Study of self-compacting concrete containing coal bottom ash and fly ash

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Abstract. This paper consists of a detailed analysis of the use of industrial by-products (coal bottom ash and fly ash) as an admixture in the self-compacting concrete. The judicious use of industrial by-products and the proper waste management can lead to a sustainable development in the field of infrastructure. This paper talks about the physical and chemical properties of these by-products used in the self-compacting concrete. Critical and definite analysis has been carried out on the reviewed literature and further scope of work in the analysis and interpretation has been addressed. On a positive note, it can be stated that the use of industrial by-products in self-compacting concrete can lead to a sustainable development.

1. Introduction
Concrete is a mixture that is used in the construction of the structural element comprising of various constituents like coarse aggregate, fine aggregate (sand), binding material (cement), water and other admixtures which gives specific qualities for specific purposes. The history of concrete is as old as of the Roman civilization and the structures made in those times are still well to do. The concrete is made so to bind itself with the ribs in the reinforcements and cement plays a vital role due to the hydration phenomenon which takes place sticking together all the rest of the components.

The concrete taken into consideration for the review study is self-compacting concrete with specific admixture. Research and development in the field of high performing concrete has led to the production of self-compacting concrete. The conventional concrete showed problems like uneven compactness which in turn exhibited negative impact on the permeability of concrete. Self-compacting concrete as the name suggests is a variety of concrete which settles down in the structural elements on its own due to its self-weight and also gives high strength and is highly workable. The history of self-compacting concrete can be dated back to 1988 where in Japan it was first developed. The outstanding deformability and segregation resistance properties have led to the increase in the demand of Self Compacting Concrete. SCC is very identical to the Normally Vibrated Concrete (NVC) with just an increase in the amount of additives like Coal Bottom Ash (CBA) and Coal Fly Ash (CFA) as a replacement to fine aggregates and Portland cement respectively.

CBA is a by-product in the combustion of coal which has not been used judiciously in the construction sector. CBA can replace the purpose of fine aggregates (namely sand) in concrete due to qualities like hardness and light weight. CBA majorly consists of silica, alumina and iron with mild traces of magnesium, calcium and other chemical sulphates. It can be compared to the sand present in the river beds in terms of size. Fresh concretes formed using CBA are quite active against water loss due to bleeding and also cause low deformation due to plastic shrinkage. On the other hand CFA is an alternative to the binding materials (namely cement) used in the construction sector which impart characteristics like increase in long term strength, decrease in drying shrinkage of surface area and suppression of alkali-silica reactions. CFA is also obtained as a by-product in the coal combustion reaction similar to CBA. Disposal of CFA is generally not done in a proper way creating hazard for the environment and...
also raising the chances of groundwater pollution which may lead to other serious health issues in the society. Thus we can say that concrete production using CFA might be an alternate method to reduce the chances of environmental and social issues. Although CFA is being used as a constituent in the manufacture of Pozzolanic Cement, CBA is still not used at such a high rate due to its less availability.

Environmental safety has always been a concern for a healthy planet and to establish sustainable development. The rapid pace of industrialization and urbanization has led to increase in the global warming due to the improper disposal of the by-products produced and lack of waste management. There has been a considerable increase in the level of by-products in the recent years. It is high time sustainable development has become the need of the hour to maintain the ecological balance in the nature. CFA produced from the factories have a severe impact on the environment when fumed in the atmosphere as it settles down on the leaves of the plants and interferes with the life processes like photosynthesis leading to global warming. They also interfere with the health of human beings as the emission of coal ashes namely CBA and CFA can lead to skin, lungs and bladder cancer and are grouped under the category of Group-I human carcinogen. Developed countries having advanced technologies like Malaysia have been using the residual CBA and CFA from their thermal powerplant as a major proportion in their concrete production. Their thermal power plants have been producing around 20-80% of CBA and CFA which is a huge amount in the case for manufacturing concrete for infrastructure use. In 2015 the use of fly ash in the production purposes was around 43% in India, whereas, it was as high as 70% in China and around 53% in USA.

The advantages of Self Compacting Concrete (SCC) over Normally Vibrated Concrete (NVC) is the elimination of external or internal vibration for compaction, comparatively better workability and flow ability as well as better bonding with the reinforcement. It provides high durability, strength and smoother aesthetic finishes which leads to its use in architectural and repairing works. Also use of SCC leads to improved construction ability and minimizes the voids present in the highly reinforced areas. This in turn reduces the permeability of the concrete. The drawback observed in the use of SCC is the high cost as the admixtures or by-products constituents used in its production are quite expensive for construction purposes. Also a large number of trial batches and laboratory tests need to be conducted to bring in use a well-designed mix. Another disadvantage observed is that we do not have a specific designed code for the use of SCC as we have for NVC.

The major aim for this study is to compare the self-compacting concrete with conventionally used concrete on these basis i.e. fresh properties and mechanical properties including various criteria such as slump value, compressive strength, tensile strength, and many other minute criteria taken into consideration for the construction purpose. Both the CBA and CFA as a replacement to sand and cement respectively to clearly judge the changes in the properties have been taken separately.

This paper brings in the comparative study of the various strengths of the papers published by other authors. It will give the idea of utilising self compacting concrete with the mentioned ingredients for the construction of infrastructure and would promote the sustainability in the resources of our nation. This would bring in the practicality in the use of self compacting concrete on the basis of the location it is being used at.

2. MATERIAL AND MIX PROPORTION
The main components of the mix was cement, course aggregate, water, fine aggregates with replacement of the fine aggregates with partial amount of CBA as observed in some of the review papers and also replacement of cement with calculated percentage of CFA in certain other review literature. The test samples in every literature examined consisted of the base sample with no by-products added to it followed by an increase in its percentage.
2.1. CBA

2.1.1. Physical Properties:

After observations in the laboratory is has been noted that CBA is a dark grey colored material mostly angular in shape. It has a major property of light weight and is also porous in nature with a rough texture. The size of the grains plays a major role in determining the characteristics of CBA. It has been observed by studying the CBA produced by various thermal power plants. The grain size analysis of CBA is very similar to that of fine aggregates with a low percentage of silty clay. Other physical parameters like water absorption, specific density, fineness modulus, bulk density and others have been given in the table below.

2.1.2. Chemical Properties:

There has been a critical analysis done in previous papers using X-ray energy dispersive spectrometry (EDS). It was observed that CBA is mainly composed of silica and alumina. The chemical composition represents that it resembles to the class F materials meaning that more than 70% of CBA is formed from raw or calcinated pozzolanic materials. Other instances are that the loss of ignition is around 8% which also shows that CBA belongs to class F materials group. Traces of unburnt carbons improve the concrete. Overall it can be stated that CBA lies more or less in between fine aggregates and class F materials. Under the chemical analysis performed on CBA traces of copper, zinc, arsenic, nickel, mercury and other harmful elements have also been found.

2.2. CFA

2.2.1. Physical properties:

Unlike CBA, CFA is spherical and round in shape may it be hollow or solid. It is in fine powdered form and orange to deep red in nature due to presence of unburnt carbon and iron. The specific gravity of CFA varies in a wide range from 1.6 to 31, but majorly found around 2.0. this vast variation is due to various factors like shape, uniformity of particles and also due to the chemical composition. On a contrary, it has a low bulk density and high specific surface area to its fine particles. On performing the sieve analysis it was observed that its size can be classified as sandy silt to Silty sand.

2.2.2. Chemical properties:

CFA has a vast number of minerals present in it making it one of the most complex compounds. It is mainly formed of oxides of silica, alumina and calcium, thus having a wide range of pH values ranging from acidic to alkaline. CFA comes under two chemical types on the basis of their industrial uses namely class C and Class F. Loss of ignition of CFA varies from less than or equal to 6% and up to 12% based on the performance and use of the fly ash.

3. TEST METHODS

Various kinds of engineering tests are conducted on the sample like slump test to measure the workability, density test, thermal conductivity test, the degree of water absorption and the test for permeability and porosity is also conducted on the sample. The strength test or the compressibility test taken into account is done for determining the cube strength on a concrete block of 150mm x 150mm x 150mm at 3, 7, 28, 90, 180 days, with each test conducted for three samples and then the mean strength taken as the final compressive strength.
Some of the major tests being conducted on the specimen concrete are:

3.1. Slump Cone Test:
This test is conducted using a frustum shaped iron frame in which the concrete mix is poured and its consistency or fluidity is measured. It has a top diameter of 10cm and bottom diameter of 20cm with the concrete fill up to a height of 30cm when filled. Also a tampering rod is used to settle the mix in the cone. The fall in the concrete mix when the cone is removed is called the slump which then categorizes the concrete having very low, low, medium or high workability. The results give the characteristic of the concrete in addition to the slump value. The various kinds of slump that can be seen are true slump, shear slump or collapse slump.

3.2. L box Test:
This Japanese test designed by Peterson especially for self-compacting concrete measures the extent of the flow of concrete through the reinforcements. The apparatus is an L shaped rectangular box section with a gate dividing both the sections. The concrete is poured in the vertical column having reinforcements of diameter 20mm and the gate is lifted to let the concrete flow to the horizontal section. The height of concrete is measured at a distance of 200mm and 400mm in the horizontal section and the respective timings are also noted. The height of concrete in the horizontal section is represented as proportion of the left concrete in the vertical section which indicates the slope of concrete at rest condition.

3.3. J ring Test
It is a test specifically designed for self-compacting concrete to check the ability of the concrete to pass through. It consists of a base plate and a ring with vertical rod like projections. The ring has a diameter of 300mm with projections at an interval of 48mm. this test requires the use of the slump cone which is filled with concrete mix of around 6 litres. But in this case the tamping is not done instead we just strike off the concrete level using a trowel. The cone is lifted up and the concrete is left to flow through the j ring. The average diameter and the height difference in just inside and outside of the J ring are calculated. The acceptable height is between 0 and 10 mm.

3.4. V funnel Test
It is a Japanese test for self-compacting concrete used to find the flow ability of the concrete consisting of 20mm aggregates. The funnel is of 490mm at the top entry and of 70mm at the neck or end of the funnel. The trap door of the apparatus is kept close and around 12 litres of concrete is filled in it and after a period of 10 seconds the door is opened and concrete is left to flow under gravity. The total flow time is noted down.
3.5. U box Test
It is also a SCC based test which is used to measure its filling ability. It consists of u shaped box with a wall dividing it into two compartments. The first compartment is filled with around 20 litres of concrete and is left to stand for 1 minute. The movable gate is then lifted up and the concrete is left to flow to the other compartment until it settles. The height of concrete column is measured in both the compartments and the difference is noted down. It shows the flowability and passing ability of the concrete.

3.6. Compression Test
This is the most commonly conducted test in the laboratory consisting of a cube of dimension 150mm x 150mm x 150mm filled with concrete mix and left to cure for specific number of days. The days of curing taken into account for the self-compacting concrete are 3, 7, 28, 90 and 180 days. After completion of curing the specimens are dried and then taken for compressive test in Universal Testing Machine (UTM).

3.7. Splitting Tensile Strength Test
This test is an important part of the concrete testing as structural loads make concrete critical in tensile failure. The tensile strength of concrete is less than the compressive strength around 10%. Cylindrical samples of concrete of diameter 15 cm and height 30 cm is casted and placed under the compression testing machine with plywood sheets at top and bottom of the specimen. A total load of 9.9 ton/minute to 14.85 ton/minute is applied on the specimen and the breaking load is noted.

4. RESULTS:
4.1. Fresh Properties:
Workability is one of the most basic and just criterion for measuring the quality of concrete mix. Tests specifically designed for SCC are slump flow test, L-Box test, V funnel test, J ring test and U box test. All the tests conducted have been majorly done on 5%, 10%, 20% and 30% of CFA or CBA replacing the cement or aggregates. In an extensive report by Siddique (2012) all the three major tests i.e. slump cone test, L box test and V funnel test were conducted. The results show a specific trend that with the increase in the portion of CBA and keeping the percentage of fly ash varying for each data set from 4% to around 10% there was a decrease in the slump value from 675mm to 625mm. The internal trend with varying fly ash content was also the same and a decline of around 10% was noticed. Esquinas et al. (2018) studied mechanical behavior of fly ash and observed that with a combination of super plasticizers with fly ash there was a decrease in the slump value. It also included the test results of L box test, V funnel test and J ring test. The results of the V funnel test consistently increased which meant that with increase in the amount of fly ash combined with super plasticizer the workability also increases. Similar results were found for the J ring test as well where the radius of flow circle kept on reducing. Siddique (2013) gave the result that with keeping the percentage of fly and super plasticizer constant and varying the amount of CBA present there was a decrease in the slump value at a point when the percentage of CBA was 0.078% where the slump value was noticed to be 591 but when the value of CBA was further increases to 0.116% an unusual phenomenon was noticed where the slump value increased again to 627. L box test, V funnel test and J ring test was also performed in regard with this paper. And the results were similar to that obtained in the slump flow test in which the best sample was found at a point where CBA percentage was 0.078%. But in case of J ring test it was seen that the results kept on increasing with increase in the amount of CBA in the mix. At 0.078% the height difference was noted to be 4.7 mm which is well within the limits but as we moved to CBA percentage as 0.116% the difference came out to be 11.6 mm which is not at all acceptable in case of SCC. Khongpermgoson et al. (2020) studied that slump for the base sample without any CBA proportion was 180mm and steeply decreased to 0mm in a matter of around 90 minutes. Furthermore fore
samples of SCC were taken with the amount of CBA as 15%, 25%, 35% and 45% and the respective values of slump were noted. It was observed that the slump value was 700mm in case of 15% replacement which reduced to 680mm for 25% but again increased to 700mm for the rest of the samples. So the findings can be concluded with concrete mix with 25% replacement with CBA as the most optimum and efficient concrete mix. Promsawat et al.(2020) experimented with a combination of fine aggregates and cement. Three proportions of fine aggregates were taken with each proportion containing three proportions of cement as 5%, 10% and 20%. Slump cone test and V funnel test were conducted for all these samples. The slump value for the base mix was 750mm. A particular pattern was noted as with increase in the amount of fine aggregates slump value increased but with the increase in the proportion of cement from 5% to 20% the value of slump decreased. The sample with 20% fine aggregates and 20% cement could be considered as the most optimum and efficient sample as the slump value was noted as 653mm which is minimum of all the observed values. The V funnel test was very similar to that of the slump cone test. The base value was 11.59 seconds. The value of the most efficient sample could be taken as 30% fine aggregates and 5% cement as its value was noted as 9.51 seconds and the desirable value for a SCC is around 10 seconds.

Mustapha et al. (2021) studied the slump cone test was performed for the mixture. The base mix gave a result of 550mm slump value and on keeping the percentage of silica fumes constant at 10% and steadily increasing the percentage of fly ash from 25% to 65% there is an increase in the slump value from 600mm to 650mm. L box test and V funnel test were also conducted for the test samples in this paper. The V funnel test results claimed that there is an increase in the time of flow for the selected test samples from a value of 12 seconds for the base mix to 10.2 seconds for the mix containing 65% flyash. Hamza et al. (2021) studied use of Bagasse ash in addition to rice husk. The results were such that the base mix having no amount of admixture had a slump value of 740mm and with a constant increase of ash percentage with an increase of 5% the slump value kept on reducing and reduced to 660mm at 15% ash percentage. In addition to this L box test and v funnel test was also carried out. The results were similar with respect to L box test i.e. a declining curve of the ratio from 0.99 to 0.82. The most suitable mix as in the case of V funnel test was found out to be at 10% replacement which was around 10.19 seconds.

4.2. Mechanical Properties:
The properties which come under the mechanical properties are compressibility test, splitting tensile test and flexural test. Many literatures have been published having the results obtained by performing the tests on SCC. This paper summarizes the trends of all these tests performed on SCC. A study by Siddique (2012) considered 5 samples each of 0%, 10%, 20% and 30%. The 28 days compressive strength for the base mix containing 0% CBA and 4.1% fly ash was found to be 35.25MPa. This value increased when the CBA percentage was increased to 10% to 35.33MPa and then consistently decreased to 25.88MPa for 30% CBA and 4% fly ash. A trend was noticed that with increase in the fly ash percentage the compressive strength kept on decreasing. The tensile strength gave a value of 2.41MPa in case of 0% CBA and 4.1% fly ash which reduced to 2.09MPa at 30% CBA and same percentage of fly ash. The trend noticed was similar to that of compressive strength. Mohammed (2011) stated that while decreasing the amount of cement in the mix and simultaneously increasing the amount of fly ash there is a consistent decrease in the compressive strength of the mix having a change from 22.26MPa at 10% replacement to 8.99MPa at 30% replacement. Also it was seen that at 40% replacement the strength increased to 19.38MPa and then further increased to 22.3MPa for 50% replacement. Sukumar et al. (2006) considered two sets of samples namely series A and B. A series included the mix using only fly ash as an admixture and B series contained fly ash along with quarry dust particles as inert filler. Comparison between the two kinds of sample was done and it is observed that B series showed a comparatively lesser slump value of when compared to A series. Similar trend was observed in the L box test as well where the ratio of the heights reduced in B series when compared to A series.
Siddique (2013) suggested that the maximum strength is actually at the base mixture and when the proportion of CBA is increased and the fly ash proportion is kept constant the strength kept on decreasing. The minimum point up to which the strength decreased was around 25.8 MPa at 30% CBA for 28 days and around 20.8 MPa for 7 days which was around 35.2MPa with 0% CBA at 28 days. Similar kind of results were found with respect to the tensile strength where the base mix strength was 2.4 MPa at 28 days and then consistently decreased to 1.9 MPa. A comparatively higher value of tensile strength was found at 90 days i.e. 2.05MPa which is an increase of around 9%. Singh and Siddique (2014a) studied both compressive strength and splitting tensile strength were taken into consideration. The results stated that with the increase in the proportion of CBA in the sample there is a decrease in the compressive strength. The value of compressive strength was noted to be 38.08MPa of the base mix. The maximum compressive strength was observed at 40% replacement at 28 days where the value obtained was 37.7MPa but was still less than that which could be attained without CBA. The tensile strength showed a completely different pattern where the base mix had a tensile strength of 6.99MPa which showed a curvy pattern in the values with increase in the CBA percentage of the mix. The maximum value was attained at a CBA content of 50% which was 7.96MPa. There was a decrease in the tensile strength at the same level if compared with the 7 day tensile strength which was 8.82MPa. In totality if compared the maximum tensile strength was attained at 100% replacement on 7 day test. Singh and Siddique (2016) studied compressive strength as well as splitting tensile strength. It considered two types of mixes namely A in which the amount of cement was in more proportion and B in which the amount of cement is comparatively less. The compressive strength at 28 days and 90 days for a sample ranging from 20% to 100% replacement with CBA was discussed. The results for sample type A have been discussed at first and then for sample type B. The average 28 day strength was around 38.21 MPa and the average 90 day strength is around 40.83 MPa for first kind of sample and 34.04 MPa and 42.32MPa respectively for the second kind of sample. Taking 28 day tensile strength into consideration the strength comes out to be around 2.67 MPa and around 3.09 MPa at 90 days for sample A and 2.57 MPa and 3.02 MPa respectively for sample B. Bostanci (2020) showed results claiming that the 20% CBA has a compressive strength of 38MPa which decreased from a value of 40.5MPa at 0% CBA for 28 days. Tensile strength test was not included in this paper. Ting (2020) studied 0%, 30%, 40% and 50% CBA. The base mix taken into consideration had a compressive strength of 38.88MPa which decreased to 32.17MPa at 30% CBA value. The 28 days splitting tensile strength was 2.82MPa for 0% CBA which kept on decreasing up to 1.62MPa at 50% CBA. The trend was same for 7 days and 90 days. Promsawat et al. (2020) considered a wide variety of concrete mixes with the base mix having a 28 day compressive strength of 56.25 MPa. The common trend noted for all the mix sets namely 20%, 30% and 50% fine aggregates with cement variation from 5% to 20% i.e. that with increase in cement content the strength decreases. The maximum strength was computed as 61.5 MPa for 20% FA and 5% Cement and tending to a minimum value of 40 MPa for 50% FA and 20% Cement.

Hamza (2020) gave a comparatively lower value of compressive strength i.e. around 26.64MPa in the case of base mix but the trend was similar to the rest of the papers. The values for 15% ash content was 15.22MPa which means that the compressive strength of the mix reduced to around 60% of the base mix on addition of the ash. The tensile strength test was also conducted for the mix and the base mix strength came out to be 2.7MPa at 28 days which firstly increased to 2.71MPa for 5% replacement but then decreased to 1.69MPa at 15% replacement which is around 65% of the base mix.
The bar chart shown in figure above gives a visual interpretation and differentiation between the compressive strength of wide range of concrete mixes obtained in the various literature taken into consideration. It can be noticed that the results given by Promsawat et al. (2020 has a comparatively higher values of compressive strength but has not included the 10% CBA content. As discussed above the trend that can be seen in the graph is also decreasing thus concluding that with CBA percentage increase the compressive strength of the mix decreases.

The above figure shows the splitting tensile strength comparison of all the papers taken into consideration. As discussed above the tensile strength also follows the same trend as in the case of compressive strength i.e. decreasing slope. The paper having a comparatively unusual trend was by Singh and Siddique (2014b) wherein the graph shows a upward slope on increasing the percentage of CBA in the concrete mix.

5. Conclusion:
Environmental safety has always been a concern for a healthy planet and to establish sustainable development. The rapid pace of industrialization and urbanization has led to increase in the global warming due to the improper disposal of the by-products produced and lack of waste management. This portion of the paper gives the critical analysis of the various points regarding the use of Coal bottom ash and Fly ash in Self compacting concrete as a replacement to the Fine aggregates and Cement respectively. The problems taking place in our environment that can be reduced by using the byproducts of the industries as an admixture is also discussed. CBA and fly ash taken in different proportions and also along with other materials like rice husk, super plasticizers, silica fumes and other such materials...
give rise to different mechanical and fresh properties impacting the strength and usability of the concrete. This papers also brings into account the flow ability of the concrete as in the case of self compacting concrete setting down of the mixture plays a vital role in the use of such concrete in the infrastructure world. The experiments and tests conducted by various authors are summarized and the results have been depicted in graphical format to show the comparison between them. The use of CBA and fly ash in the construction sector highly promotes the judicious use of such materials. Also that the safety and well being of the environment is the major concern and sustainability is one such pillar to rely upon, use of such byproducts can lead to a better environment for the generations to come. This paper can act as the gist for the probable use of the self compacting concrete in various proportions on the basis of the requirements of construction.

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