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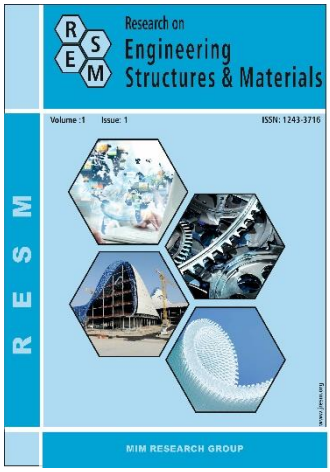

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Research Article

Physico-mechanical and corrosion behavior of acid resistant bricks developed from quarry waste silicate residues using powder metallurgy

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Abstract

The disposal of industrial wastes comprises one of the major worldwide environmental problems as these wastes render the environment unfriendly. The growing demand for waste utilization has made solid wastes- like materials from granite processing industry, and sand to be absorbed into the ceramic composition of bricks. The possibility of reduction in production costs provides a strong logic for use of these wastes. In this work, attempt was made to develop acid resistant bricks from quarry fine waste residues (stone dust, kaolin and sand). In order to investigate the possibility of producing acid resistant bricks, nine suggested batches, namely, A1, A2, A3, A4, A5, B1, B2, B3 and B4, were composed for this present study. These mixtures were composed of 40 wt% of Kaolin fine residue with 10-50 wt% of stone dust and silica sand; and 50 wt% of Kaolin fine residue with 10-40 wt% of stone dust and silica sand respectively. The bodies made with the variation of raw materials were sintered at 970^0C and their behaviors with respect to apparent porosity, water absorption, bulk density, firing volume changes, compressive strength and acid resistance as a function of temperature, stone dust and sand was studied. It was observed that most of the developed brick samples showed excellent results in both HCl and H_2SO_4 media in accordance with IS: 4860-1968 and ESS:41-1986.

1. Introduction

The disposal of wastes from industrial sectors constitutes one of the major worldwide environmental problems over the past few decades. In several countries, the usual practice has been dumping of these wastes to land filled. However, as a result of limitations in number of dumping sites and the general methods of disposal has rendered the environment unfriendly. As a result, there have been recent interests in waste utilization (waste recycling) as a consequence of environmental and financial considerations.

Recycling of wastes resulting from industries as a substitute material is not a new development and has been successfully carried out. The growing demand for optimum productivity globally has resulted into fast depletion of available natural resources and at the same time leading to the generation of high volume of rejects [1]. The main attention on utilization of wastes is as a result of depletion of our natural resources, preservation of non-renewable resources and reduction in the cost of wastes disposal. The utilization of wastes as a substitute to raw materials in the ceramic industry, which embodies part of the construction industry, offers an immense contribution to the diversification of raw materials in the manufacture of ceramic tiles and bricks, and lowers the cost in a building [2-3]. The recycling of granite wastes in ceramic industry has drawn attention technologically in recent years due to the possibility of costs reduction in production, and investigations concerning the utilization of stone wastes in the production of glass-

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ceramic, porcelain bodies, tiles and bricks have been reported [4-6]. On the other hand, quarrying of crushed kaolin and granite aggregates often produces considerable volumes of quarry fines referred to as quarry dust (stone dust) and filler grade. The fine fraction of aggregates products (stone dust) is usually lower than 5mm in size. When the quarry fines consist of grade mixture of coarse, medium and fine sand size particles, plus clay fraction of less than 0.075mm, it can be described as filler grade [7].

Acid resistant sewage bricks have been investigated by [8], wherein it was reported that local Egyptian siliceous clay alongside granite waste dust were used as the starting materials and sintered at temperature range of 1100^0C-1175^0C. it was observed that the bodies exhibited a relatively high cold crushing strength in the range of 74-124MPa and better corrosion resistance in acids with weight loss in the range of 0.22 and 0.64% which were in conformity with Egyptian standards. [4] Also carried out an investigation on the characterization of ceramic bricks and tiles, where in granite waste dust was used as a substitute to ceramic materials. This work reportedly produced bricks and tiles comprising of waste materials and ceramic materials and was concluded that the ceramic bodies met the technological characteristics of the Brazilian standards. [9] Studied the resistant of bricks to the action of chemicals; where in Kaolin fine quarry residue, granite fine quarry residue and granulated blast furnace slag were composed utilized as raw materials; the study focus on producing bricks that are resistant to sewage waters and possessing quality properties than the conventional bricks. [10] Studied the production of bricks from blending various industrial wastes with clay. The study attempt to determine the effects of the waste additions on the physical and mechanical properties of the developed bricks.

In this present work, attempt is made on the recycling feasibility of kaolin fine quarry residue, quarry stone dust and silica sand to produce a special class of brick that is resistant to chemical attacks of acids and sewage waters with good technological properties and at relatively low cost.

2. Materials and Methods

2.1. Sourcing of the Raw Materials

In this work, the raw materials used were kaolin fine quarry residue, quarry stone dust and silica sand which were locally sourced for and taken through beneficiation route to remove associated impurities.

2.2. Preparation of China Clay (Kaolin)

The collected kaolin fine quarry residue was first crushed into powdery form and soaked inside a soaking pit for five days. The soaked clay was later poured on a clean flat surface for the removal of excess water which took about one week. The clay was later dried inside an oven at 110^0C for further drying; the dried clay was then milled for further reduction in size particle and sieve through a 75μm mesh to obtain fine pieces of about 2-3 inches.

2.3. Preparation of Quarry Dust

The collected quarry residue from quarry site was first broken into smaller pieces with the use of a hammer. The broken quarry resides were then fed into jaw crusher to obtain 2-3 inches pieces required for ball milling operation. The quarry residues were then ball milled to obtain fine powder which was later sieved through a 75 μm mesh.

2.4. Preparation of Silica Sand

The collected silica sand was already in the loose form, which only required ball milling operation. The sand was fed into a ball mill and milled to obtain fine silica sand (sand dust) which was then sieved through a 75μm mesh.

The chemical composition of the quarry residues taken into consideration is shown in Table 1 below:

Table 1. Chemical composition of the materials taken into consideration [9, 14]

	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	Na_2O	K_2O	TiO_2	Loss of Ignition
Kaolin	53.92	26.76	1.75	1.37	0.32	0.16	0.04	2.09	11.95
Quarry Dust	62.48	18.72	4.83	6.54	2.56	Nil	3.18	1.21	0.48
Silica Sand	80.78	10.52	3.21	1.75	0.77	1.37	1.23	Nil	0.37

2.5. Body Formulation and Sample Preparation

In order to investigate the possibility of producing the acid resistant bricks, Nine (9) suggested batches, namely, A_1, A_2, A_3, A_4, A_5, B_1, B_2, B_3 and B_4, were composed for this present study as shown in the Table 2. These mixtures composed of 40 wt% of Kaolin fine residue with 10-50 wt% of stone dust and silica sand; and 50 wt% of Kaolin fine residue with 10-40 wt% of stone dust and silica sand.

Table 2. Body Formulation

	Composition (wt %)		
Batches	Kaolin	Silica Sand	Quarry Dust
A_1	40	10	50
A_2	40	20	40
A_3	40	30	30
A_4	40	40	20
A_5	40	50	10
B_1	50	10	40
B_2	50	20	30
B_3	50	30	20
B_4	50	40	10

The raw material was ground into fine powder form and mixed in different proportion to obtain different ratio of the samples. Powders were dry mixed in different compositions to make a dry mix. The batches were dry mixed in a mortar pestle to ensure homogenization. The Samples of each batch were prepared by uniaxial pressing machine with little amount water of (<5%). Samples were dried at a room temperature and were later sintered in a furnace at 970°C.

2.6. Tests

2.6.1. Apparent porosity test

The porosity of the fired test samples from each batch composition was determined by boiling method as stated by [11]. Test samples were dried in an oven at 110^0C to obtain a constant weight 'D'. The samples were then suspended in a beaker containing distilled water and boiled for two hours, cooled to room temperature and weighed to obtain weight 'S'. The specimen was later removed from the water and weighed to obtain a saturated weight 'W'. The apparent porosity was determined using:

$$\text{Apparent Porosity} = \frac{\text{W}-\text{D}}{\text{W}-\text{S}}\ X\ 100 \tag{1}$$

Where, W = saturated weight, D = dry weight, and S = suspended weight.

2.6.2. Bulk density

The bulk density of the fired test samples from each batch composition was also determined using the boiling method according to [11]. The fired samples were oven dried at 110˚C, and transferred into a beaker containing distilled water to boil for two hours in order to assist in releasing entrapped air. It was then allowed to soak and the saturated weight void of excess water was taken. The bulk density was afterward determined using:

$$\text{Bulk Density} = \frac{\text{D}}{\text{W}-\text{S}}\ \text{X}\ \rho\text{w} \tag{2}$$

Where, D = dry weight, W = saturated weight, S = suspended weight, and ρw = water density.

2.6.3. Water Absorption

Water Absorption (W.A) was calculated for the following samples using the Archimedes' principle. The weights of the sintered products were taken (dry weight, D) and then this was followed by soaking the samples in water, after which the soaked weight (W) of the samples was measured. The water absorption was then determined using the formula:

$$\%\text{water absorption} = \frac{W-D}{D}\ X\ 100 \tag{3}$$

Where, W = soaked weight and D = dry weight.

2.6.4. Firing shrinkage test

The dimensions of the sample prior to firing were measured and the volume was calculated. After firing the dimensions of the samples was measured again and the final volume was calculated. The firing shrinkage was determined using the formula:

$$\%\ \text{firing shrinkage} = \frac{Vi-Vf}{Vi}\ X\ 100 \tag{4}$$

Where, V_i = initial volume before firing and V_f = volume after firing.

2.6.5. Compressive Strength

This test is essential as it can be used to assure the engineering quality in the application of building materials. In this each sample is kept in such a way that it can roll along its thickness. The samples were made to stand and pressure is applied to it, and the force at

which it breaks or cracks was then noted. However, prior to it, the thickness and the diameter are measured and noted down. To find the compressive strength we use the formula:

$$\text{Compressive strength} = \frac{2 \times P}{\pi d t} \quad (5)$$

Where, P = Load on the material, d = diameter of the sample, and t = thickness/height of the sample.

2.6.6. Acid Mass Loss

10% by volume of HCl and Sulphuric acid (H_2SO_4) was prepared (100 ml) in a beaker. The dry weight of the samples was noted. The samples were lowered into the beaker containing each acid respectively and kept inside the beaker for 48 hours. After 48 hours, the samples were taken out and the mass noted.

$$\text{Acid mass loss (\%)} = \frac{Mi - Mf}{Mi} X\ 100 \quad (6)$$

Where, Mi = Initial Mass, and Mf= Mass after being dipped in acid.

Fig. 1. Soaked samples in acid

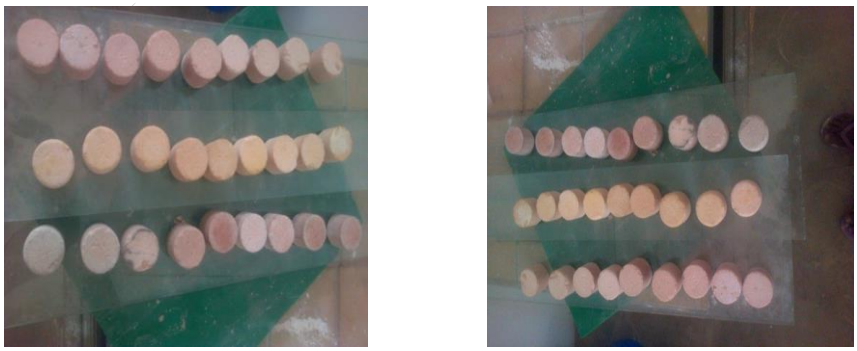

Fig. 2. Samples after Acid Reaction for 48hours

3. Results and Discussion

3.1. Apparent Porosity

It could be observed from figure 3 that the apparent porosity of the fired acid resistant bricks was quite high except for sample A_2 with the least apparent porosity of 7.66%. However, samples A_3, A_4, A_5, B_1, B_2 and B_4 still fall within the tolerable range of apparent porosity of 10-30% [12]. This can be attributable to the sintering temperature since proper vitrification of glassy phase in the materials mostly occurs at elevated temperature above 1000^0C which lowers porosity [9].

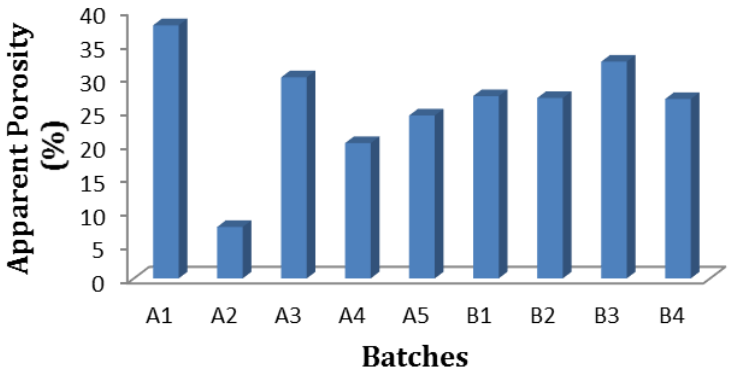

Fig. 3. Apparent porosity

3.2. Bulk Density

Figure 4 shows the bulk density of the fired acid resistible brick samples. It can be seen from the figure that the developed acid resistant bricks exhibited low bulk density which may be attributed to the level of vitrification attained at the sintering temperature (970^0C), at high temperature, vitrification increases leading to increase in bulk density [13].

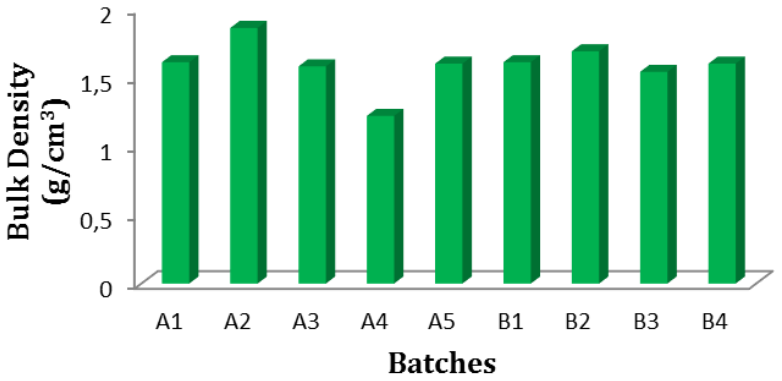

Fig. 4. Bulk density of the bricks

3.3. Water Absorption

Figure 5 shows the water absorption of the fired acid resistible brick samples. It can be observed that only sample A_2 meet the requirement for water absorption according to [14] while the other samples were of high water absorption this might be attributable to the sintering temperature (970^0C) used as it has been proven that at high sintering temperature water absorption reduces as glassier phase is formed at higher sintering temperature [9].

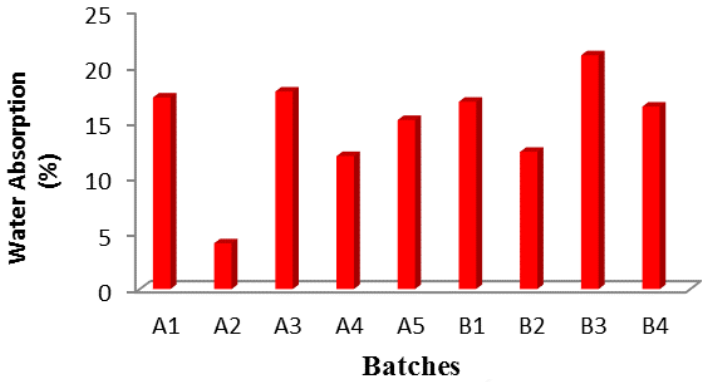

Fig. 5. Water absorption

3.4. Volume Shrinkage

The result of the volume shrinkage after firing is shown in figure 6. It can be observed that all the developed acid resistible bricks have high volume shrinkage; however this is still in acceptance with respect to previous work [13].

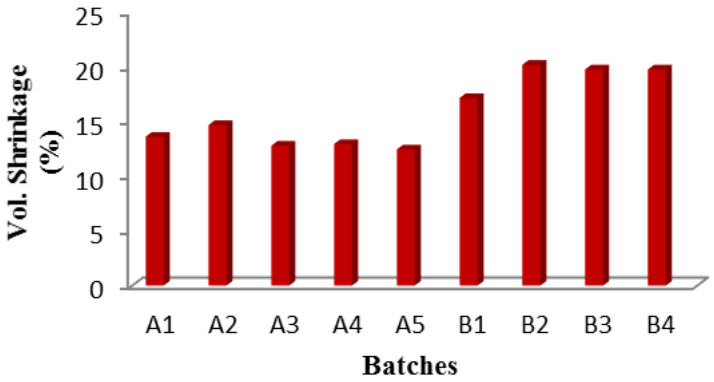

Fig. 6. Volume shrinkage

3.5. Compressive Strength

The compression test is the most important test that can be utilized to assure the engineering quality in the application of building materials. Figure 7 reports the variations of strengths as a function of the silica sand: stone dust ratio and clay amount in the samples

formulated sintered at 970^{0}C. The results show that strength values of samples A_3, A_4, B_1 and B_2 which are found to be quite high in the range of 10-15 MPa [13].

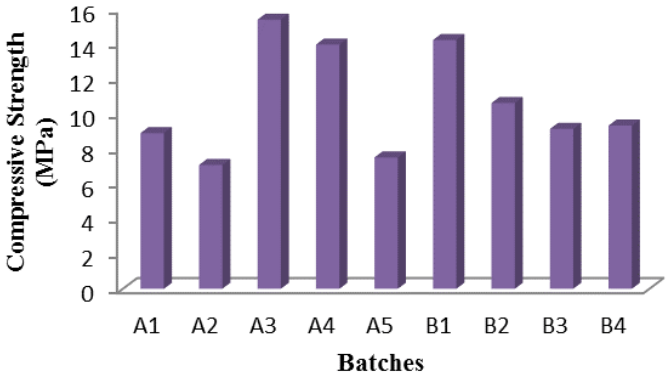

Fig. 7. Compressive strength

3.6 Acid Mass Loss

Figures 8 and 9 show the variation of resistance of the brick samples sintered at 970^{0}C to acid attack both in hydrochloric acid and sulphuric acid soaked for 48 hours. From figure 8, it can be deduced that both samples A_5 and B_3 failed the ESS: 41-1986 requirement of <3.5% in HCl, however, sample B_3 can still be used in area not prone to frequent spillage or attack of acid as stated by IS: 4860-1968 requirement of not exceeding 4%. It can also be deduced from the figure 8 that percentage acid mass loss increases with decrease in stone dust content for 40% clay while for 50% clay; there is decrease only in % acid mass loss for B_1 and B_2. In figure 9, all the samples performed better in sulphuric acid according to stipulated requirement by ESS: 41-1986 except for sample A_3 with high value of 5.84%. Increase in % acid mass loss with decrease in stone dust content can also be observed for both 40% and 50% clay content.

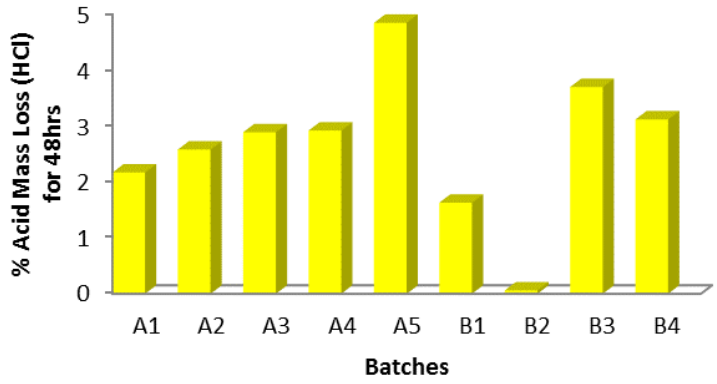

Fig. 8. Acid mass loss of bricks in HCl

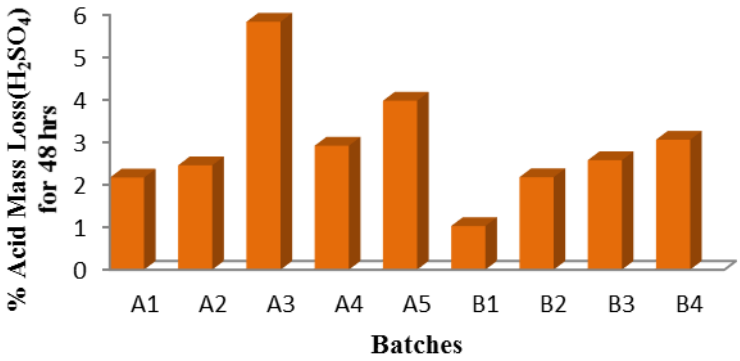

Fig. 9. Acid mass loss of bricks in H_2SO_4

4.0. Conclusion

The following conclusion can be drawn within the limit of this work:

- All the developed acid resistant bricks performed excellently well in both hydrochloric and sulphuric acid environment according to ESS 41:1986
- All the developed sample bricks showed high percentage of porosity, water absorption and volume shrinkage with low bulk density which may be attributed to the sintering temperature as proper glassy phase are ensured at more elevated temperature above 970^0C used.
- The samples showed promising results if further work can be carried out at a higher sintering temperature.

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