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Research Paper

Replacement of Sand with Bauxite Mining Waste in Concrete Production

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ABSTRACT

The use of natural sand as fine aggregate in concrete is becoming problematic due to scarcity and pressure on mining of the resource. Alternate sources such as the use of industrial waste as replacement of natural sand in concrete are gaining popularity as a sustainable construction material. The aim of this study is to examine the possibility of using bauxite mining waste as a fine aggregate replacement for concrete production. The quantities of sand replaced with bauxite mining waste used are 0, 25, 50, 75 and 100%. Cube, cylinder and beam specimens were molded and cured for 7, 14, 21 and 28 days, and tested for density, compressive strength, tensile splitting strength and flexural strength. The study found that there was a slight increase in density of bauxite mining waste produced concrete over the control as the quantity of bauxite residue increased. The study further revealed a significant increase in compressive, tensile splitting and flexural strengths of the concrete produced with bauxite residue as compared with the control, with an increase between 60.3 and 65.5%. Additionally, a good correlation was established between the bauxite contents and the density of concrete produced with bauxite mining waste, recording R^2 values between 0.9749 and 0.9896. The 100% bauxite residue replacement of sand obtained the highest strength properties in the concrete. The study, therefore, concludes that it is feasible to use bauxite mining waste as a fine aggregate replacement in concrete production. It is recommended that further studies should be conducted on the durability and chemical properties of concrete produced with bauxite mining waste as the current study only focused on the strength properties.

1 Introduction

The availability of sand for the production of concrete is becoming scarce due to the extensive methods of mining from the pit site [1]. Where conventional aggregates are scarce or the cost of haulage is very high such that they are rendered uneconomical, other known hard materials have been successfully used to produce concrete [2]. Therefore, using industrial waste as alternative sources for replacement of sand appears to be a subject that is gaining popularity all over the world. Industrial waste materials can be used as alternative sources in concrete as they can assist in solving some environmental

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concerns, decrease the problem of waste disposal and reduce the intensive use of energy and natural resources [3]. This helps in promoting sustainable advancement in the construction industry.

Sustainability is a global concern and hence the goal of humankind should be to create a sustainable world [4]. In order to achieve sustainable construction, methods to be employed should include effective utilization of available resources for a prolonged period of time, minimization of material waste, energy and controlling overuse, and ensuring that there are reserves kept for future generations without complete exhaustion [5]. The environmental imbalance has created a situation for people to focus on the adoption of new technologies and environmentally preferable materials, which will not only preserve the natural resources but also create a productive environment in which human and nature can exist in harmony [6].

Bauxite waste is a by-product from the Bayer alumina production process. According to Snars Gilkes and Wong [7], for every tonne of alumina produced there are between 0.3 and 2.5 tonnes of bauxite residue produced which depend on the type and grade of bauxite, while the physical and chemical characteristics of the residue depend mostly on the nature of the processing procedure. It is worth noting that as the demand for alumina and aluminium products keeps surging, bauxite waste will increase. In Ghana, the Bauxite Company at Awaso have large quantities of bauxite mining waste produced each year and requires a significant allocation of resources to ensure proper disposal. The use of bauxite mining waste in concrete production has the potential in alleviating the improper disposal of industrial waste and hence reduces environmental pollution.

The rapid increase in construction activities has led to acute shortage and expensive cost of conventional construction materials [8]. Studies have reported the use of industrial waste as fine aggregate such as red sand, sheet glass powder, copper slag, quarry dust, glass and fly ash, red mud-clay, steel slag, ground granulated blast furnace slag [1, 9-14]. All these studies showed an improvement in the use of industrial waste as a fine aggregate replacement in concrete. Bauxite mining waste is another potential industrial waste material that has not received much attention in terms of research. Therefore, this study seeks to investigate the possibility of using bauxite residue as a fine aggregate replacement for concrete production. A study by Mpae [15] on “utilization of tailings residue as partial replacement of sand in blocks” recommended that future works should look into the use of bauxite residue as a replacement for concrete and mortar production. There is, therefore, the need also to examine the possibility of using bauxite mining waste as a fine aggregate replacement for concrete production. The aim of this study is to examine the possibility of using bauxite mining waste as a fine aggregate replacement for concrete production.

2 Experimental Materials and Methods

2.1 Materials

The materials used for the experiments include bauxite mining waste, fine aggregate (sand), coarse aggregate (gravel), cement and water. The bauxite mining waste used was obtained from the waste dumping site of Ghana Bauxite Company at Awaso in the Western Region, Ghana. The sand used was obtained from a pit that conforms to the requirements of BS EN 12620 [16]. The chemical composition and *pH* of the bauxite mining waste and the sand were determined in accordance with the BS EN 13037 [17]. The obtained results are presented in Table 1.

Table 1 - Chemical composition and *pH* of bauxite mining waste and sand.

Chemical Composition/ <i>pH</i>	Bauxite mining waste	Sand
Aluminium Oxide (Al ₂ O ₃)	51.07	0.57
Iron Oxide (Fe ₂ O ₃)	7.15	0.80
Titanium Dioxide (TiO ₂)	1.77	0.55
Silica (SiO ₂)	2.27	55.12
Sodium Oxide (Na ₂ O)	2.84	0.11
Calcium Oxide (CaO)	1.07	0.02
Loss of ignition (LOI)	33.9	0.29
<i>pH</i> Value	10.28	6.33

It can be observed that the bauxite mining waste contains high oxide content, especially with the aluminium oxide (Al_2O_3), which has a potential of impacting on the properties of the concrete. The gravels used were crushed granite with a nominal maximum size of 14 mm and were obtained from a local quarry site at Sunyani in the Brong Ahafo Region, Ghana. Ordinary Portland cement (Type I) of grade 42.5R produced by Ghacem was used. Water from Ghana Water Company Limited (GWCL) was used for mixing the concrete.

2.2 Methods

2.2.1 Preparation of Concrete and Specimens

Batching of materials was done by weight using an electronic weighing balance with the mix ratio of 1:2:4 (cement: fine aggregate: coarse aggregate) and the water-cement ratio of 0.6. The quantity of sand replaced with bauxite mining waste (mix designs) used are 0, 25, 50, 75 and 100%. The concrete was manually mixed. The fine aggregate (sand and/or bauxite mining waste required) was first batched and spread on the platform; the required cement quantity was added and mixed to obtain a uniform color before the required quantity of coarse aggregate added. The materials were mixed thoroughly after which the required quantity of water was added. Further mixing was done until a homogeneous mix was achieved. Different mix designs were prepared in accordance with the bauxite replacement contents as shown in Table 2. The specimens were molded immediately after mixing the concrete. Each specimen was cast and compacted manually. Cube ($150 \times 150 \times 150$ mm), cylinder (150 mm diameter \times 300 mm length) and beam ($150 \times 150 \times 450$ mm) specimens were molded. The cubes were used for testing density and compressive strength, the cylinders for tensile splitting strength, and beams for flexural strength of the concrete. After 24hrs of curing, the specimens were de-molded and were subjected to immersed water curing (see Figure 1) in accordance with BS EN 12390-7 [18]. The specimens were subjected to 7, 14, 21 and 28 days curing before testing.

Table 2 - Mix design details.

Mix Design	Mix Ratio	W/C Ratio (Vol.)	Cement (kg)	Fine Aggregate		Coarse Aggregate (kg)
				Sand (kg)	Bauxite mining waste (kg)	
B1 0%	1:2:4	0.60	10	20	–	40
B2 25%	1:2:4	0.60	10	15	5	40
B3 50%	1:2:4	0.60	10	10	10	40
B4 75%	1:2:4	0.60	10	5	15	40
B5 100%	1:2:4	0.60	10	–	20	40



Fig. 1 - Specimens in curing tank.

2.2.2 Testing of Specimens

The tests conducted on the specimens are dry density, compressive strength, tensile splitting strength and flexural strength. The dry density of the specimens was determined in accordance with BS EN 12390-7 [18]. The specimens were weighed to obtain their weights and the volumes calculated to determine the density. Three replicates from each mix design were used and their averages computed to determine the density of the concrete. Compressive strength test was conducted in accordance with BS EN 12390-3 [19]. The specimens were placed in CONTROLS 50-C46G2 test machine with a maximum capacity of 2000 kN (see Figure 2), and the load applied gradually at a uniform rate until the specimens failed. Five replicates from each mix design were tested at 7, 14, 21 and 28 days of curing.



Fig. 2 - Compressive strength test set-up.

The tensile splitting strength test was conducted in accordance with BS EN 12390-6 [20], using CONTROLS 50-C46G2 test machine with a maximum capacity of 2000 kN (see Figure 3). Five replicates from each mix design were tested at 7, 14, 21 and 28 days of curing.



Fig. 3 - Tensile splitting strength test set-up.

Testing for flexural strength was also conducted in accordance with BS EN 12390-5 [21]. Each beam was loaded with a central-point load located at mid-span and on top of the beam, whilst the bottom face was supported on two simply supported ends with different shear spans (Figure 4). Five replicates from each mix design were tested at 7, 14, 21 and 28 days of curing.



Fig. 4 - Flexural (3-point load) strength test set-up.

2.2.3 Statistical Analysis

Correlation tests were carried out to determine the relationships between some of the tests performed. ANOVA tests at 95% confidence interval were used to determine significant difference and variation between the test results.

3 Results and Discussion

3.1 Density of concrete

The density test results of the specimens are presented in Figure 5.

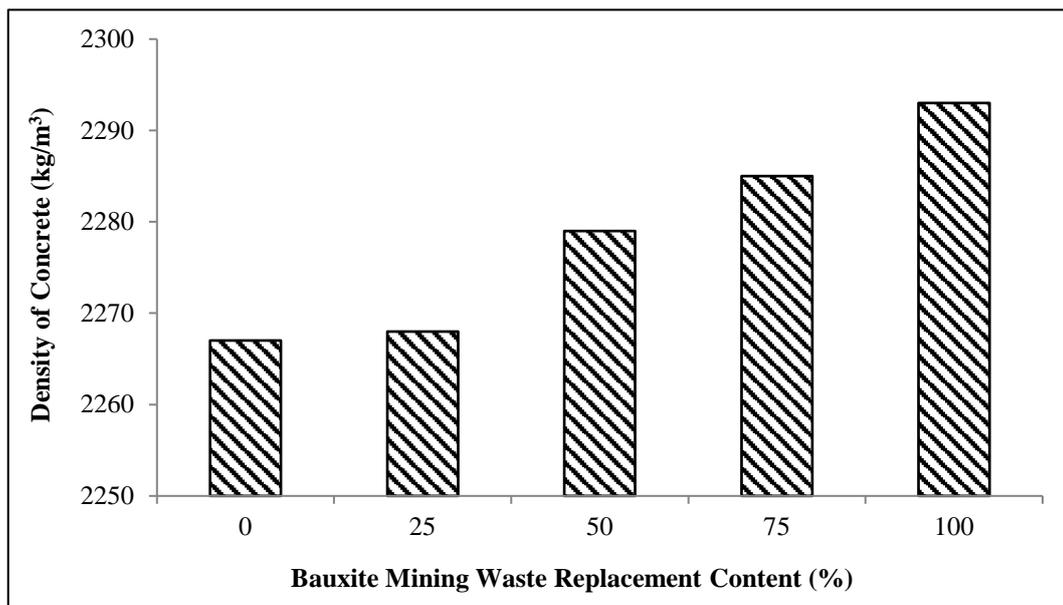


Fig. 5 - Density of concrete

The 100% bauxite mining waste placement achieved the highest density followed by 75%, 50%, 25% and 0% with average values of 2293, 2285, 2279, 2268 and 2267 kg/m³ respectively. They show a close related average density among the different proportions between 2267 and 2293 kg/m³. This indicates that the higher the bauxite content in the concrete the better the density. This also means that the specific mass to the volume of the bauxite mining waste is higher than that of the pitted sand that it replaced. The result is in line with the results obtained by earlier studies [15, 22-23]. However, the ANOVA test conducted between the 0 and 100% bauxite mining waste content values obtained a *p*-value of 0.284, indicating that there is no significant difference between the density values.

3.2 Compressive strength of concrete

Figure 6 shows the average compressive strength test results. The results show that the highest compressive strength of 25.2 N/mm² was obtained from 100% bauxite mining waste replacement at 28 days, which represent an increase of 65.5% over the 0% (control mix) at 28 days of 16.5 N/mm². It can also be observed that all the bauxite mining waste replacement concrete mixes recorded improved compressive strength over the control mix. A similar study on bauxite mining waste as a fine aggregate replacement was reported by [24], where the specimens were subjected to 28 days curing recorded strength of between 10 and 36 MPa. The increase in strength is attributed to the high presence of Al₂O₃ and Fe₂O₃ as well as some silica as they contribute to the production of cement clinker. Deshmukh and Sarode [25] attribute the increased strength to the presence of alumina, silica ferrous oxide and the binding properties due to the presence of calcium oxide that helps bauxite mining waste to develop higher strength in concrete. Furthermore, it can be seen that the higher the bauxite mining waste content in the concrete the better the compressive strength. ANOVA test result between the 0 and 100% bauxite mining waste content recorded a *p*-value of 0.01, implying a significant difference for the compressive strength. Correlation test result between the compressive strength and the density of the concrete at 28 days is shown in Figure 7. It can clearly be seen that there is a very strong positive relationship between the compressive strength and the density of the concrete. The coefficients determination (*R*²) recorded is 0.9749, meaning the increased compressive strength of the bauxite mining waste replacement concrete can be attributed to the increased density of the concrete. The result is similar to the results obtained by Raheem et al. [23] and Danso et al. [26]. This aligns with Walker [27] observation that a given increase in density will result in a greater increase in strength.

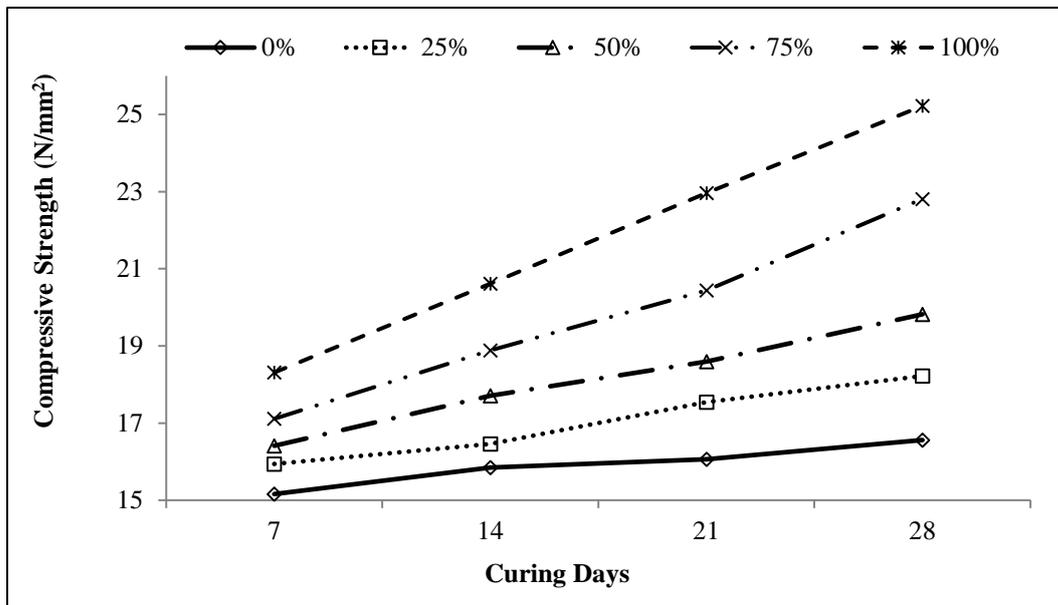


Fig. 6 - Compressive strength of concrete

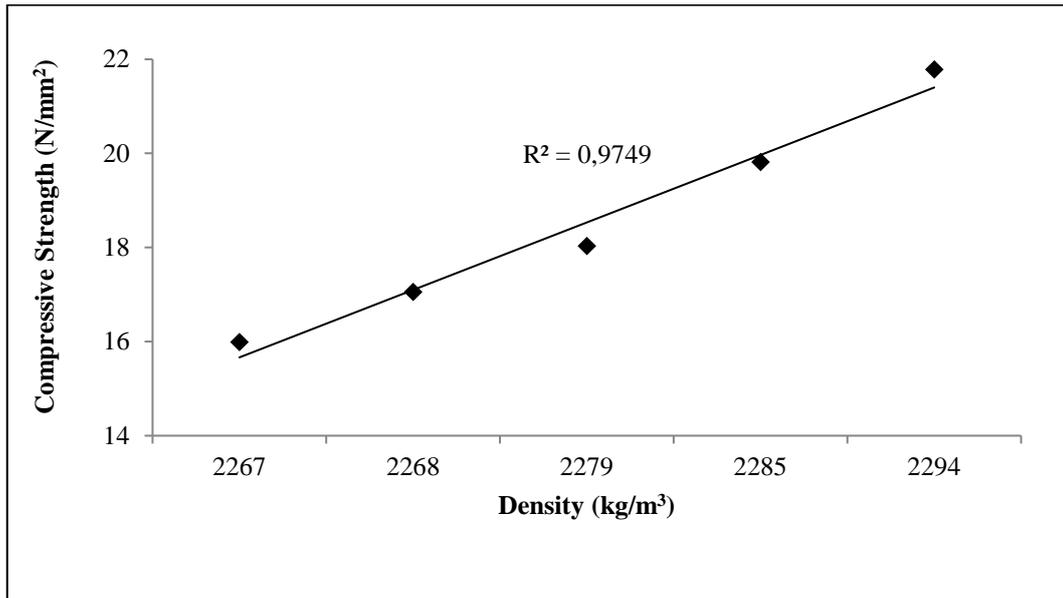


Fig. 7 - Relationship between compressive strength and density of concrete

3.3 Tensile splitting strength of concrete

The summary of the tensile splitting strength test result is presented in Figure 8. The result is similar to the compressive strength result. It shows that the highest tensile strength (6 N/mm²) was observed from 100% replacement of bauxite mining waste at 28 days of curing as compared to the control specimens' strength of 3.5 N/mm², which represents a total of 62.3% increase in strength. Furthermore, all the bauxite mining waste concrete mixes also showed tensile splitting strength values higher than the control mix. This result is consistent with the results obtained by Divakar et al. [24] and Sakthivel et al. [5]. The increase in tensile splitting strength after replacement of sand with varying proportion of bauxite mining waste is mainly attributed to the chemical composition and the mineral formation of the bauxite mining waste. The ANOVA test result between the 0 and 100% bauxite mining waste content yielded a significant difference ($p = 0.01$) for the tensile strength values. Correlation test result between the tensile splitting strength and the density of the concrete at 28 days is shown in Figure 9. This suggests a very strong positive relationship between the tensile splitting strength and the density of the concrete. The R^2 value of 0.9834 recorded implies that the increased tensile splitting strength of the bauxite mining waste replacement concrete can be attributed to the increased density of the concrete as was also in the case of the compressive strength.

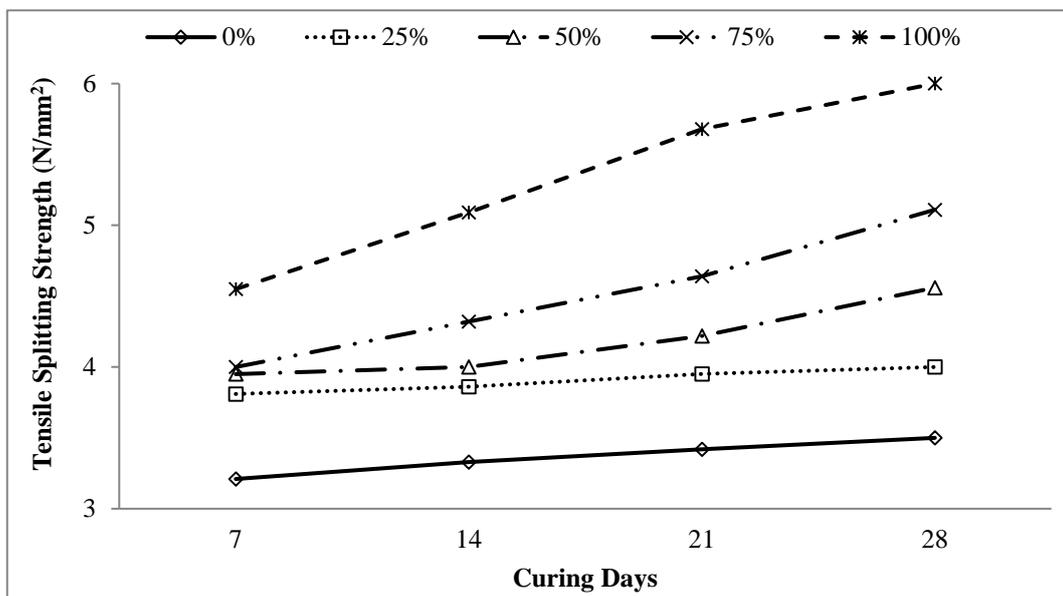


Fig. 8 - Tensile splitting strength of concrete

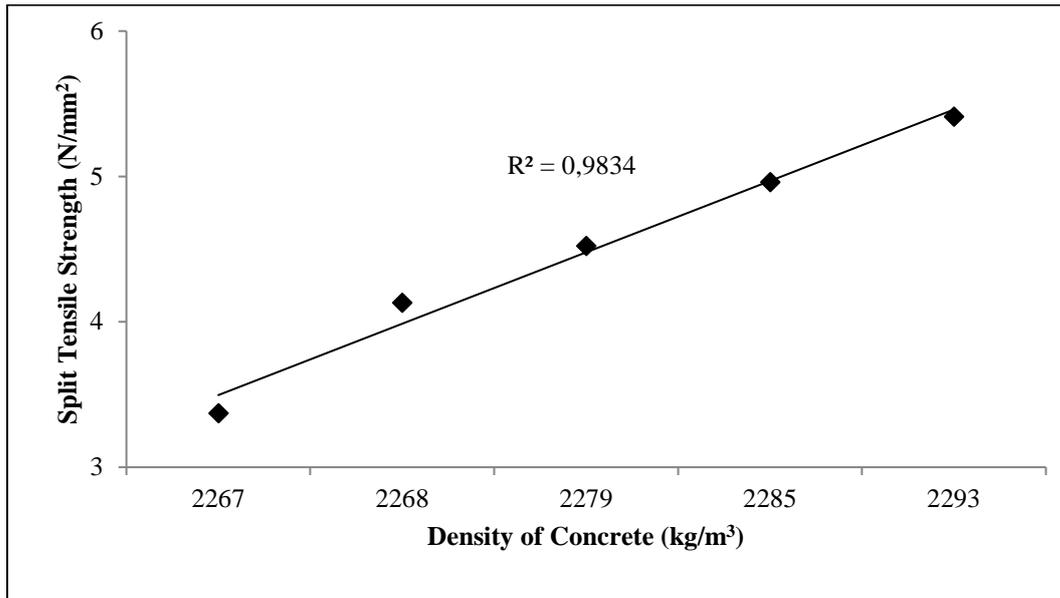


Fig. 9 - Relationship between tensile splitting strength and density of concrete

3.4 Flexural strength of concrete

Figure 10 shows the flexural strength test result. It follows a similar trend to that of the compressive strength and tensile splitting strength. The flexural strengths increase as the bauxite mining waste mix proportion increased. The results show that the highest flexural strength value of 4.84 N/mm² was obtained from 100% replacement at 28 days, which represent an increase of 60.3% over the control mix. The result aligns with the results obtained from previous studies [5, 25, 28]. The increase in flexural strength after replacement of sand with varying proportion of bauxite mining waste can be associated with the tensile strength, and therefore attributed to the high presence of Fe₂O₃ and Al₂O₃. Shihab [29] associated the increased flexural strength to the bauxite mining waste particles, which are inherently rigid, and thus influence the rigidity of the composite as a whole. As expected, all the bauxite mining waste concrete mixes showed flexural strength values that are higher than that of the control mix. The recorded *p*-value of 0.01 indicates a very strong positive relationship between the flexural strength and the density of the concrete. The R² value of 0.9896 recorded (see Figure 11), suggests that the increased flexural strength of the bauxite mining waste replacement concrete can be associated with the increased density of the concrete as was also in the case of the compressive strength and tensile splitting strength.

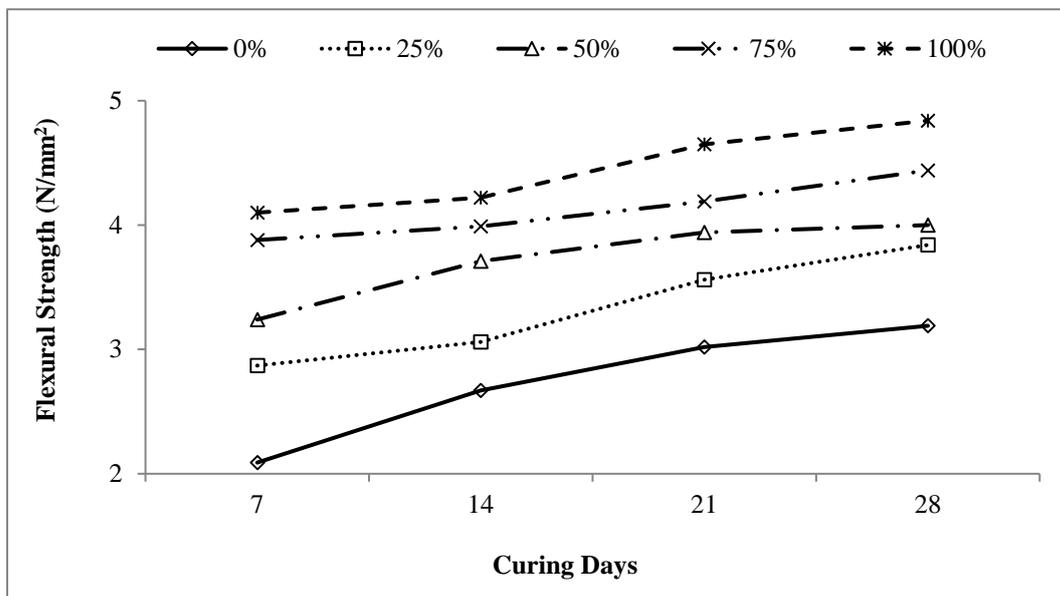


Fig. 10 - Flexural strength of concrete

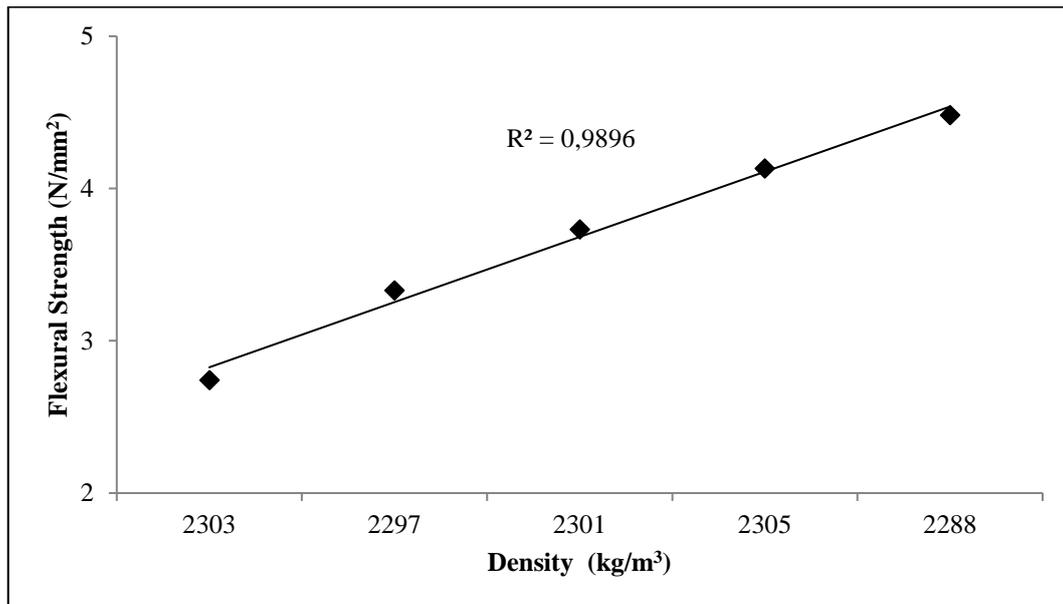


Fig. 11 - Relationship between flexural strength and density of concrete

4 Conclusion

The aim of this study was to examine the possibility of using bauxite mining waste as a fine aggregate replacement for concrete production. This is important as there is increased pressure on the demand for pit sand for the production of concrete. The study found that there was a slight increase in density of bauxite mining waste produced concrete over the control as the quantity of bauxite mining waste increase. The study further revealed a significant increase in compressive, tensile splitting and flexural strengths of the concrete produced with bauxite mining waste as compared with the control, with an increase between 60.3 and 65.5%. Additionally, a good relationship was established between the test types (compressive strength, tensile strength and flexural strength) and the density of concrete produced with bauxite mining waste, recording R^2 values between 0.9749 and 0.9896. The 100% bauxite mining waste replacement of sand obtained the highest strength properties in the concrete. From the foregoing, the study concludes that it is feasible to use bauxite mining waste as a fine aggregate replacement for concrete production. The study, therefore, recommends further studies to be conducted on the durability and chemical properties of concrete produced with bauxite mining waste as the current study only focused on the strength properties. In addition, future studies on the environmental effect of bauxite mining waste are recommended.

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