DRYING SHRINKAGE AND STRENGTH OF GGBS AND SAWDUST INCORPORATED OPC MORTAR

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Abstract

Sawdust is an excellent bio based waste material that can be effectively used in replacing fine aggregate in concrete or mortar. The available research output related to sawdust incorporated concrete is limited; however, valuable information on strength of sawdust concrete can be found. This study aimed to obtain compressive strength, flexural strength and drying shrinkage of GGBS and sawdust incorporated mortar. The maximum size of fine aggregate and sawdust is of 2.36 mm and 1.18 mm, respectively. Mortar specimens were prepared by changing the amount of GGBS as 0%, 50% and 70%. The amount of sawdust was kept constant. The measured density of sawdust mortar shows a significant difference with initial assumed density which questions the accuracy of the initial mix design of sawdust mortar. Water absorption in sawdust mortar at 7 days is approximately 14% with a slight decrease at 28 days. The highest compressive strength is achieved when the amount of GGBS replacement is 50%. The addition of extra alkali has not shown additional strength development or visible chemical reaction with sawdust. Drying shrinkage at 28 days in all specimens is in the range of 200-400 microns; however, it is increasing up to 1000 microns at 90 days. The results show that the sawdust replacement in mortar could still maintain some structural properties; however, the effect on durability properties should be investigated further.

Keywords:

Drying shrinkage, Sawdust, GGBS, Mortar

1 INTRODUCTION

Mortar is widely used as the main building material in low cost building constructions especially in the constructions using bricks or masonry. Mortar is also the main component in conventional concrete. Its contribution to the final strength and the durability is very significant; hence its properties should be carefully monitored.

The sustainability of building materials has gained a very high popularity as cement, the main cementitious material in mortar, is responsible for a significant amount of carbon dioxide emission. As a solution, though there are variety of cement replacement materials, ground granulated blast-furnace slag (GGBS) has been effectively and widely used in concrete for the purpose of reducing the use of cement. Although the incorporation of GGBS in concrete reduces its strength, the durability properties have been investigated increasing [1] which is beneficial for the structure. On the other hand, the use of sand has also some environmental concerns as the amount of sand is usually 60-75% in mortar and it is coming from rivers or rock quarries. Large amount of sand extraction creates environmental pollution. The replacement of typical sand with other possible materials has also gained a significant attention recently. Sawdust, a waste material from timber manufacturing process, can be used as a potential sand replacement material and proved to be effective.

Bio-composites made up with gypsum and 20% of sawdust addition has shown promising mechanical properties where the achieved compressive strength is 13 MPa [2]. A higher content of sawdust can lower the compressive strength; however, decreasing the density which would be beneficial. Sawdust can also be used as a sole fine material in making wood-crete. The compressive strength, however, could be very low as 0.8 MPa though the composite material has a very good thermal conductivity which is about 0.05 W/mK [3]. Sawdust is also widely used in making low density panels; however, panels cannot be used for structural purposes or load bearing purpose because of very poor mechanical properties [4].

The use of sawdust in concrete or mortar is not widely considered as its poor contribution to properties; however, some recent studies attempt to use sawdust in different types of building materials [2,3,5]. Promising properties on fresh state and mechanical strength of sawdust incorporated fly ash geopolymer paste has been identified in recent research [5].

Sawdust content has a direct impact on the setting time, density, compressive strength, and flexural strength of geopolymer paste. The properties of sawdust incorporated building materials, such as wood-crete, depends on the initial treatment condition on the sawdust. The sawdust treated with either hot water or boiling with alkali added water has positive effect on the performance of wood-crete [6]. The compressive strength can be increased by about 30% and 260% for hot water boiling treatment and hot water with 4% Sodium Hydroxide (NaOH) treatment, respectively.

Tab. 1: Mortar mix design

Group	Water (kg/m^3)	Cement (kg/m^3)	Fine aggregate (kg/m^3)	GGBS (kg/m^3)	Sawdust (kg/m^3)	$Ca(OH)_2$ (% of GGBS)
1	256	512	1280	0	50	0
2	256	256	1280	256	50	0
3	256	256	1280	256	50	5
4	256	154	1280	358	50	0
5	256	154	1280	358	50	5

Durability properties of sawdust incorporated building materials have been less focused although the impact of sawdust on the durability could be very crucial and significant. The drying shrinkage is one of the main properties of cementitious materials as it could directly affect the durability properties. The incorporation of sawdust can reduce the drying shrinkage [5]. However, the Portland cement with wood fibre waste can significantly absorb water as result of hydrophilic nature of wood [7].

The previous research studies show no or minimum evidence of using GGBS and sawdust in mortar. Therefore, this study aims to investigate strength and shrinkage properties of GGBS and sawdust incorporated mortar. The purpose of using GGBS and saw dust is to reduce the use of cement and sand content, respectively.

2 EXPERIMENTAL SETUP

2.1 Binding materials

Normal Ordinary Portland Cement (OPC) with the strength class of 42.5 and the specific gravity of 3.15 was used in this study. Ground Granulated Blast-furnace Slag (GGBS) having the specific gravity of 2.91 was used to investigate the effect of cement replacement on the strength development. The total amount of binding materials was kept at 512 kg/m^3 while introducing 50% and 70% of cement replacement with GGBS. With the aim of enhanced hydration product by GGBS, the additional alkali in the form of Calcium Hydroxide ($Ca(OH)_2$) is added to the mortar mix. The alkali content was kept at 5% of the GGBS content in the mix.

2.2 Fine aggregate and sawdust

The type of fine aggregate is river sand with all particles smaller than 2.36 mm. The fine aggregate has about 85% passing percentage at 1.18 mm and 50% passing percentage at 600 µm. The sawdust is a commercially available source unknown type with different particle sizes and shapes. However, to maintain a good mortar mix, the large and long particles were removed by sieving. The maximum particle size was kept at 1.18 mm. Sieved sawdust has about 65% passing percentage at 600 µm and 30% passing percentage at 300 µm. The Figure 1 shows the particle size distributions of both fine aggregate and sawdust. The measured specific gravity of fine aggregate is 2.65. The specific gravity of sawdust was assumed to be 0.5. The sawdust used in this study was not subjected to any pre-treatment.

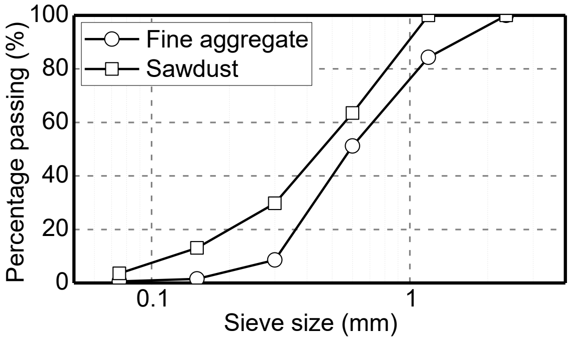

Fig. 1: Particle size distribution of fine aggregate and sawdust.

2.3 Mix design

The mortar mix design has a mass ratio between water, cement and fine aggregate is 1:2:6 and the water to binder ratio is 0.5. The mix design of all mortar specimens is shown in the Table 1. The group 1 shows that one sixth of fine aggregate content is replaced with sawdust and mixed with 100% cement. Group 2 and 3 are set to investigate the influence of 50% replacement of cement with GGBS while keeping the sawdust content the same. In group 3, a 5% of $Ca(OH)_2$ was added to investigate the effect of additional alkali available during the hydration process of GGBS mortar. Similarly group 4 and 5 are set to investigate the influence of increased GGBS content up to 70%. The compaction of mortar specimens were carried out in three layers using the vibrating table and manual compaction.

2.4 Mortar specimens

All specimens used for strength tests and moisture absorption test were water submerged and cured for 28 days. The compressive strength of mortar was measured at 7 days and 28 days using 50×50×50 mm cube specimens. Additional cube specimens were cast to measure the moisture content. The flexural strength was measured at 7 days and 28 days using 40×40×160 mm specimens. Specimens used to measure the drying shrinkage were water submerged for 48 hours after demoulding. Then all the specimens were stored in controlled environment with a temperature of 20 ^{0}C and relative humidity of 60%. Periodic length comparator readings were obtained at the age of 3, 7, 14, 21, 28, 56 and 90 days from the casting of mortar [ASTM C596-09]. The size of shrinkage specimen was 25×25×280 mm with an effective gauge length of 250 mm.

3 RESULTS AND DISCUSSIONS

3.1 Visual observation

The workability of mortar with sawdust is very low though some groups were cast with 70% of cement replaced with GGBS. By visual observation, it was clearly witnessed that the water content of mortar appeared low. The cohesion of particles was extremely low. However, at the compaction it was observed that the compaction only by vibrating table is poor while the additional compaction by hand was needed. This is mainly because the density of sawdust is low and the sawdust incorporated mortar is less cohesive. It was also observed that the mortar with sawdust behaves like a sponge where the mortar is trying to swell after the removal of the pressure applied for compaction. This implies that the strength of sawdust incorporated mortar could be significantly affected by the method of compaction and the energy input.

3.2 Wet density

The wet density of mortar was measured to compare the results with the estimated wet density. The wet density of mortar with 0% GGBS and sawdust replacement is 2304 kg/m^3. The wet density of mortar with sawdust replacement and with 100% cement was estimated at 2098 kg/m^3; however, the experimentally measured wet density is 1885 kg/m^3. This results show that the density can be significantly reduced by introducing a small amount of sawdust as its density is very low compared to fine aggregate. The results also question the accuracy of the initial mix design calculation as the estimated density has not been achieved. The Table 2 shows the measured wet density of all groups. The density has been slightly increased by introducing GGBS into the mortar mix; however the difference is not significant.

Tab. 2: Wet density of mortar.

Group	1	2	3	4	5
Wet density (kg/m^3)	1885	1974	1950	1986	1955

3.3 Moisture absorption

The moisture absorption of specimens was measured at the age of 7 and 28 days from the casting. Specimens were submerged in water until the measurement date. Initially the mass of specimens were measured after the removal of surface water. Then specimens were oven dried at a temperature of 105 ^{0}C for 24 hours. The moisture absorption capacity was then determined relative to the fully dried mortar. The measured moisture absorption results are shown in the Figure 2.

The moisture absorption of sawdust incorporated mortar is significantly high as a result of the high absorption capacity of sawdust. The moisture absorption capacity at 28 days is slightly less than that of 7 days as a result of continuing hydration process of cement and GGBS. It can also be noticed that the GGBS added to the mortar hydrates slowly at early age. Therefore higher GGBS content in mortar creates relatively higher amount of voids at early age. However, the results do not show clear evidence of the presence of any interaction between GGBS and sawdust in mortar.

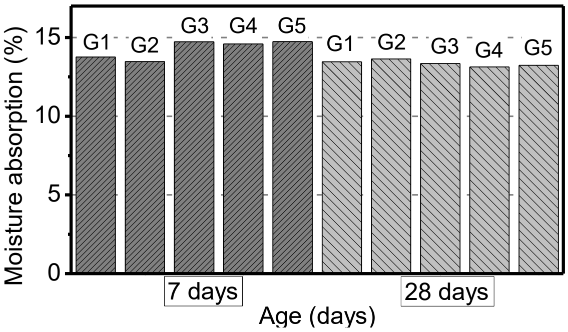

Fig. 2: Moisture absorption of mortar specimens.

3.4 Compressive strength

The compressive strength of mortar specimens with varying GGBS content is shown in the Figure 3. The compressive strength of specimens with no addition of GGBS is approximately 15 MPa which is reasonably a good strength with the addition of sawdust. However, the compressive strength at the age of 28 days is not significantly different to the strength achieved at 7 days. The compressive strength at 50% GGBS replacement is the highest showing that the interaction of GGBS with sawdust has no negative effect on the compressive strength. This is understandable as sawdust does not contribute to the hydration process but only serves as a filling material. It is also worth to note that the GGBS content up to 70% can still contribute to similar compressive strength with GGBS 50% at the age of 28 days. This fact is irrelevant with the availability of sawdust and is because of the slow hydration reaction of GGBS tends to complete at longer time.

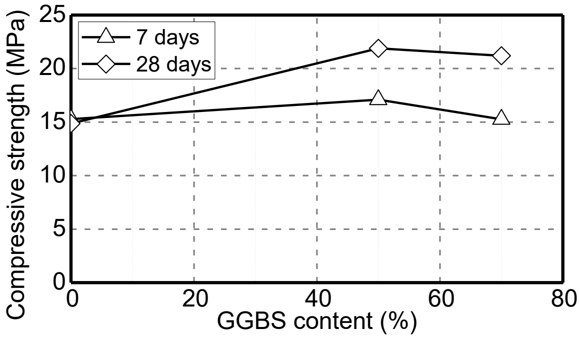

Fig. 3: Compressive strength with varying GGBS.

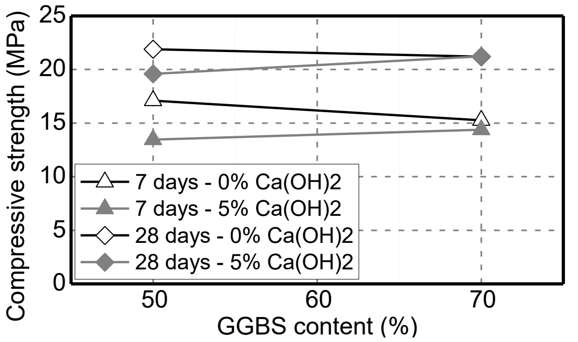

Fig. 4: Compressive strength with varying Ca(OH)2.

A 5% of $Ca(OH)_2$ was added to mixes of mortar with GGBS. As GGBS's hydration reaction consumes hydroxyl ions which are coming from the cement hydration reaction, the additional $Ca(OH)_2$ aimed to accelerate the hydration reaction. Although the Ca(OH)2 was added aiming to achieve higher strength, the results show that the mortar specimens of having a GGBS content of 50% without adding Ca(OH)2 have higher strength at 7 days and 28 days. However, when the GGBS content is 70% the strength of mortar specimens with and without adding Ca(OH)2 have approximately similar strength. This observation proves that the addition of Ca(OH)2 does not contribute to the strength development in sawdust incorporated mortar.

3.5 Flexural strength

The flexural strength of mortar specimens was measured at 28 days using the three-point bending test. The clear span between supports were kept at 100 mm. Though the mortar has 50 kg/m3 of sawdust the flexural strength of mortar is 4.3 MPa which is reasonably a good strength. The flexural strength is also following a similar trend as the compressive strength when the GGBS content is increased. The flexural strength at both 50% and 70% of GGBS content is 5.4 MPa. The addition of Ca(OH)2 into the mix of GGBS mortar is beneficial for the flexural strength as the strength is higher at 70% GGBS with Ca(OH)2.

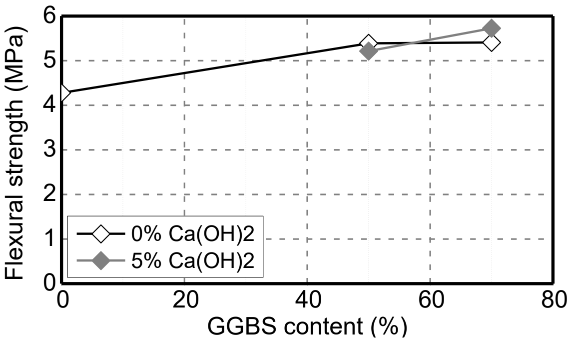

Fig. 5: Flexural strength with varying GGBS.

3.6 Drying shrinkage

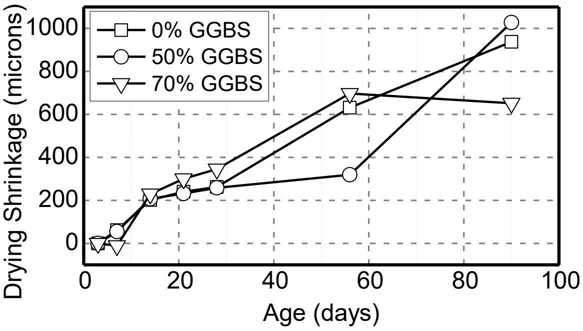

Fig. 6: Drying shrinkage of GGBS added mortar.

The mortar specimens used to measure drying shrinkage were water submerged with lime saturated condition for 48 hours after demoulding. After removal from the water, specimens were placed at controlled temperature and humidity for 90 days. The drying shrinkage measurements were calculated relative to the specimen length at the age of 3 days and shrinkage variation is shown in the Figure 6. The drying shrinkage is occurring as a result of the moisture evaporation from the mortar specimens and usually the drying shrinkage up to 28 days is considered. Regardless of the GGBS content, the drying shrinkage of sawdust added mortar specimens at 28 days varies between 250 and 350 microns. The drying shrinkage of sawdust added mortar was still increasing after 28 days; it reached nearly to 1000 micron at the age of 90 days. There is no clear evidence to say that GGBS incorporation has increased or decreased the drying shrinkage of mortar specimens. However, the drying shrinkage of GGBS and sawdust added mortar could also reach 1000 microns at the age of 90 days.

Figure 7 shows the drying shrinkage variation of the GGBS added mortar specimens when they are incorporated with additionally provided Ca(OH)2. When Ca(OH)2 is added, a slight expansion of specimens were observed at the age of 7 days. However, the drying shrinkage of Ca(OH)2 added mortar is higher than that of mortar contains only sawdust. The drying shrinkage was still continuing after 28 days regardless of the addition of Ca(OH)2. This observation is mainly because the mortar has sawdust which initially absorbs a significant amount of water and then evaporates at the drying stage.

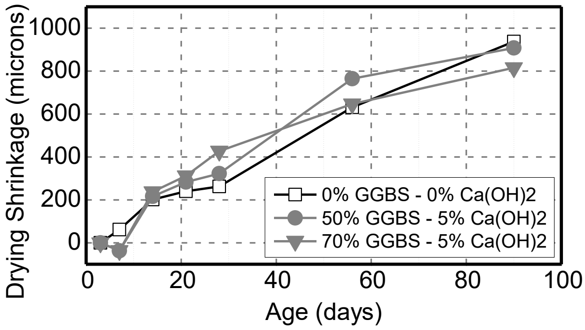

Fig. 7: Effect of Ca(OH)2 on drying shrinkage.

4 SUMMARY

This paper summarizes the experimental data of mortar specimens cast with sawdust, GGBS and Ca(OH)2. Although the experimental cases are very limited, some interesting and valuable conclusions can be drawn.

1. The sawdust incorporated mortar has a very high moisture absorption capacity and as a result the drying shrinkage is also significantly high. The drying shrinkage is gradually increasing even after 28 days and it could also reach 1000 microns at 90 days.

2. There is no apparent chemical reaction between sawdust and GGBS and therefore their properties are independently affecting the strength of mortar. The addition of Ca(OH)2 is also affecting the GGBS however no apparent influence on sawdust.

3. A small amount sawdust replacement with fine aggregate can significantly lower the density of mortar while still achieving a reasonably good compressive and flexural strength.

Further studies are needed to enhance the knowledge on the interaction between sawdust, GGBS and alkali added to mortar. This could be achieved by varying the sawdust percentage to investigate mechanical properties.

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