Coal Bottom Ash as A Partial Replacement with Fine Aggregate in Concrete

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1 ABSTRACT

This study examines the use of coal bottom ash as a fine aggregate replacement in concrete to make use of thermal power plant waste. The primary source of coal ash generation is from coal-fired thermal power facilities. Coal bottom ash (CBA) is the coal ash that has accumulated at the furnace's bottom. Exploring the potential for using coal bottom ash as a partial replacement for fine aggregate in concrete was the goal of the current research project. The characteristics of freshly-poured and hardened concrete that contains coal bottom ash were evaluated through experimental experiments. Bottom ash was substituted for fine aggregate in experiments to varied degrees (20%, 40%, and 60%, respectively).

The findings demonstrated that a higher bottom ash content results in a decrease in workability and plastic density and an increase in bleeding. Compressive strength also dramatically declined above 40% replacement of bottom ash. According to the research's test results, using coal bottom ash as a substitute for fine aggregate in concrete decreased workability and water loss from bleeding at a set water-to-cement ratio. Concrete made from bottom ash and curing for 7 and 28 days. Thus, for that particular percentage replacement, concrete can employ bottom ash from the thermal power plant in place of fine aggregate.

2 INTRODUCTION

Particles of coal bottom ash range from fine sand to fine gravel. Coal bottom ash is composed of mainly silica, alumina and iron with small amounts of calcium, magnesium sulphate, etc. The appearance and particle size distribution of coal bottom ash is similar to that of river sand. These properties of coal bottom ash make it attractive to be used as fine aggregate in the production of concrete. Previous studies have also reported promising results on the use of coal bottom ash in the partial replacement of Fine aggregate in concrete.

Coal bottom ash is a by-product of the combustion of pulverized coal. In India, coal-fired thermal power plants are the backbone of the power supply system fulfilling about 65% of the country's electricity requirements. The coal-fired thermal power plants burn about 407 million tons of coal for the generation of power and produce about 131 million tons of coal ash annually. Coal bottom ash removed from the furnace bed accounts for about 20% and is sluiced to the water tank and then pumped out in suspension into lagoons spread over thousand acres of land where the same settles down, decantation takes place and ash dries up. The stock-piled mounds of coal bottom ash on open land pose health hazards to the surrounding environment. Indian coal bottom ash has not been scientifically investigated and as such not been utilized in any form. Appreciating the environmental problems posed by the traditional method of disposal of coal bottom ash, scientific investigation to explore its possible uses is the need of the hour. The investigations specifically focused on the pozzolanic properties of coal bottom ash indicating that coal bottom ash has low pozzolanic properties. it is suitable for use in concrete.

According to the American Coal Ash Association (2006) statistics on bottom ash usage, just over 45 per cent of all bottom ash produced is used, mainly in transportation applications such as structural fill, road base material, and as snow and ice control products. Bottom ash is also used as aggregate in lightweight concrete masonry units and raw feed material for the production of Portland cement (ACAA, 2011). Using coal combustion products (CCPs) in an environmentally safe manner saves virgin resources, and reduces energy consumption and greenhouse gas emissions (GHG). In addition, it helps reduce the need for landfill space and new landfills. Using CCPs also makes good economic sense; they are often less costly than the materials they replace (American Coal Ash Association Educational Foundation, Bottom ash can be introduced as an aggregate, as a partial natural sand replacement, according to the grain size distribution of the material for utilization in structural concrete. Singh and Siddique also reported that coal bottom ash is the potentially viable Material to be used as fine aggregate in the production of concrete. The previous studies in which coal bottom ash has been targeted as a substitute for sand in the production of concrete demonstrate that the strength development pattern of coal bottom ash concrete is similar to that of conventional concrete. The research work carried out by Kim and Lee indicates that the compressive strength of concrete mixtures made with coal bottom ash as a substitute for sand was not strongly affected. However, the flexural strength and modulus of elasticity of concrete decreased with the increase in the content of coal bottom ash. Ghafoori and Bucholc observed that at the early curing age, the mean compressive strength of bottom ash concrete was lower than that of control concrete. With increased curing age, bottom ash concrete achieved compressive strength almost near to that of control concrete. On use, the compressive strength of bottom ash concrete at the age of 28 days improved by 3.5% over that of control concrete. In the case of mixtures with 600 lb. of cement or higher, the splitting tensile strength of concrete containing coal bottom ash exceeded that of control concrete. Andrade et al. concluded that the water loss by bleeding and the bleeding time increased with the increase in coal bottom ash content in concrete. Bottom ash concrete showed a higher water loss from air drying due to better connectivity of capillary pores and exhibited greater dimensional stability compared to conventional concrete. Bai et al. investigated that at fixed water-cement ratio, slump increased with the increase in coal bottom ash content but the compressive strength of bottom ash concrete decreased. In the case of a fixed slump, the requirement of water decreased with an increase in bottom ash content and the compressive strength of bottom ash concrete at all the replacement levels was comparable with that of control concrete.

The present research work aimed to ascertain the suitability of Indian coal bottom ash as a partial or full replacement of river sand in concrete. The characterization of materials used in this research work was done by evaluating their chemical and physical properties such as chemical constituents, particle size distribution, specific gravity, and fineness modulus. The strength properties of bottom ash concrete such as compressive strength, splitting tensile strength, modulus of elasticity and microstructure were compared with that of conventional concrete. The durability properties of bottom ash concrete would be investigated in future research.

Coal bottom ash is a by-product of coal combustion that is typically disposed of in landfills. It is a pozzolanic material, which means that it can react with calcium hydroxide in cement to form additional cementitious compounds. This can improve the strength and durability of concrete. Fine aggregate is the smallest aggregate used in concrete. It is responsible for filling the voids between the larger aggregates and providing a smooth surface for the cement paste to adhere to. Coal bottom ash can be used as a partial replacement for fine aggregate without significantly affecting the workability or strength of the concrete. The amount of coal bottom ash that can be used to replace fine aggregate without adversely affecting the properties of the concrete depends on a number of factors, including the type of coal bottom ash, the fine aggregate, and the mix design. In general, it is recommended to limit the replacement level to 20-30%.

- The use of coal bottom ash as a partial replacement for fine aggregate can provide a number of benefits, including: -

Reduced environmental impact: The disposal of coal bottom ash in landfills can pollute the environment. By using coal bottom ash in concrete, we can reduce the amount of waste that is sent to landfills

Reduced cost: Coal bottom ash is a relatively inexpensive material. Using coal bottom ash in concrete can help to reduce the cost of construction.

Improved sustainability: The use of coal bottom ash in concrete can help to make concrete more sustainable. Concrete is a major contributor to greenhouse gas emissions. By using coal bottom ash in concrete, we can reduce the environmental impact of concrete production.

Overall, the use of coal bottom ash as a partial replacement for fine aggregate is a viable option for sustainable concrete production. It can provide a number of benefits, including reduced environmental impact, reduced cost, and improved sustainability.

2.1 Objectives: -

1. To evaluate the properties of materials for concrete mix design.
2. To carry out concrete mix design for M-25 grade of concrete.
3. To analyze the effect of partial replacement of fine aggregate by coal bottom ash on workability and compressive strength of mix design.
4. To compare the results with nominal mix

3 LITERATURE REVIEW

1. Malkit Singh, Rafat, Saddique (Ph.D.) Karim Ait-Mokhtar (Ph.D.), And Rafik

Be Larbi (Ph.D.). Durability properties of concrete made with high volumes of low calcium coal bottom ash as a replacement of two types of sand.

- The result showed that at 7 days, the compressive strength of concrete decreased on inclusion of CBA as replacement sand. With age, rate of compressive strength gain of bottom ash concrete mixtures was more than that of control concrete. At 28 days, compressive strength of concrete mixtures incorporating up to 50% CBA for Concrete B and up to 100% CBA for Concrete A was comparable with that of respective control concrete. After 90 days, for both grades of Concretes A and B, compressive strength of bottom ash concrete mixtures were either approximately equal to or more than that of control concrete. For both grades of Concretes, A and B, initial sportively of bottom ash concrete mixtures increased with increase in CBA content. However, the secondary sportively was identical for all bottom ash concrete mixtures as well as control concrete. Cumulative capillary absorption of water was higher for bottom ash concrete mixtures than that of control concrete. Cumulative capillary absorption of water of bottom ash concrete mixtures increased almost linearly with increase in quantity of CBA.

2. E. Menéndez, A.M. Álvaro, M.T. Hernández, J.L. Parra. New methodology for assessing the environmental burden of cement mortars with partial replacement of coal bottom ash and fly ash.

- The environmental evaluation of mortars made with cements with partial FA

or BA replacements allows testing their potential behaviour in water environments with different pH values and ambient or higher temperatures to be tested. The temperature is a determinant parameter as regards the leaching of compounds into the environment. In all cases, independent of the chemical compound analysed, greater leaching is produced when the test temperature is higher. As a test parameter, pH shows more random behaviour than temperature. However, in general, greater leaching is produced when the test is carried out with an acid pH, except in the case of strontium which experiences greater leaching with a higher ph. The integral assessment of the EB value and the mechanical behaviour classify cement mortars mixtures in four groups, allowing the optimal selection of them depending of the objective parameters.

- In general, the integral assessment realized of the mechanical and environmental behaviour of the cement mortars mixture shows a better behaviour of the mortars manufactured with BA than those with FA. Specifically, the cement mortar without additions and the cement mortar mixtures with partial replacement of 10% and 25% of BA and 10% of FA had the best integral behaviour.

3. Yogesh Aggarwal, Rafat Siddique. Microstructure and properties of concrete using bottom ash and waste foundry sand as partial replacement of fine aggregates.

- As, it was observed that for initial replacements of 10%, 20% and 30%, the increase in water content was constant and thereafter for 40% and 50%, again it remained constant but almost double the value of initial replacements. The mixes can be developed by varying the water content at constant rate as specified in the study till 30% and thereafter till 50% replacement of fine aggregates. The mix FB60 is not recommended as the water content of this mix is high which also reflects on various strengths.

The mechanical behaviour of the concrete with waste foundry sand and bottom ash showed strengths comparable to that of conventional concrete except for FB60 mix, at the age of 365 days. Furthermore, it was observed that the greatest increase in compressive, splitting tensile strength and flexural strength was achieved by substituting30% of the natural fine aggregate with industrial by-product aggregate in replaced mixes. Also, the maximum replacement could be taken as 50%.

- The splitting tensile strength for FB30 mix was observed to be more than the control mix at all ages. An increase in strength from 28 to 90 days was observed to be 13.29% for CM mix whereas FB mixes showed increase in strength from 14.52% to 23.89%. Between 90 and 365 days, an increase in strength for CM mix was 6.76% and the FB mixes showed an increase of 2.02–6.94%.
- The inclusion of waste foundry sand and bottom ash as fine aggregate does not affect the strength properties negatively as the strength remains within limits. The concrete was endowed with comparable mechanical properties and greater resistance to aggressive agents (chemical, physical and environmental).

4. M. Brinda et al (2016). The durability of cement mortar replaced with bottom ash and green sand as a fine aggregate

- In this investigation, a high water to cement weight ratio was used to conduct the experiment, with a Superplastizers 2.5% weight ratio of water to cement. Bottom ash fine aggregates that pass through a 4.75mm screen are used in the experiment, along with natural sand that is the same size as the aggregate. According to the study, the weight ratio of cement to aggregate should be 1:3, and the amount of bottom ash and green sand should be adjusted.

5. T. Balasubramanian et al (2015). Mechanical properties of bottom ash concrete

- The investigations were conducted for the possibility of using bottom ash as partial replacement (10% - 50%) of manufactured sand (M-Sand) in concrete. Mechanical properties, such as compressive strength, split tensile strength, flexural strength, and modulus of elasticity of M60 concrete (Grade of mix 60N/mm2) were evaluated. The result showed that use of bottom ash improves the strength of concrete at later ages.

6. Ahmad Farhan Hamzah et al (2015). The development of fresh characteristics and mechanical compressive strength of self-compacting concrete including coal bottom ash as a partial fine aggregate replacement.

- The effect of using coal bottom ash as a partial substitute for fine aggregates in self-compacting concrete (SCC). Instead of the fresh characteristic of blends, the compressive strength qualities were explored. Three different water cement ratios (0.35, 0.40, and 0.45) and coal bottom ash as a substitute of fine aggregates in varied percentages of 0%, 10%, 15%, 20%, 25%, and 30% were used to create the SCC combinations.

4 METHODOLOGY

The bottom ash used was collected from Nashik Thermal Power Plant located at Eklahare village near Nashik in Maharashtra. The power plant is one of the coal-based power plants of Maharashtra State Power Generation Company (Mahagenco). The bottom ash was in an oven-dry state before batching the concrete mixes.

The Portland cement used was OPC 53. The experimental study deals with investigating four different mixes compared to a control mix. The labels and descriptions of the mixes are given in table 4.1. To determine the effect of bottom ash on concrete, 0%, 20%, 40%, and 60% fine aggregate replacement by weight with bottom ash.

The bottom ash-based concrete produced in this study is given in table below along with their descriptions.The coal bottom ash was screened to remove the oversized particles and the material passing through a 4.75 mm sieve was used in the manufacturing of concrete. The chemical and physical properties of coal bottom ash used in this research are given in Tables 1 and 2 respectively. The chemical analysis shows that coal bottom ash is mainly composed of silica and alumina.it is observed that the coal bottom ash has largely angular-shaped particles with a small fraction of spherical particles. The particles having a complicated shape and surface texture were also observed in the coal bottom ash. The popcorn-type particles of coal bottom ash can easily degrade under compaction.

Table 4-1

Concrete label	Description
BA 0	Normal concrete with no bottom ash replacement
BA20	Bottom ash-based concrete including 20% by mass replacement of fine aggregate
BA40	Bottom ash-based concrete including 40% by mass replacement of fine aggregate
BA60	Bottom ash-based concrete including 60% by mass replacement of fine aggregate

4.1 Bottom Ash: -

The coal fired thermal power plants are the main source of production of coal ash. The coal ash collected at the bottom of the furnace is called coal bottom ash (CBA). Screening was carried out on the bottom ash sample obtained from the thermal power station to remove the coarse particles. The sample was therefore sieved manually using the 4.75mm sieve and only the particles passing through the 4.75mm sieve were retained for use in the research. The dry sieving method prescribed as per IS code 383:2016 was adopted during the whole process. Since the main aim of this study was to investigate the substitution of fine aggregates with bottom ash in concrete, it was necessary to meet the grading size of the fine aggregates. Figure 4.1 summarizes the procedure discussed above

4.2 Preliminary Investigations: -

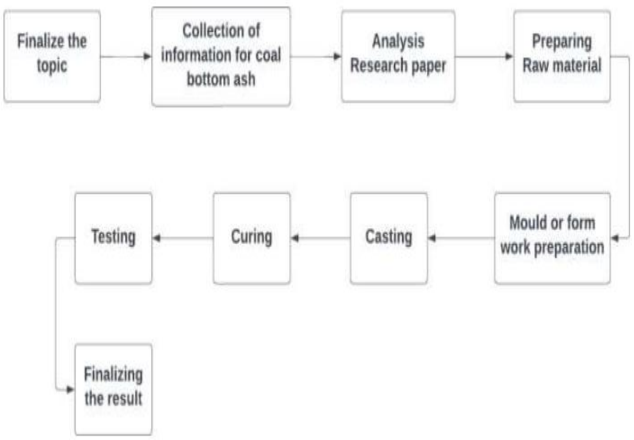
In the first place, the bottom ash and the aggregates were analysed in order to obtain data to devise the mixture proportions from the relevant mix design. Since bottom ash is a relatively new material employed in civil engineering applications, there are no such standards for testing. Therefore, the Indian Standards that were used to carry out the preliminary test on both the fine and coarse aggregates were adopted for the bottom ash as well. The sampling of the materials during the whole project was carried out by the quartering method as described in IS 456

4.3 Treatment of CBA: -

In order to utilize CBA as aggregate in concrete mixtures, there is a need for the CBA to undergo some form of treatment or the treatments applied to the concrete incorporating the raw CBA. Raw CBA is normally inappropriate to be used as concrete materials due to their physical characteristics that reduce the mechanical properties in concrete mixtures. Treatment processes which could be in terms of the addition of chemical additives or processing physically can be carried out to improve the properties of the CBA and the corresponding concrete. The chemical treatment includes inserting alkali-activators and other chemical additives into concrete mixtures to enhance the pozzolanic reaction of CBA. While, the physical treatment includes grinding, sieving, soaking, and burning of the CBA before incorporation as fine aggregate in concrete mixtures. Chemical and Physical treatments affect CBA in various ways; consequently, numerous researchers use both procedures of treatment to achieve desired properties. Sieving is commonly conducted together with grinding as a process to maximize fineness. Saturation and burning of CBA are usually utilized procedures to eliminate contaminations from CBA, such as water-soluble chlorides and unburnt carbon. The existence of chloride ions on the CBA particles when utilized in concrete mixtures could result in corrosion of the steel reinforcements in concrete.

Table 4-2: - Mix Calculation

mixture	cement (kg/m3)	w/c ratio	fine aggregate (kg/m3)	bottom ash (kg/m3)	coarse aggregate (kg/m3)	water (kg/m3)
BA 0	394.32	0.5	653.87	0	1059.05	**197.16**
BA 20	394.32	0.5	523.1	130.77	1059.05	**197.16**
BA 40	394.32	0.5	392.32	261.55	1059.05	**197.16**
BA 60	394.32	0.5	261.55	392.32	1059.05	**197.16**



5 RESULT & DISCUSSION

5.1 Workability: -

The workability of concrete mixtures was measured by performing a slump test. A fixed quantity of water was added to all the concrete mixtures. The test results show that slump values of bottom ash concrete mixtures decreased with the increase in levels of sand replacement by coal bottom ash. A similar trend was witnessed in a compaction test where compaction factor values decreased with the increase in the content of coal bottom ash in the concrete mixtures. The water absorption of coal bottom ash is higher than that of river sand. Therefore, during the mixing process, the porous particles of coal bottom ash rapidly absorbed more water internally than that of natural river sand particles and the availability of free water for the lubrication of particles was reduced. Moreover, the substitution of fine aggregate with coal bottom ash resulted in an increase in the specific surface area of fine aggregate in concrete.

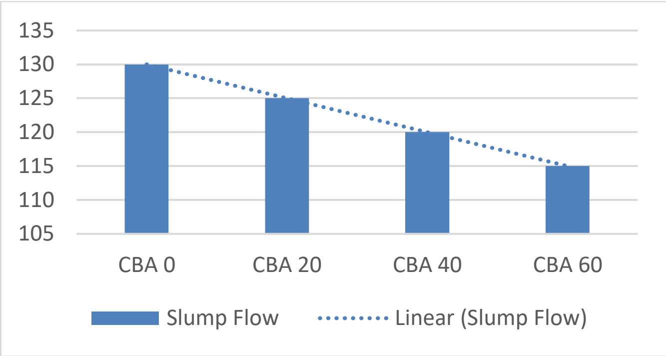


Figure 5.1: - Slump Flow

5.2 Compressive strength: -

The compressive strength of each mix was determined at 7, and 28 days of curing according to IS 10262:2019. The average compressive strengths of the 150mm x 150mm x 150mm cubes for each mix. The compressive strengths of concrete mixes containing bottom ash are lower than the control mix at all tested days. The concrete mixes containing bottom ash showed good strength development pattern with increasing age. Moreover, the 7-day strength of all the mixes reached two-third of the 28-day compressive strength.

The compressive strength of the concrete cube test provides an idea about all the characteristics of concrete. By this single test one judge that whether Concreting has been done properly or not. Concrete compressive strength for general construction varies from 15 MPa (2200 psi) to 30 MPa (4400 psi) and higher in commercial and industrial structures. Compressive strength of concrete depends on many factors such as water-cement ratio, cement strength, quality of concrete material, quality control during the production of concrete, etc. Test for compressive strength is carried out either on a cube or cylinder. Various standard codes recommend a concrete cylinder or concrete cube as the standard specimen for the test. American society for testing

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materials astm c39/c39m provides standard test method for compressive strength of cylindrical concrete specimens.

Compressive strength formula for any material is the load applied at the point of failure to the cross-section area of the face on which load was applied.

Compressive Strength = Load / Cross-sectional Area

Table 5-1: - Average Compressive strength result on 7 Day.

Mix Type	Average Weight (kg)	Average Compressive strength (N/mm^2)
BA 0	8.446	16.67
BA 20	8.238	16.22
BA 40	8.126	14.81
BA 60	7.814	11.63

Table 5-2 :- Average Compressive strength result on 28 Day

Mix Type	Average Weight (kg)	Average Compressive strength (N/mm^2)
BA 0	8.484	26.52
BA 20	8.308	25.77
BA 40	8.005	22.82
BA 60	7.800	19.70

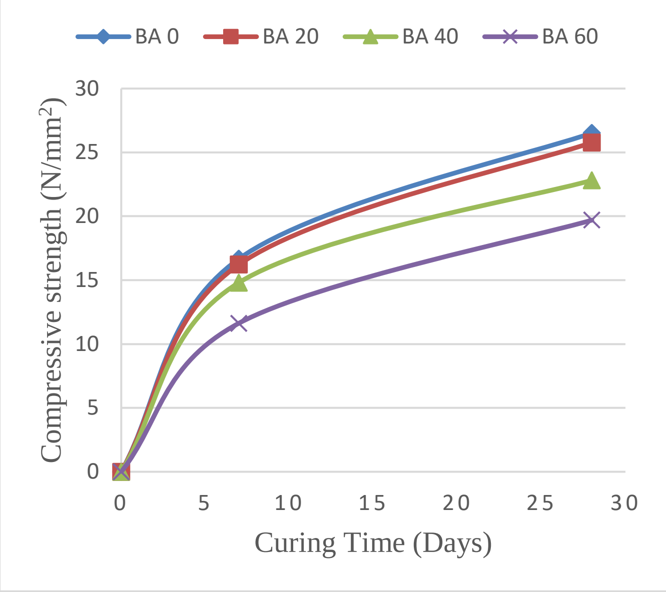

Figure 5.2 :- Compressive Strength with Bottom Ash Content

In addition, BA20 recorded the highest compressive strength at 28 days. The 28-day compressive strength of BA60 mixes was significantly reduced as compared to that of the other mixes.

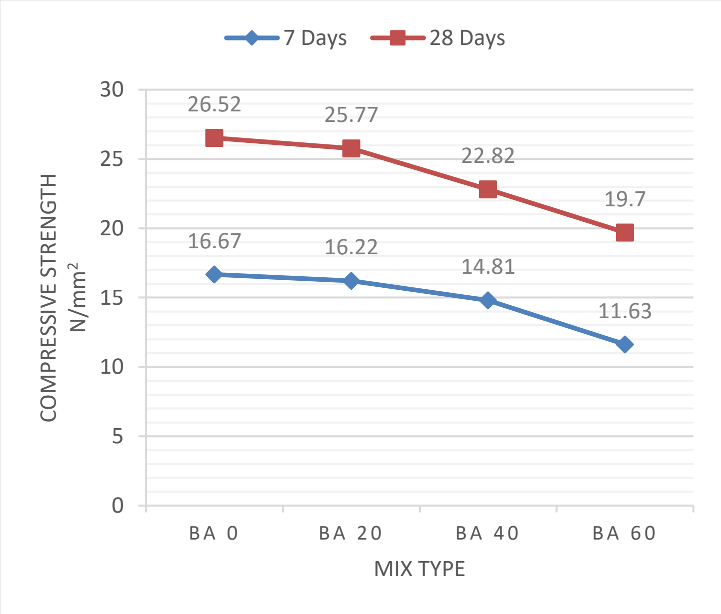

Figure 5.3 :- Relation between compressive strength and percentage of bottom ash replacement

the bottom ash concrete gains strength at a lower rate than the control mix. As the replacement level of bottom ash is increased, the gain in compressive strength decreased further. The decrease in compressive strength observed is due to the physical nature of the ash particles. Due to the porous surface structure and high absorptivity nature of the material, hydration of all cement particles may not have occurred, such that less paste is available for bonding. In addition, as water penetrates through the bottom ash, the expulsion of air bubbles may cause voids between the interface of the cement paste and the coarse aggregates resulting in lower bond strength.

6 CONCLUSION

1) In a nominal mix design, standard proportions of materials (cement, fine aggregate, coarse aggregate, and water) are used based on experience and general guidelines. The specific properties of the materials used in the nominal mix design may vary depending on local availability and standards.

2) Concrete mix design for M25 grade concrete is a systematic procedure that involves determining the right amounts of cement, fine aggregate, coarse aggregate, water-cement ratio, and admixtures. M25 grade concrete has a characteristic compressive strength of 25 MPa. The water-cement ratio is determined by variables such as exposure circumstances, curing procedures, and material availability. It has a considerable impact on the strength and durability of the concrete. To calculate the cement content, multiply the water-cement ratio by the weight of water per unit volume of concrete. The volume of fine and coarse aggregates is determined using the absolute volume method or by taking into account the aggregates' specific gravity and bulk density. The final mix proportions by weight or volume are derived using the cement.

3) A slump test was used to determine the workability of the concrete mixture. The test findings reveal that the slump values of bottom ash concrete mixtures reduced as the level of sand substitution by coal bottom ash increased. Coal bottom ash has a higher water absorption rate than fine aggregate. Each mix's compressive strength was tested after 7, 14, and 28 days of curing. Bottom ash concrete builds strength more slowly than the control mix. Compressive strength at 28 days is nearly twice that of 7 days. The compressive strength decreases as the proportion of CBA in the concrete mixture increases.

4) A nominal mix design typically relies on standard proportions of materials, where the properties of the materials used may vary based on local availability and standards. Nominal mix get good result as compare to the result with mix proportion of coal bottom ash. There is reducing values of workability and compressive strength with increase in proportion of CBA in concrete mix design.

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