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Splitting Tensile Strength of Geopolymer Concrete Exposed to Fire

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الملخص العربى :

يعرف الجيوبوليمر كبديل صديق للبيئة للخرسانة التى تحتوى على الأسمنت البورتلاندي. عادة ما تستخدم الخرسانة الجيوبوليمرية المنشط القلوي و خبث الافران العالية كمادة لاحمة. نظرا لخصائصها الشبيهة بالسيراميك ، يعتقد أن الخرسانة الجيوبوليمرية تتمتع بمقاومة عالية للحريق . لزيادة مقاومة الشد للخرسانة الجيوبوليمرية ، تمت إضافة الاستبدال مادة غبار السيليكا الى خبث الافران العالية بنسب (0 ، 5 ، 10 ، 20 ، 30٪) والتي يمكن أن تطور مقاومة الخرسانة الجيوبوليمرية. من المهم فهم سلوك الخرسانة الجيوبوليمرية والتى تتم معالجتها فى درجة حرارة الغرفة اثناء حدوث ارتفاع فى درجات الحرارة والتي لم تحظ باهتمام كبير. يقدم هذا البحث دراسة عن سلوك الخرسانة الجيوبوليمرية التى تتكون من خبث الافران العالية مع الاستبدال الجزئي لأبخرة السيليكا والمعالجة في درجة حرارة الغرفة والتي تعرضت لحريق لمدة 60 دقيقة وتم تبريدها بطريقتين مختلفتين (الهواء والماء). تم إجراء اختبار الشد على الخرسانة الجيوبوليمرية عند درجات حرارة 23 و 800 درجة مئوية. قبل الحريق ، سجلت العينة التي تحتوي على 80 ٪ من خبث الافران العالية و 20 ٪ بخار السليكا أعلى زيادة ؛ سجلت 94 ٪ من قوة الشد ، بعد 60 دقيقة من الحريق وتبريد العينات بواسطة الهواء
سجلت العينة التي تحتوي على 80 ٪ من خبث الافران العالية و 20 ٪ غبارالسليكا أعلى زيادة ؛ سجلت 100 ٪ من قوة الشد الاصلية قبل الحريق اما عند تبريد العينات فى الماء بعد 60 دقيقة من الحريق سجلت العينة التي تحتوي على 80 ٪ من خبث الافران العالية و 20 ٪ غبار السليكا أعلى زيادة ؛ سجلت 131 ٪ من قوة الشد الاصلية قبل الحريق.

Abstract :

Geopolymer has been known as an eco-friendly alternative to Portland cement-based concrete. Geopolymer concrete usually uses alkali-activated &GGBS as the binder. Due to its ceramic-like properties, geopolymer concrete is believed to have high fire resistance. To increase the splitting tensile strength of geopolymer concrete partial replacement of silica fume (SF) was added to GGBS with percentages (0, 5, 10, 20, 30 %) which can develop the desirable strength of geopolymer concrete. It is important to understand the high-temperature performance of ambient-cured geopolymer concretes which have received little attention. This paper presents a study on the behavior of GGBS geopolymer concrete with partial replacement of silica fume cured at ambient temperature which was subjected to 60 minutes fire duration and cooled down with two different methods (Air& water). A splitting tensile test was carried out on geopolymer concretes at temperatures of 23 and 800 °C. Before the fire, the specimen with 80% GGBS to 20% SF recorded the highest increase;94% splitting tensile strength, after 60 minutes of fire, cooling down with air the specimen with 80% GGBS to 20% SF recorded the highest increase; 100% splitting tensile strength and after 60 minutes fire, cooling down with water the specimen with 80% GGBS to 20% SF recorded the highest increase; 131% splitting tensile strength**.**

Key Words

GGBS, Silica fume, Alkaline solution, Fire setup test, Geopolymer Concrete, Splitting tensile strength.

I. INTRODUCTION

Environmental issue has become a crucial issue in the concrete industry, this is mostly because of the emission of greenhouse gasses from the production of Portland cement as the primary binder in making concrete in the meantime. Lots of efforts have been done to reduce using Portland cement in concrete which will also reduce the gas emissions of greenhouse. These efforts include using alternative cementing materials and. In this regard, geopolymer concrete is a good alternative and this type of concrete becomes more environmentally friendly because it uses waste materials like GGBS & fly ash [1]. The most common alkaline activator used in geopolymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate [2]. The increase in molarity of NaOH solution led to the increase in compressive strength and decreasing workability [3]. The high viscosity of alkaline solution results in Poor slump. So, the required amount of superplasticizer and water should be added to increase the workability of GPC [4]. To produce environmentally friendly concrete, it is necessary to replace the cement with industrial by-products such as fly ash, GGBS, etc. Disposal of fly ash is a growing problem, as only 15% of fly ash is currently used for high-value addition applications like concrete and building blocks, the remaining being used for land filling. The silica fume increases the strength in the case of hardened concrete. Another alternative but promising utility of SF in the construction industry that has emerged in recent years is in geopolymer concrete [5]. The geopolymer concretes produced with different combinations of SF and GGBS are able to produce structural concretes of high grades (much more than 45MPa) by self-curing mechanisms only and a percentage of 40% of SF to 60% GGBS [6]. Given that geopolymer increases in strength after elevated temperature exposure, the fire resistance of geopolymer is likely to be superior to OPC concrete which loses most of its strength after elevated temperature exposure at about 800°C [7]. The fire resistance of concrete can be increased by replacing cement in the concrete mix with different proportions of fly ash, GGBS, and Polypropylene Fiber. It helps in decreasing the cracking of concrete at higher temperatures and increasing its compressive strength [8]. Geopolymer is an emerging fire-resistant concrete. Unlike OPC, geopolymer concrete can retain a large portion of its strength during fire and geopolymer has no risk of spalling [9]. All fired specimens showed an increase in compressive strength after being exposed to 400^0C but when exposed to 700ºC, there was a significant loss of strength in all specimens [10]. The geopolymer concrete specimens were heated to 100, 200, 400, 600, and 800^0C with a heating rate of 5 °C/min. specimens could be heated until 600 °C for 120 minutes without strength loss [11].

II. EXPERIMENTAL PROGARAM

A. Matarials

Ground Granulated Blast Furnace Slag (GGBS) is a waste product and is obtained from a blast furnace in water or steam by quenching molten iron slag to produce a glassy, granular product which is then dried and ground into a fine powder with a gray color, specific gravity equaled 2.7 and size less than 0.1mm, the chemical composition of GGBS was showed that the main components were SiO_2; 34.8 %, CaO; 29.8% and Al_2O_3; 16.3% by mass.

Silica fume (SF) ferrosilicon or silicon metal is a product of electric arc furnaces the fume, which has a high content of very fine spherical particles of silicon dioxide is resulted from filtering gases that escape from the electric furnace. Silica fume used in this experimental program was produced by a local company for Construction chemicals with a gray color, specific gravity equaled 2.15, and size less than 0.008mm, the chemical composition of silica fume indicated that it was consists of 92% SiO_2, 1.6 % Fe_2O_3, 1% LOI, 0.61% K_2O, 0.51% Na_2O, 0.46% Al_2O_3, 0.29% CaO, 0.28% MgO and 0.19% SO_3 by mass.

Coarse aggregate used in this study was crushed stone with a maximum aggregate size of 10mm and specific gravity equaled 2.67. The used fine aggregate was locally collected from Egypt, It was natural sand which is composed of siliceous materials with and specific gravity equal to 2.60.

Alkali liquid consisting of sodium hydroxide (NaOH) and sodium silicates (Na_2SiO_3) were used to react with pozzolanic material, and the alkaline activators were used to produce geopolymer concrete instead of water in OPC concrete to complete the chemical reaction

with a cementitious material.
The used sodium hydroxide was brought in flakes as shown in Figure 1 with a purity of 98% and specific gravity of 1.45 from a local company in Egypt, the sodium hydroxide solution was prepared by dissolving the flakes in water, and the mass of NaOH solids in the solution depending on the concentration of the alkaline solution called molar (M). many trials were done to determine the best quantity of NaOH solids to make one liter of the solution, the molar ratio was taken at 12 M where the mass of solids was 361 grams/kg of Sodium hydroxide solution and the corresponding mass of water was 639 grams/kg. It is recommended that sodium hydroxide solution is prepared at least 24 hours before its use because of the exothermic heat produced during the dissolution process. shows sodium hydroxide in flakes form used in the study. The used sodium silicate was brought from a local company in Egypt, the chemical composition of the sodium silicate solution was SiO_2=29.4%, Na_2O=14.7%, and water 55.9% by mass. Sodium silicate is manufactured by melting sand (SiO_2) with sodium carbonate (Na_2CO_3) at temperatures in excess of 1100 $^{\circ}$C and dissolving the product with high-pressure steam into a semi-viscous liquid. Sodium silicate solution is commercially available in different grades but powdered Sodium Silicate leads to lower performance compared to the liquid one. The used sodium silicate was in a liquid form; the specific gravity of the utilized sodium silicate solution was 1.35 and the ratio between Na_2SiO_3 and NaOH was 2.5 by mass. The presence of silicate materials improves the bonding between aggregates and geopolymer mortars.

Figure. 1 Sodium hydroxide in flakes form.

B. Experimental program

Mix Design

Many trials were performed before reaching the best mix, the experimental program consists of five different mixes to study the effect of using the difference percentage of GGBS and silica fume on the performance of geopolymer concrete in the fire

 

Figure 2. Geopolymer concrete specimens

situations, the ratio between Na_2SiO_3, and NaOH is constant for all mixes and equals 2.5. The molarity of NaOH solution is 12 M for all mixes, the different percentage of silica fume that used in this study as a cementitious material is (0&5&10%20,30%) and the alkaline solution to binder content ratio is 0.45. For the control mix with 100% GGBS, the mix components were 400kg/m3 GGBS, 762 kg/m^3 fine aggregate, 1143 kg/m^3 coarse aggregate, 51.5 kg/m^3 sodium hydroxide solution and 128.5 kg/m^3 sodium silicate solution, for other mixes the silica fume was a percentage of GGBS quantity and the other parameters were constant.

Samples preparation

The binder (GGBS, Silica fume, fine aggregate, and coarse aggregate) were added to a mixer and dry-mixed for 3 minutes. Preparing the sodium hydroxide by dissolving the flakes in water Sodium hydroxide solution and sodium silicate in liquid form were mixed and stored at room temperature for 24 hours before its use. The alkaline activator was then added to the binder materials and the wet mixture was stirred for additional 4-6 minutes to form a homogenous state. After mixing, geopolymer concrete was cast into different molds. The GPC was transferred into a 15 cm diameter and 30 cm height for cylindrical molds and 15cm x15cm x15 cm for cubic molds to make sure of the strength of the mix and they were cast in three equal layers at three-time intervals as shown in figure 2.

Fire setup test

The furnace has a length of 4 m, a width of 2 m, and a height of 1 m. It was built with thermal bricks and covered with ceramic fiber to prevent heat and fumes from going away from the furnace as shown in figure 3. The furnace is closed by sheets of iron. The temperature of the furnace reaches above 1000 ^{0}C**.** Specimens of geopolymer concrete were subjected to fire at 800^{0}C for different 60 minutes fire duration and different firefighting methods (Air &water). The furnace consisted of 4 flames working together to reach the temperature needed and covered with fiber to prevent heat and fumes from going away from the furnace.

Figure 3. Fire furnace

The specimens that firefighting with water and through air are presented in figure 4 and figure 5 respectively.

Figure 4. Firefighting with water

Figure 5. Firefighting with air

C.Results and analysis

- Splitting Tensile strength results before and after fire

The splitting strength test was carried out on standard cylinders with dimensions of 30cm in height and 15 cm in diameter as shown in figure 6. The test was performed on two specimens at the age of 28 days, the results of splitting tensile strength before and after the fire were reported in table 4. Group (A) is a control mix then different percentages of silica fume are added as a partial replacement of GGBS (5, 10, 20, 30) %. Mix contained (80 % GGBS & 20 % SF) gave the maximum value of splitting tensile strength. At 1 hour of fire and cooling down in the air; mix which contained (100 % GGBS), the splitting tensile strength was 1.15 MPa then started to increase with increasing SF percentage in the mix until reaching the optimum value that equaled 2.3 MPa at mix which contained (80 % GGBS & 20 % SF), At 1-hour fire and cooling down with water; mix which contained (100 % GGBS), the splitting tensile strength was 0.85 MPa then started to increase with increasing SF percentage in the mix until reaching the optimum value that equaled 1.97 MPa at mix which contained (80 % GGBS & 20 % SF) as shown in figure 7.

Figure 6. Splitting tensile strength test

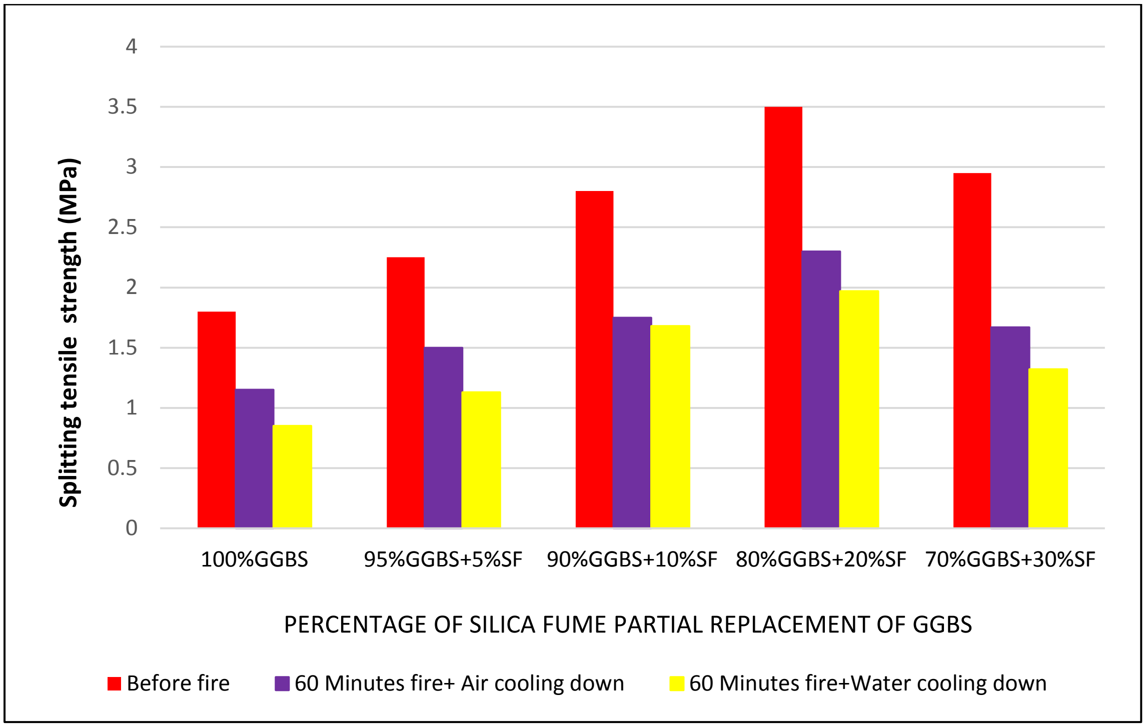

Figure 7. Splitting tensile strength of geopolymer concrete before and after fire

- Effect of adding silica fume on splitting tensile strength before fire

Adding silica fume to the mix led to increase the splitting tensile strength of geopolymer concrete as shown in figure 8 , the increasing started from (25 % :55 %) at ratio from 5% to 10% of silica fume then there is a big increase of tensile strength at 20 % SF, this ratio of increase equaled (94 %) from the tensile strength for specimens which didn't contain any silica fume in its content and the ratio of increasing tensile strength is very big compared with the increasing of compressive strength so adding silica fume to the mix is very important for geopolymer concrete. After a ratio of 20 % SF & 80 % GGBS, a small increase of SF resulted in decreasing the splitting tensile strength of geopolymer concrete.

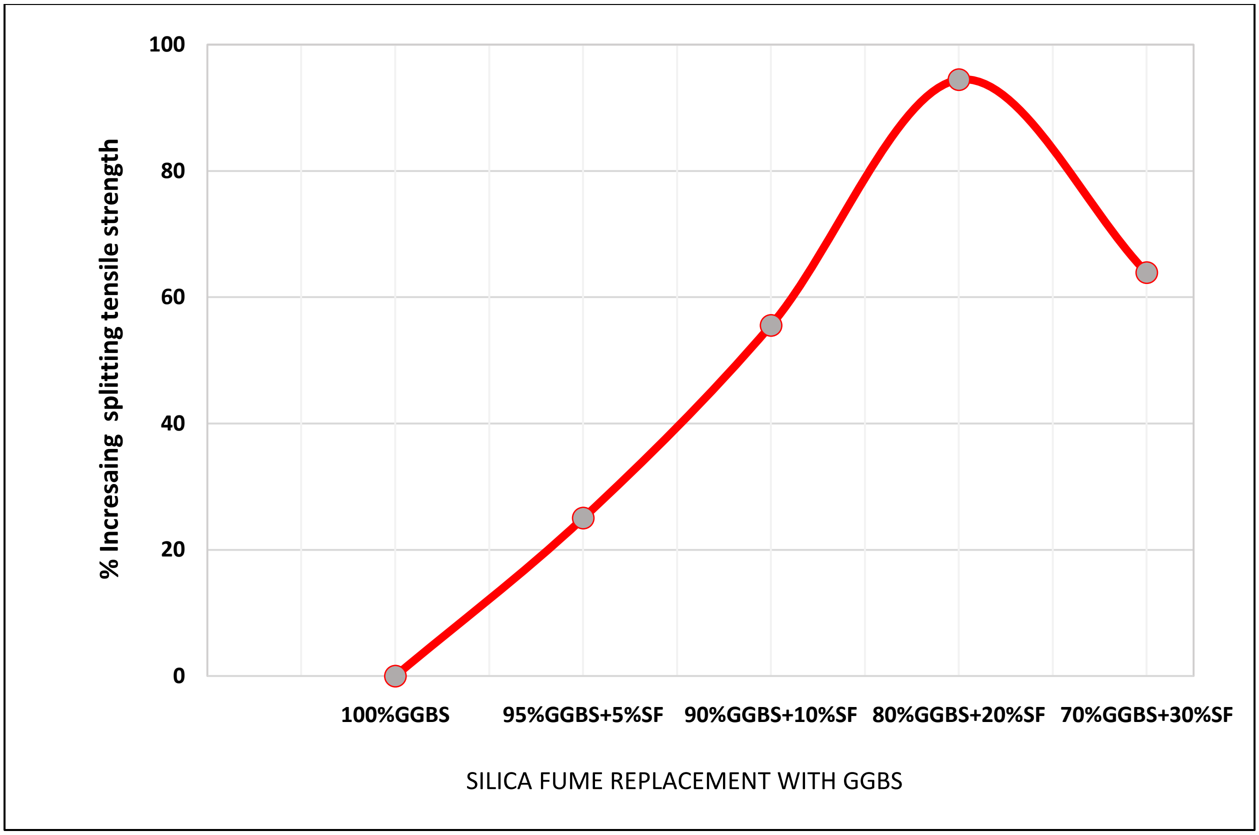

Figure 8. % Increasing of Splitting tensile strength of geopolymer concrete at 28 days before fire

-Residual Splitting Tensile Strength of Geopolymer Concrete after Firing

The effect of the different cooling down methods was analyzed to measure the effect of it on the splitting tensile strength of GPC for all studied mixes. It is found from figure 9 that the cooling down method affected the residual splitting tensile strength of geopolymer concrete, mix which contained (90 % GGBS & 10 % SF) approximately gave the highest residual splitting tensile strength after water cooling down equaled 60 % of the actual strength but the mix contained 5 % SF gave the best residual splitting strength after air cooling down and equaled 68.2 % from the actual splitting tensile strength.

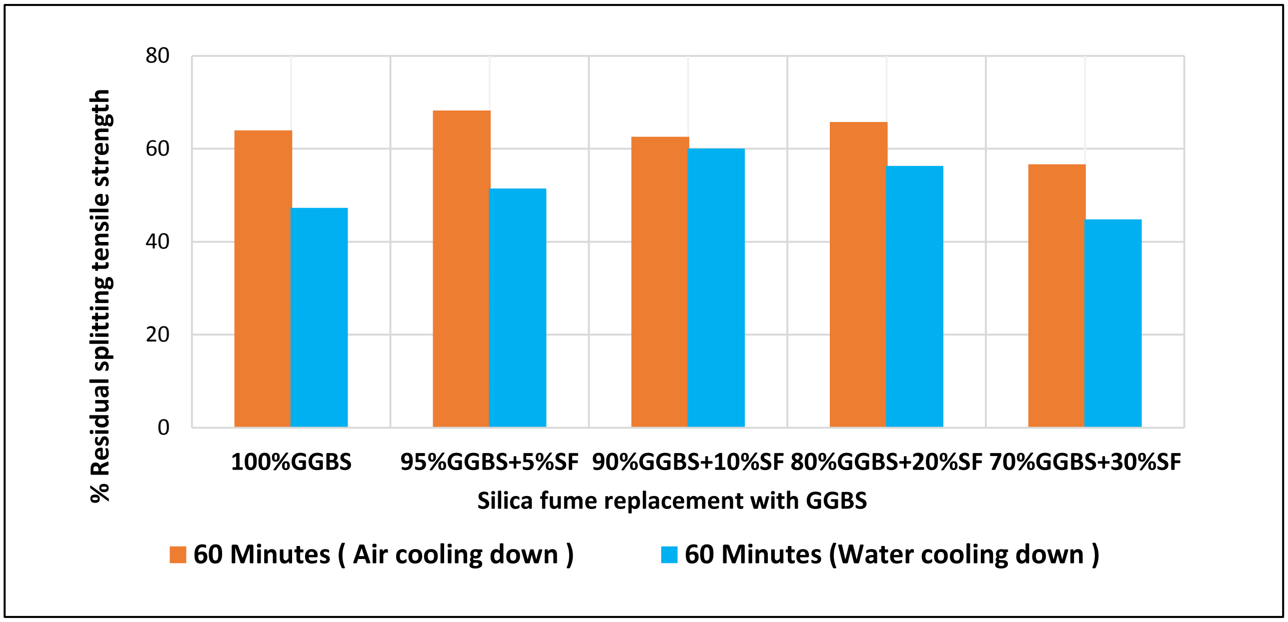

Figure 9. percentage of residual splitting tensile strength at 28 days after fire

D.Conclusion

This paper presents the behavior of geopolymer concrete subjected to fire. The binder used in this study is GGBS and silica fume with different ratios. The percentages of silica fume used were (0,5,10,20,30). The alkaline solution consists of sodium hydroxide and sodium silicate with a constant ratio of 1:2.5

Samples were cast and cured at room temperature. Five mixes of geopolymer concrete were made; mix A was a control mix, other mixes B, C, D, and E with different percentages of silica fume then samples were fired for 1 hour and cooled down with two different methods (Air & Water).

The results show that :

- The optimum ratio of silica fume to reach the maximum splitting tensile was 20% of the total binder content.
- A big increase in tensile strength after adding 20 % SF to the mix before the fire, this ratio of increase equaled 94 % of the original tensile strength for specimens that didn't contain any silica fume.
- Cooling down the specimens through water gave lower results of splitting tensile than cooling down through the air.
- The maximum residual splitting tensile strength after 1-hour fire and cooling down through air is 68.1 % in the mix with 95 % GGBS +5% SF and the minimum residual tensile strength is 56.6 % in the mix with 70 % GGBS +30% SF.

- The maximum residual splitting tensile strength after 1-hour firet and cooling down through water is 60 % in the mix with 90 % GGBS +10% SF and the minimum residual tensile strength is 44.7 % in the mix with 70 % GGBS +30% SF.

III. REFERENCES

[1] Steenie Edward Wallah. (2009), Drying Shrinkage of Heat-Cured Fly Ash-Based Geopolymer Concrete ,Modern Applied Science, Vol. 3, N0. 12.

[2] Hardjito, D., Wallah, S. E., Sumajouw, D. M. J. & Rangan, B. V., 2005c,'Introducing Fly Ash Based-Geopolymer Concrete: Manufacture and Engineering Properties', in Our World in Concrete and Structures International Conference, Singapore, pp. 271-278.

[3] Reddy, B.S.K., Varaprasad, J., and Reddy, K.N.K. (2010). "Strength and workability of low lime fly-ash based geopolymerconcrete", Indian Journal of Science and Technology, 3(12), 1188-1189.

[4] A.A. Aliabdo, A.E.M.A. Elmoaty, H.A. Salem(2016), Effect of water addition, plasticizer and alkaline solution constitution on fly ash based geopolymer concrete performance. Constr. Build. Mater. 121, 694–703.

[5] C.D. Atis, F. O¨ zcan, A. Kilic , O. Karahan, C. Bilim, M.H. Severcan, Influence of dry and wet curing conditions on compressive strength of silica fume concrete‖, Building and Environment, vol. 40,pp. 1678– 1683,(2005).

[6] Ahmed Mohmed Ahmed Blash (2015) , "Properties of Geopolymer Concrete Produced by Silica Fume and Ground-Granulated Blast-Furnace Slag", International Journal of Science and Research (IJSR) ISSN , 2319-7064.

[7] GUERRIERI, M. & SANJAYAN, J. G. (2010), Behavior of combined fly ash/slag based geopolymers when exposed to high temperatures. Fire and materials, 34, 163-175.

[8] Mohit Rathi. (2018), Fire Resistant Geopolymer Concrete, Journal of Civil Engineering and Environmental Technology, Vol. 5, pp. 28-30

[9] NATH, P. & SARKER, P. K. 2015. Use of OPC to improve setting and early strength properties of low calcium fly ash geopolymer concrete cured at room temperature. Cement and Concrete Composites, 55, 205-214.

[10] Ibrahim, R. K., Hamid, R., & Taha, M. (2012). Fire resistance of high-volume fly ash geopolymer concrete with nano silica addition. Construction and Building Materials, 36, 779-786.

[11] HongenZhang,LangLi,ChengYuan,,Prabir Kumar Sarker,Xiaoshuang Shi. (2020) , "Deterioration of ambient-cured and heat-cured fly ash geopolymer concrete by high temperature exposure and prediction of its residual compressive strength" , construction and building materials
", Journal Vol. 262, 120924.