

Enhanced Flow Ability and Mechanical Characteristics of Cemented Paste Backfill with a Chemical Admixture

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ABSTRACT

Cemented paste backfill (CPB) with excellent flow ability and a high rate of early strength gain achieved in an economical manner is a key target in the backfill technology. This paper presents the results of an experimental investigation of the effect of a novel chemical admixture (Master Glenium 7500) on the rheological properties (yield stress, viscosity) and mechanical properties of CPB. The yield stress and viscosity of CPB samples containing 0%, 0.05%, 0.125% and 0.25% admixture were tested up to 4 hours. Unconfined compressive strength (UCS) of the samples was also determined after 1, 3, 7 and 28 days. The results obtained show that the admixture significantly reduces the viscosity and the yield stress of CPB. The admixture also proved to be important for strength development. At the initial stage, up to 3 days curing period, samples with admixture show lower UCS but become stronger than the treated samples after 7 days. This shows that this admixture can significantly improve the rheological properties, strength and strength gain rate of CPB. The findings of this study will, therefore, help to prepare CPB with enhanced performance properties.

INTRODUCTION

Disposal of tailings, which make up the bulk of the solid waste from mining process, has been a challenge in the industry for many years, largely due to their toxicity to human health and the environment (Wills and Finch 2016; Adiansyah et al. 2015; Nguyen and Boger 1998). One of the innovative ways of handling the waste has been the cemented paste backfill (CPB), which is a technological innovation that makes use of the tailings together with water and a binder to refill mine openings (Fall 2008; Pengyu and Li 2015).

In order to avoid delay in the mining process and also to ensure the safety of the miners, a CPB mix is required to have good flow ability and attain sufficient strength at an early stage. The mixing plant is usually located at the surface from where the CPB is transported under gravity or by pumping to the mine stopes being backfilled. Adequate fluidity is therefore needed to ensure effective and efficient delivery of the CPB from the mixing plant to the excavated stopes (Simon and Grabinsky 2013). A CPB mix that does not flow properly can result in pipe clogging thereby causing operational delay and financial loss to the operators (Clark et al. 1995). Improving the transportability of CPB while making sure its strength development is not compromised is a crucial aspect in mine backfill operations (Li and Fall 2016).

In order to improve the rheology of CPB materials, certain measures are often employed, one of which is the addition of water-reducing admixtures or superplasticizers (Ercikdi et al. 2010). When used in concrete, these admixtures can produce concretes with high strength without increasing the binder

content (Erdogdu 2002, Papayianni et al. 2005). Some studies have been carried out recently to understand how the superplasticizers can also be used in CPB technology. Ercikdi et al (2010) investigated the effect of three different superplasticizers on the rheology and strength characteristics of CPB produced from sulphide-rich tailings. They found out that admixtures containing polycarboxylate compounds improve the performance CPB and can, therefore, be adopted by the industry. In another study by Huynh et al. (2006), the effect of polymeric dispersants on flow ability of CPB was investigated with a focus on yield stress. The compounds reduce the yield stress of the CPB by increasing the electrostatic repulsive force between particles. As it follows, the study of commercial admixtures gives a better perspective on their applicability and efficiency.

In the current study, the effect of Master Glenium 7500, a novel chemical admixture, on the flow ability and strength characteristics of CPB are investigated. This is important because since the admixture was developed there has not been a similar study to fully explore its application in backfill operations.

EXPERIMENTAL PROGRAM

Materials

The CPB specimens used in the study constitute varying compositions of tailings, binders, water, and the Master Glenium chemical admixture.

Tailings. Silica tailings (ST) containing 99.8% quartz by weight were used in the study. These tailings have an advantage over natural tailings for experimental study due to their non-reactive nature. Natural tailings usually contain reactive chemicals that may affect the hydration process of binders (Pokharel and Fall 2013). Thus, the use of ST minimizes uncertainties in experimental results. The chemical composition of the tailings is given in Table 1.

Binders. Ordinary Portland cement type I (PCI) was the main binder used in the study. The physical and chemical characteristics of this binder are given in Table 2.

Mixing water. Tap water was used for all the specimens prepared for the study at appropriate water cement ratios.

Chemical admixture. Master Glenium 7500 (Master G), a product of the chemical company, Badische Andilin und Soda Fabrik (BASF), was used as the superplasticizer in the CPB mix. It is a full range water reducing admixture generally used for workability improvements and early strength achievement. It meets the ASTM requirements for high range water reducing admixtures (BASF 2015).

Table 1. Chemical properties and pH of the silica tailings

Mineral composition (% wt)								LOI (% wt)	pH
SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	TiO ₂	CaO	MgO	Na ₂ O	K ₂ O		
99.8	0.035	0.05	0.02	0.01	<0.01	<0.01	0.02	0.1	7

Table 2. Chemical and physical properties of the binders

Binder Type	Mg (wt.%)	Ca (wt.%)	Si (wt.%)	Al (wt.%)	Fe (wt.%)	S (wt.%)	Relative Density	Specific surface area (cm ² /g)
PCI	1.6	44.9	8.4	2.4	1.8	1.5	3.2	1300

Specimen Preparation

Multiple specimens of CPB were prepared for yield stress, viscosity and UCS tests with different binder contents, water to cement ratios, and admixture contents. For every batch, the tailings materials, binder, water and when applicable, the admixture were mixed in a mechanical mixer for about 7 minutes to achieve homogeneity. For both yield stress and viscosity tests, the proportions of PCI and the water to cement ratio were maintained at 4.5% and 7.35, respectively. Weight proportion of Master G was then varied as 0%, 0.05%, 0.125%, and 0.25%. The prepared CPB was poured into beakers of 8 cm diameter and 12 cm in height and enclosed in plastic containers under room temperature before testing.

Samples for UCS test were prepared with PCI proportion and water to cement ratio of 4.5% and 7.6, respectively. Proportion of Master G was also varied as 0%, 0.05%, 0.125%, and 0.25%. Prepared CPB was cast into airtight cylinders of 5 cm diameter and 10 cm in height and kept under room temperature to cure before testing. For the mix composition with 0.125% Master G, water to cement ratio and binder type were varied. Water to cement ratios of 5.5, 6.5, and 7.6 were used.

Testing of Specimens

Viscosity test. The viscosities of the CPB samples were measured using Brookfield digital viscometer (DV-E model). The device measures fluid viscosity through an immersed spindle rotated with a calibrated spring. Viscous drag of the fluid with respect to the spindle is then measured by the spring deflection with the help of a rotary transducer that provides torque signal (Brookfield 2014). For this study, RV4 spindle was used and each time a test was being run, an appropriate rotor speed was selected making sure that the recorded viscosity is within an acceptable limit. The spindle was first inserted into the specimen gently in a tilted position (to avoid air trapping) and centered. A guard leg was mounted before attaching the spindle to the spindle coupling nut of the device. The viscometer was then turned on and the reading was allowed to stabilize before recording. Samples were tested at 0, 1, 2 and 4 curing hours. Tests were repeated at least twice to ensure repeatability of results.

Vane shear test for yield stress determination. Vane shear test developed for soil strength determination has been used for efficient measurement of yield stress and other properties of non-Newtonian fluids (Elaty and Ghazy 2012). It allows for the yield stress of the fluid to be measured directly and accurately by a single-point measurement (Bauer et al. 2007; Nguyen 1983). For this study, Wykeham-Farrance vane shear apparatus was used. Maximum torque required to cause the CPB specimen to yield was measured using a four-bladed vane of 2.5 cm diameter and 2.5 cm height. For each test, the vane was slowly inserted into the middle of the sample and allowed to stabilize for about 30 seconds. The motor was then turned on and the vane rotated at a constant rate of 0.18rpm until a maximum torque was attained. Corresponding yield stress was calculated in accordance with ASTM D4648/D468M-13. Samples were tested at 0, 1, 2 and 4 curing hours. Tests were repeated at least twice to ensure repeatability of results.

Unconfined compressive strength test. The mechanical tests were conducted on the CPB samples after curing periods of 1, 3, 7, and 28 days. Tests were done in accordance with ASTM – C 39 standards with a computer-controlled mechanical press. A deformation rate of 0.8 mm/min was used. Tests were repeated at least twice to ensure repeatability of results.

Zeta potential measurements. Zeta potentials of CPB samples containing 0%, 0.125%, and 0.25% Master G were measured using Zetasizer Nano series. The device measures the electrophoretic mobility of suspended particles and then the zeta potential of the particles is evaluated using Henry equation

(Clogston and Patri 2011). Each zeta potential test was repeated at least three times to ensure result repeatability.

Microstructural analysis. In order to understand the hydration process of the cement under the influence of the admixture, thermogravimetric (TG) analysis was conducted on cement paste samples containing 0%, 0.125% and 0.25% Master G. Water to cement ratio of 2 was used for each mix. The test was conducted using thermogravimetric analyzer and differential scanning calorimeter (SDT) which monitors and records weight change, heat flow, and temperature transition in the sample. The samples were allowed to cure for four hours and then oven-dried at a 45°C until the mass reached a constant value.

RESULTS AND DISCUSSION

Effect of Master G Admixture on the Viscosity of CPB

The variation of viscosity of CPB samples with different admixture content as a function of time is given in Figure 1. It can be observed that the viscosity of CPB is influenced by both admixture content and time after mix. There is a consistent increase in the viscosity of each of the samples from the time of mixing to four hours curing time. This time-dependent thickening of the CPB is largely attributed to the hydration process of cement which lowers the capillary water in the specimen (Jensen and Hansen 2011; Wong et al. 2013). Consumption of the capillary water leads to a reduction of solid particles spacing thereby increasing attractive forces among them (Ahari et al. 2015). Several studies on the rheology of concrete made with PCI also observed an increase in viscosity with time (Kostrzanowska-Siedlarz and Golaszewski 2016; Amer et al. 2016; Choi et al. 2006).

As expected of a water-reducing admixture, the result in Figure 1 proves that addition of Master G to CPB mix reduces its viscosity. The addition of 0.125% resulted in about 50% reduction in the viscosity at the mixing time. Superplasticizers such as Master G exhibit a dispersion effect based on their capability to impart a negative charge on cement molecules resulting in electrostatic repulsion (D'Souza 2013). An important observation is the trend exhibited by the CPB treated with 0.125% Master G. The viscosity of the mix only increases by 0.53 Pa.s which is the lowest of all the mixes. The percentage is considered to be the optimum in improving the flow of CPB among other proportions used in this study.

Effect of Master G Admixture on the Yield Stress of CPB

The yield stress evolution of CPB samples treated with different admixture contents is presented in Figure 2. The development of yield stress over time varies among the samples with different admixture contents. The CPB sample with 0% has the highest yield stress while that containing 0.25% has the lowest for all the curing periods. The behavior is similar to that observed on viscosity as the admixture improves the flow ability of the CPB. Time-dependent increase of yield stress is also largely associated with the cement hydration and surface adsorption that lowers the free water in the material (Mehta and Montero, 2006).

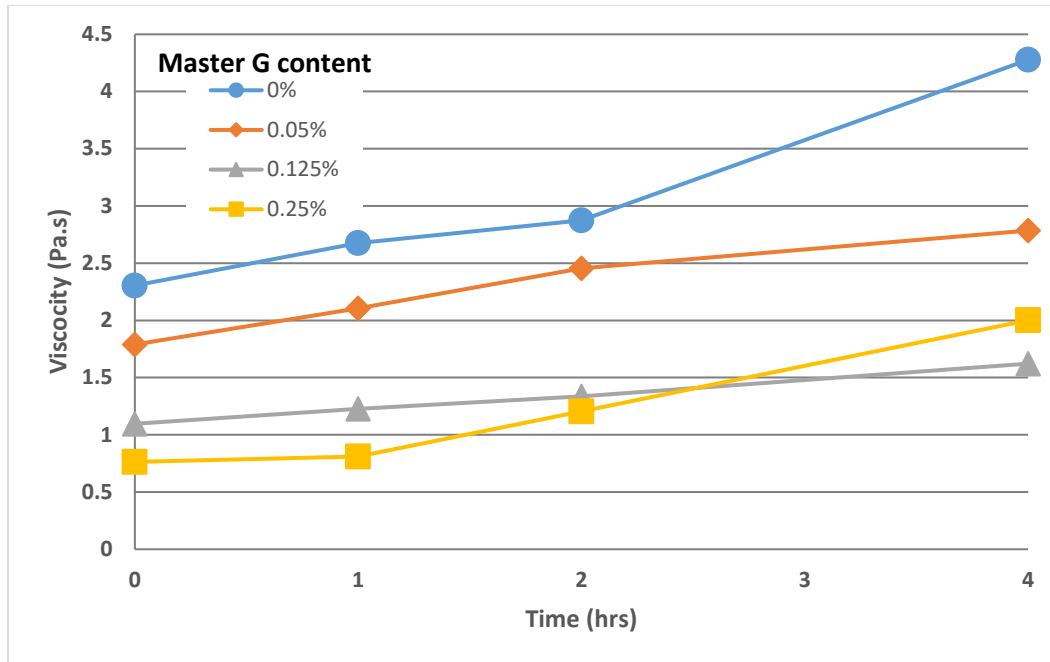


Figure 1. Effect of admixture and curing time on the viscosity of CPB

The more important variation caused by the Master G content can be explained by the mechanism through which plasticizers work. Master G contains carboxyl compounds which surround particles and results in dispersion due to the repulsive force between each polymer chain (Subramanian 2008). This means that the presence of the chemical makes the CPB less sticky thereby lowering its yield stress and ultimately improving its flow. The dispersion caused by the admixture also means that less byproducts of hydration process are generated which results in a less sticky CPB. The results of thermal analysis of cement 4-hour hydration with different admixture contents are shown by the TG/DTG diagrams in Figure 3. They confirm that more hydration products are generated within the CPB without admixture. Indeed, the first two peaks which occurred at about 100°C and 400 °C indicate highest weight loss is from the sample containing 0% Master G followed by that containing 0.125% and lastly the mix containing 0.25%. The results of zeta potential analysis given in figure 4 may also explain the yield stress reduction when Master G is added. The CPB mixes containing Master G showed higher negative zeta potentials than the untreated samples. Higher zeta potential value indicates high electrostatic repulsion and, thus, lower yield stress (Huynh et al. 2006).

Effect of Master G Admixture on the UCS of CPB

Figure 5 presents the strength gain of CPB samples containing different percentages of admixture over a period of 28 days. Initially, the CPB with 0% admixture started off with the highest strength but then taken over by the 0.25% sample after 3 days. Both CPB mixes containing 0.125% and 0.25% exhibited compressive strengths higher than the CPB sample without admixture. This is an important finding that shows that Master G improves the strength of CPB in addition to enhancing its flow ability. The strength gain could be explained by the dispersing effect of the admixture which neutralizes the particles charges causing them to self-consolidate (Arezoumandi and Volz 2013; Li 2014; Haiqiang et al. 2016). Other studies have also reported strength improvement when plasticizers are used (Koohestani et al. 2016; Aleem et al. 2014; Ercikdi et al. 2010). Further studies are necessary to confirm these

explanations. Again, strength achievement with curing time can be associated with precipitation of cement hydration products (Puertas et al. 2000). A stronger cemented matrix is formed as a result of development of cohesion among tailing particles (Papadakis and Tsimas 2002; Puertas et al. 2000).

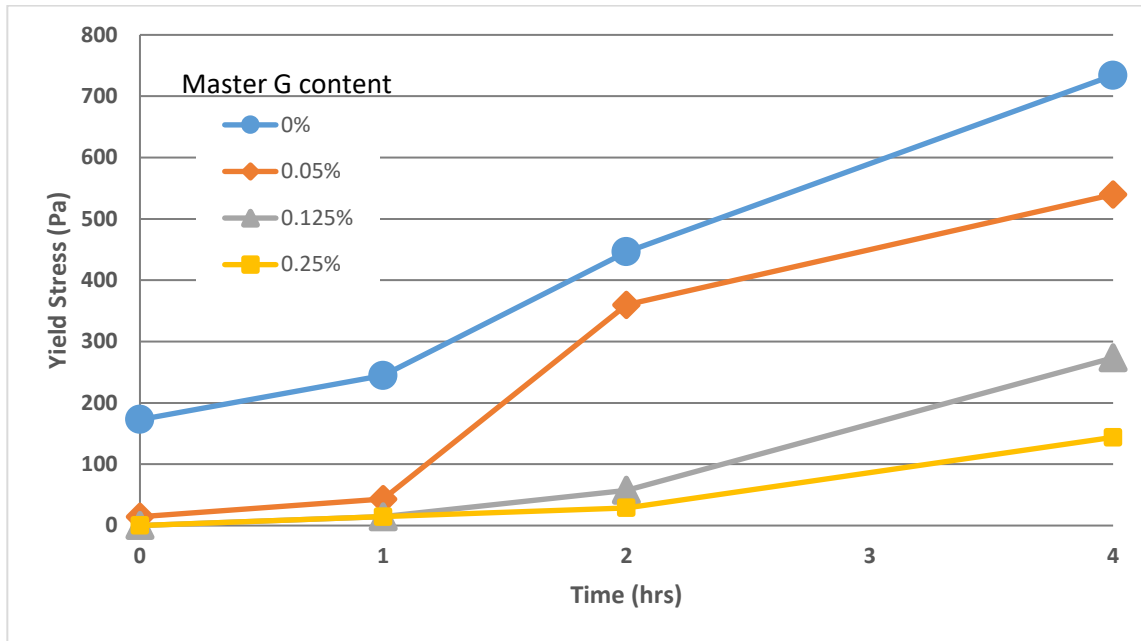


Figure 2. Effect of admixture and curing time on the yield stress of CPB

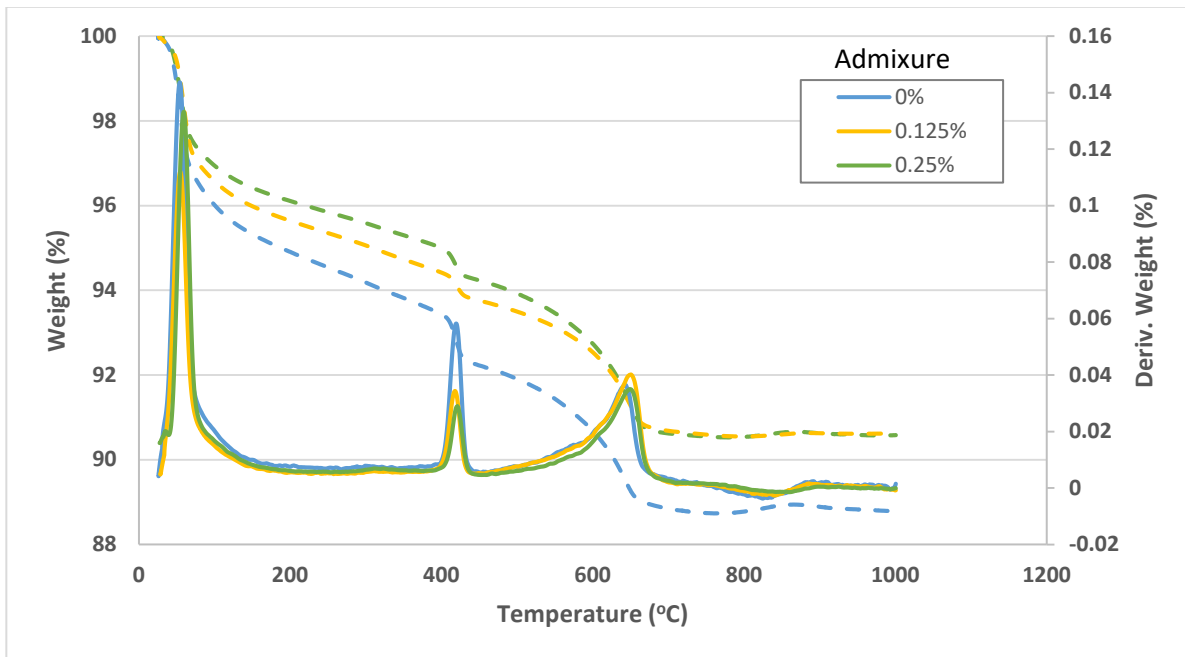


Figure 3. TG/DTG diagrams for 4 hour cement paste containing different admixture contents

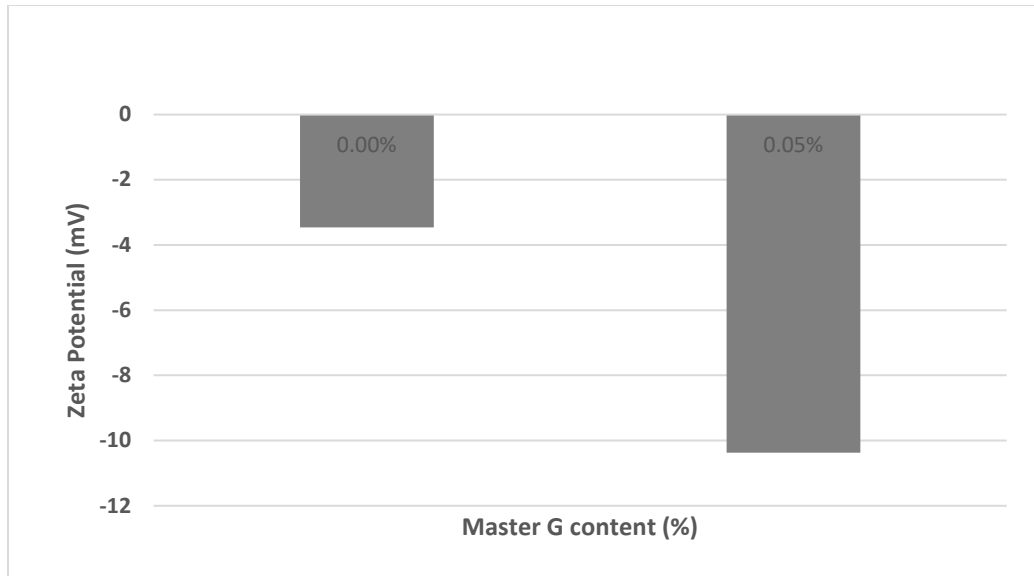


Figure 4. Zeta potentials of CPB with different admixture content

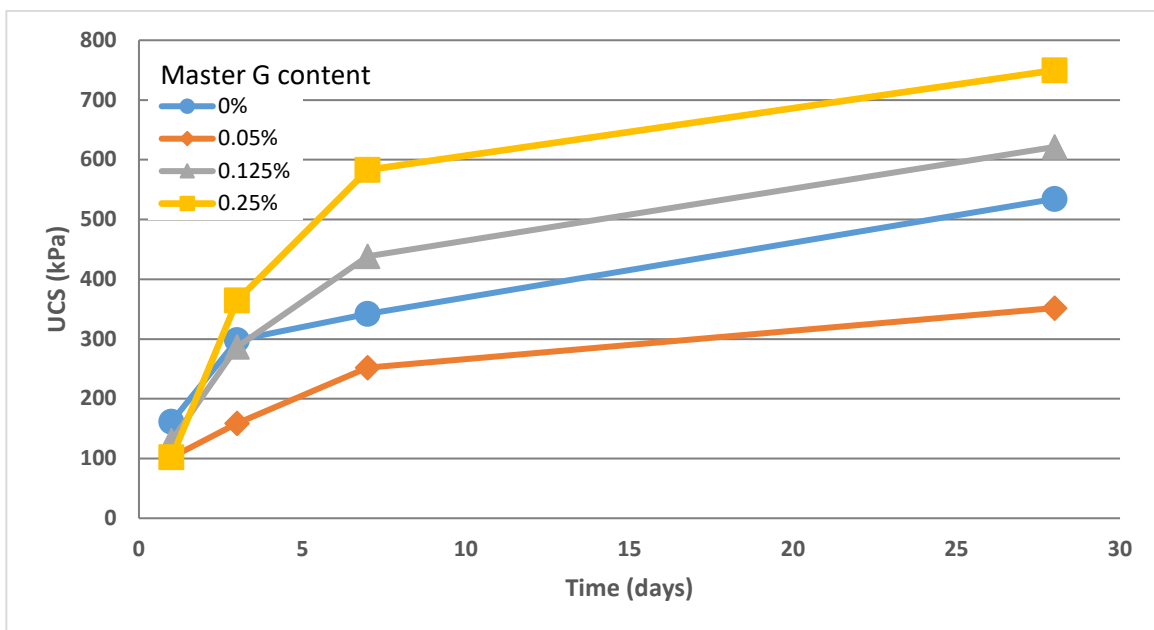


Figure 5. Effect of admixture and curing time on the UCS of CPB

SUMMARY AND CONCLUSION

The rheology and strength evolution of CPB mixtures containing different percentages of Master Glenium 7500 admixture and binder types were investigated in this study. Yield stress and viscosity were measured for fresh CPB mixes from preparation time up to 4 hours. UCS was conducted on samples after curing time of 1, 3, 7 and 28 days. Zeta potential and thermal analysis were also carried out to understand the behavior of the binder when mixed the admixture. The results obtained led to the following conclusions.

1. Master G is an effective plasticizer that significantly improves the flow ability of CPB. Samples containing the admixture exhibited lower viscosity and yield stress than the samples without the admixture. Optimal viscosity value was recorded for a mix containing 0.125% Master G.
2. The admixture does not inhibit the strength gain of the CPB, but rather improves it. At the initial stage, up to 3 days curing period, treated samples show lower UCS but become stronger than the treated samples after 7 days.

The findings from this study show that the admixture can significantly improve the rheological properties, early age strength and strength gain rate of CPB. As the study only investigated strength development over a short period, it will be useful in the future to look at the long time effect of the admixture on durability and strength performance of CPB.

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