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Research Article

Efficiency of Sodium Polyacrylate to Improve Durability of Concrete under Adverse Curing Condition

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The conventional external curing process requires supply of large amount of water in addition to mixing water as well as strict quality control protocol. However, in a developing country like Bangladesh, many local contractors do not have awareness and required knowledge on importance of curing which often results in weaker concrete with durability issues. Moreover, at times it is difficult to maintain proper external curing process due to nonavailability of water and skilled laborer. Internal curing can be adopted under such scenario since this method is simple and less quality intensive. Usually, naturally occurring porous light weight aggregates (LWA) are used as internal curing agent. However, naturally occurring LWA are not available in many countries like Bangladesh. Under these circumstances, Super Absorbent Polymer (SAP) can be utilized as an alternative internal curing agent. In this study, sodium polyacrylate (SP) as SAP has been used to produce internally cured concrete. Desorption isotherm of SP has been developed to investigate its effectiveness as internal curing agent. Test results showed that internally cured concrete with SP performed better in terms of both strength and durability as compared to control samples when subjected to adverse curing conditions where supply of additional water for external curing was absent.

1. Introduction

Internal curing (IC) is a process of supplying additional internal water to the concrete mix to ensure proper hydration. Generally, porous light weight aggregates (LWA) are used as internal curing agent since such type of porous aggregates can absorb sufficient quantity of water when submerged in water and later can transfer the absorbed water to the concrete mix [1–4]. Internal curing process is very useful when proper curing of concrete is difficult to manage due to adverse ambient temperature and relative humidity, unavailability of skilled workers, absence of appropriate quality control protocol, and so forth. Such process of internal curing is relatively simple which only requires an internal curing agent and does not require any sophisticated equipment or technique. In addition, a number of benefits like increased hydration, reduced shrinkage, and increased durability can be achieved from internal curing [2, 5, 6]. Moreover, Zou and Weiss [7] observed that utilization of expanded shale as internal curing agent can also diminish the risk of cracking in mortar. Usually, different types of naturally occurring LWA are used to produce internally cured concrete. Nevertheless, different types of porous aggregates or materials with high absorption and desorption capacity have also been utilized by different researchers to produce internally cured concrete. A recent significant study by Zou et al. [8] showed effectiveness of a new type of porous normal weight aggregate as internal curing agent in mortar. The researchers observed improved compressive strength, splitting tensile strength, and shrinkage in internally cured mortar as compared to plain mortar. In another research [9], few properties of internally cured concrete made with artificially produced porous LWA and SAP are described in brief. It is, therefore, evident that there is a continuous thrive for producing internally cured concrete or mortar using different types of suitable materials since internal curing has numerous benefits. Moreover, naturally occurring LWA are not available in many countries like Bangladesh and import of these aggregates increases the overall construction cost. Consequently, researches have been going on to find out alternate materials that have potential to be used as internal curing agent in concrete. Such researches are extremely important in the context of a country like Bangladesh where a good number of local contractors do not have the awareness and skill for ensuring proper external curing. In addition, it is often difficult to ensure appropriate external curing mechanism due to non-availability of sufficient amount of water and skilled laborer, high temperature, high wind speed, and so forth. As a result, performance of general concreting work is often not up to the mark particularly in terms of durability [10]. Internal curing, therefore, can be considered as a potential solution to the curing related issues of general concreting works of the country. Hence, identification of relative low cost suitable internal curing agent is of immense importance.

Super Absorbent Polymer (SAP) is polymeric materials that have the ability to absorb a large amount of fluid from the surroundings and retain the fluid within their structure. SAP is crushed crystalline partial sodium salt of cross-linked "polypromancic acid" rated at 2,000 times absorption for pure water [11]. Once the SAP hydrates, swells, and releases the stored water, it becomes inert and unable to rehydrate. This additional water can be a source of internal water within fresh concrete and therefore can be used to produce internally cured concrete. A comprehensive literature review revealed few significant studies on utilization of SAP in concrete. In one study [12], it has been found that SAP addition resulted in a reduction of the stress buildup and cracking during restrained hardening of high-performance concrete. Hasholt et al. [13] studied the effect of SAP on the mechanical strength of concrete by optimizing the dosage rate and internal water added. The researchers arrived at the conclusion that addition of SAP could increase the strength of concrete by preventing self-desiccations. In another research, Assmann and Reinhardt [14] also found that SAP can be used to mitigate long-term self-desiccation of concrete by providing additional water to the mix. Gifta et al. [15] studied the effect of SAP on concrete and compared it to internally cured concrete having either SAP or LWA. They observed better durability performance of SAP concrete as compared to both LWA and conventional concrete. The reswelling capacity of SAP in cement paste and the effect of SAP on microstructure of cement paste were investigated by Lee et al. [16]. A research was performed on the effect of SAP on the characteristics of mortar by Lee et al. [17]. The test result showed that flow properties of mortar decreased with the increase in SAP volume. Around 31% improvement in strength compared to plain mortar was noticed from this experiment. On the contrary, Nasra [18] found that excess amount of SAP resulted in large voids in concrete and produced weaker concrete in terms of both strength and durability. Small amount of SAP, on the other hand, had negligible effect on the concrete performance. Nasra [18] found around 10% increase in 28-day compressive strength of concrete through addition of SAP. Daoud and Nasra [19] found that inclusion of SAP within concrete creates additional voids which, in general, lessens concrete strength but improves the workability and consistency, reduces the concrete susceptibility to freezing thawing cycle, and thereby improves concrete stability under such condition. Mechtcherine et al. [20] observed that effect of SAP addition on rheological behavior of concrete depends on the availability of free water in the mix. The research by Kevern and Farney [11] found that 33% higher compressive strength and 35% less water permeability can be achieved by adding SAP within concrete. It is, therefore, apparent that SAP has the ability to modify various properties of cement paste and concrete depending on amount, type, mix proportions, and so forth. It is evident from the previous study that high absorption and desorption capacity of SAP can be used for improving concrete mechanical behavior. However, effect of SAP inclusion in concrete is quite variable and can have negative impact. Therefore, control and careful utilization of SAP within concrete is extremely important. Moreover, limited study has been performed on durability of concrete having SAP. In the present study, an effort has been made to investigate the suitability of SAP as an internal curing agent for improving the performance of general concreting work of the country. Two pertinent points need to be considered while developing internally cured concrete for Bangladesh. The method for producing internally cured concrete should be simple to implement in field and at the same time must not impose significant extra cost. With this end in view, sodium polyacrylate (SP) has been used as SAP in this study since it is available at comparatively low price in the country. Initially, absorption and desorption properties of SP were investigated. Desorption is the process of releasing absorbed water due to internal or ambient change in humidity and temperature [5, 21, 22]. Desorption isotherm of SP was developed for proper understanding of the effectiveness of SP as internal curing agent. From the study, it has been observed that SP absorbs a significant amount of water and then desorbs almost all part of absorbed water at suitable temperature and relative humidity condition. The conducive condition for effective desorption of SP matches with the internal temperature and relative humidity of concrete particularly at earlier ages of hydration. So, the amount of desorbed water by SP could be utilized as internal curing water which can contribute to hydration of cement in the absence of sufficient amount of water in the mix due to unavailability of proper curing conditions. Four different curing conditions were used in the study to simulate common prevailing adverse curing conditions of the country. In this study, adverse curing condition is defined as the condition where supply of external water is not maintained due to nonavailability of water or absence of proper quality control protocol. Control samples without SP as SAP were also prepared for comparison. Both control samples and samples with SP were kept under simulated curing conditions. Performance of SP concrete under different curing conditions with respect to control samples was observed and compared. It has been found that samples with SP showed better performance as compared to control samples in all cases of adverse curing conditions.

2. Experimental Investigation

Sodium polyacrylate (SP), also known as waterlock, is a sodium salt of polyacrylic acid with the chemical formula of $(C_3H_3NaO_2)_n$ as shown in Figure 1 and has wide application in consumer goods. It has the ability to absorb water as much as 200 to 300 times of its mass. While sodium neutralized polyacrylic acids are the most common form used in

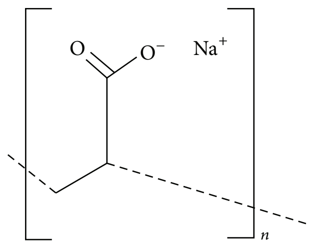

Figure 1: Structure of sodium polyacrylate.

manufacturing, there are also other salts available including potassium, lithium, and ammonium. Multiple chains of acrylate compounds possess a positive anionic charge which attracts water-based molecules to combine with it to produce sodium polyacrylate or SP. SP is used extensively in the agricultural industry by infusing in the soil of many potted plants to help them retain moisture. Density of SP is around $1.22\,g/cm^3$.

Two mixes were prepared with CEM II cement [23], Sylhet sand as fine aggregate, and 19 mm (1/2 inch) downgraded crushed stone chips (SC) as coarse aggregate in a volumetric ratio of 1 : 1.5 : 2.5. Water to cement ratio was kept as 0.4. Gradation curves of fine and coarse aggregates are shown in Figures 2 and 3, respectively. In first case, no SP was used as SAP to produce control samples. In second case, SP was used as internal curing agent to produce internally cured concrete. Sodium polyacrylate was collected from locally available baby diapers and used with a dosage rate of 1.25 g per kg of cement [18, 24]. The amount of SP was selected from an initial trial based analysis since excessive amount of sodium polyacrylate has substantial negative effect on concrete strength. Super plasticizer was used to ensure uniform dispersion of SP within mixing water. Otherwise, SP has tendency to agglomerate. Addition of super plasticizer also improved the overall workability of the mix. Super plasticizer was used in the amount of 1% of cement weight. After casting, these samples were kept at four different simulated adverse curing conditions for up to 28 days. All simulated curing conditions had no supply of external water. One set of control samples (without SP) was also kept under four curing conditions for comparative study. In the first curing condition, termed as C1, specimens were placed inside laboratory in a dry space covered with polythene to simulate concreting work under shades. In the second curing condition (C2), samples were again placed inside laboratory but without providing polythene cover. In the third (C3) and fourth (C4) curing conditions, specimens were placed in a dry place outside laboratory-building with and without polythene cover, respectively. The samples were placed outside laboratory to simulate open space concreting work. It has been learned from an extensive survey that a good number of concreting works suffer from appropriate covering to protect mix water from evaporating due to lack of awareness and proper quality control. Therefore, samples were placed without covering to simulate such conditions. As already mentioned, no external curing was applied in any cases.

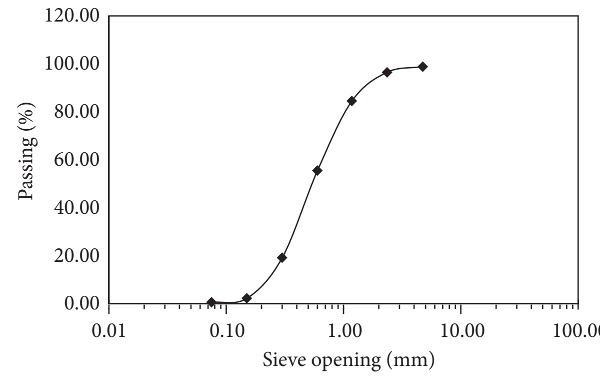

Figure 2: Gradation curve of fine aggregate (sand).

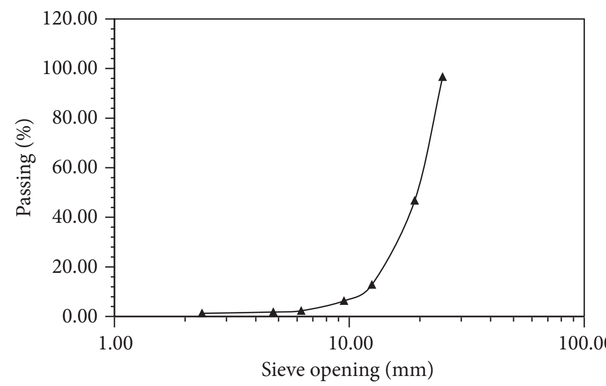

Figure 3: Gradation curve of coarse aggregate (SC).

The absorption and desorption properties of SP are important to determine their effectiveness as an internal curing agent [25, 26]. A dehumidifier, as shown in Figure 4, was used in this experiment to evaluate the effectiveness of SP as internal curing agent. ASTM C1761 [27] method was followed for this experiment. The dehumidifier has relative humidity (RH) range from 22% to 90% and temperature range between 5° and 40° Celsius. The internal temperature and humidity during hydration of concrete usually range from 20° to 40°C [28] and 72.4% to 95.3% [29], respectively. Hence, the utilized dehumidifier is capable of simulating internal temperature and relative humidity that exist within conventional concrete mixes during hydration.

Total thirty experiments were conducted with six different temperatures of 14.5°C, 18°C, 24°C, 28°C, 31°C, and 34°C and five different RH of 60%, 73%, 77%, 85%, and 90%. Dry weight of SP samples was taken initially and then samples were submerged in water. After submergence, SP samples were reweighted. From the test, it was found that SP absorbed nearly 100% of water of its own weight. Once absorption was completed, SP samples were placed in dehumidifier at different preselected temperature and relative humidity. Water loss was measured in 30-minute interval. Experimental results are shown in Figure 5.

In order to investigate the efficiency of SP as internal curing agent within concrete mix, compressive strength,

(a) (b) (c)

Figure 4: Desorption test: (a) dehumidifier; (b) weighting of SAP; (c) placing SAP in dehumidifier.

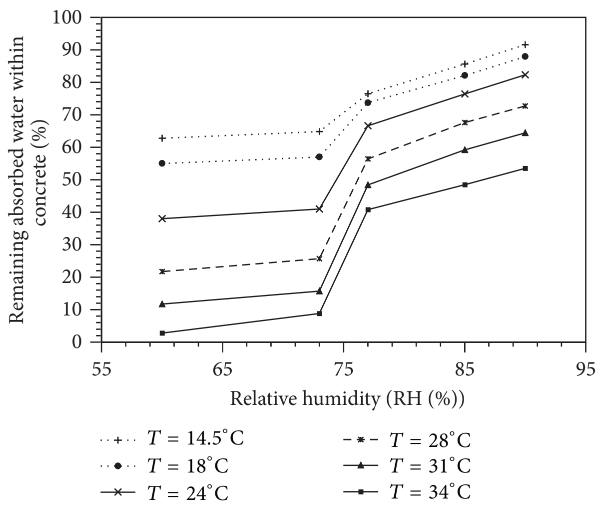

Figure 5: Desorption isotherm of SAP.

modulus of elasticity, water permeability, and chloride permeability tests were performed. After 28 days of curing under four different simulated conditions, compressive strength test was performed according to ASTM C39 method [30]. Modulus of elasticity of concrete was obtained using axial stress strain method according to ASTM C469 method [31]. Water permeability test was conducted according to BS-EN 12390-8 [32]. Rapid Chloride Permeability Test (RCPT) was performed according to ASTM C1202 [33, 34].

3. Results and Analysis

3.1. Desorption Test and Results. The desorption isotherm of SP is shown in Figure 5. From this figure, it is observed that desorption rate increases with temperature and decreases with relative humidity. In this experiment, maximum desorption rate of 97.2% with respect to OD weight of SP was observed at 34°C temperature and 60% RH. Minimum desorption rate was found as 8.4% at 14.5°C temperature and 90% RH. It is evident that desorption rate has upward trend with temperature; that is, it increases with increase in temperature. As mentioned earlier, in a typical concreting work, the temperature within the concrete mix ranges between 20°C and 40°C in initial phase of hydration. In case of mass concrete, the temperature within concrete is even higher. On the other hand, the relative humidity drops quite rapidly due to loss of water as a result of hydration and evaporation. So, internal temperature and relative humidity of a concrete mix appear to be favorable to expedite complete desorption of SP. In later stage of hydration, ambient temperature and relative humidity have significant influence on concrete temperature and relative humidity. And the ambient conditions during hot summer weather of the country match well with the favorable condition for desorption of SP. Table 1 shows the maximum desorption obtained from SP in this experiment and from a different SAP material in an experiment conducted by Zhang [35]. It is, therefore, evident that SP has comparable desorption capacity to be used as SAP. Quantitatively, the dosage rate of 1.25 g of SP per kg of cement ensures around 495 g of water per cubic meter of concrete available for internal curing since SP can desorb more than 90% of absorbed water.

Table 1: Maximum percent desorption of water by SAP.

SP as SAP	97.2%
Copolymers of acrylic acid	96.1%

3.2. Compressive Strength and Modulus of Elasticity Test and Results. Compressive strength and modulus of elasticity of control samples and samples with SP as SAP are presented in Figures 6 and 7, respectively, for four different curing conditions. It is evident that SP concrete resulted in higher compressive strength and modulus of elasticity in all four curing conditions than that of control samples (without SP). Samples, covered with polythene sheet, exhibited better strength and stiffness as compared to uncovered ones. The best result was obtained for C3 condition; that is, samples with SP as internal curing agent showed superior performance when kept outside the laboratory and covered with

Table 2: Percent increase in compressive strength and modulus of elasticity of SP concrete with respect to control samples under similar curing conditions.

Property	Curing conditions			
	C1	C2	C3	C4
Compressive strength	18	11	18	4
Modulus of elasticity	0.9	0	3	1.1

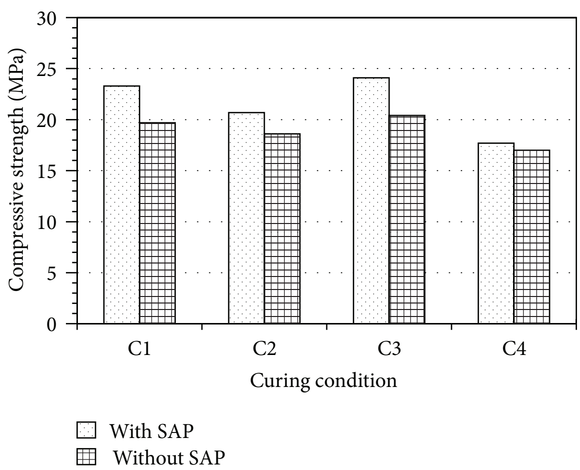

Figure 6: Test results on compressive strength of different type of concrete.

polythene sheets. Polythene sheet covering prevented the loss of water from the mixture and relative higher temperature at outside laboratory ensured better hydration. Samples under C4 condition experienced the lowest strength and elasticity. In C4 curing condition, samples were placed in open space (outside the laboratory) without any polythene covering. The exposed condition of samples at outside laboratory caused greater loss of water from mixes and eventually affected the hydration process. Table 2 shows the percent increase in compressive strength and modulus of elasticity of SP concrete as compared to control samples for similar curing condition. It is evident that, even under the worst curing conditions, inclusion of SP resulted in higher compressive strength and elasticity. It is also observed that covering of internally cured samples yielded the best performance and increased the compressive strength by about 20% with respect to control samples.

3.3. Durability Test and Results. Test results of water and chloride permeability are shown in Figures 8 and 9, respectively. It is noticed from Figure 8 that significantly less water permeability was obtained for concrete with SP as internal curing agent than control samples for all four curing conditions considered in the study. Although C3 curing conditions yielded the best performing internally cured concrete in terms of water permeability, the relative higher performance of internally cured samples in comparison with control samples was also obtained for C2 and C4 curing conditions (Figure 10). It is, therefore, evident that utilization of SP as

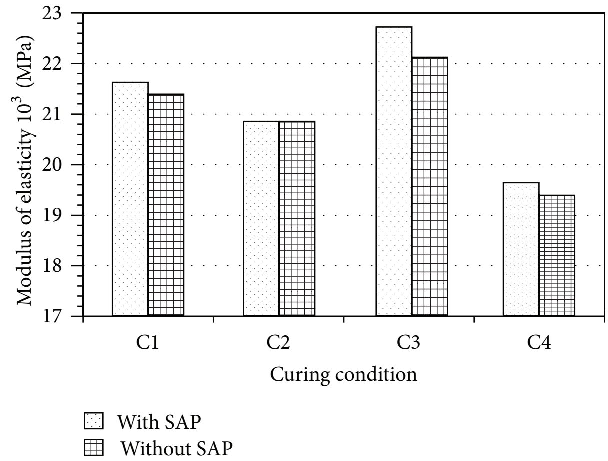

Figure 7: Test results on modulus of elasticity of different type of concrete.

SAP can considerably reduce the water permeability as compared to control samples particularly under extreme curing conditions where supply of external water and appropriate covering are absent. Similar to water permeability test results, concrete with SP exhibited better chloride permeability than that of control samples (Figure 9). Samples under C3 curing conditions showed the lowest chloride permeability whereas samples under C4 curing conditions experienced the highest permeability. Around 70% reduction in water permeability and 17% reduction in chloride permeability compared to control samples were observed for C3 condition. It is also observed that all samples under C4 curing condition showed the poorest permeability performance. Hence, a comparison has been made on permeability performance of internally cured samples under four different curing conditions with respect to the control samples under C4 curing condition (Figure 11). Internally cured samples under C3 condition experienced about 85% and 40% drop in water and chloride permeability, respectively, as compared to control samples under C4. Such behavior is analogous to the strength and elastic modulus test results. It is, therefore, obvious that covering of samples is extremely important to ensure benefit of internal curing; otherwise the additional water may be lost through evaporation. Even a simple covering technique, consisting of using polythene sheet, can increase the reduction of chloride permeability from 17% to 40%.

Both strength and durability test results confirmed the effectiveness of SP as internal curing agent within concrete. In all cases, concrete with SP as SAP performed better than control samples when kept under similar adverse curing conditions. Since no other technique was adopted, the only reason for better performance of SP concrete was the additional water supplied by the desorption of SP. This desorbed water ensured better hydration in internally cured samples than control samples and produced concrete with better performance. Better hydration resulted in pore refinement within concrete and eventually reduced water permeability as well as chloride permeability of tested internally cured concrete samples. Overall, water and chloride permeability can be reduced by more than 80% and 40%, respectively,

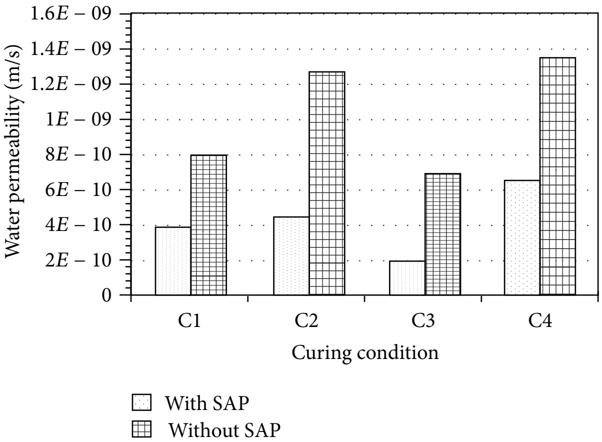

Figure 8: Test results on water permeability of different type of concrete.

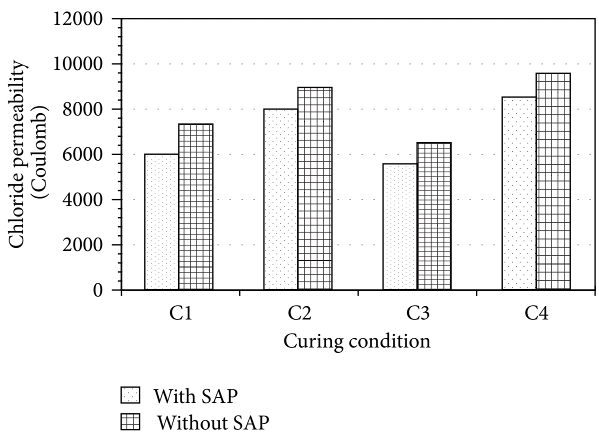

Figure 9: Test results on chloride permeability of different type of concrete.

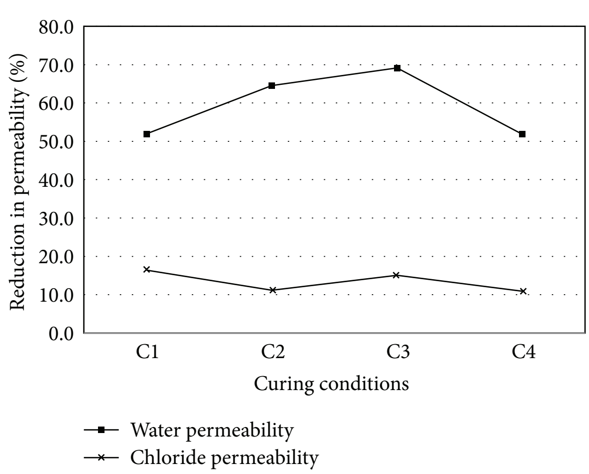

Figure 10: Reduction of water and chloride permeability in SP samples with respect to control samples under similar curing conditions.

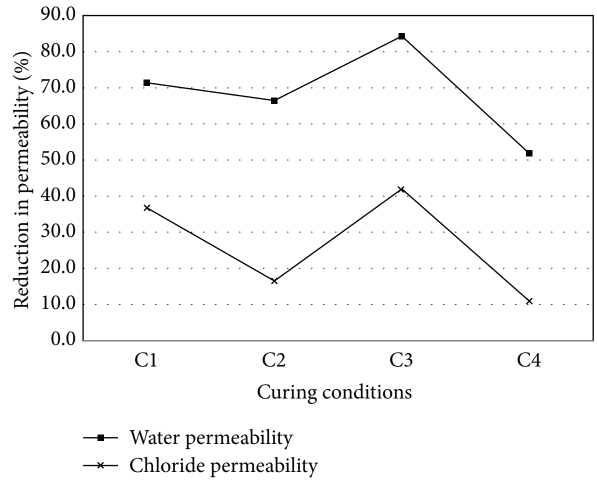

Figure 11: Reduction of water and chloride permeability in SP samples with respect to control samples under C4 curing condition.

through utilization of SP as internal curing medium and placement of polythene sheet covering on concrete in the absence of continuous supply of additional water required for external curing.

4. Significance of the Research

Generally, external curing mechanism is followed in most of the countries of South Asia region including Bangladesh. The external water is supplied either by sprinkling or by ponding method. Both these methods require especial care from the workers as well as large amount of water. In addition, this large amount of water needs to be available throughout the entire curing period. Such continuous supply of external water requires availability of sufficient amount of water as well as stringent quality control protocol. If these two conditions could not be maintained during external curing, the resulting concrete may exhibit extremely poor performance particularly in terms of durability. This is due to the absence of adequate quantity of water within concrete mix required for proper cement hydration which in turn produces porous concrete with lower strength and higher permeability. It is obvious from the current study that concrete with SP significantly increases the durability performance of concrete under adverse curing conditions without requiring any additional special device or quality control mechanism except polythene sheet covering. Even SP concrete samples without covering exhibited marked better performance than control samples in the absence of external supply of water. The cost of using SP as SAP is also within tolerable range since this process can save large amount of water required for external curing. The result of the study shows significant potential of SP as SAP to be used as internal curing agent within concrete in Bangladesh.

5. Conclusions

It is found from the desorption test that SP absorbs large quantity of water of its own weight when immersed in water and later can release the absorbed water at relatively high temperature and low relative humidity. More than 90% of absorbed water can be desorbed by SP under favorable conditions. Such favorable conditions of temperature and humidity exist within concrete mixes especially during initial phases of hydration. As a result, concrete with SP as internal curing agent exhibited enhanced strength and durability performance. In all instances, concrete with SP showed higher strength and reduced permeability as compared to control samples without internal curing ability when subjected to adverse curing conditions. However, concrete with SP exhibited superior performance when kept in open space with polythene sheet covering. Around 18% more compressive strength, 70% less water permeability, and 17% less chloride permeability were attained through utilization of SP in concrete as compared to control samples without SP under this condition. The better performance of internally cured concrete was due to the proper hydration of cement ensured by additional internal water supplied by SP. Moreover, the importance of utilization of SP as SAP to produce internally cured concrete for improving durability performance of concrete where appropriate conventional external curing cannot be ensured is also evident from the results of the study. However, this study of inclusion of SP as SAP to produce internally cured concrete is the first of its kind in the country and therefore, further investigation is required with more sample size and different commonly used mix proportions for recommending a suitable mix design for SP concrete.

Abbreviations

IC: Internal curing
RH: Relative humidity
RH%: Relative humidity percentage
SAP: Super Absorbent Polymer
SP: Sodium polyacrylate
LWA: Light weight aggregate
SSD: Saturated surface dry
OD: Oven dry
SC: Stone chips
RCPT: Rapid Chloride Permeability Test
C1: Inside laboratory with polythene cover (laboratory condition)
C2: Inside laboratory without polythene cover (laboratory condition)
C3: Outside laboratory with polythene cover (field condition)
C4: Outside laboratory without polythene cover (field condition).

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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