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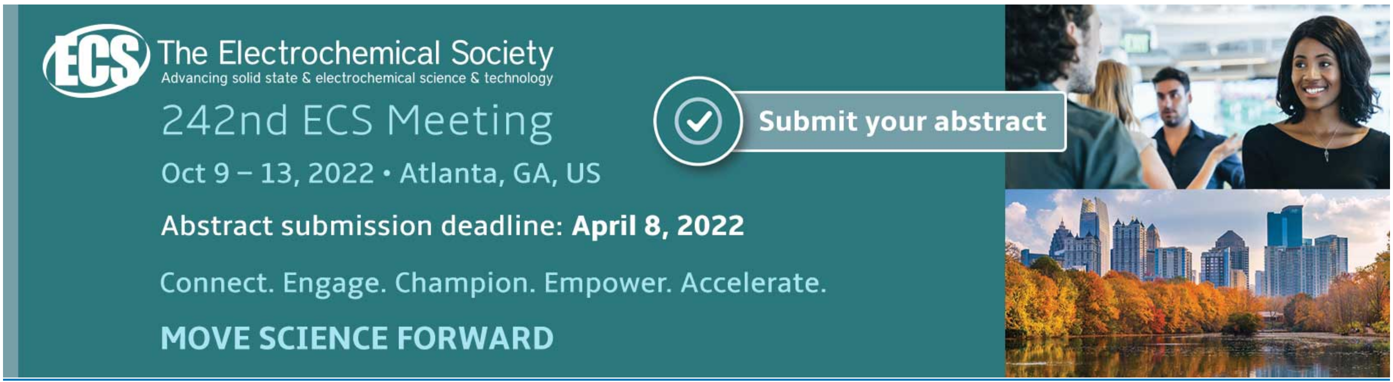

The Application of Sodium Acetate as Concrete Permeability-Reducing Admixtures

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Abstract. The study is aimed to introduce the application of sodium acetate into the concrete mix for water permeability-reducing admixtures. The sodium acetate was treated as concrete admixture by dissolving in it through the water. Three kinds of concrete strength (fc' = 30 MPa, 40 MPa, and 50 MPa) and five mixture proportions of sodium acetate were involved to provide the specimens. To evaluate the performance of variation sodium acetate mixtures, a series of water permeability test was conducted on 28 days after concrete casting. A separate test of the temperature belongs to the concrete paste was measured in order to investigate the role of the sodium acetate solution for decreasing the temperature during the hydration process. The experiment results show a considerable reduction of water ingress for the lower concrete strength with the addition of sodium acetate greater than 3%. However, the opposite results were obtained for the highest concrete strength. A scanning electron microscope (SEM) test on the lowest strength can confirm the evolution of crystal structure inside the concrete pores.

1. Introduction

Concrete is one of the most commonly used for building and construction material. Nevertheless, concrete is susceptible to damage and deterioration from water and chemical penetration [1], [2]. It is mainly due to the nature of concrete: porous and permeable. Porosity refers to the amount of holes or voids left in concrete, is expressed as a percentage of the total volume of a material [1]. Whilst, permeability is the ability of liquid water to flow through a porous material under pressure, is expressed as the interconnection of voids (permeation) [2].

The aforementioned concrete characteristics will impose the water penetration, which may carry aggressive agents into the concrete [3]. Hence, how to reduce the porosity and permeability, and to come off effective concrete waterproof protection, has become a key issue to ensure concrete durability [4]. Several techniques associated with some materials for waterproofing technology have been introduced [5]. One of the current technology for reducing the water permeability utilizes crystalline based materials [6–9].

The crystalline material used in most of the experiments [4,7,8,10–12] was primarily constituted from cement, active silica, and other chemical compounds. There also some available factory based products in the market which effectively worked as waterproofing material from the research [13,14]. However, the chemical composition of the material is kept confidential.

The new technology, based on the application of sodium acetate for concrete surface treatment, has shown a capability to reduce the water permeability effectively [6]. The sodium acetate is a crystalline based material product and it is being hygroscopic when introduced with water. The non-soluble crystal volume grows vastly and they will block the concrete pores by filling and plugging the capillaries, micro-cracks, and other voids. Owing to the high absorption of water, the moisture condition of the environment accelerates the crystal growth.

In contrast with [6], a study by [15] found that the usage of sodium acetate was deleterious. An excess of sodium acetate treatment contributed to noticeable deterioration during freezing and thawing cycles. It was because the exposure of cement paste to sodium acetate led to the dissolution of calcium silicate hydrates. The disintegration of the cement paste formed new cement hydrates (calcium formate hydrates crystals), which caused considerable weight loss.

Several studies [8–13,16] utilized crystalline based material to perform a self-healing process. Such process has a different mechanism with the waterproofing technique since it is considered as autonomous healing phenomena. This is also known as the capability of concrete to close the cracks and to recover their properties, either mechanical or durability-based [8]. In contrast with autonomous healing, the autogenous healing process uses only the concrete compound materials without any composite materials. The autogenous healing happens when the concrete is composed of engineered cementitious material (ECC) which includes fly ash, fibre reinforced, and blast furnace slag [16].

This study was conducted to investigate the performance of sodium acetate crystal enhancing the water permeability characteristic. There were three concrete classes and five variations of sodium acetate dosage in the concrete mix were involved. The additive was applied as a concrete admixture by providing dissolving in it through the water. The methodology used in this research is based on the water penetration depth measurement, comparing the results of with and without sodium acetate. It was hypothesized if the proposed application method would have better performance due to homogeneity dispersion of the crystalline structure formed.

2. Method and materials

2.1. Sampel Preparation

The experimental variables which were studied in this research were:

- Concrete strength (at 28 days): fc' = 30 MPa, fc' = 40 MPa, fc' = 50 MPa;
- Sodium acetate dosage: 0% (control specimens), 1% to 5% by the weight of cement (SA specimens).

Table 1 . Specimen variable combinations

Specimen code	**Description**	**fc' (MPa)**
300	Control	30
30X	SA	30
400	Control	40
40X	SA	40
500	Control	50
50X	SA	50

Table 1 shows the combination of the variables involved in the experiments. The number of specimens is applicable for compressive strength test and permeability test, respectively. "X" denotes the percentage of SA (Sodium Acetate), measured from the cement weight of each concrete class; It was ranged from 1% to 5%. For each concrete strength, there were 15 specimens which had SA content for each test.

Figure 1. Sodium acetate crystal

The sodium acetate used was available in the market within 25 kg packaging. The appearance can be seen in Figure 1. It has a form of powder, whereas the texture is crystal-like. It absorbs water easily so the storage condition shall be dry.

2.2. Method

The sodium acetate was dissolved in the 1 litre of water, taking from the water volume which is used for the mix. The solution of sodium acetate was mixed prior to the rest of water volume. During concrete mixing and pouring, the influence of additional SA dosage to the workability was monitored by conducting the slump test. The environmental temperature between 20° – 25°C during curing process was set up in order to get uniform hardening process as well as to create moist condition. This condition was to endorse the sodium acetate reaction within concrete mix.

Table 2 . Mix design of control specimens

Material (kg/m^3)	fc' = 30 MPa	fc' = 40 MPa	fc' = 50 MPa
Cement*	370.37	476.19	606.06
Sand 0.15 – 0.6 mm	423.01	334.23	225.26
Gravel 4.8 – 19 mm	1219.98	1219.98	1219.98
Water	225.53	225.40	225.24
W/C ratio	0.54	0.42	0.33

*Volume of cement were the basis to count the SA weight for the SA specimens.

The mix design was carried out based on ACI method [17]. The proportions of the cement, water, gravel, and sand for all three concrete classes with and without SA were the same. An additional SA did not decrease any concrete material composition. Table 2 presents the proportion of mix design for the three concrete classes.

Each concrete grade had one batch of control specimen and 5 batches of SA specimens, represented 1% up to 5% SA content in the mixture. The SA weight were counted from the percentage belongs to the variation in the cement weight. For each batch, it is comprised of 3 cylindrical and 3 cubical specimens, respectively. In total, there were 18 batches for both cylindrical and cubical specimens. A cylinder of ∅ 100 mm x 200 mm was prepared based on ASTM C 39 [18], while cubes 200 mm were provided based on EN 12390-8 [19].

One day after the specimens produced, the specimens were removed from the mould. Then, they were cured by means of water immersion in the temperature (20 ± 2)° C for 28 days. The curing process conformed to [20]. Once the specimen age retained (minimum) 28 days, a series of compressive strength and permeability tests were conducted.

In parallel with the strength tests, the permeability tests were undertaken based on [19]. The specimens were loaded with 0.5 MPa water pressure within 72 hours (Figure 2). For each batch, three cube specimens were put together in the machine. At the end of the test, the cubes were split and the water seepage was measured (Figure 3).

Figure 2. Specimens in the permeability test apparatus

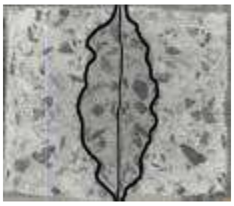


Figure 3. A split cube with visible boundary of seepage

In order to demonstrate the crystal growth within the specimens, a scanning electron microscope (SEM) test was conducted. The test was used to understand the microstructure of the specimens and a distribution of acicular-like crystals evolved throughout the curing process. The broken test specimens from the permeability test were selected randomly to perform this test.

During mixing works, it was realized that temperature of sodium acetate solution dropped after the sodium acetate had dissolved in the water. In order to verify the chilling effect in the hydration process, a separate test was involved to record the temperature changes of the concrete pastes with and without sodium acetate. The experiment was shown in the Figure 4.

The measurement was recorded for three hours since the cement mixed with sodium acetate solutions. There were three concrete grade specimens (fc' = 30 MPa; 40 MPa; 50 MPa) with SA percentage ranging from 0 – 5% involved in the measurement. During the tests, the environment temperature was kept between 25°C - 26 °C.

Figure 4. Temperature recording of cement pastes (from left to right: 0% – 5% of SA volumes)

3. Results and Discussions

3.1. Compressive Strength Test

All the cylinder specimens with and without sodium acetate were tested according to [18]. The tests were carried out in order to convince the target strength used in the mixed design consistent with the actual compressive strength of the specimens. The effects of the additional SA to the concrete strength were also investigated. The test results are presented in the Figure 7.

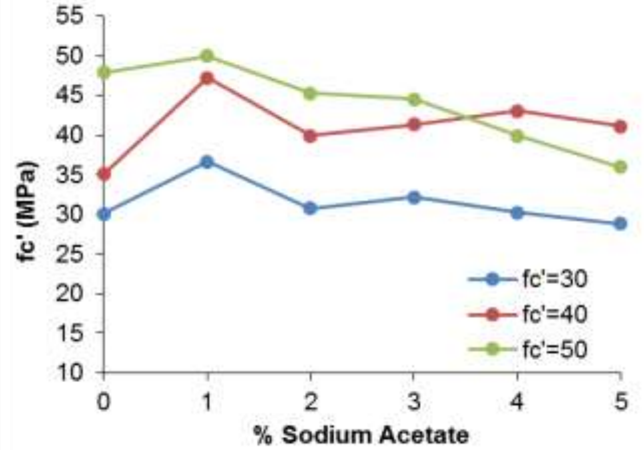


Figure 5. Cylinder test results for various specimens

From the Figure 5, it can be concluded if all the specimens meet with the expected concrete strength at 28 days. Most of the specimens with the target compressive strength of fc' = 30 MPa and fc' = 40 MPa reach slightly higher than target strength. In contrast, all the specimens with the highest target strength (fc' = 50 MPa) yield cylinder strength lower than the target. However, there are no specimens fall below 85% of the target strength as required by [21].

The line charts in the figure also indicate the insignificant advantage of additional SA volume to the concrete strength at the age of 28 days. The rise of SA volume in each concrete mix gave minor impact to the compressive strength. The same trend were also obtained from the other concrete grades even though the weight of SA was greater. This result is associated with foregoing studies while using different crystalline material and its treatment [6,7].

3.2. Permeability test

The measure of permeability test was based on the water seepage into the cubic specimens. After it had been loaded by the water pressure for 72 hours, the specimens were split (refer to Figure 8) and the outermost distances from the wet surface were taken as penetration depth. The test results were collected as penetration depth at the age of 28 days, as presented in Figure 8.

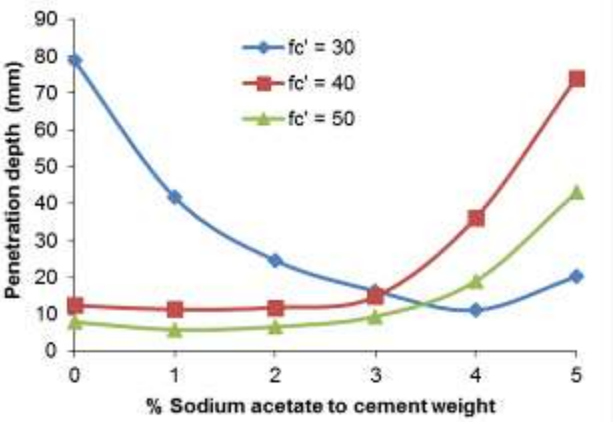


Figure 6. Effect of various SA concentration on the specimens permeability

From the Figure 6, it can be seen the influence of various SA concentration is not always consistent with all concrete strength. For the lowest strength, there is a significant benefit on the additional SA into the mix. By increasing the percentage of sodium acetate, the water permeability plummets. The lowest permeability is achieved for 3 to 4% SA content into the concrete.

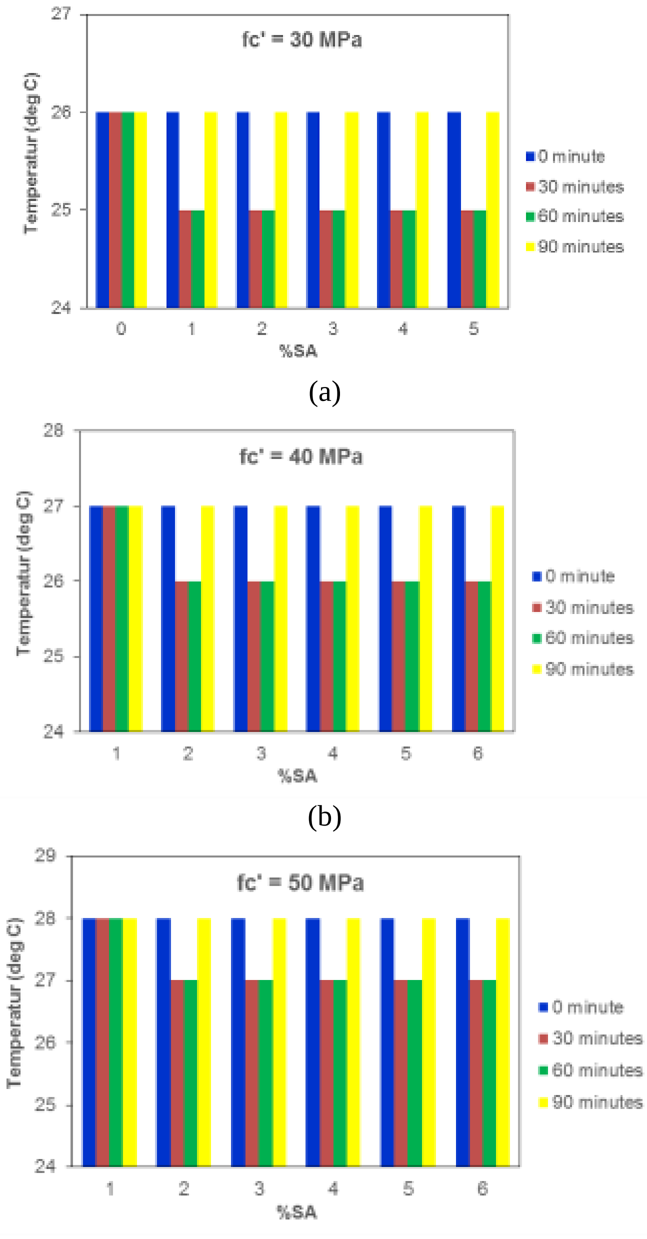
The role of SA admixture for reducing the water permeability is obvious on the lowest concrete strength. Along the curing time, the SA solution reacted chemically by the fresh concrete paste and it absorbed the water excess in the mix. Later during treatment, the crystals were being hygroscopic when the specimens were immersed in the water. It filled the concrete capillary pores and block the water intrusion to the concrete. As a result, the number of pore volumes reduced and promoting more permeable concrete.

It is also illustrated in Figure 6, if there is a contrast result of additional SA admixture for the high concrete strength (40 MPa and 50 MPa) compare to the lowest strength. Both specimen strengths reveal a similar trend by adding more SA volume. The penetration depth is jumping up when the SA percentage beyond 3%. Whilst, there was a constant result of permeability test for concentration lower than 3%.

The larger SA volume corresponds with the increase of cement weight in the mix. This presumably made an adverse effect on the high strength concrete permeability. The greater SA volume into the mix apparently caused deceleration of concrete hydration. Hence, it also disrupted the concrete hardening process. Meanwhile, the negative impact on the permeability on the highest concrete strength is associated with the compressive strength test results.

3.3. Temperature Test

During the concrete mixing, it was found out that the temperature of the solution dropped when SA had dissolved in the water. This led to the analysis of mixing temperature for the first 90 minutes of setting time. The results of the temperature observation for each concrete strength as described in the Figure 9. All colours in the three figures indicate the same time sequence of temperature monitoring.



(a)

(b)

(c)

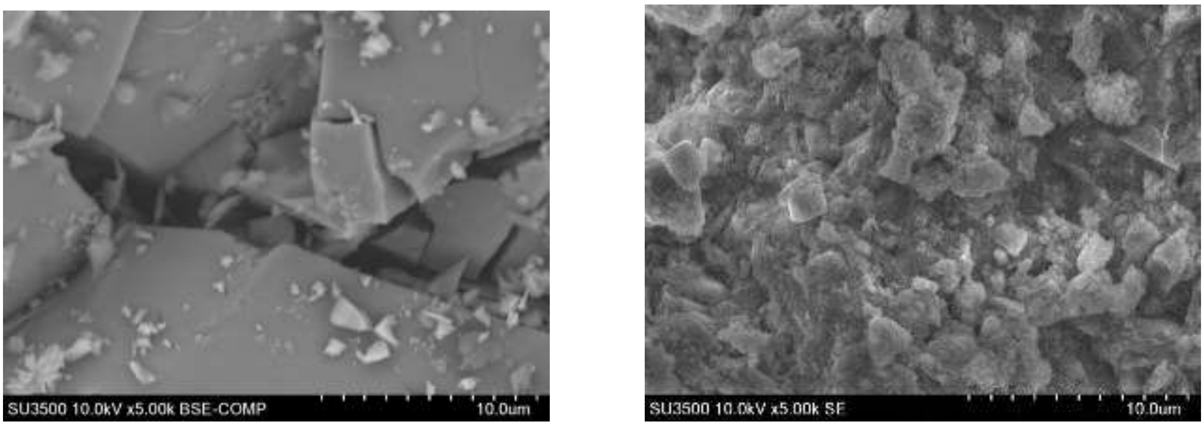
Figure 7. Temperature observation of the cement paste mixed (a) fc’ = 30 MPa, (b) fc’ = 40 MPa, (c) fc’ = 50 MPa

From the Figure 7, it is shown a slight temperature decreasing when adding SA to the concrete mixtures. The temperature change happened after the first 30 minutes mixing (red chart). All concrete strengths decreased similarly, which are 1 degree lower. However, this phenomenon is independent of the variation of SA content. Due to the limitation of the available thermometers in this experiment, a more precise temperature declining with the accuracy less than 1 degree was difficult to measure.

The effect of SA portions lasted for only 60 minutes. For the first one hour, the hydration of cement had occurred but the heat release still remained. Therefore, in the 90th minute (yellow chart), the temperature was returned to the initial temperature. This was also true for all concrete strengths.

3.4. Scanning Electron Microscope (SEM) Test

To investigate the crystal evolution of the SA specimens, the SEM photographs (5000x magnification) were taken from substrate sample with and without SA through random selection. The sample code 300 and 305 were chosen to represent the specimen with 0% and 5% SA, respectively. The results are presented in Figure 8.



(a) (b)

Figure 8. SEM picture (5000x) sample (a) 300, (b) 305

Figure 10b exhibits that the acicular crystal shape was formed in the SA specimen. In contrast, a more porous condition is shown the SEM photograph of control specimens (Figure 8). They grew during the curing time and treatment period. This was possible because the specimens were treated in the moist environment promoting a chemical reaction between crystalline material and water. As a result, they also created pore blocking system and seal the capillary tracts. The admixture worked as integral waterproofing which yielded to impermeable concrete.

4. Conclusions

This paper presents the results of the potential of using sodium acetate (SA) as concrete admixtures to reduce the water permeability. Based on the experiments, it was found that an additional SA was beneficial for the permeability of normal concrete strength (fc' = 30 MPa). The water seepage was dipped by addition of 3% (minimum) SA into the concrete. In addition, the presence of SA did not affect the compressive strength. A scanning electron microscope test result of 5% SA specimen confirms the crystal growth inside the concrete pore which gives to permeability enhancement.

The opposite situation was found for additional SA into the higher concrete strength. On both strengths used in this study, the penetration depths were considerable increase and there was a tendency on reducing the compressive strength. It was an impact from the large volume of SA into the concrete which caused deceleration of binder process in the concrete matrix. In fact, there should be further investigation to verify the adverse impact of SA on the high concrete strength.

In general, the additional SA into the concrete has promoted a cost-effective technology for concrete waterproofing. The crystals which developed due to bonding between cement, water and SA can fill the concrete voids. It certainly enhances the durability and service life of concrete structures. This new technology will contribute to the sustainable environment.

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