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Optimizing Coal Ash as a Sustainable Substitute of Cement and Aggregate in Structural Concrete

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ABSTRACT

The manufacture of concrete for constructing the structures like highways, bridges, and buildings requires large amounts of cement and aggregates. This high concrete production depletes natural resources like sand and gravel for the construction industry. It also negatively impacts the environment due to cement usage. This study looked at using waste materials like coal bottom ash (CBA) and fly ash (FA) in concrete as substitutes for some of the typical aggregates and cement. The goal was to reduce the environmental impact and preserve natural resources. The study made concrete with regular Portland cement, sand, 10mm coarse aggregate, locally available CBA, and FA. 15% fly ash was selected as an optimal level from initial testing. The CBA was used to replace 0-35% of the fine aggregate sand. Test cubes and cylinders were made with different mixes. Compressive strength, tensile strength, carbonation, and sulfate attack tests were done after curing. Results showed 25% CBA improved the concrete's mechanical performance. The compressive and tensile strengths increased but not above conventional concrete. This is because CBA needs more moisture for full hydration over longer curing times. Also, the concrete's durability improved in terms of resistance to carbonation and sulfate attack.

Keywords: Mechanical properties; Fly Ash (FA); durability properties; Coal Bottom Ash (CBA)

INTRODUCTION

Concrete is widely used in construction material in today's era due to its ease of use, good performance, and long lifespan. It's even called an artificial rock because of its durability in extreme weather. However, the high demand for concrete is depleting natural resources like sand and gravel. Studies show the major issues are the large amounts of industrial waste and environmental pollution from concrete production. This points to the need for more sustainable solutions. The key is improving resource efficiency by decreasing energy and material usage. Considering industrial wastes like coal bottom ash, fly ash, silica fume and waste glass in concrete could be a possible

SPLIT TENSILE STRENGTH

Figure 4 shows the split tensile strengths after 7- and 28-day curing, for both saturated surface dry (SSD) and oven-dried conditions. The results showed decreasing tensile strength with higher CBA levels. The 20% and 25% CBA mixes had 3.1% and 2.7% lower tensile strength versus the control concrete.

Singh and Siddique found 25% CBA had the best tensile strength (Singh & Siddique 2015), though it declined steadily beyond 28 days. The lower density and more porous structure of CBA particles is believed to cause internal cracks under load, reducing tensile strength. Further testing is needed to better understand the impacts of CBA on concrete tensile performance.

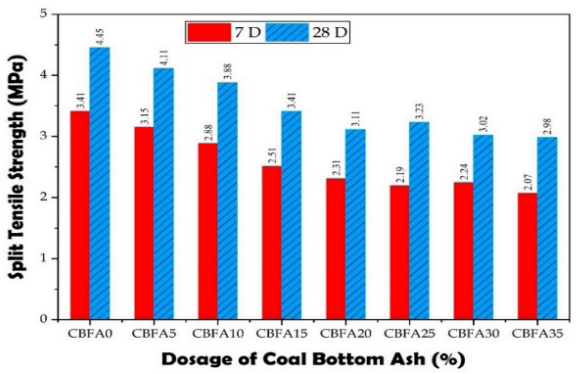

FIGURE 3. Details of compressive strength of different mixes

The test results showed a significant decrease in splitting tensile strength as CBA content increased. Compared to the control concrete, the mixes with 20% and 25% CBA had 3.1% and 2.7% lower tensile strengths respectively, as CBA increased from 0% to 35%. This reduction in tensile performance with higher CBA levels may be attributed to the lower density and more porous structure of CBA particles versus natural sand. Further testing is required to better understand the impact of coal bottom ash on the tensile properties of concrete.

CORROSION ANALYSIS

It is known that chloride ingress causes corrosion of steel reinforcement, negatively impacting reinforced concrete structures. The findings here and in other studies (Al-Saadoun & Al-Gahtani, 1992; Berke, 1989; Khedr & Idriss, 1995; S.-C. Kou & Poon, 2009; Singh & Siddique, 2014) show that adding fly ash (FA) and coal bottom ash (CBA) enhances resistance to chloride penetration in concrete. Figure 5 illustrates that increasing CBA dosage improved chloride resistance. The control mix with 15% FA and 0% CBA had -290 mV, while the mix with 15% FA and 35% CBA measured -197 mV. This clearly demonstrates the beneficial effect of FA and CBA on concrete's corrosion protection.

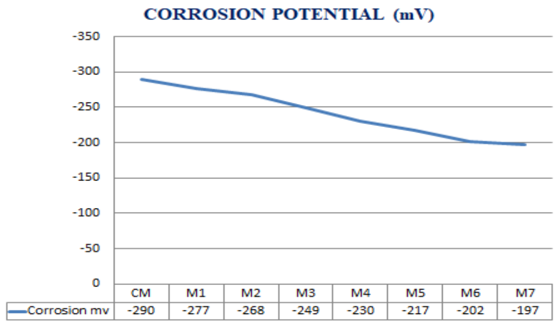

FIGURE 4. depiction of corrosion potential

As explained by Singh and Siddique (Singh & Siddique, 2014), CBA is more resistant to chloride ingress than regular aggregates. Other researchers like (Yazıcı, 2008), (S. C. Kou & Poon, 2009), and Detwiler (Detwiler et al. 1994) also found FA and CBA boost chloride resistance in concrete. The industrial byproducts outperform standard concrete and enhance durability against chloride exposure.

SULPHATE ATTACK

Table 2 shows the sulfate attack results. Resistance improved with higher CBA percentages. The samples were immersed in Na2SO4 solution and length change measured. The control mix had 0.56% expansion, while the 35% CBA mix only expanded 0.18% after sulfate exposure.

Other studies confirm these findings Mangi et al (Mangi et al. 2019) found CBA reduces the effects of sulfates in concrete. Moreover, they showed optimum silica fume dosage (5-15%) as cement replacement boosted concrete's sulfate resistance. Ghafoori and Cai (Ghafoori & Cai, 1998b, 1998a) demonstrated the benefits of bottom ash against sulfate attack. The collective results clearly show fly ash and bottom ash enhance concrete durability against detrimental sulfate exposure.

TABLE 2. Details of the sulphate attack results immersed in Sodium sulphate solution at 28-days

Mix	%	Initial Length (mm)	Final Length (mm)	% Increment
Control Mix	CM0%	286.2 ± 0.03	287.1± 0.04	0.55
Mix 1	FC5	284.8 ± 0.02	285.1± 0.04	0.41
Mix 2	FC10	284.7 ± 0.01	286.2± 0.04	0.34
Mix 3	FC15	286.1 ± 0.05	285.9± 0.04	0.33
Mix 4	FC20	284.1 ± 0.05	285.9 ± 0.04	0.29
Mix 5	FC25	284.6 ± 0.03	285.9 ± 0.04	0.24
Mix 6	FC30	286.4 ± 0.01	287.1 ± 0.04	0.22
Mix 7	FC35	286.7 ± 0.02	285.9 ± 0.04	0.17

CONCLUSION

This study examined the effects of coal bottom ash (CBA) and fly ash (FA) on the mechanical and durability properties of concrete. Based on the results following conclusions could be drawn from the current study:

1. This study used an optimal 15% fly ash dosage combined with 0-35% coal bottom ash (CBA) as fine aggregate substitution. Cylinder and cubes were tested after 7 and 28 days of water curing.
2. The results revealed that the decreasing compressive and tensile strengths with higher CBA content, with maximum reductions of 12.8% and 33% respectively at 28 days versus control concrete. This is attributed to the porous CBA particles causing internal cracks under load.
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In summary, coal combustion products enhance durability but can reduce strength if curing is insufficient. Adequate hydration time allows strength development by densifying the porous CBA microstructure. Optimizing curing and fly ash and CBA levels is key to maximizing strength, durability, and sustainability.

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DECLARATION OF COMPETING INTEREST

None.

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