Investigation of the Effect Fly Ash on the Water pH of the Concrete Mixture in Terms of Compressive Strength and Absorption

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ABSTRACT

Indonesia's construction industry often encounters challenges related to the availability of water with a neutral pH (7), particularly in regions with aggressive environmental conditions such as peatlands and sulfate-rich areas. Acidic water, characterized by a low pH, can negatively affect the properties of concrete, leading to decreased durability and strength. This study investigates the effectiveness of fly ash as an additive to neutralize acidic water (pH 5) and its influence on the compressive strength and water absorption of concrete. The experimental program includes three variations of concrete mixtures: (1) concrete mixed with neutral pH water, (2) concrete mixed with acidic water (pH 5), and (3) concrete mixed with acidic water that has been neutralized using fly ash. The acidic water was simulated by adding 2.5 mL of hydrochloric acid (HCl) to 10 liters of water. Neutralization was achieved by dissolving 200 grams of fly ash per liter of water for 5–15 minutes, resulting in a pH level of 7. Compressive strength and absorption tests were conducted on cylindrical specimens, with dimensions of 15 cm × 30 cm for compressive strength and 10 cm × 5 cm for water absorption, at curing ages of 28 and 56 days. The results show that concrete mixed with acidic water exhibited a decrease in compressive strength compared to concrete mixed with neutral pH water. However, concrete produced with fly ash-treated water demonstrated improved compressive strength, indicating that fly ash contributes to pH stabilization and enhances hydration.reactions. The absorption tests reveal that concrete mixed with acidic water has a higher absorption rate due to increased porosity, whereas fly ash-treated concrete shows reduced absorption, indicating improved durability.

Keywords: Fly ash, acidic water, pH neutralization, compressive strength, water absorption, concrete durability.

1 INTRODUCTION

Indonesia, as an archipelagic nation, consists of over 17,000 islands and is characterized by a combination of extensive water bodies and land areas. This unique geographical configuration subjects the country to various environmental challenges and aggressive natural conditions. One such challenging environment is acidic areas, such as peatlands, which have a low pH level. The acidic conditions in peatlands are caused by the accumulation of organic acids from decaying plant material (Carroll, R. et al., 2025). Peatlands in Indonesia are located on three major islands, namely Sumatra, Kalimantan and Papua with a total area of peatlands of around 14.9 million hectares, as shown in the peatland map compiled by BB Litbang SDLP (Ritung et al., 2011). The Peat environment is characterized by high organic content, high acidity (pH 3-5) and low bearing capacity, making it unsuitable for concrete construction (Moayedi et al., 2014).

Water is a major constituent of concrete which has a significant effect on workability and is important for efficient cement hydration. Therefore, the quality and quantity of water during the manufacture of concrete must be considered carefully (Mahmoud et al., 2019). Reduction in pH of concrete is also attributed to the carbonation process, it is a vital parameters in the chemistry of concrete. The scale of pH is ranged from 0 to 14, and a pH value of 7 is considered neutral (Indexed et al., 2018). One of the challenges in construction is the availability of clean water with a neutral pH of 7, which is essential for producing high-quality concrete. The ideal water for concrete mixing should be free from contaminants that can affect the strength and durability of the final structure. In some areas, construction workers use water from local sources such as swamps, rivers, or wells near the project site without testing its pH level. This can be problematic because the water may have either an acidic or alkaline pH, which can interfere with the chemical reactions in concrete mixtures.

An aggressive environment can cause material damage, primarily due to chemical reactions such as sulfate elements (SO4) and chloride ions (Cl). In peat environments, acid ions attack the cement paste bonds in concrete. The chemical effects on high-performance concrete using various concentrations of hydrochloric acid (HCl) in mixing and curing showed that higher acid content decreased the compressive strength compared to concrete mixed and cured with normal water (Arunakanthi et al., 2012). Acidic water contains more dissolved carbon dioxide than organic or inorganic acids, making it more aggressive in reactions. Acid solutions can react with cement mortar or concrete, partially dissolving the cement, thereby gradually weakening the material, breaking the bonds between the aggregates, and forming a soft and mushy mass (Kucche et al., 2021).

Water is essential in concrete mixtures, but when dealing with acidic water, additional materials are required to neutralize the acidity and ensure the concrete's durability and strength. To neutralize the acidity of peat water, additives such as quicklime, alum, and chlorine are commonly used (Tizia et al., 2020). In the development of research on acid water neutralization, one potential material that can be utilized is fly ash derived from the combustion of steam power plants (Gobel et al., 2018). Fly ash is defined as the residue resulting from coal combustion, consisting of fine particles and possessing potential neutralizing properties (Taylor et al., 2005). When fly ash is mixed with portland cement and water, it produces a compound similar to that formed by the hydration of cement, but with a finer structure, resulting in a denser material (Nath and Sarker, 2011). Based on the facts above, this research focuses on investigating the effectiveness of using fly ash as an additive to adjust the water pH in concrete mixtures. The evaluation will be based on compressive strength as an indicator of the mechanical properties of concrete, and absorption capacity as an indicator of its durability.

2 MATERIAL AND METHOD

2.1 Material

The samples used in this research were cylinders with a diameter of 15 x 30 cm for the compressive strength test of concrete and 6 cylinders with a diameter of 10 x 5 cm for the absorption test. The material used in this research is normal concrete made with coarse aggregate, fine aggregate, portland cement and in the concrete mixture using neutral pH water, acid water with pH 5 and acid water which has been neutralized with fly ash. Fly ash is a fine particle with a size ranging from 0.2–200 lm. Fly ash particle size depends on the fineness of the crushed coal and the type of flue gas scrubbing system. (Tokyay, 2016). The fly ash used in this study was type C fly ash obtained from the Paiton Steam Power Plant, Probolinggo, East Java, Indonesia. After the procurement of materials, the next stage is the trial mix design. The mix design was carried out using the Design of Experiment (DOE) method for Normal Concrete, based on the guidelines of SNI 03-2834-2000. During the trial mix design stage, several variations of concrete mix proportions were tested to determine the most effective composition for achieving the desired performance. This phase was conducted prior to the preparation of test specimens, with the aim of producing concrete with optimal compressive strength. In this study, the target compressive strength was set at 25 MPa (fc'). The trial mix was conducted in two separate experiments by varying the ratio of fine aggregate (sand) to coarse aggregate (gravel), while maintaining a constant water-cement ratio. Table 1 presents the detailed proportions of each material used in both Mix Design 1 and Mix Design 2, including the quantities of cement, water, fine aggregate, dan coarse aggregate.

Table 1 Mix Design Recapitulation

Material Mixed Proportion					
	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Water (liter)	Water Cement Ratio
Mix Design 1	450	900	1110	202,5	0.45
Mix Design 2	500	680	1280	225	0.45

Based on the trial mix design that was carried out, it can be concluded that the ratio of fine aggregate (sand) to coarse aggregate (gravel) has a significant effect on the compressive strength of concrete, even when the water-cement ratio remains constant. The compressive strength tests conducted at the ages of 7, 14, and 28 days showed that Mix Design 1 consistently produced lower compressive strength values compared to Mix Design 2. This indicates that the specific proportion of aggregates in Mix Design 2 provides a more optimal internal structure, allowing for better bonding and load distribution within the concrete mix. Therefore, Mix Design 2 was selected for the fabrication of test specimens in this study, as it demonstrated superior performance in terms of compressive strength development over time. The results also highlight the critical role of aggregate gradation and proportioning in achieving the desired mechanical properties of concrete, even when other key parameters such as the water-cement ratio are held constant. Figure 1 shows the compressive strength test results at the ages of 7, 14, and 28 days for Mix Design 1 and Mix Design 2.

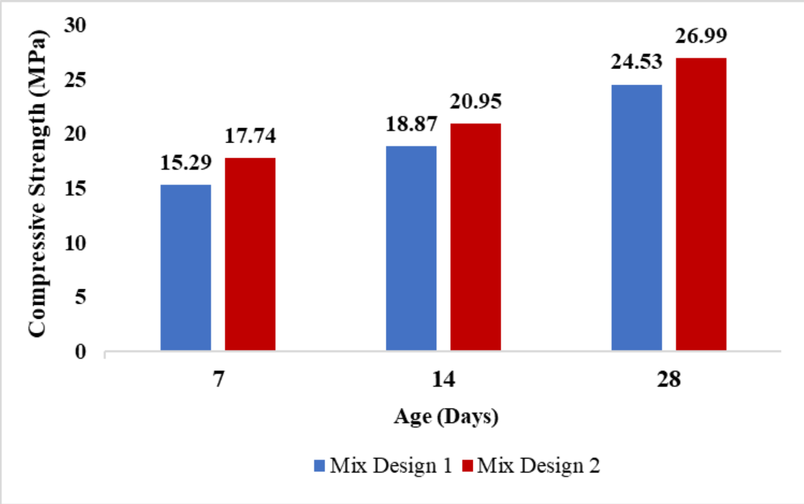

Figure 1 Mix Design Trial Results

2.2 Method

There are three types of samples used in this test, namely Normal Concrete (N), Acid Concrete (A) and Fly Ash Concrete (F). In this study, the compressive strength of concrete was tested using ASTM C39/C39M – 14 references at the age of 28 and 56 days. The number of samples used in this test were 18 concrete cylinders with a diameter of 15 cm and a height of 30 cm. After the age of 28 and 56 days for testing the compressive strength of the concrete, firstly weigh the concrete sample, then it is given a capping (sulfur layer) on the concrete surface so that the surface is flat. Next, the concrete sample is placed on the compressive strength tester right in the middle of the pressure plate and the loading is carried out slowly until the test object is destroyed and the pointer on the test tool does not move upwards again so that the maximum load shown by the tester is obtained. The value of the compressive strength of concrete can be calculated using the Eq. 1.

$$f_c' = \frac{P}{A} \text{ (MPa)} \tag{1}$$

The absorption test was carried out based on ASTM C 642 – 06 with the number of samples used in this test were 6 concrete cylinders with a diameter of 10 cm and a height of 5 cm. The absorption value can be determined by calculating the percentage difference between the mass of concrete from dry conditions to SSD (saturated surface dry) conditions. The absorption test was carried out on specimens aged 28 and 56 days, namely the concrete sample was dried for 1 x 24 hours and then weighed, after that it was soaked again for 1 x 24 hours to obtain the wet weight of the concrete. Next, the sample was placed in an oven for 1 x 24 hours at a temperature of ± 105 C, weighed and the dry weight of the concrete was obtained. The equation for the calculation of concrete absorption can be calculated using the Eq. 2.

$$\text{Absorption} = \frac{(B - A)}{(A)} \text{ x } 100\ \% \tag{2}$$

Description:

A : Dry weight after oven (gr)

B : SSD dry weight (gr)

3 RESULT AND DISCUSSION

3.1 Fly Ash

The fly ash requirement test was carried out on acidic water pH 5 with the addition of fly ash every 10 grams in 1 liter of water and 50 grams in 10 liters of water. Measurements were carried out every 5, 10 and 15 minutes after the fly ash was added to pH 5 water and stirred for a few minutes. Changes in the pH value of water with the addition of fly ash in 1 liter of water are shown in Table 2 and in 10 liters of water in Table 3.

Table 2 Trial Results of 1 Liter of Water and Fly Ash

Fly Ash **(gr)**	**Water pH**
10	6,5
20	7,1
30	8,1
40	8,9
50	9,2

The addition of fly ash in water has a significant impact on its pH value. As the amount of fly ash increases, the pH of the water also rises, indicating a shift toward a more alkaline environment. This occurs because fly ash contains compounds such as calcium oxide (CaO) and other pozzolanic materials, which react with water to form alkaline substances. This increase in pH can be beneficial in certain applications, such as improving the durability of concrete in acidic environments. Higher pH levels help neutralize acidic conditions, reducing the risk of corrosion in reinforced concrete structures. Additionally, the pozzolanic reaction of fly ash enhances the long-term strength of concrete by forming additional calcium silicate hydrate (C-S-H) gel, which strengthens the cement matrix.

After conducting the initial test with 1 liter of water, a subsequent test was carried out using 10 liters of water to evaluate the required amount of fly ash. This experiment aimed to analyze whether the relationship between fly ash addition and pH changes remained consistent when the water volume increased. By increasing the water quantity, the distribution and reaction of fly ash particles in a larger volume were observed to determine its effect on alkalinity.

Table 3 Trial Results of 10 Liters of Water and Fly Ash

Fly Ash **(gr)**	**Water pH**
50	5,7
150	6,7
200	7,9
250	8,8

Based on the trial of water mixtures that have been carried out, it was found that to obtain water with a neutral pH or pH 7, 20 grams of fly ash were used for 1 liter of water and for 10 liters of water only 150 grams of fly ash were used. In this study, the addition of fly ash to acidic water with a pH of 5 can neutralize the pH value of the water due to the presence of calcium oxide (CaO) which can increase the pH value of acidic water. This indicates that fly ash is effective in stabilizing water pH, making it a useful material for improving water quality in construction applications.

3.2 Compressive Strength of Concrete

The compressive strength test was conducted at concrete ages of 28 and 56 days using a Compression Testing Machine (CTM). The cylindrical specimens used for the compressive strength test were designed according to standard dimensions, with a diameter of 15 cm and a height of 30 cm. These dimensions ensure uniformity in testing and allow for accurate comparisons between different types of concrete. Each type of concrete—Normal Concrete (N), Acid Concrete (A), and Fly Ash Concrete (F)—was represented by six samples to ensure reliable results and minimize variations due to material inconsistencies.The compressive strength test was conducted at different curing ages to assess the strength development of each concrete type over time.

The results, as shown in Figure 2, highlight the differences in compressive strength among the three concrete variations. Normal Concrete (N) exhibited the highest compressive strength, indicating optimal hydration and bonding. In contrast, Acid Concrete (A) showed a reduction in strength due to the acidic environment affecting the cement paste. Fly Ash Concrete (F) demonstrated moderate strength development, benefiting from the pozzolanic reaction, which enhances long-term performance. The differences in compressive strength between the three concrete types underscore the significant impact of water quality and supplementary materials on concrete performance.

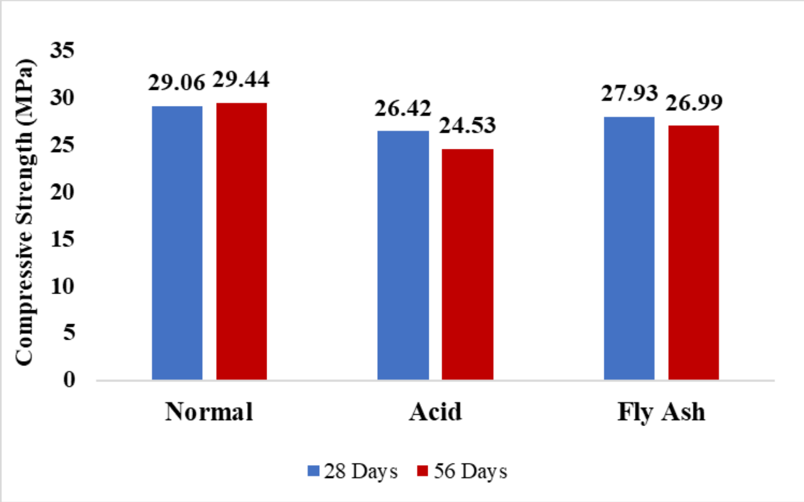

Figure 2 The Compressing Strength Result

As shown in Figure 2, it can be concluded that the use of water with a pH of 5 can cause a decrease in the value of the compressive strength of concrete due to a chemical reaction between cement and the use of water with an acidic pH value. The reaction between cement and water produces a hydration product, namely Ca(OH)2 or calcium hydroxide which is a strong base with a pH = 12.5 (Fatimah, et al., 2018). This pH value causes the concrete to be sensitive to acids. Acids react with the cement paste will dissolve calcium in the concrete which makes the cement hydration process less than optimal. The cement hydration process that is not optimal results in the bond between the aggregates being reduced so that the compressive strength value of concrete decreases from the normal concrete compressive strength.

Meanwhile, the test object uses fly ash as a material to neutralize water acid, namely from water pH 5 to pH 7 can improve the strength of concrete at the age of 28 days and 56 days compared to the compressive strength of concrete using water pH 5. Fly ash is the result of burning coal in factory heat which has been used for cement replacement in terms of increasing the compressive strength of concrete (ACI 232 2003). The use of fly ash can increase the value of the compressive strength of concrete because fly ash contains silica (SiO2). The inclusion of silica fume in the concrete mixture affects the short-term compressive strength of concrete, because there is a further reaction of silica with calcium hydroxide (Regunathan, 2015). which is more reactive and when chemically reacts with Ca(OH)2 or calcium hydroxide to form cementitious compounds Silica in fly ash will react with calcium hydroxide to produce CSH (Calcium Silicat Hydarate) which is the main compound that contributes to increasing the compressive strength of concrete (Fatimah, et al., 2018). The use of fly ash in acidic water can indeed increase the pH value of water and increase the value of the compressive strength of concrete at the age of 28 and 56 days from the compressive strength of concrete using pH 5 water decrease gradually with age.

3.3 Rate of Water Absorption

The absorption test was conducted in accordance with ASTM C 642-06, using cylindrical specimens with a diameter of 10 cm and a height of 5 cm. The test was carried out when the specimens reached the ages of 28 and 56 days. This method is used to evaluate the porosity characteristics of concrete by comparing the dry mass of the specimen to its mass after being immersed in water. A higher absorption value typically indicates greater porosity and reduced durability, whereas a lower absorption value reflects a denser and more durable concrete mix. The results of this test are crucial for assessing the long-term performance of concrete, particularly in structures exposed to moisture or aggressive environmental conditions.

At the age of 28 days, concrete mixed with acidic water exhibited higher absorption values compared to normal concrete, indicating increased porosity due to the influence of the acidic. However, the addition of fly ash to the mix containing acidic water was effective in reducing the absorption value, suggesting that fly ash plays a role in mitigating the impact of low pH on concrete porosity. By the age of 56 days, the average absorption values across all specimens were generally lower than those at 28 days. This reduction is attributed to the continued hydration and densification of the concrete over time, which leads to a refinement of pore structure and decreased water absorption.

The water absorption rate for each concrete type is presented in Figure 3.

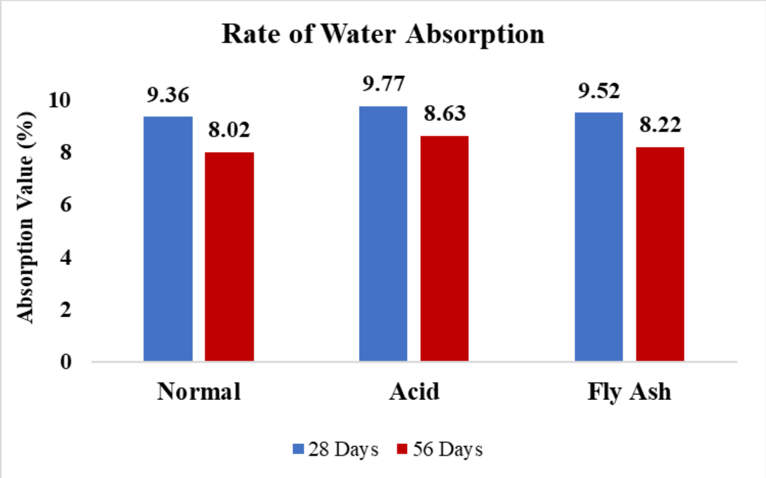

Figure 3 Rate Of Water Absorption

As shown in Figure 3, it can be concluded that the use of water with acid or pH 5 has a higher absorption value than normal concrete and fly ash concrete. A large absorption value in concrete is an indication that concrete tends to be less durable or has low durability because concrete easily absorbs water and this causes a decrease in the strength of the concrete (Rommel et al., 2015). Acid water causes an acid reaction to dissolve calcium in concrete and has a negative effect in the form of enlarging the pores in the concrete so that it has a greater water absorption value (Tizia et al., 2020).

The analysis of concrete microstructure revealed that fly ash particles are covered with amorphous SiO2 and alkali reaction product (Nagrockiene and Rutkauskas, 2019). Specimen that use fly ash as an ingredient to neutralize acidic water, namely from ph 5 water to ph 7 cause a decrease in the absorption value of concrete using acid water or ph 5 water although not as big as normal concrete. Concrete using fly ash is lower because it has pores that tend to be smaller than cement so that the bonding properties between aggregates are better due to the influence of silica fly ash is more reactive. In this study, the addition of fly ash to acidic water with a ph of 5 intended to improve the ph of acidic water, but it turns out that fly ash has contributes to reducing the pores in the concrete thereby reducing the absorption value. This causes the smaller the pores in the concrete, the more difficult it is for water to penetrate the concrete.

3.4 Relation between Compressive Strength and Rate of Water Absorption

The correlation between compressive strength and water absorption is determined by analyzing the test results of specimens subjected to different water mixture treatments. Based on the conducted research, the obtained compressive strength and absorption values are presented in Figure 4.

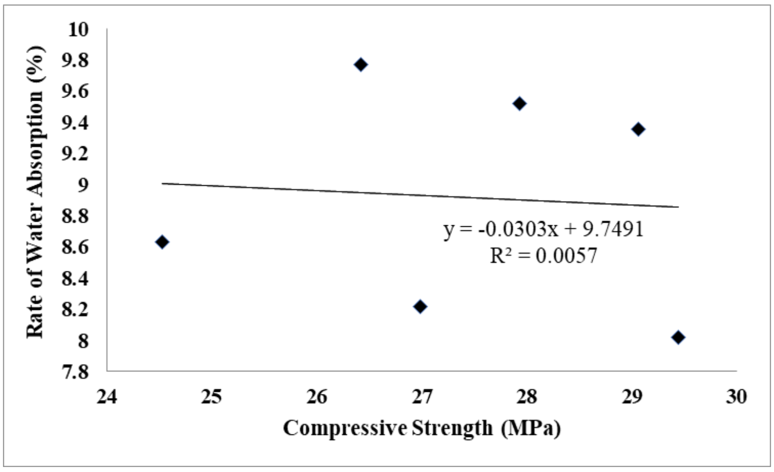

Figure 4 Relation between Compressive Strength and Rate of Water Absorption

As shown in Figure 4 the absorption value does not have a close relationship with compressive strength. In the graph above, R square of 0.0057 indicates that the correlation or relationship between the two variables is very small. The overall strength of concrete depends on the surface and the inner structure of the concrete so that the strength of concrete cannot be judged solely from the absorption or absorption of water (Zhang and Zong, 2014). Compressive strength has a strong relationship with the cavity of the mortar mixture, but the relationship between compressive strength and absorption water is not as strong as this relationship (Hatungimana, et al., (2019). While the research of Prayuda, et al., (2017) the relationship between absorption or absorption of water with compressive strength shows that the smaller the water absorption, the greater the compressive strength of the bricks. strength is due to the large number of cavities, so that the voids of concrete greatly affect the quality of the concrete it has.Our research is in line with research obtained by Zhang and Zong (2014) and Hatungimana, et al., (2019) which concluded that the relationship between the compressive strength value and the absorption value does not have a clear relationship or a non-linear relationship, so the concrete strength does not can be judged only from the absorption or water absorption capacity. The findings highlight that while water absorption is often considered an indicator of concrete porosity, it does not provide a reliable measure of compressive strength. This is because the strength of concrete depends not only on its ability to resist water penetration but also on factors such as aggregate bonding, hydration process, and overall material composition.

4. CONCLUSION

Based on the research conducted on compressive strength and water absorption in concrete using different water conditions—neutral pH water, acidic water with a pH of 5, and acidic water that has been neutralized with fly ash—four key conclusions can be drawn. First, fly ash has proven to be effective in neutralizing acidic water. The addition of 20 grams of fly ash per liter of water or 150 grams per 10 liters successfully increased the pH from 5 to 7, making the water suitable for concrete mixing. This demonstrates the potential of fly ash as an environmentally friendly solution for improving water quality in construction applications. Second, using acidic water with a pH of 5 in concrete mixtures negatively impacts compressive strength at both 28 and 56 days of curing. However, when fly ash is used to neutralize the acidic water before mixing, the compressive strength improves compared to concrete mixed directly with pH 5 water. Despite this improvement, the resulting compressive strength does not reach the same level as that of concrete mixed with neutral pH water, and its strength continues to decrease over time. Third, the water absorption rate of concrete mixed with pH 5 water is higher than that of concrete mixed with neutral pH water and water neutralized using fly ash. This indicates that acidic conditions contribute to increased porosity, affecting the concrete’s durability and resistance to moisture penetration. Finally, the study confirms that water absorption does not have a significant correlation with compressive strength. With an R-squared value of 0.0057, the relationship between these two variables is negligible. This finding reinforces that concrete strength cannot be solely determined by its absorption rate, as other factors such as material composition, hydration process, and internal structure play a more critical role in determining overall performance.

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