	1274	148	4.11	8.22	20.55

A total ten group of specimens were cast, each group consists 3 cubes. ten groups are used for improvement of strength characteristics. They are plain concrete without crystalline admixture RM and plain concrete with crystalline admixture CRM, Perlite concrete without sodium meta silicate as crystalline admixture (PE_5, PE_{10}, PE_{15} & PE_{20}) and Perlite concrete with sodium meta silicate as crystalline admixture (CPE_5, CPE_{10}, CPE_{15} & CPE_{20}). Ten groups are used for structural cracks self-healing study under the three environmental exposure conditions i.e., Water Immersion (WI), Water Contact (WC) and Air Exposure (AE) conditions.

1. Cube specimens of 150X150X150mm were prepared to determine compressive strength of plain concrete with and without Crystalline admixture and Concrete with Perlite and with and without Crystalline admixture.
2. Creation of damage (pre- cracking process); cube specimens (150X150X150mm) were pre- cracked at the age of 28 days for structural cracks by means of a compression test. Controlled damage; this was meant as the width of the crack, which was set to reach a target value by controlled loading.
3. Exposure simulation; three environmental exposure conditions were considered in order to determine the influence of water availability and its temperature on the self-healing capability of the tested specimens, comparing reference concrete with Perlite and crystalline admixture concrete. All specimens were left to heal for 7, 14, 28 and 56 days.
4. Determine the regained compressive strength of concrete after healing cracks in concrete specimens under different environment exposure conditions at 7, 14, 28 and 56 days.

4. RESULTS & DISCUSSIONS

Regained compressive strength was analyzed for both with and without crystalline admixture conditions for all the exposure conditions over a time period of 7, 14, 28 & 56 days. The results obtained were plotted in the graphs for all the exposure conditions with respect to 7, 14, 28 & 56 days and represented below.

The Regained compressive strength of Perlite concrete without crystalline admixture for 7, 14 28 & 56 days are depicted in the figure 3-6 below. It was found that the compressive strength obtained for the mix containing 10% of Perlite replacement without crystalline admixture reached the maximum value in all the exposure conditions. At 28 days it was found that the compressive strength obtained for the mix containing 10% of Perlite replacement addition from figure 5 is higher among the all the mixes and found to be 29.4N/mm^2 for Water Immersion condition. Similarly at 56 days it was found that the compressive strength obtained for the mix containing 10% of Perlite replacement addition from figure 6 is higher among the all the mixes and found to be 31.2 N/mm^2 for Water Immersion condition and from 3-6 it can be noted that the healing rate was in the order of WI > WC > AE.

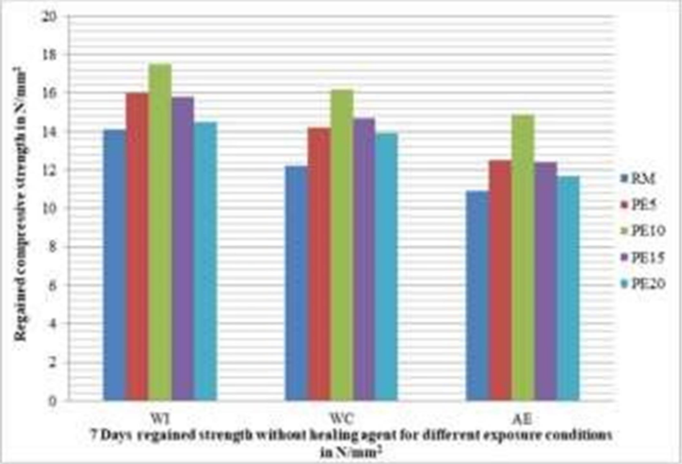

Fig 3. 7 Days regained strength without healing agent for different exposure conditions in N/mm^2

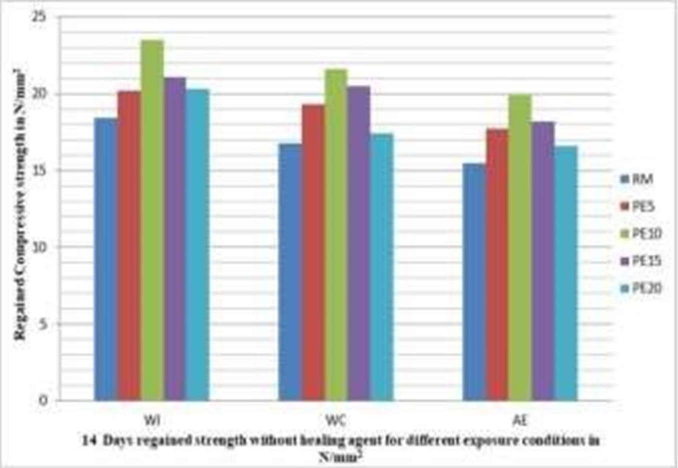

Fig 4. 14 Days regained strength without healing agent for different exposure conditions in N/mm^2

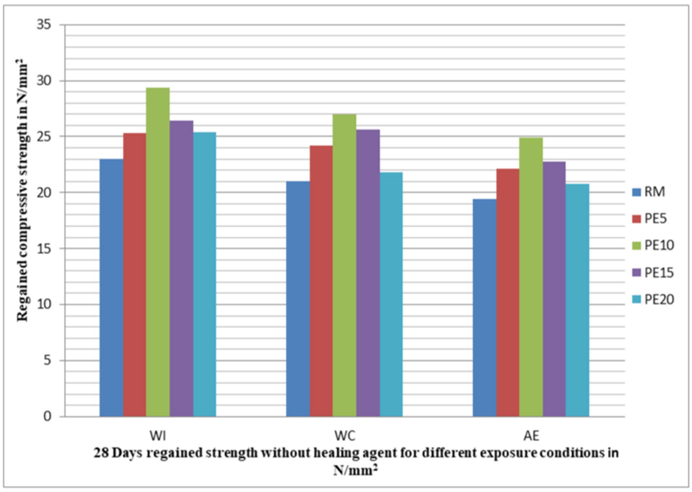

Fig 5. 28 Days regained strength without healing agent for different exposure conditions in N/mm^2

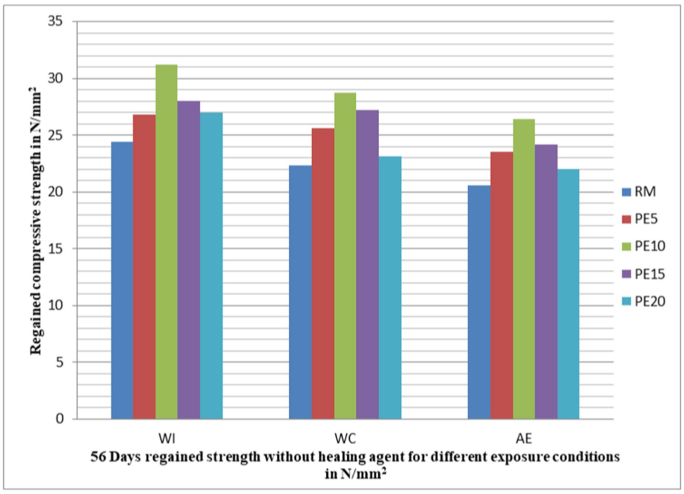

Fig 6. 56 Days regained strength without healing agent for different exposure conditions in N/mm^2

The Regained compressive strength of Perlite concrete with crystalline admixture for 7, 14 28 & 56 days are depicted in the figure 7-10 below. It was found that the compressive strength obtained for the mix containing 10% of Perlite replacement with crystalline admixture reached the maximum value in all the exposure conditions. At 28 days it was found that the compressive strength obtained for the mix containing 10% of Perlite replacement addition from figure 9 is higher among the all the mixes and found to be 48.7 N/mm^2 for Water Immersion exposure. Similarly at 56 days it was found that the compressive strength obtained for the mix containing 10% of Perlite replacement addition from figure 10 is higher among the all the mixes and found to be 54.1 N/mm^2 for Water Immersion condition and from 3-6 it can be noted that the healing rate was in the order of WI > WC > AE.

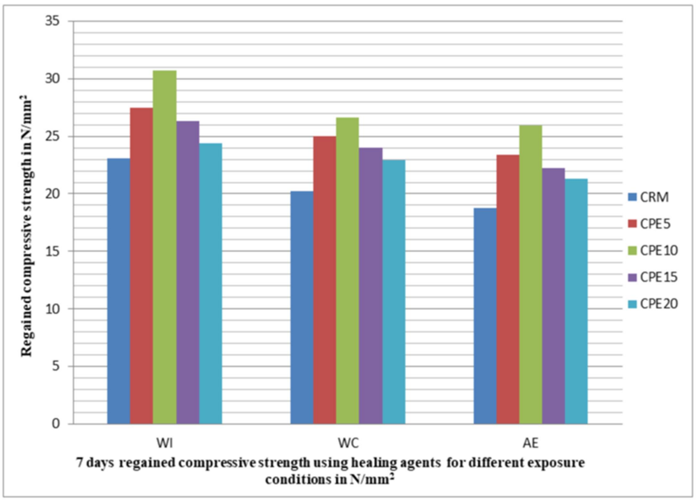

Fig 7. 7 Days regained strength with healing agent for different exposure conditions in N/mm^2

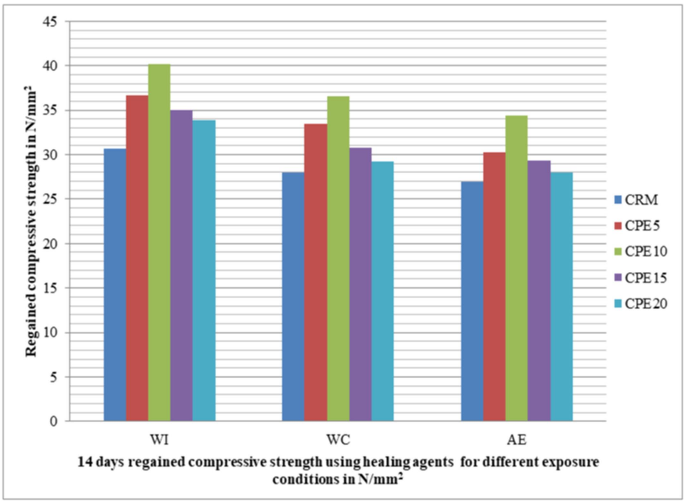

Fig 8. 14 Days regained strength with healing agent for different exposure conditions in N/mm^2

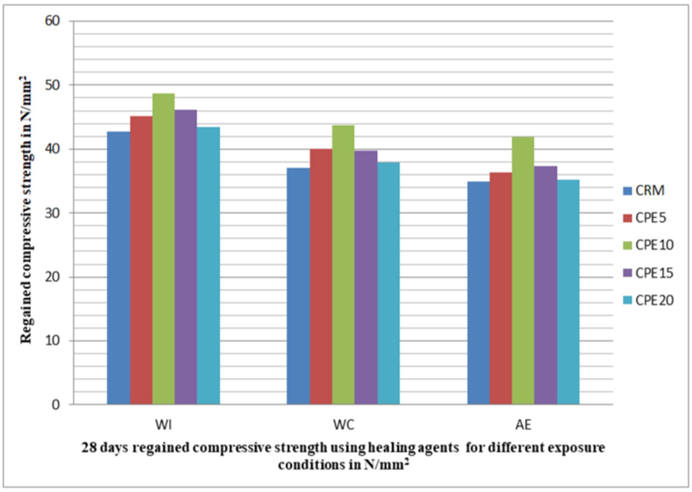

Fig 9. 28 Days regained strength with healing agent for different exposure conditions in N/mm^2

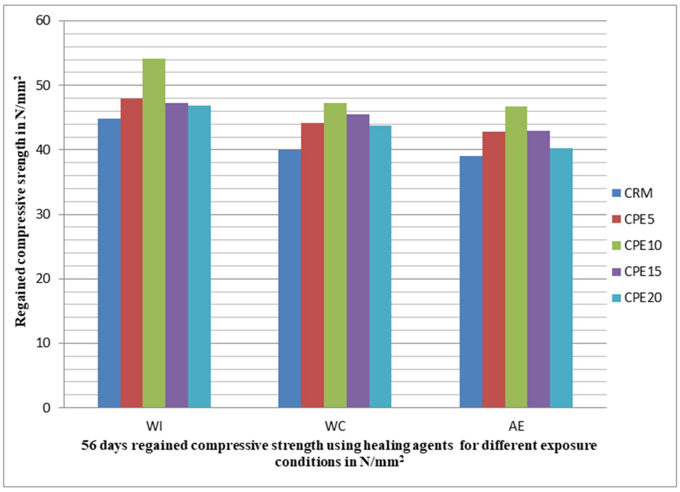

Fig 10. 56 Days regained strength with healing agent for different exposure conditions in N/mm^2

The findings of this study highlight the function of sodium meta silicate in concrete as a healing agent, enabling the production of C-S-H gel, a substance essential for the efficient healing and closure of fractures. This process, which is essential for complete recovery of the concrete, develops naturally inside the matrix of the concrete under the influence of these reactive components. The reaction shown below between sodium meta silicate (Na2SiO3) and calcium ions (Ca2+) in the concrete matrix produces calcium silicate hydrate (C-S-H) gel, which is necessary for sealing and filling cracks in concrete.

$$Ca^{2+} + Na_2SiO_3 \longrightarrow Ca_3Si_2O_7 \cdot 2H_2O \text{ (C-S-H gel)}$$

When cracks appear in the concrete, sodium meta silicate interacts chemically with the calcium ions present in the concrete matrix, causing more C-S-H gel to develop. As a cohesive binding agent, this gel precisely fills in the tiniest cracks and gaps in the concrete structure. This gel gradually covers, seals, and closes the fractures over time. It makes a substantial contribution to the structural integrity of the concrete when it hardens. The C-S-H gel formed as a result of sodium meta silicate's effect increases the longevity of the concrete by bolstering its resistance to further crystalline and cracking attacks. This improvement significantly adds to the concrete structure strength, serving as a permanent witness to both its good construction.

5. CONCLUSIONS

After analyzing the regained compressive strength and crack closure capabilities over the curing period with respect to different environmental exposures the following conclusions are made.

1. The mixes which contains both the crystalline admixture and Perlite has given a very exceptional results for all the exposure conditions.
2. The optimum compressive strength for 28 days curing was obtained for the mix containing 10% of Perlite replacement and without crystalline admixture addition and it was found to be 29.4 N/mm^2 at 28 days and 31.2 N/mm^2 at 56 days for Water Immersion condition.
3. The optimum compressive strength for 28 days curing was obtained for the mix containing 10% of Perlite replacement and with crystalline admixture addition was found to be 48.7N/mm^2 at 28 days and 54.1 N/mm^2 at 56 days for Water Immersion condition.
4. The concrete with 10% Perlite as a partial replacement to fine aggregate with crystalline admixture Sodium meta silicate gained complete strength at 56 days is 1.02 times higher than original strength.

5. From the crack closures and regained compressive strength values obtained for the mixes with absence of crystalline admixture and presence of Perlite, it was proved that Perlite has contributed partial amount of healing.
6. From the above study the healing rate was in the order of WI > WC > AE.

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