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The Technical Characteristics of Eco-Friendly Concrete Reinforced with Coal Bottom Ash

Martyana Dwi Cahyati¹, Aulia Rahman²
Department of Civil

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Abstract

One of the leading global contributors of carbon dioxide is the building material concrete. Yet, research shows that concrete manufacturing will keep going up until 2050, particularly in emerging nations. Multiple studies have shown that cement production ranks high among the concrete industry's major carbon dioxide emitters. Furthermore, the excessive use of aggregates in concrete manufacturing also leads to inevitable harm to the environment. As an eco-friendly alternative to cement and fine aggregate, bottom ash waste was used in the building process. It is believed that this study would enable the complete use of industrial waste, leading to a greener concrete with reduced carbon dioxide emissions throughout production. Part one of this research focuses on using bottom ash in place of cement, while part two examines its potential use as a fine aggregate alternative. The studies in this research examined the engineering qualities of the concrete in both its fresh and hardened phases. To find out how workable new concrete is, one does the slump test. Tests for the hardened attributes include mass density, flexural strength, compressive strength, and splitting tensile strength. The use of bottom ash as a substitute for cement shows that the hardened qualities of concrete are negatively affected by increasing the proportion of bottom ash. It has been observed that the performance of hardened characteristics has improved with increasing proportions of bottom ash when utilizing it as a substitute for fine aggregate.

Keywords: Bottom Ash; Cementitious Materials; Fresh Properties; Hardened Properties; Sustainable Material.

1. Introduction

In terms of global consumption, the building sector ranks concrete among the top materials. Because it is inexpensive and readily available, concrete is a popular building material. The five main components of concrete are water, coarse aggregate, fine aggregate, superplasticizer, and cement. In addition to being inexpensive, durable, resistant to a wide range of conditions, and easy to shape to any desired design, concrete also possesses a strong resistance to compressive pressures and fire. The concrete construction life cycle includes the following steps: material selection, mixing, transportation to the site, operational service, maintenance, and destruction [1]. Inevitably, concrete will have an adverse effect, especially on the environment, at every stage of its life cycle, from building to destruction. Multiple studies have shown that all stages of the concrete life cycle result in substantial atmospheric gas emissions. How much gas is discharged into the atmosphere each year It is believed to be around 8% in the atmosphere [2, 3]. The manufacturing of cement ranks high among the concrete industry's major contributors to carbon dioxide emissions. Because it solidifies the mixture of fine and coarse aggregates, cement is a crucial ingredient in concrete. Cement is expected to continue seeing increased usage and production by the year 2050, according to certain studies [4-7]. In recent years, concrete has become more popular around the globe, especially in emerging markets like India and China. In developed nations, where new building projects are unlikely to materialize, cement consumption is predicted to fall. Sustainable development objectives, as recently declared by the UN, include long-term industrial infrastructure, including the cement sector. Cement manufacturing is a

known contributor to greenhouse gas emissions. As a result, taking into account the environmental effect, sustainable materials are essential to boost economic growth, particularly in the infrastructure sector. The building sector may reduce its cement use with the help of new eco-friendly materials. Several recent research has discovered that organic and inorganic waste can be used as cementitious material since they are similar to cement. Two commodities that have been marketed for building materials and got excellent feedback are fly ash [8-10] and blast furnace slag [11-13]. Meanwhile, rice husk ash [14-16], bagasse ash [17-19], palm oil waste [20-22], and Kaolin [23-25] are among the materials being researched as alternatives for cement replacement.

In addition to manufacturing cement, exploitation of both fine and coarse aggregates also causes natural damage, especially the dysfunction of the river system. While concrete output rises in tandem with aggregate consumption, the two go hand in hand. According to reports, several nations including France, Singapore, and the US import aggregates for their building industries [26]. Several methods have been developed to limit aggregate exploitation and thus reduce carbon dioxide emissions and pollution caused by concrete production. One option that has emerged in recent years is the use of recycled material as a substitute to aggregate. In general, demolished infrastructure will be reprocessed such that the trash produced becomes aggregate (fine aggregate and coarse aggregate), which may then be utilized to make concrete [27-29]. Several studies were also found to use various wastes to replace aggregates, especially fine aggregate, including using waste from agriculture palm oil waste [30-32], rice husk ash [33-35], bagasse ash [36-38], glass waste [39-41], and plastic recycle [42-44]. Based on the various types of materials described above, other materials are often also alternative materials, either as a substitute for cement or as a substitute for fine aggregate. Bottom ash is a byproduct of a process that is no longer in use. Bottom ash is typically made up of coal combustion leftovers from industrial power plants. In contrast, to fly ash that already has standards and is commercialized, bottom ash is currently not much in demand. Several studies on the properties of concrete using coal bottom ash as a substitute for cement have been found [45-47] and a substitute for fine aggregate [48-50]. In Indonesia, several studies have been found regarding bottom ash as an alternative material for concrete production [51-53]. However, the results of an investigation from a literature review regarding the use of bottom ash indicate that the power plant source has a significant effect on the quality of the bottom ash. This difference in bottom ash characteristics indicates the need for further evaluation as an alternative material for concrete production. This study aims to investigate the engineering properties of concrete using an alternative material of coal bottom ash for manufacturing concrete. This research consists of two main series: the utilization of coal bottom ash waste as a cement replacement and the utilization of coal bottom ash waste as a substitute for fine aggregate. The properties of the constituent materials have been examined, including a scanning electron microscope (SEM) and Energy Dispersive X-ray (EDX) for the binder. This study also utilizes silica fume to help improve performance at the early age of concrete. Additionally, a superplasticizer was used in this study to improve fresh concrete performance during the mixing process. The workability of concrete is determined by testing its fresh properties. Meanwhile, compressive strength, split tensile strength, flexural strength, and hardened concrete mass density are measured. Additional information about the use of bottom ash as an alternative material for the manufacture of concrete as a cement and fine aggregate substitute is expected to be obtained from this test.

2. Experimental Program

2.1. Raw Materials

Cement, silica fume, bottom ash, water, sand, gravel, and a superplasticizer were used in this study. The cement used is classified as a type of Portland pozzolan cement according to ASTM C595 [54], whereas the silica fume is classified according to ASTM C494 [55]. Before the manufacture of specimens, each constituent material is first examined for its characteristics and properties. Scanning Electron Microscope (SEM) and an Energy Dispersive X-Ray (EDX) tests were

conducted to determine the characteristics of binders (cement, silica fume, and bottom ash). Figure 1 is the result of the EDX inspection for each binder. The results on cement showed that the content of calcium (Ca), Silica (Si), and (O) was very significant. This demonstrates the true nature of cement because this component has an important contribution to the hydration process. It should be noted that the results of the EDX test for bottom ash show a similar pattern to cement, so it can be concluded that bottom ash can be used as a cement replacement material. SEM testing was also carried out to see the particle shape of each binder constituent. The results of SEM and EDX show that cement contains CaO components, as shown in Figure 2. Meanwhile, Al_2O_3 and SiO_2 components dominate bottom ash binders, and SiO_2 components are seen in Silica fume.

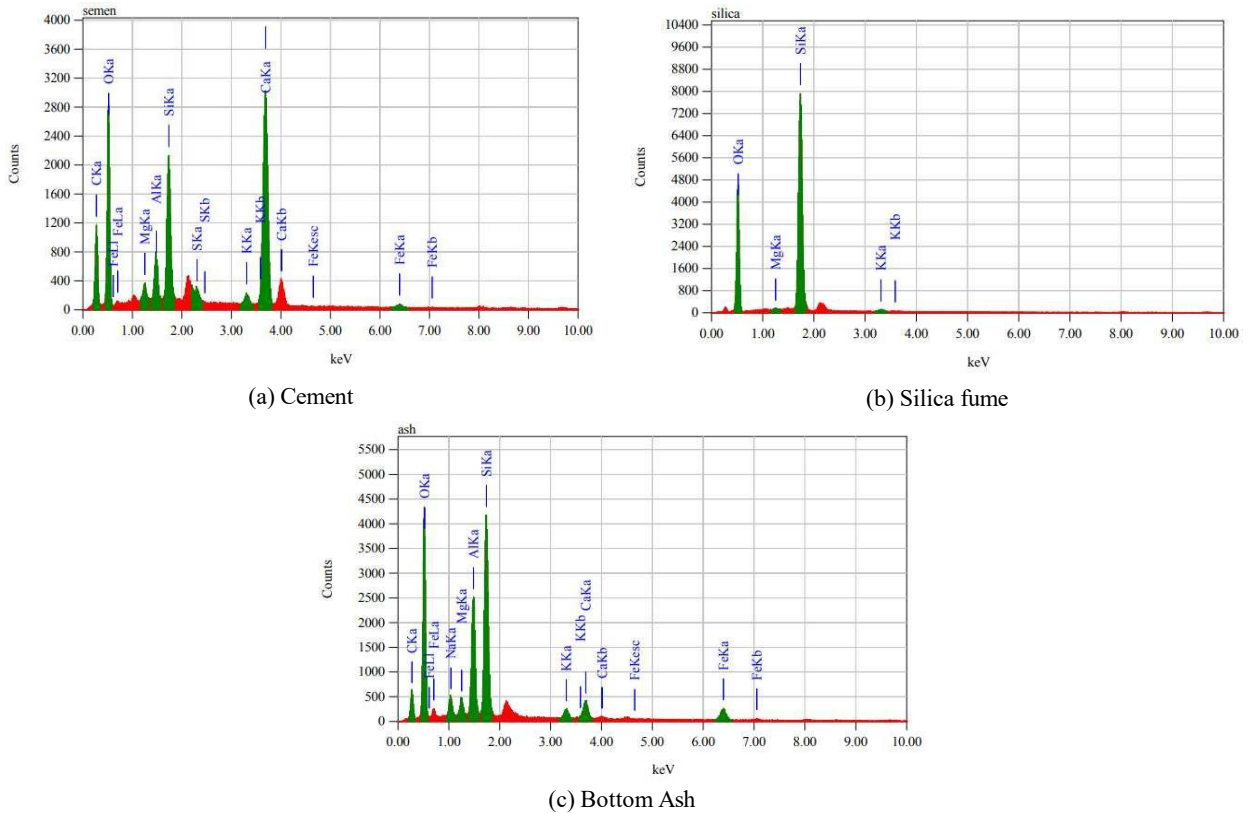


Figure 1. Results of Energy Dispersive X-Ray (EDX)

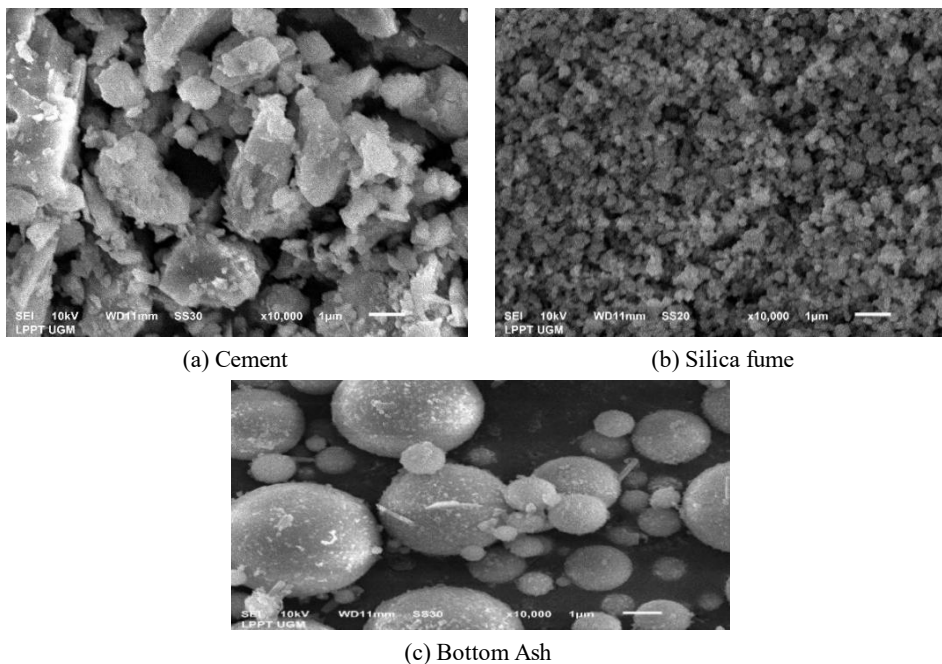


Figure 2. Results of Scanning Electron Microscope (SEM) for binder

Table 1 shows the results of the mechanical properties of fine aggregate consisting of sand and bottom ash and coarse aggregate in the form of gravel. A study of the grain size gradation is also carried out while assessing the properties of fine aggregates, with the results shown in Figure 3. Specific gravity, water absorption, mud content, water content, mass density, fineness modulus, and roughness testing utilizing a Los Angeles machine for coarse aggregate are all part of the examination of the aggregate characteristics. In addition, it should be noted that the water absorption in bottom ash is much higher than that of fine aggregate (sand), this is due to the finer particle size of bottom ash which makes it very easy to absorb water. The obtained bottom ash has lower specific gravity than sand or cement. Additionally, bottom ash has a higher mud content than the other materials used in this study.

Table 1. Properties of aggregates

Properties	Unit	Sand	Bottom Ash	Coarse Aggregate
Specific gravity	-	2.36	2.01	2.56
Water Absorption	%	2.70	27.9	1.40
Mud Content	%	2.40	4.59	0.95
Water Content	%	1.70	3.09	0.89
Mass Density	g/cm ³	1.33	2.45	1.44
Fineness modulus	%	2.40	1.83	-
Roughness	%	-	-	28.56

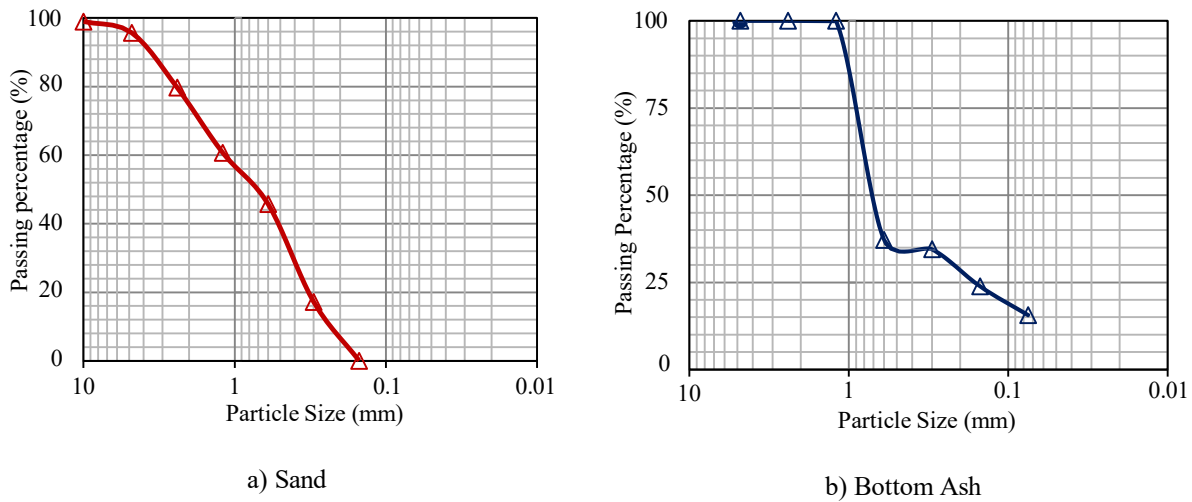


Figure 3. Size distribution of fine aggregates

2.2. Mix Proportion

This study focuses on two main series: bottom ash as a substitute for cement (BBA) and bottom ash as a substitute for fine aggregate (FABA). Table 2 is the mix proportion of concrete for 1m³ with each mixture variation. Cement reduction is carried out by 10, 20, and 30% in bottom ash as a substitute for cement. Meanwhile, sand is substituted with bottom ash to the tune of 30, 40, and 50% as a fine aggregate alternative. This study also used silica fume and superplasticizer with the constant amount for all variations.

Table 2. Mix proportions for 1 m³ in kg

Variation	Cement	Silica fume	Bottom Ash	Sand	Coarse Aggregate	Water	Superplasticizer
NM	485.70	29.30	-	585.70	990	205	3.50
BBA10	437.13	29.30	48.57	585.70	990	205	3.50
BBA20	388.56	29.30	97.14	585.70	990	205	3.50
BBA30	339.99	29.30	145.71	585.70	990	205	3.50

FABA30	485.70	29.30	145.71	439.99	990	205	3.50
FABA40	485.70	29.30	234.28	351.42	990	205	3.50
FABA50	485.70	29.30	292.85	292.85	990	205	3.50

2.3. Test Method

Inspection of concrete properties in this study consisted of two types, namely inspection of fresh properties and hardened properties. Inspection of fresh properties is carried out by slump testing to determine the workability of fresh concrete during the mixing process. In addition, slump loss testing is also carried out to determine when the concrete can be worked during the mixing process before the initial setting time. While the hardened properties test consists of

compressive strength, splitting tensile strength, flexural strength, and mass density. The test for compressive strength and split tensile strength uses a cylindrical specimen with a height of 300 mm and a diameter of 150 mm, where the compressive strength test refers to ASTM C39 [56], and the split tensile strength test refers to ASTM C496 [57]. The flexural strength test was carried out with specimens with dimensions of $150 \times 150 \times 600$ mm with a 4-point test method based on ASTM C239 [58]. Hardened properties testing was carried out on the concrete, aged 3, 7, and 28 days with the results being the average of 3 test objects. The curing method used in this research is water curing and sealed curing, where water curing is done by immersing the test object in a tub filled with water. In contrast, sealed curing is done by wrapping the test object in 5-layer plastic wrap to avoid evaporation.

3. Results and Discussion

3.1. Slump Test and Slump Loss

You may find out what new concrete looks like when you replace some of the cement and fine aggregate with bottom ash by doing a slump test or a slump loss. Results from tests measuring slump and slump loss while using bottom ash in place of cement are shown in Figure 4. Up to five checks are performed every seven minutes to check for slump loss. In the absence of bottom ash, the slump value of regular concrete is 21 cm. Adding more bottom ash reduces the slump value. Slump values range from 15.5 cm when using 30% bottom ash as opposed to 30% cement, 17 cm when using 20% bottom ash instead of cement, and 19 cm when using 10% bottom ash. Since bottom ash is in a dry condition when mixed, it may absorb a lot of water, making new concrete less workable; so, an increase in the quantity of bottom ash causes a reduction in slump. Slump loss test findings show that produced slump value decreases with increasing inspection length. At the 35-minute mark, the combined standard concrete and bottom ash combination produces a slump value less than 5 centimeters. The longer the mixing process, the more heat is released by the cement, which in turn reduces the quantity of water in the new concrete via evaporation, resulting in a lower slump value.

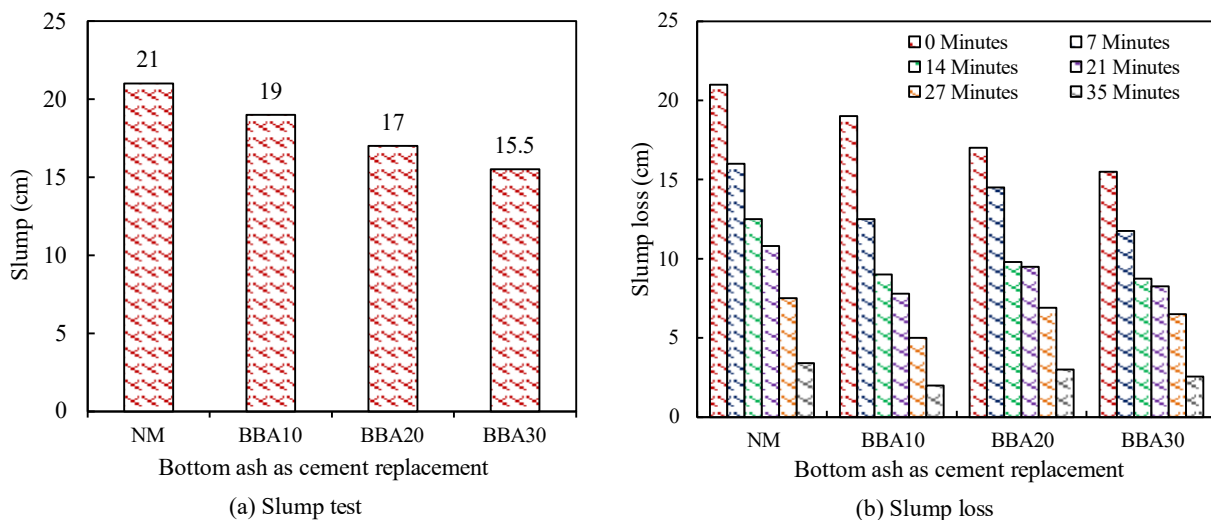


Figure 4. Slump test results and slump loss for bottom ash as cement replacement

Figure 5 is the result of the slump and slump loss inspection for utilizing bottom ash as a substitute for fine aggregate. The amount of sand used in this series reduces as the bottom ash composition increases, while the cement content remains constant throughout all variations. A slump of 21 cm is produced in normal concrete, while a slump of 17 cm is produced in concrete containing 30% bottom ash as a fine aggregate replacement. As bottom ash is used as a substitute for sand, workability continues to decrease with 14 cm for 40% sand replacement and 11 cm for 50% sand replacement. Because the amount of bottom ash utilized is higher, the drop in slump value is greater than when using bottom ash as a cement replacement. Because bottom ash absorbs more water than sand, it can be expected that as the amount of bottom ash increases, the water content will increase to prevent a drop in the workability of fresh concrete. Figure 5b

shows that the slump loss increases when the time test is increased. The 50% bottom ash replacement variation produces a slump value of 0 cm at the 27th minute, while the 40% replacement variation produces a 0 cm slump value at the 35th minute. It should be noted that with the high amount of bottom ash used as a fine aggregate replacement, the working time for mixing fresh concrete will be shorter.

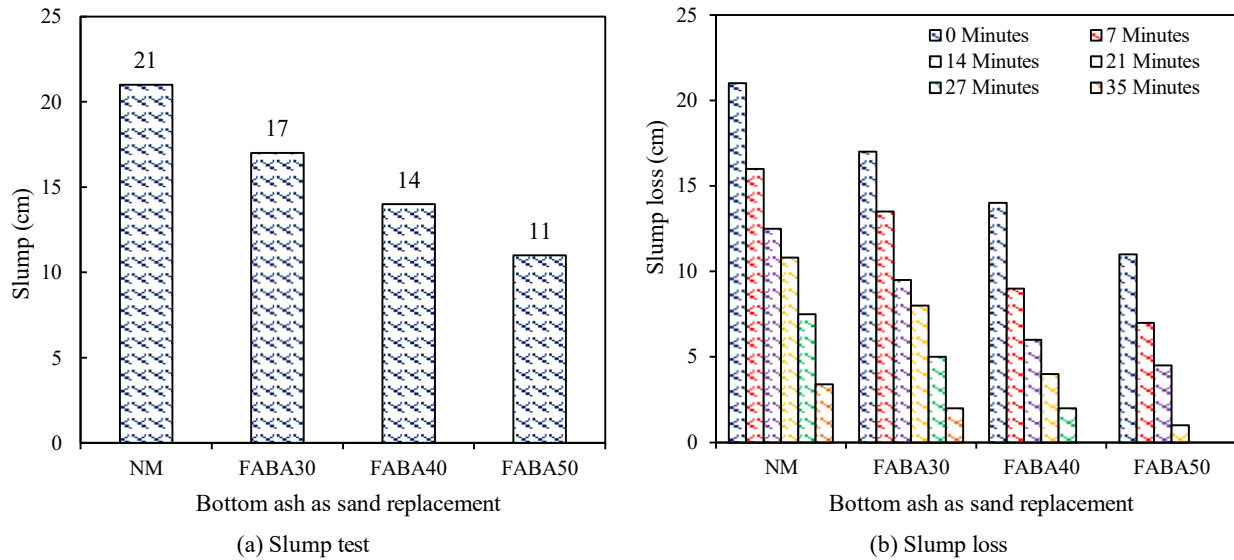


Figure 5. Slump test results and slump loss for bottom ash as fine aggregate replacement

3.2. Compressive Strength

Compressive strength tests were conducted on unconfined specimens at 3, 7, and 28 days of age. Compressive strength testing at the age of 3 and 7 days to determine the performance of early age of concrete. Figure 6 shows the results of the compressive strength of concrete using bottom ash as a substitute for cement with various types of curing (water curing and sealed curing). The compressive strength developed by both water and sealed curing shows that as the age of the concrete increases, so does the compressive strength produced. The increase in concrete compressive strength is because it goes through a hydration process that allows it to harden and become compact as the concrete ages. Compressive strength indicates that when the amount of bottom ash used increases as cement replacement, the compressive strength of concrete decreases both in early and 28-day ages. The utilization of bottom ash as cementitious material causes the amount of cement used to decrease when the percentage of replacement increases. The decrease cement content indicates that compressive strength will be decreased. When concrete is in a fresh state, cement reacts when mixed with water to produce hydration. However, bottom ash cannot react directly in a fresh state of concrete. The reaction of bottom ash is always slower than cement reaction so that by using a high amount of bottom ash causes the hardened process to become slower. As a result, the compressive strength of bottom ash concrete is low at an early age also when concrete is at 28-day age. It can be concluded that the utilization of bottom ash as cement replacement has some limitations in maintaining the performance of concrete, especially at an early age

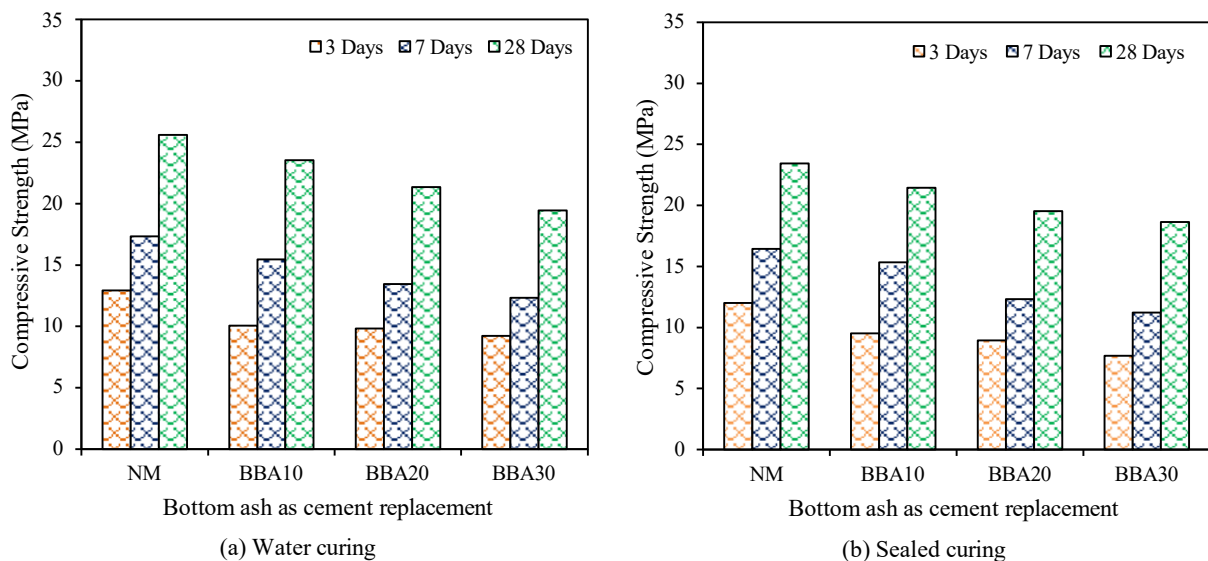


Figure 6. Compressive strength for bottom ash as cement replacement

Figure 7 shows the compressive strength of concrete with bottom ash as fine aggregates replacement with water and sealed curing. The results show that the compressive strength increase when the amount of bottom ash as sand replacement increases. When the high percentage of bottom ash replacement is used, the amount of sand will be

decreased, but the amount of cement remains constant to all variations. As a result, the hydration of cement will be similar for all specimens with bottom ash as sand replacement. Moreover, the particle size of bottom ash is smaller than sand, so that by using bottom ash fills the small pores inside the concrete cause the volume of pores on bottom ash concrete to decrease. The compressive strength of the concrete will improve in both water and sealed curing by minimizing the number of pores. Another factor contributing to an increase in compressive strength is the chemical properties of bottom ash, which are comparable to cement. This serves to strengthen the strength of the paste on the concrete, increasing compressive strength.

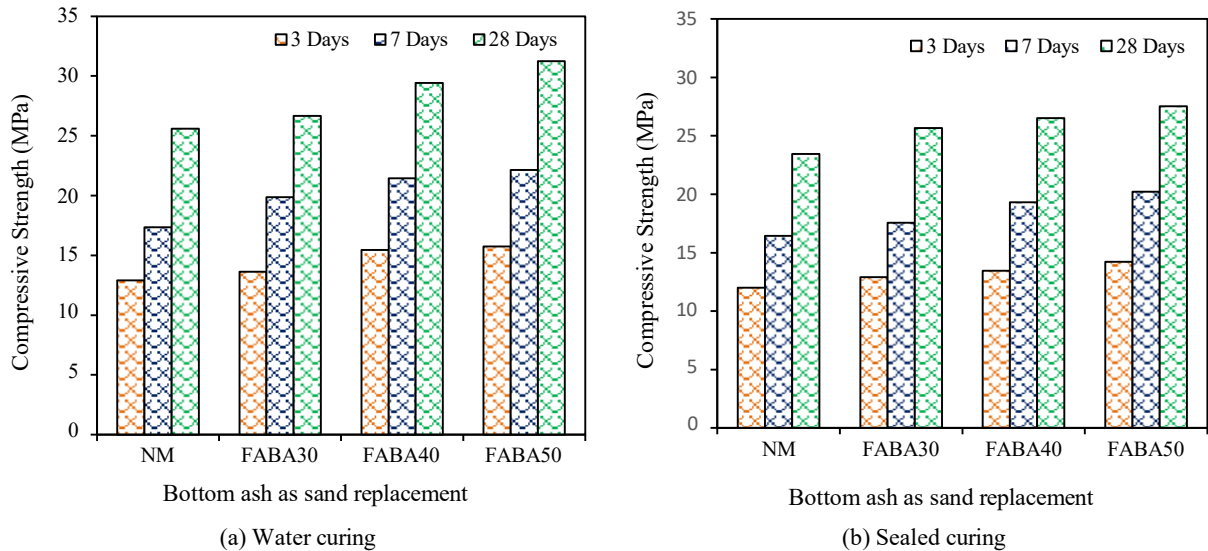


Figure 7. Compressive strength for bottom ash as fine aggregate replacement

3.3. Splitting Tensile Strength

Splitting tensile strength tests were carried out for all variations to utilize bottom ash as a substitute for cement and fine aggregate. Figure 8 shows the splitting tensile strength for the utilization of bottom ash as a substitute for cement with water and sealed curing. While Figure 9 is the result of splitting tensile strength for bottom ash as a substitute for fine aggregate. The splitting tensile strength test pattern results in all these variations is very similar to the compressive strength. It can be concluded that the causes of both the decrease and increase in splitting tensile strength were the same as those found in the compressive strength test described above. The splitting tensile strength decreased as the amount of bottom ash increased and the amount of cement reduced in the use of bottom ash as a cement substitute. Meanwhile, variations in the incorporation of bottom ash as a fine aggregate substitute enhanced the value of splitting tensile strength.

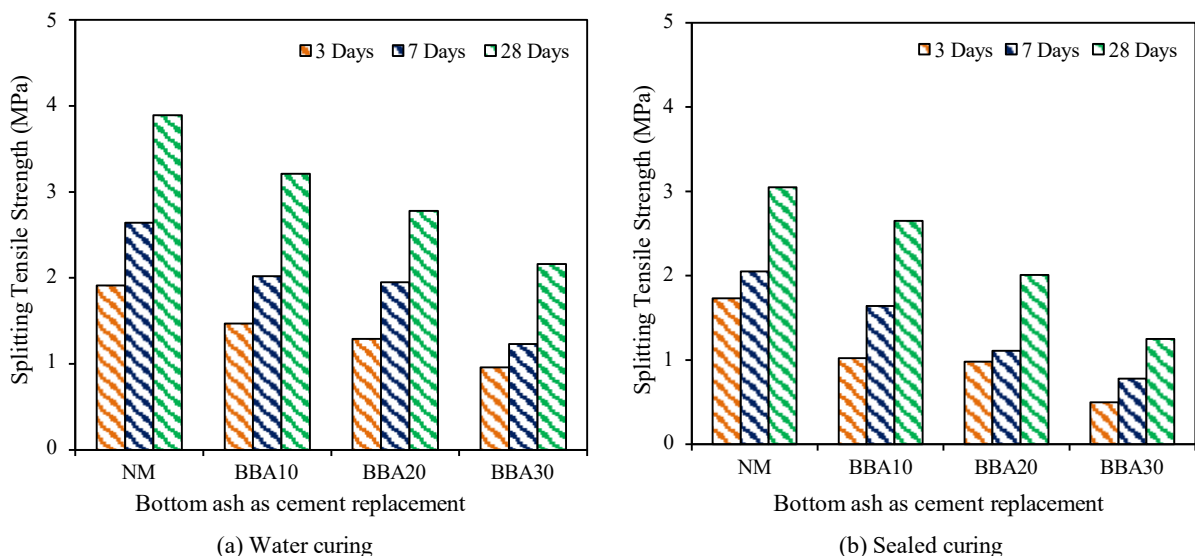


Figure 8. Splitting tensile strength for bottom ash as cement replacement

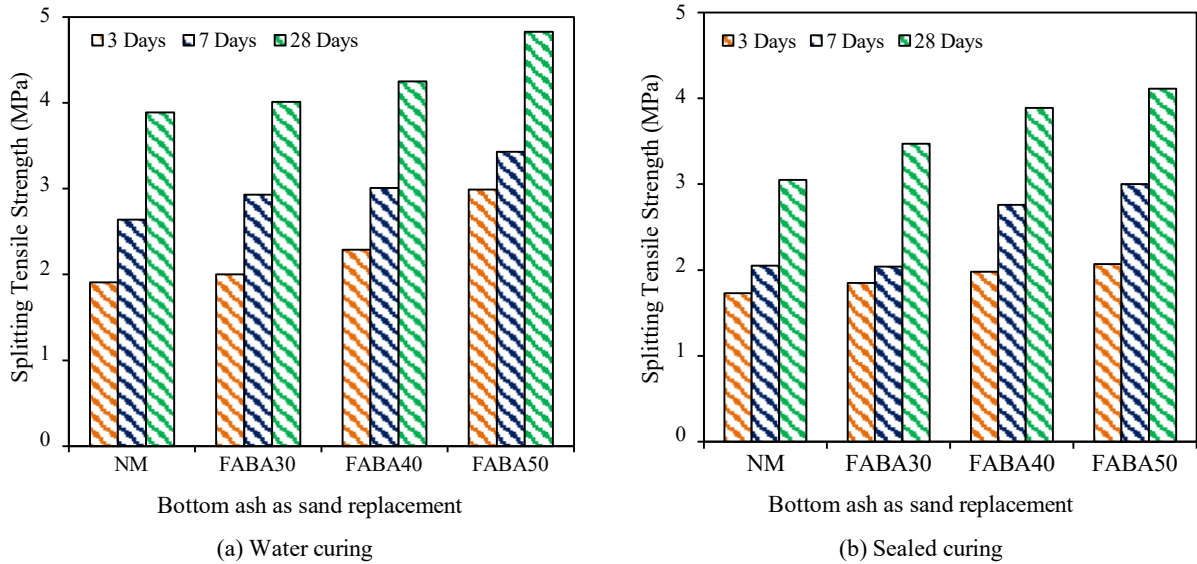


Figure 9. Splitting tensile strength for bottom ash as fine aggregate replacement

3.4. Flexural Strength

At 3, 7, and 28 days after curing, concrete specimens with either water curing or sealed curing were tested for flexural strength. The results of the flexural strength tests conducted using bottom ash in place of cement and fine aggregate are shown in Figures 10 and 11, respectively. There is no way to document the load-displacement connection using the flexural strength test. The tests are designed to measure the maximum load that each specimen of concrete can withstand before bending fails. As the quantity of bottom ash used as a cement replacement increased, the flexural strength declined. The decline in compressive strength of concrete was identical to this. The flexural strength has grown in direct proportion to the quantity of bottom ash added when fine aggregate is replaced with it. Bottom ash has several limits when it comes to its toughened performance when used as a cement alternative. Reduced compressive, splitting tensile, and flexural strengths are indicative of a cement replacement % trend toward bottom ash. Before using bottom ash as a cement alternative, make sure you know how much to use. At the same time, using more bottom ash as a replacement for fine aggregate greatly increased concrete's performance. It is possible to cut sand use by as much as half.

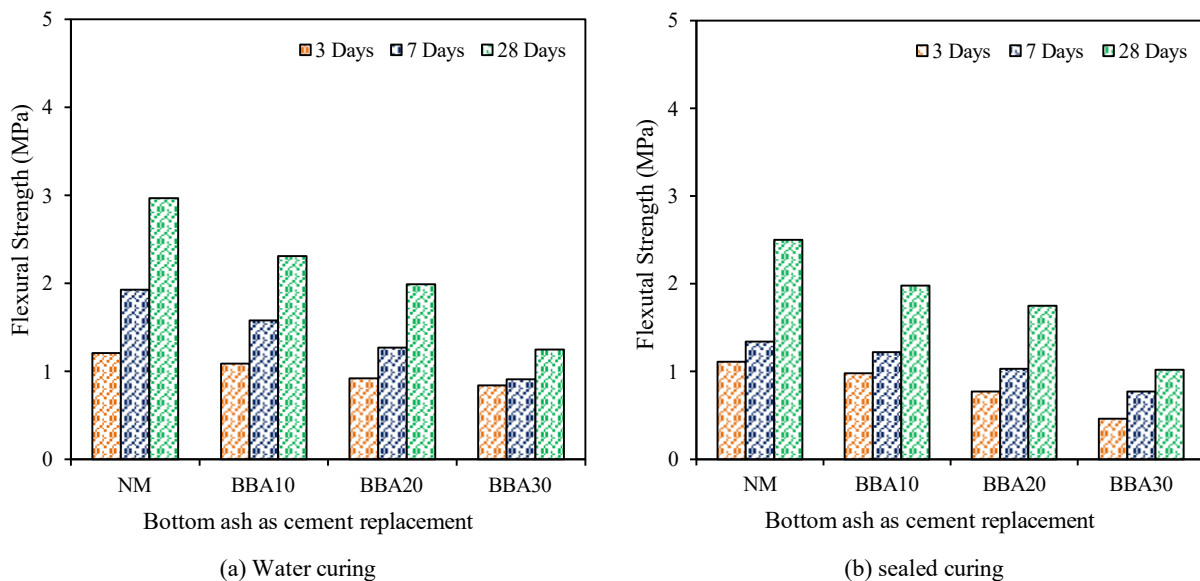


Figure 10. Flexural strength for bottom ash as cement replacement

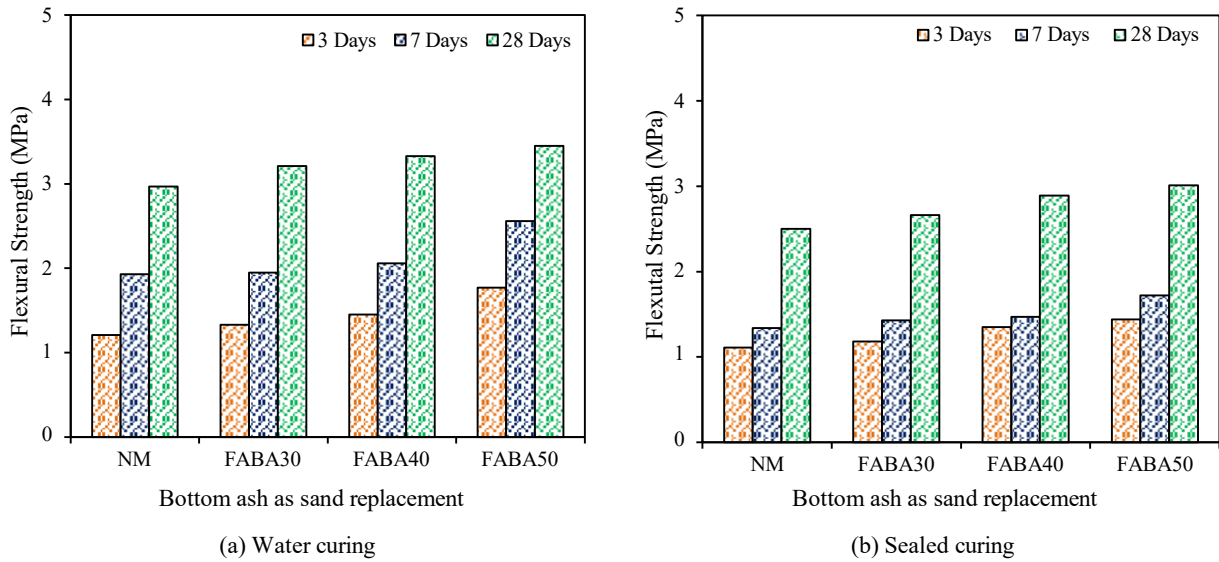


Figure 11. Flexural strength for bottom ash as fine aggregate replacement

Figure 12 shows the comparison of concrete performance between sealed curing and water curing. The results showed that the compressive strength, splitting strength, and flexural strength in water curing were higher than sealed curing. On a laboratory scale, water curing is appropriate because it is disputable and the test object size is smaller, but it is not easy to apply in the field. Meanwhile, by covering the concrete surface, sealed curing is more feasible in the field. Therefore, it is necessary to evaluate concrete performance results by comparing these two types of curing. This research shows that it is necessary to convert 0.9977 from water curing to sealed curing. Water curing produces better performance because, during the hydration process, the concrete is submerged with water. The temperature between outside and inside concrete is almost the same, and there is no significant evaporation during the hardening process. On the other hand, sealed curing of concrete is always in a dry condition so that it allows for a significant temperature difference between outside and inside the test object. Furthermore, sealed curing prevents faster evaporation during the hardening process by wrapping the concrete surface with plastic. In addition, it should be noted that the number of wrap layers in sealed curing also affects the evaporation of concrete with sealed curing.

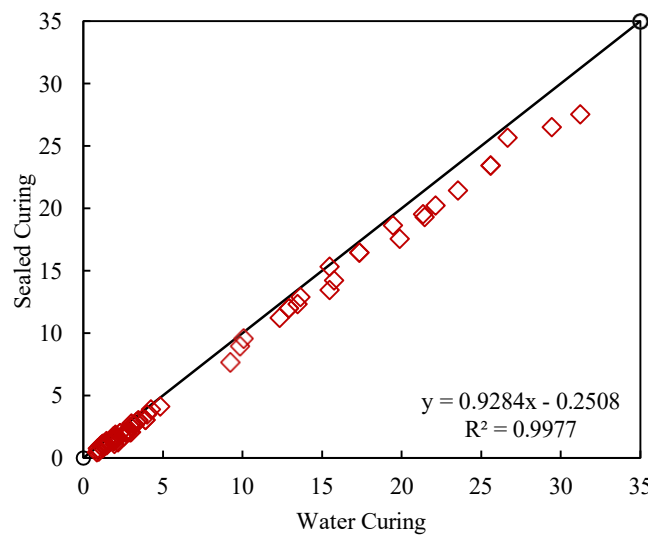


Figure 12. Strength comparison between sealed curing and water curing

3.5. Mass Density

Mass density testing was carried out on each variation, both on the water curing and sealed curing. Figure 13 is the result of mass density for bottom ash as a substitute for cement. It was discovered that as the amount of bottom ash increased in both water and sealed curing, the final mass density dropped. However, the decrease in mass density is not

significant. The decrease in mass density in concrete is due to the lower mass density of bottom ash than cement. Concrete with age of 7 days with water curing in Figure 13a shows that the mass density of concrete has increased compared to concrete with age of 3 days. The increase in mass density is due to increasing the volume of concrete due

to the hydration process where bottom ash produces CaO. Furthermore, the condition that the concrete was still wet during the testing process can increase mass density. Meanwhile, the mass density for sealed curing shows that the concrete with the age of 7 days produces a lower mass density compared to the concrete with the age of 3 days. This is because the hydration process occurs so that the concrete becomes drier than the concrete at three days.

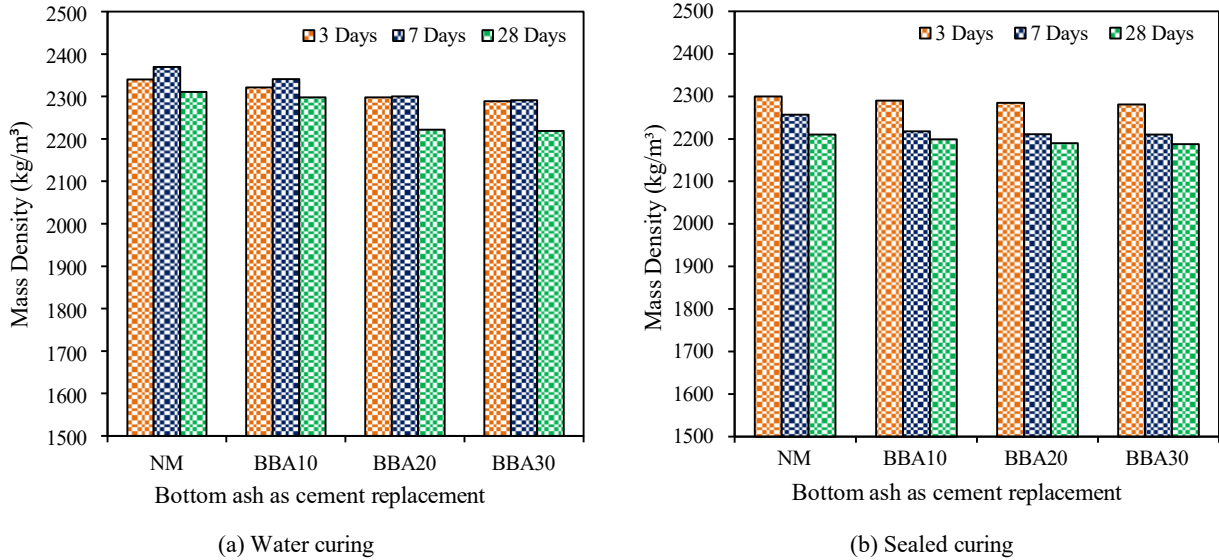


Figure 13. Mass density for bottom ash as cement replacement

Figure 14 shows the results of the mass density inspection for variations using bottom ash as a substitute for fine aggregate. The test results show that the resulting mass density decreases as the amount of bottom ash increases. The decrease in mass density for sand replacement was significantly higher than that of the concrete mixture with bottom ash as a substitute for cement. This significant decrease in mass density occurred due to the larger amount of bottom ash used in this series, as shown in Table 2. The lower mass density of bottom ash compared to sand causes the use of bottom ash as a substitute for sand to reduce the mass density of concrete. These results indicate that using bottom ash as a substitute for fine aggregate can produce lightweight concrete and higher compressive strength than normal concrete without bottom ash.

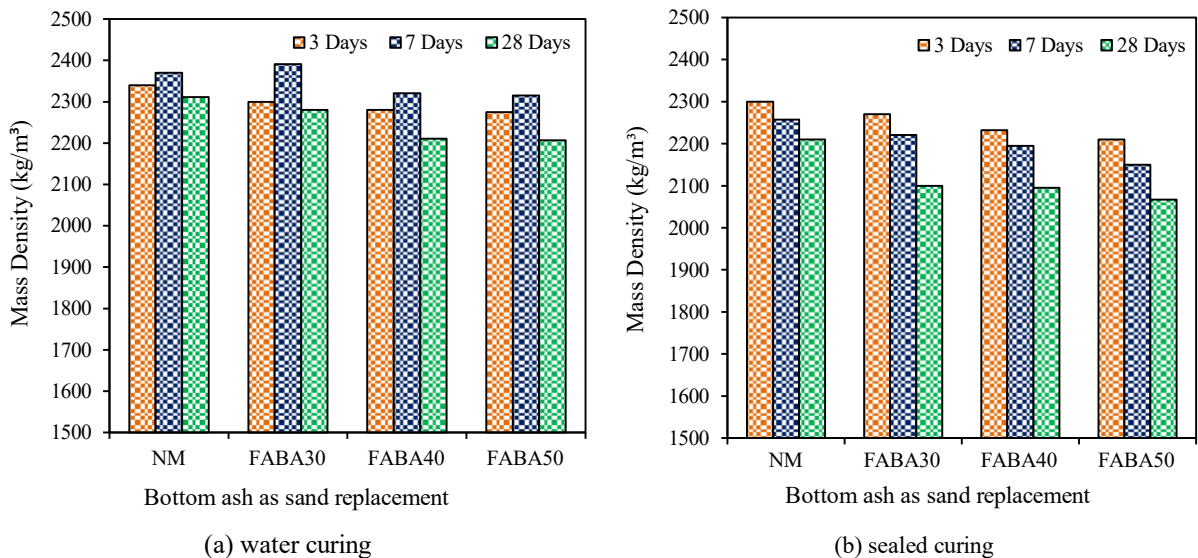


Figure 14. Mass density for bottom ash as fine aggregate replacement

4. Conclusions

The experimental findings show that using bottom ash instead of cement and fine aggregate allows us to draw various conclusions: Bypassing cement in favor of bottom ash lowers concrete's

performance in compressive, split tensile, and flexural strengths. Because of this drop in performance, the quantity of bottom ash that may be used as a cement replacement is limited.

Testing for compressive strength, flexural strength, and split tensile strength shows that performance improves as the quantity of bottom ash used to substitute fine aggregate increases. The performance of freshly mixed concrete declines with increasing amounts of bottom ash, as shown by all versions of the mixture including this material. If you want your freshly mixed concrete to be stable and workable, you need to think about the kind of superplasticizer you apply. Based on the mass density data, using bottom ash in place of fine aggregate produces concrete that is both lighter and more performant than regular concrete. This makes it an ideal material for this use, particularly in places that are vulnerable to earthquakes.

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