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A review on the effect of fly ash, RHA and slag on the synthesizing of coal bottom ash (CBA) based geopolymer †

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Abstract: Geopolymerisation is widely used in the construction sector for its characteristics of strong compressive strength, quick hardening, long term durability, fire resistance and erosion resistance. This paper have gone through the geopolymer performances utilising coal bottom ash, coal bottom ash blended with fly ash, coal bottom ash mixed together with slag and coal bottom ash with rice husk ash (RHA). CBA shown a better performance than FA in strength. This paper have discovered several elements that influence geopolymerisation, the curing time, curing temperature, silicate and hydroxide ratio and grinding CBA surfaces. The combinations of CBA and RHA is suitable for the lightweight concrete as the range of volumetric weight is within 1192kg/m^3 to 1655kg/m^3. The slump result decreases as the ratio of CBA and slag increases. Slag particles are uneven in shape, which increases water consumption and has a honeycombed structure, whereas CBA particles are spherical in shape, which enhances workability.

Keywords: geopolymer; CBA based geopolymer; slag; rice husk ash; fly ash

1. Introduction

Geopolymer concrete is a type of concrete that is made by reacting materials containing aluminates and silicates with a caustic alkali activator. Waste materials such as coal ash or slag from iron and metal production are often used to help achieve a cleaner environment. This is because the waste is actually encapsulated in concrete and does not have to be disposed of during use. Geopolymer concrete does not require heating to be manufactured and does not produce carbon dioxide. The standard Portland cement-based concrete or OPC requires heat and carbon dioxide. There are nine different types of geopolymer, but the largest potential application category for transportation infrastructure is made up of aluminosilicates materials, and can be used to completely replace Portland cement in concrete buildings (Davidovits 2008). These geopolymers are based on thermally activated natural materials or industrial by-products (coal bottom ash, fly ash or slag) to provide with sources of silicon (Si) and aluminum (Al), which are dissolved in an alkaline activation solution, and the polymer chains and networks are then polymerized to form a hardened binder. This system is commonly referred to as alkali activated cement or inorganic polymer cement [1].

In recent years, people's awareness of the quantity and diversity of hazardous solid waste and its impact on human health has continued to increase. Increasing attention to the environmental consequences of waste treatment has led to investigations into new ways of using it. The biggest problem facing the industry is the safe and efficient disposal of by-products such as emissions, sludge, and a large amount of coal ash generated during the combustion of coal for power generation. It is estimated that by the year 2010, the amount of the fly ash produced will be about 780 million tonnes annually. While the US Environmental Protection Agency or EPA have reported that, it estimated that, 140 million tons of coal ash is produced annually. This makes coal ash the second largest industrial waste stream in the United States, after mining waste [2].

2. Chemical Composition of Coal Bottom Ash

In keeping similarity with [3], among the analyzed chemical composition of the coal bottom ash, the highest percentage is 29.15% silica (SiO^2), followed by 26.685% alumina (Al^2O^3). So, there may be a slightly lower sulphur trioxide (SO^3) content in the bottom ash. This may be due to the low porosity of the bottom ash particles which makes the coal bottom ash is classified in the F-class based on the ASTM C 61803. Due to the different sources of coal used, there are slightly differences in the chemical composition of the CBA. This classification is strengthened by [4], where the total coal bottom ash of SiO^2, Al^2O^3, Fe^2O^3 is more than 70%. Following table is the chemical compositions of coal bottom ash in different power plant.

Table 1. Chemical composition of bottom ash.

Power Plant Station/Chemical Composition (%)	Spanish Power Plant	TNB Electric power plant Perak, Malaysia	Tanjung Bin Power Station Johor, Malaysia	Guru Hargobind Power Plant Bathinda,India	Seocheon coal-fired power plant, South Korea
SiO_2	52.30	54.80	29.15	56.44	44.2
Al_2O_3	25.14	28.50	26.68	29.24	31.5
Fe_2O_3	9.23	8.49	7.28	8.44	8.9
CaO	2.37	4.20	16.36	0.75	2.0

MgO	1.84	0.35	1.51	0.40	2.6
Na_2O	0.66	0.08	1.15	0.09	-
K_2O	3.72	0.45	0.53	1.29	-
TiO_2	1.45	2.71	-	3.36	2.4

3. Performance Comparison of Coal Bottom Ash with other pozzolans

3.1. Performance of Coal Bottom Ash Geopolymer

According to the [9] have stated that the average compressive strength for pure CBA was 13.58 MPa, 18.34 MPa, 24.06 MPa, and 22.77 MPa after the pastes were cured at 70°C and tested after 3,7,14, and 28 days. The geopolymer pastes reached their maximum strength after 14 days, according to general observations, these findings also indicated that as the curing period lengthens, mortar strength increases. At an elevated temperature, the microstructure of CBA appears to be weakening after 14 days. [18]. However, the gap in strength between the 14th and 28th days is not statistically significant. Afterwards the 100% CBA specimens were cured for 12 hours at room temperature, and the strength was found to be 6.95 MPa. This means that the curing temperature has a significant impact on the strength of geopolymer concrete. Another important idea claims that increasing the concentration of alkali contained in (Na,K metallic ions) or decreasing silicate Sio2 increases compressive strength. [9] determined that increasing the ratio of sodium silicate to sodium hydroxide has an impact on geopolymer strength performance. Compressive strength increased as the Si/Al ratio increased with increasing percentage of NaOH, this statement supported by [19]. Furthermore, the use of finer CBA (4.3 mm) increased compressive strength due to the inherent pore refinement action of finer particles filling the pores in the paste, increasing the hydration products formed during pozzolanic reactions [16]. Physically and chemically, ground CBA resembles FA. Almost all investigations have revealed that adding grinded CBA reduces compressive strength at early ages, but the same has been found to be greater in proportion to their respective control concretes over extended curing periods (28 days). Due to natural pore refinement activity, finer particles filled the pores in the paste, increasing the hydration products generated during pozzolanic reactions, the incorporation of finer CBA, i.e. 4.3-mm, showed an improvement in compressive strength. [17] have found that the by reducing the particle size of CBA in concrete, the qualities of the concrete were enhanced. Compressive strength of CBA is influenced by the grinding time of CBA by high ball mill. Most research recommended that, the grinded CBA has a potential to be a good pozzolanic material by increase in fineness.

3.2. Performance of Coal Bottom Ash And Rice Husk Ash (RHA) Geopolymer

As mentioned before, Geopolymerisation is an inorganic polymer compound consisting of alumino-silicate networks, which are the result of reactions between alumino-silicate materials in a high alkaline condition. Coal bottom ash and rice husk ash were combined, with the CBA serving as the principal source of reactive alumina and silicate and the RHA serving as the key source of reactive silica. According to [5], geopolymers with an average 28th day compressive strength of 17.4MPa, water absorption of 259.9 kg/m3, and volumetric weight of 1655 kg/m3 were produced using a solid powder mix of 50% CBA and 50% RHA and alkaline activated with 28% (by weight of solids) of water glass (silica modulus of 2.5). After a period of time [6], with the same portion of solid powder mix as [5] with alkaline-activated using 30% (by weight of solid) after an average of 28 days, the compressive strength of coal bottom ash with rice husk ash was determined to be 37.41MPa, with water absorption of 129.94 kg/m3, and volumetric weight of 1192 kg/m3. Afterwards, with the proportions of 35% CBA and 35% of RHA and 30% of water glass solution it achieved the best performance where the compressive strength is 17.41MPa, volumetric weight is 1485.30kg/m3 and the water absorption reached until 189.94 kg/m3 [7]. These results were in good compliance with the ASTM C55 and C90 requirements for the development of lightweight concrete. Summary of the specimen performance can be shown in the Table 2.

Table 2. Engineering properties of geopolymer (CBA + RHA) specimen.

Mixture Proportions	Volumetric Weight (kg/m^3)	Water Absorption (kg/m^3)	Compressive Strength (MPa, psi)
CBA 50% + RHA 50% WGS 28%	1655	259.9	17.4, 2523.657
CBA 50% + RHA 50% WGS 30%	1192	129.94	37.41, 5425.8618
CBA 35% + RHA 35% WGS 30%	1485.30	189.94	17.41, 2525.107

3.3. Performance of Coal Bottom Ash And Fly Ash (FA) Geopolymer

Apart from that, the combination of coal bottom ash and coal fly ash as geopolymer paste showed very satisfied performances in terms of compressive strength. According to [8], the 90% of CBA and 10% of coal fly ash (CBA90FA10) combination generated the highest compressive strength of all the CFA and GBA combinations, 22.44 MPa after 14days. While, the combinations of 50% of CBA and 50% of coal fly ash (CBA50FA50) was found 20.82 MPa after 14 days of curing period. On the other hands, 70% of CBA and 30% of coal fly ash (CBA70FA30) recorded that after 14 days of curing period the compressive strength achieved around 22.13MPa. The results reveal that as the curing period is lengthened, the strength increases. In addition, the curing temperature has a significant impact on the strength of geopolymer concrete. Compressive strength appears to decrease after 14 days in many situations. Nevertheless, the difference between 14 and 28 days may not be statistically significant. Besides that, ratio of sodium silicate: sodium hydroxide, the strength increased at the same curing period. It can also be seen that during the curing time on the 14th day and the 28th day, even if the proportion is increased, no significant increase in the strength of the paste is recorded. This theory supported by [9], which has found that the CFA/CBA ratio and the concentration of activating solution may have a considerable impact on the mechanical characteristics of geopolymers made from fly ash and bottom ashes.

Table 3. Engineering properties of geopolymer (CBA + FA) specimen.

Mixture Proportions	Compressive Strength at Room Temperature Curing for 12hours	Compressive Strength (after 14th days at Elevated Temperature curing)
CBA 50% + FA 50%	-	20.82MPa
CBA 70% + FA 30%	-	22.13MPa
CBA 100%	6.95MPa	24.06MPa
FA 100%	5.25MPa	20.46MPa

3.4. Performance of Coal Bottom Ash And Slag Geopolymer

The engineering characteristics of concrete including coal bottom ash and granulated blast furnace slag have been studied. It was discovered that when (GBFS + CBA) increases, the workability of new concrete decreases. This might be related to the particle form of the substance, according to [13]. CBA particles are spherical in shape, which improves workability, whereas slag particles are irregular in shape, which increases water consumption and has a honeycombed structure, which may impact workability performance, and aggregate porosity may also influence workability. Although the water content in the mixture was increased, the workability of the mortar decreased when 75% of bottom ash was combined with it. This was related to the angular form and irregular texture of bottom ash impacting high-interparticle friction. [14]. Concrete's water absorption capacity is influenced by its permeability and porosity. Because the replacement components have a higher water absorption capacity than sand, concrete permeability is important. Porosity is vital for the concrete's surface. The GBFS and CBA particles have a distinct surface texture than sand. The creation of a stronger connection between aggregate and cement paste is aided by a rougher texture. As a result, the potential replacement ratio for (GBFS + CBA) in concrete should be low, or new precautions to lessen water absorption capacity should be considered. Second, replacing CBA and slag as fine particles in concrete reduces the compressive strength, depending on the blend of (CBA+ slag +FA) is higher in compressive strength to compare with the combination of (CBA + slag). It is claim that, existence of FA in the mixture, balancing some extent. It is previously been reported that FA contributes to the strength and improve the durability of concrete. The compressive strength of concrete was determined by the curing time and temperature, since as the curing time and temperature increase, so did the compressive strength [14].

Table 4. Engineering properties of geopolymer Coal Bottom Ash with GBFS specimen.

Mixture Proportions	Measured Slump (cm)	Water Absorption (%)	Compressive Strength after 7th day (MPa)	Compressive Strength after 28th day (MPa)
Slag Cement 100% Aggregates 100%	14	4.14	24.25	37.77

Slag Cement 100% GFBS 30% + CBA 30%	**6**	**6.87**	**14.14**	**21.91**
Slag Cement 100% GFBS 15% + CBA 15%	10	6.11	17.34	27.54
Slag Cement 100% GFBS 25% + CBA 25%	6	6.66	15.63	25.67
Slag Cement 95%, FA 5% GFBS 5% + CBA 5%	13	4.4	21.30	33.22

4. Conclusion

The conclusion that can be drawn throughout this study are, there are several factors affecting the development of geopolymer. The CBA geopolymer and (CBA + FA) investigation has found that the curing period lengthens, mortar strength increases. And, increase in strength for curing periods beyond 14th days is not very significant. Because prolonged curing at elevated temperatures breaks the granular structure of the geopolymer mixture, compressive strength will decrease at higher temperatures for longer periods of time. Secondly is the curing temperature is found to be a vital factors in geopolymerisation as explained in depth 3.1. Thirdly, is the concentration of alkali contained in (Na,K metallic ions) or decreasing silicate Sio2 increases compressive strength, this is because excess sodium silicate hinders water evaporation and structure formation. The Matrix activated with potassium silicate KOH obtained the greatest compressive strength while sodium silicate/NaOH activated matrixes were generally weaker followed by potassium silicate [9]. Geopolymer serves a better alternatives to OPC for immobilizing toxic metals. About 90% of the heavy metals got locked into the geopolymeric matrix. Future study in the field of utilising geopolymer can be commercially done.

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