International Journal of Advance Research in Science and Engineering
Vol. No.4, Special Issue (01), September 2015
www.ijarse.com
IJARSE
ISSN 2319 - 8354

ASSESSMENT OF DEMOLISHED CONCRETE AS COARSE AGGREGATE IN GEOPOLYMER CONCRETE

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ABSTRACT

Concrete is widely used material for various construction activities due to its versatile character. But it causes environmental pollution that causes by production of Portland cement and cause by the increasing of construction waste materials. Low calcium Fly ash and alkaline liquid as a binder is being used to replace the Portland cement to produce geo polymer concrete is one of the methods to reduce the environmental pollution. The alkaline liquid that been used in geopolymerisation is the combination of sodium hydroxide (NaOH) and sodium silicate (Na2SiO3). This study discusses the possibility to replace natural coarse aggregate with demolished concrete in the geo polymer concrete and the structural characteristics of geo polymer concrete were studied using demolished concrete as a complete replacement for coarse aggregate. Different molar of sodium hydroxide (NaOH) which are 8M, 10M and 12M were adopted. The development of compressive strength, split tensile strength and flexural strength of geopolymer concrete at the age of 3 & 7 days were studied after oven curing at 80^{0}C .By the production and use of demolished concrete, these advantages include that lower environmental pollution, reduction in valuable landfill space, and savings in natural aggregate resources.

I. INTRODUCTION

The usage of concrete is second only to water. Concrete is one of the most widely used construction material and Ordinary Portland cement is the key ingredient of concrete. However, large amount of natural resources such as limestone, fossil fuels, electricity, and natural gas are required in Portland cement concrete production. High temperatures are required in the production of PC, and calcination of limestone has resulted in a larger amount of carbon dioxide (CO_2) emission into the atmosphere Therefore, the production of PC is extremely resource and energy intensive process. Several studies have been carried out to reduce the use of Portland cement in concrete to address the global warming issues. These include the utilization of supplementary cementing materials such as fly ash, silica fume, granulated blast furnace slag, rice-husk ash and metakaolin. These pozzolanic materials contain rich silicon (Si) and aluminium (Al) and can also be used to produce geo-binder when mixed with alkaline solutions. Geopolymer concrete (GPC) proposed by Joseph Davidovits [1988; 1994] and it was an alternative binder system with source material to produce concrete eliminating cement. The most common alkaline liquid used in geopolymerisation is a combination of sodium hydroxide or potassium hydroxide and sodium silicate or potassium silicate. Geopolymer binders are used together with aggregates to produce geopolymer concretes which are ideal for building and repairing infrastructures and for precasting units. Production and utilization of concrete is rapidly increasing, which results in increased consumption of natural aggregate as the largest concrete component. A possible solution to these problems is to recycle demolished concrete and produce an alternative aggregate for structural concrete. Thus in recent years, the use of recycled concrete aggregate has gained tremendous momentum in constructional engineering.

In this project demolished concrete is used as coarse aggregate for making the geopolymer concrete. It involves breaking, crushing and removing irrelevant and contaminated materials from existing concrete and then using it for making geopolymer concrete.

II. EXPERIMENTAL PROGRAM

This experiment studies the strength characteristic of geopolymer concrete that containing demolished concrete coarse aggregates. The studies were carried out using two different types of demolished concrete with different strength class and different mixture proportions were used to find the influence of concentrations of NaOH solution and different total aggregate content. Compressive strength, flexural strength, split tensile strength were conducted at 3 and 7 days, and water absorption test conducted at 28 day.

2.1 Materials

2.1.1. Fly ash

Fly ash is a by-product after combustion of coal. Fly ash used in the study was low-calcium (ASTM Class F) dry fly ash sourced from Mettur Thermal Power Station in Tamilnadu. The specific gravity of fly ash used was 2.14. Class F fly ashes are produced from bituminous and sub bituminous coals and contain alumina silicate glasses as active components. This fly ash is pozzolanic in nature and contains less than 10% lime (CaO). The chemical composition of fly ash as per the manufacturer is summarized in Table 1.

Table 1. Chemical Composition of Fly ash

Sl No.	Characteristics	Content in %
1	$SiO_2 + Al_2O_3 + Fe_2O_3$	93.60
2	SiO_2, % by mass, min	60.50
3	MgO, % by mass, min	0.67
4	SO_3, % by mass, min	0.66
5	Na_2O, % by mass, min	0.28
6	Total Chlorides, % by mass	0.01

2.1.2. Alkaline Liquid

Generally alkaline liquids are prepared by mixing of the sodium hydroxide solution and sodium silicate at the room temperature. When the solution mixed together, the both solution start to react (i.e. polymerization takes place) and it liberate large amount of heat so it is recommended to leave it for about 24 hours thus the alkaline liquid is get ready as binding agent.

Generally NaOH is available in market in pellets or flakes form with 96% to 98% purity where the cost of the product depends on the purity of the material. The mass of NaOH solids in a solution varies depending on the concentration of the solution expressed in terms of molar, M. For instance, NaOH solution with a concentration of 8M consisted of 8x40 = 320 grams of NaOH solids (in flake or pellet form) per litre of the solution, where 40 is the molecular weight of NaOH. Similarly, the mass of NaOH solids per kg of the solution for other concentrations were measured as 10 M: 314 grams, 12 M: 361 grams. Note that the mass of NaOH solids was only a fraction of the mass of the NaOH solution, and water is the major component. The specific gravity of Sodium Hydroxide was 1.37.

Sodium Silicate is also known as water glass which is available in the market in gel form. The ratio of SiO_2 and Na_2O in sodium silicate gel highly affects the strength of geopolymer concrete. The chemical composition of various compounds in the solution was Na2O 18.69% by mass, SiO2 41.31% by mass and remaining water and the specific gravity of sodium silicate was 1.59.

2.1.3. Fine Aggregate

Fine aggregate used in this study is M sand. Fine aggregates are the aggregates whose size is less than 4.75mm.

Table 2. Properties of Fine Aggregate

Properties	Value Obtained
Specific Gravity	2.65
Fineness Modulus	3.28
Grading Zone	Zone I

2.1.4. Demolished Concrete Aggregate

In this work, demolished concrete was used as coarse aggregate and having maximum size of 20 mm recycled coarse aggregates were selected as standard aggregate. Demolished concrete aggregate was produced by crushing of old concrete cubes used for compressive strength testing (DC 1) and concrete after demolition of machine foundation structure (DC 2).The strength class of old demolished structure was M30.Demolished concrete manually crushed up to the size of natural coarse aggregate that are shown in figure.1and the properties of aggregate are shown in table 3.

Figure.1.Demolished Concrete Aggregate

Table 3. Properties Demolished concrete Aggregate

S. No.	Properties	Values Obtained	
		DC 1	DC 2
1	Specific gravity	2.31	2.35
2	Bulk density	1.113 kg/lit	1.221 kg/lit
3	Water absorption	0.554%	0.573%

When demolished concrete is crushed, a certain amount of mortar and cement paste from the original concrete remains attached to stone particles in recycled aggregate. This attached mortar is the main reason for the lower quality of demolished concrete aggregate compared to natural aggregate. Demolished concrete aggregate compared to natural aggregate has following properties:

» increased water absorption
» decreased bulk density
» decreased specific gravity
» increased quantity of dust particles

2.1.5. Superplasticizer

Conplast – SP 430, a concrete super plasticizer based on Sulphonated Naphthalene Polymer was used as a water-reducing admixture in this study. Conplast - SP 430 has been specially formulated to give high water reductions up to 25% without loss of workability or to produce high quality concrete of reduced permeability. The dosage of superplasticizer varied from 0.5% to 2% by weight of fly ash in geopolymer concrete.

2.2. Test Variables

The variables taken for preparation of geopolymer concrete mixes were; 8M, 10M, 12M NaOH concentration and total aggregate content of 60%,65%,70% and 75%. Alkaline liquid to fly ash ratio (by weight) was taken as 0.3 while the ratio of sodium silicate solution to sodium hydroxide solution (by weight) in alkaline liquid was 2.5.

2.3. Preparation of Geopolymer Concrete

In the beginning, numerous trial mixtures of geopolymer concrete were manufactured. The trial mixes were prepared inorder to obtain a mix with good consistency and workability and to understand the basic nature of the mix.

2.3.1. Mixing and Casting

Geopolymer concrete can be manufactured by adopting the conventional techniques used in the manufacture of Portland cement concrete. Drum mixer was used for mixing.

The sodium hydroxide solution and sodium silicate solution were mixed together one day before for mixing. First the sodium hydroxide (NaOH) solids were dissolved in water to make the solution. Then required quantity of sodium silicate solution was added.

Weighed quantity of fly ash and the aggregates were first mixed together about 3 minutes in concrete drum mixer. The aggregates were prepared in saturated surface dry condition. Alkaline liquid was mixed with the super plasticiser was added to the dry materials and mixed together for another 4 minutes. Extra water was added to improve consistency and workability.

The fresh fly ash-based geopolymer concrete was dark in colour and shiny in appearance. The mixtures were usually cohesive. The workability of the fresh concrete was measured by means of the conventional slump test.

The fresh concrete was cast into the moulds immediately after mixing as shown in figure 3.13, in three layers for cubes and cylindrical specimens and beams. Cubes with 15 cm × 15 cm × 15 cm, cylinders with 10 cm × 30 cm and beams with 50 cm × 10 cm × 10 cm sizes were casted.

Cubes, cylinders and beams were casted for complete replacement of natural coarse aggregate with demolished concrete aggregate.

2.3.2. Curing

Heat-curing substantially assists the chemical reaction that occurs in the geopolymer paste. Figure 3.14 shows the curing of geopolymer concrete. Both curing time and curing temperature influence the compressive strength of geopolymer concrete. The test specimens were heat-cured at 80^{o}C in an oven for 24 hours. Longer curing time improved the polymerization process resulting in higher compressive strength. After the curing period, the test specimens were left in the moulds for at least six hours in order to avoid a drastic change in the environmental conditions. After demoulding, the specimens were left to air-dry in the laboratory until the day of test.

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www.ijarse.com
IJARSE
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Figure.2 Curing of Geopolymer Concrete Specimen

2.3.3. Mixture Proportion

The mix proportion of the concrete mix was designed based on the literature surveys conducted .The different mixture proportions used to make the trial geopolymer concrete specimens in this study are given in Table1.

Various parameters considered for the mixture proportion of geopolymer concrete such as the sodium silicate solution-to-sodium hydroxide solution ratio by mass, ratio of fly ash to alkaline solution by mass. In this parameter, the total mass of water is the sum of the mass of water contained in the sodium silicate solution, the mass of water used in the making of the sodium hydroxide solution, and the mass of extra water, if any, present in the mixture. The mass of geopolymer solids is the sum of the mass of fly ash, the mass of sodium hydroxide solids used to make the sodium hydroxide solution, and the mass of solids in the sodium silicate solution (i.e. the mass of NaOH and SiO_2).

Based on the results obtained from numerous mixtures made in the laboratory over many years, the data proposed for the design of low-calcium fly ash-based geopolymer concrete are the ratio of mass of fine aggregate to total aggregate was varied from 0.2 to 0.4. The alkali-fly ash ratio selected by different investigators ranges from 0.25 to 0.75 and the ratio of Na_2SiO_3 to NaOH ranges from 0.17 to 3.

Table 4. Mixture Proportion of Geopolymer concrete

Materials		Mass (kg/m^3)			
		Mixture 1 60% TA	**Mixture 2 65% TA**	**Mixture 3 70% TA**	**Mixture 4 75% TA**
Fly ash		436.56	395.9	335.98	276.06
Coarse Aggregate	**DC1**	871.46	918.99	989.021	1059.07
	DC2	856.63	903.35	972.18	1041.04

Fine aggregate	655.14	690.87	743.535	796.193
Sodium Silicate	171.51	155.532	131.99	108.45
Sodium Hydroxide 8M,10,12M	68.6022	62.21	52.796	43.38
Super Plasticizer	4.36	3.95	3.35	2.76

III. RESULTS AND DISCUSSION

3.1. Workability

The fresh fly ash-based geopolymer concrete has a stiff consistency and is glossy in appearance. As in the case of Portland cement concrete, water content of the mixture influences the workability of geopolymer concrete, as measured by the conventional slump test.

Table 5.Slump Value of Different mix

S. No.	Specimen	Slump value (mm)
1	Normal Geopolymer Concrete	80
2	Geopolymer Concrete With DC 1	87
3	Geopolymer Concrete With DC 2	85

The test results showed that it is required to increase the water content to achieve the same level of workability when using demolished concrete aggregate. This can be referred to rough surface of recycled aggregates and the existence of adhering mortar to the aggregates in the case of recycled aggregate. Table 5 shows that replacement of recycled coarse aggregate in concrete decreases the workability of the concrete hence water demand increases to achieve the required workability.

3.2 Compressive Strength

150 mm × 150 mm × 150 mm cubes were casted for carrying out compression strength test and the test was performed at 3 day and 7 day. The specimens were tested on a compression testing machine with capacity of 3000 kN.

Geopolymer concrete specimens were casted with complete replacement of natural coarse aggregate with demolished concrete. Two different types of demolished concrete with different strength were used as coarse aggregate that are collected from demolition of old cube specimen (DC 1) and from demolition waste of machine foundation (DC 2) to find the influence of type of demolished concrete aggregate. The results of compressive strength test are shown in Table 6.

Table.6 Compressive Strength at 3rd day and 7th day

S.No.	Specimen	3 Day Strength	7 Day Strength
1	NGC	29.33 N/mm²	32.88 N/mm²
2	GCDC 1	29.11N/mm²	32.88 N/mm²
3	GCDC 2	28.33N/mm²	31.11N/mm²

NGC – Normal Geopolymer Concrete

GCDC1- Geopolymer Concrete with DC1

GCDC2- Geopolymer Concrete with DC2

Compressive strength results from the above table shows that all three concrete types have approximately the same compressive strength development with time and all three concrete types have 7-day compressive strength that is larger than 30 N/mm².

Different mixtures of geopolymer concrete were prepared to find the influence of total aggregate content (55%, 60%, 65%and 70%) and molarity of sodium hydroxide (8M,10M and 12M). The variation of compressive strength at varying percentage of total aggregate content is shown in Figure. 3 and variation of compressive strength at 3rd day and 7th day with molarity of sodium hydroxide in geopolymer concrete is shown in Figure. 4.

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www.ijarse.com
IJARSE
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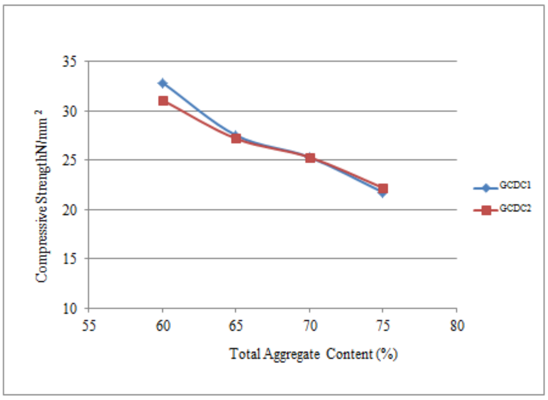

Figure 3. Variation of Compressive Strength with Total Aggregate Content

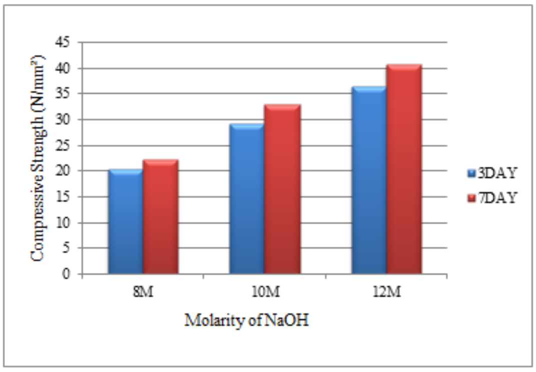

Figure. 4. Variation of Compressive Strength with Different Molarity of NaOH

From figure 3 and 4, it could be observed that the influencing parameters in the strength gain of geopolymer concrete with demolished concrete aggregate is the molarity of NaOH and binder content. It was concluded that differences between measured compressive strengths of normal geopolymer concrete and geopolymer concrete with demolished concrete aggregate are insignificant (all results belong to the same set of results). This conclusion led to the fact that demolished concrete coarse aggregate type did not influence the geopolymer concrete compressive strength value in this experimental research. Compression testing of geopolymer concrete is shown in figure 5 and failure pattern of concrete specimen after compression test is shown in figure 6.

Figure.5 Compression Testing of Geopolymer Concrete Cube

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www.ijarse.com
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Figure 6. Failure Pattern of Concrete Specimen After Compression Test

3.3 Split Tensile Strength

The split tensile strength of geopolymer concrete is only a fraction of compressive strength, as in case of Ordinary Portland cement concrete. It was found that split tensile strength of geopolymer concrete with demolished concrete aggregate with different molarity of 10M and 12M. Two types of demolished concrete aggregate (DC1 and DC2) were used for preparing the cylinder specimen.

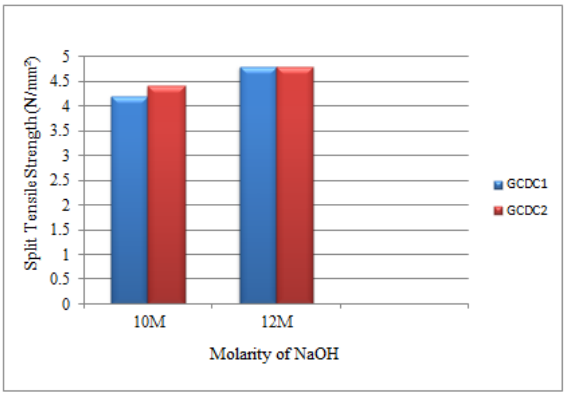

Figure .7 Variation of split tensile strength age of 7days

Figure 7.shows the results at the variation of split tensile strength age of 7 days and it was concluded that differences between measured splitting tensile strengths of different geopolymer concrete specimens are significant. The split tensile strength increases with increasing the molarity of sodium hydroxide as in the case of compressive strength and it confirmed that tensile strength of geopolymer concrete with recycled coarse aggregate is not significantly affected by the amount and strength of demolished concrete.

3.4 Flexural Strength

Flexural strength test were conducted on standard beams of dimension 10cm x 10cm x 50cm. The variation of flexural strength with molarity and different aggregate are shown in figure.8.

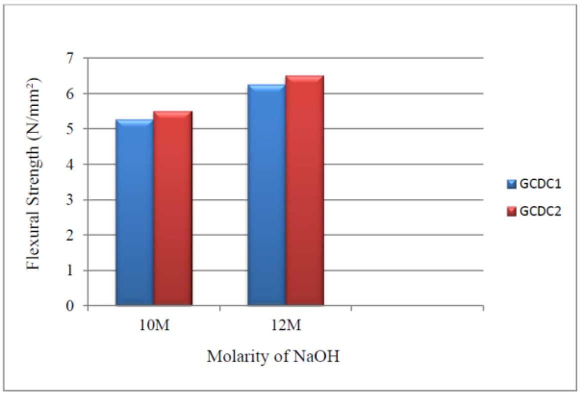

Figure 8. Variation of Flexural Strength of geopolymer concrete with molarity

3.5 Water Absorption

Water absorption tests were performed at 28 day on cubes. Table. 6 shows the result of the tests on water absorption of geopolymer concrete specimen.

Table.6. Water absorption test results of geopolymer concrete specimen

S. No.	Specimen Designation	Average Water Absorption (%)
1	GNC	2.7
2	GDC1	2.99
3	GDC2	2.95

The water absorption of geopolymer concrete depends on the quality of coarse aggregate. Here the water absorption of geopolymer concrete with demolished concrete aggregate is more than normal geopolymer concrete and it is because of a certain amount of mortar and cement paste attached to stone particles in recycled aggregate. This attached mortar is the main reason for the lower quality of recycled coarse aggregate compared to natural coarse aggregate. However the water absorption percentage is less than 5%, so penetration of water into specimen is low and it is impermeable one.

IV. CONCLUSION

On the basis of comparative analysis of test results of the basic properties of normal geopolymer concrete and geopolymer concrete with demolished concrete as coarse aggregate, the following conclusions are made.
The way of preparing demolished concrete aggregate for geopolymer concrete mixtures influences the concrete workability: workability of geopolymer concrete with recycled aggregate decreases due to the rough surface of demolished concrete aggregates and the existence of adhering mortar to the aggregates in the case of demolished concrete aggregate. But the additional water is added during mixing, the same workability can be achieved.
Geopolymer Concrete compressive strength mainly depends on the binder content and aggregate content of geopolymer concrete. It was concluded that differences between measured compressive strengths of normal

geopolymer concrete and geopolymer concrete with demolished concrete aggregate are insignificant because all compressive strength test results belong to the same value. This conclusion led to the fact that demolished concrete coarse aggregate type did not influence the geopolymer concrete compressive strength value. If good quality aggregate (obtained by crushing higher strength class concrete as in this case) is used for the production of new geopolymer concrete, the demolished concrete aggregate has no influence on the compressive strength. The same conclusion is valid for concrete tensile strength and flexural strength. And also the concentration (in term of molarity) of sodium hydroxide and total aggregate content influenced the strength characteristic of geopolymer concrete. The higher concentration of sodium hydroxide (NaOH) solution, higher compressive strength of geopolymer concrete will produced because the higher concentration of sodium hydroxide will make the good bonding between aggregate and paste of the concrete.

The water absorption of geopolymer concrete depends on the aggregate used for the preparation of mixture. Water absorption of geopolymer concrete with demolished concrete aggregate was more than normal geopolymer concrete and it depends on the porosity of binder in the new concrete and porosity of cement matrix of the demolished concrete aggregate.

According to these test results, the performance of geopolymer concrete with demolished concrete aggregate, even with the total replacement of coarse natural aggregate with coarse demolished conrete aggregate, is mainly satisfactory, not only in terms of the mechanical properties, but also the other requirements related to mixture proportion design and production of this geopolymer concrete type. So geopolymer concrete can be successfully produced using concrete aggregate that have been produced from demolition and construction waste. It has good compressive strength and is suitable for structural applications.

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