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FEASIBILITY OF MAKING CONCRETE USING LIGNITE COAL BOTTOM ASH AS FINE AGGREGATE

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Concrete is generally produced using materials such as crushed stone and river sand to the extent of about 80-90% combined with cement and water. These materials are quarried from natural sources. Their depletion will cause strain on the environment. To prevent this, bottom ash produced at thermal power plants by burning of coal has been utilized in this investigation into making concrete. The experimental investigation presents the development of concrete containing lignite coal bottom ash as fine aggregate in various percentages of 25, 50, and 100. Compressive, split tensile, and flexural strength as part of mechanical properties; acid, sulphate attack, and sustainability under elevated temperature as part of durability properties, were determined. These properties were compared with that of normal concrete. It was concluded from this investigation that bottom ash to an extent of 25% can be substituted in place of river sand in the production of concrete.

Keywords: Concrete, Bottom Ash, Fine Aggregate, Strength, Durability

1. INTRODUCTION

One million housing units are required annually at present in India to provide accommodation to its homeless people. Concrete is a popular material in the construction of these housing units because it is cheap, durable and it can be produced using locally available materials such as crushed stone, sand, and water. According to an estimate, Indian Construction Industry is currently consuming about 400 million tons of concrete every year and this quantity may likely to reach billion tons in a decade.

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It is well known that all the materials required to produce such a huge quantity of concrete come from the earth's crust. Therefore the natural resources are depleted gradually, thus creating ecological strains. Among different wastes that are worth recycling as useful building materials are solid wastes. The most prominent among them are bottom ash, fly ash, blast furnace slag, rice husk ash, silica fume and others from construction demolition [1].

Physically, bottom ash is typically grey to black in colour and is quite angular [2]. Bottom ash is coarse, with grain sizes spanning from fine sand to fine gravel. It is similar to natural sand. It is clear from published literature that there is a strong possibility of coal bottom ash being used as substitute/replacement of the conventional fine aggregate, i.e., river sand. Its use in concrete becomes more significant in view of the fact that sources of natural sand are getting depleted gradually [3]. Hence, it is inevitable that substitute for sand has to be explored [4].

According to Bai [5], bottom ash is fit to be used as a replacement for sand as fine aggregate and is usually sufficiently well-graded in size to avoid the need for blending with other fine aggregates to meet the requirements of gradation. The Research Institute of The College of Judea and Samaria, Ariel, Israel conducted preliminary research on utilization of bottom ash obtained from thermal power stations by using pulverized coal combustion [6]. Utilization of lignite bottom ash as a fine aggregate in standard grade concrete was explored by Ghafoori and Bucholc [7]. Investigation was conducted by Aggarwal et al [2] on the effects of bottom ash as replacement of fine aggregate in concrete.

From the review of literature it is clear that not much progress on research about the use of bottom ash in concrete has been made particularly with reference to its mechanical and durability properties, especially considering the fact bottom ash is not a standard product universally and its characteristics are also not the same because the properties of coal are different. In view of this problem it has been proposed to establish the feasibility of making concrete using lignite coal bottom ash procured from Neyveli Thermal Power plant, Tamil Nadu, India as a replacement for sand in percentages of 25%, 50%, and 100%. The objective of the investigation is to cast bottom ash concrete specimens to test them in order to evaluate the strength and durability properties and compare these parameters with normal concrete and promote the industrial waste bottom ash concrete as a building material in construction.

2. EXPERIMENTAL INVESTIGATION

In the present experimental investigation, ordinary Portland cement of 53 grade conforming to the IS: 12269 [8] was used. River sand and crushed stone aggregate used in this investigation conformed to IS: 383 [9]. The maximum size of the coarse aggregate used was 20 mm. The cumulative percentage passing of river sand conforms to limits prescribed by IS: 383 [9] as well as BS: 882 [10]. The mix proportion adopted in the preparation of concrete was 1:1.32:2.88 with w/c ratio of 0.45. The concrete used in this investigation was of 25 MPa grade as designated by IS: 456 [11] that is equivalent to BS 8110 [12]. The bottom ash obtained from Neyveli Thermal Power Plants, Tamil Nadu, India was substituted in place of river sand in percentages of 25, 50, and 100. Different particle sizes of bottom ash are presented in Table 1. In this investigation, concrete without bottom ash is designated as NC. Concrete with 25% bottom ash content is designated as BA-1, with 50% bottom ash content is denoted as BA-2 and that with 100% bottom ash content as BA-3. In each category 3 specimens were cast and tested. Results are presented as the average of three tested specimens.

Table 1. Sieve analysis of bottom ash

S. No.	I.S. sieve size (mm)	Quantity retained (gm)	% Retained	Cumulative percentage retained	Cumulative percentage passing	Limits for Zone - III (IS: 383 [9])
1	10.000	0	0	0	100,0	100
2	4,750	11	1,1	1,1	98,9	90 – 100
3	2,360	39	3,9	5,0	95,0	85 – 100
4	1,118	50	5,0	10,	90,0	75 – 100
5	0,600	220	22,0	32,0	68,0	60 – 79
6	0,300	640	64,0	96,0	4,0	12 – 40
7	0,150	40	4,0	100,0	0,0	0 – 10

Normal and bottom ash concrete containing various percentages of ash of 25, 50 and 100 were tested in wet condition to determine their slump as per IS: 1199 [13] which is similar to ASTM C 143 [14] as shown Fig. 1; compaction factor as per IS: 1199 [13] identical to BS: 1881 [15] as in Fig. 2; and flow table test as per IS: 1199 [13] as depicted in Fig. 3. From these tests consistency, compactability and flow characteristics of fresh concrete were determined. The test results are presented in Table 2. Ultrasonic pulse velocity [16] test was conducted on hardened concrete and the results are presented in Table 2.

Fig. 1. Slump test

Fig. 2. Compaction factor test

Fig. 3. Flow table test

Table 2. Workability and UPV of concrete

S. No.	Specimen designation	Workability			UPV Readings		
		Slump	Compaction factor	Flow	Time taken	Velocity	Quality
1	NC	70.00 mm	0.90	74.00%	19.80 µs	4.89 km/s	Excellent
2	BA-1	80.00 mm	0.95	82.00%	24.50 µs	4.28 km/s	Good
3	BA-2	50.00 mm	0.83	72.00%	23.20 µs	4.29 km/s	Good
4	BA-3	20.00 mm	0.76	67.00%	22.50 µs	4.54 km/s	Excellent

The compressive strength of concrete was determined by testing 150 mm × 150 mm × 150 mm cubes at 28 days in Compression Testing Machine (CTM) as per IS: 516 [17] that is identical to BS: 1881 [18]. Three cubes of normal concrete and three cubes of bottom ash concrete with each percentage of bottom ash content were tested in a similar manner. Average of the three test results of both categories of concrete were taken and are presented in Table 3. The split test was conducted as per IS: 5816 [19] in Compression Testing Machine and the results are presented in Table 3. The flexure test was conducted as per IS: 516 [17] on prism of size 100 mm × 100 mm × 500 mm of both normal and bottom ash concretes under four point bending and results are presented in Table 3.

Table 3. Results of compressive, split and flexural strength

S. No	Specimen designation	Compressive strength	Split tensile strength	Flexural strength
1	NC	31.90 N/mm^2	3.00 N/mm^2	6.50 N/mm^2
2	BA-1	48.00 N/mm^2	3.45 N/mm^2	7.51 N/mm^2
3	BA-2	40.60 N/mm^2	2.51 N/mm^2	7.20 N/mm^2
4	BA-3	34.00 N/mm^2	2.12 N/mm^2	5.25 N/mm^2

3. Resistance to environmental attack

In this investigation resistance to chemical and sulphate attacks, and sustainability under elevated temperature of concrete were studied. After 28 days of curing, the specimens of size 100 mm × 100 mm × 100 mm were removed from curing tank and weighed. A 5% solution of hydrochloric acid (HCl) with pH value of about 2 was used for acid attack test. The cubes were immersed in the acid solution for a period of 30 and 60 days (Fig. 4). The concentration of the solution was maintained throughout this period. After these periods of immersion in acid solution, the loss in mass of the concrete cubes with and without bottom ash was recorded, and the improvement of resistance of acid attack of bottom ash concrete cubes was studied as shown in Table 4. No specific British standard or ASTM test method relating to the evaluation of the resistance of concrete to sulphate attack is available at present. The resistance of concrete to sulphate attack can be tested by storing the specimen in a solution of sodium or magnesium sulphate or in a mixture of both. This test was carried out on the specimens of size of 100 mm × 100 mm × 100 mm after 28 days of normal curing. The specimens were taken out of the curing tank and initial weight was recorded. Five percent of sodium sulphate (NaSO4) solution and five percent of magnesium sulphate (MgSO4) solution were prepared and the specimens were immersed continuously in the solution for a period of 30 and 60 days (Fig. 5). The concentration of the solution was maintained throughout this period by changing it every week. The specimens were taken out from the sulphate solution after 30 or 60 days as required. In each test, three cubes were used. The loss in mass of the concrete cubes with and without bottom ash was recorded and presented in Table 4. Three prisms of bottom ash concrete in each percentage of replacement levels of 25, 50 and 100 after 28 days of curing were kept in an oven at 250ºC for 120 hours continuously as shown in Fig. 6 along with normal concrete prism.

Fig. 4. Acid attack

Fig. 5. Sulphate attack

Fig. 6. Sustainability under elevated temperature

Table 4. Results of environmental attack

S. No.	Specimen designation	Loss of mass			
		Acid Attack		Sulphate Attack	
		30 days	60 days	30 days	60 days
1	NC	4.25%	2.12%	0.59%	2.71%
2	BA-1	2.74%	3.16%	0.59%	0.39%
3	BA-2	4.04%	0.58%	0.97%	1.75%
4	BA-3	0.79%	1.50%	2.65%	3.01%

4. RESULTS AND DISCUSSION

The physical properties of both river sand and bottom ash as fine aggregate of concrete were almost similar. The particle size distribution of both river sand and bottom ash conforms to BS: 812 [10]. The mix proportion of concrete adopted in this investigation was 1:1.32:2.88 with w/c ratio of 0.45. With this w/c ratio the concrete could be compacted well with a tamping rod and there was no need for admixture. The test results of slump, compaction factor and flow percentage of various concrete mixes were presented in Table 2. The slump, compaction factor and flow percentage of the normal concrete of M25 grade were 70 mm, 0.9 and 74, respectively, whereas corresponding values for bottom ash concrete with 25% replacement were 80 mm, 0.95 and 82, respectively and for other percentage replacements the values were much lower. Slump of concrete containing 25% bottom ash as fine aggregate was greater than normal concrete by 14.3%.

The cumulative passing percentage of finer particle in the 600 μm - 150 μm range for river sand is 52%. The corresponding value for bottom ash concrete is 72%. As the bottom ash contained more fine materials than the river sand concrete prepared with bottom ash disclosed higher workability. The compaction factor of bottom ash concrete was higher by 5.56% over normal concrete. The flow in respect of bottom ash concrete was 10.81% greater than that of normal concrete. Normal concrete recorded a velocity of 4.89 and was graded as excellent. Concrete containing 100% bottom ash recorded a value of 4.54 which can also be graded as excellent. The velocity recorded by concretes containing 25% and 50% bottom ash were less than 4.5 and weregraded as good. The UPV readings of bottom ash concretes indicated that they did not contain flaw or void and they were sound. Results of compressive strength of different concretes are presented in Table 3. The strength of normal concrete was 31.9 MPa. The acceptance criteria recommended by IS: 456 [11] for 25 MPa grade concrete is 31.6 MPa. Therefore the normal concrete has passed the acceptance criteria. The compressive strength of concrete containing 25% bottom ash was 48 MPa, which was 50.47% higher than that of normal concrete. With higher percentages of bottom ash the strength decreased, more than that of normal concrete. The results of split tensile strength of different concretes are presented in Table 3. The split tensile strength of normal concrete was 3 MPa.

Corresponding value for 25% bottom ash concrete was 3.45 MPa. This is 15% higher than that of normal concrete. For other percentages of replacement, the values were lower than that of normal concrete. As is quite evident from Table 3 the split tensile strength achieved a peak value at 25% replacement level. According to Table 3, the flexural strength of bottom ash concrete with 25% level has achieved the highest strength of 7.51 MPa as against the value of 6.5 MPa in the case of normal concrete. This is 15.54% greater than that of the normal concrete. In this investigation the resistance of concrete to acid attack was measured as mass loss of concrete. Similar measurement in terms of mass loss has been carried out by Turkel et al [20]. The results of acid test on both normal and bottom ash concretes are presented in Table 4. Accordingly, the loss of mass in the case of normal concrete for 30 days was 4.25% as against that of 2.74% for bottom ash concrete with 25% replacement. This is 35.53% lower than that of normal concrete. It is now clear that the resistant to acid attack of concrete containing 25% bottom ash is better than the normal concrete.

Corresponding values for 60 days of exposure are 2.12% and 3.16%, respectively for normal and 25% bottom ash concretes. Therefore for a longer exposure of acidic environment the mass loss in the case of bottom ash concrete was higher by 49% than the normal concrete. From Table 4, in the case of normal concrete for 30 days exposure, the mass loss was the highest whereas with 25% addition of bottom ash the mass loss decreased and was lower than the normal concrete. With the addition of more bottom ash the loss increased further and reached a peak value at 50% replacement. With further addition of bottom ash the loss percentage decreased and became the lowest at 100% replacement.

For 60 days, the mass loss in the case of normal concrete was lower and this value increased with enhanced bottom ash content reaching a maximum value slightly more than that of the normal concrete at 25% replacement. With further addition of bottom ash there was a decrease in the loss of mass attaining lowest value at 50% replacement. Again, there was an increase in the loss of mass with addition of bottom ash reaching a value higher than compared to that at 50% replacement. The effect of sulphate attack on concrete was ascertained in this investigation by measuring the weight loss of concrete.

Results of sulphate attack test obtained in this experimental investigation on both concretes for 30 and 60 days are given in Table 5. Accordingly, for 30 days, normal concrete and bottom ash concrete with 25% replacement have the same percentages of loss of mass of 0.59. For 50% bottom ash the mass loss increased to 0.97% and for 100% replacement the mass loss was 2.65% which is 4.5 times over that of normal concrete. In Table 5, it can be seen that the mass loss in the exposure of 30 days keeps on increasing with the increase in bottom ash content and attains a maximum value at 100% replacement. In 60 days exposure, mass loss for normal concrete was the highest and with addition of bottom ash the loss decreases and reaches a lowest value in the case of 25% replacement level. After 28 days of curing, three cubes each of normal concrete as well as bottom ash concrete with each percentage replacement of 25%, 50% and 100% were kept in an oven at 250ºC for about 120 hours continuously. No damages were observed.

5. Conclusions

It was observed that the compressive strength of bottom ash concrete with 25% replacement was 50.47% higher than normal concrete. In general, there was an increase in strength with addition of bottom ash up to 25% beyond which there appeared to be no specific enhancement in strength. The split tensile strength of bottom ash concrete with 25% replacement was 15% higher than the normal concrete. For other percentages, the split tensile strength was lower than that of the normal concrete. The flexural strength of bottom ash concrete with 25% replacement level was 15.54% higher than normal concrete. For 100% replacement level the flexural strength was lower than that of the normal concrete.

The increase in strength appeared to be true for compressive, flexural strength and split tensile strength for bottom ash content of 25%. Therefore from the strength consideration the optimum replacement level of bottom ash as fine aggregate in concrete appeared to be 25%. The experimental investigation has revealed a better performance of the concrete with 25% bottom ash in respect of acid attack, sulphate attack and sustainability under elevated temperature.

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WYKORZYSTANIE POPIOŁU DENNEGO ZE SPALANIA WĘGLA BRUNATNEGO JAKO KRUSZYWA DROBNEGO DO BETONU

Keywords: beton, popiół denny, kruszywo drobne, wytrzymałość, trwałość

STRESZCZENIE

Beton jest popularnym materiałem budowlanym przygotowywanym przy użyciu lokalnie dostępnych materiałów, takich jak tłuczeń kamienny, piasek i woda. Cement natomiast jest fabrycznie produkowanym składnikiem łączącym wszystkie te materiały. Materiały są dostosowane do wymagań, dobrze wymieszane i umieszczone w formie szalunkowej. Po około 18 do 24 godzin, usuwa się formę szalunkową, a beton pozostawia się do stwardnienia, jednocześnie pielęgnując go poprzez polewanie wodą przez około 28 dni lub aż do dnia badania. W miarę wydobywania tłucznia kamiennego oraz piasku z naturalnych źródeł, wykorzystywanie tych materiałów na dużą skalę nie tylko wyczerpuje źródła, ale również negatywnie wpływa na środowisko. Zbadanie alternatyw dla tych materiałów okazuje się być tym bardziej konieczne.

Obecnie działalność człowieka generuje duże ilości odpadów przemysłowych, rolniczych, itp. Jednym z takich odpadów przemysłowych jest popiół denny otrzymywany z elektrowni cieplnych po spalaniu węgla w procesie wytwarzania energii elektrycznej. Struktura popiołu dennego uznaje się za podobną do piasku rzecznego, używanego jako drobne kruszywo do wytwarzaniu betonu. Charakterystyka popiołu dennego nie wszędzie wygląda tak samo, ponieważ właściwości węgla również zmieniają się w zależności od miejsca. Popiół denny z węgla brunatnego uzyskano z elektrociepłowni Neyveli Thermal Power Plant w Indiach i wykorzystano w badaniu eksperymentalnym, jako drobne kruszywo do przygotowania betonu. Popiół denny został użyty w celu zastąpienia piasku rzecznego według wskaźnika 25%, 50% i 100%. Określono właściwości fizyczne i chemiczne popiołu dennego.

Klasyfikacja popiołu dennego powstała na skutek przeprowadzonego badania i została porównana z klasyfikacją piasku rzecznego. Maksymalny rozmiar kruszywa łamanego wynosił 20 mm. Maksymalna wielkość drobnego kruszywa wynosiła 10 mm. Mieszanka w proporcji 1:1.32: 2.88 przy stosunku woda/cement wynoszącym 0,45 była stosowana w celu wytworzenia betonu. Wykorzystując ten beton, próbki kontrolne zostały odlane zagęszczając beton za pomocą pręta do ubijania (sztychowania). Po utwardzeniu, próbki były badane pod kątem ścisku, wytrzymałości na rozszczepianie i zgięcia. Zaprezentowano wytrzymałość na ściskanie zarówno normalnego betonu, jak i betonu z popiołu dennego. Wytrzymałość betonu normalnego wyniosła 31,9 MPa. Kryteria akceptacji zalecane przez IS: 456 dla 25 MPa klasy betonu to 31,6 MPa. W związku z tym, normalny beton przeszedł kryteria akceptacji. Wytrzymałość na ściskanie betonu zawierającego 25% popiołu dennego wyniosła 48 MPa, czyli 50,47% wyższa niż w przypadku normalnego betonu.

Wraz z wyższymi wartościami procentowymi popiołu dennego poziom wytrzymałości spadł, jednak nadal jest on wyższy niż w przypadku normalnego betonu. Przedstawione zostały również wyniki wytrzymałości na rozszczepianie i rozciąganie różnych typów betonu. Wytrzymałość na rozszczepianie i rozciąganie normalnego betonu wyniosła 3 MPa. Odpowiednia wartość dla 25% betonu z popiołu dennego wyniosła 3,45 MPa. Wartość ta jest 15% wyższa niż w przypadku normalnego betonu. Dla innych wartości procentowych zamiennika, wartości były niższe niż w przypadku normalnego betonu. Wytrzymałość na rozszczepianie i rozciąganie osiągnęła wartość szczytową na poziomie zastępczym 25%. Wytrzymałość na zginanie betonu z popiołu dennego na poziomie 25% osiągnęła najwyższą wytrzymałość 7,51 MPa wobec wartości 6,5 MPa w przypadku normalnego betonu. Wartość ta jest 15,54% większa niż wartość normalnego betonu. Oba rodzaje próbek betonu były również badane w celu oceny ich odporności na działanie kwasu, siarczanu i podwyższonej temperatury. Zaprezentowano wyniki testu płynności zarówno w przypadku normalnego betonu, jak i

betonu z popiołu dennego. W związku z tym, ubytek masy w przypadku normalnego betonu w ciągu 30 dni wyniósł 4,25% w porównaniu z 2,74% dla betonu z popiołu dennego w przypadku 25% zamiennika. Wartość ta jest 35,53% niższa niż w przypadku normalnego betonu. Oczywiste jest, że odporność na działanie kwasu w przypadku betonu zawierającego 25% popiołu dennego jest lepsza od zwykłego betonu. Odpowiednie wartości dla 60 dni ekspozycji wynoszą 2,12% i 3,16%, odpowiednio dla normalnego betonu oraz betonu zawierającego 25% popiołu dennego. W związku z tym, dla dłuższej ekspozycji w kwaśnym środowisku, utrata masy w przypadku betonu z popiołu dennego była wyższa o 49% w porównaniu z normalnym betonem.

Podane są wyniki działania siarczanu, uzyskane w badaniu eksperymentalnym na obu typach betonu w ciągu 30 i 60 dni. W związku z tym, przez 30 dni, normalny beton oraz beton z popiołu dennego w przypadku 25% zamiennika charakteryzują te same wartości procentowe utraty masy, które wynoszą 0,59. W przypadku 50% popiołu dennego, utrata masy wzrosła do 0,97%, a dla 100% wyniosła 2,65%, a więc 4,5 razy większa niż w normalnym betonie. Podczas 60-dniowej ekspozycji, utrata masy normalnego betonu była najwyższa, a z dodatkiem popiołu dennego zmniejszyła się i osiągnęła najniższą wartość w przypadku 25% poziomu zastępczego. Po 28 dniach pielęgnacji, trzy kostki różnych rodzajów betonu: normalnego, a także betonu z popiołu dennego o procentowych wartościach tego zamiennika wynoszących 25%, 50% i 100% były trzymane w piecu w temperaturze 250 ºC, nieprzerwanie przez około 120 godzin. Nie zaobserwowano żadnych uszkodzeń. Stwierdzono, że beton z popiołu dennego spełnił wszystkie kryteria normalnego betonu i dlatego jest traktowany na równi z piaskiem rzecznym. W związku z tym, zaleca się, aby popiół denny, podobnie jak piasek rzeczny, był stosowany do produkcji cementu oraz w budownictwie.