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Recycling Billet Scales as Fine Aggregate in Concrete Production

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Abstract: Billet scales are by-products from steel rolling mills in Nigeria that presently constitute environmental pollution. This paper reports studies carried out using these solid wastes as a partial replacement for sand in the production of concrete. Various percentages of billet scales were used in a concrete mixture of 1: 2: 4 by weight to cast concrete specimens. The compressive and tensile strengths developed were tested after 7, 14, 21, and 28 days of curing. The result of the compressive and splitting tensile strengths tests indicated that concrete strength increased with curing age. The compressive strength of 0%, and 15% replacement of sand with billet scales as obtained at 28 days are 26.0N/mm^2, 26.2N/mm^2. 15% optimal replacement of sand with billet scales had similar results as the control mixture of 0%, which could be used in reinforced concrete structures. Other replacements could be useful as mass concrete for non-structural construction applications.

Keywords: billet scales, soil pollution, erosion control, solid waste management.

Introduction

It is a known fact that the incessant generation of solid waste materials presents a serious environmental problem. For this reason it is very important to study and develop any technology, procedure or method that may help to exploit their use efficiently [1]. The high cost of building materials in Nigeria has made affordable housing out of reach of the average citizen of the country. This difficulty has lead to inward sourcing of some local wastes as alternatives to conventional materials in the construction industry. Concrete is a widely used construction material and its use cut across all the fields of civil engineering: structural, geotechnical, environmental, transportation, and highway engineering. This is because it is a very strong and durable construction material that can be formed into various shapes and sizes ranging from simple rectangular shapes to curved domes and shells [2]. Sand obtained naturally from stream deposits is most satisfactory for use as fine aggregate in concrete production, because individual particles are rounded while weaker materials are removed by abrasion. Natural rocks make very good aggregates due to their hardness and toughness [3].

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The necessity for earth-based materials leads to resource depletion, environmental degradation, and energy consumption. In Nigeria, sand and other materials for construction are mined from riverbeds and hillsides to service construction industry leaving mines areas un-reclaimed. Environmental degradation accompanies such mining activities with air pollution and remains after the mines cease operations, leaves scars on the landscape, and negative effects on surface waters and groundwater. Consequently, it is desirable that there should be major emphasis on the use of post-consumer wastes and industrial by-products (secondary materials) in cement and concrete production. According to McEntire [4], such materials can be substituted for natural aggregate materials in construction applications, to achieve acceptable performance properties. With the on-going current economic reform programmes and privatization of public industries in Nigeria the five steel rolling mills in the country are expected to produce up to capacity. This would result in production of more billet scale wastes creating more environmental pollution. This paper examined the potential use of billet scales as fine aggregates in concrete, billet scales are complex iron oxide formed on the steel surface during hot rolling operation or formed on steel parts that are heat treated in the presence of oxygen [5].

Materials and Methods

The billet scales used for this work were sourced from Osogbo Steel Rolling Company, Osogbo, Nigeria. Tests carried out include: Sieve analysis, Specific gravity, Moisture content, Slump test for the concrete mix. Sieve analysis was to determine the proportion of different particles sizes of sand and billet scales to compare their classification in compliance with BS882 [6] requirement that gave a range of 0.075mm – 4.75mm for fine aggregates, the grading curves for sand, billet scales and granite are presented in Figures 1, 2, and 3 respectively. Table 1 presents specific gravity and moisture content results. Specific gravity that was to compare sand with billet scales and moisture contents were determined in order to calculate water/cement ratio. Water/cement ratio used for different percentage of sand replacement by billet scales 0%, 15%, 30%, 45%, 60%, and 75% respectively are 0.65, 0.64, 0.63, 0.62, 0.61 while the slump for the mixes are 45mm, 44mm, 46mm, 45mm and 48mm respectively.

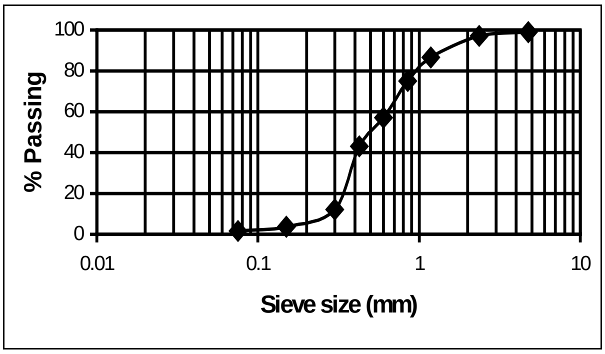

Fig. 1. Fine Aggregates (Sand) grading curve

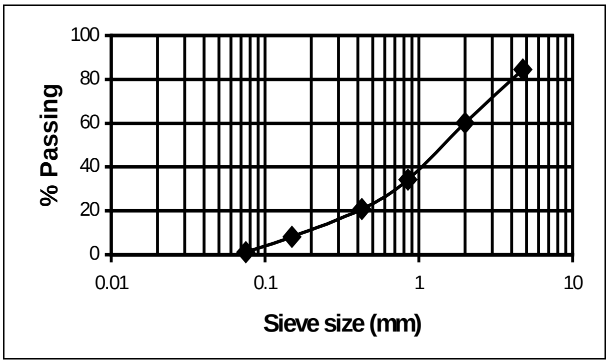

Fig. 2. Billet Scales grading curve

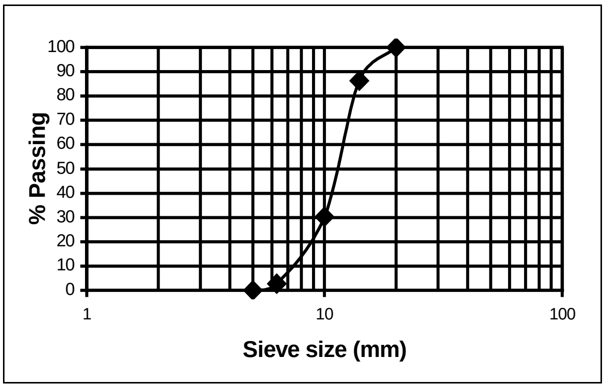

Fig. 3. Granite (coarse aggregate) grading curve

Table 1. Results of preliminary tests

Test	Result for Sand	Result for Billet scales
Specific gravity	2.60	2.63
Moisture Content	0.17%	0.47%

The mix proportion used is 1: 2: 4 by weight. The percentage replacement of sand by billet scales was in the range of 15%, 30%, 45%, 60%, and 75% as fine aggregate. Total replacement of fine aggregates with billet scale was not experimented because billet scales is a metal based waste material, with the need to be mixed with naturally occurring material (sand). Freshly mixed concrete was cast into 150 x 150 x 150 mm cubic moulds and 150mm (diameter) x 300mm (height) mould moulds and left for 24 hours before they were removed and placed in a water tank for curing. Compressive and splitting tensile tests of the specimen were carried out at 7, 14, 21, and 28 days in accordance with BS8110 [7] and Reynolds and Stedman [8].

The concrete specimens were also tested for electrical conductivity was carried out to check possibility of electrical conductivity of the concrete material. A digital multi-meter was used to check for this property. Magnet was moved against the concrete to assess magnetic property for different percentage replacements of sand with billet scales. This test for the magnetic property of the concrete was to observe the response of the concrete specimens to magnetic substances. Test for corrosion of concrete was conducted by leaving crushed concrete specimens in the open air of rain and sunshine for four months.

Results

The results of compressive and splitting tensile tests are presented in Figures 4, 5, and 6. Compressive strengths after 28 days curing for 0%, 15%, 30%, 45%, 60%, and 75% replacements of sand with billet scales are 26.0N/mm^2, 26.2N/mm^2, 21N/mm^2, 19.5 N/mm^2, 17.6N/mm^2, and 16.8N/mm^2 respectively. Tensile strengths for the same percentage replacements are 2.15N/mm^2, 2.55N/mm^2, 1.91N/mm^2, 1.84N/mm^2, 1.87N/mm^2, and 1.77N/mm^2 respectively. Figure 4 shows the plot of the compressive strengths of various percentage replacement of sand with billet scales in relation to curing age. It is observed from the graph that there is increase in strengths of various percentage replacements with time. Strength increments for 30%-75% replacements of sand with billet scales still fell below the control (0%), however, the result of 15% replacement of billet scales with sand showed progressive increase of compressive strength with age that is higher than that of the control. Figure 5 presents a variation of splitting tensile strength of tested concrete cylindrical specimens with curing time. The Figure indicates a general trend of decrease in splitting tensile strength with billet scales addition in various percentages except for 15% billet scales content at 28 days curing which is higher than the control at the same age. Figure 6 represents a plot of tensile strength versus compressive strength.

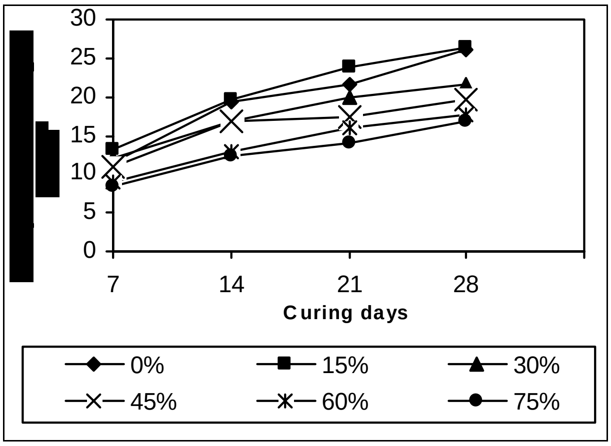

Fig. 4. Compressive strength vs Curing days

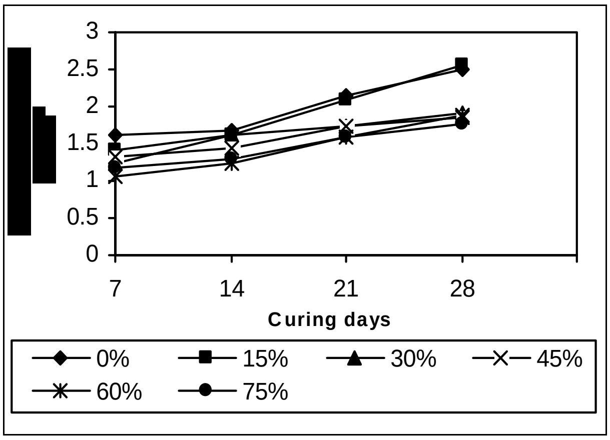

Fig. 5. Tensile strength vs Curing days

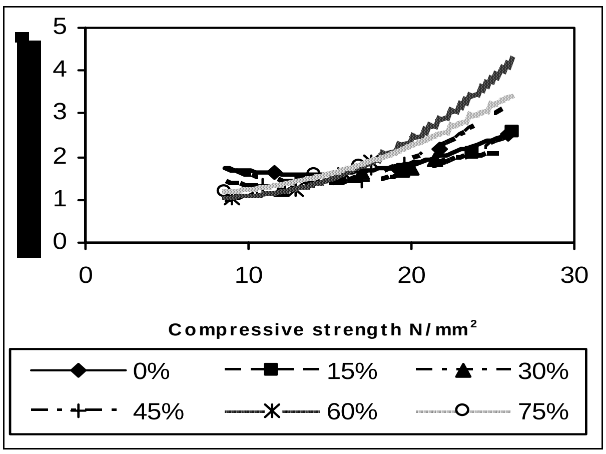

Fig. 6. Tensile strength vs Compressive strength

Discussion

The gradation of the billet scale, sand, and crushed granite aggregate was performed and the results are as shown in the particle size distribution curves in Figures 1, 2, and 3, respectively. It was observed that the billet scales grading curve compares well with that of normal sand. The coarse aggregate used also had normal distribution. Hence, these materials were classified appropriate for use.

The result of the specific gravity for billet scales is as shown in Table 1. The specific gravities of sand and billet scale are within the range of 2.6 – 3.0 specified by BS 882 [6], for normal weight aggregate.

The moisture content for sand and billet scales was determined and the results were 0.17% and 0.47% for sand, and billet scales respectively. The amount of moisture in the materials was taken into consideration during the batching to arrive at the required water-cement ratio. Strengths of concrete specimens increased generally with age as indicated in Figures 4 and 5. As presented by the plots in Figure 4 that strength increased proportionately as curing time increased for all the percentage replacements of sand with billet scales. In same Figure 4, there was an increase in strength at 15% replacement when compared with the control, but there is decrease in strength as the percentage replacement increases. Splitting tensile strength test follows a similar pattern to that of compressive tests results as presented in Figure 5. It is however, observed that the increment in strength for 15% replacement over the control is between 21 days to 28 days curing. Probable reason is because there is slow acquisition of initial strength of billet scales used as partial replacement, when compared to sand. This is evident from Figure 4 for the compressive strength where the control at 7 days curing has higher strength than 15% replacement. From Figure 6, the equations for the plots and correlation coefficients of various percentage replacements are presented below:

0% $y = 0.0061x^2 - 0.1627x + 2.6892$ $R^2 = 0.9185$
15% $y = 0.0086x^2 - 0.253x + 3.2513$ $R^2 = 0.9997$
30% $y = -0.0009x^2 + 0.0967x + 0.2147$ $R^2 = 0.9854$
45% $y = 0.0099x^2 - 0.2392x + 2.7415$ $R^2 = 0.8297$
60% $y = 0.0103x^2 - 0.18x + 1.8446$ $R^2 = 1$
75% $y = 0.0056x^2 - 0.0675x + 1.3452$ $R^2 = 0.9312$

The correlations coefficients are very close to one, which gives a good relationship between tensile and compressive strengths. Digital multimeter was used to test all percentage replacements of sand with billet scales in the concrete specimens. None of the test specimens were found to exhibit any trace of conductivity; the reason for this is to find out probability of electrical conductivity because of the metal based aggregate involved. A magnet was moved round the different crushed test specimens. No magnetic influence was noticed on the concrete specimens, this was carried out to know the effect any magnetic material may have on the concrete. It was also observed that there were no sign of corrosion on crushed concrete specimens that were disposed at the dumping site over the span of four months. There was a drop in strength for sand replacement by billet scales of greater than 15% replacement. A reason for this may be because the equivalent weight of both sand and billet scales will not give the same volume since billet scale has slightly higher specific gravity. This deficiency could be taken care of with the use of appropriate plasticizer that will help boost the strength of the concrete.

Conclusions

From the results presented in this paper the following conclusions can be drawn:

1. The maximum compressive and tensile strengths at the age of 28 days of curing time peaked at 15% replacement of sand with Billet scales. The strength of concrete produced was higher than the control, which indicated the use of 15% replacement of sand with Billet Scales is the optimum that can be used to produce concrete for structural works. This is because concrete grade 25 is the minimum grade of concrete that is usually recommended for structural works in Nigeria.
2. Presently this waste material (billet scales) is used to fill potholes on roads in the localities where the steel rolling mills are located in Nigeria. The sieve analysis for billet scales, shown in Figure 2 compares well with that of sand in Figure 1. This shows that billet scales can be mixed with sand for use in road construction where the use of sand is required, this support McEntire [4], that some waste materials can be used for road construction. The maximum replacement with 75% mixture could be useful as mass concrete as in erosion controls and slope embankment in road constructions. This is because the compressive strength is more than the minimum requirement for light weight concrete, which is 15N/mm^2.
3. The material is presently available at no cost as it is waste material from the steel rolling mills and the use of this material as a partial substitute for sand would take care of its negative impact on the environment [9].

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