Effect Of Attapulgite as Internal Curing in High-Performance Concrete with Variable Temperature Curing to Enhance Mechanical Properties

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Abstract. One of the most important elements in the development of compressive strength is concrete curing, and a large temperature differential during curing may decrease strength. This exudation is caused by microcracks in the concrete caused by the continuous temperature fluctuation. By minimizing autogenous shrinkage, internal curing has become popular for reducing the danger of early-age cracking in high-performance concrete (HPC). The efficacy of internal wet curing provided by fine Attapulgite aggregate is investigated in this research. On three different HPCs, both with and without internal curing materials, the development of observed mechanical properties is investigated. Two different amounts of normal weight fine aggregate were replaced with attapulgite fine aggregates. Internal cure has been found to benefit from attapulgite fine aggregates. It has been found that adding 20% Attapulgite fine aggregates to HPC enhances the material's characteristics, resulting in low internal stress and a significant increase in compressive strength. It should be noted that, unlike certain conventional lightweight aggregates, the different amounts of Attapulgite fine aggregates added at various ages have shown no decrease in compressive strength.

Keywords: Internal curing agent, High-performance concrete (HPC), local Attapulgite, fine aggregate, replacement of fine aggregate, curing temperature.

1. Introduction and Literature Review
The inclusion of silica fume to high-performance concrete (HPC) mixes, along with a low water/binder (w/b) ratio, results in a substantial reduction in relative humidity during the hydration process. The self-desiccation process causes the cement paste to shrink. Because the aggregates’ Young's modulus is higher than the hardening paste's, autogenous shrinkage causes tensile strains in the cement paste and bulk deformation of the concrete. Both of these occurrences should be avoided as much as possible since they may cause micro- or macrocracking, lowering the quality of the concrete(1). Microcracking may develop as a result of aggregates in the mixture causing internal constriction. Many authors have utilized analytical techniques to predict when these fractures would appear(2) or numerical methods(3). Due to sample preparation issues, identifying shrinkage microcracks via microscope observations is more difficult(4). When a concrete structure reaches a certain size, autogenous shrinkage combined with temperature-induced
deformations may cause surface and through fractures. Even though autogenous shrinkage is the only source of deformation in isothermal sealed curing, self-induced tensile strains exerted by external restriction may cause concrete cracking(5)(6)(7) potentially jeopardizing the durability. At room temperature, autogenous deformation measurements are often performed. Only a few studies have looked at the effect of different curing temperatures on autogenous shrinkage thus far. The bulk of these experiments are focused on cement pastes(8)(9)(10). The temperature dependence of autogenous deformation is derived in an ad hoc way from these studies(1). Only a maturity function can predict autogenous deformation at different curing temperatures, according to Ref. (6). They do, however, exhibit a more regular behavior, and the authors conclude that autogenous deformation may be reproduced using the maturity idea provided a temperature-correcting element is added. Portland cement mixtures have been the subject of the bulk of autogenous shrinkage research(11). Blast-furnace slag (BFS) cement has been utilized in several European countries for almost a century. In the Netherlands, BFS cement (which includes up to 70% slag) has been utilized widely and effectively, especially in marine structures(12). Environmental friendliness (because to the reuse of waste material), decreased hydration heat, and a finer pore structure that increases water tightness are only a few of the advantages of this kind of cement(13) and durability(1). The shrinkage behavior of BFS cement blends is expected to differ from that of Portland cement mixes due to the chemical composition of the cement influencing both self-desiccation and autogenous deformation(14) as well as the pore size distribution of the cement paste(15). Others have found that BFS combinations have greater shrinkage values.(16)(17)(18).

The drying process is known to influence the strength and microstructure of concrete and mortar. Insufficient curing conditions result in inferior features and performance when significant quantities of water are removed from cement paste before maturation. Furthermore, at any age, the moisture content of a cement-based material affects its mechanical properties. The degree of shrinkage and stress condition of the system are both affected by drying(19). Drying shrinkage has a variety of effects on the microstructure, with two main effects on mechanical characteristics. It increases strength in one way by increasing surface energy and bonding between calcium silicate hydrate particles (C-S-H). Because it is a quasi-brittle material, microcrack development reduces the material’s strength. Cracking is influenced by the rate and severity of drying, as well as the sample shape(20). Concrete cast and cured at low temperatures, according to common wisdom, develops strength far more slowly than concrete poured at room temperature.

According to traditional thought, concrete cast and cured at low temperatures develops strength much more slowly than comparable concrete placed at ambient temperature(21), as Price (1951)(22) and Klieger (1958) (23) demonstrate. According to the results, cold-cast and cured concretes from Gardner et al. (1988) (24) and Ho et al. (1989)(20) did not show the anticipated progressive strength growth at low temperatures. The cement, on the other hand, will continue to hydrate in the concrete’s core as long as there is adequate pore water. Some of the pore water will be consumed by the hydration process, while some will be lost by the drying surface. According to Powers (1947)(25), cement hydration almost ceases when the relative water vapor pressure in capillaries falls below 0.8. Continued curing below 80 percent relative humidity, according to Spears (1983)(26), does not result in an increase in cement hydration, which is needed for further concrete quality improvement. In reality, site concrete is exposed to daily humidity cycles, which are exacerbated by seasonal variations, and active curing may be stopped before the cement has fully hydrated(21). Curing is required to improve the quality of the concrete cover while also limiting the penetration of hostile chemicals into the concrete structure. Chloride ion corrosion of reinforcing steel is a significant problem(27).
The goal of this research is to utilize wet lightweight aggregate as an internal water supply in restricted settings to prevent self-desiccation and strain development. It's important to keep in mind when developing this concept and assessing its impact that the opposite effect, namely internal shrinking caused by water absorption from matrix holes into aggregate pores, may occur (28). Merikallio et al (29) discovered this for a particular kind of normal-strength concrete. The influence of the lightweight aggregate's initial moisture condition relative to the absolute humidity matrix must be taken into account when evaluating its efficacy as an internal curing agent supplying a water reservoir.

The aim of this study was to show the effect of using local Attapulgite fine aggregates on the HPC’s mechanical characteristics. The effect of the 10% replacement rate and the 20% replacement rate were studied with three ages, which are 60, 120, and 180 days, amid an additional external treatment with a variable temperature.

2. Materials and Methods

The next section covers the experimental program's stages, which include material preparation, concrete mix design, and experimental testing.

2.1. Materials

Ordinary Portland cement was used to produce the HPC mix, in addition to silica fume with a percentage of up to 11%. In order to achieve the required precipitation, a certain percentage of superplasticizer was added to the water to improve the workability of the concrete mix. Natural fine and coarse aggregates with a maximum nominal aggregate size of 4.75 and 12 mm, respectively, were used. The fine Attapulgite aggregate was used after it was ground and burned, and its gradations were re-adjusted to conform to the natural fine aggregate gradation. It has been immersed in water before being used in partial replacement in order to achieve the condition of dry-surfaced saturated aggregate as an internal treatment material.

![Figure 1. Attapulgite clay, crushed and burnt.](image)

2.2. Concrete Mixtures

Three mixtures were made as shown in Table 1. The first mixture was a reference mixture to compare other mixtures and it was without internal treatment materials. As for the second mixture, it contained the fine aggregate of Attapulgite with a percentage of 10% replaced by volume from the natural fine aggregate. The third mixture also contains the fine aggregate of Attapulgite, which is replaced by volume from the natural aggregate, with a replacement rate of 20%.

| Types of Mix | Fine Aggregate (kg/m³) | Cementitious Material Content (kg/m³) | Gravel (kg/m³) | W/B | Superplasticizer (L/100 Kg) |
|--------------|------------------------|--------------------------------------|----------------|-----|-----------------------------|
|(reference)   |                        |                                      |                |     |                             |
|               | fine aggregate          | 10% replacement rate                 |                |     |                             |
|               | fine aggregate          | 20% replacement rate                 |                |     |                             |

Table 1. Concrete mix proportions.
2.3. Specimen Preparation
Immediately after pouring to avoid water loss from the concrete mix forms, the concrete samples were covered with a plastic bag for 24 hours, after which the molds were removed. All samples were placed in the external ripening water for the first sixty days only, after which the samples were taken out of the water. The treatment was carried out in the winter, amid a change in the outside air temperature of about 16 degrees Celsius. Three factors were studied, namely, compressive strength, cleavage resistance, and dry density of concrete mix samples. Through these tests, the HPC's mechanical characteristics were studied in the midst of a large difference in temperature.

2.4. Testing Methods
To calculate the compressive strength, a total of 9 concrete cubes measuring 10 * 10 * 10 cm were poured, as well as the same in number to calculate the density. To calculate the splitting tensile strength, a total of 9 concrete cylinders measuring 10 * 20 cm were poured. Where 3 samples were determined for each age, then the average of the three samples was taken to evaluate the value of the studied result.

3. Results and Discussion
This part of the research presents the test results, such as compressive strength, splitting tensile strength, and dry density.

3.1. Compressive Strength
As demonstrated in Figure 2, the compressive strength of the reference concrete mix was significantly reduced. Whereas at the age of 120 days, the percentage of decline was 10.29 percent, and at the age of 180 days, the percentage of drop was 27.33 percent. Mixtures including internal curing ingredients, on the contrary, exhibited a significant increase in compressive strength. The combination containing 10% Attapulgite aggregate exhibited a 41.14 percent rise in the age of 120 days, but only a 53.96 percent increase in the age of 180 days. Also, at the age of 120 days, the mixture containing 20% Attapulgite aggregate increased by 0.73 percent, but at the age of 180 days, it only increased by 0.88 percent. The concrete mixture with a 20% replacement rate was determined to be the best among the mixes and the best in terms of outcomes in the research. It is clear that modern concrete treatment amid significant temperatures added in a cold atmosphere causes micro-cracks that reduce the characteristics of the concrete mixture either with the treatment of concrete treatment as well as the use of concrete materials that may be compensated by the interaction of hydration from these micro-cracks.
3.2. Splitting Tensile Strength

The behavior of HPC mixes in terms of cleavage strength was significantly different from the behavior shown in compressive strength. The results showed a decrease in the cleavage resistance of the reference concrete mix at the age of 120 days by 5.14 percent, and the percentage of decrease at the age of 180 days was 13.33 percent. While the mixtures containing internal processing aggregates showed a significant increase in the fission resistance. Fission resistance at 120 days of age increased by 4.89 percent in the mixture containing 10% attapulgite aggregate, but only 6.31 percent in the mixture containing 20% attapulgite aggregate. Also, at the age of 120 days, the mixture containing 20% fine attapulgite aggregate increased by 8.28 percent, but at the age of 180 days, it increased by only 10.02 percent. It was found through the analysis of the results that the concrete mixture with a replacement rate of 10% has better results among other mixtures.
3.3. Dry Density
Figure 4 illustrates that the density of concrete without internal curing ingredient rises somewhat with age and then returns to a nearly neutral state. Because the replaced materials are less dense than fine aggregates, the density of mixes with internal curing is lower than that of concrete without internal curing. There was also a reduction in density as people became older. This reduction may be related to the quantity of internal curing water contained inside the internal curing granules decreasing.

![Dry Density Chart](image)

**Figure 4.** Dry density for all mixes.

4. Conclusions
The aim of this research was to improve cement hydration reaction and concrete behavior in HPC mixes by utilizing underutilized local material “local fine Atta pulgite aggregates” as a saturated fine aggregate dry surface. Through the results shown in the search is clear that the use of Atta pulgite as internal curing material has an effective impact on the properties of concrete mixture. It is noted that the use of Atta pulgite is improving mechanical properties and especially in the late concrete. A substantial improvement in structural behavior has occurred from increased replacement of fine Atta pulgite from the surrounding environment. The mechanical behavior has been significantly improved by increasing the proportion of local fine Atta pulgite that is replaced. Atta pulgite aggregate is considered as a sustainable interior curing medium since it may be produced from discarded local resources. The above study shows that using Atta pulgite has only a good effect, and its direction is widely used is part of sustainability so we recommend it using Atta pulgite as internal curing materials in concrete mix.

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