Impact of Wood Ash, Silica Fume, and Calcium Oxide on the Compressive Strength of Mortar

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Abstract - *Ordinary Portland cement is the most common type of cement used around the world, and it is used as a binding material in the production of mortar and concrete. However, during the production of ordinary Portland cement, there have been substantial amount of CO_2 emissions. Therefore, supplementary cementitious materials have been used to minimize the production of ordinary Portland cement, reducing pollution due to CO_2, preserving limestone, and also helping to save energy used during cement production. Wood ash and silica fume have been considered as some of the supplementary cementitious materials used. These materials are by-products from other processes or natural materials, and they are used to improve the workability, durability, and strength of the mortar and concrete. In this study, a fixed amount of wood ash and silica fume was used to replace the cement content of the mortar, and their influence on the compressive strength of the mortar was investigated. The compressive strength of the mortar was evaluated and measured at the curing periods of 7 and 28 days. The test results show that the addition of silica fume increased the compressive strength of the mortar, while the addition of wood ash showed a gradual increase in compressive strength. However, when calcium oxide (CaO) was added to the mortar containing wood ash, it showed an increase in compressive strength over a length of time. The study concluded that the use of wood ash and silica fume improves strength over time and is therefore recommended as an additional cementitious material.*

***Key Words*: Wood Ash, Silica Fume, Calcium Oxide, Compressive Strength, Mortar**

1. INTRODUCTION

Wood ash is generated as a by-product of combustion in wood-fired plants, paper mills, and other wood-burning industries. Fly ash, which is produced during the combustion of coal in electricity power plants, can be compared to wood ash [1]. However, since the use of coal-fired power plants has been considered dangerous due to the increase in CO_2 emissions. According to a study by Hossain Masum [2], switching from coal to a different fuel source could reduce carbon emissions by 43%. The study suggested that the use of wood biomass, such as wood chips and logging, could be the best fuel source, which is more cost-effective and environmentally friendly. For many years, fly ash was used in place of cement to create more durable and affordable building materials. However, as coal-fired power facilities close throughout the world, less fly ash is available. An industrial by-product of wood-fired facilities, wood ash is created as an alternative to fly ash [3].

Wood ash is produced at a rate of roughly 4600 million tons per year. It is predicted that it will be challenging to locate the necessary landfills due to the growth in the production of this waste. However, the disposal of fine and light wood ash would result in serious contamination of the air, water, and soil, which may have an adverse effect on human health and the ecosystem. As a result, the wood ash has been recycled and used as an additional cementitious material in mortar and concrete. It has been viewed as a way to dispose of waste in large quantities without affecting the environment [3][4].

Silica fume is one of the pozzolanic materials with a high content of amorphous silicon dioxide, ranging from 85% to 98%, in the form of very fine spherical particles averaging diameters of about 0.1 to 0.5 microns. It is mainly used in the production of mortar and concrete [5]. Silica has become useful in the production of high-strength concrete because of its ability to increase the bond between cement paste and aggregate by making the interfacial zone denser. It increases the mechanical strength of concrete and mortar due to its pozzolanic nature [6]. In a study conducted by Antonia and Lucky Chandra, 0–10% of silica fume, 0–30% of fly ash, and 0–15% of calcium carbonate were used as cement content, respectively. They came to the conclusion that the use of silica fume reduced the workability of fresh mortar, necessitating the addition of superplasticizer to increase workability after evaluating the workability and compressive strength of hardened mortar at ages 7, 14, 28, and 58 days. Whereas, at the age of 56 days, they obtained the highest compressive strength when 20% fly ash and 2.5% silica fume were used. However, the use of calcium carbonate content up to 15%, increased the compressive strength of the mortar at the early stage [7]. Therefore, calcium oxide, which is produced when calcium carbonate is heated, was suggested to be used in this study to examine how it can affects the mortar, which contains silica fume and wood ash, respectively.

Herry and Hermawan conducted a study to investigate the influence of calcium oxide doses as an activator on the compressive strength and mechanical characteristics of cement-free mortar containing ground granulated blast furnace slag. In this study, 5%, 15%, and 25% CaO doses were used on the cement-free mortar containing GGBFS, and compressive strength was investigated. The results of the 5%, 15%, and 25% CaO doses were 21.45, 32.03, and 25.80 MPA, respectively. The results obtained showed that 15% had the highest compressive strength. Usually, GGBFS has a slow hydration reaction; however, various activators have been used to improve compressive strength. In this case, CaO was used as an activator [8]. Likewise, in this study, CaO was used as an activator.

In this study, 0%, 4% and 8% calcium oxide (CaO) were used on the mortar containing 20% wood ash, 20% silica fume and 10% wood ash and 10% silica fume, respectively

2. MATERIAL AND EXPERIMENT

2.1 Materials

In this study, PO 42.5 type Portland cement, which confirms the requirements of GB175-2007, was used [9]. Natural river sand was collected, cleaned, and dried and used as fine aggregate. Wood ash and silica fume were used as supplementary cementitious materials. Water was partially substituted with 0%, 4% and 8% calcium oxide doses. The water-to-cement ratio is 0.45.

2.2 Specimen

A total of 54 specimens measuring 50 x 50 x 50 mm were used to investigate the compressive strength of the mortar. The tests were conducted at 7-day and 28-day curing periods. A Compressive Testing Machine with a capacity of 2000 KN was used. Figure-1: shows specimens under compressive testing. The loads were recorded until the specimens failed. The cube compressive strength of each specimen can be calculated by

$$F = P/A$$

Where F is cube compressive strength of the mortar specimen, P is the corresponding failure load under compression and A is bearing area of specimens [9].

Figure -1: Specimens under compressive testing.

2.3 Mixing Process

The aim of this study was to investigate the impact of using wood ash, silica fume, and calcium oxide on the compressive strength of mortar. In the process of mixing, dry materials such as cement, sand, wood ash, and silica fume were added first and mixed for 3 minutes. Then water was replaced with 0%, 4%, or 8% calcium oxide, which was added gradually. After finishing the mixing process, the fresh mortar was placed into molds of 50 x 50 x 50 mm and then vibrated on a vibrating table for some minutes to make it more workable. Then the molded cast was cured and tested for compressive strength at the ages of 7 and 28 days. The mix design of the specimens used in this study are shown in Table 1 and Table 2. In the mixes M1, M3 and M5 the cement content was replaced by wood ash and silica fume as follows: M1, 20% wood ash and water was replaced at three levels with 0%, 4%, and 8% calcium oxide; M3, 20% silica fume and water was replaced with 0%, 4%, and 8% calcium oxide; M5, 10% wood ash and 10% silica fume and water was replaced with 0%, 4%, and 8% calcium oxide, respectively.

Table -1: Mix design of mortar containing different levels of wood ash and silica fume.

Mixes	Mix Details	Cement (kg)	Sand (kg)	Wood Ash (kg)	Silica Fume(kg)
M1	C+S+W.A +CaO+W	80% (1.228)	2.303	20% (0.308)	0% (0)
M3	C+S+S.F+ CaO+W	80% (1.228)	2.303	0% (0)	10% (0.308)
M5	C+S+W.A +S.F+CaO +W	80% (1.228)	2.303	10% (0.154)	10% (0.154)

Table -2: Mix design of water replaced at three levels with 0%, 4%, an 8% Calcium Oxide (CaO).

Mixes	Mixes No.	Calcium Oxide (CaO) (kg)		Water (L)
M1	M1-1	0%	0	0.675
	M1-2	4%	0.027	0.648
	M1-3	8%	0.054	0.621
M3	M3-1	0%	0	0.675
	M3-2	4%	0.027	0.648
	M3-3	8%	0.054	0.621
M5	M5-1	0%	0	0.675
	M5-2	4%	0.027	0.648
	M5-3	8%	0.054	0.621

3. RESULTS

In this study, wood ash, silica fume and calcium oxide were investigated to determine their impact on the compressive strength of the mortar.

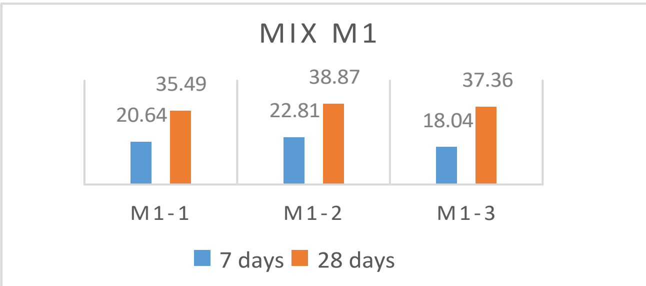
3.1 Wood Ash

In M1, 20% wood ash was used to replace cement content in all mixes M1-1, M1-2, and M1-3. Then CaO doses were added to the mixes of M1 as follows: 0% CaO of M1-1, 4% CaO of M1-2, and 8% CaO of M1-3 as shown in Table 2.

Table -3: Compressive strength (MPa) at 7-day and 28-day curing period.

MIX M1	7 days (MPa)	28 days (MPa)
M1-1	20.64	35.49
M1-2	22.81	38.87
M1-3	18.04	37.36

Chart -1: Compressive strength (MPa) at 7-day and 28-day curing period.



From the results listed in Table 3 and Chart 1, it was observed that when 4% CaO was added to the mix M1-2, the compressive strengths at the 7-day and 28-day curing periods increased by 9.51% and 8.69%, respectively, when compared to the strength of M1-1 with 0% CaO content. But when 8% CaO was added to M1-3, it was observed that the compressive strength decreased at the 7-day curing period by 12.59%, while at 28 days, it increased by 5.00% when compared to the strength of M1-1. Furthermore, we noticed that the compressive strength of the M1-3 mix increased significantly between the 7-day and 28-day curing periods, by 51.71%. In other studies, it has been shown that the compressive strength of concrete and mortar often decreases as the percentage of wood ash increases [10][11], while M. Abdullahi [1] found that the replacement of cement by wood ash by 20% increased the compressive strength of the concrete at 60 days. In this case, the increase in the compressive strength of the M1-3 mix between the 7-day and 28-day curing periods may be attributed to the addition of 8% CaO to the mortar. By adding 8% CaO to the mortar, the amount of CaO was raised in the mortar containing wood ash, which is rich in both CaO and K_2O. Then, when these compounds reacted with water, they formed K-A-S-H and C-S-H gels [12]. At the same time, some amount of CaO that reacts with water during hydration produces calcium hydroxide [13]. As a result, these compounds that are formed work as fillers and fill voids in the mortar, improving the compressive strength of the mortar [14]. In a study done by Cheah CB, Part WK, and Mahyuddin R [3][12], they observed an increase in strength with prolonged water curing of the mortar blocks for a duration of 28 days and 90 days at a lower rate. So based on this study, we can conclude that the same cause occurred during the 7-day and 28-day curing periods.

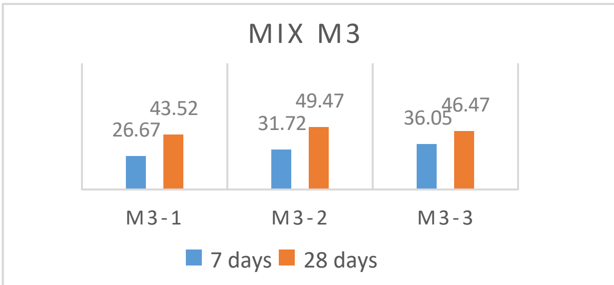
3.2 Silica Fume

In M3, 20% silica fume was used to replace cement content in all mixes M3-1, M3-2, and M3-3. Then CaO doses were added to the mixes of M3 as follows: 0% CaO of M3-1, 4% CaO of M3-2, and 8% CaO of M3-3.

Table -4: Compressive strength (MPa) at 7-day and 28-day curing period.

MIX M3	7 days (MPa)	28 days (MPa)
M3-1	26.67	43.52
M3-2	31.72	49.47
M3-3	36.05	46.47

Chart -2: Compressive strength (MPa) at 7-day and 28-day curing period.



From the results listed in Table 4 and Chart 2, it was observed that the compressive strength for all mixes increased gradually during the 7-day curing period, while at the 28-day curing period, M3-2 with 4% CaO increased by 12.03% and M3-3 with 8% CaO increased by 6.35% when compared to the mix M3-1 with 0% CaO. The highest compressive strength obtained was 49.47 MPa of M3-2 at the 28-day curing period, and it increased by 35.88% from the 7-day to the 28-day curing period. The increase in compressive strength can be associated with the pozzolanic influence of silica fume [15]. However, in other studies, it was noticed that when an excessive amount of CaO was used, the compressive strength decreased. In a study conducted by Herry Suryadi [16], it was observed that the utilization of excessive CaO could heat up the fresh mortar when CaO reacted with water. This caused water loss from evaporation. And due to water loss, the compressive strength decreased with the addition of 15% CaO. In another study that was conducted by Antoni David Christian, Alexander, Jimmy, and Hardjito [17], when 5% CaO was added to the mortar, it did not have any detrimental effect on the compressive strength, but when 10% CaO was added, the compressive strength of the mortar decreased. In this study, we noticed that when 4% CaO was added to M3-2, it did have an impact on the compressive strength of the mortar; the strength increased by 15.92% and 12.03%, respectively, when compared to the results of M3-1 with 0% CaO. Similarly, when 8% CaO was added to M3-3, the compressive strength of the mortar also increased by 26.02% and 6.35%, respectively, when compared to the strength of M3-1. This increase may be due to the increase in initial setting time caused by CaO. And the study resulted in the conclusion that the dosage of CaO should be limited to 10% to avoid exceeding rapid hardening [17]. Other studies have concluded that the addition of silica fume to the alkali-activated mortar improved the compressive strength of the mortar [18] [19]. However, to further explore the effects of silica fume in the mortar, we looked at the study by Dr. T.L. Ramadasu and Ch. Venugopal Reddy, who discovered that the increase in compressive strength observed was concluded to be due to two occurrences: chemical and physical. They found that the physical occurrence acts at an early age when the chemical occurrence is inert. Therefore, due to the large specific area of silica fume, there is a limit to capillary water inside the mortar because the silica fume particles fill the existing voids, reducing the breeding and improving the compressive strength [20] [21]. Then later, when the pozzolanic reaction between the silica fume and calcium hydrate occurs, hydrated calcium silicate is formed. Then the compound fills up the voids surrounding the hydrated cement particles, which results in the formation of a denser matrix, which reduces the porosity of the mortar and improves its compressive strength [14] [21]. Therefore, in this study, it was concluded that the same action occurred, which resulted in an increase in compressive strength.

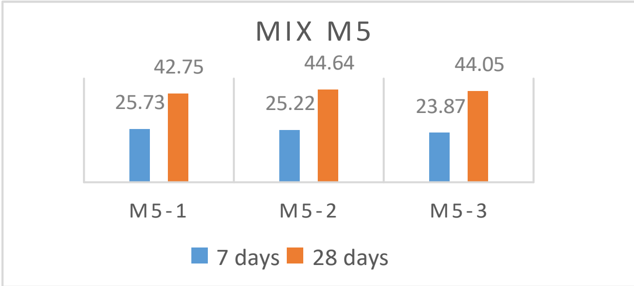
3.3 Wood Ash and Silica Fume

In M5, 10% silica fume and 10% wood ash was used to replace cement content in all mixes M5-1, M5-2, and M5-3. Then CaO doses were added to the mixes of M5 as follows: 0% CaO of M5-1, 4% CaO of M5-2, and 8% CaO of M5-3.

Table -5: Compressive strength (MPa) at 7-day and 28-day curing period.

MIX M5	7 days (MPa)	28 days (MPa)
M5-1	25.73	42.75
M5-2	25.22	44.64
M5-3	23.87	44.05

Chart -3: Compressive strength (MPa) at 7-day and 28-day curing period.



From the result Table 5 and Chart 3, it is observed that the compressive strength of M5-2, when compared to the compressive strength of M5-1, decreased by 2.02% at 7-day curing period and increased by 4.23% at 28-day curing periods, respectively. Likewise, for M5-3, the compressive strength shows that it decreased by 7.79% and increased by 2.95% when compared to the compressive strength of M5-1. Yet, we can see its increase in compressive strength between the 7-day and 28-day curing periods by 45.81%. This increase in compressive strength between the 7-day and 28-day curing periods can be attributed to the pozzolanic influence of silica fume and wood ash that occurs during the curing period [22]. Few studies have shown that wood ash can be pozzolanic. Zubaid Hamid and M. Abdullahi's test results showed that wood ash is slightly pozzolanic [1][23]. And silica fume is a highly active pozzolanic material [5][24]. Therefore, we concluded that the presence of 10% wood ash and 10% silica fume in the mortar mix enhanced the pozzolanic reaction during the curing period. So, we can also compare the results of the mix M5-3 with the results of the mix M1-3 listed in Table 3 and Chart 1. From the results shown, we discovered that when 8% CaO was added to the mortar of M1-3, the amount of CaO was raised due to the presence of wood ash, which is rich in CaO and K_2O. These two compounds react with water to form K-A-S-H and C-S-H, which act as fillers and fill voids in the mortar, hence improving the compressive strength. Also for silica fume, we can draw a conclusion from the study results listed in Table 4 and Chart 2 for the mix M3-1. According to our findings, we concluded that when the amount of silica fume and calcium hydrate reacts, hydrated calcium silicate is formed, which fills up the voids surrounding the hydrated cement particles and results in the formation of a denser matrix, which reduces the porosity of the mortar, therefore increasing its compressive strength. We concluded that these conclusions can be used to explain why the compressive strength of the M5-3 increased during the 7-day and 28-day curing periods.

4. CONCLUSIONS

This study analyzed the impact of using wood ash, silica fume, and calcium oxide on the compressive strength of mortar. Based on these results presented in this paper,

We could draw the following conclusions:

a) The addition of CaO to the mortar containing 20% wood ash increased the compressive strength over the longer curing period.

b) The addition of 8% CaO to the mortar containing 20% silica fume gradually increased the compressive strength, whereas the addition of 4% CaO significantly increased the compressive strength of the mortar between the 7-day and 28-day curing periods.

c) The addition of 10% wood ash and 10% silica fume showed an increase in the compressive strength of the mortar due to the pozzolanic reaction, whereas 4% and 8% CaO increased the compressive strength between the 7-day and 28-day curing periods gradually.

According to the results obtained in this study, the use of wood ash and silica fume as supplementary cementitious materials improves the compressive strength of the mortar.

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