Sustainable Concrete Innovations: Enhancing Alkali-Activated Concrete With Marble Waste For Eco-Friendly Construction

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ABSTRACT

Concrete remains the most widely used man-made construction material due to its versatility and cost-effectiveness. However, the production of Ordinary Portland Cement (OPC), a conventional binder in concrete, generates significant carbon dioxide emissions—approximately 0.8 to 1 ton per ton of cement produced—contributing to environmental issues such as the greenhouse effect and ecological imbalance. To mitigate these concerns, sustainable alternatives like alkali-activated binders using industrial by-products rich in alumino-silicate materials, such as Ground Granulated Blast Furnace Slag (GGBS) and fly ash, have gained attention. GGBS, a by-product of the steel industry, and fly ash, a coal combustion residue, can serve as sole binders in Alkali-Activated Concrete (AAC) when activated using sodium hydroxide and sodium silicate solutions. The study investigates the mechanical performance of AAC incorporating a cementitious blend of 60% fly ash and 40% GGBS, with coarse aggregate partially replaced by marble waste at varying levels (10%, 20%, 30%, 40%, and 50%). The concrete specimens were subjected to both oven curing at 60°C and ambient curing for 7 and 28 days. The results indicate that AAC with up to 30% marble waste replacement exhibited superior compressive strength after 28 days of ambient curing. This research highlights the potential of integrating industrial waste materials into sustainable concrete production, offering an eco-friendly alternative for the construction industry.

Key words: AAC(alkali activated concrete), Sodium Silicate, Oven Curing, Sustainable Materials.

1. INTRODUCTION

Concrete is the most versatile material used worldwide for construction purposes in Civil Engineering works because of its mouldability, strength, durability and low cost. Portland cement is the major constituent of concrete. In the developing world, demand for cement is growing rapidly which causes an urgent need for alternative binders to meet the infrastructure and housing needs of billions of people, without further compromising the carbon dioxide (CO_2) levels of Earth's atmosphere (Taylor et al. 2006). The production of cement requires decomposition of limestone i.e., calcium carbonate ($CaCO_3$) at high temperatures to generate reactive calcium silicate and aluminate phases. Ordinary Portland Cement (OPC) is normally made by heating a mixture of raw materials in a rotary kiln to about 1,450°C, cooling this semi-molten material to form a solid clinker, then inter grinding with calcium sulfate to generate a fine powder. The major raw material used is limestone i.e., calcium carbonate ($CaCO_3$), which is blended with materials such as shales or clays to provide the necessary alumina and silica. The clinker is predominantly calcium silicate, which is rapidly cooled to stabilize a mixture of tricalcium silicate ($3CaO.SiO_2$) and dicalcium silicate ($2CaO.SiO_2$), with minor (but important) CaO-rich aluminate and alumino ferrite phases. The production of the clinker or Portland cement is an energy-intensive process and consumes 4 GJ per ton of cement.

2. LITERATURE SURVEY

Bakharev et al. (1999) investigated the alkali activation of Australian slag using sodium silicate, sodium hydroxide, sodium carbonate, sodium phosphate and combinations of these activators. Compressive strengths for the pastes were achieved in the range from 20 to 40 Mpa. The liquid sodium silicate was used as a most effective activator. The effect of curing at 60°C, modulus of sodium silicate solution and concentration of alkalis on the compressive strength and setting times were studied with this activator. In the present investigation, sodium silicate solution with comparatively lower Na content and modulus of 0.75 was recommended for formulation of alkali activation of Australian slag concrete.

Puertas et al. (2000) studied the activation of fly ash / slag pastes with the help of NaOH solutions. In this process different parameters were studied such as activator concentration (NaOH – 2M and 10M), curing temperature (25°C and 65°C), and fly ash / slag ratios (100/0, 70/30, 50/50, 30/70, and 0/100). The models describe the mechanical behaviour of the alkali – activated fly ash / slag pastes. Compared to the other two factors, curing temperature in the development of the strength of the pastes was found out to be less. For the development of compressive strength to increase the NaOH concentration and higher strengths can obtained when activator concentration of 10M was used. As, the slag content in the pastes increases, it was studied that the compressive strengths increase. The main reaction product in 50% fly ash/50% slag activated with 10M NaOH solution of pastes is a Hydrated Calcium Silicate, like that of C-S-H gel, with high amounts of tetra coordinated Al and inter layer Na ions in its structure.

Collins et al. (2001) investigated the level of micro cracking that occurs in alkali activated slag concrete subjected to various types of curing regimes. Without the use of Portland cement the AASC was obtained by activating GGBS with alkalis. The compressive strength development of alkali activated slag concrete were monitored. The level of micro cracking was measured using three divergent tests: (i) frequency and size of surface cracks using crack-detection microscope (ii) water sorpitivity tests measuring absorption of water by capillary attraction and (iii) mercury intrusion porosimetry tests which measured the pore size distribution of alkali activated slag concrete and alkali activated slag pastes. The results obtained show that due to the lack of moist curing of AASC not only enhanced the level of micro cracking but also reduced the strength development of alkali activated slag concrete.

Zuda et al. (2006) carried out a study on the properties of alkali activated aluminosilicate material based on alkali activated slag. i.e., porosity, bulk density, compressive strength, thermal conductivity and specific heat capacity of the material were determined at the room temperature conditions under a thermal load ranging up to 1200˚C prior to the measurements and is compared to the reference material data. This shows that if it exceeds 1200˚C reference material is not exposed to any thermal load. By the help of water vacuum saturation measurements, bulk density and porosity were determined. The porosity of the material ascended significantly after it is pre-heated up to a temperature of about 1200˚C. In case of tunnels, this makes it suitable for replacing the traditional cement based as fire protection materials or utilizing it in the form of protective layers. By using mercury porosimetry measurements, the global characteristics of porous space, pore distribution curves were measured. The compressive strength was determined as the most characteristic for alumino-silicates. The thermal conductivity was measured in laboratory conditions using Isomet, a commercial device. These results were determined by using material characterization experiments, such as X-ray diffraction analysis and scanning electron microscopy.

Bougara et al. (2007) investigated the activation of Algerian slag mortars, which exhibit low reactivity due to its lower CaO/SiO2 ratio and it was mechanically activated by grinding the slag to 250, 360 and 420 m2 /kg Blaine surface area, thermally by curing mortar specimens at 20, 40 and 60Oc, and chemically by mixing the slag with two alkalis, NaOH and KOH at varying concentrations. The compressive strength was determined at the age of 1, 3, 7, 28 and 90 days respectively. It was observed that all the three methods augmented the reactivity of the slag. It was observed from the results that the slag was highly reactive to the rise in temperature whereas the increase in the fineness was observed along with increased strength development. Alkali activation of the slag resulted in the enhanced strength development, yet the strength was lesser than that of the controlled mortar.

Huang et al. (2009) investigated a cementitious material by utilizing two industrial wastes, Phospho Gypsum (PG) and Steel Slag (SS), combined with another industrial byproduct ground granulated blast-furnace slag and Limestone (LS). The 28 days compressive strength of a mixture of 45% PG, 10% SS, 35% GGBS and 10% LS exceeded 40 Mpa. X-ray diffraction analysis and scanning electron microscopy analyses revealed that the formation of ettringite and C–S–H gel. Where a part of the PG reacted with GGBS and SS to develop into ettringite. It was observed that SS present in the cement acted as alkalinity activator and the extra dosage of SS might cause unsoundness of the cement.

Winnefeld et al. (2009) studied the alkali activation of the low calcium hard coal fly ash and four high calcium lignite coal fly ash by employing conduction calorimetry, X-ray diffraction, thermo gravimetric analysis and scanning electron microscopy and to estimate their potential in the production of mortar and concrete respectively. These ashes were activated by different additions of sodium silicate. Barring the chemical analysis of the hydrated samples, strength tests have been carried out on mortars, under various curing regimes. The results obtained stipulated a high content of vitreous phase and low calcium content are important factors in governing the reactivity and performance of fly ashes in the alkali activated systems. In the high calcium fly ashes, less alkali aluminate silicate hydrates and a much more porous

Rovnanik et al. (2013) studied the micro – structural changes in the alkali activated granulated blast furnace slag exposed to high temperatures. By using SEM, HT-XRD analysis and FTIR and MASS, NMR spectroscopy it was determined that the micro structural changes caused due to heat. Only partial dehydration and decomposition of C–A–S–H phase can be observed up to a temperature of about 600˚C.This significant change in micro structure is responsible for an increase in compressive strength that reaches 180% of the reference value, and also for the considerable shrinkage of the AAS material. When the dehydration of C–A–S–H phase is complete and new phases start to crystallize, among which akermanite is dominant, the principle changes in the microstructure of alkali activated slag occur between 600˚C and 800˚C.

Aydm et al. (2014) investigated the effects of various activators on the properties of alkali – activated slag mortars by the developing the workability, setting times, mechanical properties, drying shrinkage, water absorption characteristics and microstructure of alkali activated slag cement binders to establish the modulus ratios and Na2O contents of the solutions. According to the investigation it was found out that by the activation of slag without heat curing, Portland cement free high-performance composite with compressive strength values ranging up to 100 Mpa can be easily obtained and in case of activation by optimum modulus ratio, sodium silicate alkali activated slag mortars present higher compressive strength, lower water absorption, higher workability, lower porosity and a wide range of setting times in comparison with NaOH activated slag mortars and Portland cement mortars. Alkali activated slag mortars may be used as a binder for the production of high performance composites. Reduced values of capillary water absorption, total water absorption and volume of permeable voids of alkali activated slag mortars were observed for the mixture modulus of 0.8 at 6 % Na2O content.

Mithun et al. (2014**)** investigated the effects on the workability and strength characteristics of the self-cured alkali activated Indian slag concrete mixes when the dosage of Na2O in the range of 4% - 8%. It was obtained that the relative increase in modulus resulted in the decrease of workability of the AASC mixes but it is higher than that of the workability of the specimens prepared with OPC. Also, it was deduced that the use of Portable water instead of de-ionized water doesn"t significantly vary in the strength development characteristics of AASC mixes.

Qureshi et al. (2014) studied the effects of curing conditions on the Engineering properties such as water absorption, apparent porosity and compressive strength of the alkali activated slag pastes. The combination of potassium hydroxide and sodium silicate was used for alkali – activation. Specimens were then subjected to compressive strength test and water absorption at the age of 3, 7 and 28 days which includes curing types (water curing at room temperature 28˚C, heat curing at 40, 50 and 60˚C respectively) and alkali content (6.41, 10.41 and 12.41% of the mass of blast furnace slag). For all types of curing methods, it was observed that the compressive strength increases with increase in alkali content from 6.41 % to 10.41 % and reaches a maximum of 47.50 Mpa for alkali content of 10.41 % for water cured specimens followed by oven cured specimens at 50˚C. The study also revealed that the 28 days strength of water cured specimens were 86.27, 30.55, 57.28 % higher than that of oven cured specimens at 40, 50 and 60˚C respectively for the optimum 10.41 % of alkali content. The higher apparent porosity and water absorption were observed in the oven cured specimens. The compressive strength was 36.50 Mpa at 50˚C which was found to be the optimum oven curing temperature.

Adam et al. (2015**)** conducted studies and compared the strength of the alkali activated slag and fly ash based geopolymer mortar. Mortars were prepared with slag activated by a low dosage of alkaline solution and fly ash activated by high alkaline solution. The mix was prepared with a 5-liter Hobart mixer, after which it was poured into 5 cm cubic moulds and vibrated for 1 minute. Two sets of specimens AAS and geopolymer with 1 set being left for 24 hours at room temperature and the other set was cured in 20˚C water bath for 6 days before being demoulded and tested. It was observed that the compressive strength obtained for the heat cured specimens at 3 days was relatively equal to the 28 days compressive strength. Although the alkali activated binders along with slag and fly ash are not eco-friendly, they are capable of obtaining high compressive strengths at an early curing age.

Bernal (2015) conducted studies on the effects of the activator dosage on the compressive strength and accelerated carbonation resistance of alkali silicate activated slag Metakaolin blended materials. The Metakaolin reaction, high strengths and reduced permeability were favoured by the increased activator concentration. By adding the Metakaolin, increased activator concentrations had reduced the susceptibility to carbonation, associated with the refinement of the pore network under the enhanced carbon dioxide exposure. The effect of adding an alumino-silicate precursor to an alkaliactivated slag system is strongly dependent on the activator concentration.

Chi (2015) investigated the micro-structural characteristics and properties of alkali activated fly ash mortars. A couple of eloquent factors influencing the characteristics of geopolymer mortar-based fly ash are alkaline modulus ratio and the dosage of Na2O. Compressive strength, drying shrinkage, water absorption, initial surface absorption, mercury intrusion porosimetry (MIP), scanning electron microscopy (SEM) and X-ray diffraction analysis tests were carried out and their performance was discussed. The compressive strength of AAFA mortars increases with dosage of Na2O means at the same dosage of Na2O, the higher the modulus ratio of alkaline solution, the more superior the compressive strength of AAFA mortars. The increasing dosage of sodium oxide for AAFA mortars can reduce effectively the drying shrinkage, porosity and initial surface absorption. For the optimum mix design, AAFA mortars with Na2O dosage of 150 kg/m3 under the alkaline modulus ratio of 1.23 and liquid/binder ratio of 0.5 may be suitably considered. Wardhono et al. (2015) carried out investigations on the strength of the alkali activated slag (AAS)/fly ash (AASF) mortar blends. Using a mix of GGBS and low calcium class F fly ash activated by high alkaline solution, the AASF specimens were prepared and were cured at the standard ambient temperature. 50 mm x 50 mm x 50 mm cubes were molded and vibrated for about 1 minute which was to ensure the absence of any air voids in the mix prepared. The specimens were then directly subjected to a water bath at 20 ± 2˚C until the time of testing without and heat curing treatment. It was inferred from the investigation conducted that by the use of slag and fly ash in the mixes instead of OPC reduces the amount of carbon production. AASF Mix 1 (made by 100% slag) demonstrated the highest initial compressive strength, however, it showed a reduction in strength over periods of time and reached the lowest compressive strength at 28 days. The blending of slag and fly ash could provide a solution for the need for heat in the curing of fly ash based-geopolymer concrete.

Assi et al. (2016) carried out investigations on the effects of various types of activating solutions, curing procedure and sources of fly ash in relation to the resulting compressive strength. The microstructure of the fly ash based geo-polymer paste along with density, absorption and voids were measured. A couple of activating solutions were used, a mixture of sodium hydroxide, silica fume, and water and a mixture of sodium hydroxide solution, sodium silicate, and water. Materials used for fabrication of the fly ash based geopolymer concrete test specimens included fly ash, activating solution, fine aggregate, water and super plasticizer. In case of the silica fume based activating solution, sodium hydroxide flakes were dissolved in water and silica fume powder was then added and stirred.

It was obtained from the investigations that a high early compressive strength was achieved with fly ash-based geopolymer concrete using type F fly ash and silica fume activating solution, which exhibits the promise of developing and using alternative concrete. The use of silica fume based activating solution resulted in higher compressive strength values as compared to similar specimens cast using sodium silicate based activating solution. The use of different fly ash sources had a significant impact on the compressive strength of fly ash-based geopolymer concrete due to the variation in the particle size distribution and isolated fly ash particles which led to significant differences in the microstructure as well. The high alkalinity of fly ash based geopolymer concrete promoted alkali silica reaction degradation.

Bilek et al. (2016) studied the alkali activated concrete properties by conducting non – destructive tests like compressive strength test, fracture and fatigue property tests were conducted simultaneously. Prisms of 40 mm × 40 mm × 160 mm and 80 mm × 80 mm × 480mm dimensions were molded for the testing purpose and 150 mm cubes were used for compressive strength measurement at the age of 1, 2, 3, 7, 28 and 90 days respectively. Fatigue properties were tested using the three-point bend test of prisms with the central notch, the ratio depth of notch/depth of prism (a/W) of 0.10 and Wohler curves were obtained from tests carried out in a computer-controlled servo hydraulic testing machine.

From the study conducted it was found that some plasticizers provided an enhancement of workability with a relatively sharp point of saturation where as some kinds of melamine and poly sulfonated naphthalene based plasticizers were found to be the best. Mortars with reduced water/ GBFS ratio show good 28-day strengths even if the activator dosage is reduced up to value 6%. Early strengths of mortars with as low activator dosage are low. It is possible to reduce water/GBFS ratio of alkali activated concrete up to a value of 0.40 and reduce activator dosage up to 6% without any negative impact on mechanical properties and frost resistance. Non-destructive tests with Schmidt hammer show a similar course as in the case of concretes with Portland cement. The use of a specific relationship between rebound and compressive strength is recommended.

Chang et al. (2016**)** investigated properties of pervious concrete made with electric arc furnace slag and alkali – activated slag cement. Cylindrical specimens of 10 cm diameter and 20 cm high were casted on which the unit weight test, sound absorption coefficient test, connected porosity test, water permeability coefficient and compressive strength were carried out and as for the British pendulum test, concrete blocks of size 5 cm x 10 cm x 2.5 cm were molded. The optimum mixture obtained in the investigation was of the pervious concrete. The 28-day compressive strength obtained was 35 Mpa, the water permeability coefficient was 0.49 cm/s, the BPN was 79 and the sound absorption coefficient at 125 Hz was 0.94. It was observed that the electric arc furnace slags, porous nature furnished a strong interlocking effect and the AASC was observed to be a stronger binding material than the OPC. Consequently, a high strength pervious concrete is possible and it can be applied to many engineering applications where the water permeability and strength was required at the same time.

Criado et al. (2016) investigated the microstructural and mechanical properties of alkali activated binders based on blends of Colombian granulated blast furnace slag (GBFS) and fly ash (FA). Synthesis of these alkali activated binders was carried out with various slag/fly ash ratios ranging from 100:0, 80:20, 60:40, 40:60, 20:80 and 0:100 at 85Oc for about 24 h. In this study the X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), Scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM/EDS) and Nuclear magnetic resonance (NMR) were conducted to study the mineralogical and microstructural characterizations whereas the mechanical properties were evaluated through compressive strength, modulus of elasticity and Poisson‟s ratio. Based on these results, it was deduced that a couple of reaction products were detected in the slag/fly ash mixtures, a C-A-S-H gel and a N-A-S-H gel with higher number of polymerized species and low content in Ca. It was also observed that with the increase in the amount of slag added, the amount of C-A-S-H gel also gets increased and the amount of N-A-S-H gel is subsequently decreased. The matrix was observed to be denser and compact with the absence of pores. The predominance of slag affected positively the compressive strength, Young‟s modulus and Poisson‟s ratio, with 80% slag and 20% fly ash concrete being the best mechanical performance blend.

Diaz et al. (2016) investigated the effects of the curing temperature on various long term properties and reactions of silicate-activated slag – Metakaolin binders. To evaluate the compressive strength and microstructural evolution, cubic specimens at 20, 60 and 70˚C for up to 520 days were cured. Where in it was observed that by the treatment of fresh pastes at an elevated temperature enhanced the strength development at early ages but in the long run, curing at 20˚C was considered to be more advantageous. For 100% slag pastes, increasing the curing temperature from 20 to 60˚C advocated an intense dissolution of the slag particles and resulted in the formation of a strong microstructure that reached 100 Mpa which contrasted with the pastes of 100% Metakaolin and composites of 50% Metakaolin.

It was also observed that for a rapid strength gain, the highest compressive strengths were observed after curing at 20˚C. Considering the individual formulations, curing at 60˚C was found out to be more beneficial for the slag binders forming dense microstructures, while the contrast was observed in Metakaolin geo-polymers and in composite binders with 50% Metakaolin and the higher temperature favored the initial reactions but caused water evaporation, which affected the reaction processes. The geo-polymeric pastes of 100% Metakaolin exhibited the formation of N-A-S-H gel, with an increase in the Si/Al ratio in proportion with the curing temperature. Curing at 20˚C was observed to be highly advantageous for the compressive strength. Composite binders with 50% Metakaolin were also affected by the temperature, at 60˚C the concentration of Na had a high variability and the average chemical composition of the condensed gel was 7% Ca, 27% Na, 15% Al and 52% Si, manifesting the formation of various phases with the high content of Si and Na and lower concentration of Ca and Al, being more favorable the curing at 20˚C for the advance of the reactions and development of compressive strength.

Kathirvel et al. (2016**)** studied the impact of recycled concrete aggregates which were obtained from the demolished concrete waste on the mechanical properties of geopolymer concrete. River sand was the fine aggregate with a maximum size of about 4.75 mm and crushed granite as coarse aggregate with a maximum size of about 16 mm. Alkaline activation of GGBS was carried out by the use of commercially available sodium hydroxide flakes with 99% purity and sodium silicate solution (Na2O.SiO2.H2O) which was composed of 28% SiO2, 11.2% Na2O and 60.8% H2O by mass. The silica modulus i.e.., the ratio between SiO2 and Na2Owas found to be 2.5. In the present study poly carboxylic ether type super plasticizer, a light brown colored liquid of relative density 1.08 at 25˚C, chloride ion content < 0.2% and Ph value 6 was adopted. Steel bars of 12 and 8 mm diameter were used as the longitudinal reinforcement whereas 6 mm diameter bars were used as shear reinforcements in the beams and were tested under uniaxial tension. The mixes were prepared with an alkaline ratio of 2.0 with a liquid–binder ratio of 0.50 and NaOH concentration of 14M. GGBS and sand were mixed homogenously and the coarse aggregate of desired size and quantity was prepared separately. Dry mix of GGBS-sand was mixed with coarse aggregate thoroughly after which a permissible quantity of super plasticizer was poured into the prepared alkaline solution and stirred for about two minutes to obtain the homogeneity and a heap was formed in the dry mix. Alkaline liquid-super plasticizer solution was gradually poured to get the cohesiveness of the mix in the fresh concrete.

It was finally observed that the reduction in the slump was greatly reduced with the inclusion of super plasticizer with increasing amount of recycled concrete aggregates. The study also showed that the mix with 50% recycled concrete aggregates (GPC50RA) exhibited improved compressive strength and water absorption characteristics.

Liu et al. (2016) carried out investigations on the impact of addition of the incinerator fly ash on mechanical strength, chemical structure and heavy metal leaching of alkaliactivated GGBS – incinerator fly ash binders. Incinerator fly ash is a residue of after incineration of municipal solid waste. Alkali-activated GGBS indicated the enhanced heavy metal immobilization capability. Incinerator fly ash was less reactive than that of the GGBS and due to the high crystallinity and lesser Si and Al content it has a lower efficiency factor of 0.13. At high incinerator fly ash content was observed that about 60% of GGBS was replaced by incinerator fly ash, alkali activated GGBS binders provides a possible measure to utilize incinerator fly ash as construction materials for Civil Engineering applications.

Lopez et al. (2016**)** conducted studies on the statistical analysis (Taguchi method) and characterization of microstructure and products formed by composite binders of urban waste glass/blast furnace slag activated by NaOH and NaOH/Na2CO3. The Taguchi method showed to be an efficient way to optimize the experimental work. This indicates that the influence of each of the factor of % urban water glass, curing temperature, % Na2O and alkali activator ratio at curing ages of 28 and 180 days, depending on the glass content the microstructure and composition of the hydration products varied. The presence of waste glass became an important factor for the enhancement of strength which indicated a variation in the kinetics of reactions among the slag and the waste glass. The slag and waste glass particles dissolved under the alkaline attack resulting in the formation of cementitious products. The particles of slag showed rims of reaction products, but not the waste glass, indicating different mechanisms of reaction.

Paiste et al. (2016) experimented and assessed the potentiality of oil shale ash wastes as a source material for the geopolymeric or alkali activated construction materials using structural, XRD, SEM, SEM-EDX, ATR-FTIR and Si MAS-NMR methods respectively. Four different series of mixtures were prepared after which the fresh paste was poured into a 40 mm-high and 40 mm-diameter cylindrical mold and was placed on vibrating plate for about a minute, the mixing was then carried out in the laboratory environment at an ambient temperature of 22˚C and relative humidity of 50 % –55 %, after which they were subjected to curing under the same conditions in the open air for a period of 7 and 28 days.

The results obtained from the experimentation indicated that a fresh oil shale ash can be used to manufacture materials with amorphous C-(A)-S-H matrix that exhibit geopolymeric properties which could eventually be used as a replacement binder in the production of construction materials. In different alkali media it is shown that the alkaline medium alone is not ample to dissolve the glass phases in the ash and an additional source of silicate is required to achieve the polymerization and enhancement of strength. The Si MAS-NMR, ATR-FTIR and SEM-EDS results implied that this phase in the samples activated using soluble silicate containing solutions is predominantly a depolymerized one dimensional structure, a structure of the amorphous phase and its formation is controlled by the dissolution and presence of reactive calcium bearing phases and the amount of soluble silicate in the activator solution.

Rashad et al. (2016) investigated by using quartz powder to improve the workability as well as the compressive strength of alkali-activated fly ash (AAFA) pastes before and after exposure to thermal loads. The specimens were exposed to thermal loads of about 400˚C to 1000˚C with a heating rate of 6.67 ˚C/min for about a time period of 2 h. By using X-Ray diffraction (XRD) and thermo gravimetric (TGA) techniques different decomposition phases formed upon exposure to thermal loads were detected. The results obtained displayed that with an increase in the content of quartz powder, the workability and compressive strength variably increased before and after firing. In AAFA matrix flow ability increased with increase in the amount of quartz powder. Quartz powder content increased in the sample, the higher the compressive strength was obtained this is because quartz powder can fill the pores inside the microstructure of fly ash/quartz powder pastes as well as quartz powder containing large amount of silica. Compared to AAFA paste, the included 30% quartz powder can enhance the 7, 28 and 91 days compressive strength by approximately 2.38, 3.42 and 1.96 folds respectively. Activated fly ash/quartz powder pastes used in the applications of fire resistance.

Rashad et al. (2016) studied the effects of GGBS (slag) pastes when they were chemically activated by using sodium silicate with different Na2O concentrations of 3.5, 5.5, 6.5 and 10.5%, by slag weight. The specimens were subjected to elevated temperatures ranging from 200˚C to 1000˚C with an increment of 200˚C for about 2 h. The compressive strength was obtained and also the water quenching test was carried out to determine the thermal shock resistance. Various decomposition phases were formed and the morphology of formed hydrates was identified using X-ray diffraction (XRD), thermo gravimetric analysis (TGA), derivative thermo gravimetric analysis (DTG), scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS). Finely ground slag was utilized to obtain a surface area of about 300 m2 /kg with specific gravity of 2.9. Four alkali activated slag paste mixtures were prepared which were activated with sodium silicate and were formulated with concentrations of Na2O estimated at 3.5, 5.5, 6.5 and 10.5%, by slag weight. The mixtures were designated as N3.5, N5.5, N6.5 and N10.5, respectively.

It was observed that Na2O concentration had a greater effect on the compressive strength before and after being exposed to different elevated temperatures. As concentration of Na2O increased, the matrices of hydration products were observed to be more compact and dense and also the compressive strength increased. Increasing the concentration of Na2O up to 10.5% did not display any further increase in the strength instead a reducing trend of the strength was observed. The hardened alkali activated slag pastes aggravated the lower concentration of Na2O displayed an enhanced thermal shock resistance than that of the other pastes. The thermal shock resistance of the pastes activated with lower Na2O concentration showcased that it was 1.67 times greater than that activated with higher concentrations of Na2O.

Song et al. (2016) investigated the effects of internal curing by the use of super absorbent polymers for mitigating the autogenous shrinkage of alkali-activated slag mortars. By using different dosages of super absorbent polymers to determine the compressive strength, internal relative humidity and autogeneous shrinkage of alkali activated slag mortars. Test results obtained showed that as the dosage of super absorbent polymers increased, reduction of the internal relative humidity owing to self-desiccation and autogeneous shrinkage both decreased, indicating that the super absorbent polymers can be effectively used as internal curing agents. Modeling of the internal curing zone is useful in determining the appropriate dosage of super absorbent polymers in alkali activated slag mortars. To determine the autogenous shrinkage the minimum dosage of super absorbent polymers is required.

Soutsos et al. (2016) investigated various factors affecting the reactivity of fly ash as a precursor for geopolymer concrete, which included physical and chemical properties of various fly ash sources, inclusion of GGBS, chemical activator dosages and curing temperature. Geopolymer and alkali activated binders were found to offer a possible alternative to Portland cement concrete. A mixture of sodium hydroxide and sodium silicate was used in the present study after which a detailed physical and chemical characterization was carried out on thirteen fly ash sources. Micro-structural characterization with scanning electron microscope (SEM) coupled with energy dispersive X-ray spectroscopy (EDS) was performed on fly ash/GGBS pastes and the reaction product of fly ash and GGBS obtained in these binary systems was calcium aluminum silicate hydrate gel (C–A–S–H) with inclusion of Na in the structure. From the investigations it was observed that the curing temperature had a very significant effect on the strength of the fly ash based geopolymer specimens which were cured at 70˚C and were observed to be considerably stronger than that of the specimens which were cured at 50˚C. To achieve the required early age properties along with the effect of compressive strength, the dosage of activators was found to be highly important. Often dubbed as „sweet spot" of the optimum alkali modulus and dosage combinations, alkali dosage of 12.5 % and alkali modulus of 1.25, displayed a compressive strength of about 70 Mpa. The important which was observed to be affecting the factors such as the potential compressive strength was the average grain size. C-A-S-H gel with inclusions of Na+ cations in the structure was found in the samples containing GGBS. This was denser than the N–A–S–H gel found for 100% fly ash samples and this could explain the improved compressive strengths.

M. Adaway & Y. Wang (2015) In this research work it was found out that the flow ability of concrete has reduced trend with surge in fraction of fine aggregate since the glass particles have angular nature. Even there is a decreasing trend the concrete is workable. Optimum percentage was found out to be at 30% of fine total is substituted by fine glass. There is gain in resistance towards compression at optimal substitute of standby. There's a improved bond with the cement adhesive. By using beyond 30% it was found out that there was a negative effect on compressive strength. If in larger quantities are used, voids will be formed in the microscopic level in the concrete since cement paste will be reduced due to the angular shape of the glass total used.

Rosan Lal and Kuldeep Kumar (2014), investigated on strength characteristics of concrete containing natural aggregate and with partial replacements by granite and marble waste aggregates with different percentages. Results revealed that the compressive strength increases up to 30% replacement of granite and marble waste with equal proportions, beyond 30% the compressive strength decreases slightly. Therefore, it can be concluded that production of concrete with normal strength by the waste marble and waste granite aggregates without compromising the strength characteristics.

Zhang et al. (2016) investigated the mineralogical and elemental compositions in six alkali-activated cements which were prepared by sodium silicate-activated ternary systems of fly ash, slag and silica fume under ambient conditions. The dominant reaction products were C-(N)-A-S-H which were derived from the hydration of slag and N-I-A-S-H derived from activation of fly ash. It was observed that the Alkali activated cements were poorly crystalline and extremely heterogeneous in nature of the reaction products at 1 year by using XRD and SEM coupled with EDX. There was no clear compositional boundary to separate the two hybrid gels and by comparison with the composition of the gel, the porosity and pore structure were observed to be more relative and determining to the compressive strength development of the alkali-activated cements.

3. PROPOSED SYSTEM

The proposed system focuses on developing Marble Waste-Based Alkali-Activated Concrete (AAC) as a sustainable alternative to traditional Ordinary Portland Cement (OPC) concrete. The system aims to enhance the mechanical properties of AAC while reducing environmental impact by incorporating industrial by-products such as Ground Granulated Blast Furnace Slag (GGBS), Fly Ash, and Marble Waste.

1. Materials and Mix Design

- **Binders:** A combination of 60% Fly Ash and 40% GGBS is used as the primary cementitious material.
- **Alkali Activation:** Sodium Hydroxide (NaOH) with a 10M molarity and Sodium Silicate (Na_2SiO_3) are used for activating the binders.
- **Coarse Aggregate Replacement:** Marble waste replaces coarse aggregate at varying levels (0%, 10%, 20%, 30%, 40%, and 50%).
- **Curing Methods:** Two curing conditions are implemented:
    - Oven Curing (60°C)
    - Ambient Curing (7 & 28 Days)

2. Workability Assessment (Slump Test)

The slump test is performed to determine the workability of AAC with different percentages of marble waste. The results indicate a gradual decrease in workability as the percentage of marble waste increases, highlighting the need for adjustments in mix design to balance both workability and mechanical performance.

3. Hardened Properties Evaluation

- **Compressive Strength Test:**
    - Concrete cubes (15 cm × 15 cm × 15 cm) are cast and tested to evaluate compressive strength.

- The results show that compressive strength increases up to 30% marble waste replacement and then decreases, with peak strength observed at 30% replacement for 28-day ambient curing (68 N/mm²).
- Oven-cured specimens also show significant strength gain, reinforcing the efficiency of alkali activation.

4. Key Findings

- **Optimal Performance:** 30% marble waste replacement achieves the highest compressive strength.
- **Workability Reduction:** Increasing marble waste reduces the slump value, impacting concrete flowability.
- **Sustainability Impact:** The proposed system significantly reduces cement dependency, lowering CO_2 emissions and promoting waste utilization in construction.

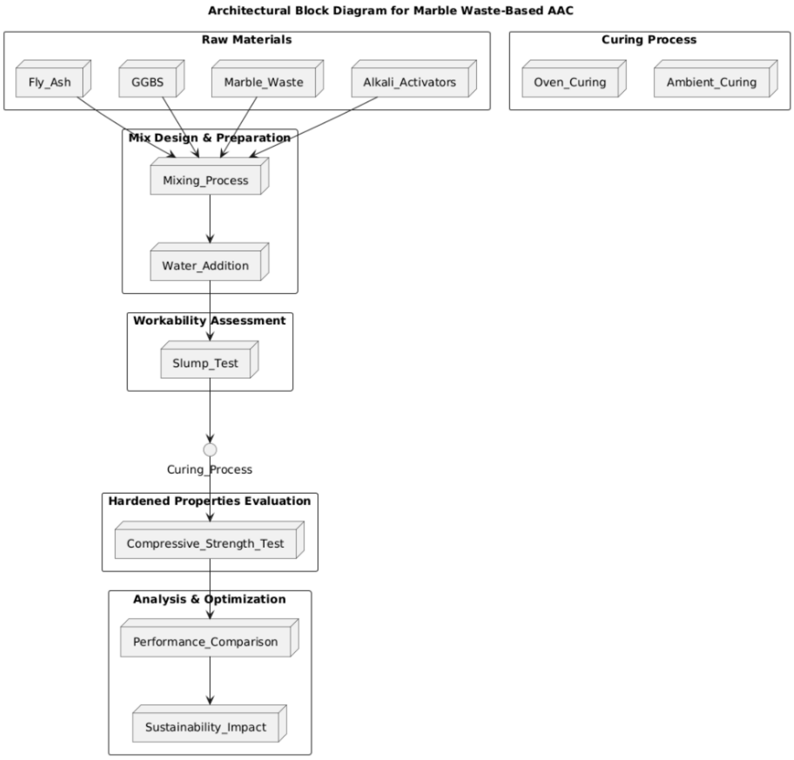

Figure 1 Presents the Block Diagram of Proposed System.

4. RESULTS AND DISCUSSIONS

The plot of the AAC concete, slump values for different percentages of marble waste is shown in Table 5.1 & Fig 5.1, according to which it can be concluded that with the increase in % Marble waste from 10 to 50% workability decreases.

Table 4.1 Slump values

MW (%)	Slump (mm)
0	100
10	95
20	93
30	90
40	87
50	85

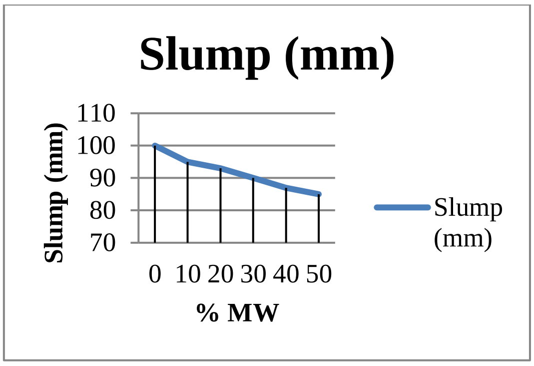

Fig 4.1 Slump values

4.2 Harden properties of concrete

4.2.1 Compressive Strength Test

The compressive strength test was performed on the cubes of size 15 cm x 15 cm x 15 cm to check the compressive strength of marble waste-based alkali activated concrete and the results obtained are given in Table 5.2. From the below results it was observed that with the increase in percentage of marble waste from 0% to 30% in AAC the compressive strength increases after that decreases. The maximum strength gained for 28days ambient curing with 30% replacement of coarse aggregate with waste marbles.

Table 4.2 Compressive strength

MW (%)	Compressive strength (N/mm2)		
	Oven curing (60^0C)	Ambient curing	
	1 day	7 days	28days
0	25	39	58
10	27	42	62
20	28	43	65
30	31	48	68
40	27	45	60
50	20	40	59

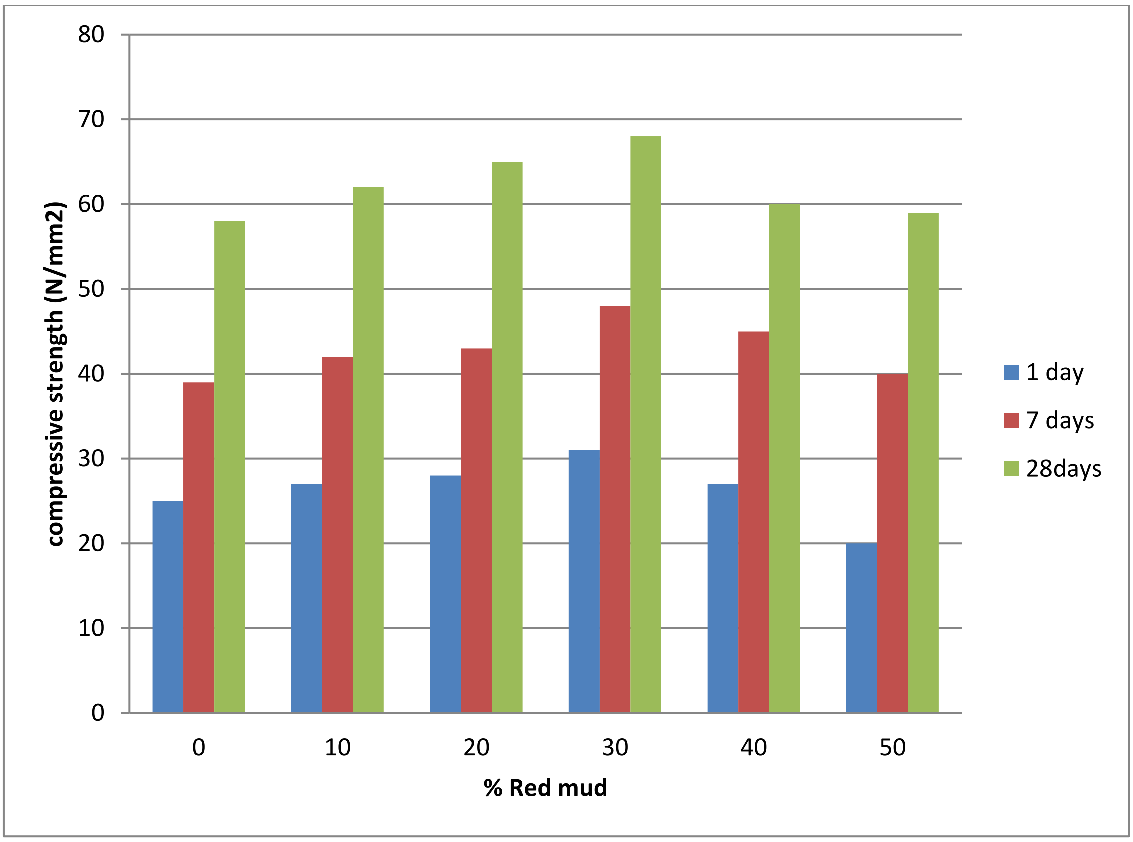

Fig 4.2 Compressive strength graphs

5. CONCLUSION

The study on Marble Waste-Based Alkali-Activated Concrete (AAC) demonstrates its potential as a sustainable alternative to conventional concrete. The findings indicate that AAC specimens exhibit higher compressive strength under ambient curing compared to oven curing, with a peak strength of 68 MPa at 28 days for 30% marble waste replacement—a 17.24% improvement over the control mix. This highlights the beneficial role of marble waste in enhancing AAC performance. Additionally, by completely replacing cement with Fly Ash and Ground Granulated Blast Furnace Slag (GGBS), AAC significantly reduces carbon dioxide emissions, addressing environmental concerns associated with traditional cement production. The successful integration of marble waste as a coarse aggregate substitute further supports resource conservation by minimizing dependency on natural granite. With low energy requirements and reduced CO_2 emissions, AAC presents a promising solution for sustainable construction and the future development of eco-friendly concrete materials.

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