Indian Journal of Science and Technology, *Vol 9(48), DOI: 10.17485/ijst/2016/v9i48/109367, December 2016*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Partially Replacing Sand with Coal Bottom Ash and Cement with Metakaolin– A Review

Aanchna Sharma* and Divya Chopra

Department of Civil Engineering, Lovely Professional University, Phagwar - 144411, Punjab, India;
aanchnas@gmail.com, divyachopra90@yahoo.co.in

Abstract

Objective: In order to follow the ecological trend, the utilization of alternate materials in construction industry is a growing interest. This review shows the effects of incorporation of coal bottom ash and metakaolin on the fresh and hardened properties of self compacting concrete. **Methods:** For fresh properties slump cone, L-Box, U-box, J-ring and V-funnel were used. In order to find out the mechanical properties, tests were done on compression testing machine and flexure testing machine. Scanning electron microscope and X-ray diffraction techniques have also used in order to study the microstructure of self compacting concrete having coal bottom ash and metakaolin. For durability properties, tests like sorptivity, water absorption and Rapid Chloride Permeability Test (RCPT) were done. **Finding:** Utilization of a material which is otherwise a waste is of great significance. Coal bottom ash which is a waste product of thermal power plants can be utilized in self compacting concrete to partially replace natural sand. Likewise metakaolin has a potential to partially replace cement in Self Compacting Concrete (SCC) in order to reduce the consumption of ordinary portland cement, manufacturing of which is quite hazardous to the environment. This paper presents the findings of various researchers who have studied the effect of using coal bottom ash and metakaolin in self compacting concrete. Based on these studies it has been found out that coal bottom ash has a size almost similar to that of natural sand and pozzolanic activity of metakaolin is quite high. Throughout this paper, impact of coal bottom ash and metakaolin on fresh and hardened properties of self compacting concrete are reviewed and optimum percentage of replacement is also analyzed based on the basis of practical approach. **Application:** Coal bottom ash and metakaolin can be effectively used to partially replace natural sand and cement in self compacting concrete. Introduction of these two materials in SCC leads to an economical and environment friendly concrete. Construction with demand of high compressive, split tensile and flexural strength can be achieved by incorporation of these materials.

Keywords: Coal Bottom Ash, Compressive Strength, Flexural Strength, Metakaolin, Self Compacting Concrete, Split Tensile Strength

1. Introduction

In the past two decades, technology in concrete has made astounding strides. Concrete has revolutionized from being a material just having cement, aggregates, water and few admixtures to engineered material with various new constituents giving better performance under different exposure conditions. Every researcher interested is racing against time to get an array of features different from these currently used. It is self-compacting concrete that virtues to be exemplified as the most important and innovative advancement in the form of technique revolution for decades. In practice of reducing the pollution, waste materials are being utilized in the construction industry. One of these waste materials is coal bottom ash which is produced at a large scale in thermal power plants during the combustion of massive amounts of coal. Then another alternative material is metakaolin. It is a refined kaolin clay that is calcined at about 650-800°C under carefully controlled conditions. Metakaolin is considered as a material which is neither an end product of any industrial processing nor it is completely natural. It is obtained from a naturally occurring mineral and is produced particularly for cementing operations.

*Author for correspondence

2. Literature Review

2.1 Fresh Properties

Workability decreases as the amount of coal bottom ash increases. This decrease in workability is contributed to the higher water absorption of coal bottom ash. The illustration of decreasing value of slump on addition of coal bottom ash is given in Figure 1[1]. The effect of coal bottom ash on the workability of SCC at different percentages like 10%, 20% and 30% were studied and the results are being shown in Table 1[2]. The experimental results of fresh properties of Self Compacting Concrete (SCC) with addition of coal bottom ash as partial replacement of natural sand at various percentages like 0%, 10%, 20% and 30% by weight were obtained. Water powder ratio of the mix was maintained at 0.31 and the ratio of paste volume to void volume of compacted aggregate phase (γ) was kept at 1.5. The effects that coal bottom ash is producing on properties of SCC were explored by comparing the test results of SCC mixed with bottom ash with those of the control SCC composed of river sand and it was found that there is a certain decrement in the workability of mixes having coal bottom ash in them. According to[3] various tests on coal bottom ash were performed in order to examine it for the possibility of using it in concrete. They found out that there will be a decrease in workability of concrete because of the complicated shape and texture of coal bottom ash[4]. Trial program to study the properties of SCC having CBA as partial replacement of natural sand were conducted. Mixes with varying percentages of CBA were prepared and tests like J-ring, L-box, V-funnel, U-box and slump flow were performed to check the workability of the mixes and the same trend of decrement in workability was being followed and the reason for the same was higher water absorption and the surface area of coal bottom ash[5]. Tests on different SCC mixes were done and the mixtures having 10% and 30% bottom ash showed highest and lowest slumps respectively[6]. It was found out mandatory to use at least 3% of superplasticizer in order to maintain the workability of mix after replacing cement with metakaolin. After employing superplasticizer in the mixes a moderate slump of 730 mm was obtained at 0.45 of w/b ratio[7]. It was showed that the slump flow values for different SCC mixes with metakaolin were found to be in the range of 675-690 mm[8]. The effects of using metakaolin on SCC were studied and it was analyzed that addition of metakaolin increases the water demand which consequently increases the demand of superplasticizer in order to make the mix workable[9]. A research was conducted to check the influence of metakaolin and coal bottom ash on SCC. The study concluded that as the amount of CBA increases, workability came to be lower and 10% metakaolin as replacement of cement was giving acceptable values of slump flow[10]. It was concluded that cement should not be replaced with metakaolin at a percentage higher than 30%[11]. A detailed study was done on the influence of metakaolin in self compacting concrete and the findings are shown in Table 2[12]. The properties of SCC by introducing metakaolin as partial substitution of cement were studied. It was found that large amount of superplasticizer was needed to achieve SCC on the incorporation of metakaolin as compared to the SCC without metakaolin[13].

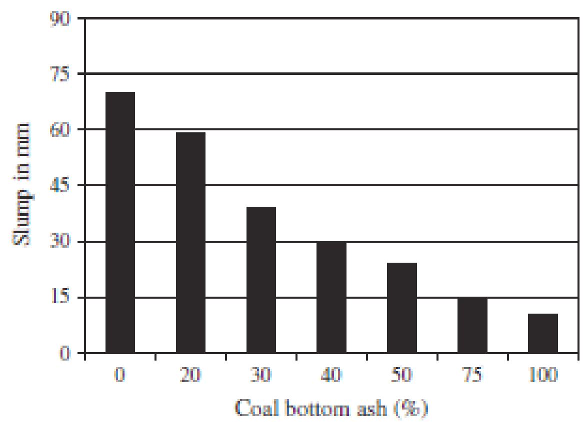

Figure 1. Slump Flow of concrete having coal bottom ash[22].

Table 1. Slump flow and T_{500} of SCC having CBA (Siddique et al., 2012)

MIX	SLUMP FLOW	
	Diameter (mm)	$T_{500\ (s)}$
SCC 0% CBA	673	3.5
SCC 10% CBA	673	4.5
SCC 20% CBA	627	4.9
SCC 30% CBA	591	5.5

Table 2. Fresh properties of SCC having metakaolin (MK)[12]

Mixes	0% MK	10% MK	20% MK	30% MK
Slump Flow	690 mm	720 mm	710 mm	680 mm
V-funnel Test	6.65 sec	6.60 sec	6.76 sec	6.47 sec
L-Box Test	0.88	0.9	0.92	0.89

2.2 Hardened Properties

The effect of w/c ratio on SCC having CBA as a partial replacement of natural sand at different proportions of 0-30 % was found out. Strength tests were done at the age 28 days, 90 days and 1 year. Results showed that there is an increase in the strength with decrease in w/c ratio. A rise in the strength was observed on decrease of water to powder ratio starting from 0.439 to 0.414 for 0% CBA, 0.50 to 0.47 for 10% CBA, 0.58 to 0.51 for 20% CBA and 0.620 to 0.546 for 30% CBA. Mixes presented a significant strength gain beyond 28 days. It was found that CBA can be used to 20% for optimum results[2]. It was presented that increasing amount of coal bottom ash reduces the compressive strength of SCC and this decrease is due to the slow pozzolanic activity of coal bottom ash[3]. A research was conducted to examine the option of deployment of CBA as a partial substitution of sand. Strength in compression, unit weight, modulus of elasticity, microstructure and split tensile strength of concrete with CBA were inspected. The 28 days strength in compression of concrete having coal bottom ash was adversely affected. Later at 90 days of curing period, the strength in compression exceeded as compared to that of control mix as illustrated in Figure 2. The Split tensile strength was enhanced at all the curing periods which varied from 28 to 90 days. The elasticity modulus declined with the usage of bottom ash at all the curing ages. Scanning Electron Microscopy (SEM) and X-Rray Diffraction (XRD) test results specified that C–S–H gel shape was not so massive as compared to the control mix and the full strength in ettringite remained unchanged by the introduction of CBA to the control mix[1]. The mechanical properties of SCC having CBA were studied and it was found out that

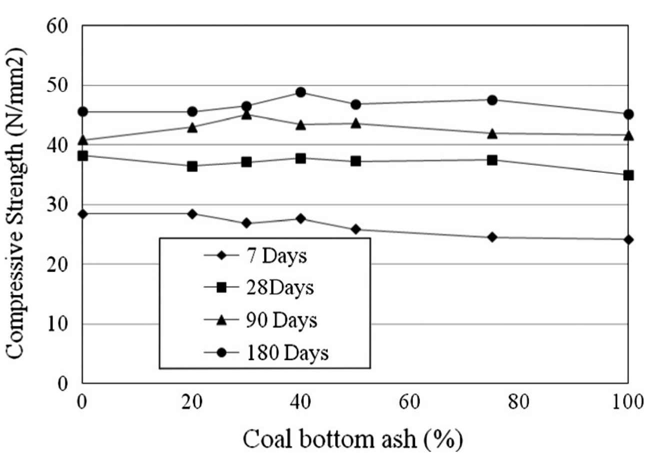

Figure 2. Variation of compressive strength[22].

the strength development of SCC having coal bottom ash was relatively slow but after 28 days, the pozzolanic activity started and then an increment in strength was observed. It was also observed that the strength in compression, flexure and the density of concrete was decreased when the replacement level was increased[14]. The rheological, mechanical and durability properties of self-compacting concrete (SCC) mixes produced using metakaolin were investigated. The rheological properties of SCC mix with metakaolin are characterized by significant yield stress and relatively low viscosity The compressive strength of SCC with metakaolin grows very fast during the initial hardening period and remains significantly higher[15]. The utilization of CBA in various mixtures of concrete was studied. It was concluded that increasing amount of CBA, reduces the compressive strength because of less formation of C-S-H gel at early ages while this incorporation enhances the split tensile strength of the mix by enhancing the paste[16]. Tests were conducted to check the potential of using high-reactivity metakaolin in concrete. He concluded that it can be used in concrete to enhance its hardened properties[17]. It was found that the compressive strength of SCC mix was maximum at 10% replacement level. Above this a decrement was observed[8]. It was concluded that the addition of metakaolin increases the strength of the SCC as compared to the control mix. The 5% metakaolin replacement increases the compressive strength by 11% and 15% replacement increased the strength by 32%. The mix prepared with 10% metakaolin replacement gave an optimal SCC mix with 40% increase in strength[18]. Three key factors were identified which influences the effect of metakaolin that it makes on SCC. The immediate filler effect, the acceleration of cement hydration and the pozzolanic reaction are maximum for 7-14 days with 5-10 % replacement of cement with metakaolin[7]. A literature review was performed on usage of metakaolin and fly ash in concrete. It was concluded that these materials substantially reduce the cement content and add strength to the mix and the resulting mix is much more environment friendly than the control mix[19]. The effect on the split tensile strength after the incorporation of metakaolin in the SCC mix was illustrated which has been shown in Figure 3[12]. Different morphology of SCC by means of grain-size distribution was studied. The findings showed that combination of more than one additive of mineral or dust materials can enhance packing density of particle and decrease the friction among the particles and viscous effect of SCC. It was

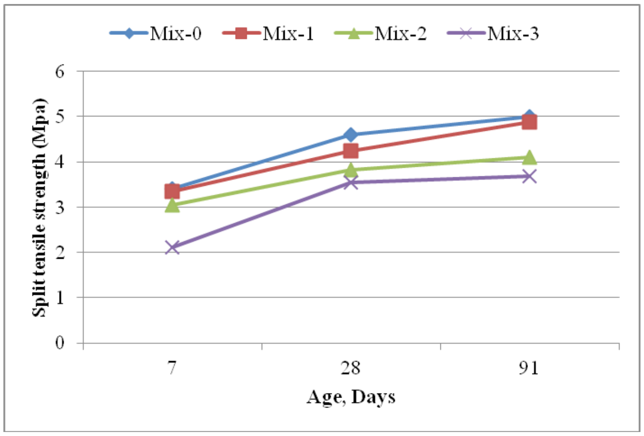

Figure 3. Variation of split tensile strength[12].

observed that the total porosity of concrete was increased with higher contents of CBA mixes in SCC which resulted in decreased compressive and flexural strength[20].

2.3 Durability Properties

Durability properties like sorptivity, porosity, water permeability, gas permeability and chloride penetration were studied. Nine mixes of SCC were prepared out of which 5 mixes were replacing cement with metakaolin and others were replacing limestone powder with metakaolin. It was found out that incorporation of metakaolin improves durability. But near surface permeability was not affected significantly[21]. The volumetric contractions of concrete mixes after the incorporation of metakaolin was investigated and it was observed that incorporation of coal bottom ash leads to the reduction of plastic shrinkage and this decrease was due to higher stability of bottom ash particles in terms of dimensions as compared to that of natural sand[22]. The microstructure of concrete having coal bottom ash was studied and it was found out that usage of coal bottom ash results in more distributed and circular grains[23]. It was found out that coal bottom ash mixes have higher chloride permeability as compared to control mixes. A drastic decrease in chloride permeability was observed on the usage of superplasticizer. 120% greater average current flow was observed when no admixture was added and after the usage of admixture it reduced to 61%. It was concluded that coal bottom ash mixes exhibit more chloride ion permeability as compared to normal mix[24]. The durability properties of various mixes incorporating bottom ash in them were studied. It was found out that bottom ash mixes have excellent resistance for external sulphate attack[25]. Expansion characteristics were found out to be improved. Investigations about the durability properties of concrete having metakaolin were done and concluded that the sulphate resistance and overall permeability gets reduced after the incorporation of metakaolin[12]. The microstructure of coal bottom ash was studied and hence inferences were made that it can be used in SCC. The SEM image is shown in Figure 4[26].

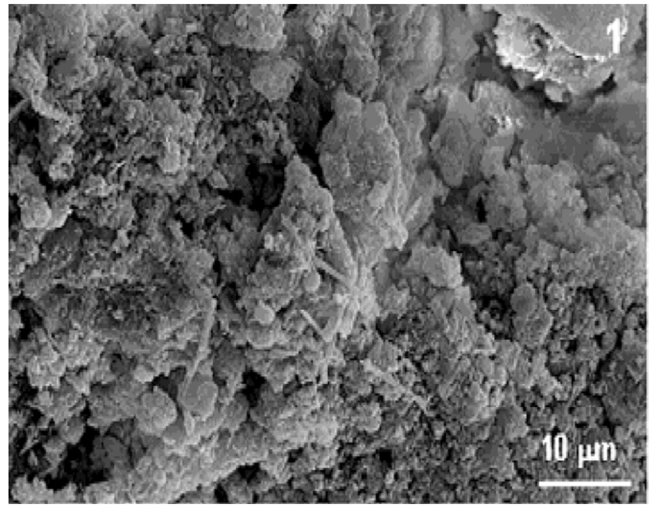

Figure 4. Scanning Electron Microscopy (SEM) secondary-electron image of Bottom Ash[26].

3. Conclusion

Based on the thorough review on incorporation of alternative materials in SCC, certain observations were common. Positive effect of metakaolin and coal bottom ash is worth bringing a change in self compacting concrete. Both the materials have potential to be used in SCC and are reducing the impairment to environment which is the need of hour. Detailed study of coal bottom ash and metakaolin has lead us to draw certain conclusions which are as discussed below.

- Incorporation of coal bottom ash and metakaolin in SCC is possible but usage of superplasticizer is must as increased amount of both the materials reduces the workability of the mix.
- Compressive and flexural strength of SCC decreases initially when CBA is added to it but a significant increase occurs at later stages. This delay is because of the slow pozzolanic activity of coal bottom ash. On the other hand, strength increases when metakaolin is added in SCC because of metakaolin being highly pozzolanic reactive material.

- Incorporation of metakaolin reduces efflorescence because metakaolin consumes calcium hydroxide which is the key material to cause efflorescence.
- Split tensile strength increases when CBA and metakaolin are used in SCC because both the materials have tendency to enhance the paste and refine the pores.
- Both the materials give best results when replacement level is 10%.

4. References

1. Singh M, Siddique R. Strength properties and micro-structural properties of concrete containing coal bottom ash as partial replacement of fine aggregate. Construction and Building Materials. 2014 Sep; 50:246–56.
2. Siddique R, Aggarwal P, Aggarwal Y. Influence of water/powder ratio on strength properties of self-compacting concrete containing coal fly ash and bottom ash. Construction and Building Materials. 2011 Oct; 29;73–81.
3. Kasemchaisiri R, Tangtermsirikul S. Properties of self-compacting concrete incorporating bottom ash as a partial replacement of fine aggregates. Science Asia. 2008 Nov; 34:87–95.
4. Mandal A. A review on current research status on bottom ash: An Indian prospective. concrete. 2014 Dec; 95(4):277–97.
5. Siddique R. Compressive strength, water absorption, sorptivity, abrasion resistance and permeability of self compacting concrete containing coal bottom ash. Construction and Building Materials. 2013 Jun; 47:1444–50.
6. Hamzah A, Jamaluddin N. Split tensile strength on self-compacting concrete containing coal bottom ash. Procedia-Social and Behavioral Sciences. 2015; 195:2280–9.
7. Wild S, Khatib J, Jones A. Relative strength, pozzolanic activity and cement hydration in superplasticised metakaolin concrete. Cement Concrete Res. 1996; 26(10):1537–44.
8. Kavitha O. Fresh, micro and macrolevel studies of metakaolin blended self-compacting concrete. Applied Clay Science. 2015 Jun; 114:370–4.
9. Sabir B, Wild S. Metakaolin and calcined clays as a pozzolans for concrete: A review cement and concrete composites. 2001 Dec; 23:441–54.
10. Jaleel J. Influence of metakaolin on concrete containing bottom ash as fine aggregate. International Journal of Research in Advent Technology. 2015 Jun. E-ISSN: 2321-9637.
11. Karjinni V, Anadinni S, Patil S. An investigation on the characteristic properties of high performance SCC with mineral admixture. Indian Concrete Journal. 2009; 15–9.
12. Mahure H, Mohitkar V, Ravi K. Effect of metakaolin on fresh and hardened properties of self compacting concrete. Indian Journal of Civil Engineering and Technology. 2014 Feb; 5(2):137–45
13. Vejmelkova E, Robert C. Properties of self-compacting concrete mixtures containing metakaolin and blast furnace slag. Construction and Building Materials. 2010 Sep; 25:1325–31.
14. Kurama H. Usage of coal combustion bottom ash in concrete mixture. Construction and Building Materials. 2008; 22:1922–8.
15. Caldarone M. High reactivity metakaolin: A new generation mineral admixture. Concrete. 1994; 16:37–40.
16. Mahajan S, Singh D. Fresh and hardened properties of self compacting concrete incorporating different binder materials. International Journal of Emerging Technology and Advanced Engineering. 2013 Dec; 3(12):2250–59.
17. Naik T, Chun Y, Kumar R, Ramme B. Development of high-strength self-consolidating concrete. Construction and Building Materials. 2004; REP-508.
18. Abubakar A, Baharudin K. Properties of concrete using coal bottom ash and fly ash. International Journal of Sustainable Construction Engineering and Technology. 2012; 3(2).
19. Vejmelkova E, Keppert M, Grzeszczyk S, Ski B, Cerny R. Properties of self compacting concrete mixtures containing metakaolin and blast furnace slag. Construction and Building Materials. 2011 Sep; 25:1325–31.
20. Benipal G, Singh K. Strengthening of cement concrete using fly ash and metakaolin: A review. IJEDR. 2015; 3(4):722–5. ISSN: 2321-9939.
21. Badogiannis E, Sfikas I, Voukia D, Trezos K, Tsivilis S. Durability properties of metakaolin self compacting concrete. Construction and Building Materials. 2015 Feb; 82:133–44.
22. Singh M, Siddique R. Effect of coal bottom ash as partial replacement of sand on properties of concrete. Resources, Conservation and Recycling. 2013; 72:20–32.
23. Yuksel I, Genc A. Properties of concrete containing non groung ash and slag as fine aggregate. ACI Materials Journal. 2007; 104:397–403.
24. Ghafoori N, Bucholc J. Investigation of lignite based bottom ash for structural concrete. Journal of Materials in Civil Engineering. 1996; 8:128–37.
25. Ghafoori N, Cai Y. Laboratory-made roller Compacted Concretes containing dry bottom ash. ACI Material Journal. 1998; 95:121–30.
26. Fernandez J, Georgakopoulos A, Gimeno D, Papastergios G, Kolovos N. Ash deposition in a pulverized coal-fired power plant after high-calcium lignite combustion. Energy and Fuels. 2004; 18:12–8.