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The influence of using Cattle Bone Ash and Waste Glass Powder on Mortar and concrete compressive strength

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ABSTRACT

In this study, the effect of using cattle bone ash (CBA) and waste glass powder (WGP) on the mechanical properties of mortar and concrete is investigated. The two materials were chosen because one of them is a source of silica oxide and the other one is a source of calcium oxide; where these two oxides are the main constituents of ordinary cement. The two materials were used as additives to the mortar/concrete mixtures. For (CBA), the powder was added to the mortar/concrete mixtures as percentages of the cement by weight .The percentages used were 0%, 1%, 3%, 5%, and 7% by weight. Like the CBA, (WGP) was added to the mortar/ concrete in the percentages of 0%, 1%, 3%, 5%, 7% and 10% of the cement weight. Atomic absorption spectroscopy analysis test was conducted on CBA, while XRF analysis was conducted on WGP to obtain the chemical composition of each material . A total number of 150 cube specimens were tested in the experimental program and the results showed that both materials are beneficial to mortar and concrete mixtures from the compressive strength perspective. The results showed that the CBA has significant effect in the early ages of concrete while WGP has significant effect on the long term.

Keywords: *cattle bone ash, waste glass powder, compressive strength.*

1. Introduction

Recycling wastes into concrete has been a point of interest for many researchers. It is well known that the main two oxides in the cement composition are calcium oxide and silica oxide. Consequently, the main concept of using the waste materials in concrete is to find wastes that contain either of these two oxides.

Through pozzolanic reaction, silica can convert the calcium hydroxide to calcium silicate hydrate that densifies the concrete and the strength.

Different waste materials that is rich of silica had been investigated to check its feasibility to be used in concrete, for example Rice Husk Ash (RHA) contains high percentages of silica that was found to improve the mechanical properties of concrete when it is used to partially replace the cement [1-2]

One of the materials that are rich in silica is glass that has been used in different forms in concrete , for example the glass wastes were used as a replacement of coarse aggregate in concrete [3-5], and was also used to replace the fine aggregates[6-8] and the results were satisfactory. But in the research carried out to investigate the former two forms of glass wastes, scholars examined the feasibility of using the glass wastes as aggregate replacement where the size of the glass particles was not fine enough to possess the pozzolanic activity. Other studies were carried out to investigate the pozzolanic effect of the silica contained in the glass wastes where the scholars used glass waste powder as a partial replacement of cement [9-14] or as an addition to concrete [7,15]. All the scholars agreed that the use of glass powder affects the workability of concrete according the percentages used and according to the nature of glass-waste source, and when it comes to the compressive strength there is a debate whether it increases or decreases the strength of concrete. Scholars showed that the use of glass powder in concrete increases the strength in the long term [14], while others reported that it increases the strength at early ages [9,11].

For calcium oxide, most of the studies showed that the use of materials that contain high contents of calcium can improve the mechanical properties of concrete [16-19]. Counterversy, other researchers showed that materials containing calcium oxides can negatively affect the compressive strength of concrete when added to the concrete mixes [20,21].

When comparing the effect of using materials with calcium oxide to that containing silica oxide, one finds that the effect of calcium oxide appears in the short term while the effect of silica oxide appears in

the long term i.e. after 28 days, as higher calcium content impacts the early strength of concrete [22].
In this research two different types of wastes were investigated; Waste Glass Powder as a source of silica oxide and Cattle Bone Ash as a source of calcium oxide. The two materials were investigated separately to obtain the optimum ratio of each material that can be added to mortar/concrete mixtures and leads to a significant increase in the mechanical properties, then a mix containing the two optimum percentages of each material was examined to check the combined effect when the two materials are added together.

2. Methods

The experimental program carried out in the research included testing a total number of 150 specimens, where the program was divided into two phases. Phase one designed to examine the effect of CBA and WGP on the compressive strength of mortar cubes, while phase two examined their effect on the compressive strength of concrete cubes.
For the mortar specimens, standard cubes 50x50x50 mm were used while for concrete standard cubes 150x150x150 mm were used. The samples were prepared and tested according to Egyptian Code of Practice (ECP 203).

2.1. Phase (1) Mortar.

A normal mortar mix having a ratio of 1:3 cement to fine aggregate and the W/C used in this phase was 0.5. The materials were mixed according to the percentages by weight of each component. CBA and WGP were added as a percentage of cement weight. The percentages adopted in the research were 0%, 3%, 5% and 7%. The mortar cube samples were cured for 7days, 28days, and 56 days. The used materials are expected to have a pozzolanic effect, in which the reactive silica will react with the calcium hydroxide formed from the hydration of cement and convert it to calcium silicate hydrate and this process will occur only after the hydration of cement so it requires more time to take place and hence testing the samples at 56 day ages was selected to measure the long term effect of the pozzolanic materials.

2.3. Phase (2) concrete.

British method (DOE) was used to design the concrete mixture with a characteristic strength of 30 MPa. The W/C ratio was obtained to be 0.56. All the specimens were placed in the curing tank the next day of casting. The specimens were left in the air until the surface was dry to obtain Saturated Surface Dry (SSD) conditions during testing. Table 1 shows the concrete mix proportions for different concrete mixtures.

3. Materials

Crushed dolomite was used as coarse aggregates with a maximum size of 20mm and specific gravity of 2.58, while medium sand with fineness modulus of 2.76 was used as the fine aggregate.
CEM I 42.5 N was used as the binding material. Table 2 shows the XRF results for the chemical composition of the cement used.
Cattle Ribs bones were used as source for the cattle bone ashes utilized in the current study. The procedures used to prepare the CBA started by washing the cattle bones to obtain dirt-free bones, then the bones were left in direct sunlight for two weeks, after that the bones were burnt in the air then the ashes were placed in an oven with elevated temperature for 6 hours to ensure that the organic matter had completely been burnt and that was ensured as the black ash powder turned into a white powder. This process led to the loss of about 80% of the bone mass where the obtained ash represented only 20% of the mass of the dry bones before burning. The obtained ash was then ground in a small kitchen grinder. Only the CBA passing sieve 170 micrometer was used in the experimental program
Atomic Absorption spectroscopy (A.A.S) test was conducted on the obtained ashes to identify the oxide composition of the sample, specific surface area and specific gravity of the CBA were also determined.
Potable water free from acids, alkalis, salts, organic materials, and suspended substances, was used in concrete mixing and curing.
For the glass powder, glass was crushed and ground into powder form, then an air classifier and jet mill were applied with a grinding speed of 15,000 (rpm). This process produced a micro-sized glass powder, and in this way, the obtained material tends to have a pozzolanic activity [9, 14, and 23]. Otherwise, the (WGP) will act as filler. Glass powder was analyzed by using the X-Ray fluorescence (XRF) technique.

3.1. Chemical composition of CBA

Atomic Absorption spectroscopy (AAS) test was used to obtain the chemical composition of the CBA. The results of AAS analysis of CBA are shown in Table 3, where the total combined percentage of iron oxide, aluminum oxide, and silicon dioxide was found to be less than 70% (which is identified as the minimum required percentage by ASTM C 618 for a cementitious material to be regarded as pozzolanic material). Thus, the oxide composition of CBA was not satisfactory to act as a pozzolanic material; however, it can be regarded as a cementitious filler/additive considering its high content of CaO which was found to be 36.87% by weight. The specific gravity and specific surface area of CBA were measured to be 3.05 and 1927 cm^2/g respectively.

The chemical analysis of the CBA showed negligible silica oxide content and high calcium oxide content. That indicates the possibility of having pozzolanic activity, beside it might exhibit a binding property due to the high content of calcium oxide. CBA was thoroughly grinded to obtain particle sizes less than that of the cement so it can have the micro-filler effect.

3.2. Chemical and physical properties of WGP

The chemical composition of the glass powder sample is determined using the XRF technique. Table 4 shows the chemical composition of WGP. The glass powder samples were expected to show pozzolanic behavior as the summation of the oxides (SiO_2+Al_2O_3+Fe_2O_3) were more than 70%. The increased percentage of SiO_2 in the powder facilitates its reaction with calcium hydroxide $Ca(OH)_2$ resulted from the hydration of cement. The specific gravity and specific surface area of WGP were 2.39 and 2547 cm2/g respectively.

Table 1. Concrete Mix Proportions

	Coarse aggregate (kg/m3)	Fine aggregate (kg/m3)	Cement (kg/m3)	Water (kg/m3)	CBA (kg/m3)	WGP (kg/m3)
Control	1220	600	370	210	-	-
CBA 1%	1220	600	370	212.1	3.7	-
CBA 3%	1220	600	370	216.3	11.1	-
CBA 5%	1220	600	370	220.5	18.5	-
CBA 7%	1220	600	370	224.7	25.9	-
WGP 1%	1220	600	370	212.1	-	3.7
WGP 3%	1220	600	370	216.3	-	11.1
WGP 5%	1220	600	370	220.5	-	18.5
WGP 7%	1220	600	370	224.7	-	25.9
WGP 10%	1220	600	370	231.0	-	37
CBA 5% +WGP 7%	1220	600	370	235.2	18.5	25.9

Table 2. Chemical analysis of cement used (XRF Analyses)

Oxides	SiO2	Al2O3	Fe2O3	CaO	MgO	So3	Na2O	K2O	Total
Result%	21.2	4.67	5.05	64.73	1.5	2.05	0.3	0.22	99.8

Table 3 Chemical analysis of CBA (AAS Analyses)

oxides	SiO2	Fe2O3	Al2O3	CaO	MgO	K2O	Na2O
%(w/w)	0.07	0.28	0.91	36.87	0.85	0.17	1.23

Table 4 Chemical analysis of WGP (XRF Analyses)

oxides	SiO2	Fe2O3	Al2O3	Al2O3	CaO	MgO	K2O	Na2O	SO3	TiO2	ZrO2	LOI
%(w/w)	76.00	0.07	0.44	9.94	3.70	0.03	0.03	11.00	0.29	0.05	0.01	0.40

4. Results and discussion

4.1. Slump

Slump test was conducted on different concrete mixtures having various percentages of CBA, Table 5 shows the results obtained. The results show that the slump values were affected significantly by the variation of CBA percentages. There was no change in slump value at the 3% addition, but with increasing the addition ratios the slump increased significantly to reach a 20% increase at a 7% addition ratio. That can be attributed to the fact that the CBA particles had a lower specific surface area than that of the cement, as a result CBA will demand less water leading to the increase in slump

values. The slump test was carried out according to the Egyptian Code of Practice procedures (ECP 203-2018)

Table 6 shows the slump values for concrete mixes with different percentages of WGP. For the slump values, the results showed that by increasing the percentages of WGP, the concrete mixtures tends to be more workable. Similar results were obtained by other researchers [7, 9, and 12]. The increase in slump with increasing WGP content is due to the fact that the mixes became wetter and more workable as the WGP content increases. This may be attributed to the lower absorption of WGP compared to that of the cement. The maximum slump obtained was 75 mm at 10% WGP corresponding to 87.5% increase in slump compared to control mix.

Table 5 Slump values for concrete mixed with (CBA)

Concrete type	**CBA content (%)**	**Water/binder ratio**	**Slump (mm)**
Control	0%	0.56	40
Cattle Bone Ash (CBA)	3%	0.56	40
	5%	0.56	45
	7%	0.56	48

Table 6 Slump values for concrete mixed with (WGP)

Concrete type	**WGP content (%)**	**Water/binder ratio**	**Slump (mm)**
Control	0%	0.56	40
Glass Powder (WGP)	5%	0.56	45
	7%	0.56	45
	10%	0.56	75

4.2. Compressive strength of mortar mixed with WGP

The average compressive strength of mixtures with different percentages of (WGP) are presented in Figure 1. The results showed that the addition of WGP at low percentages (i.e less than 7%) reduced the compressive strength of mortar cubes at all ages. While for the 7 % and 10 % addition ratios, the compressive strength increased significantly especially at 56-day age as the increase in compressive strength was 12.4% and 22.4% respectively.

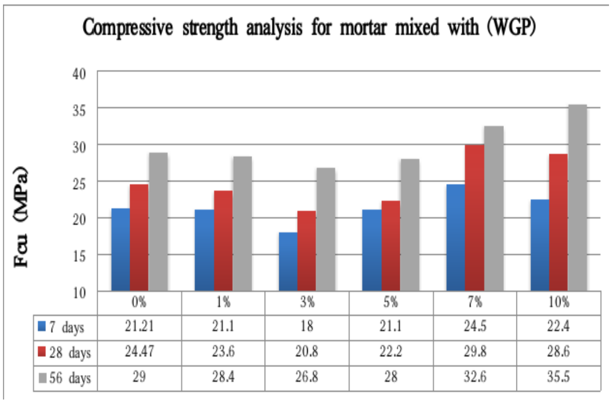

Figure 1: Compressive strength of mortar cubes with different WGP ratios (all ages).

4.3. Compressive strength of mortar mixed with CBA

Adding CBA to mortar pastes resulted in increasing the compressive strength for all addition percentages. The results showed that 5% addition ratio was the optimum ratio for all ages, Kotb et al. [24] obtained similar results where 5% addition ratio was the optimum ratio.

On the contrary to that of WGP, the use of CBA showed early strength gaining for the mortar samples when different addition ratios were used.

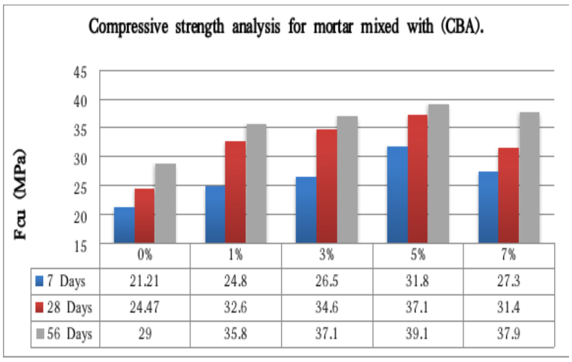

Figure 2: Compressive strength of mortar cubes with different CBA ratios (All ages).

4.4. Compressive strength of concrete mixed with WGP

When the WGP was used in concrete, the results showed that using 7% of WGP was the optimum addition ratio. Abraham et al. [20] showed that the optimum addition ratio of glass powder was 5% after which any more addition leads to the deterioration of the mechanical strength of concrete. Also, the rate of gaining strength at early ages was trivial (5% and 6% at 7-day and 28-day age, respectively, and became more significant (16%) at 56-day age. Similar observations were obtained by Sadiqul et al. [12] who showed that the effect of pozzolanic action of silica in glass powder occurred at late ages of concrete (90-day age and more) in both mortar and concrete mixes.

In this study, the optimum addition ratio for WGP is 10% in mortar mixes, while the optimum ratio is 7% in concrete mixes.

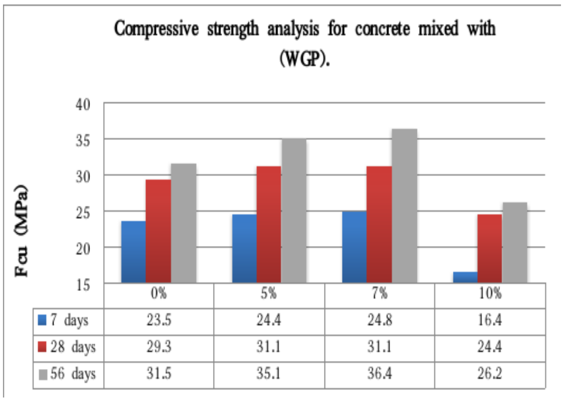

Figure 3: Compressive strength of Concrete cubes with different WGP ratios (All ages).

4.5. Compressive strength of concrete mixed with CBA

Depending on the results obtained from mortar cubes which showed that the highest compressive strength obtained was corresponding to 5% CBA addition, only 5% CBA addition ratio samples were tested at ages 7 days, 28-day, and 56 days ages while for the other two ratios (3% and 7%) specimens were only tested at 28 day age. The increase in compressive strength for the 5% CBA ratio was 20% increase, where 3% and 7% showed an increase of 12% and 7.5% respectively.

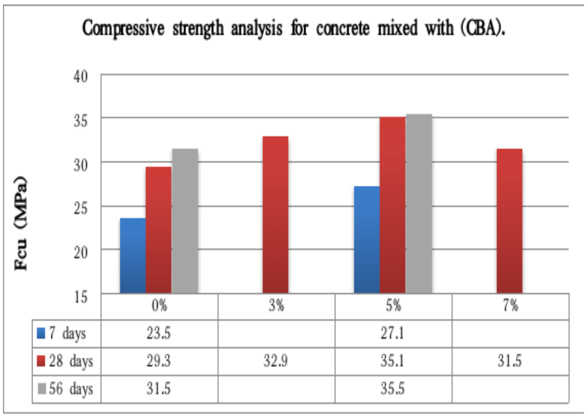

Figure 4: Compressive strength of Concrete cubes with different CBA ratios (at different ages).

4.6. Concrete mixed with (CBA) and (WGP)

To study the combined effect of using the CBA and WGP, another concrete mixture was examined including the optimum addition ratio of each material. Therefore, concrete mixed with CBA and WGP with addition ratios of (5% CBA) and (7% WGP) was tested to determine the compressive strength. The results show that the compressive strength for the mixed mixture was lower than that of control one at all ages, the reason can be clarified as that there is an optimum percentage of additives that should be added to concrete that leads to superior behavior of concrete, but when adding the two types of additives together, this ratio was surpassed and led to the degradation in compressive strength. On the other hand, the use of the two additions resulted in a significant increase in the workability as the slump obtained was 55 mm compared to the control one (40 mm). The increase in slump value is due to maintaining water/binder ratio constant, so when the masses of WGP and CBA were added to that of the cement and the mass of water was taken as a percentage of the combined masses of the three (Cement+WGP+CBA) that resulted into more workability of the concrete mix due to the lower absorption values of both glass powder and bone ash.

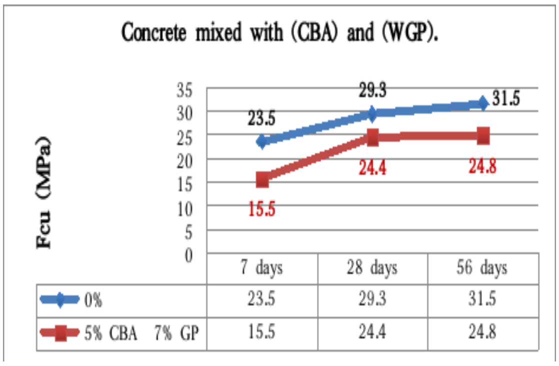

Figure 5: Compressive strength of Concrete cubes with WGP and CBA additions (All ages).

5. Conclusions

This study investigated the possibility of using Cattle Bone Ash (CBA) and Waste Glass Powder (WGP) as additives to mortar and concrete mixtures. The following conclusions were obtained:

1. The waste glass can be grounded to produce a powder that can be added to mortar/concrete mixtures to increase its compressive strength.
2. The amount of WGP and CBA additives can be taken as a percentage of weight of cement.
3. The optimum value for adding WGP is 10% in mortar mixtures and 7% in concrete mixtures.
4. The ashes of burning cattle bones can be used in mortar and concrete mixtures as it has significant effect on the compressive strength.
5. The optimum value of adding CBA was 5% for both mortar and concrete mixtures.
6. Materials containing calcium oxide has significant effect at early ages while the materials containing silica has significant effect on the long term.

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