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Properties Study for Geopolymer Concrete

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المخلص

الهدف من هذه الدراسة هو تحقيق الإستفادة الكاملة من المخلفات الصناعية المتوفرة محليا في مصر وإستخدامها كبديل لمواد الربط التقليدية المستخدمة في تصنيع الخرسانة الجيوبوليميرية. حيث تتكون الخرسانة الجيوبوليميرية من المكونات التقليدية للخرسانة العادية مستبدلا فيها الاسمنت (المادة الرابطة) بمواد جيوبوليميرية (خبث الافران المطحون - رماد متطاير - ميتاكاولين). البرنامج العملي تم عمل عشرة خلطات بإستخدام خبث الحديد بمحتوى 450 كجم/م³ و خلطتان تحكم من خبث الحديد فقط بمولارية (10 - 12) مولر. أربعة خلطات تم أحلال (10% - 20%) ميتاكاولين بمولارية (10 - 12) مولر. أربعة خلطات تم أحلال (10% - 20%) رماد متطاير بمولارية (10 - 12) مولر. ثم تم عمل اختبارات مقاومة الضغط عند الـ 7 أيام و الـ 28 وتم عمل اختبارات لتحديد مقاومة الإنحناء عند عمرو 28 يوم.

ABSTRACT: The aim of this study is to achieve full utilization of industrial waste available locally in Egypt and use it as an alternative to traditional bonding materials used in the manufacture of geopolymer concrete, where concrete consist of traditional components of normal concrete replacing cement with geopolymer marital (ground granulated blast furnace slag, fly ash and metakolin). The practical program: ten mixtures were made using granulated blast furnace slag contents (450) Kg/m³, four granulated blast furnace slag only control mixes with molarities (10 % – 12 %) molar, four mixes (10 % - 20 %) metakolin were replaced by (10 -12) molar and four mixes (10 % - 20 %) fly ash were replaced by (10 - 12) molar. Then compressive strength tests were performed at the age 7 and 28 dayes and attest was performed to determine the flextuer strength at the age of 28 days.

KEYWORDS: Geopolymer concrete, Ground granulated blast furnace slag (GGBFS), Flay ash (F.A), Metakolin (M.K), Molarty(M)

I. INTRODUCTION

The National Ready Mixed Concrete Association [1] proved that producing 1 ton of Portland cement generates approximately 1 ton of CO₂ and that the cement industry accounts for about 5% of global greenhouse gas emissions. Therefore, new techniques to produce concrete with reduced greenhouse gas emissions are needed. The global use of concrete is second only to water. As the demand for concrete as a construction material increases, so also the demand for Portland cement. It is estimated that the production of cement will increase from about from 1.5 billion tons in 1995 to 2.2 billion tons in 2010 [2]. On the other hand, the climate change due to global warming has become a major concern. The global warming is caused by the emission of greenhouse gases, such as carbon dioxide (CO₂), to the atmosphere by human activities. Among the greenhouse gases, CO₂ contributes about 65% of global warming [3]. The cement industry is held responsible for some of the CO₂ emissions, because the production of one ton of Portland cement emits approximately one ton of CO₂ into the atmosphere [3, 4]. Several efforts are in progress to supplement the use of Portland cement in concrete in order 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, and the development of alternative binders to Portland cement. Concrete structures were designed to withstand various types of environmental conditions categorized as from mild to very severe conditions. Fire represents one of the most severe environmental conditions to which concrete structures may be subjected to such as close conduit structure like tunnel [3, 4]. Geopolymer concrete (GPC) is an alternative for cement with waste materials such as fly ash and GGBFS. Ground granulated blast furnace slag (GGBFS) is such pozzolanic material which can be used as a cementitious ingredient in either cement or concrete composites. GGBFS is a by-product in the manufacture of pig iron, the amounts of iron and slag obtained are of the same order. Slag is defined as “the non-metallic product consisting essentially of calcium silicates and other bases that is developed in a molten condition simultaneously with iron in a blast furnace. The slag is a mixture of lime, silica, and alumina, the same oxides that make up Portland cement, but not in the same proportion. It was found that GGBS gave high early compressive strength, corrosion resistance better than



OPC concrete, better crack resistance and long-term durability because of GGBFS are more homogeneous and well-bonded to the aggregate [3]. Also, GGBFS gave better sulphate attack, tensile strength and higher temperature resistance more than OPC concrete [4].

II. EXPERIMENTAL PROGRAM

The experimental program consists of two main phases as following: The first phase presents the used materials in geopolymer concrete and its properties, the method of mixing, casting and curing of geopolymer concrete and all mixtures which did in the laboratory. The second phase presents the tests on the specimens and their results which included the tests of compressive strength at 7 and 28 days, and flexural strength of geopolymer specimens. six standard cubes 150 x 150 x 150 mm for compressive strength at 7 and 28 days, and one prism 100*100*500 mm for flexural strength were cast.

2.1 MATERIALS

GGBFS is an industrial by-product resulting from rapid water cooling of molten steel. This material is available in Iron and Steel Factory, Helwan city. It has favorable properties for cement industry, as it is relatively inexpensive, highly resistant to chemical attack and maintains excellent thermal properties. The physical properties and XRF analysis of used GGBFS was showed in Table (1) and Table (2) respectively. The major components of the utilized slag were Silicon Dioxide (SiO₂), Carbon Oxide (CaO), Magnesium Oxide (MgO), Aluminum Oxide (Al₂O₃), Barium Oxide (BaO) and Manganese Oxide (MnO)

Table (1): Physical properties for the used GGBFS

Fineness (µm)	84.7
Specific weight	3.1
Color	Black yellow

Table (2): Chemical Composition of GGBFS

Oxide	Content%
SiO₂	35.08
TiO₂	0.59
Al₂O₃	9.32
Fe₂O₃	0.63
MnO	4.56
BaO	2.79
MgO	6.02
CaO	35.97
Na₂O	0.95
K₂O	0.57
P₂O₅	0.05
SO₃	3.15
Cl	0.05

Fly Ash The used of fly ash (FA) is by-product material rich in silicon and aluminum, such as low-calcium fly ash according to the ASTM C 618 Class F. In the present experimental work, low-calcium (Class F). The chemical composition of the fly ash, as determined by x-ray fluorescence (XRF) analysis is given in Table (3).



Table (3): XRF analysis for the used fly ash

Oxide	Content %	Limitation % *
SiO ₂	61.3	Min. 70%
AL ₂ O ₃	29.4	
Fe ₂ O ₃	3.27	
CaO	1.21	-----
MgO	0.75	-----
K ₂ O	1.20	-----
SO ₃	0.003	Max. 3%
TiO ₂	0.01	-----
Na ₂ O	0.73	Max. 1.5%
CL	0.04	Max. 0.05%
L.O.T	0.67	Max. 6%

Metakaolin Heating up of clay with kaolinite Al₂O₃.2SiO₂.2H₂O as the basic mineral component to the temperature of 500 °C – 600 °C causes loss of structural water with the result of deformation of crystalline structure of kaolinite and formation of an unhydrated reactive form so called metakaolinite. Physical and chemical properties of Metakaolin (MK) in Table (4), and Table (5).

Table (4): Physical properties of the used Metakaolin.

Property	Test Results
Specific surface area (cm ² /gm)	3950
Bulk density (kg/m ³)	1250
Specific gravity	2.5
Color	Off white, Gray to Buff
Physical Form	Powder

Table (5): XRF Analysis for the used Metakaolin.

Oxide	Content %	Limitation % * for fly ash
SiO ₂	58.3	Min. 70%
AL ₂ O ₃	37.3	
Fe ₂ O ₃	0.09	
CaO	0.41	-----
MgO	0.29	-----
K ₂ O	0.05	-----
SO ₃	0.001	Max. 3%
TiO ₂	1.51	-----
Na ₂ O	0.04	Max. 1.5%
CL	0.04	Max. 0.05%
L.O.T	0.42	Max. 6%

2.2 CONCRETE MIXES

Table (6), Geopolymer concrete mixture proportions

Mix No.	Alumina Silicate Source (Kg/m ³)	Fine Aggregate (Kg/m ³)	Coarse Aggregate (Kg/m ³)	NaOH Solution (Kg/m ³)	Na ₂ SiO ₃ Solution (Kg/m ³)	Extra Water (Kg/m ³)
1	450 (Slag Only , 10 M)	645.4	968.1	57.9 (17.4 S-40.5 W)	144.6	66.3
2	450 (10% M.K , 10 M)	645.4	968.1	57.9 (17.4 S-40.5 W)	144.6	66.3
3	450 (10% Fly ash , 10 M)	645.4	968.1	57.9 (17.4 S-40.5 W)	144.6	66.3
4	450 (20% M.K , 10 M)	645.4	968.1	57.9 (17.4 S-40.5 W)	144.6	66.3
5	450 (20% Fly ash , 10 M)	645.4	968.1	57.9 (17.4 S-40.5 W)	144.6	66.3
6	450 (Slag Only , 12 M)	643	964.5	57.9 (19.1 S-38.8 W)	144.6	68.7
7	450 (10% M.K , 12 M)	643	964.5	57.9 (19.1 S-38.8 W)	144.6	68.7
8	450 (10% Fly ash , 12 M)	643	964.5	57.9 (19.1 S-38.8 W)	144.6	68.7
9	450 (20% M.K , 12 M)	643	964.5	57.9 (19.1 S-38.8 W)	144.6	68.7
10	450 (20% Fly ash , 12 M)	643	964.5	57.9 (19.1 S-38.8 W)	144.6	68.7

2.3 MIXING, CASTING AND COMPACTION OF GEOPOLYMER CONCRETE

The method of manufacturing of Geopolymer concrete as the same conventional techniques as Portland cement concrete as following: Firstly, slag, fine aggregate and coarse aggregate were mixed together in the dry condition in the pan mixer for three minutes and the coarse aggregate should be in saturated-surface-dry (SSD) condition. Secondly, the liquid solution which was consisted of Hydroxide Sodium (NaOH) and Silicate Sodium (Na₂SiO₃) was prepared. sodium hydroxide solution should be prepared 24 hours before casting. The solution was mixed with extra water and super plasticizer if mixture need that. Thirdly, the liquid solution was added with the dry mixture and mixed for another

four minutes as shown in figure (1). Finally, the fresh concrete shall be filled into the cube molds in 3 layers in standard six cubes (150 *150*150) mm for each mix. Each layer should be compacted by not less than 35 blows by hand such as the usual methods used in the case of Portland cement concrete as shown in figure (1). we measured the workability of the fresh concrete by the conventional slump test shown in figure (2). When the time of wet-mixing time increased the compressive strength of geopolymer concrete increased [5].



a) The mixing process



b) compaction of fresh geopolymer concrete

Figure (1), Mixing and compaction of geopolymer concrete

2.4 SPECIMENTS CURING

The system of curing for cubes which were remolded after 24 hours from casting. After casting, specimens were left to harden for 24 hours. After removing specimens form molds, they are transferred to the steam curing tank. Steam curing interval was used; three days.

as shown in figure (2).



Figure (2), The steam curing tank

2.5 CONCRETE TESTS

Compressive strength, and flexural strength tests were conducted on specimens as shown in figure (3). Compressive strength tests were conducted according to standard specification BS EN 12390-3:2009 [6]. Flexural strength tests were conducted according to standard specification ASTM C78/C78M-18[7].



a) Compressive strength test b) Flexural strength test

Figure (3) Tests of specimens

3. RESULTS

3.1 Compressive strength

Effect of wastes type and content on compressive strength of geopolymer concrete. Figure (4) shows the effect of different binders (10% M.K, 10% F.A, 20% M.K and 20% F.A) -10 M were replacement to slag on the compressive strength for geopolymer concrete. In general, geopolymer concrete manufacture with (20% F.A) showed the highest compressive strength among all mixes. and geopolymer concrete manufacture with (100% slag) showed the lowest compressive strength. Compared with the compressive strength of geopolymer concrete with 100% slag (mix1), it can be found that the compressive strength of mix 2 (10% M.K) was 5.66% higher than that for mix 1 at 28 days, while the compressive strength of mix 3(10% F.A) was higher than that for mix 1 by 13.83% at 28 days. while the compressive strength of mix 4(20% M.K) was higher than that for mix 1 by 14.2% at 28 days. On the other hand, the compressive strength of mix 5 was higher than that for mix 1 by 17.9% at 28 days.

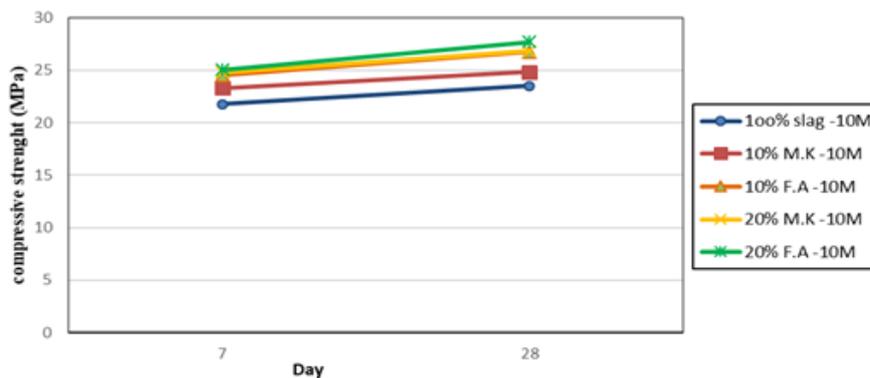


Figure (4), The relationship between compressive strength and age for all mixes (10 M)

Figure (5) shows the effect of different binders (10% M.K, 10% F.A, 20% M.K and 20% F.A)12 M were replacement to slag on the compressive strength for geopolymer concrete. In general, geopolymer concrete manufacture with (20% F.A) showed the highest compressive strength among all mixes. and geopolymer concrete manufacture with (100% slag) showed the lowest compressive strength. Compared with the compressive strength of geopolymer concrete with 100% slag (mix 6), it can be found that the compressive strength of mix 7 (10% M.K) was 1.28% higher than that for mix 6 at 28 days, while the compressive strength of mix 8 (10% F.A) was higher than that for mix 6 by 6.61% at 28 days. while the compressive strength of mix 9 (20% M.K) was higher than that for mix 6 by 12.02 % at 28 days. On the other hand, the compressive strength of mix 10 was higher than that for mix 6 by 41.37 % at 28 days. This increase in the mechanical properties can be attributed to the increase in the aluminum oxide content in the geopolymer concrete mix. Also the longer steam curing period enhanced the geopolymer reaction and led to improve the mechanical properties of geopolymer concrete. The higher rate of developing strength of GPC could be attributed to two reasons.

Firstly, high alkaline substances content which accelerate the activation reaction. Second reason is the high temperature curing for one or two days in the steam curing of GPC specimens that increased the degree of polymerization and led to higher rate of strength developing. Increase in compressive strength may be attributed to the formation of C-A-S-H gels, which would reduce the porosity and condense the microstructure of AAS matrix [8].

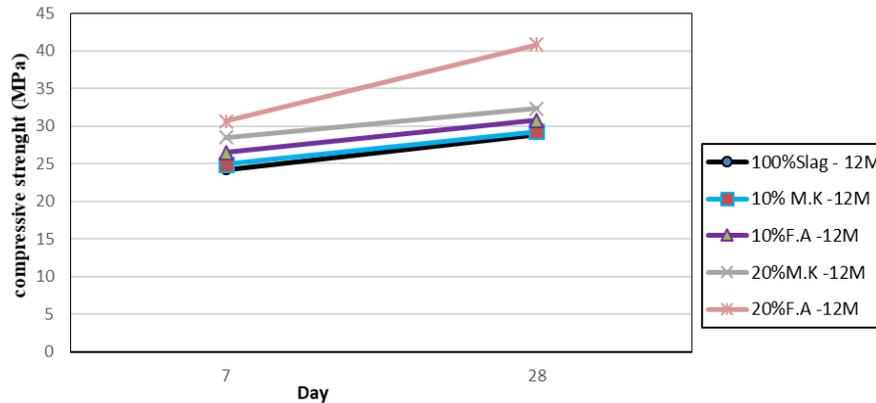


Figure (5), The relationship between compressive strength and age for all mixes (12 M)

The effect of molarity of sodium hydroxide (NaOH) on compressive strength of geopolymer concrete. Figure (6) shown in for steam curing at 28 days' mix 1 (100% slag, 10 M) had the minimum compressive strength; 23.5 MPa, mix 2 (10% M.K, 10M) had compressive strength; 24.83 MPa, mix3 (10% FA,10M) had compressive strength; 26.75 MPa , mix 4 (20% M.K, 10M) had the compressive strength; 26.83 MPa, mix 5 (20% FA,10M) had the compressive strength; 27.7 MPa , mix 6 (100% slag, 12 M) had the compressive strength; 28.88 MPa, mix 7 (10% M.K, 12M) had compressive strength; 29.25 MPa , mix8 (10% FA,12M) had compressive strength; 30.79 MPa , mix 9 (20% M.K, 12M) had the compressive strength; 32.35 MPa and mix 10 (20% FA,12M) had the maximum compressive strength; 40.83 MPa. Increasing the molarity from 10M to 12M increased the compressive strength by 41.38%. It can be noted that increasing the molarity of NaOH from 10 M to 12 M gradually increases the compressive strength of geopolymer concrete. Higher concentration (in terms of molar) of sodium hydroxide solution results in higher compressive strength of geopolymer concrete [9]. In general, high NaOH concentration leads to high average compressive strength at both 7 and 28 days. However, the influence of high NaOH concentration became insignificant as the age increased.

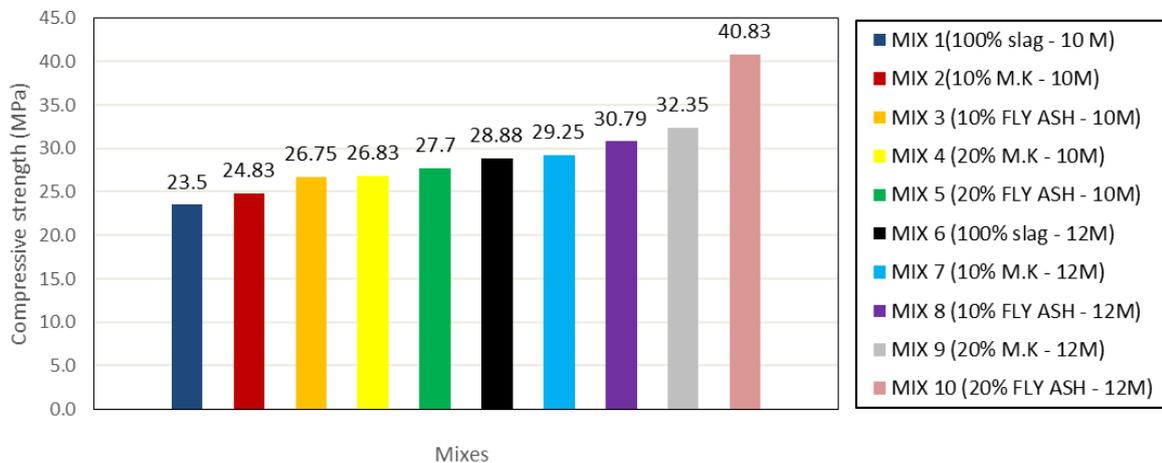


Figure (6), The relationship between all mixes molarity (10- 12) and compressive strength

3.2 Flexural strength

Effect of wastes type and content on Flexural Strength of geopolymers concrete. Figure (7) shows the effect of different binders (10% M.K, 10% F.A, 20% M.K and 20% F.A) were replacement to slag on the flexural strength for geopolymers concrete. In general, geopolymers concrete manufacture with (20% F.A) showed the highest flexural strength among all mixes. and geopolymers concrete manufacture with (100% slag) showed the lowest flexural strength. Compared with the flexural strength of geopolymers concrete with 100% slag (mix 1), it can be found that the flexural strength of mix 2 (10% M.K) was 31.43% higher than that for mix 1 at 28 days, while the flexural strength of mix 3 (10% F.A) was higher than that for mix 1 by 41.43% at 28 days. while the flexural strength of mix 4 (20% M.K) was higher than that for mix 1 by 55.7 % at 28 days. On the other hand, the flexural strength of mix 5 was higher than that for mix 1 by 57.14 % at 28 days.

Figure (8) shows the effect of different binders (10% M.K, 10% F.A, 20% M.K and 20% F.A) were replacement to slag on the flexural strength for geopolymers concrete. In general, geopolymers concrete manufacture with (20% F.A) showed the highest flexural strength among all mixes. and geopolymers concrete manufacture with (100% slag) showed the lowest flexural strength. Compared with the flexural strength of geopolymers concrete with 100% slag (mix 6), it can be found that the flexural strength of mix 7 (10% M.K) was 15.8% higher than that for mix 6 at 28 days, while the flexural strength of mix 8 (10% F.A) was higher than that for mix 6 by 21.1% at 28 days. while the flexural strength of mix 9 (20% M.K) was higher than that for mix 6 by 35.1 % at 28 days. On the other hand, the flexural strength of mix 10 was higher than that for mix 6 by 77. % at 28 days., Lee and Van Deventer reported higher bonding at the interface of geopolymers paste and aggregate, which contributes to the improvement of flexural strength (Lee and Van Deventer, 2003) [10].

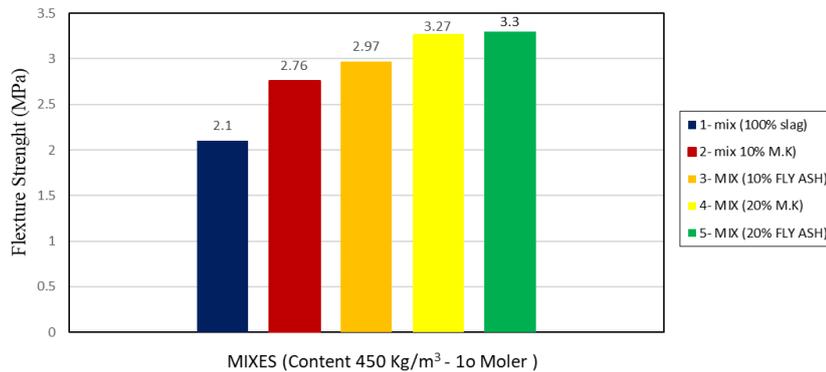


Figure (7), The relationship between flexural strength and mixes (content 450 Kg/m³ – 10 Moler)

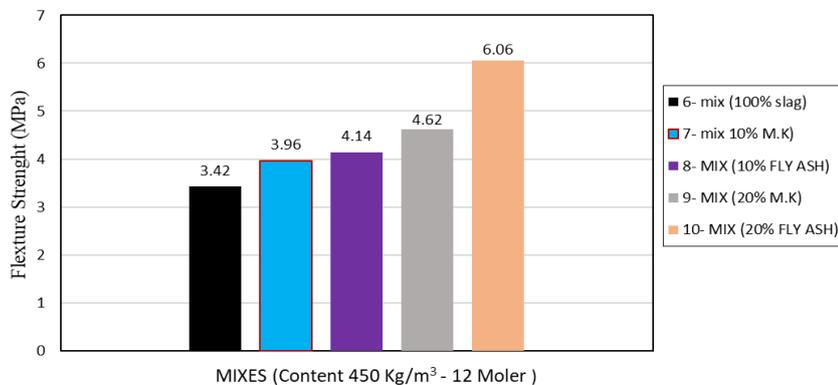


Figure (8), The relationship between flexural strength and mixes (content 450 Kg/m³ – 12 Moler)

The effect of molarity of sodium hydroxide (NaOH) on flexural strength of geopolymers concrete. Figure (9) shown in for steam curing at 28 days' mix 1 (100% slag - 10 M) had the minimum flexural strength; 2.1 MPa, mix 2 (10% M.K -

10M) had flexural strength; 2.76 MPa, mix3 (10% FA - 10M) had flexural strength; 2.97 MPa, mix 4 (20% M.K, 10M) had the flexural strength; 3.27 MPa, mix 5 (20% FA - 10M) had the flexural strength; 3.3 MPa, mix 6 (100% slag, 12 M) had the flexural strength; 3.42 MPa, mix 7 (10% M.K, 12M) had flexural strength; 3.96 MPa, mix8 (10% FA, 12M) had flexural strength; 4.14 MPa, mix 9 (20% M.K, 12M) had the flexural strength; 4.62 MPa and mix 10 (20% FA - 12M) had the maximum flexural strength; 6.06 MPa. Increasing the molarity from 10M to 12M increased the flexural strength by 83.63%. It can be noted that increasing the molarity of NaOH from 10 M to 12 M gradually increases the flexural strength of geopolymer concrete.

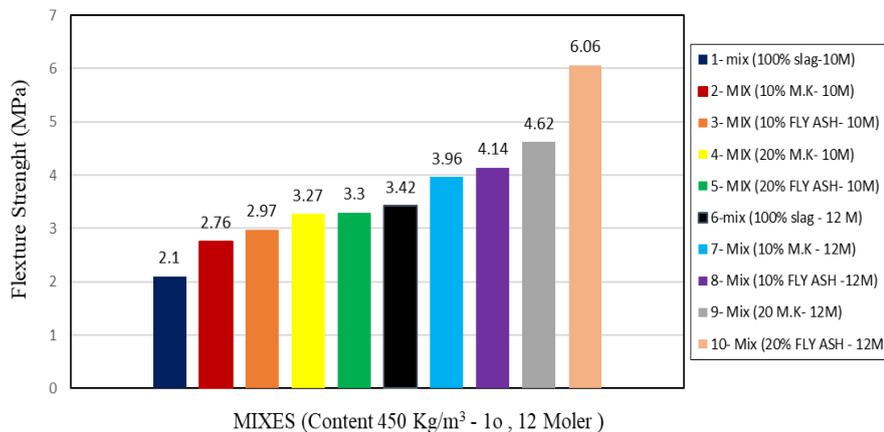


Figure (9), The relationship between flexural strength and all mixes (content 450 Kg/m³ – 10, 12 Moler)

VI. CONCLUSIONS

From the analysis and discussion of test results obtained from this research, the following conclusions can be drawn:

1. compressive strength at 7 days develop from 85% to 90% of the total compressive strength in all geopolymer concrete mixtures comparing with conventional concrete.
2. The increase in molarity of NaOH from 10 M to 12 M gradually increases the compressive strength, flexure strength and splitting tensile strength of geopolymer concrete.
3. The use of (20% F.A) as a replacement to slag in the geopolymer concrete was better than the use of slag only or mitakolin.
4. The use of (20% fly ash, 10 M) as a replacement to slag in geopolymer concrete was better than the use of slag only or using of (10% M.K – 10% fly ash – 20% M.K).

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