Kufa Journal of Engineering
Vol. 9, No. 4, October 2018, P.P. 174-186
Received 5 December 2017, accepted 16 January 2018

PRODUCTION OF GEOPOLYMER CONCRETE FROM LOCAL MATERIALS

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http://dx.doi.org/10.30572/2018/kje/090412

ABSTRACT

Geopolymer concrete is still a new construction material in Iraq and needs tremendous research to get more information about the production technique. In this study, the foreign fly ash and local fly ash produced from Baghdad south gas power plant were used with good specifications to obtain geopolymer concrete. Also, the local attapulgite clay as a pozzolan material is used to investigate the possibility for production the geopolymer concrete. The experimental results showed that the method of curing of geopolymer concrete has a significant effect on the development of compressive strength. Water immersion curing is not recommended. The heat treatment method is the best due to accelerating the reactions and formation of geopolymer concrete. The attapulgite is the best suited locally for geopolymerization in terms of compressive strength and tensile strength.

KEYWORDS: Geopolymer concrete; local materials; Attapulgite; Fly Ash.

1. INTRODUCTION:

Concrete material is the most widely used in building. Also, demand for concrete will increase in the future because of the increasing concrete consumption of infrastructure development, (Mehta, 2001). Meanwhile, concrete is a mixture of Portland cement, aggregates, and water. The manufacture of cement produces carbon dioxide (CO_2) into the atmosphere. Thus, traditional concrete affected life and safety i.e. the environmental pollution (Li et al., 2004). Therefore, many researchers studied the concrete production by using environmentally friendly materials to replace the cement such as fly ash, metakaolin, and rice husk ash (Malhotra, 1999; Wallah and Rangan, 2006; Basil et al., 2015; Jian et al., 2013).

Al-Shathr et al., 2015 [5] found that local manufactured metakaolin is possible to be used for producing geopolymer concrete. Moreover, metakaolin based geopolymer concrete needs a high skill to work more than traditional concrete and a considerable speed is required during casting and compaction.

Geopolymer concrete is more durable than normal concrete (Malhotra, 2002). According to Wallah and Rangan, 2006, geopolymer concrete has a high compressive strength, low shrinkage, low creep, and excellent resistance for sulphate. It was also found that geopolymer possess an excellent resistant of fire and high mechanical performance (Davidovits, 2011). Moreover, geopolymer has significantly properties, such as fast setting with high early strength, low cost production, and less energy consumption leding to a little emission of CO_2 (Duxson et al., 2007).

Geopolymer showed a high potential in the domains of construction and infrastructure applications. Thus, the development and implementation of geopolymer concrete is a great importance for the environment protection.

2. RESEARCH SIGNIFICANCE:

Focuses on producing geopolymer concrete from the local materials are limited in Iraq. Attapulgite clays are available in Karbala and Al-Najaf regions in a large amounts and need grinding by storming and burning to suitable calcinations temperature to transform to pozzolana. Moreover, there are local by product materials from power plant named as fly ash. These local materials will be a good resource of alumina and silica and could be used to produce sustainable geopolymer concrete. By using these local materials (attapulgite and local fly ash), this study is likely to be the prime experiments to manufacture geopolymer concrete in Iraq.

3. MATERIALS:

3.1. Fine Aggregate:

In this study, the fine aggregate (natural river sand) was used. Tests were performed to determine the properties. Results indicated that the sulfate content and grading comply with the requirements of the Iraqi Standard IQS 45-1984 (Iraqi Specification, No.45, 1984), as shown in Table 1.

Table 1. Grading of fine aggregate.

Sieve size, mm	Cumulative Percentage passing	Limits of Iraqi Standard IQS 45-1984, zone 2
10	100	100
4.75	96	90-100
2.36	78	75-100
1.18	64	55-90
0.6	53	35-59
0.3	26	8-30
0.15	6	0-10

3.2. Coarse Aggregate:

Crushed gravel was used from Al-Nebai quarry as coarse aggregate. Tests were performed to find the grading and physical properties. Table 2 demonstrates the properties of coarse aggregate that comply with the requirements of the Iraqi Standard IQS 45-1984 (Iraqi Specification, No.45, 1984).

Table 2. Grading of coarse aggregate.

Sieve size mm	Cumulative Percentage passing	Limits of Iraqi Standard IQS 45-1984
20	100	100
14	95.5	90-100
10	75.8	50-85
5	6.5	0-10
2.36	-----	------

3.3. Fly Ash

The two types of fly ash used in this investigation are local and foreign. The local fly ash was used in this investigation as the source material for making geopolymer concrete which was supplied from Baghdad south gas power plant 2 as a result of coal combustion during production of electricity. The chemical composition of local fly ash is presented in Table 3.

Table 3. Chemical analysis and physical properties of local fly ash.

Chemical composition *		
Oxides	**Content %**	**Requirements of class N pozzolan (ASTM 618-02)**
SiO_2	35.99	
Fe_2O_3	14.83	≥ 70
Al_2O_3	27.70	
CaO	8.31	
MgO	1.18	
K_2O	2.68	
Na_2O	0.83	
SO_3	2.79	Max. 4%
L.O.I	5.06	Max. 10%
Physical properties *		
Specific surface area m^2/Kg	1650	-
Specific gravity	1.7	-

* Chemical and physical tests were conducted by national center for construction laboratories and research

The foreign fly ash was supplied by BASF Company in Baghdad. The chemical composition of foreign fly ash is presented in Table 4. The results showed that the local and foreign fly ash used according the requirement of (ASTM C 618, 2002), as shown in Table 5.

3.4. High Reactivity Attapulgite (HRA):

The attapulgite clay was used from Tar AL-Najaf region. The high reactivity attapulgite was produced by burning the attapulgite powder at 750°C for a half hour then kept to cool down. This procedure was done by previous work (Samer et al 2014). The physical and chemical properties of high reactivity attapulgite clay are shown in Table 6.

Table 4. Chemical analysis of foreign fly ash*.

Oxide	Content, %
SiO_2	56.29
Al_2O_3	28.12
Fe_2O_3	5.32
CaO	2.21
MgO	0.98
SO_3	0.67
Na_2O	0.21
K_2O	2.32
L.O.I	2.77

* Chemical tests were conducted by national center for construction laboratories and research

Table 5. Chemical requirements of1 natural pozzolan according1 to the ASTM C 6181 (ASTM C 618, 2002).

Oxide composition	Pozzolan class F	Fly ash
SiO_2+Al_2O_3+Fe_2O_3, min. percent	70	89.73
SO_3, max. percent	5	0.67
Loss on ignition, max. percent	6	2.77

Table 6. Properties of attapulgite*.

Chemical composition *		
Oxides	**Content %**	**Requirements of class N pozzolan (ASTM 618-03)**
SiO_2	47.91	
Fe_2O_3	4.81	≥ 70
Al_2O_3	20.94	
CaO	10.06	
MgO	6.18	
SO3	Nil	
L.O.I	9.54	
Physical properties *		
Specific surface area m_2/Kg	2100	-
Specific gravity	2.4	-

*Chemical analysis and physical properties was carried by the State Company of Geological Survey and Mining

3.5. Superplasticizer (SP1):

RHEOBULD SP1 was used to produce geopolymer concrete. RHEOBULD SP1 should be mixed with limit content of water. Table 7 shows the properties of the superplasticizer (SP1).

Table 7. Properties of superplasticizer (SP1) *.

Property	Description
Color	Dark brown / black liquid
Specific gravity	1.15 – 1.168 at 25° C
Air entrainment	Maximum 1%
Chloride content	Nil
Nitrate content	Nil
Freezing point	0° C

* According to manufacturer

4. EXPERIMENTAL WORK:

The experimental program consists of three cases. The first case studied the possibility of using local fly ash for production geopolymer concrete. The second case was about studying the possibility of using local attapulgite for geopolymer concrete production. While, the third experimental case produced the geopolymer concrete by using foreign fly ash. Additionally, a comparison was developed based on the difference in the results between case one (LFGC) and case three (FFGC). Generally, the compressive strength and splitting tensile strength were investigated. The slump test was also done.

4.1. Mixture Proportions of Geopolymer Concrete:

The mixture proportions were derived based on the previous studies on geopolymer concrete (Hardjito and Rangan, 2005). The details of the mix properties are given in Table 8.

Table 8. Mixture proportions of geopolymer concrete (Hardjito and Rangan 2005).

Materials	Mass (kg/m^3)
Coarse aggregates	1090
Fine aggregates	670
Fly ash or Attapulgite	404
Sodium hydroxide solution	41
Sodium silicate solution	102
Super plasticizer	9
Extra water	35.5

4.2. Manufacturing Fly Ash Based Geopolymer Concrete:

4.2.1. Preparation Alkaline Solution for Geopolymer:

The NaOH solution is constituted of sodium silicate and sodium hydroxide. Sodium hydroxide has flakey form and high purity more than 98 percent, which could be dissolved in the filtered water. The solution was with the suitable concentration.

Sodium silicate Na_2SiO_3 as solution is commercially available. After preparation NaOH solution is added to the Na_2SiO_3 solution. Alkaline liquid is a mixture of NaOH solution and Na_2SiO_3 solution. At least 24 hours before the use of alkali fluid is made by mixing both solutions together (Rangan, 2011).

To improve workability, extra water is typically added to geopolymer concrete with different contents. As well, the superplasticizer (High range water reducing) can be used to improve the strength. The mixing of superplasticizer with additional water is continued until a homogenous solution is achieved.

4.2.2. Mixing Procedure for Geopolymer Concrete:

The mixing method of geopolymer concrete can be performed by adopting the traditional techniques used in production of normal concrete (Lloyd and Rangan, 2010). Firstly, all materials fly ash, fine aggregate, and coarse aggregate are mixed in a dry condition in the concrete mixer for approximately three minutes. The alkaline liquid, superplasticizer, and extra water were mixed for approximately two minutes. After that, the liquid component was added to the dry materials and mixed for four minutes in the concrete mixer (Rangan, 2011). The specimens were casted in 12 cubes and 12 cylindrical. Then, the compaction is done by using table vibrator. After casting, the specimens were maintained at room temperature for 3 days. Curing was delayed for time periods to increase the compressive resistance of concrete (Hardjito and Rangan, 2005). After 3 days, three types of curing were used (water tank curing, sunlight lab curing, and heating curing inside furnace at 60˚C for 24 hours).

The previous procedures were used for attapulgite instead of local and foreign fly ash. Table 9 describes the brief of geopolymer concrete mixes.

Table 9. Sets and description1 of mixes.

Mix notation	Description of mix
LFGC	Local Fly Ash based Geopolymer Concrete
FFGC	Foreign Fly Ash based Geopolymer Concrete
AGC	Attapulgite based Geopolymer Concrete

5. INVESTIGATING THE PROPERTIES OF FLY ASH BASED GEOPOLYMER CONCRETE:

5.1. Slump Test:

Slump test was directly performed for the geopolymer concrete as normal concrete test. The slump was performed according to the ASTM C143-10a.

5.2. Compressive Strength Test:

The concrete compressive strength test was conducted according to (BS. 1881: Part 116: 1989). The hydraulic concrete compression machine is used to test the cubes with dimensions of 100 mm. The test was performed at 7 days as the international literature (Davidovits, 2011).

5.3. Splitting Tensile Strength Test:

The splitting tensile test is done according to ASTM C496-2004. The cylindrical sample of geopolymer concrete (100×200) mm is used. The hydraulic concrete compression machine is used to test the cylindrical concrete specimen.

6. RESULTS AND DISCUSSION:

6.1. Slump Test:

Immediately after mixing, the slump test was done on fresh geopolymer concrete. As shown in Table 10, Attapulgite and local fly ash of geopolymer concrete exhibited no slump values. There was no significant amelioration in the slump value with increasing superplasticizer and extra water. The high CaO percent of fly ash particles increased the stickiness and filtrate of silica and alumina, thus, geopolymer concrete workability will be reduced (Rattanasak et al. 2011). On the other hand, foreign fly ash is having a perfect slump value of geopolymer concrete because of low CaO percent. In addition to the spherical shape particles, hollow and smooth of fly ash has increased workability. These result phenomena are in agreement with the findings of (Davidovits, 2011). The slump value of foreign fly ash geopolymer concrete was 245 mm.

Table 10. Sets of concrete slump test.

Mix designation	Slump (mm)
LFGC	0
FFGC	245
AGC	0

6.2. Studying the Effect of Different Curing Systems on Strength of Geopolymer Concrete:

In this research, different types of curing are studied to find out the perfect curing of geopolymer concrete. Table 11 displays the effect of different curing methods on compressive strength of geopolymer concrete.

Table 11. Compressive strength for all mixes with different curing methods.

No.	Mix designation	Curing system	Compressive strength (MPa): at age 7 days *
1		Water curing	8.21
2	LFGC	sunlight and laboratory curing	12.46
3		Inside furnace at 60°C	19.67
1		Water curing	10.73
2	FFGC	sunlight and laboratory curing	16.91
3		Inside furnace at 60°C	25.33
1		Water curing	11.18
2	AGC	sunlight and laboratory curing	18.92
3		Inside furnace at 60°C	27.17

* Average of three test results.

According to the compressive strength findings shown in Table 11, the following conclusions could be made:

1-The curing method has a significant effect on compressive strength for all types of geopolymer concrete. Heating-curing method inside furnace has the highest effect to increase the compressive strength. Meanwhile, the compressive strength of geopolymer concrete decreased obviously in sunlight laboratory curing methods when the temperature lab was between 22 - 29 °C. The temperature accelerated the consistence of hard structure essentially in early phase of geopolymerisation reaction (Rovnaník, 2010). This indication clearly showed in Fig. 1.

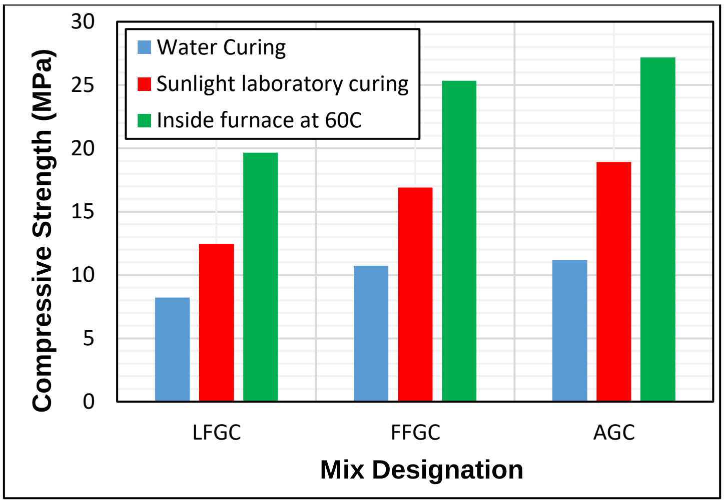

Fig. 1. The effect of curing method on compressive strength for all mixes.

2- The water curing method for geopolymer concrete is considered ineffective to provide concrete with the lowest increase in compressive strength. This curing was inappropriate and led to dragging of the reaction. That is because water enters inside concrete and causes cracks expansion in the geopolymer concrete structure (Kirschner and Harmuth, 2004).

3- Fig. 2 illustrates local attapulgite based geopolymer concrete. It is clearly shown that it has the highest in compressive strength than the other two geopolymer concrete, especially with heating curing method inside furnace. This indicates that the local attapulgite is a suitable material to produce a geopolymer concrete.

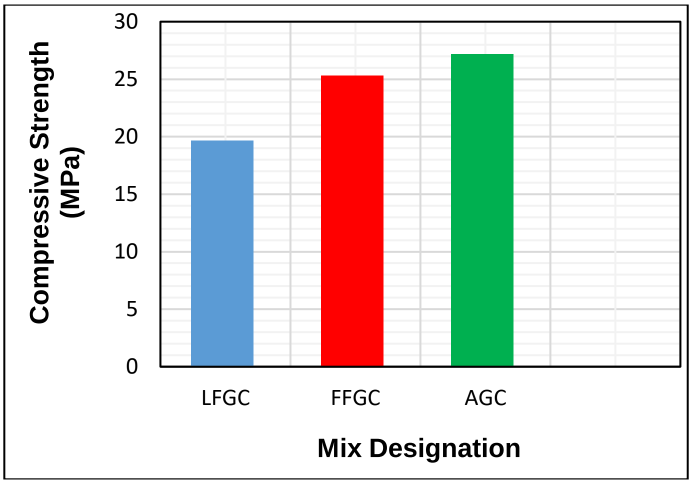

Fig. 2. Compressive strength for all mixes that cured in furnace with 60˚C.

6.3. Splitting Tensile Strength Test:

One of the indirect tension test methods of concrete is the splitting test. To measure split tensile strength was carried out by the universal testing machine. Splitting tensile strength was conducted by using a cylindrical sample with dimensions of 100 mm diameter and 200 mm height at age of 7 days. The experimental results are summarized in Table 12. The optimum concrete mix was used in this study. The GPC specimens were inside furnace curing at 60˚C for 7 days. The geopolymerisation process displays adequate properties for all GPC mixes at earlier ages. It is clear from Fig. 3 that the difference in splitting tensile strength for geopolymer concrete based on fly ash or attapulgite was slight. As well as, the splitting tensile strength increases with increase the compressive strength for all concrete mixes although this increment was slight.

Table 12. Splitting tensile strength results mix.

Mix designation	Splitting tensile strength (MPa) *
AFGC	2.37
FFGC	2.83
AGC	3.04

*Average of three test results.

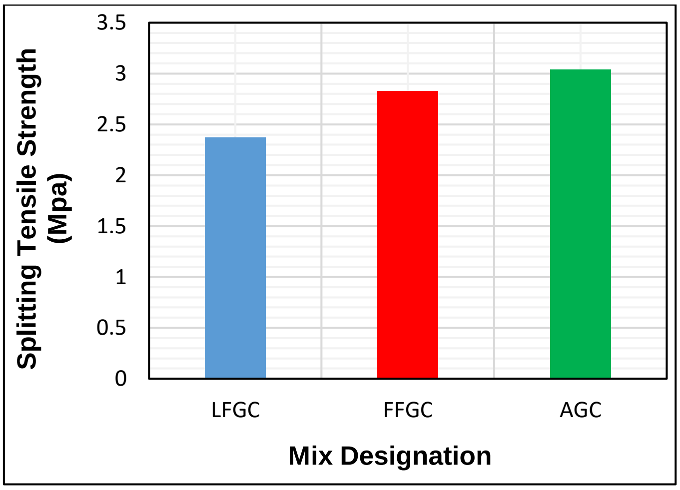

Fig. 3. Average splitting tensile1 strength for all mixes.

7. CONCLUSIONS:

1- By using local fly ash that is produced from the Baghdad south gas power plant 2, it can be reported that it has a good quality to obtain geopolymer concrete although its specifications less than the specifications of forgin fly ash.

2 - It is possible to produce geopolymer concrete by using local attapulgite as a pozzolan material.

3 - The method of curing the geopolymer concrete has a significant effect on the development of compressive resistance.

4- The immersed in water curing is not recommended.

5- The method of heat curing was the best because it accelerates the reactions and formation of geopolymer concrete.

6 - Local attapulgite geopolymer concrete is the best in terms of compressive strength and tensile strength.

8. REFERENCES

ASTM C618, (2002) “Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete”, American Society for Testing and Materials.

Basil S. Al-Shathr, Tareq S. Al-attar, and Zaid A. Hasan (2015), “Optimization of Geopolymer Concrete Based on Local Iraqi Metakaolin”. The 2nd International Conference of Buildings, Construction and Environmental Engineering (BCEE2-2015), pp. 97-100.

Davidovits, J. (2011) “Geopolymer Chemistry and Applications”, 3rd. edition, Institute Géopolymère, France.

Duxson, P.A., Jimenez, A.F., Provis, J.L., Lukey, G.C., Palomo, A. and Van Deventer, J.S.J. (2007) “Geopolymer technology: the current state of the art”, Journal of Materials Science, Vol. 42, pp. 2917–2933.

Hardjito, D. and Rangan, B. V. (2005) “Development and properties of Low- Calcium Fly Ash-based geopolymer Concrete”. Research Report GC-1, Faculty of Engineering, Curtin University of Technology.

Iraqi Specification, No.45/1984, “Aggregate from Natural Sources for Concrete and Construction”

Jian He, Yuxin Jie, Jianhong Zhang, Yuzhen Yu, Guoping Zhang (2013) “Synthesis and characterization of red mud and rice husk ash-based geopolymer composites”. Cement and Concrete Composites

Kais J. Frieh, Dr. Waleed A. Abbas, and Samer H. Malik (2014) “Investigate about the Iraqi Attapulgite Clay as a Mineral Admixture for Concrete”, Eng. &Tech. Journal, Vol. 32, Part A, No.10, pp. 2364- 2375

Kirschner, A.V. and Harmuth, H. (2004) “Investigation of Geopolymer binders with respect to their application for building materials”, Ceramics, Vol. 48, Issus 3, pp.117-120.

Lloyd, N.A. and Rangan, B.V. (2010) “Geopolymer Concrete with Fly Ash”, Second International Conference on Sustainable Construction Materials and Technologies, Vol. 3, pp. 1493- 1504.

Li, Z., Ding, Z. and Zhang, Y. (2004) “Development of sustainable cementitious materials”, International Workshop on Sustainable Development and Concrete Technology, Beijing, China.

Malhotra, V. M. (1999) “Making concrete greener with fly ash” ACI Concrete International, 21, pp. 61-66.

Malhotra, V. M. (2002) “Introduction: Sustainable development and concrete technology, ACI Board Task Group on Sustainable Development.” ACI Concrete International, 24(7); 22.

Mehta, P. K. (2001) “Reducing the environmental impact of concrete”. ACI Concrete International, 23 (10); pp. 61-66

Rangan, B.V. (2011) “Fly Ash-Based Geopolymer Concrete”, Proceedings of the International Workshop on Geopolymer Cement and Concrete, Mumbai, India, December, pp. 68-106

Rattanasak, U., Pankhet, K., and Chindaprasirt, P. (2011). “Effect of chemical admixtures on properties of high-calcium fly ash geopolymer.” Int. J. Miner. Metall. Mater., 18(3), 364–369.

Rovnaník, P. (2010) “Effect of curing temperature on the development of hard structure of Metakaolin-based Geopolymer”, Construction and Building Materials, Vol. 24, pp. 1176-1183.

Wallah, S.E. and Rangan, B.V. (2006) “Low-Calcium Fly Ash-Based Geopolymer Concrete: Long-Term Properties”, Research Report GC2, Faculty of Engineering. Curtin University of Technology. Vol. 37, pp.108-118.