Effect of silica fume and metakaolin on properties of GGBS ternary concrete

Noor Azline Mohd Nasir

Department of Civil Engineering

Faculty Engineering, Universiti Putra Malaysia

43400 UPM Serdang, Selangor, Malaysia.

***Abstract*—The paper is concerned with the use of GGBS as a binder in binary and ternary concretes. Various levels of silica fume and metakaolin in GGBS ternary concrete were evaluated. A short term study was carried out to examine the strength development and permeation characteristics of ternary concrete compared to GGBS binary and Portland cement concretes up to the age of 28 days. Mix proportions were designed at 0.35, 0.50 and 0.65 w/c. The studies shown that GGBS ternary concrete show better performance compared to GGBS binary concrete and Portland cement concrete. 10% silica fume addition exhibits better strength development and low capillary suction.**

Keywords-GGBS ternary; silica fume; metakaolin; blended concrete

I. INTRODUCTION

Concrete is the most widely used building material, with more than 10 billion tonnes produced annually by the construction industry worldwide [1]. Cement production in 2003 was approximately 1.2 billion tonnes/year and this was expected to grow to about 3.5 billion tonnes/year by 2015[1]. The reason for this reflects population growth and global developments in infrastructure and the excellent mechanical and durability properties that concrete provides [2].

While concrete can be considered a major contributor to modern civilisation, cement is considered to be responsible for approximately 5% of global carbon emission production which is believed to cause climate change, which is damaging to the planet [2][3]. Given this contribution to carbon dioxide emissions by the construction industry, it is understandable that the use of Portland cement has come under increasing scrutiny [4]. Thus, one of approaches that has been accepted widely in reducing embodied carbon dioxide of concrete is through the use of ground granulated blastfurnace slag (GGBS) or fly ash (FA) as cement replacement, which can reduce carbon dioxide emissions by up to 40% [5]. It has also discovered that GGBS or FA enhancing concrete durability [3].

[1] This was before the global recession in 2010-11 which is likely to influence what levels are achieved.

Although cement combinations concrete has been used in construction industry for ages, the literature indicates that these have tended to be relatively limited particularly in the application of ternary cement and high addition levels in concrete systems. Thus, this paper describes a study performed on the properties of GGBS-based concrete, such as compressive strength and capillary suction. The concretes were produced by combining Portland cement (CEM I) with various proportions of GGBS for the combinations of binary concretes and the use of silica fume (SF) or metakaolin (MK) for the combinations of the ternary concretes.

II. MATERIAL AND MIX PROPORTIONS

A CEM I and four additions, GGBS, SF and MK were used and chemical characteristics are given in TABLE I. The concretes had a fixed free water content of 165 l/m^3. Superplasticiser was used to achieve the target slump between 60-90 mm. The w/c ratios used were 0.35, 0.50 and 0.65 to provide a range of typical concretes and strength used in structures. CEM I was replaced with GGBS at levels of 35% and 55% for binary concretes. Then, part of GGBS was replaced with each of the other additions at level of 5% and 10% in the 35% GGBS and 55% GGBS concretes, respectively. All concretes were cured in water at 20°C to 28 days, prior to testing.

III. RESULT AND DISCUSSION

A. *Compressive Strength*

1) Binary Concretes

In general, GGBS reduced strength compared to those of CEM I concrete, regardless of w/c ratio. Binary concretes gave a systematic decrease with increasing GGBS content, as shown in Figure 1 and Figure 2. The strength reductions were around 25%-40% less (with regard to 3 day strength) than CEM I concrete at 35% GGBS (with lower percentage reductions at lower w/c ratio) but the reductions increased at 55% GGBS contents. These results confirm that the slow initial hydration of GGBS affects the development of strength in concrete containing GGBS, particularly at early ages and agrees with other research in this area [6][7][8][9]. In addition, another reason for the reduction in compressive strength of GGBS-based concretes at early ages may be attributed to the effect of CEM I dilution, which decreases the CH supply and increases the effective water (due to the reduced in CEM I level) in the mix [7]. Thus, CEM I dilution and GGBS level have a significant effect on strength, in which case the chemical reactivity is influenced by the former factor particularly at the initial stage whereas the latter factor corresponded to its physical effect, which has two roles including as filler and as nucleation sites.

TABLE I. PROPERTIES OF BINDER CONSTITUENTS

Property	CEM I	GGBS	MK	SF
Fineness (m^2/kg)	409	450	3474	15750
Loss on Ignition	0.90	0.90	1.00	-
Particle Density	3.14	2.91	2.59	2.20
Bulk Oxide Composition, %				
CaO	64.6	39.6	0.15	0.3
SiO_2	20.0	35.5	57.3	95.3
Al_2O_3	4.6	12.8	38.6	0.7
Fe_2O_3	3.8	0.5	0.6	0.3
MgO	2.5	8.4	0.3	0.4
MnO	0.1	0.6	<0.1	-
TiO_2	0.3	0.5	<0.1	-
K_2O	0.6	0.5	2.3	0.8
Na_2O	0.3	0.2	0.1	0.2
P_2O_5	0.1	-	0.1	-
SO_3	3.1	-	0.0	3.2

On the other hand, the strength of 35% GGBS binary concretes was equal to that of CEM I concrete at all w/c ratios at 28 days. This could be explained by the higher CEM I content which may supply sufficient alkali giving greater reaction of GGBS particles. In contrast for 55% GGBS binary concrete, the strength at all w/c ratios was less than that of CEM I up to 28 days. Thus, this shows that the CEM I dilution have a significant effect on strength development.

2) Ternary Concretes

In general, ternary concretes followed a similar trend to the GGBS binary mixes which had low early strength in comparison to CEM I concrete as shown in Figure 1 and Figure 2. However, the inclusion of either MK or SF at all GGBS levels enhanced early strength development after 3 days, compared to GGBS binary concretes. The pozzolanic reaction is slow at very early ages (1 to 2 days), since the initiation of the pozzolanic reactions can only begin after the hydration of CEM I [10]. The results also show a greater reduction in early strength development with increasing addition levels. Another possible reason affecting the early strength of concrete could be associated with the lower degree of hydration of GGBS-based concrete corresponding to CEM I dilution, as discussed earlier.

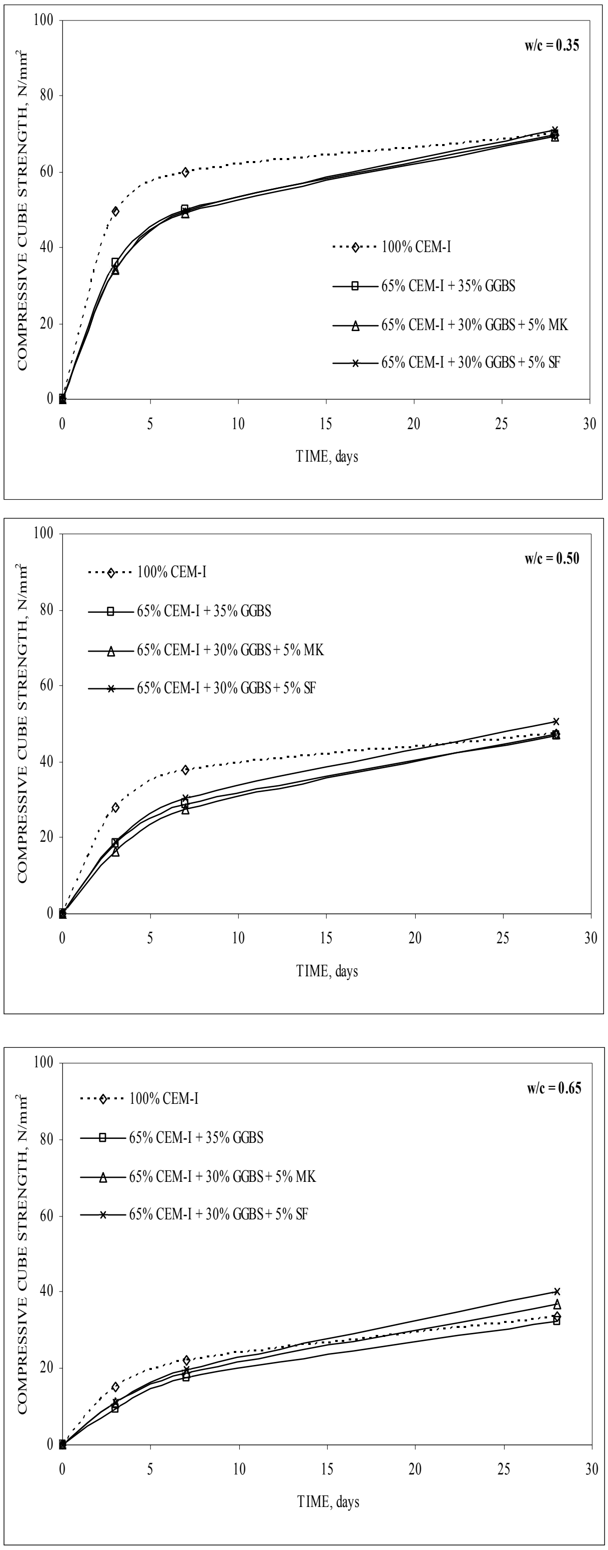

Figure 1 Compressive strength of GGBS cement combinations concrete with 35% replacement

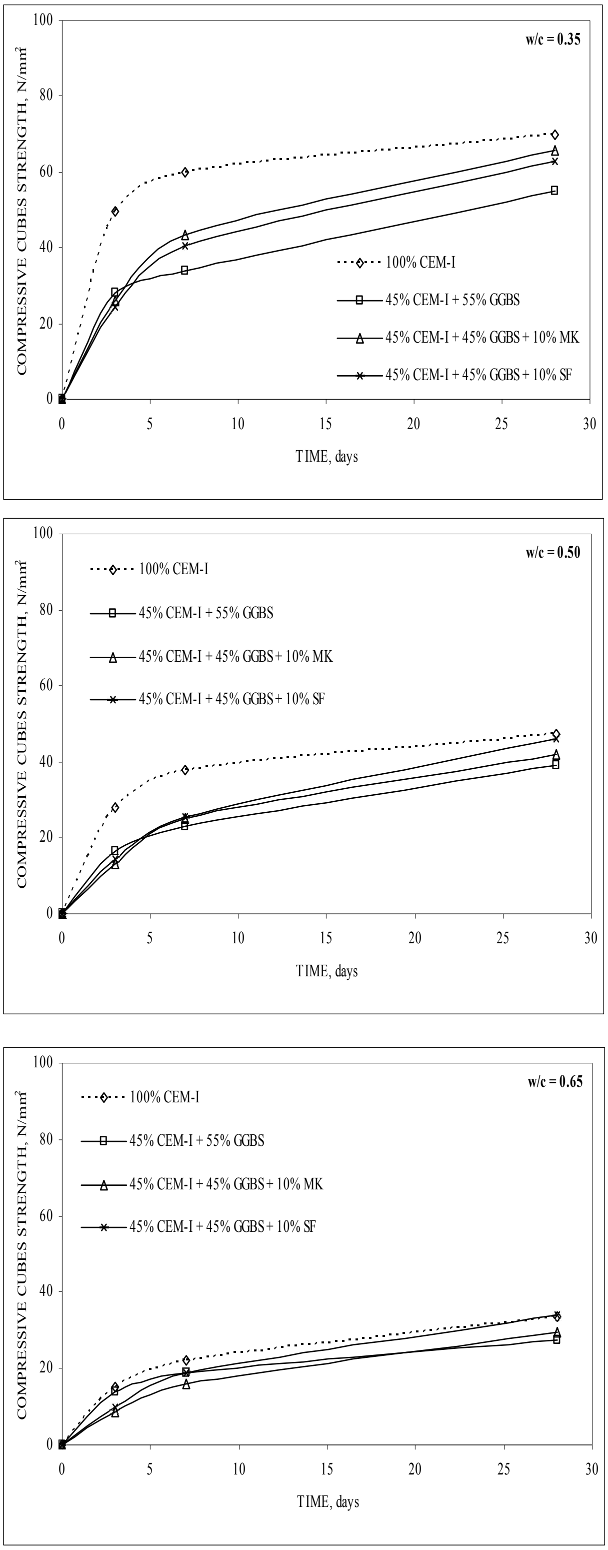

Figure 2 Compressive strength of GGBS cement combinations concrete with 55% replacement

On the other hand, the results indicate that the strength of GGBS ternary concrete at 7 days was significantly higher than equivalent GGBS binary concrete. As noted previously, this can be attributed to the pozzolanic reactivity which enhances the ternary blend cement hydration reactivity with time. Furthermore, the results indicate that the rate of strength development (strength at 7 days) was higher at low w/c ratio compared to other w/c ratios. This appears to be consistent with the results observed for GGBS binary concretes. As noted above, the early strength development of GGBS ternary concretes was found to be greater than those of binary concretes, although the CEM I level decreased simultaneously. This indicates that apart from the effect of pozzolana, the early strength development of GGBS-based concrete is also influenced by CEM I levels.

At 28 days, either MK or SF gave similar strengths to binary mixes at 28 days and higher for ternary concrete containing 65% CEM I (see Figure 1). It was also noted that at equal pozzolana level, both MK and SF gave comparable strength of concrete, reflecting their highly pozzolanic characteristics [11]. It was also apparent that the inclusion of pozzolana materials to concrete influenced strength development in different ways, reflecting their chemical reactivity and particle size [12].

Figure 2 shows that the strength development of 55% GGBS ternary concretes was comparable to that of CEM I. It should be understood that increasing the addition level affect the chemical reactivity due to limitation on CH supply. Thus, this indicates that a higher rate of strength development in ternary concrete was achieved due to a greater effect from filler effect of the additions apart from their chemical reactivity. On the other hand, at equal pozzolana level indicates that 10% SF was more effective than 10% MK. As noted earlier, this is probably due to the particle characteristics of SF, which are finer than MK particles, resulting in a denser microstructure, particularly in the transition zone surrounding the aggregate particles [13][14].

B. Capillary Suction

1) Binary Concretes

The effect of w/c ratio on sorptivity of GGBS-based concretes is shown in Figure 3. The effect of GGBS level on the sorptivity of GGBS binary concrete indicates that GGBS binary concrete had a slightly lower rate of sorptivity than CEM I concrete, regardless of w/c ratio. The results also show the expected trend of increasing sorptivity with w/c ratio. This is because the w/c ratio influences the spacing between cement particles [15]. The proportion of fluid filled space to solid phase is therefore greater at high w/c level, which causes a more porous and interconnected microstructure in concrete.

2) Ternary Concretes

The results of sorptivity for GGBS ternary concrete are shown in Figure 4 and Figure 5. The results indicate that the presence of either MK or SF reduced the sorptivity of ternary concrete compared to those of equivalent GGBS binary. The improvement in sorptivity of concrete is closely related to the quality of cement paste, which corresponds to chemical reactivity and the particle packing between CEM I and addition particles. Furthermore, decreasing the CEM I level to 45% gave a similar reduction in sorptivity for ternary concrete (see Figure 5). Again, a further decrease in sorptivity is due to the greater reduction in both pore size and continuity due to pozzolanic reactivity and, can also be attributed to the physical effect of the finer pozzolana particles, which give the micro-filler effect [3].

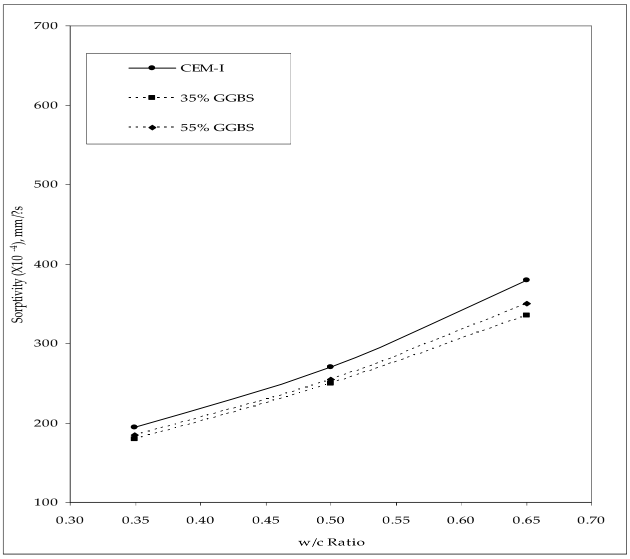

Figure 3 Effect of w/c ratio on sorptivity of concrete at various GGBS content

The results also show a consistent decrease in sorptivity with increasing pozzolana level (see Figure 4 and Figure 5). The results also indicate that GGBS-based ternary concretes containing 10% SF with 45% CEM I had a denser concrete microstructure due to both pozzolanic and filler effects. The results agree with the findings of others [17][18].

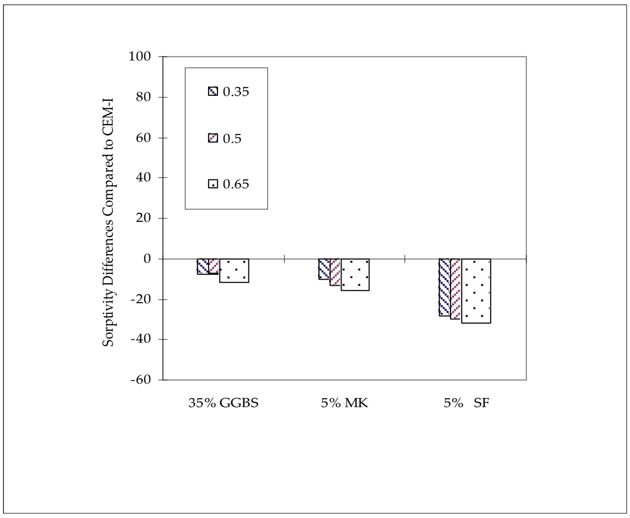

Figure 4 Comparison of sorptivity on GGBS cement combinations concrete with 35% replacement level to CEM I concrete

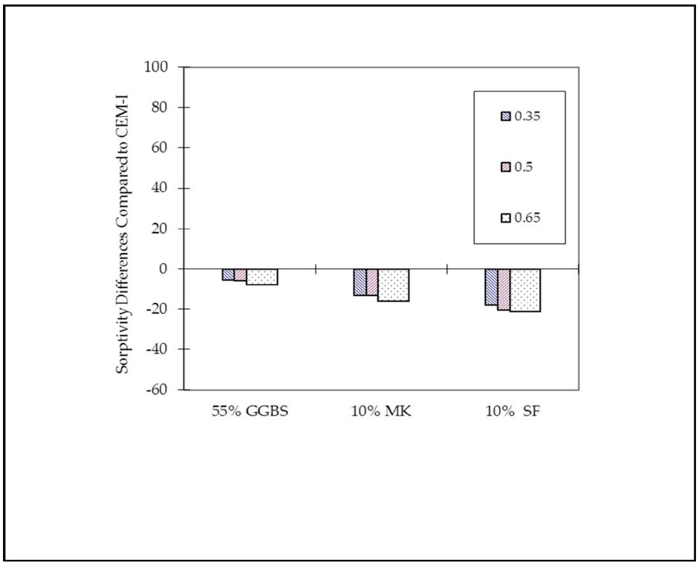

Figure 5 Comparison of sorptivity on GGBS cement combinations concrete with 55% replacement level to CEM I concrete

IV. CONCLUSION

1. GGBS binary gives low early concrete strength and the adverse strength effect is more pronounced at concrete with high GGBS levels. Similar early strength effect was found on GGBS ternary concretes compared to both CEM I and binary concrete.

2. The strength of ternary concrete found to be higher compared to binary after 7 days.

3. The compressive strength increased with curing time but only exceeded the CEM I strength at later ages for 35% GGBS ternary concretes.

4. The strength of ternary concrete improved than those of binary concrete regardless combinations level.

5. The compressive strength of ternary concretes is higher by presence of either SF or MK.

6. Sorptivity reflect the quality of the concrete microstructure and are affected by w/c ratio and cement type used.

7. Both MK and SF improved the concrete microstructure but 10%SF gave the lower sorptivity rate between the two.

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