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TOWARD A GREENER CONSTRUCTION: DEVELOPMENT OF ALKALI ACTIVATED GROUT FOR TWO STAGE CONCRETE

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Abstract: This study focuses on the development of an alkali-activated grout with acceptable fresh and hardened properties satisfying two stage concrete requirements. The effect of different factors including activator type, water to binder ratio, percentage of superplasticizer and viscosity modifier on flowability and compressive strength of the grout were evaluated. The grout produced by activating slag with lime and 1% superplasticizer showed good flowability. Viscosity modifier was needed to counteract the segregation; however, it had decreased the flowability of the alkali activated grout drastically. The overall result of this experimental study shows that the right combination of the optimum level of superplasticizer, and viscosity modifier would help to achieve a flowable grout with good strength.

1 INTRODUCTION

Demand of concrete has increased over the years, and it's expected to rise in coming decades due to rapid developments all over the world (Naucler and Enkvist, 2009). Ordinary Portland cement (OPC) is the main binder in concrete, and the production of OPC has been attributed to be responsible for about 5% of the world's human induced carbon emissions (Allwood and Cullen, 2011; OECD and IEA, 2009). For every 1 tonne of OPC, approximately 1 tonne of carbon dioxide equivalent is emitted into the environment. This high emission is as a result of large amount of carbon dioxide (CO_2) released from the raw materials, and high energy usage during its production. Over the years, various studies have been carried out to make concrete more sustainable by partial and total replacement of cement in concrete.

The field of alkali activated materials (AAMs) have been explored extensively due to the possibility of totally replacing cement in concrete with aluminosilicate materials. These aluminosilicate materials are mostly industrial waste materials such as slag, fly ash, etc. In order to use aluminosilicate materials as binder, an alkali medium is required to dissolve the silicate and aluminate monomers from the material to form a binding gel in a process called alkali activation.

However, with all the advancement made in the field of AAMs; high embodied energy and carbon are still recorded, which does not eradicate the purpose while it was developed in the first place (i.e. reduction in carbon emissions). This high embodied energy and carbon is as a result of the activators and high curing temperature required by some of the AAMs. In addition, the activators used are very corrosive and expensive which hinders the universal acceptance and application of AAMs (Provis, 2017).

In order to have huge reductions in carbon emissions and energy usage, the use of hydrated lime is employed in this study to activate slag at ambient conditions. Hydrated lime is a readily available material in most household stores. Also, it is cheap and less corrosive compared to the convectional ones. Also, activating slag with convectional activators such as sodium hydroxide and sodium silicate leads to low flowability which makes certain applications of alkali activated slag (AAS) for grout limited. Therefore, the use of an alternative green activator might help to overcome these limitations.

More embodied energy and carbon reduction can be achieved by using a special type of concrete called two stage concrete (TSC). TSC concrete is a type of concrete made it two stages by first filling the mold with coarse aggregate, followed by injection of a structural grout to fill the voids between the aggregates. TSC has high coarse aggregate content which minimizes the binder content. In addition, energy savings are achieved as no additional vibration is needed after injecting the grout. TSC is good for the construction of underwater structures, mass concrete, dams, and elements with close reinforcements (Abdelgader et al., 2018). However, the grout used for TSC must possess excellent fresh properties in terms of its followability and setting time. A flowable grout would enable the grout to fill the voids between the coarse aggregate easily. Generally, an efflux time of 20 to 25 seconds can be used to produce structural TSC, but an efflux time between 35 to 40 seconds results in higher strength concrete in TSC made with OPC as binder (ACI 304.1, 2005).

This study explored the use of hydrated lime as an alternative green activator to activate slag targeting adequate fresh and mechanical properties for grout material for TSC.

2 EXPERIMENTAL PROGRAM

The experimental program is divided into two phases. Initial phase to optimize the mixture proportion, while the second phase was to evaluate optimum mixtures

2.1 2.1 Materials and mixtures

Slag with the chemical composition shown on **Table 1** is used as the main binder. The slag has a specific gravity of 2.92 with Blaine fineness value of 509m^2/kg, and 97% strength activity index. The slag was activated with only hydrated lime. Viscosity modifier admixture (VMA) was used to prevent segregation and superplasticizer (SP) to improve the workability of the grout.

Table 1. Chemical composition of slag

Compound	Percentage (%)
Silicon Dioxide (SiO_2)	32.40
Aluminium Oxide (Al_2O_3)	14.96
Iron Oxide (Fe_2O_3)	0.83
Sulphur Trioxide (SO_3)	2.74
Calcium Oxide (CaO)	40.70
Magnesium Oxide	5.99
Total Alkali as Na_2O_{eq}, %	0.70

2.2 Testing procedures

The flowability of the grout is determine by measuring the efflux time in accordance to ASTM ASTM C 939 (Standard Test Method for Flow of Grout for Preplaced-Aggregate Concrete). ASTM C 939 entails pouring 1725 ml of grout into the flow cone, and measuring the time it takes the grout to flow through the 12.7mm orifice. After the flow cone test was done, samples are made to determine the segregation of the grout and cubic samples of 50mm x 50mm x 50mm were casted to evaluate compressive strength.

3 RESULTS AND DISCUSSIONS

3.1 Phase I

Segregation was observed in all samples irrespective of the composition. To the best of authors' knowledge, this is the first to report segregation problem for slag activated by lime. Several other types of activators such as sodium silicate (SS), sodium carbonate (SC), sodium hydroxide (SH) used in existing studies does not result in segregation (Duxson, 2007). The segregation was determined by the percentage of the sand that settled at the base of the lime activated slag. The percentage of segregation was observed to increase with reduction in efflux time (i.e. increase in segregation with higher flowability).

As the aim of this study is to develop a greener grout by using a green binder (hydrated lime) instead of the conventional ones with high embodied energy and carbon (SS, SH, etc.), extensive study was carried out to provide solution for the segregation problem.

3.2 Phase II

In order to prevent the segregation observed in the initial phase, VMA is used at different levels to observe how it can prevent segregation. The segregation in this study was measured by the percentage of the height of the grout that settled. VMA prevent segregation in cementitious composites by stabilizing the air void system in the freshly mixed grout, and improving its stability (Sika Canada, 2017).

3.2.1 Effect of viscosity modifier on segregation and efflux time

In order to prevent segregation that was observed when lime was used to activate slag, VMA was used at different percentages by mass of slag. VMA at 0.5% by mass of slag was initially used to observe its effect on the segregation. However, segregation was still observed in all samples. Hence, the amount of viscosity modifier was increased to 1%, no segregation was observed in all samples tested as shown in **Figure 1**. Therefore, 1% of viscosity modifier by mass of slag was concluded to be the optimum level to prevent segregation in lime activated slag.

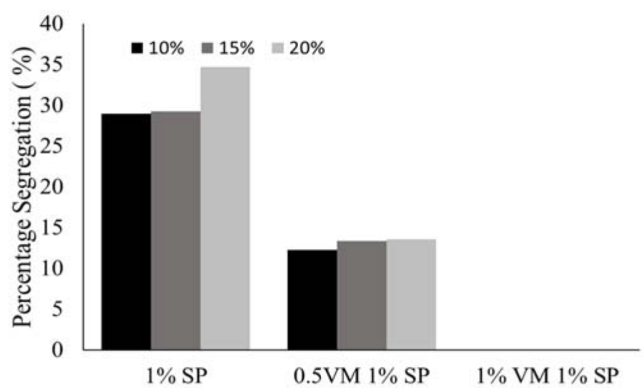

Figure 1: Effect of VMA on the percentage segregation of lime activated grout with water to solid ratio 0.35

However, the inclusion of VMA increased the efflux time of the lime activated grout (i.e. the flowability reduces) as shown on **Figure 2**. This would be as a result of increasing the viscosity of the mixing water, thereby reducing its flowability (Lucie et al., 2003)

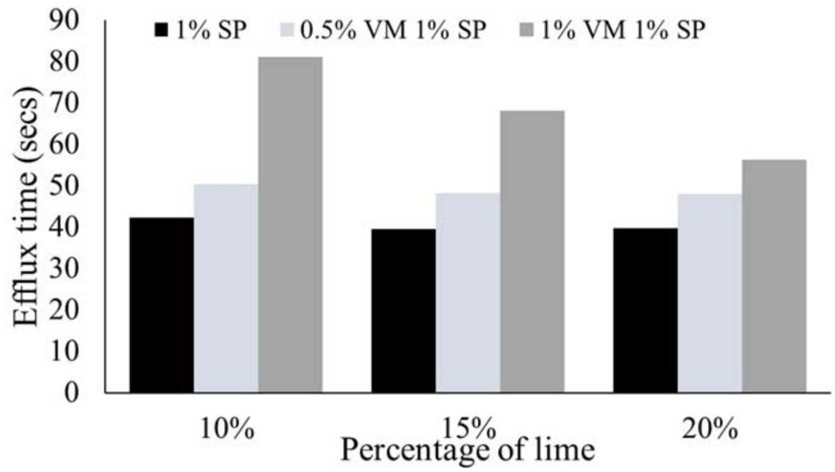

Figure 2: Effect of VMA on the efflux time of lime activated grout with 0.30 water to solid ratio.

3.2.2 Effect of superplasticizer on efflux time

As the VMA increases, the efflux time of the lime activated grout increased. This limits its application as grout in cases where a more flowable grout is required (e.g. TSC). Therefore, in order to achieve a flowable grout that can be used for various applications, SP was introduced at different percentage into the mixes. It was observed that as the percentage of SP increases in lime activated grout incorporating VMA by 1% the mass of the slag, there's a reduction in the efflux time as shown on **Figure 3**. This would be as a result of the SP capability to improve workability (Nkinamubanzi et al., 2016)

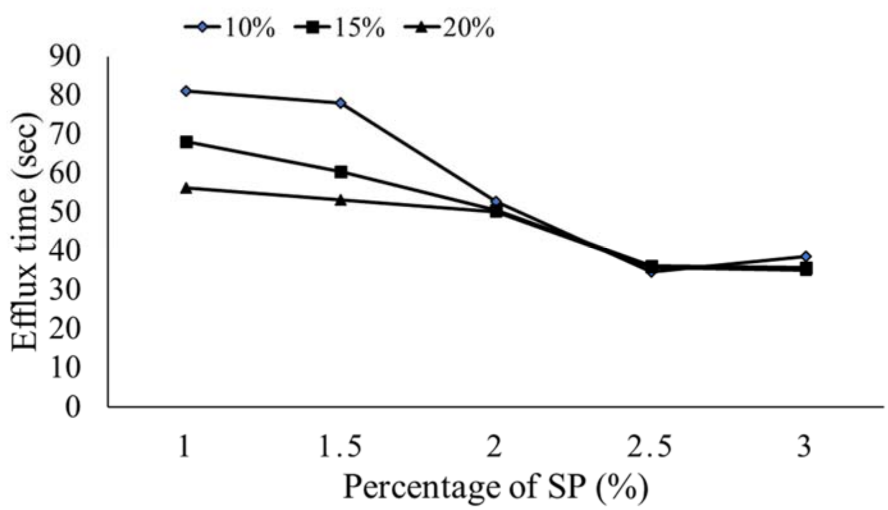

Figure 3: Effect of percentage of SP on the efflux time of lime activated slag with water to solid ratio of 0.30 and 1% VMA

3.2.3 Effect of water to solid ratio on efflux time

As the water to solid ratio increases, a reduction in efflux time was observed as a result of supplying more water into the system as shown on **Figure 4**. This was observed at different levels of activators used. These results are similar to other studies, where increasing the amount of water in the system leads to an increase in the flowability of the grout (Najjar et al., 2016). The lower the efflux time of the grout, the higher its capability to penetrate and fill the voids between the coarse aggregates.

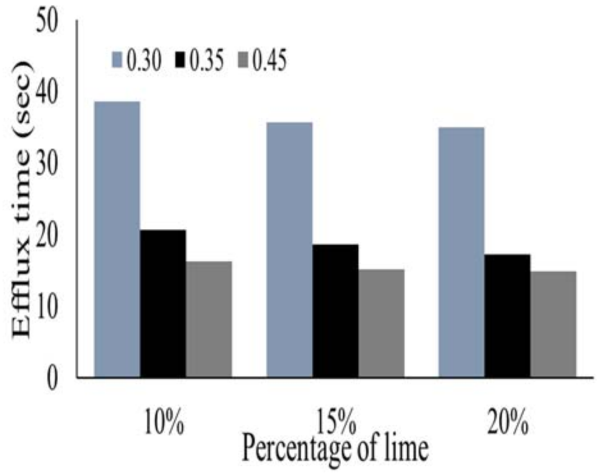

Figure 4: Effect of water to solid ratio on the efflux time of lime activated slag with 3% SP and 1% VMA

3.2.4 Compressive strength

The compressive strengths of samples without segregation and incorporating 3% SP by mass of slag were measured as shown on **Table 2**. For this test, the percentage of VMA was fixed at 1% and SP at 3%. **Table 2** shows the composition, efflux time and the compressive strength of the grout at 28 days

Table 2. Compressive strength of grout mixes

Water/solid ratio	% of Lime	Slag/sand	Efflux time (sec)	Compressive strength (MPa)
0.30	10	1.5	38.57	28.1
0.30	15	1.5	35.68	36.8
0.30	20	1.5	35.03	24.6
0.35	10	1.5	20.66	28.0
0.35	15	1.5	18.73	31.6
0.35	20	1.5	17.39	18.8

It would be observed from **Figure 5** that the compressive strength of the grout decreased with increasing water to solid ratio. This as a result of dilution effect of the water on the activator, leading to less reaction products formed. However, there was no significant effect when 10% lime was used to activate slag at a water to solid ratio of 0.30. At 15% and 20% of lime used to activate slag, it would be observed that the effect of water to solid is more pronounced, with mixtures with lower water to solid ratio having higher strength. This shows similar results with conventional OPC composites, where reduction in water to solid ratio led to higher strength.

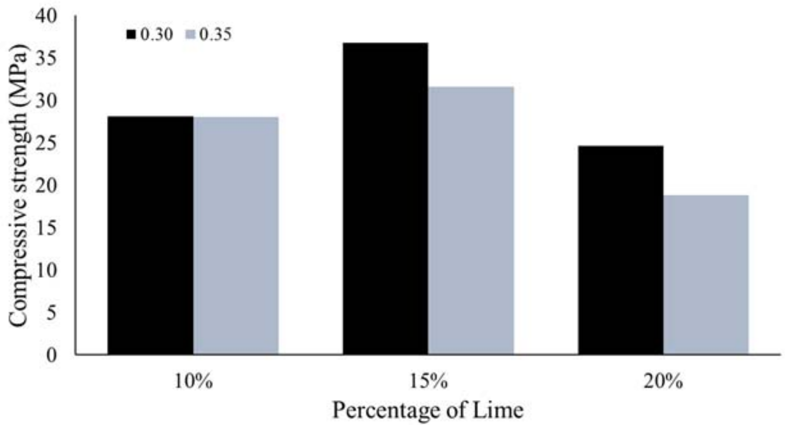

Figure 5: Effect of the water to solid ratio and percentage of lime on compressive strength of the grout

Figure 6 shows that the optimum percentage of lime to get higher strength is 15%. Though an increase in strength was observed when the percentage of lime was increased from 10% to 15%, the strength decreased when the percentage of lime was further increased to 20%. This effect was observed in the two water to solid ratio considered (i.e. 0.30 and 0.35).

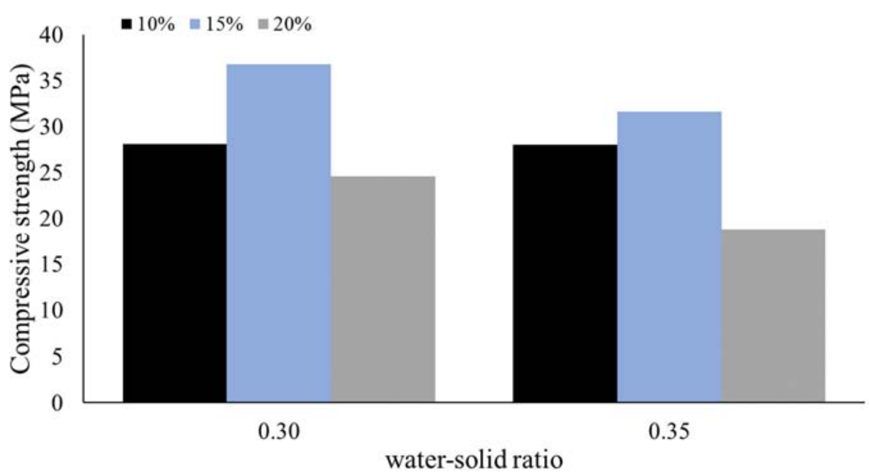

Figure 6: Effect of the percentage of lime on compressive strength of the grout

In order to determine if there's a direct relationship between the strength of the grout and the efflux time, comparison was made between the strength and flow of the 6 selected mixes as shown in **Figure 7**. It would be observed that there's no direct relationship between the efflux time (i.e. flow) of the grout and the corresponding compressive strength. For example, mix 3 with a higher flow have less compressive strength compared to mix 5 with a lower efflux time but higher strength. Therefore, the strength of the grout is mainly dependent on its composition (i.e. percentage of lime and water to solid ratio), rather than the flow. However, in order for grout to be used for some special types of applications such as two stage concrete, a grout with efflux time of less than 40 seconds is recommended to ensure proper filling of voids (Najjar et al., 2017).

Therefore, ensuring a balance between the flowability and compressive strength of grout when designing lime activated grout would result in a grout that can be used for various applications. This would also contribute to a greener construction as cementitious material with low environmental impact is used.

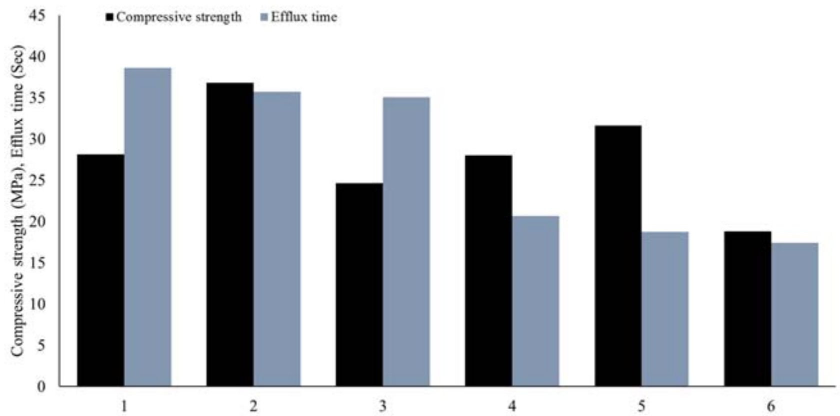

Figure 7: Compressive strength and efflux time of 6 selected mixes

4 CONCLUSION

This study shows the viability of using hydrated lime only to activate slag, which contributes to having a greener construction by the development of alkali activated grout (AAG) for various applications such as Two stage concrete. The use of hydrated lime activated grout would reduce the high embodied carbon and energy induced by conventional activators used which are corrosive, expensive and have high embodied energy and carbon. Based on this study, the following conclusions can be made;

- A more sustainable construction material have been developed using hydrated lime to activate slag.
- In order to prevent segregation in slag activated with hydrated lime VMA is required.
- Incorporation of viscosity modifier admixture leads to an increase in the efflux time, therefore of water and/or superplasticizer would have to be adjusted.
- The use of hydrated lime at 15% by mass of the slag is the optimum to achieve good strength and workability

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