

Compressive Strength and Water Absorption Relationship of Alkaline Activated Concrete

S.Dhavamani Doss, S.Thirugnanasambandam, P.Murthi, K.Poongodi



ABSTRACT: Sustainability is an emerging term in the field of innovative materials for productions, especially in construction arena. There are numerous complications such as global warming, material exhaustion and high energy loss. These are the freezing issues ascends in the world due to the urbanisation enlargement. In this research, conventional concrete and alkaline activated concrete are cast to find the suitability of new sustainable material for making concrete. Cement is replaced by silica and rich reactive silica materials such as fly ash and Ground Granulated Blast Furnace Slag (GGBS). Further river sand is replaced with M-Sand. By replacing these materials, the reduction of CO₂ emission and exhaustion of river sand can be minimised. Three different combinations of materials are tried for M40 grade with the mix ratio of 1: 1.63: 2.64. The experimental investigations exhibit that, the alkaline activated concrete with river sand and M-Sand are better in compressive strength than conventional concrete. Alkaline solution is used in concrete matrix for activating the binding property of alkaline activated concrete.

Key Words: Alkaline solution, Binding property, M-sand, Eco-friendly concrete.

I. INTRODUCTION

The materials are the important phenomenon which develops the life style of the human beings. The life style of the people before a century and today is not similar. This dissimilarity in their life is because of the kind of materials available at that particular era. So the nature of the human life is mainly depends upon the kind of materials. At the moment, the availability of natural raw materials are a million dollar question, especially in the field of construction. An important accomplishment in the construction industry is the development of concrete. It is generally made up of cement, river sand and crushed stone.

At present, there is a lot of setbacks in producing concrete. The production of the concrete is mainly influenced by the availability of raw materials. The increase in the use of these raw materials will make an imbalance in ecosystem. At present, the availability of these raw materials are becoming scarce. Cement is enriched with calcium and silica. This makes it, an inevitable material as a binder in concrete.

Revised Manuscript Received on February 28, 2020.

* Correspondence Author

S.Dhavamani Doss*, Research Scholar, Structural Engineering Department, Annamalai University, Annamalainagar, India.

S.Thirugnanasambandam, Professor, Structural Engineering Department, Annamalai University, Annamalainagar, India.

Dr.P.Murthi, Centre for Construction Methods and Materials, Department of Civil Engineering, S R Engineering College, Warangal, India. E.mail:dr.murthi@srecwarangal.ac.in.

Dr.K.Poongodi, Centre for Construction Methods and Materials, Department of Civil Engineering, S R Engineering College, Warangal, India.

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The increased utilization of cement in the construction field creates vulnerable effects to the environment [1-2]. Production of cement increases the rate of emission of carbon dioxide in the atmosphere.

The rate of emission of carbon dioxide is 100% from the cement industry. Due to this the pollution rate is increased, resulting in global warming [2].

The production of cement also involves high utilization of natural limestone and energy. The energy used for calcination process is very high next to energy used in the steel plant. To resolve these problems, evolution of new eco-friendly material must occur. On the other side the continuous usage of sand from river for construction leads to serious issues in the ground water table. It takes hundreds of years to form river sand by weathering of rock. The continuous usage of river sand endangers its availability. It is mandatory to reduce the use of natural river sand to maintain the environment balance. Now the focus of the construction industries turned on finding an eco-friendly material for producing concrete. Since the need for concrete is vastly increasing due to the development of infrastructure. The main purpose of this research is to enhance the concrete production without affecting the environment by developing sustainable concrete called alkaline activated concrete. It is produced by using silica and aluminum rich materials such as fly ash [2], rice husk ash [3] Ground Granulated Blast Furnace Slag (GGBS) [2], Bagasse ash [4] and silica fume [5]. Cement is replaced by fly ash and GGBS. Simultaneously the river sand is replaced by M-Sand. In this concrete an alkaline reagent solution is required to activate the binding property of the binder material (fly ash and GGBS) hence the concrete is known as alkaline activated concrete. Development of this concrete will be appropriate to find solutions to resolve the difficulties in the traditional concrete production.

II. ALKALINE ACTIVATED CONCRETE

Alkaline activated concrete is a mixture of alkaline activated cement (fly ash + GGBS), fine aggregate, coarse aggregate and alkaline reagent solution. The Figures 1-5 shows the materials used for making alkaline activated concrete. The concrete is known as alkaline activated concrete since the binder used in this concrete is activated by alkaline reagents. The alkaline reagents is a mixture of potassium or sodium hydroxide and potassium or sodium silicate solution with minor amount of water. The alkaline reagent is used to trigger the binding ability of alkaline activated cement or silica-aluminum rich cement with other filler materials.

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The alkaline activated concrete is also known as geopolymer concrete. The name geopolymer was characterized by Joseph Davidovits in 1978 [6-7]. The alkaline activated concrete has a lot of advantageous over normal cement concrete such as quick hardening, ecofriendly, fire resistance, ambient curing etc. [1,6].

A. Alkaline Activated Cement

Alkaline activated cement is generally classified into four types, such as the slag based geo-polymer cement, the rock based geo-polymer cement, the fly ash based geo-polymer cement and the ferro-silicate based geo-polymer cement. In this, fly ash based geo-polymer cement is further classified as alkali activated fly ash geo-polymer cement and slag/fly ash based geo-polymer cement. Slag/fly ash based geo-polymer cement is chosen to achieve the hardening of concrete in ambient conditions [5]. The hardening of geopolymer cement is entirely different from the Ordinary Portland Cement. The hardening of alkaline activated concrete is not attained by the hydration process. In alkaline activated concrete, hardening is attained by polycondensation process where sodium oligo (sialate – siloxo) into sodium poly (sialate – siloxo) cross linked network [2,6]. The reaction of polycondensation of sodium based geopolymer concrete is mentioned [8]. Combination of fly ash and GGBS are added in a ratio of 50:50. Fly ash and GGBS are rich reactive silica material which will readily react with alkaline reagents to form a binder to the alkaline activated concrete.



Fig.1. Fly Ash



Fig.2. GGBS



Fig.3. River Sand



Fig.4. M Sand



Fig.5. Alkaline Reagent Solution

B. Fly Ash.

Fly ash is generally, a byproduct but it is considered as hazardous waste material from the thermal power plants. Fly ash is classified into class C type fly ash and class F type fly ash. Class C type fly ash consists of high calcium content more than 10% and it is known as high calcium fly ash. Class F type fly ash consists of calcium content lesser than 10% and it is known as low calcium fly ash. Among these two types of fly ash, low calcium fly ash is used for making alkaline activated concrete [7]. Low calcium fly ash is collected from the Mettur thermal power plant, Tamil Nadu. The specific gravity of fly ash is 2.1. The particle size of fly ash ranges from 4 to 16 micro meter. The bulk density of fly ash is 995 kg/m³ and the specific surface area of fly ash 410 m²/kg.

C. Ground Granulated Blast Furnace Slag.

GGBS is a byproduct from the steel industries. GGBS is an efficient material for the replacement of Ordinary Portland Cement. GGBS consists of ample amount of calcium silicates and other constituent of a cementitious material. GGBS is developed simultaneously with iron in the blast furnace in molten condition [7]. GGBS was added with the geo-polymer cement to enable hardening of cement in ambient temperature and it also improves the mechanical property of the cement paste [8]. The GGBS is brought from a steel manufacturing industries. The specific gravity of GGBS is 2.65. The particle sizes of GGBS ranges from 0.4 to 40 micro meter. The bulk density of GGBS is 1220 kg/m³ and the specific surface area of GGBS is 422 m²/kg.

D. Ordinary Portland Cement (OPC)

OPC is used to cast conventional concrete specimens for the comparison of results with alkaline activated concrete. OPC 53 grade cement is used for casting research specimens. The specific gravity of cement used is 3.15. The particle size of OPC is ranges from 6.6 to 31 micro meter. The specific area of OPC is 337 m²/kg. OPC used for casting concrete is confirming IS 12269:1987.

C. Alkaline Reagent Solution (ARS)

Alkaline reagent solution is mandatory for the use of alkaline activated concrete [13]. Mostly, alkaline reagent is differentiated into two categories such as hostile product and friendly product. User friendly alkaline reagent is chosen for casting concrete specimen. The usage of hostile reagent requires usage of glasses, gloves and mask are must for safety considerations [3] hence it is only suitable for laboratory purposes. Till now for casting alkaline activated concrete, user-friendly reagent product is advisable. The alkaline reagent solution used is a fusion of sodium hydroxide solution with a molar concentration of 10 M [4]. The ratio of alkaline reagent solution to fly ash is chosen as 2.5. 10 molarity of ARS is obtained by dissolving 400 grams of sodium hydroxide pellets in 1000 ml of water. The concentration of the solution will influence the compressive strength of the alkaline activated concrete specimen. Higher addition of water to the alkaline reagent solution will decrease the strength of the concrete. For cost-effective and superior performances, sodium hydroxide and sodium silicate solution are utilized [8]. The ARS will kindle the binding capability of fly ash. The ARS concentration rely upon the amount of sodium hydroxide liquefied in the solution. The properties of sodium hydroxide and sodium silicate solution are given in Table 1 and 2.

D. Fine Aggregate

Investigation being carried out to replace fine aggregates are replaced by alternate materials like M-sand and waste silica mineral waste [10]. This investigation was carried out for casting concrete specimen with river sand and M-sand. Locally available river sand is used for casting concrete specimens. The specific gravity of river sand is 2.68 and falls under the zone II. River sand is used and confirming the IS 383:1970. The fineness modulus of sand is 3. The usage of M Sand have been started for practice in construction industries to overcome the drawbacks [12] in using river sands such as extinction of river sand, rough packing of particles in concrete matrix and etc. It is manufactures in industries, which will ensure proper particle shape and size of the material. The impurities present in the M Sand can be removed. The cubical shape of the M-Sand will ensure the packing of the matrix and will increase the mechanical properties of the alkaline activated concrete. The specific gravity of M sand is 2.70. The particle sizes of M Sand, ranges from 0.4 to 40 micro meter. The bulk density of M Sand is 1820 kg/m³ and the fineness of modulus of M Sand is 2.85 and M Sand chosen is confirming the IS: 383-1970 and falls under the category zone II.

E. Crushed Stone Aggregate (CSA)

The natural CSA is used. Clean hard and dense crushed granite stone of size passing 20 mm and retained 12.5 mm sieves were taken for the study. The specific gravity of CSA used was 2.70. The fineness modulus of CSA used was 6.75 and the bulk density of 1535 kg/m³. The CSA chosen for test confirms the IS: 2386-1963 part IV and V.

F. Super Plasticizer (SP)

The Conplast 430 with a specific gravity of 1.2 was used for casting of concrete. The SP used was a naphthalene based agent. The percentage of SP used was 0.50 by weight of cementitious material.

Table 1. Specification of sodium silicate solution

Specification	
Chemical Formula	Na ₂ O x SiO ₂ (Colour less)
pH	Neutral
Assay of Na ₂ O	7.5-8.5%
Assay SiO ₂	25-28%
Wt per ml 20°C	1.35 g/ml
Appearance	Liquid (Gel)

Table 2. Specification of sodium hydroxide solution

Specification	
Purity	97% min
Sulphate (SO ₄)	0.05% max
Potassium (K)	0.1% max
Zinc (Zn)	0.02% max
Chloride (Cl)	0.1% max
Silicates (SiO ₃)	0.05% max
Iron (Fe)	0.001% max

III. INVESTIGATIONAL REPORT

A. Mix Proportion

Three mixes with three different materials are successfully cast. The grade of concrete was proportioned for M40 grade. OPC, river sand and crushed stones are used for conventional concrete (CC). Alkaline activated cement, river sand and crushed stone are used for casting alkaline activated concrete with river sand (GPCRS). Alkaline activated cement, M Sand and crushed stones are used for casting alkaline activated concrete with M Sand (GPCMS). The ratio was not changed for all the mix proportions as 1: 1.63: 2.64. The alkaline reagent solution was chosen as 2.5. The molarity of the solution is 10 M. The alkaline reagent solution to fly ash ratio is taken as 0.38. The alkaline reagent solution was prepared before 24 hours prior to mixing of alkaline activated concrete. The sodium hydroxide solution was prepared by mixing sodium hydroxide pellets with sufficient water. Then sodium silicate solution has been mixed with the sodium hydroxide after an ample period. The mixed solution is kept in room temperature for 24 hours.

B. Casting and mixing of Control Concrete (CC) and GPCRS (Alkaline Activated Concrete with River Sand) and GPCMS (Alkaline Activated Concrete with M Sand)

CC was cast by using materials such as OPC and river sand are mixed for 2 minutes under dry condition. 75 % of the water is mixed with concrete materials initially and the remaining 25 % of water is mixed with SP. Then the water with SP was mixed well and it is applied to the concrete mix and mixed thoroughly. Then concrete was poured into steel moulds of size 150mm x 150mm x 150mm. Slump value of 65 is obtained through slump cone test in the laboratory. For GPCRS river sand is mixed with the concrete mix and M Sand is used for GPCMS. In alkaline activated concrete mix SP is added with 25 % of ARS. Other than this the mix procedure were same for both conventional and alkaline activated concrete. Figure 6 shows the mixing and casting of cube specimens. In addition water absorption of cubes was also conducted. The cube specimens were kept under water for 24 hours for water absorption and the saturated specimens were placed in an oven for drying for 24 hours for measuring the water absorption.

C. Curing and testing of specimens

The compressive strength is determined by testing cube specimens under uniaxial compression. The conventional cube specimens are exposed to water curing for 28 days. The alkaline activated concrete is exposed to ambient curing for 24 hours [12]. The conventional cubes take 28 days for complete (90%) hardening while alkaline activated concrete takes 24 hours for hardening. The compressive strength of conventional concrete specimens at 7, 14 and 28 days are given in Tables 3-5. Figure 7 and 8 shows the ambient curing of the concrete specimen. The compressive strength of alkaline activated concrete with river sand and M-Sand are given in Table 6 and 7.



Fig.6. Casting of Concrete Cube Specimens



Fig.7. Ambient curing of concrete specimens



Fig.8. Testing of concrete specimens

IV. RESULTS AND DISCUSSIONS

A. Compressive strength

The compressive strength test is successfully conducted on the concrete specimens and the strength development are shown in Figure 9. Among them alkaline activated concrete with M-Sand shows better strength. The experimental result shows that the alkaline activated concrete performs well. The alkaline activated concrete attains higher value than the conventional concrete. Alkaline activated concrete achieved its maximum strength within 7 days. The conventional concrete achieved its maximum strength at 28 days. The Figure 9 shows that the 7 days compressive strength of alkaline activated concrete are higher than the 28 days compressive strength of conventional concrete. Among the compressive strength of alkaline activated concrete, M Sand based concrete shows higher strength than the river sand based concrete is shown in Figure 9. The increase in strength in alkaline activated concrete is attributed to the presence of silica-aluminum rich cementitious materials. The smaller particle size of fly ash, GGBS and the addition of alkaline reagent solution improves the binding property of the alkaline activated concrete.

B. Water absorption

The water absorption test results of conventional concrete and alkaline activated concretes are shown in Figure 10. The experimental result shows that the alkaline activated concrete performs well when compare with conventional concrete. Among the alkaline activated concrete, M-sand based alkaline activated concrete shows better strength than Fly ash based concrete. Figure 10 shows that the 7 days absorption of alkaline activated concrete are lower than the 28 days the conventional concrete. Figure 11 had shown the comparison between compressive strength and water absorption of the corresponding specimen conventional and alkaline activated concrete. The linear correlation was predicted as $f_c = -3.6549 (w) + 86.584$ with higher correlation coefficient as 0.9111, where w is the water absorption of concrete.

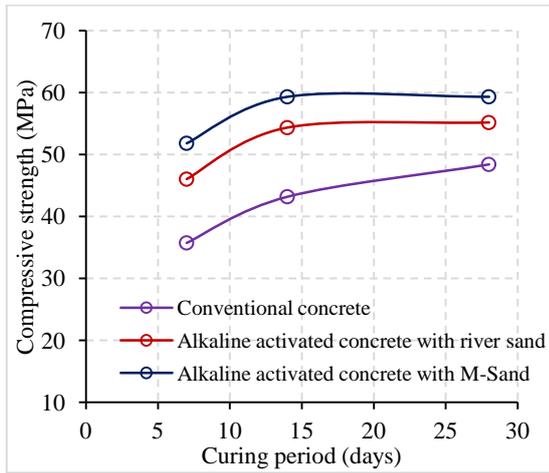


Fig.9. Comparison strength variations of Alkaline activated concrete

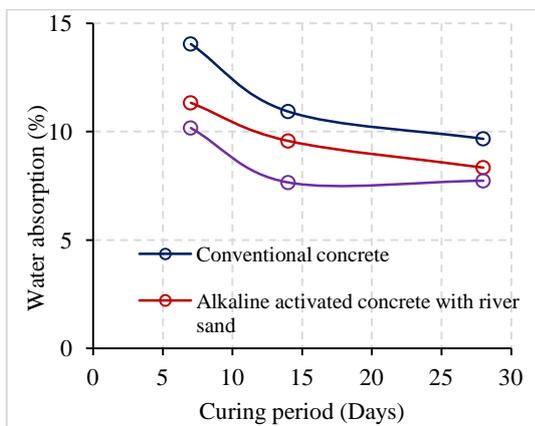


Fig.10. Water absorption variations of alkaline activated concrete

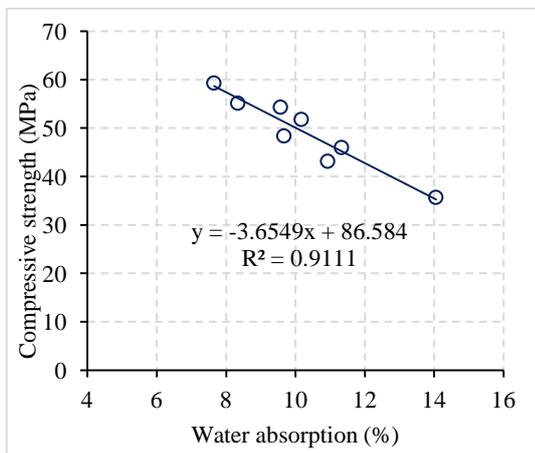


Fig.11. Water absorption variations of alkaline activated concrete

V. CONCLUSIONS

Alkaline activated concrete with M sand and river sand are successfully cast and compared with the compressive strength of conventional concrete. From the results, it is found that the alkaline activated concrete with M Sand achieved higher compressive strength compared to conventional and alkaline activated concrete with river sand. At same time the alkaline activated concrete with river sand achieved higher strength than the conventional concrete but lesser strength compared to alkaline activated concrete with

M Sand. The compressive strength of alkaline activated concrete with M-Sand is 27.7% higher than cement concrete and 10.33 % higher than alkaline activated concrete with river sand. The water absorption of alkaline activated concrete achieved lower than the conventional concrete. The correlation between compressive strength and absorption was found as $f_c = -3.6549 (w) + 86.584$ with higher correlation coefficient as 0.9111.

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AUTHORS PROFILE



Mr. S.Dhavamani Doss, is a research scholar in the department of civil and structural engineering at Annamalai University. He completed his undergraduate and postgraduate degree in civil and structural engineering at Annamalai University during 20011 and 2013 respectively. His area of interest is geopolymer concrete, behavior of concrete members.



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Dr.S.Thirugnanasambantham, working as Professor in Department of Civil and Structural Engineering, Annamalai University. He has more than 30 years of academic experience. He has published more than 90 papers in conferences and journals. Currently, guiding 4 Ph.D research scholars and he is member of doctoral committee member of various universities. His area of interest is Geo-polymer concrete, repair and rehabilitation of structures.



Dr.P.Murthi, working as Professor in Department of Civil Engineering at S R Engineering College, Warangal, Telangana State. He has published more than 50 research papers in indexed journals and conferences. He has 32 years of teaching experience including 12 years of research experience. He guided 5 Ph.Ds and currently 1 Ph.D scholar pursuing Ph.D under his supervision.



Dr.K.Poongodi, working as Professor in Department of Civil Engineering at S R Engineering College, Warangal, Telangana State. She has published more than 10 research papers in indexed journals and conferences. She has 14 years of teaching experience including 6 years research experience.