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Study The Impact of Geopolymer Mortar Reinforced by Micro Steel Fibers

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ABSTRACT

In this research, geopolymer mortar had to be designed with 50% to 50% slag and fly ash with and without 1% micro steel fiber at curing temperature of 240°C. The molarity of alkaline solution adjusted with 12 molar sodium hydroxid to sodium silicate was 2 to 1, reaspectivly. The heat of curing increased the geopolymerization proceses of geoplymer mortar, which led to increasing strength, giving the best result and early curing age. The heat was applied for two days by four hours each day. It was discovered in the impact test that the value first crack of each mix was somewhat similar, but the failure increased 72% for the mixture that did not contain fiber. For the energy observation results it was shown that the mixtures with fiber increased by about 40% compared with the mixtuers without fibers at the first crack and 72% at the failure, respectively.

Keywords: geopolymer mortar, fly ash, ground-granulated-blast-furnace-slag, alkaline solution.

دراسة الصدم للمونة الجيوبوليمرية المسلحة بالياف الحديد الدقيقة

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الخلاصة

تطلب العمل تصميم خلطة مونة جيوبوليمرية من 50% الى 50% من خبث الافران والرماد المتطاير مع وبدون استخدام 1% من الياف الفولاذ الدقيقة باستخدام حارة معالجة 240 درجة سيليزية . وقد تم تحديد المولارية للمحلول القلوي ب 12 مولر ونسبة هدروكسيد الصوديوم الى سليكات الصوديوم 2:1 على التوالي . ادى استخدام المعالجة الحرارية الى تسريع عملية البلمرة للمونة

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الجيوبوليمرية مما ادى الى زيادة القوة مع اعطاء افضل نتيجة في الاعمار المتقدمة . في فحص مقاومة الصدم كانت نتيجة حدوث الشق الاول للنماذج الحاوية على الالياف وغير الحاوية على الالياف متقاربة نوعا ما , اما عند حدوث الفشل كانت الزيادة بنسبة 72 % بالنسبة للخلطة الحاوية على الالياف . في فحص امتصاص الطاقة بينت النتائج الخلطة الحاوية على الفايبر زيادة بنسبة 40% مقارنة مع الخلطة غير الحاوية على الفايبر بالنسبة الى الشق الاول و 72 % بالنسبة الى الفشل على التوالي

الكلمات الرئيسية: مونة الجيوبوليمر , الرماد المتطاير , خبث الافران , محلول قلوي.

1. INTRODUCTION

In 1978, Davidovits developed the word "geopolymer" to refer to a category of mineral binders with chemical properties comparable to zeolites. However, as opposed to conventional Portland/pozzolanic cement, geopolymers employ silica and alumina precursors polycondensation to create the matrix and provide strength **(Provis and Deventer, 2009).** By adding environmentally friendly materials to civil engineering projects, it is possible to reduce CO_2 emissions from cement producers and assist recycling industrial wastes that have a substantial impact on environmental contamination **(Muhsin and Fawzi, 2021).**
In addition to conventional concrete, there are several types of cement composites. GGBFS, fly ash, and silica fume are examples of supplementary cementitious materials **(Sicakova et el., 2020).** Environmentally friendly materials have been developed in an effort to reduce global warming. There have been attempts to make mortar and concrete using fractional replacement of cement with other materials such "Rice Husk Ash, Fly Ash, Silica Fume, Metakaolin, and Ground Granulated Blast Furnace Slag (GGBFS)". Another attempt was to come up with a cement replacement as a binder **(Duxson at el., 2007).**
If thermal power plant fly ash and slag refuse are not treated and reused, they constitute a significant environmental threat. When thermal power plant fly ash is deposited, it causes long-term environmental damage (contaminating groundwater supplies, destroying farmland, etc.) by polluting groundwater and harming farmland **(Phan and Nguyen, 2021).** To address these drawbacks, a lot of work has gone into developing "Geopolymers," an environmentally favorable innovative alternative to traditional Portland cement. Using this kind of geopolymer cement to make geopolymer concrete offers environmental and economic benefits for the construction and civil engineering sectors, as well as the potential to reduce CO_2 emissions by up to 80% **(Davidovits, 1994) and (Hussein and Fawzi, 2021).**

2. LITERATURE REVIEW

(Najeb and Fawzi, 2022) studied the effect of additional steel fibers on the mechanical properties of slurry infiltrated fiber concrete and found the increment compressive strength increased by (1.5%, 6.9%) and flexural strength (23%, 6.5%), respectively, for both sets.

(He. et al., 2020) said that the remaining compressive strength of the micro steel fiber reinforced concrete cubic and prismatic specimens might be as high as 65.3% to 81.6% and as low as 62.6 percent to 77.0 percent of the original loading strength correspondingly. In the same way, Type I micro steel fibre reinforced concrete has more residual strength than Type II micro steel fibre reinforced concrete. Micro steel fibre (cold-drawn wire with a diameter of approximately 0.2mm, typically smooth).
(Satpute et al., 2012) explained that all other test variables were kept constant while examining the impact of geopolymer concrete's compressive strength when heated at a higher temperature. Compressive strength rises with increasing heating temperature for the same curing time. After curing for 24 hours, the rate of strength growth increases linearly. The difference between curing

for 16 hours and 24 hours is negligible. As a result, after curing at 120°C for 24 hours, compressive strengths of above 60 MPa can be obtained.
(Hussein, 2021) studied different mix compositions of fly ash to slag (75%:25%, 65%:35%, 55%:45%), respectively, and found the increased proportion of Slag to Fly ash leads to increase compressive strength.
(Girawale, 2015) made researchers test Geopolymer concrete's compressive strength as well as flexural and split tensile strength as part of the project. They found the strengths mentioned above largely depend on changes in various parameters, such as (Na_2SiO_3/ NaOH) ratio and molarity of the alkaline solution, while keeping the curing temperature constant at 80°C. Faster construction is possible because geopolymer concrete's compressive strength may improve dramatically in the first 24 hours.
(Fawzi, 2006) studied that reinforced concrete mortar hardness is interpreted in the mechanical feature of reinforcement pulling and breaking ductility. The friction resistance of their shared surface is improved by good adhesion between the bonding substance and support, increasing the absorption capacity of reinforcement and helping to improve these qualities in the presence of (feldspar or silica powder). A lot of energy is needed to pull the clamps out of the binder (lightweight cement mortar) without breaking, so the reinforcement (lattices and fibers) acts as interconnected bridges to prevent crack expansion. Short iron fibers with a uniform random distribution are added to the binder to further increase this energy absorption.

3. EXPERIMENTAL WORK

3.1 Materials

3.1.1 Fly ash

The properties composition of the Fly ash used in this study is shown in **Table (1)**. According to the findings, the fly ash used in this research satisfies **ASTM C618,2015** standards, as indicated in the table.

Table (1) Analyses of the chemical composition of fly ash compering with ASTM C618

Oxide	Contents, %	(ASTM C618) Requirement
Fe_2O_3	5.35	Total Sum. > 70%
Al_2O_3	17.59	
SiO_2	65.63	
SO_3	0.21	Maximum 5%
MgO	0.84	--
CaO	0.98	--
L.O. I	2.76	Maximum 6%
K_2O	3.53	--
Na_2O	2.36	--

3.1.2 Ground Granulated blast furnace slag

GGBFS chemical composition is given in **Table (3)**. The results show that the Ground Granulated blast furnace slag The materials utilized in this investigation met **ASTM C618** standards.

Table (2) Analyses of the chemical composition of GGBS compared with ASTM C618

Oxide	Contents, %	(ASTM C618) Requirement
Fe_2O_3	0.35	Total Sum. > 70%
Al_2O_3	25.53	
SiO_2	45.88	
SO_3	1.98	Maximum 5%
Mg.O	1.87	--
Ca.O	19.24	--
LOI	2.53	Maximum 6%
K_2O	1.8	--
Na_2O	0.8	--

3.1.3 NaOH

Hydroxide sodium is made by melting caustic soda flakes with water. Different molar concentrations can be derived based on a ratio. This experiment's NaOH solution is described in further detail in **(ASTM E291-2009)**. In this investigation, 12 Molar was utilized as the proportion.

3.1.4 Sodium silicate, Na_2SiO_3

The concentration of Na_2SiO_3 is determined by the ratio of Na_2O to SiO_2 and H_2O. In addition, the Na_2SiO_3 used in this formulation was produced in the UAE.

3.1.5 Water

To produce the NaOH solution, distilled water must be used to dissolve flakes of NaOH. To the geopolymer mix, tap water was added. Design as an additional water source to enhance workability, and it conforms to **IQS 1703-(2018).**

3.1.6 Fine aggregate

The fine aggregate in this study was natural sand from the Al-Ekhadir (Karbala city) region. As indicated in **Tables (3) and (4)**, it was zone two and met the physical and chemical criteria of the Iraqi standard requirements **IQS (No.45/1984)**.

Table (3) Sieve Analysis of The Fine Aggregates

Size of the Sieve, mm	Cumulative % pass	IQS (45-1984), zone2
10	100	100
4.750	91	90-100
2.360	80	75-100

1.180	71	55-90
0.60	53	35-59
0.30	22	8-30
0.150	7	0-10

Table (4) Physical and Chemical properties of The Fine Aggregates

Physical characteristics	Tests results	IQS (45-1984)
Density (kg/m^3)	1595	----
Fineness modulus	2.76	----
Specific gravity	2.3	----
Absorption, percent	1.7	----
Fine materials that pass through 75 µm sieve	1.4	3% maximum
Sulfate content, percent	0.15	0.5% maximum

3.1.7 Micro steel fiber

Table (5) shows the length of the micro steel fibers used in this study and the other property.

Table (5) properties of Micro steel fiber

Properties	Micro Steel Fiber
T. S. (MPa)	2600
Dia. -(mm)	0.2
Dens. (kg/m^3)	7800
L. (mm)	13
Aspect ratio	65
M.O. E. (GPa)	250

According to the Data Sheet

3.1.8 Superplasticizer

A locally sourced product, KUT PLAST SP400, was made accessible. The **ASTM C494 Type F** standard was followed. It is used to increase workability.

3.2 Preparation of alkaline solution

When producing the geopolymer concrete, the alkaline solution must be prepared first. The sodium hydroxide molar proportion was set at 12 molars, and the sodium silicate-to-sodium hydroxide ratio was set at 2:1., thus the solution's weight availability. While dividing the result by 3, we found the weight of sodium hydroxide to get the value, but multiplying by 2 brings us to sodium silicate, which has a mass of sodium hydroxide. **Table (6)** shows how much sodium hydroxide flakes weigh.

Table (6) Amount of NaOH solids for 1 kg of solution at specified molarity and wight concentration according to **(Rangan, 2010)**

Mix	Fine Agg.	Water*	FLY / SLAG Ration	SLAG	Fly Ash	Sodium Silicate Solution	NaOH	Micro Steel percentage
G1	1400	75	0.5:0.5	375	375	225	112.5	-
G2	1400	75	0.5:0.5	375	375	225	112.5	1

Molarity (mole/L)	Sodium Hydroxide in weight %	Weight NaOH Flakes (g)	Weight of Water (g)
8	26.2	262	738
10	31.4	314	686
12	36.2	362	638
14	40.4	404	596
16	44	440	560

3.3 MIXING

Before beginning the mixing procedure, the alkaline liquid was made a day ahead of time and blended with the superplasticizer. GGBFS, fly ash, fiber, and sand were manually mixed for about 2 minutes before adding the alkaline solutions. To achieve homogeneity, mixing takes around 10 to 15 minutes.

3.4 CURING

After one day of casting, the specimen was put in the oven at a selection of temperatures (80, 160 and 240)°C for four hours through two days and then stored in another oven for cooling and retaining temperatures until the date of the test, as shown in **Fig. (1).**

Figure (1) Impact Samples While curing

3.4 TESTS

These tests utilized a 6.35 cm (dia.) hardened steel ball, thrown from a meter high over a (500*500*50) mm slab to determine the impact resistance of one percent micro steel fibre for (28) days of curing age, inspired by **(ACI 544.2R-10)**. The equipment used for these tests includes:

- A strong steel bracket supports the device throughout the test, and another stand constructed of steel angle plate is used to hold the test specimen in position, so it does not move about during the test. Together, these two stands provide enough support for the device and are impact-resistant.
- An inner diameter of 10.5 cm cylindrical tube secured with brackets prevents it from moving throughout the test. This tube includes an aperture of various heights (0.5, 1.5, and 1) m; a 1.5-meter height was chosen for conducting this test.
- A 3.07 kg hardened steel ball thrown from a height of one and a half meters onto the specimen many times to measure its resistance to impact is the standard method for determining the mass of a falling object.
- To calculate the impact energy, the following equation was used:

$$\text{Impact energy (N.m)} = N * m * g * h$$

Where :
N = number of steel balls thrown
m = mass of steel ball (kg)
g = acceleration of gravity (m/s^2)
h = hight of thrown balls (m)

4. RESULT AND DISCUSSIONS

The impact resistance test was carried out after 28 days of curing ages with 240℃ heat of curing for two samples of 1% of fiber and two samples without fibers. **Table (7) and Fig. (2) and (3)** describe the impact test results. From the table, it is clear that when the fibers are additional, the impact resistance increase (the number of blows increases until the sample crush and failure occur). The raising in impact resistance is due to the interlocking of the fiber network in the mortar, which increased the absorption energy due to additional fibers that complied with **(Kiran et al., 2015).**

Table (7) Impact tests result of geopolymer mortar at 28 days

Samples	First Crack / No.	Failure / No.
G1	8	69
G2	11	119

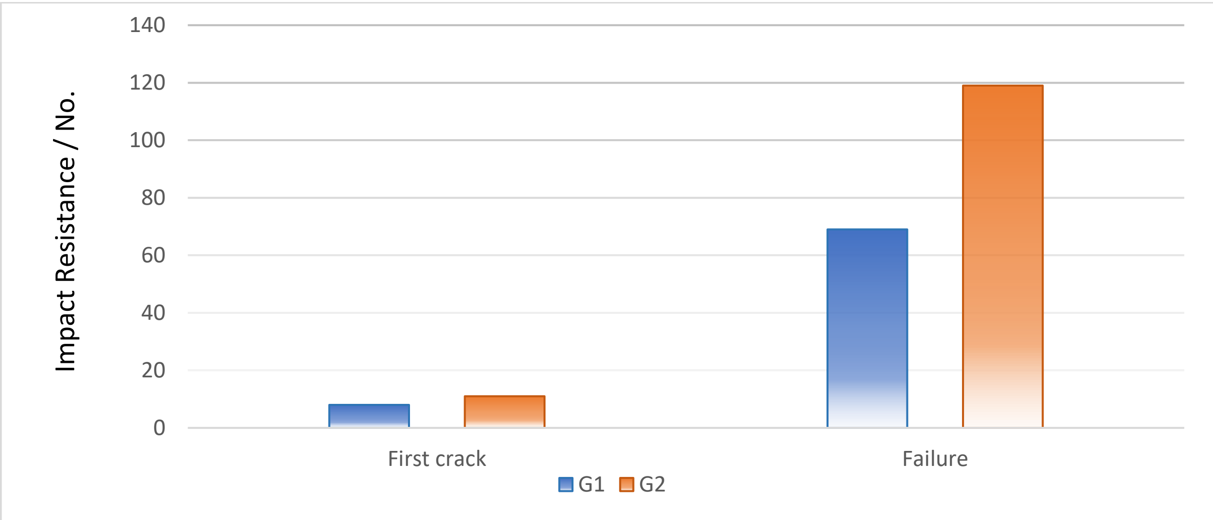
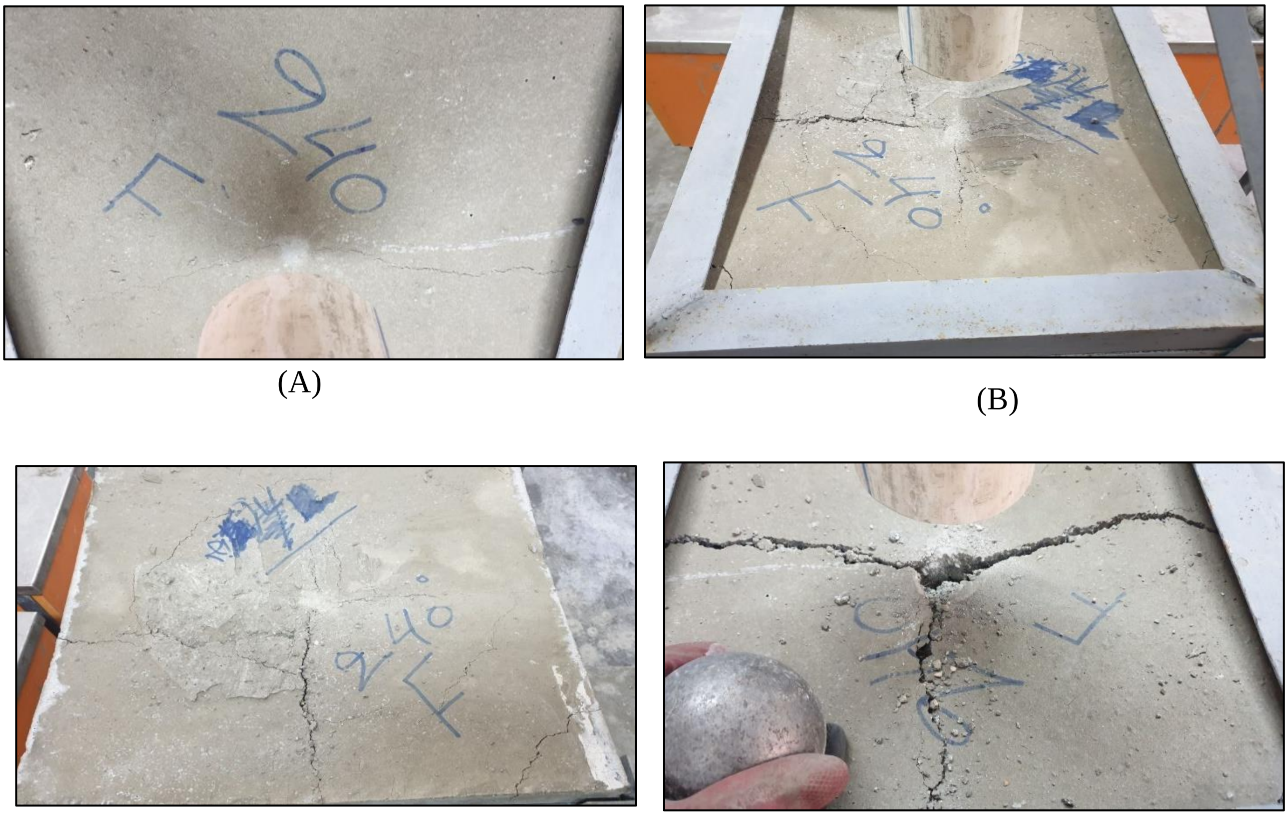


Figure (2) Impact resistance results

As shown in **Table (8)** and **Fig. (4)**, the results reveal that adding micro steel fibers to mixes G2 increases energy absorption in the first crack and failure when compared to mixes G1 at 240°C and 28 days of curing time.

Table (8) Energy absorbed result of geopolymer mortar at 28 days

Samples	Energy absorption (Joule) at	
	First Crack	Failure
G1	339.15	3120.3
G2	474.8	5381.3



(A) (B)

(C) (D)

Figures (3) Impact resistance tests

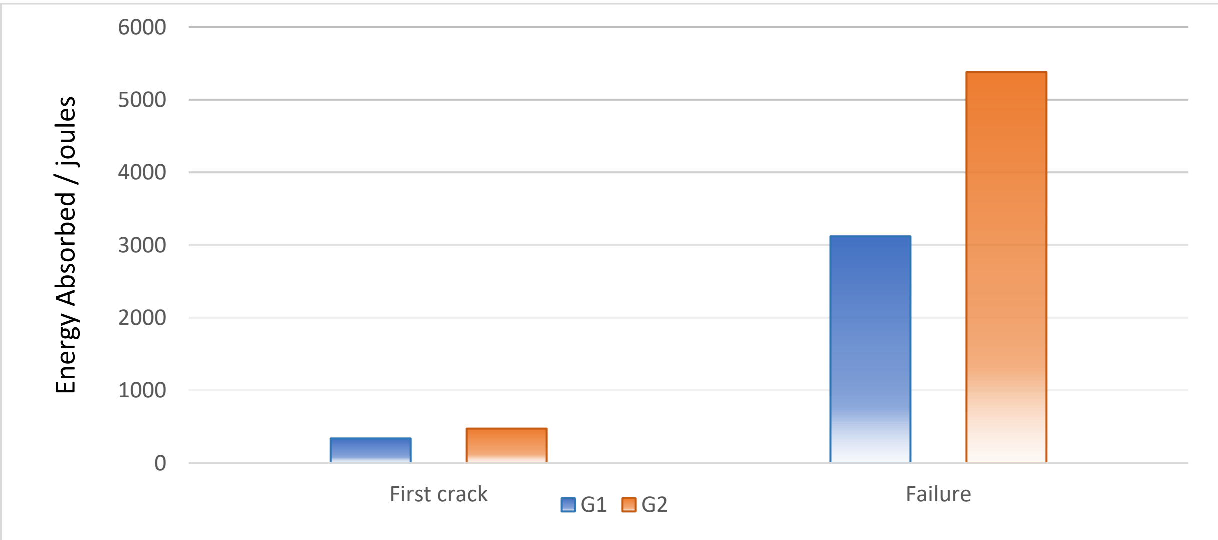


Figure (4) Energy Absorbed results

5. CONCLUSIONS

1- Impact test results show increasing of 40% concerning additional micro steel fiber for the first crack results and 72% for the failure of the specimen.
2- The observation results showed that the mixed G2 increased about 40% compared with mixed G1 at the first crack and 40% at the failure of the specimen.

REFERENCE

ACI 544-2R, 2018. Measurement of properties of fiber reinforced concrete.

Adraa M. Najeeb, and Nada Mahdi Fawzi, 2022. Effect of Distributing Steel Fibers on Some Properties of Slurry Infiltrated FiberConcrete, ***Journal of Engineering***, Vol. 28, No. 4, pp. 64–76.

Alena Sicakova, Erika Kardosova, and Matej Spak, 2020. Perlite Application and Performance Comparison to Conventional Additives in Blended Cement, *Engineering, Technology & Applied Science Research*, Vol 10, No. 3, p.p 5613-5618.

ASTM C618, 2015. Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete.

ASTM E291, 2009. Standard Test Methods for Chemical Analysis of Caustic Soda and Caustic Potash (Sodium Hydroxide and Potassium Hydroxide).

ASTM C494 / C494M, 2005. Standard Specification for Chemical Admixtures for Concrete.

Davidovits, J.,1994. Properties of Geopolymer Cements", published in Proceedings First International Conference on Alkaline Cements and Concretes, Scientific Research Institute on Binders and Materials, Kyiv State Technical University, Kyiv, Ukraine.

Girawale, M. S., 2015. Effect's of alkaline solution on geopolymer concrete, *International Journal of Engineering Research and General Science*, Vol 3, Issue 4.

IQ. Specification, 2018. No. 1703, used water in concrete.

IQ. Specification, 1984. No. 45, Aggregate from natural sources for concrete and construction.

John L. Provis, and Jannie S.Van Deventer, 2009. "Geopolymers, Structures, Processing, Properties and Industrial Applications", 1st Edition, Woodhead Publishing

Nada Mahdi Fawzi, 2006. The properties of light weight ferrocement sheets and highly compact, Ph D, University of Baghdad, Civil Engineering Department.

Peter Duxson, John L Provis, Grant C.Lukey, and Jannie S.J.van Deventer, 2007. The role of inorganic polymer technology in the development of 'green concrete, *Cement and Concrete Research*, Vol 37, Issue 12, p.p 1590-1597.

Rangan, B.V., 2010. Proceedings of the International Workshop on Geopolymer Cement and Concrete, Allied Publishers Private Limited, Mumbai, India.

Satpute Manesh B., Wakchaure Madhukar R., and Patankar Subhash V., 2012. Effect of Duration and Temperature of Curing on Compressive Strength of Geopolymer Concrete, *International Journal of Engineering and Innovative Technology*, Vol 95, p.p 410-414.

Sarah Sameer Hussein, and Nada Mahdi Fawzi, 2021. Influence of Using Various Percentages of Slag on Mechanical Properties of Fly Ash-based Geopolymer Concrete, ***Journal of Engineering***, Vol. 27, No. 10, pp. 50–67.

Sarah Sameer Hussein, 2021. Study Some Properties of geopolymer Concrete by using sustainable fibers, M.Sc., University of Baghdad, Civil Engineering Department.

Van Tien Phan, and Tien Hong Nguyen, 2021. The Influence of Fly Ash on the Compressive Strength of Recycled Concrete Utilizing Coarse Aggregates from Demolition Works, *Engineering, Technology & Applied Science Research*, Vol 11, No 3, p.p 7107-7110.

Xiaobing He, Yakun Fang, Qi Luo, Yong Cao, Han Lu, and Runping Ma, 2021. Mechanical Properties of Microsteel Fiber Reinforced Concrete and Its Gradient Design in the Partially Reinforced RC Beam, *Hindawi-Advances in Civil Engineering*, Vol.2020, Article ID 6639312.

Zahraa F Muhsin and Nada Mahdi Fawzi, 2021 Effect of Fly Ash on Some Properties of Reactive Powder Concrete, *Journal of Engineering*, Vol 27, No 11,p.p 32-46.

T Kiran, Sadath Ali Khan Zai., and Srikant Reddy S., 2015. Impact Test on Geopolymer Concrete Slabs, *International Journal of Research in Engineering and Technology*, Vol 04, Issue12.