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MINERAL ADDITIVES IN CONCRETE DURABILITY: A COMPREHENSIVE REVIEW

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Abstract

The body of literature on concrete using mineral admixtures covers a number of review studies on the durability characteristics of various materials used in concrete, such as fly ash (FA), rice husk ash (RHA), ground granular blast furnace slag (GGBS), fly ash (SF), and met kaolin (MK) are reviewed in this work. The features that are related to durability have been evaluated, and they include permeability, resistance to chloride ion penetrations, abrasion, fire resistance efflorescence. Incorporating mineral admixtures in concrete affects various properties. Concrete's permeability decreases and its ability to resist chloride ion penetration rises when admixtures containing a greater alumina content are used. Use of mineral admixtures enhances compressive strength and enhancing abrasion resistance. Moreover, highly reactive mineral admixtures mitigate efflorescence. Notably, while heating PFA concrete improves fire resistance, it reduces overall durability. SF concrete, on the other hand, behaves similarly to standard concrete but can be more brittle. MK concrete exhibits increased strength at 200°C, but its durability and strength decline at higher temperatures compared to other concrete types.RHA pozzolans can replace OPC up to 15% by weight after curing for up to 200 days without lowering the concrete's compressive strength.

Keywords: Chloride-ion-Penetration, Durability of Concrete, Mineral admixture, Permeability, Fire resistance

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Introduction

Due of its superior durability properties, Concrete is meant to thrive for decades or even centuries. The ability to resist hazards from the environment while conserving desired technical features has been defined as "durability". Risks related to the environment comprise freezing and thawing, abrasion, alkalinity, carbonation, chemical attack, and weathering. Published research shows the characteristics of durability of concrete are affected by curing, installation, and service conditions; however, the ratios and mixing of the constituents have a significant impact on the durability of the concrete. Various mineral admixtures are usually added to concrete to improve the mechanical characteristics of hardened concrete, in addition to its rheology, durability, and fresh concrete quality.

It is widely accepted that changes and deterioration of concrete limit the service life of concrete structures. In addition to decreasing the cement content and reducing heat of hydration, the addition of mineral admixtures to concrete also improves resistance against sulfate attack, alkali-silica reaction (ASR), carbonation, chloride attack on reinforcement, freezing and thawing, abrasion, fire, and acid. This ends up resulting in more durable and higher-quality concrete.Numerous examples have been identified in the literature that illustrate how mineral admixtures improve concrete's durability properties. By presenting the findings of cores extracted from 30-year-old buildings that were operating good at the time, Thomas (2012), presented examples of how the addition of FA increases durability by reducing the permeability of the concrete. Maage's et al.,(1987) , 20-year results show that concrete containing SF was almost better than concrete made with sulfate-resisting cement. The durability of concrete against sulfate attack is improved by using MK and RHA. Since a few mineral admixtures were explored, there is literature that examines the mechanical qualities and properties of fresh concrete that contains mineral admixtures.(Khatri etal.,(1995) , Soranakom and Mobasher (2007) and Khabit and Hibbert (2005)) .This study compares the durability properties of hardened concrete with and without mineral admixtures, comprising FA, GGBS, SF, MK, and RHA.

Durability in concrete

In the context of concrete technology, durability is resistance to deterioration. Low porosity, or low permeability, high-quality concrete is the main factor that determines durability. Durable concrete also offers improved corrosion protection, lower heat of hydration, and resistance to sulfates and the alkali-silica reaction. The researchers partially replaced the cement due to the usage of wastes and industrial by-products. According to Thomas et al. (2012) and Thomas (1996) , the use of mineral admixtures is highly beneficial as they decrease the damage that concrete causes the environment and increase its lifespan. Concrete's pore structure has been altered to decrease permeability, which increases the material's resistance to water-related deterioration and penetration, including frost damage, corrosion of reinforcement, and sulfate and acid assault . Keck and Riggs (1997), discussed the benefits of adding Class C and Class F FA. The use of FA in concrete has several durability-related benefits including decreased permeability, Keck and Riggs (1997), Resistance to alkali-silica reaction (ASR), Alasali and Malhotra (1991), and sulfates (Newman and Choo , 2003) , enhanced corrosion protection, and less heat of hydration. GGBS is useful for long-term durability in concrete because it has smaller pores, a finer pore size distribution overall, resistance to sulfate attack, resistance to ASR, and resistance to chloride attack.

As an analogous example, SF creates extremely dense microstructure concrete with high impermeable, resistance to chloride ion diffusion , and sulfate resistance . MK has been shown to be a useful way to improve pore structure and, as a result, exhibit improved resistance against detrimental environmental attack when used in part substitute of cement.. Slag concrete that has properly dried out is usually going to be more resilient than Portland cement concrete of a similar kind , (Newman and Choo , 2003) .Compared to SF concrete, RHA concrete is more sulfate resistant(Silica fume concrete, 2012) and decreases permeability.(Kartini et al., 2010) The following has been examined in length regarding these mineral admixtures' durability properties:

Permeability

The literature lists the advantages of utilizing FA in terms of low permeability and indicates that adding FA to concrete can improve its durability, (Keck and Riggs , 1997) . When FA is added to a cement matrix, the small diameter pore increases. Concrete gets less permeable and has improved resistance to medium penetration as a result of the shift in pore size distribution,(Padmarajaiah and Ramaswamy, 2004) . Figure 1 illustrates the permeability of concrete both with and without the addition of FA. It is clear that adding FA considerably lowers the concrete's permeability. The reduction in permeability is caused by acid, salt, and sulfate attack as well as freeze-thaw deterioration, which is minimized with concrete's higher density and cementitious components , (Fly ash, 2013).

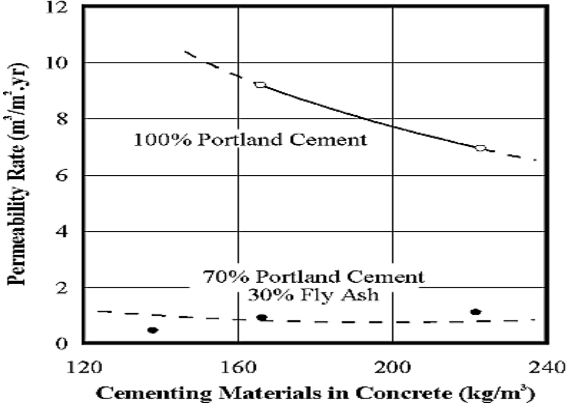

Figure 1: ***Concrete's permeability both with and without FA (Elfert, 1973)***

Since GGBS hydrates continuously, which occurs much after 28 days, it has been observed that adding GGBS to well-cured concrete, particularly during higher temperatures, improves its long-term durability. The overall pore size distribution gets finer and there will be smaller pores as the slag content rises, (Newman and Choo , 2003) . Like GGBS, very dense concrete forms when SF is added, so there is often no weak layer around the particles, very little SF concrete is permeable to impermeable, (Newman and Choo , 2003) . The permeability of the concrete has been studied by Cheng et al.,(2005) , in relation to 0, 40%, and 60% replacement of cement with GGBS. The results were 2.56×10−13, 1.52×10−13, and 1.32×10−13 m/s, respectively. This shows that adding extra GGBS results in a denser structure and keeps water out of the concrete.

To minimize water absorption, the MK and Pore size are initially reduced to a tenth of their diameter. This is done by adding around 27% of water in place of 20% of the cement, which produces additional calcium silicate hydrate (CSH) and calcium silicate aluminum hydrate (CSAH). MK concrete contains less pores overall to improve strength, density, and acid resistance . Findings of Pradip and Ajay's (2013), research on the water permeability of concrete show that the substitution of metakaolin at quantities of 4, 6, and 8% for 8% of the cement (Refer the Fig. 2) led to the lowest permeability.

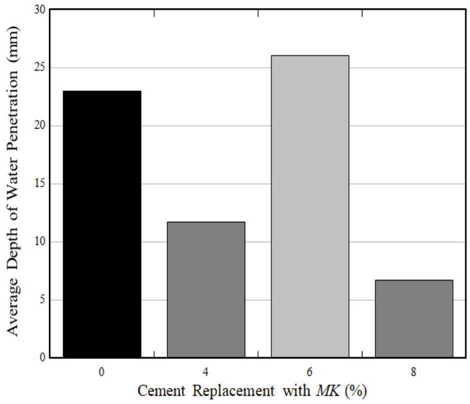

Figure 2 ***Average water penetration depth of MK concrete with 4, 6 and 8% cement replacements (w/b=0.29) , (Pradip and Ajay's ,2013)***

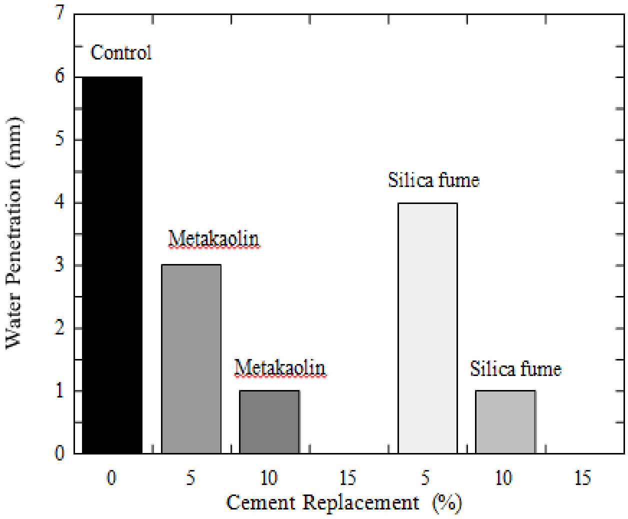

Figure 3 **MK *and* SF *concretes water penetration (w/b =0.26) (Bonakdar et al ., 2005)***

The degree to which metakaolin and silica fume concretes pierce water was compared by Bonakdar et al.(2005) , by substituting 5, 10, and 15% of the cement content with each of the two mineral admixture and found that metakaolin concrete had less permeability than silica fume concrete at the 5% replacement level. Similar water penetration results were seen at the 10% replacement level, however both concretes were declared impermeable at the 15% replacement level (see Fig. 3). The permeability of concrete is decreased when RHA is used in place of regular Portland cement (OPC), as shown by the experimental results of Kartini et al., (2010) . In addition, they found that, up to 20% and 30%, respectively, OPC concrete was almost three times more permeable than concrete that contained RHA. Overall porosity decreased (see Fig. 4) when Dakroury et al., (2008)

, looked at the relationship between the volume percentage of RHA and the total porosity of cement paste.

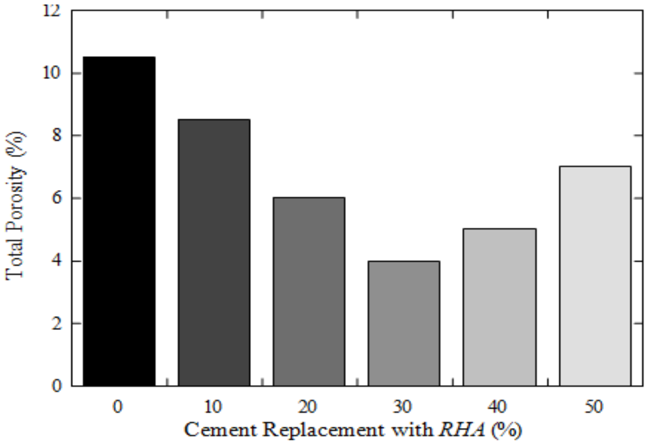

Figure 4 ***Effect of substituting*** **RHA for cement** ***on the cement pastes and total porosity (Dakroury and Gasser, 2008) .***

Hooton (1986) , carried out an experimental investigation regarding sulfate-resisting cement pastes using FA, slag, and cement paste SF; and reported the findings from experiments at 7, 28, 91, and 182 days after moist curing with respect to the distribution of pore diameters, permeability to water, and strength development. According to research that was published, SF was the most effective material in lowering the calcium hydroxide content of cement pastes and reducing permeability at an early age. Slag was the least successful in these areas. Fig. 6 shows the reduction in permeability caused by varying cement w/b ratios and cement replacement levels with silica fume. It is clear that the w/b ratio and permeability are directly correlated. When silica fume replaces 6% of the cement in concrete between w/b=0.35 and0.4, the concrete becomes impermeable; still permeability increases when over ten percent of the cement is replaced (Song et al., 2010).

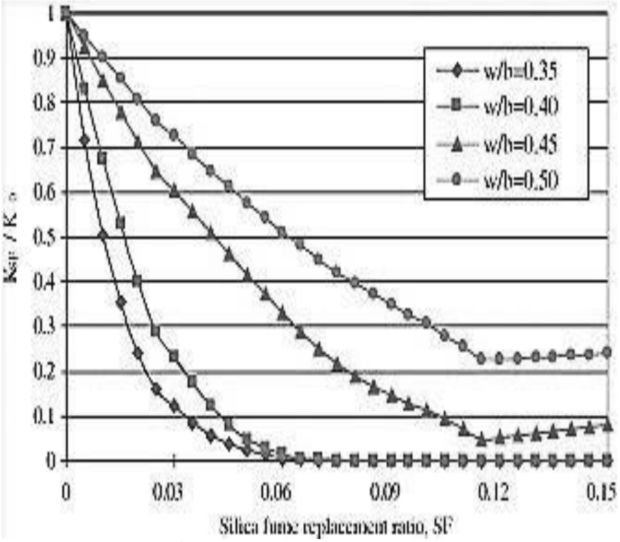

Figure 5 ***Reduction in permeability as a result of partially substituting SF for cement in varying w/b ratio (Song et al ., 2010)***

However, using ultrafine RHA better inhibits water absorption (see Fig. 5), according to Givi et al., (2010) , investigation on the impact of RHA particle size on concrete's ability to absorb water).

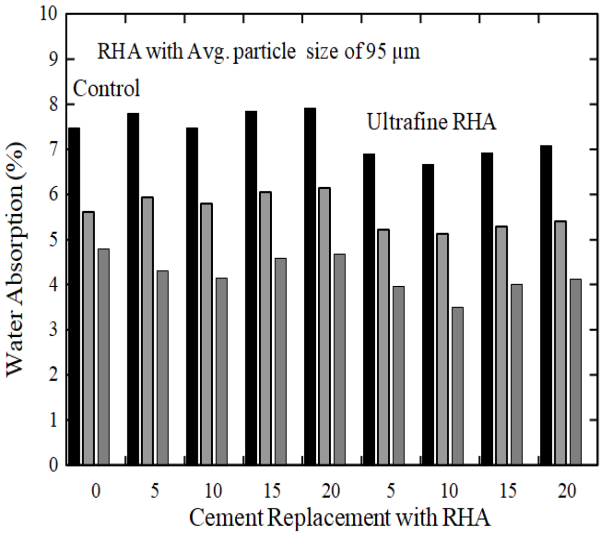

Figure 6 ***Effect of RHA particle on concrete water absorption (Givi et al., 2010)***

Resistance to Chloride Ion Penetration

Diffusion of chlorides, which might come from outside sources or be part of the constituents of the mix, leads the steel to become evident. Decreased permeability of the concrete is required to minimize the entry of chlorides because there are several possible sources of chlorides, such as saltwater and de-icing salts. Klieger and Gebler (1987) , state that the class of FA has no effect on the permeability of concrete containing FA to chloride ions. When substituting 20, 40, and 60% of the cement content with coarse FA, Horsakulthai and Paopongpaiboon (2013) , have presented the 7, 28 and 90-day test results of the chloride ion permeability of concrete. They found that 40% is the optimum cement replacement level in order to lower the chloride ion permeability. (Refer Fig. 7).

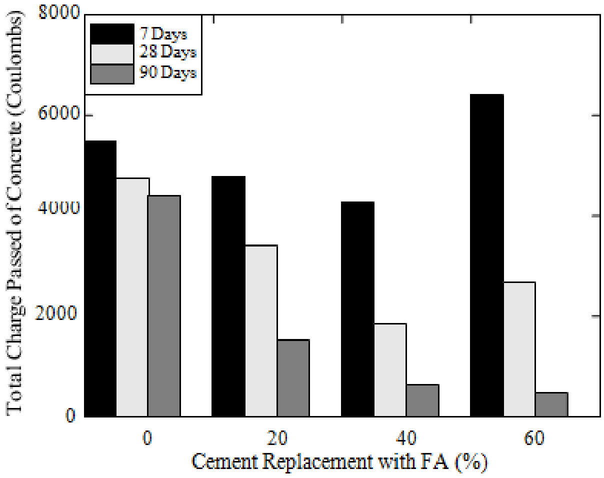

Figure 7 ***Permeability of*** **FA** ***Concrete to Chloride ions (w/b=0.5) (Horsakulthai and Paopongpaiboon , 2013)***

The diffusion test results of concrete with SF up to 3–6% and moderate levels of high CaOFA (20–30%) were published by Thomas et al.,(2012), indicating a very high resistance to the penetration of chloride ions. Higgins and Uren (1991) , proposed that concrete's resistance to chloride could be increased by partially replacing GGBS for cement.

Chloride ion penetration is reduced when a larger quantity of GGBS is used in place of some cement, according to Cheng et al., (2005) . They also studied the impact on the total charge transferred of substituting 0, 40%, and 60% of the cement with GGBS (See Fig. 8). In a study by Hooton et al., (1997) , SF was used as a substitute for 0,7, and 12% of the cement content at various water-cement ratios to cast a number of concrete slab parts. This showed that using SF that was dispersed properly increased concrete's resistance to the diffusion of chloride ions.

The use of MK in concrete is essential in marine areas and structures near the sea . The permeability of concrete affects the distribution of chloride ions, and it is claimed that using MK reduces pore diameter, reducing the passage of chloride ions. The chloride penetrability of the concrete with MK at w/b ratios of 0.3 and 0.5 was reported by Poon et al., (1997) . Compared to the control, total ion penetration was lower in both MK concrete samples. The best w/b for concrete with a 10% MK was 0.3, but the best w/b for 20% replacement was 0.5.A study by Justice et al., (2005) , showed that MK concrete reduces rapid chloride ion permeability more efficiently than SF mixtures. Caldarone et al. compared the quick chlorine permeability findings of high reactive metakaolin with silica fume and control concrete, and after a total of 56 days of moist-curing concrete, the lowest chloride ion permeability was achieved with metakaolin.(Refer Fig. 9).

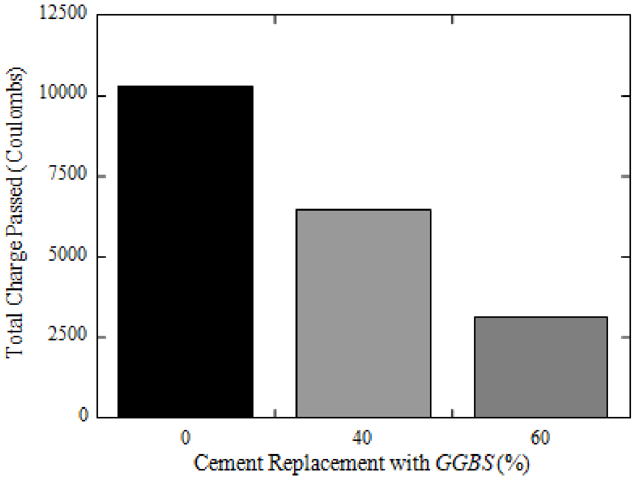

Figure 8 ***GGBS replacement effect on the chloride ion resistance(Cheng et al., 2005)***

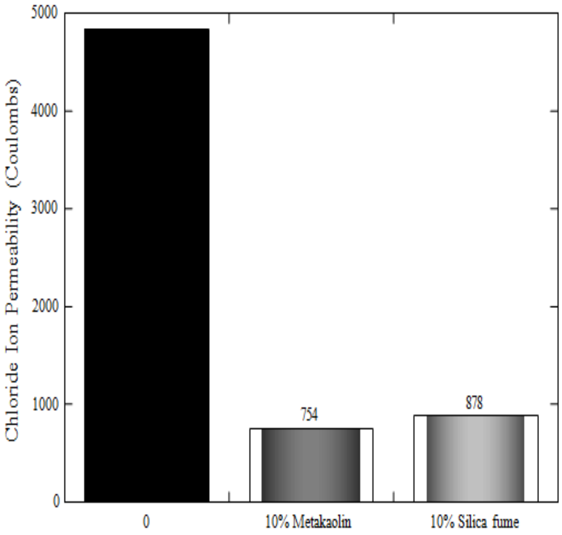

Figure 9 ***Results of MK and SF concrete after 56 days of moist curing for chloride ion penetration (Caldarone et al., 1994)***

Resistance to Abrasion

High volume FA concrete's resistance to abrasion was studied by Cengiz Duran Atis (2010). Concrete with different water binder ratios was made with FA present in mass basis at 50% and 70%. A Dorry abrasion machine was used to measure the abrasion value. The findings of the examination indicate that when compressive strength rises, so does abrasion resistance. More abrasion resistance was provided by concrete with 70% FA than by regular concrete and concrete with 50% FA. However, superplasticizer and curing conditions have very little effect on the abrasion of concrete.

After the concrete has fully hardened, utilizing GGBS has a small benefit over regular Portland cement concrete of the same grade in terms of abrasion resistance; nevertheless, when concrete is not properly cured, GGBS-containing concrete will be more affected than regular concrete. The resistance to erosion and abrasion is significantly improved when high-strength SF concrete is used (Newman and Choo , 2003).

Resistance to Fire

The ability of a structural part to withstand load without losing that ability or to act as a barrier to stop the spread of a fire is known as fire resistance (Harris, 2007) .The mechanical and long-lasting qualities of concrete, Y. Xu et al., (2010) , heated the PFA concrete. Various PFA concentrations and water binder ratios were employed. The results indicate that exposure to 250°C increases compressive strength. This phenomenon may be attributed to the drying process of cement paste and subsequent hydration of cementitious materials. Conversely, a decrease in durability was noted, which could potentially be the result of a fragile transition zone along with the hardened cement paste and aggregate. Because PFA retains its compressive strength at high temperatures, it increases fire resistance. This effect is amplified at maximum temperatures of 450°C and 650°C. SF concrete acts like regular concrete in a typical fire; but, because of its enhanced brittleness, ultra-high-strength SF concrete may be more prone to failure .

During an experimental research, Poon et al., (2008) , evaluated the performance of MK concrete at temperatures as high as 800°C. MK concentrations are 0%, 5%, 10%, and 20% in normal and high strength concrete, respectively. The average pore diameters, porosity, chloride-ion penetration, and residual compressive strength were compared with those of SF, FA, and OPC concrete. At 200 °C, a rise in compressive strength was observed. Comparing MK concrete to SF, FA, and OPC concrete, higher temperatures resulted in a loss of compressive strength and permeability-related durability..

Use 0.6 water/cement ratios to attain up to 200-day curing times. After 60 days of curing, RHA concrete has a higher compressive strength at 5% weight than OPC concrete. The weight of RHA concrete showed a 10% increase in compressive strength after 30 days of curing, and a 15% increase in compressive strength during 200 days of curing when compared to OPC concrete. Englehardt and Peng (1995) suggest that the sluggish pozzolanic-cement reactions could be the cause of this behavior.

After 200 days, the maximum compressive strength of 40 N/mm2 was achieved for 5% weight of RHA mixed concrete. The result shows that the compressive strengths of RHA increases with the percentage of OPC replaced with pozzolanic. As the curing age increases the blended cement composites decreases. Compared to OPC concrete, RHA concrete has a higher compressive strength due to longer curing times. Based to these results, cement may have replaced up to 15% of the weight in binary pozzolanic concrete after 200 days of curing. (Refer Fig. 10).

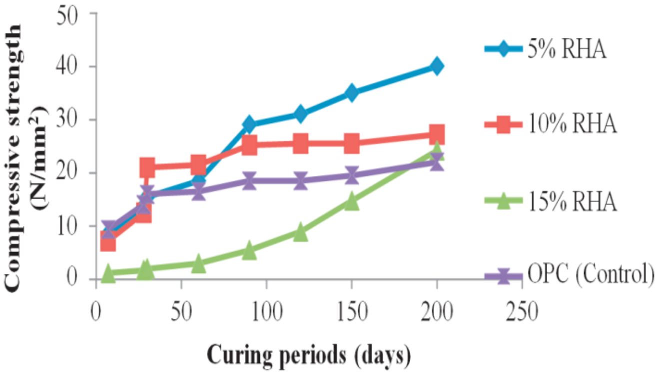

Figure 10 ***Compressive strength and curing period are corelated at 0%-15% weight of RHA replacement (Englehardt and Peng , 1995) .***

Additional calcium silicate hydrate (C-S-H) and calcium aluminate hydrate (C-A-H) deposited in the pore system as a result of the admixture's (RHA) reaction with the free lime may have contributed to the specimens' compressive strength up to 200 °C (Adefemi et al., 2013). The 10% weight of RHA mixed concrete only showed good fire resistance between 100 and 200 degrees Celsius; above 200 degrees Celsius, it decreases. The residual compressive strength of RHA pozzolanic concrete at 15% weight declined with increasing temperature, with the exception of 200 days of curing at 100 °C, during which it grew from 24.2 N/mm2 to 25.3 N/mm2. (Refer Fig. 11).

Temperature exposure between 100 ◦C and 700 ◦C caused the control's residual compressive strength to gradually decrease from 22.0 N/mm2 to 4.9 N/mm2. Khoury (2000) suggests that the temperature drop in residual compressive strength could be caused by the dehydration of calcium carbonate (CaCO3) at about 600 °C, which results in the production of calcium oxide (CaO) and water (H2O).

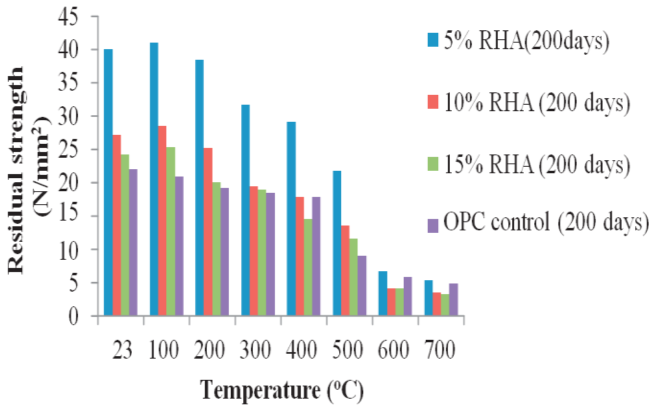

Figure 11 ***Temperature and residual strength of RHA mixed concrete after 200 day (Adefemi et al., 2013)***

Efflorescence

A white deposit known as efflorescence can be seen on concrete surfaces, diminishing its visual appeal without compromising its strength. Efflorescence comes in two different forms: Because of the reaction between lime and atmospheric carbon dioxide, insoluble lime or calcium carbonate is deposited on the concrete surface during the early curing stages of a structure, causing primary efflorescence. Secondary efflorescence is the second type that develops when water seeps through the surface of wet, hardened concrete and dissolves some of the leftover lime. Salts are deposited at the surface by the salt-laden fluid moving to the surface during subsequent drying (Newman and Choo , 2003).

According to a study by M. A. Smith et al., (1977) , the cement produced by mixing fine GGBS with untreated FA contained a sodium hydroxide solution as an activator. Concrete was made and tested for compressive strength using a mixture of 60% slag and 40% fly ash with 7% sodium hydroxide solution. After 28 days, very little strength gain was observed, but the risk of efflorescence and alkaline-aggregate reaction was decreased..

Due to the increased pore structure and increased consumption of calcium hydroxide, the addition of SF lowers efflorescence; however, longer and more effective curing is needed for greater resistance (Newman and Choo , 2003). The addition of MK aims to slow down the rate of CO2 absorption and stop efflorescence development by lowering the alkali content of the concrete. In addition, it controls efflorescence by removing some of the Ca(OH)2 and improving the pore structure to reduce water absorption and the amount of salty water that rises to the surface (Siddique and Klaus , 2009). Similarly, when mineral admixtures replace cement in concrete, there is less calcium hydroxide, that is related to a decreased risk for efflorescence when RHA is used (Huang and Deng , 2010).

Discussion

The study on mineral additives in concrete durability by authors offers a comprehensive examination of the complex effects of several mineral admixtures explaining how these compounds affect important factors like efflorescence, abrasion resistance, fire resistance, permeability, and chloride ion penetration. The thorough analysis uncovers complex relationships between the mineral additive content and the final concrete qualities.on concrete qualities. The paper includes a thorough examination of materials including metakaolin, fly ash, rice husk ash, and pulverized granular blast furnace slag.

The suitable connection between a higher alumina content in admixtures and decreased permeability as well as improved resistance to chloride ion penetration are significant findings. The study carefully assesses the effectiveness of several mineral admixtures, highlighting, for example, the notable increase in fire resistance seen in Portland fly ash concrete. This study is a valuable resource for researchers, engineers, and practitioners involved in concrete technology and construction since it offers a comprehensive understanding of the role that mineral additions play in the durability and performance of concrete.

Conclusion

The percentage of alumina in mineral admixtures influences the permeability of concrete; the higher the alumina content, the less permeability, resulting in a higher resistance to sulfate and chloride ion penetration. Several others cementitious materials, including fly ash (FA), metakaolin (MK), silica fume (SF), ground granulated blast furnace slag (GGBS), and fly ash (SF), can effectively lower the permeability of chloride ions in concrete, making them useful for improving durability, especially in structural elements that are near the sea. Heating PFA concrete enhances fire resistance but reduces durability, while SF concrete behaves like regular concrete but may be more brittle. MK concrete improves strength at 200°C but loses durability and strength at higher temperatures compared to other concrete types.

In binary mixed cement concrete of grade 20, RHA pozzolans can replace OPC up to 15% by weight after curing for up to 200 days without lowering the concrete's compressive strength (Siddique and Klaus , 2009). Five percent of the weight of RHA binary blended cement concrete shows fire resistance 200 days after curing, reaching 500 °C in temperature. Since abrasion resistance increases with compressive strength, applying FA, GGBS, SF, MK, or RHA to concrete will generally increase its resistance to abrasion. The addition of FA, GGBS, SF, MK, and RHA in concrete has been linked to a decreased risk for efflorescence when calcium hydroxide decreases as a result of cement replacement by mineral admixtures (Huang and Deng , 2010).

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