EFFECT OF COAL BOTTOM ASH ON FRESH PROPERTIES OF NORMALLY VIBRATED CONCRETE

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ABSTRACT. The current investigation covers the concerns of workability behaviour of normally vibrated concrete (NVC) prepared with coal bottom ash (CBA) obtained from coal thermal power plants. For the same, several NVC mixes have been made in which CBA has been used as replacement of granular contents i.e. Portland Cement (PC) and natural fine aggregates (NFA). To evaluate the workability behaviour, slump and compaction factor tests were conducted on freshly prepared NVC mixes prior to casting. The investigation results in ample variation in workable nature of NVC mixes made with fixed proportion of Grinded coal bottom ash (GCBA) as PC and variable proportion of CBA as NFA. The study inferences that the substitution of GCBA as PC and CBA as NFA up to propose limit (up to 50%) can be used in formulating various NVC mixes. Further, the achieved performance in terms of workability of CBA blended NVC mixes has been found to be comparable/higher to that of conventional NVC mixes which leads to its wider use as Supplementary cementitious material (SCM) as well as an alternate of NFA in concrete industry. The aforementioned approach undoubtedly leads to sustainable production of PC with the reduced energy consumption and CO_2 emissions.

Keywords: Coal bottom ash, Supplementary cementitious material, Compaction factor, Workability.

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INTRODUCTION

Workability describes the consistence/firmness and ability with which the concrete flows [1]. The workable state of concrete depends on various factors like water/cement ratio, nature of aggregates, content of binder, presence of mineral admixtures, environmental factors etc. For past decades, various industrial bi-products like Fly ash (FA), GCBA, Blast furnace slag (BFS), Silica fume (SF) have been successfully incorporated as fractional substitution of PC [2-5]. The utilization of FA as adopted worldwide recognition as alternate material of PC due to its physical (size/fineness) as well as its chemical behaviour (pozzolanic nature) [6-7]. Apart from FA, CBA is primary bi-product of coal thermal power plant which is normally un-utilised and has not been used in any form but rather dumped in the nearby vicinity. Coal bottom ash has potential to utilize as an alternate constituent in manufacturing of concrete due to its identical gradation with fine aggregates. Likewise, CBA after grinding results in comparable gradation of FA and hence can be used as a substituent material of PC to some extent. Earlier investigations revealed that substitution of constituents with by-products affect the workable nature of concrete. For example, CBA used as replacement of NFA from 0% to 100% has considerably decreased the consistency of the concrete, while its effects seemed to be marginal for lower substitution levels (up to 30%) [6]. Likewise the workability has been affected in case of concrete made with GCBA as replacement of PC.

Currently, a chunk of CBA has been used as land fill material/base material in road construction only [8]. Despite of its advantages CBA is disposed of in ponds and in open areas which leads to serious health hazards and environmental concerns [9-10]. An ideal solution for resolving the aforesaid concerns is the utilization of industrial by-products in construction industry in form of concrete. Utilizing of GCBA and CBA as alternate products can certainly help in preserving natural stocks/resources for future use. Incorporation of coal industry by-product in form of GCBA/CBA not only results in creating economic benefits but also leads to greener environment.

SIGNIFICANCE AND OBJECTIVES

It has been witnessed from the previous literature that CBA/GCBA has been used as substituent of either NFA or PC wherein its influence has been studied in terms of workability aspects [10-11]. However, it has been noticed that the workability behaviour of concrete made with collective use of GCBA and CBA as replacement of PC and NFA respectively has not been examined so far. The literature has confirmed that CBA has an assured potential to be effectively used as alternate of NFA for the reason of its similar characteristics. Therefore, the main objective of the current investigation is to evaluate the workability aspects of concrete made with GCBA/CBA as parallel replacement of PC and NFA in well-defined proportions. A fixed percentage of PC has been replaced with GCBA (20%) while different proportions of CBA as NFA (0%, 25%, 50%, 75% and 100%) has been used for making different concrete combinations. The findings of current investigation will probably help in understanding the workability of NVC containing GCBA/CBA, following its possible applications in the field of civil engineering and construction.

EXPERIMENTAL PROGRAMME

Materials

The ingredients used for making various concrete combinations in the present study complied with Indian Standards (IS). For Portland Cement (PC) and for aggregates (coarse and fine) IS 8112: 1989 and IS 383:1970 has been used respectively. Table-3 presents the physical and chemical properties/composition of PC. Likewise Table- 1 & 2 shows the results of physical and chemical tests performed on CBA prior to casting of specimens. Natural coarse aggregates of maximum nominal size of 20 mm have been used for casting of specimens. Natural river sand with a maximum particle size of about 4.75 mm was used as FNA. The particle size gradation attained through sieve analysis of different constituents PC, CBA, NFA and NCA is presented in Fig.-1. Super plasticizer (SP) based on poly carboxylic ether with specific gravity of 1.060 as quoted by supplier was employed to gain the required workability in accordance with design concrete mix (M25).

Coal Bottom Ash

Coal bottom ash has been collected from the Coal Thermal Power Plant situated in authors region. The physical tests have been performed on the collected samples of CBA and were compared with the results of NFA. The workability was determined by means of the slump test / compaction factor test and was conducted according to BIS: 1199-1959, BIS: 7320 and BIS: 5515 respectively. Bottom ash of Class-F has been used for current investigation [12]. The gradation of CBA has been made similar to that of NFA prior to casting of specimens (Fig.-1). The CBA was sieved in the material testing laboratory and the content has been passed from 4.75 mm IS sieve prior to casting of specimens. Further, CBA was grind in a laboratory ball mill up to Blaine's fineness varying from 3270-6355 cm^2/g [11]. The residue GCBA has been passed through 45μm sieve (less than 5% by weight retained).

Table 1 Physical properties of CBA

BULK DENSITY (KG/M^3)	PHYSICAL FORM	COLOUR	CLASS
1300	Powder	Grey	F

Table 2 Chemical composition of CBA [11, 12]

COMPONENT	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	LOI	IR
Coal bottom ash (%)	57.41	26.92	5.21	2.05	0.71	0.085	1.18	93.12

Table 3 Physical properties of cement

CHARACTERISTICS	UNITS	RESULT OBTAINED	PERMISSIBLE RANGE SPECIFIED
Specific gravity	--	3.15	3.10 - 3.15
Fineness (specific surface)	cm^2/gm.	2340	2250 (minimum)
Soundness (expansion by Le-Chatelier test)	Mm	3	10 (maximum)
Normal consistency (percent of cement by weight)	%	34	30 - 35
Setting time		65	30 (minimum)
(i) initial	Minutes	410	600 (maximum)
(ii) final			
Compressive strength		23	23.00 (minimum)
(i) 3-days	MPa	35.5	33.00 (minimum)
(ii) 7-days		45.1	43.00 (minimum)
(iii)28-days			
Chemical composition		Percentage (%)	
Calcium oxide		61.3	
Magnesium oxide		2.6	
Silica		20.1	-
Aluminium oxide		6.80	
Ferrous oxide		4.3	
Silicon trioxide		1.3	

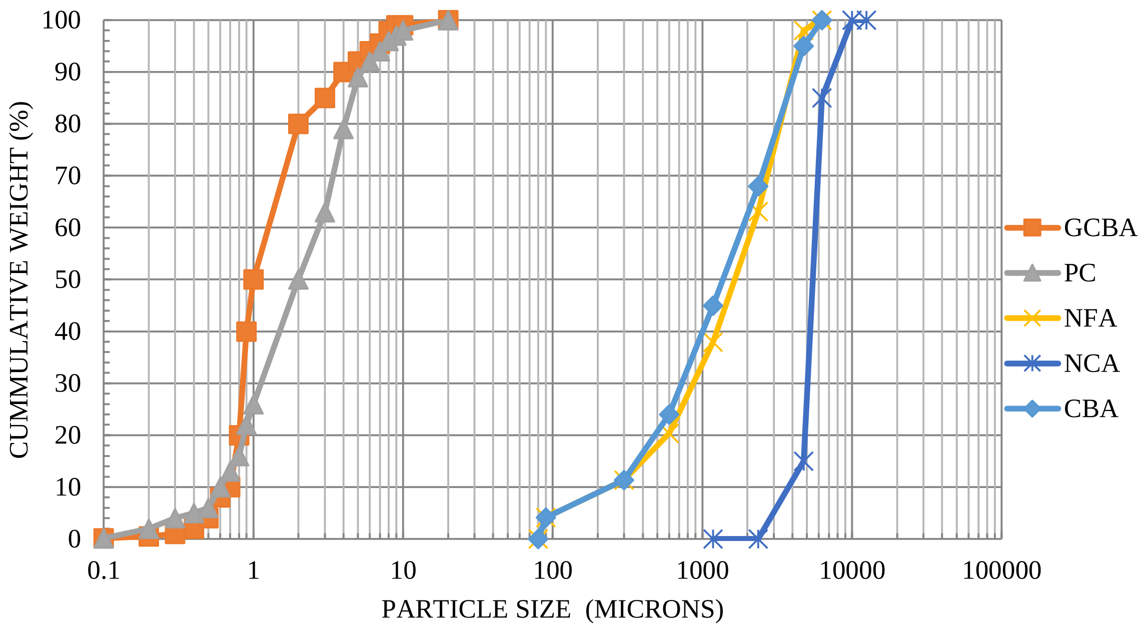

Figure 1 Gradation curves of the GCBA, PC, NFA, NCA, CBA used in experiments.

MIX DETAILS AND PROPORTIONS

The concrete NVC mixes were designed to obtain minimum compressive strength of 25N/mm² at 28 days of standard curing in accordance to IS 10262: 2016. A base concrete mix has been made for validating the results of other concrete combinations. The details of reference combination have been mentioned in Table-4. In addition to base mix, five numbers of concrete combinations comprising different substitution levels of NFA with CBA and fixed proportion of PC with GCBA were prepared for examining workable behaviour. The replacement level of PC with GCBA has been kept at 20% in all combinations while the replacement levels of NFA with CBA has been varied from 0% 25% 50% 75% 100%. The level of replacement of PC with GCBA has been selected from earlier investigations since this amount helps in enhancing the pozzolanic activity of the concrete [13-14]. The details of the various combinations along with the replacement levels of various ingredients and mix codes are presented in Table-4. The replacement levels of FNA with CBA were kept at 25%, 50%, 75% and 100%.

The control mix of C20F0 comprises 20% replacement of PC with GCBA with no replacement of NFA (100%) with CBA (0%). Similarly, concrete combinations C20F25 comprises 20% of GCBA and 25% CBA and 75% NFA by weight i.e. (PC80% + GCBA20% + NFA75% + CBA25%). Likewise, the details of other concrete combinations are presented in Table-4. The content of CNA has been kept constant in all design concrete combinations. In addition to above a reference concrete combination (Table-4-1*) has been designated as C0F0 (M25) which was prepared without any replacement of constituents. In order to attain desired slump (minimum 75 mm), the w/c ratio has been adjusted accordingly in all concrete combinations due to higher water absorption of CBA compared to that NFA (approximately from 1.5% to 33%)[16-17].

Table 4 Details of NVC mixes

S NO	NOTATION	MIX DESCRIPTION
1*	C0F0	100%PC+0%GCBA+100%NFA+0%CBA+100%NCA
1	C20F0 (Control)	80%PC+20% GCBA+100%NFA+0%CBA+100%NCA
2	C20F25	80%PC+20% GCBA+75%NFA+25%CBA +100%NCA
3	C20F50	80%PC+20% GCBA+50%NFA+50%CBA +100%NCA
4	C20F75	80%PC+20% GCBA+25%NFA+75%CBA +100%NCA
5	C20F100	80%PC+20% GCBA+0%NFA+100%CBA +100%NCA

WORKABILITY TESTS

Compaction Factor Test

The compaction factor is the ratio of weights of partially compacted to fully compacted concrete according to BIS: 5515. It is used for concrete which have low workability for which slump test is not suitable. The compaction factor for normally vibrated concrete varies from 0.78 to 0.92 according to BIS: 456-2000.

Slump Test

The concrete slump test measures the consistency of green concrete before setting. The slump of the concrete is evaluated by measuring the distance from the top of the slumped concrete to the level of the top of the slump cone according to BIS: 1199-1959 and BIS: 7320. The values of slump for standard concrete mixes generally vary from 50mm to 100mm in accordance to BIS: 456-2000.

RESULTS AND DISCUSSIONS

The slump flow and compaction factor tests as discussed in earlier section have been conducted on base concrete mix C0F0 for reference. The performance of control concrete mix C20F0 has been found to be equivalent to that of base concrete mix C0F0 as inclusion of GCBA in place of PC has not deteriorated the workable nature. Similar findings have been noticed in previous studies in 20% of GCBA is added as cement addition in concrete mixes [12-14]. Therefore, for the present investigation concrete mix C20F0 is considered as the control concrete mix for comparison with NVC mixes.

The NVC mixes having various substitutions of NFA with CBA (0, 25%, 50%, 75% and 100%) along with constant amount of GCBA (20%) with PC were tested for estimating workability by slump flow and compaction factor tests.
Compaction factor test the workable nature of NVC mixes containing CBA has been found to be identical to the trends as that of slump tests. The compaction factor of 0.87 and 0.81 for NVC mixes C20F25 and C20F50 has been noticed in contrast to compaction factor of 0.92 to that of the control NVC mix C20F0. Similarly, the compaction factor of 0.74 and 0.72 for NVC mixes C20F75 and C20F100 has been attained in relative to that of control NVC mix C20F0 as mentioned above. In general, with the incorporation of CBA in place of NFA in different proportions (0%, 25%, 50%, 75% and 100%) results in overall drop in workability of NVC mixes. However for the control NVC mix C20F0 the addition of 20% of GCBA resulted in increase in workability in comparison to base NVC mix C0F0. On comparing base mix C0F0 with control NVC mix C20F0 an increment of around 17% and 9% in slump and compaction factor tests have been noticed respectively (Fig.-2).

Further, in case of slump flow test, for NVC mixes C20F25 and C20F50 the slump values have been noticed to be lower than that of control NVC mix C20F0 by around 10% and 25% respectively. Further, slump values of NVC mixes containing 75% and 100% of CBA in place NFA has been dropped maximum by 33% (for both) in relative to the control NVC mix C20F0.The similar findings have noticed for workability tests for various NVC mixes in which either GCBA [11-14] or CBA has been replaced with PC or NFA separately at different proportions [15-19]. It has been examined from the noticed trends of workability tests that NVC mix C20F25 has been found to be comparable to that of control NVC mix C20F0 whereas the workability has been declined with regular increase of CBA as NFA (>25%). However, to achieve the required slump flow and compaction factors of NVC mixes made higher content of CBA (>25%) can be done by modifying the volume of superplasticizer.

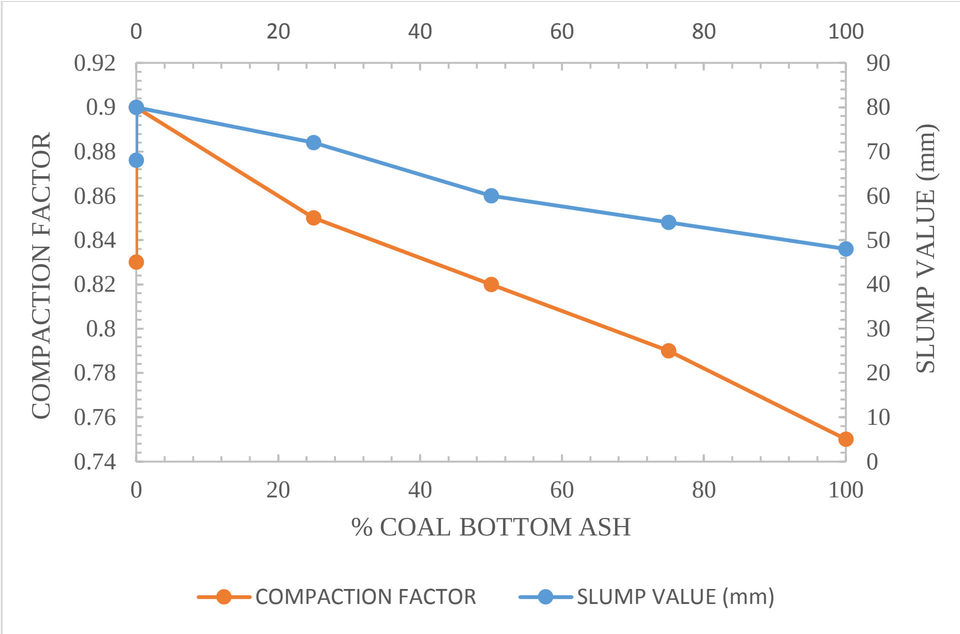

Figure 2 Slump value and Compaction factor results of NVC mixes.

CONCLUSIONS

The current study concludes that the workability of GCBA/CBA based NVC mixes prepared with varying content of CBA and fixed amount of GCBA has declined in comparison to control NVC mix. The worst performance in aspect of workability has been identified for NVC mix C20F100 whereas the comparable performance has been noticed for C20F25 compared to control NVC mix C20F0. The maximum deviation in slump tests has been found for NVC mix C20F100 while the least changes have been witnessed for C20F25. Alike trends of workability behaviour has been witnessed for compaction factor tests for the above said NVC mixes. The variation in slump and compaction factor values have been constrained maximum by 32 % for NVC mixes made up to 75% replacement of NFA with CBA and 20% GCBA replacement with PC respectively. Further it has been concluded from the results of fresh properties that incorporation of GCBA (20%) and CBA up to 25% doesn’t impart any negative effect on the workability behaviour of NVC as most of the conditions have been satisfied in accordance to BIS standards.

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