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EFFECT OF POLYPROPYLENE FIBER ON PROPERTIES OF GEOPOLYMER CONCRETE BASED METAKOLIN

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Abstract: Climate changes and global warming are an international issue around the world and caused by the accumulation of greenhouse gases, and one of these reasons Portland cement industry which releases high amounts of CO_2, which causes 65% of the global warming effect. So the essential component for sustainable development in the construction industry is the improvement of alternatives for cement. One of the promising materials in the field of concrete industry is the geopolymer concrete, which attracted spotlight over the past decade with its comparable performance with Portland cement. This paper presents a systematic review of different research works done in the region of geopolymer concrete based metakoalin reinforced with polypropylene fiber and under ambient temperature. The mechanical behavior was enhanced significantly through experimental results. The compressive strength was improved 14.75% with 1% of polypropylene fiber while the increment of splitting tensile strength was 12.3 %, 15.76 % respectively. The flexural strength of specimens was also improved when compared with the non-fiber geopolymer concrete. The highest increment obtained with 1.5% of fiber volume content was 27.3%. Modulus of elasticity was also improved with increment to 13.1%, when compared with the non-fiber geopolymer concrete, also from experiment adding of fibers lead to a decrease in the density of GPC. The compressive performance and flexural performance of fiber-reinforced geopolymer concrete were also better than specimens without fiber.

Keywords: *Geopolymer concrete, metakaolin, polypropylene fiber, carbon emissions, sodium silicate, sodium hydroxide.*

1. Introduction

Concrete is the most used material after water. Constructing by portland cement concrete is in continuous increase; therefore, more Portland cement is being produced. The information about the contribution of portland cement for the carbon dioxide CO_2 emissions are terrified, the production of one ton of Portland cement emits approximately one ton of CO_2 into the atmosphere [1]. The rising concerns regarding global warming and climate change, industries, paid researchers to invent alternatives to OPC. Geopolymer Concrete (GPC) is a new environment-friendly inorganic binder, can be produced by alkaline solution activating aluminosilicate source material, such as metakaolin (MK), fly ash (FA), and slag. Among these materials, metakaolin is commonly used due to less impurities and good mechanical properties exhibited on MK-based geopolymers. [2, 3].

Water is not involved in the chemical reaction of GPC concrete and instead, water is expelled during curing and subsequent drying. This is in contrast to the hydration reactions that occur when Portland cement is mixed with water, which produces the primary hydration products calcium silicate hydrate and calcium hydroxide. This difference has a significant impact on the

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mechanical and chemical properties of the resulting GPC concrete, and also renders it more resistant to heat, water ingress, alkali-aggregate reactivity, and other types of chemical attack. [4, 5]

The superior properties of GPC concrete are set at room temperature; nontoxic and bleed free; long working life before stiffening; impermeable; higher resistance to heat and resist all inorganic solvents; higher compressive strength, these characteristics prompted researchers to investigate the possibility of its use it in the structural elements [6].

2. Objective and Novelty of the Study

- The aim and objectives of the present study are to investigate the behaviors of geopolymer concrete composite with a different volume fraction of fiber under ambient temperature to find out the extent of its ability to withstand loads and the possibility of using within the structural members in constructions.

  Zhang et al., (2009)[7] stated that although the polypropylene fiber (pp) has been extensively used in reinforced cement and concrete industries due to its distinctive characteristics, however, the available studies about PP fiber modifying GPC are few.
- Produce GPC mixes based on locally available materials and natural (Metakaolin). And the reason of using Polypropylene fibers causes it one of the cheapest and abundantly available polymers and resistant to most of the chemicals and it would be cementations matrix which would deteriorate first under aggressive chemical attack. Its melting point is high (about165 degree centigrade).So that a working temp (about 100 degree centigrade).

3. Literature Review

Geopolymer concrete (GPC) is a new type of construction material which have appeared as an alternative to ordinary Portland cement concrete and has the potential to revolutionize the construction industry. Many researches proved it to be a very promising concrete of the coming decade [8].

Hardjito, et al (2008) [9] studied the influence of various parameters on hardened and fresh properties of fly ash low calcium-based Geopolymer mortar. They found that the increasing concentration of alkaline activator gives higher compressive strength. S. Mandal et al. (2009) [10] investigated the concentration of activator fluid and the fluid to fly ash ratio which shows a great effect on the compressive strength, especially at higher concentration (in terms of molarity) and at the low fluid to fly as the ratio, the strength of the mortar seems to be maximum and found when the curing temperature in the range of 250 C to 900 C increases, the compressive strength of the mortar also increases. Sarker and Nath,(2014) [11] investigated the improvement of fresh and hardened properties of FA-based geopolymers using SL without using elevated temperature at curing. The results demonstrate adding fly ash with SL helped to provide equivalent setting time and compressive strength comparable to concrete OPC's.

Talib et al,(2016),[12] studied GPC preparation with (16M) of sodium hydroxide, and with polypropylene fiber (pp) and found there is a 30%,50%,16% increment in the compressive strength, flexural tensile strength, split tensile strength with the addition of pp fiber.

S. Subbiah Ilamvazhuthi et al., (2013) proposed that low calcium fly ash based Geopolymer concrete with fibers has excellent compressive strength even higher than Geopolymer concrete and is suitable for structural applications [13].

4. Materials used in Geopolymer Concrete

4.1 Metakaolin

Metakaolin is one of the most effective pozzolanic materials for use in concrete and showed some interest in recent years. [14] This product is produced for use instead of a by-product and is formed when kaolin is mineral and it calcined at high temperatures around 600oC to 800oC. Throughout production, the consistency of the material is controlled, resulting in a much less volatile material than the by-products of the industrial pozzolans.

4.2 Alkaline Liquid

Alkaline liquid Sodium hydroxide and Sodium silicate solution are used in this project as binders. It is used in Geo polymerization process. These solutions were chosen, because they were cheaper than Potassium based solutions.

4.3 Fine Aggregate

Natural sand passing from a sieve size of 4.75 mm is used as the fine aggregate in a concrete mixture. Sand collected from rivers should be properly washed and checked when used in a geopolymer concrete mix.

Ascertain that the total percentage of clay silt, silt, and other organic matter does not exceed the IQS (No. 45/1984) [15] specified limit for Iraqi standard specifications.

4.4 Coarse Aggregate

Normal weight crushed aggregate suitable to the IQS [15], 12 mm maximum size, and the bulk density was (2665) kg/m3.

4.5 Water

Water is used in the mix was distilled water.

4.6 Super Plasticizer

The superplasticizer type (F) of brand name Glenium 51was used in this work. It is based on sulphated naphthalene formaldehyde condensate and conforming to ASTM C494-04[16].

4.7 Polypropylene Fiber

Polypropylene fibers of 12mm cut length and 25 µm diameter were used for this purpose.

5. Mix Design and Experimental Procedure and Preparation of Geopolymer Concrete Specimens

In the present study, the portland cement is 100% replaced by metakaolin. To prepare the alkaline solution, the sodium hydroxide solution is first prepared by dissolving the NaOH flakes in the distilled water; the amount of NaOH flakes in the solution depends on the required concentration. Three NaOH solution prepared with (10, 12, and 14) molar, using (262, 314, and 361 g) NaOH flakes respectively to prepare (1kg) of the solution[17]**,** Sodium silicate was added slowly to the sodium hydroxide liquid and stirred for one minute. Whenever the solution is not being directly used for mixes, the solution was left to cool down then it was protected from the surrounding air by a plastic cover. It left around a day before using it**.**

First of all, the fine and coarse aggregates are mixed together around three minutes by a mixer. After the aggregates mixed, the metakaolin was then added to the mixture, and then the alkaline solution, Water, and Superplasticizer were added to the aggregates mixed and sterling for two minutes to prepare the geopolymer concrete. The additional mixing time of about two minutes was provided for the PP fibers to cement concrete mixtures to ensure homogeneity. After mixing, nine cubes of size (10 x 10 x 10) cm were prepared and cast in three layers for each concentration of sodium hydroxide. All layer was well compacted by 20 mm diameter tamping rope. After compaction of mortar, the top surface was leveled using a trowel and the sides of mold were gently tapped to remove any entrapped air. After 24 hours, the specimens were demolded.

One geopolymer concrete mix was used in this investigation from three trial mixes. Details of these mixes are given in Table (2). The group No.3 with 14 moles of NaOH is used as a mix in all specimens (cubes, cylinders, beams) with nominal cube compressive strength (30.5 MPa) in 28 days.

For compressive strength was used cubes with (100mmx100mmx100mm), for flexural strength was used beams with dimensions (100mmx100mmx500mm), and for modulus of elasticity and splitting were used cylinders with dimensions (300mmx150mm and 200mmx100mm) respectively.

The basic mixture proportions used for GPC depend on previous work on the proportions of the geopolymer mixture [18] and are presented in Table (1).

Table (1) Mix Proportion of GPC [18]

Details	Quantity in a cubic meter
Metakaolin (kg)	400
Sand (kg)	720
Gravel (kg)	1100
Alkaline solution (lit.)	180
Water (lit.)	40
HRWRA (lit.)	12

Table (2) Trail Mixes

Molarity (mole/L)	Weight NaOH Flakes (g)[17]	Weight of Water (g)[17]	Experimental Cube Compressive Strength F_{cu} (MPa)
10	314	686	25
12	362	638	27
14	404	596	30.5

Figure 1. Materials used for research (a) Metakaolin (b) Polypropylene fiber (c) Alkaline Liquid (d) coarse aggregate (e) fine aggregate.

6. Curing

After 24 hours of casting, all specimens were removed from molds and then positioned to sun curing then placed in room temperature until the test. However, this study mainly focused on characterizing the mechanical properties of fiber-reinforced geopolymer concrete at ambient temperature.

7. Tests of Fresh Geopolymer Concrete

7.1 Slump Test and Setting Time

The slump test was done immediately after mixing on fresh geopolymer concrete with and without fiber, according to ASTM C143-10a [19].

The setting time test results were obtained by using the Vicat needle apparatus according to ASTM. The results of the slump and the setting time are shown in Table (3). The quantity of slump and setting time of the GPC with fibers is fewer than that without fiber. More Polypropylene fiber added resulted in faster initial and final setting times because more fiber makes the mixtures more viscous resulting in decreased workability and faster setting. In this situation, a superplasticizer is required to ensure the workability of the mixture on a wider application scale.

Table 3. Results of Slump Test and Setting Time

Test	Geopolymer Concrete without fibers	Geopolymer Concrete with fibers
Slump result (cm)	3.5	0.5
Initial Setting Time(min)	30	20
Final Setting Time(min)	150	120

8. Properties of Hardened Geopolymer Concrete

8.1 Compressive Strength Test

The cubes at age 28 days are tested under the Compression testing machine (Fig. 2).

Figure 2. GPC Cube at Test Machine

Table 4. Compressive Strength Test Results

Mix Type	The volume fraction of PP fibers%	Cube Strength f'cu (MPa)
GPC1	0%	30.5
GPC2	0.5%	31.5
GPC3	1%	35
GPC4	1.5%	33

It can be seen from the table (4) and figure (3) that the increase of Polypropylene fibers from 0 to 0.5%, 1%, and 1.5 %, resulted in an average increase in the value of (fcu) from 30.5 MPa, 31.5 MPa, 35 MPa, and 33 MPa respectively and with an increasing percentage from 0% to 3.28%, 14.75%, and 8.2% respectively. The results demonstrate the improvement of the compressive strength due to adding polypropylene fibers. This may be attributed to the role of fiber in preventing the propagation of microcracks by arresting these cracks when developed in a matrix. This makes the microcracks take a meandering path. Thus, more energy is needed to propagate more cracks resulting increase in ultimate load. From results was found the maximum value was obtained from 1% of fibers addition. The marked reduction in the compressive strength at 1.5% Vf can be related to the high fiber content can cause mixing difficulties, leading to poor compaction, non-uniform fiber distribution and an increase in the volume of voids. The same conclusions were reached by Porkodi et al. [20], Sathish Kumar et al. [21].

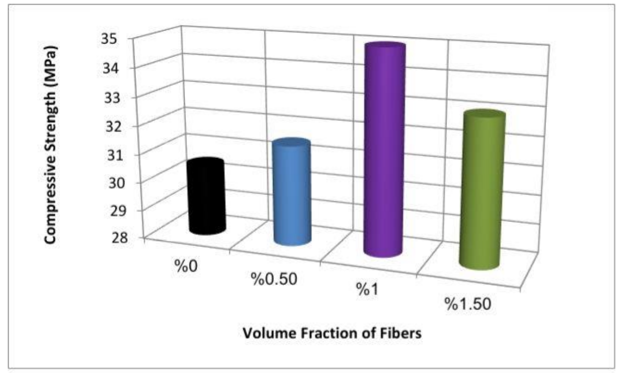

Figure (3) Compressive strength.

8.2 Split Tensile Strength Test

The cylinders at age 28 days are tested under the Compression testing machine (Fig. 4).

Figure 4. GPC Cylinder before and after testing

It can be observed that Polypropylene fibers have a significant influence on the tensile strength of GPC. It is clear from Table (5), figure (5) that the increase in the volume of fraction fiber from 0.0 % to 0.5%, 1.0 %, and 1.5 % resulted in a percentage increase in the splitting strength of the order 12.3 %, 15.76 % and sudden descent by 9.1% respectively, and these results match with A.Talib et al. [12] who found There is a 16% increment in the split tensile strength of geopolymer concrete with the addition of polypropylene fiber. Farther increased also of polypropylene fibers more than 1% individually lead to diminishing the splitting strength due to the presence of more fibers and therefore increase in air content attributes in reducing workability.

Table 5. Results of Split Tensile Test on Geopolymer Concrete Cylinders

Mix Type	The volume fraction of PP fibers%	indirect tensile strength *ft* (Mpa)
GPC1	0%	3.3
GPC2	0.5%	3.706
GPC3	1%	3.82
GPC4	1.5%	3.6

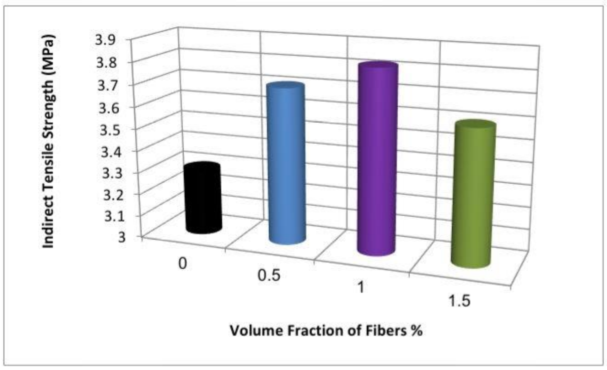

Figure 5. Splitting Strength

8.3 Flexural Tensile Strength Test

The beams at age 28 days are tested under the Flexural tensile strength testing machine under a two-point loading condition (Fig. 6).

It is clear from Figure (7) and Table (6) that the influence of the fiber content Vf on the flexural

Figure 6. Beams before and after Failure

Values of (fr) for non-fibrous GPC is about (3.3) MPa, while fibrous GPC (fr) values marked (3.5) MPa, (3.8) Mpa, and (4.2) Mpa for specimens have vf of 0.5%, 1%, and 1.5% respectively, resulted in an increase of 6.06 %, 15.15 % and 27.3% in flexural tensile strength was obtained as compared with the nonfibrous specimen. This clearly illuminates that the addition of polypropylene fiber improves the flexural strength of GPC. The enhancement in flexural strength is achieved due to improvement in the mechanical bond between the cement paste and fiber. As the amount of fiber increases in the mix, it greatly helps to reduce the widening of cracks more effectively. The effect of fibers leads to good flexural strength also increases toughness which in turn improved performance in resisting fatigue, impact, and impulse loading. Moreover, the improved toughness also leads to better ductility. Divya S Dharan, Aswathy La [22] observed the enhancement in flexural strength is when adding fibers to cement paste. Similar results were observed by K. Pham et al. [23] who investigated the flexural tensile strength for polypropylene fiber-reinforced geopolymer concrete and they found when the volume fraction of fiber increased from 0.5% to 1.5%, the flexural strength increased.

Table 6. Results of Flexure Test on Geopolymer Concrete Beams

Mix Type	The volume fraction of PP fibers%	Flexural Strength *fr* (MPa)
GPC1	0%	3.3
GPC2	0.5%	3.5
GPC3	1%	3.8
GPC4	1.5%	4.2

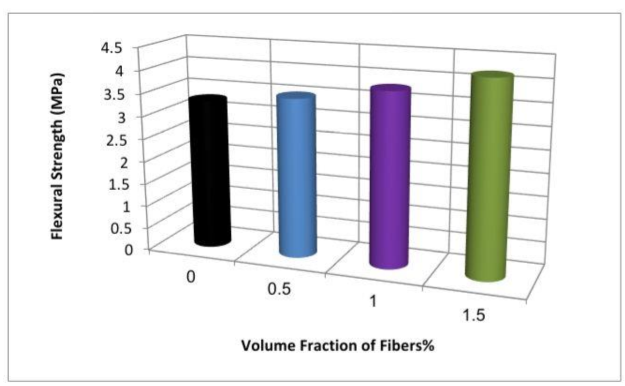

Figure 7. Flexural Strength

8.4 Modulus of Elasticity Test

According to ASTM C469-87a[24] standard, the elastic modulus was measured experimentally by a testing standard cylinder (150×300) mm was loaded vertically until 40% of the ultimate load for each mix. The universal hydraulic test machine was used to apply compression on the top surface of the cylinder as shown in figure (8).

Figure 8. Modulus of Elasticity Test

It is clear from Table (7) and figure (9), that there is a significant effect on the addition of polypropylene fibers on the modulus of elasticity and the maximum value was obtained from 1% of fibers addition. Also, some factors affect the values of geopolymer modulus as mention by researchers like, Olivia and Nikraz[25]attributed to the high silicate content that might increase the elasticity of Geopolymer concrete. When Vf increased from 0.0, 0.5 %, 1.0 % and 1.5 % the percentage increase from 0.0 to 5.7 %, 13.1 % and 9.56 % respectively, and similar results were observed by K. Pham et al. [23] when adding pp fibers to GPC.

Table 7. Modulus of Elasticity Test Results

Mix Type	The volume fraction of PP fibers%	Modulus of Elasticity Ec (GPa)
GPC1	0%	21.038
GPC2	0.5%	22.236
GPC3	1%	23.795
GPC4	1.5%	23.05

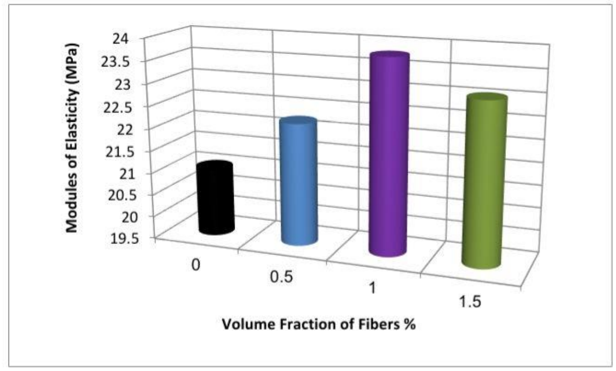

Figure 9. Modulus of Elasticity

8.5 Dry Density

The density is the key determinant of a material's strength as stated in the previous study the density mainly depends on the aggregate type and quantity and also shows that the density of geopolymer concrete is slightly lower than that of ordinary Portland cement mortar [26]. The density depended on the solid volume inside the body as this reduces the strength capacity of the samples as pores increase in the tested samples, the strong component which will hold on and withstand the stresses.

The average dry density of the mixtures was tested, evaluated and analyzed at 28 days, the results of the tests are tabled (8) and plotted in figure (10), the densities range between (2175–2305) kg / m3. It should be noted that the inclusion of polypropylene fibers in mortar mixtures slightly decreases the weight of the hardened unit; and this can be due to the specific gravity of the fiber which decreases the general density. The sums of declines in polypropylene fibers are 4.43% and 5.3% and 5.64%from the reference mix.

Table 8. Dry Density for Geopolymer Concrete

Mix Type	The volume fraction of PP fibers%	Dry density (kg /m3)
GPC1	0%	2305
GPC2	0.5%	2203
GPC3	1%	2183
GPC4	1.5%	2175

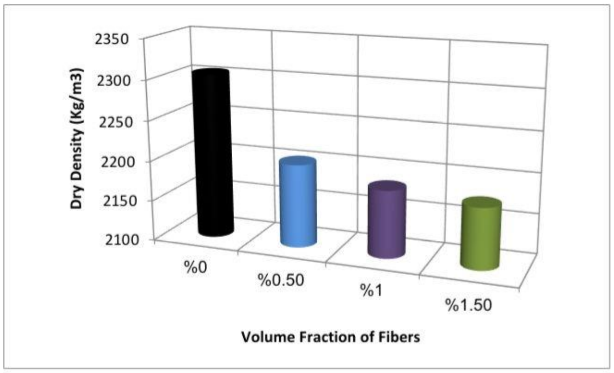

Figure 10. Dry density for GPC

9. Conclusions

The experimental results showed a clearer and deeper understanding of metakaolin-based geopolymer composites generated with polypropylene fibers' mechanical strength. The main parameters affecting structural performance were the mechanical properties, including compressive, flexural, and tensile strength, and elastic modulus. Understanding the fiber influence is useful for the application of GPC composites in modern design and construction. The following, Findings obtaining experimental results:

1. The strength of geopolymer concrete was significantly improved, especially the flexural performance. The adding of PP fibers also enhanced the compressive strength and the splitting tensile strength.
2. The suitable volume fraction of fiber was 1% to polypropylene fiber. Where it recorded the highest strength to compressive, flexural, and splitting tensile 14.75%, 15.15%, and 15.76% respectively. Also accompanied increasing in modulus of elastic reached 13.1%.
3. The addition of fiber makes a decrease in density.

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

10. References

1. G. Cook (2009) *"Climate Change in the cement industry"*,Trumpington Street Cambridge, CB2 1QA, UK, 13-14p,.
2. Bernal S.A, Rodriguez E.D, de Gutierrez R.M, Gordillo M, Provis J.L., Mechanical and thermal characterisation of geopolymers based on silicate-activated metakaolin/slag blends, Journal of Materials Science 46(16), p.5477,2011.
3. Kong D.L., Sanjayan J.G., Sagoe-Crentsil K., (2007) *"Comparative performance of geopolymers made with metakaolin and fly ash after exposure to elevated temperatures"*, Cement Concrete Reseach 37(12), p. 1583,.
4. Geopolymer Institute., (2010) *"What Is a Geopolymer?"* Introduction. Institut Géopolymère", SaintQuentin, France. Accessed on January 29, at http://www.geopolymer.org/science/introduction.
5. Rangan, B.V., (2008) *" Low-Calcium, Fly-Ash-Based Geopolymer Concrete"* Concrete Construction Engineering Handbook. Taylor and Francis Group, Boca Raton, FL.
6. Hardjito, D., S. Wallah, D. M. J. Sumajouw, and B. V. Rangan., (2004) *"On the Development of Fly Ash– Based Geopolymer Concrete"* ACI Materials Journal, vol. 101, no. 6,.
7. Zhang, Z. et al. (2009) *"Preparation and mechanical properties of polypropylene fiber reinforced calcined kaolin-fly ash based geopolymer"*, Journal of Central

South University of Technology. Springer, 16(1), pp. 49–52,.

8. Raijiwala DB, Patil HS. (2011) *"Geopolymer concrete: A concrete of the next decade"*. In: Grantham M, Mechtcherine V, Schneck U, (Eds.) CRC Press, Taylor and Francis Group. *Proceedings of Concrete Solutions, 4th International Conference on Concrete Repair*;; Dresden, Germany; 287-291p, Sept 26-28,.
9. Hardjito Djwantoro, Cheak Chua Chung and Lee Ing Carrie Ho, (2008) *"Strength and Setting Times of Low Calcium Fly Ash-based Geopolymer Mortar"*, Modern Applied Science, Vol. 2, No. 4, p 9, , www.ccsenet.org
10. Mandal.S and Majumdar.D, (2009) *"Study on the Alkali Activated Fly Ash Mortar"*, the Open Civil Engineering Journal, Vol 3, pp 98-101,.
11. Nath, P.,Sarker ,P. K., Rangan, V. B. (2015) *"Early age properties of low-calcium fly ash geopolymer concrete suitable for ambient curing"*. The 5th Intentional Conference of Euro Asia Civil Engineering Forum (EACEF-5) Surabaya, Indonesia, 601-607.
12. *A. Talib, M.Y. Khan, A. Baqi, M. K. Vakil*, (2016) *"Effects of Polypropylene Fibre on Strength of GeopolymerConcrete"*, DOI: 10.13140/RG.2.2.19402.77763 September.
13. Ilamvazuthi SS, Gopalakrishna GVT. Performance of geopolymer concrete with polypropylene fibres. *IJIET*. 3(2): 148-156p, 2013.
14. Siddique R, Klaus J, (2009) *"Influence of MK on the properties of mortar and concrete: A review"*, Applied Clay Science 43 392–400,
15. IOS No.45, Iraqi Specification, (1984) *"Aggregate from Natural Sources for Concrete and Construction"*, Central Agency for Standardization and Quality Control, Baghdad,.
16. ASTM C494 "Standard Specification for Chemical Admixtures for Concrete", Annual Book of American Society for Testing and Material Standards, 2004.
17. Hardjito, D. and Rangan, B. V., (2005) *"Development and Properties of Low-Calcium Fly Ash-based Geopolymer Concrete"*, Research Report GC1, Faculty of Engineering, Curtin University of Technology, Perth, available at espace@curtin or www.Geopolymer.org,.
18. Al-Shathr, B.S., Al-Attar, T.S., and Zaid, A.H (2015) *"Optimization of Geopolymer Concrete Based on Local Iraqi Metakaolin"* The 2nd International Conference of Buildings, Construction and Environmental Engineering,pp 97-100,.
19. ASTM C143 / C143M - 10a (2010) *"Standard Test Method for Slump of Hydraulic-Cement Concrete" American National Standard*, 3pp.
20. Porkodi.R, Dharmar.S, Nagan.S. (2015) *"Experimental Study on Fiber Reinforced" International Journal of Advanced Research in Science and Engineering,.*
21. Sathish Kumar, Blessen Skariah Thomas, Alex Christopher. (2012) *"An Experimental Study on the Properties of Glass Fibre Reinforced Geopolymer Concrete"* International Journal of Engineering Research and Applications vol 38, pp. 722-726,.
22. Divya S Dharan, Aswathy Lal, (2016) " Study the Effect of Polypropelene fibers", International Research Journal of Engineering and Technology (IRJET), Vol.: 03 Issue: 06, June-, PP.616, www.irjet.net.
23. Khoa V. A. Pham, et al (2019) *"Assessment of Performance of Fiber Reinforced Geopolymer Composites by Experiment and Simulation Analysis"*, Journal of applied sciences, 9, 3424.
24. ASTM C469-87a,*"Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression"* ASTM International.
25. Olivia, M. and Nikraz, H.R. (2011) *"Strength and water penetrability of fly ash*

geopolymer concrete", Engineering and Applied Sciences, Vol. 6, Issue 7, pp. 70-78.

26. Ahmed Mushrif Swaif (2017*) "Production of Geopolymer Boards Reinforced with Carbon or Polypropylene fibers"*, Master thesis Submitted to the University of Technology.