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Use of coal fly ash to manufacture a corrosion resistant brick

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Abstract

In this article, we investigate the use of an environmental waste (coal fly ash) in the manufacture of an ammonium nitrate corrosion resistant brick. Ammonium nitrate (AN) fertilizer spillages and vapors continuously corrode the civil structures in a fertilizer manufacturing plant situated in Zimbabwe. This situation is a safety hazard to more than a hundred plant personnel and hence a priority area for research. Our experimental results show that addition of sodium silicate improved the performance of the brick. Water absorption of bricks generally decreased with an increase in the amount of sodium silicate added. Our results also show that the compressive strength generally increased with increase in amount of sodium silicate added and that the corrosion resistance increases with the amount of sodium silicate added to the coal ash bricks.

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Keywords: Corrosion resistance bricks; coal fly ash; clay

1. Main text

In this article, we investigate the use of an environmental waste (coal fly ash) in the manufacture of an ammonium nitrate corrosion resistant brick. Ammonium nitrate (AN) fertilizer spillages and vapors continuously corrode the civil structures in a fertilizer manufacturing plant situated in Zimbabwe. This situation is a safety hazard to more than a hundred plant personnel and hence a priority area for research. Our experimental results show that addition of sodium silicate improved the performance of the brick. Water absorption of bricks generally decreased with an increase in the amount of sodium silicate added. Our results also show that the compressive strength generally increased with increase in amount of sodium silicate added and that the corrosion resistance increases with the amount of sodium silicate added to the coal ash bricks.

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Fig. 1. Corrosion effects of Ammonium Nitrate on (a) plant floors (b) concrete bases supporting heavy machinery.

The combustion of coal gives result to desired products as well as a solid waste material. The solid combustion waste material consists of fine (fly) ash as well as the coarser ash that falls to the bottom of the furnace. Fly ash is the lightweight particles in the flue gas that exits the furnace and moves away from the high-temperature combustion zone. The particles are fine-grained, typically silt-sized, ranging from 1 to 100 microns in diameter, with median particle diameter of 20 to 25 microns (American Coal Ash Association, 2003). The fly ash that was employed in this investigation was obtained from particulate collection devices in the boiler that produces steam which is used in the plant.

Fly ash contains different minerals like Ca, K, Mg, Mn and P which are essential for plant growth (Ahmaruzzaman, 2010) as well as trace elements like As, B, Hg, Pb and Se (Xu et al., 2003) and oxides of silica, aluminum and ferrites which are raw materials of brick manufacture. The trace elements in coal ash like As, Hg, Se have detrimental health and environmental effects (Mguni, 2015). Despite the dangers posed on the environment and health, several studies have found some beneficial industrial uses of the coal ash, hence effective ways of disposing it. Although fly ash is an environmental pollutant it can be used in the construction industry (Ahmaruzzan, 2010; Kula et al., 2001; Mguni et al., 2016; Pairsh, 2002; Pan et al., 2014) and in the synthesis of zeolites (Mondragon et al., 1990). Kayali (2005) manufactured high performance bricks (with high compressive strength, higher modulus of rapture and lower absorption capacity) from 100% fly ash which were lighter than clay bricks.

Sodium silicate binder can be used as a cement sealant, providing chemical and physical durability to concrete surfaces. The potential use of silicate as a binder will produce bricks which are resistant to nitric acid and nitrous derivatives, as silicates can only be destructed by hydrofluoric acid and its derivatives (Merrill, 1945). Panda et al (2012) observed increased compressive strength with addition of sodium silicate. In this project coal ash which is a byproduct of the steam producing plant used in this plant was utilized as a supply of raw materials for brick synthesis; hence providing a safe way of its disposal.

2. The brick making process

All Clay is a major raw material in the brick manufacturing process. Clay is made up of alumina and silica, in which the latter component acts as a flux that promotes fusion of the particles at lower temperatures and determines the color of the product brick. The shape and size of the brick can be formed in three ways namely: extrusion, molding and dry-pressing (Brick Industry Association, 2006).

The brick manufacturing process (Figure 2) is mainly done in five steps which include raw materials preparation, brick forming, drying, firing and cooling and finished products storage (Brick Industry Association, 2006).

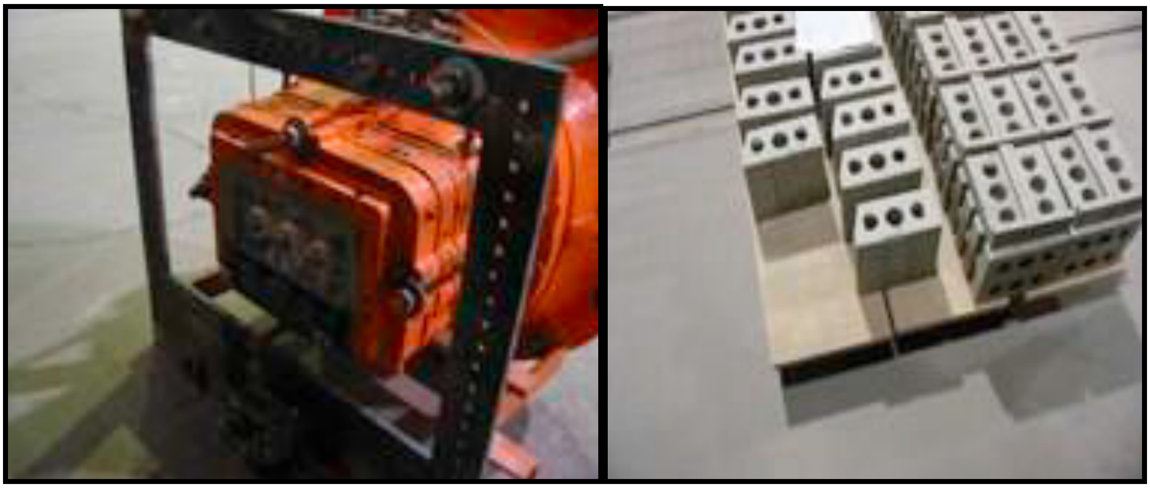


Fig. 2. The brick manufacturing process

3. Experimental procedure

3.1 Sampling

Fly ash was collected from the boilers used to provide steam within the plant. The coal ash was thoroughly mixed in order to obtain homogenous and representative samples. Using the standard cone and quartering method, the ash was poured onto a polythene sheet and made into a conical heap. The heap was flattened down to two thirds its height and then divided it into quarters. Two opposite quarters were extracted and the remaining two returned into the original batch. The extracted quarters were remixed and formed into a conical heap. The procedure was repeated with reduction in size until the required mass of 100 g was obtained for sieve analysis. (1)

3.2 Sample preparation

Sieves were arranged in descending order of the apertures from top (250 μm) to bottom (75 μm) and the stack of sieves was placed on a pan and then sieve shaker. A standard sieving procedure was then followed in which a timer was set at 15 minutes to allow all material to be classified. After sieving, the top sieve was removed and the material retained was transferred into a bowl. The underside of the sieve is gently brushed to remove near size material. The procedure is repeated with a time of 25 minutes.

3.3 Synthesis of sodium silicate solution from Silica gel and Sodium Hydroxide.

Sodium silicate was synthesized by reacting silica gel with sodium hydroxide, 20 g of NaOH pellets were placed in a beaker and dissolved in 50 ml distilled water and the solution was heated. Sodium hydroxide reacts with silicon dioxide according to the equation:

$$2NaOH + SiO_2 = Na_2SiO_3 + H_2O \quad (1)$$

30g of silica gel was weighed and added into the hot NaOH solution slowly, allowing the solution to boil whilst stirring until the silica gel dissolved and a sticky solution was observed.

3.4 Brick manufacturing

Fly ash was mixed manually in a pan with water in varying proportions. A solution of sodium silicate was then added and mixed thoroughly. Water was then added to the required proportion and mixing done to enable molding. The mixture was then placed into a brick molder machine, where the bricks were pressed manually and then released onto wooden pallets with polythene sheet on top for drying. A small molding machine producing prisms of average size; length= 100 mm, width = 50 mm and height = 35mm was used.

The bricks were dried using heat from the sun whilst spraying/sprinkling water three times a day for 3-5 days to maintain optimum moisture content and water absorption by cement. The process was repeated varying the amounts of sodium silicate. The bricks for each set of proportions were then heated at 250°C to achieve high strength and completely drive out all water from the silicate. Water absorption, compressive strength and corrosion resistance tests were performed on the synthesized bricks.

3.5 Water absorption capacity

The bricks of different sodium silicate concentrations and different solid proportions were heated at a temperature of 105°C to 115°C until they attained substantially constant mass. They were then allowed to cool to room temperature. The bricks were weighed in their dry cool condition to obtain mass M1. All bricks were fully immersed in 25 litres of fresh water at about 27°C for 24 hours. After 24 hours of immersion the bricks were taken out from water and wiped out with cloth. In their wet condition, the bricks were weighed to obtain mass M2. The difference between weights is the water absorbed by brick given by: Water absorbed = M2-M1. The percentage of water absorption was then calculated. The less water absorbed by brick the greater its quality. Good quality bricks do not absorb more than 20% water of its own weight (Mohan et al., 2016).

Water absorption, % by mass, after 24 hours immersion in cold water as shown in equation 2:

$$W = \frac{M2 - M1}{M1} x100$$

3.6 Compression test

Compression tests for the bricks were carried out at Road lab in Bulawayo. These tests (also called the crushing strength of bricks) were done according to the standard loading rate of concrete testing and cement products- SANS 5863. Figure 3 shows a brick under compression. The strength at which the bricks under compression crushed was noted and recorded.

Fig. 3. Brick compression tests

On testing the bricks for compression, the cube sizes (100 mm x 50 mm x 40 mm) were considered together with their masses in order to make use of the appropriate loading rate (88 kN/min) and appropriate conversion factor (4.8 for the synthesized coal ash bricks) from kilo-Newton to Mega-Pascal. A brick specimen was put on a crushing machine and pressure applied onto it until it broke. The ultimate pressure/load at which brick was crushed was taken into account.

3.7 Ammonium nitrate corrosion resistance

All bricks of known concentration of the silicate were weighed and the masses recorded before tests were made. Ammonium nitrate prills were dissolved in distilled water to make up a 50% solution. The solution was heated until all the prills dissolved and some of the water was driven off to form a thick solution. The bricks were immersed into the solution for two hours to allow total exposure to the Ammonium nitrate. The bricks were then taken out after 2 hours and placed in an oven at 80°C for 23 days. They were then removed and washed in water. Mass changes, physical appearance as well as texture were noted after the test period.

4. Results and discussion

The synthesized bricks with varying amounts of cement, coal ash, sand and sodium silicate are shown in Figure 4.

Fig. 4. Sodium silicate treated coal ash brick

Table 1 shows the XRF analysis of coal fly ash. The characteristics of fly ash show over 55% of SiO_2 and over 28% Al_2O_3 which are raw materials for brick manufacture.

	Al_2O_3	BaO	CaO	Cr_2O_3	Fe_2O_3	K_2O	MgO	Na_2O	P_2O_5	SiO_2	TiO_2
1.	28.77	0.11	0.32	0.02	0.53	2.77	0.74	0.72	0.07	64.34	1.53
2.	29.28	0.12	0.31	0.02	1.43	2.92	0.48	0.49	0.06	62.76	1.62
3.	28.03	0.12	4.13	0.03	2.40	0.60	0.14	0.34	0.73	60.16	1.67
4.	30.63	0.13	3.57	0.03	3.23	0.72	0.09	0.34	1.02	57.94	1.87
5.	32.12	0.15	3.81	0.03	2.22	0.72	0.12	0.36	1.12	55.57	2.13
6.	28.39	0.12	3.63	0.03	2.56	0.74	0.18	0.37	0.81	58.15	1.69
7.	33.20	0.14	3.84	0.03	3.31	0.66	0.16	0.42	1.42	58.90	1.98
8.	33.37	0.14	3.97	0.03	2.71	0.72	0.16	0.40	1.14	56.13	2.06
9.	30.62	0.13	3.37	0.03	2.74	0.65	0.15	0.37	1.14	56.04	1.86

4. 1 Water absorption

Figures 5a, b and c show results of the water absorption tests for the bricks. The amount of water absorbed by the bricks after 24 hours generally decreased with an increase in the amount of sodium silicate added. The percentage water absorbed by these bricks ranges from 23.05% to 15.87%, with the bricks treated with 25 ml sodium silicate having the least percentage.

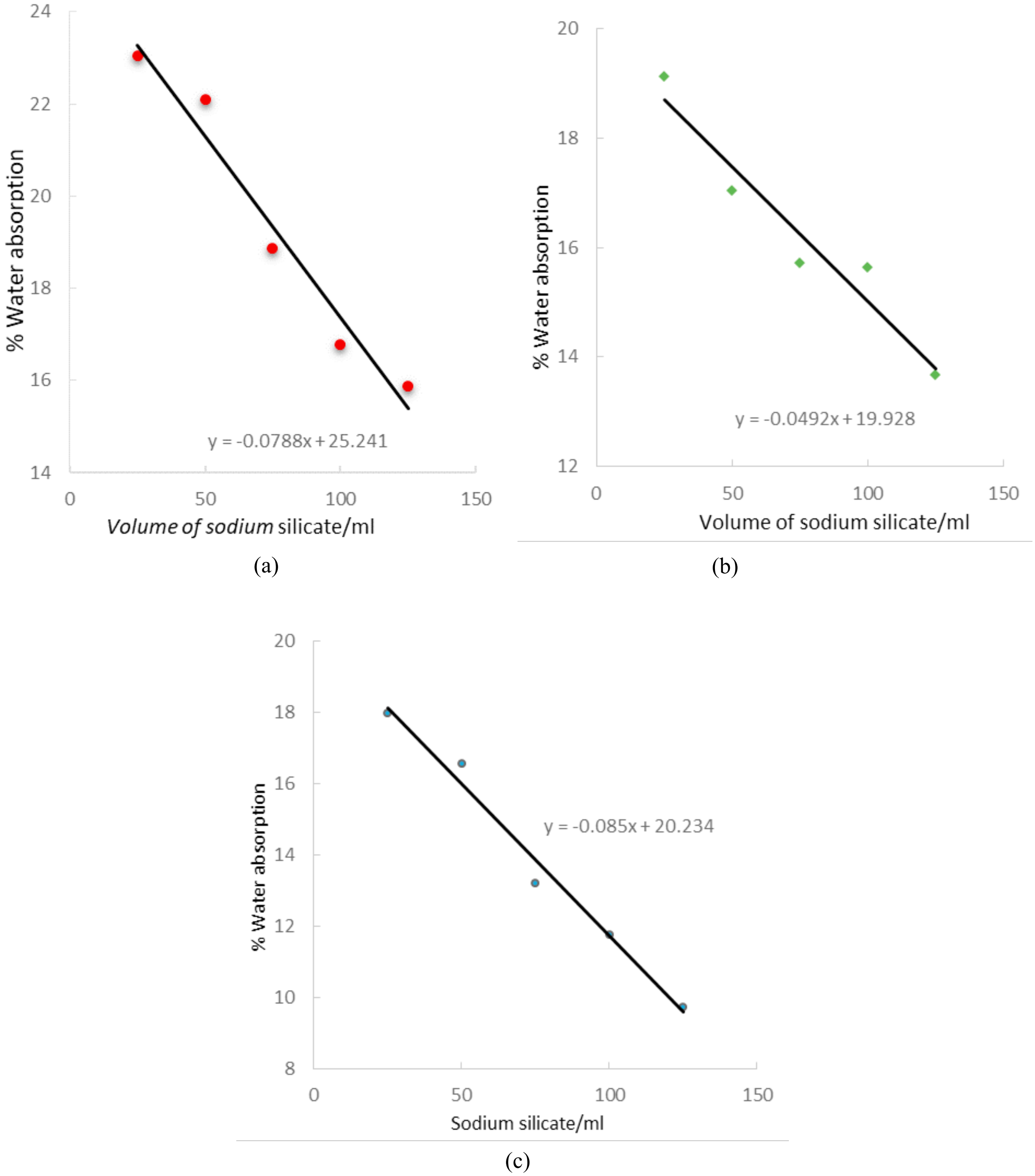
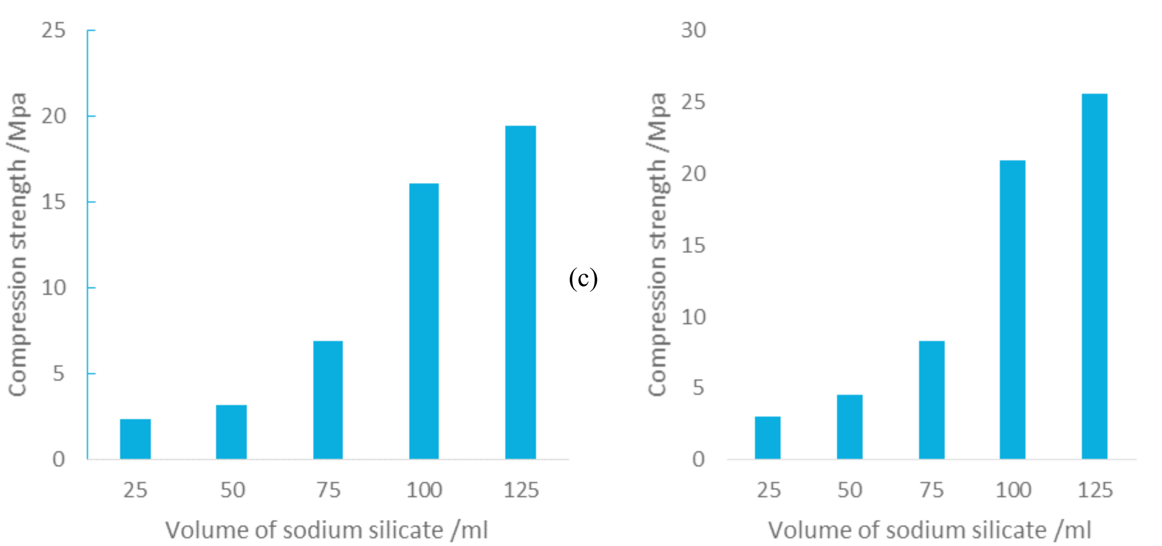


Fig. 5. Water absorption capacity test (a) 40% fly ash, 40% sand, and 20% cement (b) 30% fly ash, 50% sand and 20% cement (c) 30% fly ash, 40% sand and 30% cement

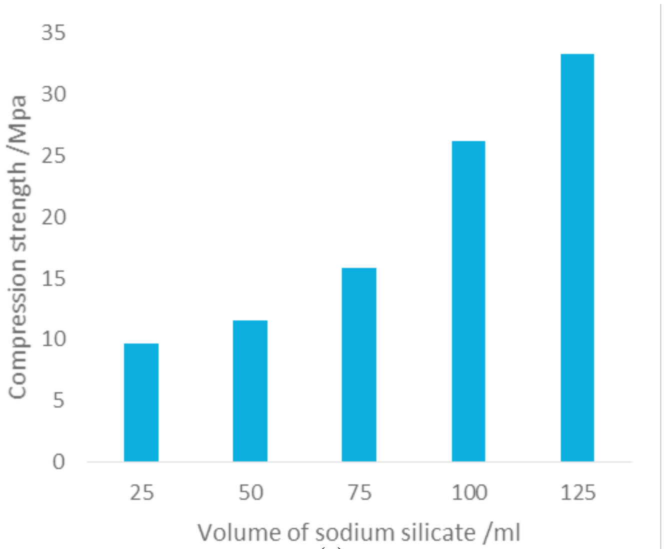
A different set of results was obtained for the water absorption test for the bricks with 30% fly ash, 50% sand and 20% cement. From the results, the percentage water absorbed generally decreases with an increase in the volume of sodium silicate added. The percent water absorbed ranges from 19.13 to 13.68 with the bricks treated with 125 ml silicate having the lowest percentage of water absorption. The bricks generally absorbed less water compared to those described earlier above. Shown in the figure above is a plot graph of water absorption against volume of sodium silicate added.

4.2 Compression tests

The different amounts of pressures that could be handled by the 5 different bricks under compression are shown in Figures 6a, b and c. The compressive strength increases with an increase in the amount of sodium silicate. The 255 gram brick containing 25 ml of sodium silicate crushed at a pressure of 2.33 Mega Pascal. The strongest, treated with 125 ml of sodium silicate crushed at a pressure of 19.46 Mega Pascal.



(a) (b)



(c)

Fig. 6. Compression (a) 40% fly ash, 40% sand and 20% cement (b) 30% fly ash, 50% sand and 20% cement (c) 30% fly ash, 40% sand and 30% cement

The bricks of the highest sand proportion of 50% showed high strength when put under compression (Figure 6b). The strengths were relatively higher than those of corresponding bricks of the same silicate volume made from 20% cement. The presence of a higher proportion of the sand solids increased strength due to the ordered packing arrangement of the sand particles within the structure. Generally, the strength increases with the volume of sodium silicate binder in contact with the aggregates. The brick treated with 25 ml of sodium silicate had the lowest compressive strength of 3.04 MPa while those of 125ml Silicate crushed at 25.56 MPa.
For the bricks with the amount of cement from 20% to 30% and sand lowered from 50% to 40%, silicate volumes were maintained. The bricks also showed an increase in strength with increase in volume of sodium silicate. The highest compressive strength obtained was 32.29 Mpa for the brick treated with 125 ml sodium silicate (Figure 6c). The bricks generally showed greatest strength compared to the corresponding bricks of the same silicate volume. At 25ml of sodium silicate binder, a compressive 9.67 Mpa was obtained, which is greater that of all the other bricks of different aggregate proportions treated with the same silicate volume.

4.3 Ammonium nitrate corrosion

After 23 days of exposure of the bricks to the ammonium nitrate and heating in the oven, the appearance of the bricks was as shown in Figure 7.

Fig. 7. Appearance of bricks with low sodium silicate content after exposure to ammonium nitrate

Bricks with low sodium silicate showed a significant increase in mass as shown in Figures 8a, b and c. The low silicate bricks had a mass change of 9.46% on testing. A yellowish permanent stain caused by the exposure to ammonium nitrate appeared on the surface. The bricks had weakened and allowed ammonium nitrate to enter into the spaces within the solid resulting in increase in mass. The interaction resulted in degradation of the bricks and poor appearance even after rinsing and drying of the bricks. The bricks had a strong pungent smell of ammonia. High sodium silicate bricks were least affected by ammonium nitrate as indicated in Figures 8a, b and c, showing a 0.29% mass change after the test period.

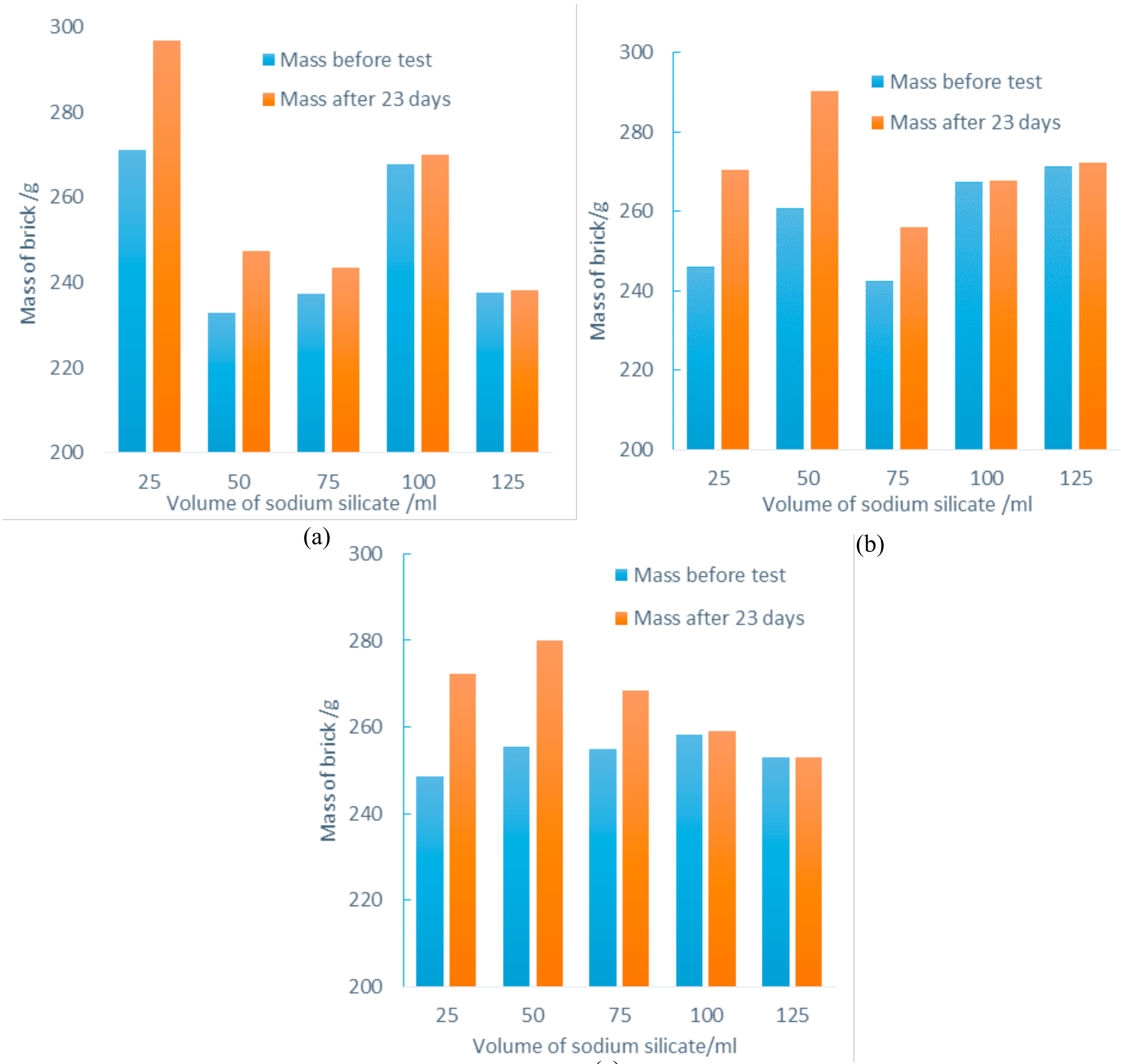


Fig 8: Corrosion test (a) 40% fly ash, 40% sand and 20% cement (b) 30% fly ash, 50% sand and 20% cement (c) 30% fly ash, 40% sand and 30% cement

The bricks with low sodium silicate were also affected most by ammonium nitrate with % mass increase of 11.35% for a brick with 50ml (Figure 8). Very low percentage increase (0.03%) was obtained for the brick treated with 100 ml sodium silicate. The bricks with higher sodium silicate still maintained their original texture while those with low silicate showed clear signs of disintegration. There was no significant increase in mass in the 125 ml sodium silicate bricks as well as no observable visual corrosion effects shown in Figures 8a, b and c. The bricks with low sodium silicate showed high mass increase and degradation effects after the tests.

5. Conclusion

Our experimental results show that addition of sodium silicate improved the performance of the brick. Water absorption of bricks generally decreased with an increase in the amount of sodium silicate added. Our results also show that the compressive strength generally increased with increase in amount of sodium silicate added. Sodium silicate had the desired effect of agglomerating the particles, with the enhanced help of cement resulting in higher bonding strength with increased volume of the silicate. An increase of sand ratio in the solid aggregates enhances better packing of the solids within the structure hence increased strength. The fine coal ash particles fill in to the small spaces between the sand resulting also in a compact structure that enhances strength.

Our experimental results further showed that corrosion resistance increases with the amount of sodium silicate added to the coal ash bricks. The soluble sodium silicate reacts with other metal ions present in coal ash to form the corresponding insoluble metal silicates. The sodium silicate brick can then be used to arrest the corrosion effects of ammonium nitrate fertilizer at the ammonium nitrate fertilizer synthesis plant.

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