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ASSESSMENT OF GEOPOLYMER MORTAR CURED AT AMBIENT TEMPERATURE IN TERMS OF STRENGTH AND WORKABILITY

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ملخص البحث :

يعتبر استخدام الخرسانة التقليدية من اهم العوامل الملوثة للبيئة وبالتالي اتجه العالم الي انتاج نوع جديد من الخرسانة صديقة للبيئه والتي يطلق عليها اسم الخرسانة الجيوبوليمرية، حيث يتم تصنيع الخرسانة من مخلفات التصنيع. وبالتالي، شهدت السنوات الأخيرة تضخم هائل في الابحاث التي تدرس خواص الخرسانة الجيوبولمرية المتصلدة والطازجة. وقد اظهرت الدراسات السابقه أن فقدان قابلية التشغيل، سرعة التصلد والاحتياج الي المعالجة الحرارية يقيد انتاج الخرسانه الجيوبولمريه بالموقع.

يهدف هذا البحث الي دراسة تاثير النسب المثلي للمنشطات والتي يمكنها تحقيق أقصي مقاومة ضغط وبقابلية تشغيل مقبولة. تم تنفيذ الاختبارات المعملية علي أربعة خلطات مختلفة باستخدام منتجات صناعيه مثل خبث الأفران، هيدروكسيد الصوديوم و سيليكات الصوديوم، و يعتبر المتغيرات الأساسية في هذا البحث هي معامل السيليكات (1.1، 1.3، 1.5، 1.7)، كما أنه تم فحص الخواص المتصلدة والطازجة باستخدام اختبار الانسياب واختيار قوة الضغط علي التوالي.

ABSTRACT:

Nowadays, using green concrete as an alternative for conventional concrete has become popular worldwide. The innovative green concrete can be manufactured using waste materials as one of its components. Therefore, recent years witnessed a huge increase in the researches that investigate geopolymer’s fresh and hardened properties. The previous studies showed that workability loss, rapid setting time and the need for heat curing are the main constraints that restrict the production of the cast in place geopolymer concrete. This study owes to reach the optimum activator modulus which achieves the maximum compressive strength with acceptable workability. Four different mixtures were blended using industrial by-products, such as Ground Granulated Blast Furnace Slag (GGBS). Sodium hydroxide and sodium silicate were used as an activator. The main variables were the modulus of silicate (1.1, 1.3, 1.5, and 1.7). Fresh and hardened properties were examined using the flow table test, and compressive strength test, respectively.

Keywords: Geopolymers; Slag; workability; setting time; compressive strength.

1. Introduction

Portland cement is the main ingredient in concrete. It varies in dosages from 1400 kg/m^3 to 75 kg/m^3 for rich and poor concrete, respectively, **[1]** with an average of 400 kg for one cubic meter of concrete. In fast-growing markets and owing to various applications that concrete is involved in cement become vital material as oil with annual production costs hundreds of billions of dollars. Statista estimates that in 2020 the total world cement production will reach 4.4 billion tons.

Nowadays, Portland cement industry produces 1.5 billion tons per year. It is worth mentioning that production of one ton of cement emits about one ton of CO_2 **[2]** and a very high-temperature more than (1300 ºC) is involved in such process **[3]**. In addition to the emission of greenhouse gases and the high energy required to produce Portland cement, cement production has a significant influence on the natural resources (quarries) too, as the manufacturing of cement starts from the mining of raw materials especially limestone and clay quarry. Consequently, it is necessary to rely on Geopolymer concrete as a new alternative for Portland cement with better technical and environmental performance, to conserve energy and protect the environment **[4-5].**

Since 1978 plenty of studies have discussed the alkali-activated cement materials with sporadic use. Recently, alkali-activation (Geopolymer) is gaining an increase in recognition; this is due to the potential reduction in CO_2 **[2-9].** Geopolymer concrete is derived from industrial by-products which lead to little negative environmental footprint **[10].**

Geopolymer concrete can be classified into two main categories based on the base material used in Geopolymer binder: Rich calcium and low calcium. Rich calcium materials such as blast furnace slag need a calm activation medium to produce calcium silicate hydrate gel (C-S-H). While the latter category of low calcium materials such as; metakaolin and type F fly ash needs high alkaline media and high curing temperature in order to initiate the reaction and create Sodium aluminosilicate hydrate gel (N-A-S-H) **[11].**

Efforts were exerted through several researches conducted to explore and investigate the application of Geopolymer concrete from different aspects. There are various factors affecting alkali activated Geopolymer concrete such as the type of alkali activator, dosage of alkali activator components, type of base material (fly ash, slag or metakaolin), fineness of slag, curing condition…..etc **[12-14].** Since early of 90^{th} many studies investigated the parameters that may have either a positive or negative influence of Geopolymer concrete’s mechanical properties. It was observed that high workability loss rate, quick setting time and the need for heat curing are the major disadvantages of Geopolymer concrete and the main limitation on Geopolymer concrete applications. The most noticeable factors which affect the strength of alkali activated slag are; the type of alkali activator, the dosage of alkali, the type and fineness of slag, SiO_2/Na_2O ratio which is called Modulus of silicate (Ms). The optimum ranges for Na_2O to slag percentages and slag fineness are (3.0 to 5.5%) and (4000-5500 g/cm^2), respectively. **[15]**

Yang found that the relative initial flow of the Alkali Activated (AA) mortars decreased with the increase of both the alkali quality coefficient and the fineness of the slag. As for the compressive strength, it was noted that the relative compressive strength at 28 days of the Alkali Activated (AA) mortars tested commonly increased with the increase of alkali quality coefficient (SiO_2/Na_2O) and the fineness of slag. No meaningful compressive strength at both the early and long-term ages developed in the Fly Ash (FA)-based AA mortars **[16].**

The main challenge in this study is to eliminate the necessity of heat curing and produce workable Geopolymer mortar with acceptable strength. Many studies investigate different ways to improve Geopolymers fresh properties and assess the hardened properties as well. It was concluded that the different activator ratios and concentrations have a great effect on the Geopolymer's fresh and hardened properties. This study aims to eliminate the necessity of heat curing and to solve the problem of Geopolymer's poor fresh behavior by identifying a solid parameter which effects directly both hardened and fresh properties.

Four different mixtures were mixed -with a different modulus of silicate (Ms) was tested in the fresh and the hardened state to illustrate the effect of the abovementioned parameters on the compressive strength and the workability of the Geopolymer mortar.

2. Materials and Experimental Program

2.1. Material Properties

The experimental program has been conducted on four mixtures varies in modulus of silicate, as shown in **Table 1**. Water cooled slag was used as a base material. The X-ray fluorescence (XRF) analysis of slag is shown in **Table 2**. Sand of size smaller than 5.0 mm was used as fine aggregate; the specific gravity and the fineness modulus of the used sand are 2.65 and 2.25, respectively. The used alkali activator consists of sodium hydroxide and sodium silicate. Sodium hydroxide contains 60.25% Na_2O and 39.75% H_2O. On the other hand, sodium silicate consists of Na_2O, H_2O, and SiO_2 with percentages of 11.98%, 57.0%, and 31.0%, respectively. The Modulus of silicate ranges between 1.1 to 1.7. The concept of calculating modulus of silicate based on choosing constant values of binder, sodium hydroxide, and sand. The amount of sodium silicate (X) to achieve modulus of silicate of (1.1, 1.3, 1.5 and 1.7) was calculated as follow:

(a) Choose constant amount of binder, NaOH and Sand to be 500, 57.4 and 1254.4 kg/m^3, respectively. **[17]**

(b) Calculate the amount of Sodium Silicate (X) to obtain activator modulus (1.1, 1.3, 1.5, and 1.7).

$$Ms = \frac{(SiO_2 in \cdot Sodium \cdot silicate)}{(Na_2O \cdot in \cdot Sodium \cdot silicate) + Na_2O \cdot in \cdot Sodium \cdot Hydroxide)}$$

Table 1: Mixture Constituents in (kg) per Cubic Meter of Mortar

Mixture ID	Slag	Mk	Sand	S.S	NaOH
S-1.1	500	0	1254.4	213.363	57.369
S-1.3	500	0	1254.4	291.29	57.369
S-1.5	500	0	1254.4	397.905	57.369
S-1.7	500	0	1254.4	552.568	57.369

Binder-(1.1, 1.3 …etc.): The number refers to the modulus of silicate.

Table 2: Chemical Composition (%) of slag by XRF

Chemical compositions	Slag	Chemical compositions	Slag
SiO_2	35.4	Na_2O	0
Al_2O_3	17.4	Alkalis	0.2
Cao	36.87	Sulphide Sulphur	0.24
MgO	6.83	Insoluble Residue	1.4
Fe_2O_3	1.4	Loss on Ignition	0.5
MnO	0.35	TiO_2	0.11

2.2. Experimental Procedures

2.2.1. Mixing Sequence

Geopolymer concrete requires precise mixing procedures and high-quality control. Firstly, sand and binder were mixed together as a dry mix for 3 minutes. Meanwhile, Sodium Hydroxide was dissolved in Sodium Silicate liquid separately. Once the sodium hydroxide flakes were completely dissolved in the solution, the solution was added to the binder and then the whole mixture was mixed together for 3 minutes.

2.2.1. Casting, Curing, and Testing

Flowability test was conducted immediately after mixing as per ASTM C230 **[18]** requirements to assess workability and consistency of Geopolymer mortars. The apparatus consists of a rigid circular top of 250 mm diameter over cast iron frame. A shaft with a contact shoulder was mounted to raise and drop the circular surface vertically in certain height (12.5 mm). The top surface should be plan surface clear of any holes or defects. The mortar was filled and compacted in two layers in a small cone. The small frustum cone of 100 mm upper diameter was raised and to allow mortar to spread on flow table. The top circular surface was raised and dropped freely 25 times. Consequently, the mortar flow and forms a circular shape. The flowability is calculated in terms of the change in upper cone diameter and the final mortar diameter. On the other hand, nine cubes of 50x50x50 mm were prepared for each mixture to determine the compressive properties. Mixtures S-1.5 and S-1.7 are flowable and self-compacted, however other mixtures were compacted using vibrating table in three layers, each layer was vibrated for 20 seconds. Specimens were de-molded after 24 hours. Cubes were cured in potable water at room temperature from the day after casting until the testing day, three compressive strength cubes were tested for each curing age 7, 28 and 90 days as per ASTM C109 **[19]**. The value of compressive strength is the average value of the three tested cubes.

3. Results and Discussions

3.1. Activator Parameters

On the way to achieve solid parameter with direct influence on Geopolymer's fresh and hardened properties, efforts were exerted to reach precisely the effect of the modulus of silicate in the activator on compressive strength and workability. Modulus of silicate can be defined as the mass ratio of SiO_2 to Na_2O. The effect of modulus of silicate on both workability and compressive strength was evaluated. Mixtures with Modulus of silicate ranges between 1.1 to 1.7 were tested in its fresh and hardened state.

3.2. Flow-Table Test Results

Due to the high slump values at the early stage, the Flow table test was held according to ASTM C230 **[18]** to evaluate the workability of the mixtures as shown in Table 3. It was obviously concluded that with increasing the modulus of silicate, the workability increases and the compressive strength decreases. The results show that the workability of geopolymer mortars is directly proportional to the modulus of silicate as shown in **Fig. 1.**

3.2. Compressive Strength Test Results

The compressive strength of all specimens are shown in **Table 3**. The rate of strength gain during the curing time is slightly higher in S-1.1 and S-1.3 mixtures. It is clear that the slag based mixtures with modulus of silicate 1.1 and 1.3 are considerably higher in compressive strength than their counterparties of 1.5 and 1.7. The strength gain results are presented in **Fig. 2**. The change in compressive strength was traced with the variation of the modulus of silicate. In light of the results shown in **Fig. 3** it was observed that the compressive strength is inversely proportional with the modulus of silicate. The results show that the compressive strength dropped slightly with the increase of Ms from 1.1 to 1.3 and the same trend was observed during the increase of Ms from 1.5 to 1.7. However, there was a great drop in the compressive strength during the increase of Ms from 1.3 to 1.5.

Table 3: Compressive Strength and Flow Table Test Results

Mixture ID	Compressive Strength (MPa) (Curing Time)			Flowability
	7 (days)	28 (days)	90 (days)	
S-1.1	50.0	64.8	77.0	20%
S-1.3	49.2	60.8	70.0	40%
S-1.5	20.2	37.4	43.8	90%
S-1.7	19.6	33.4	40.2	150%

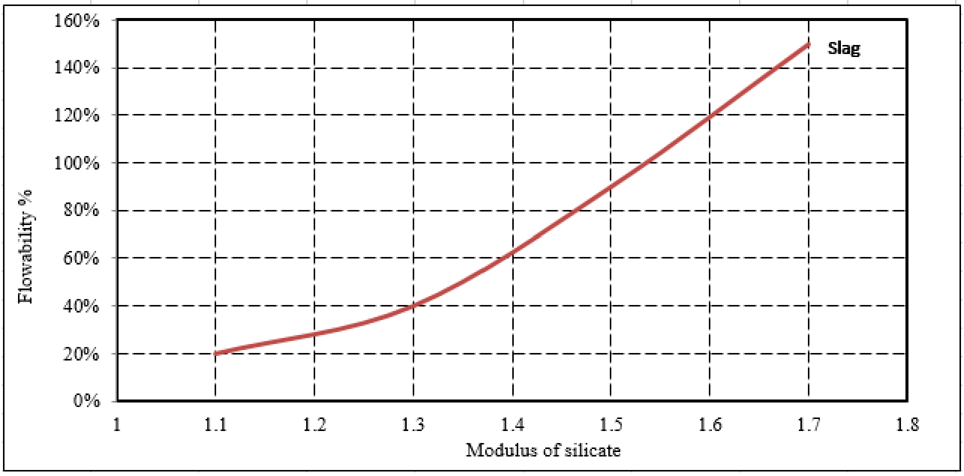

Fig. 1: The effect of Ms on the flowability

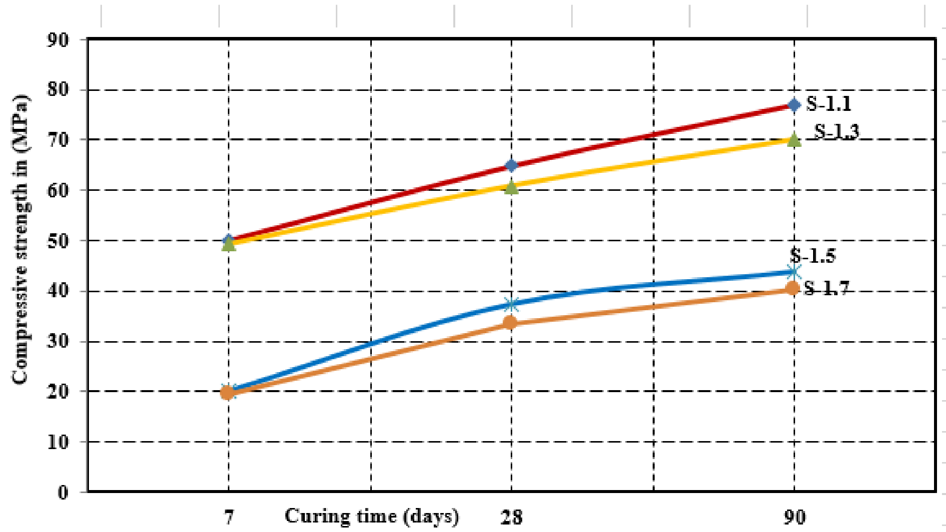

Fig. 2: Strength gain for slag mixtures

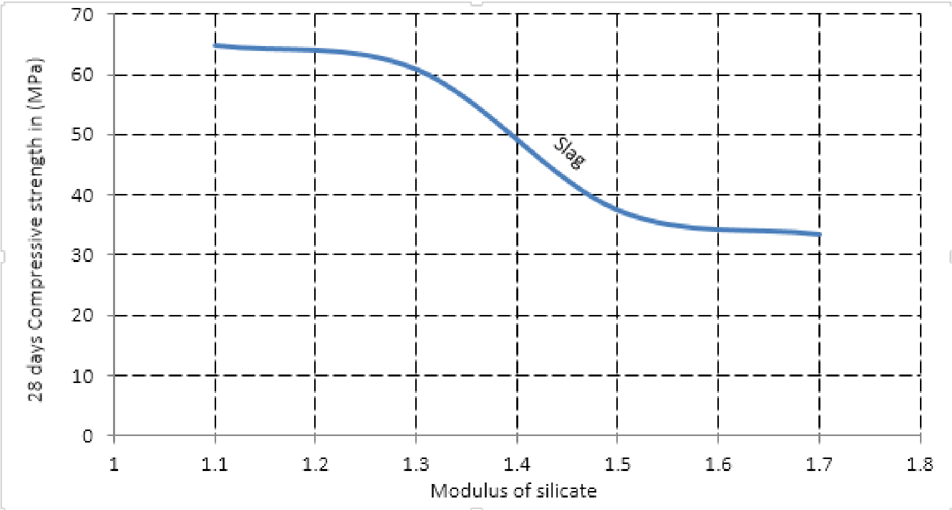

Fig. 3: The effect of Ms on 28 days compressive strength

4. Conclusions

Based on the findings of this research study, the following conclusions can be drawn:

- Activator parameters (Ms) is inversely proportional with the compressive strength but directly proportional with the workability.
- Compressive strength test shows that the Geopolymer mortar can reach high early strength (50 MPa) and (77 MPa) after 7 and 90 days of water curing, respectively. On the other hand, the self-compacted mortar with 150% workability has a considerably good compressive strength after 7 days (19.6 MPa) and high strength after 90 days (40.2 MPa).

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