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Characteristic Properties of Concrete with Recycled Burnt Bricks as Coarse Aggregates Replacement

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ABSTRACT

To counter the depletion of river sand and to reduce the menace caused by disposal of crushed brick wastes, the use of crushed bricks to produce a more environmentally sustainable and economical concrete is explored. This project studied the properties of concrete made using crushed burnt bricks as an aggregate in comparison with concrete made using natural coarse aggregates. Experimental investigation was carried on the concrete in its wet and dry state to determine the durability and mechanical properties of the concrete by testing the workability, water absorption, density and compressive strength test of the concrete. The result of the water absorption test shows that concretes made using crushed burnt bricks as coarse aggregates absorbed more water with value of 7.83% than conventional concrete with value of 2.83% at 28 days curing. The strength test result carried out indicates that conventional concrete at 28 days has strength of 22.96 N/mm2 higher than that of concretes made using crushed burnt bricks at 28 days of curing with value of 15.45 N/mm2, however, the strength of concretes from crushed burnt bricks still lies within the acceptable limit. Other test carried out on the crushed burnt aggregates to ascertain their suitability were, Aggregates Impact Value test (AIV) with value at 15.68% and Aggregates Crushing Value test (ACV) with value at 23.36%. The properties and quality of the crushed burnt bricks aggregates were also determined.

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1. Introduction

The concept of sustainable construction has become paramount as a result of the growing concern for the environment as the construction industry consumes a huge amount of natural resources and also generates lots of wastes. Concrete is one of the most widely used construction material in the world and for this reason is one of the biggest consumer of natural resource. Because of its composite nature (a binder, aggregates and water) concrete is seen as material with a potential place for wastes and because it is used in every part of the world, it implies that if a waste could be incorporated into concrete, then most likely tremendous amount of it can be recycled. Since aggregates constitute about 60% to 75% of concrete constituents any reduction in the usage of natural aggregates will have an immense impacts in the environment. As a result of the environmental challenges of stone pits, ranging from vibrations, noise, dust to considerable impact on the countryside, not to talk of the utilization of non-renewable material tend to reduce the rate at which they can be exploited. On the other hand, the use of construction and demolition waste (CDW) and other industrial wastes as alternative materials are increasingly being investigated and employed as replacement of natural aggregates in producing a more environmentally sustainable concrete [1].

Wastes generated from demolition constitute large amount of waste that enters landfill, the predominant source of these waste by weight includes asphalt, bricks and concrete [2]. Since one of the major material in residential construction is bricks [3], they form a large portion of wastes generated from demolished building sites [4,5]. It was recently reported that in the next 50 years the second most important building material in concrete will remain bricks [3]. Brick materials are regarded as waste when they are damaged or broken in the production process or from demolished construction sites [4–6]. Researches in the past have proven that 75% of CDW are bricks and concrete [4,5]. Owing to the fact that most of the used building materials or wastes are not being recycled, such materials have left the environment unhealthy as they litter the environment causing pollution and environmental degradation. Besides littering the environment, they may also cause injury to lives. As a result of poor recycling, raw materials are over extracted and resources are wasted in purchasing new building materials [6]. This act however put serious pressure on the scarce natural resources and threatens the sustainability of these resources. It is well known in the construction industry, how expensive it is to purchase coarse or natural aggregates from crushed rocks. The recycling of any of these components will immensely reduce the amount of wastes from demolished project causing environmental hazards and deposited into landfills [7]. Recycle can be described as the process of converting waste material into reusable form. Previously, researchers have tried to recycle some of these waste materials as filler for base course in road construction and other non-structural purposes [8]. Report shows that the cost of landfilling one ton of concrete, brick and block is more than six times the amount of recycling it [7]. As space for landfilling natural aggregates has become very expensive in some parts of the world [9], thereby shifting more attention to the usage of recycled crushed bricks as a concrete constituent. Adopting crushed bricks as constituents of concrete will help in the preservation of the source of natural aggregate and waste reduction. The use of cement with crushed brick for concrete production was first reported in Germany in the mid 19th century [10,11]. Brick masonry has long been used as building materials that are reliable in many parts of the world [12]. However, surveys report that in the United States alone approximately 11.5kg/ton of produced bricks are deposited in landfills and not recycled back [13]. Considering the world yearly production of clay brick is approximately 6.25×10^{8} ton [14], of which 7×10^{6} ton bricks return to the landfills. A preferable solution to this menace could be reuse the waste bricks, either excess new bricks, or waste from demolished buildings and incorporate them into concrete as aggregates. With increased awareness about environmental degradation and dilapidation in the past ten years and economical importance of recycle waste, attention is being given once more to the use of masonry rubble.

Burnt brick is a brick that has been treated in a kiln at an elevated temperature to harden and give mechanical strength and improve its resistance to moisture. Depending on the methods of firing (Heating) and handling in the manufacture of bricks, a certain percentage is broken, under burnt or over burnt. It possess chemical elements such as magnesia, silica, lime, alumina and iron etc. thus making its use in concrete production very practical. One of the advantages of concrete containing burnt bricks or clay is that it has greater fire resistance than concrete made with natural aggregates. Agarwal and Krishan [15] conducted an experiment on the development of a sustainable construction material using construction and demolition (C & D) waste bricks. The experiment involved the use of fly ash and cement as binder alongside waste crushed bricks as substitutes for fine and coarse aggregates. The results indicate that C-type brick with composition ratio 1:2.75:2.25 showed compressive strength and water absorption ratio of 9.91 N/mm^2 and 8.8% respectively exhibiting self-weight of 3.6 kg. It was concluded that C & D waste bricks can be applied over any specified location and serve the purpose for solid waste management. Dey and Pal [16] looked into the feasibility of incorporating waste brick aggregates in concrete. The research concluded that standard concrete of M20 and M30 can be produced with crushed bricks at water-cement range values of 0.35 to 0.45 and show good resistance to heat at maximum temperature of 600^{0} C. Dwivedi [17] investigated the suitability of over burnt brick chips and demolished concrete waste as partial surrogate of coarse aggregate in concrete. The study concluded that 25% and 35% of over burnt brick chips and demolished concrete waste can be used as alternative replacement of coarse aggregate for M25 concrete. Over burnt brick chops and demolished waste concrete showed 10% and 25% reduction in cost respectively. Subramani and Kumaran [18] analyzed concrete incorporated with over burnt brick ballast and concrete waste for its mechanical properties. They noted that 0.40 water-cement ratio yielded an increase in compressive strength by 30% for crushed over burnt brick concrete and a more economical infrastructure system compared o nominal concrete. Veerakumar and Saravanakumar [19] conducted a detailed study on partial replacement of fine aggregate with brick debris. In the study, fine aggregate was replaced at levels of 5%, 10%, 15% and 20%. The results indicate concrete made of brick debris gave compressive strength that is comparable to those without ground brick. Hiremath [20] considered the volumetric substitution (0%, 25%, 50%, 75% and 100%) of gravel by brick aggregate. The 25% replacement of RCBA was regarded as the best in terms of strength and economy, hence recommended for usage in structures with medium loading. Yiosese et al. [21] reported the suitability of broken tiles in concrete as partial replacement for crushed granite. Maximum compressive strength and density were recorded at 100% crushed granite and minimum at 40% broken tiles content with equivalent strength of (23 N/mm^2 and 20.3 N/mm^2) and density of (2622 and 2441 kg/m^3) respectively. Shohana [22] compared the relationship between density and compressive strength of lightweight concrete made with crushed brick and concrete made with coarse aggregate. The experimental investigation showed that the increase in strength and density of concrete is directly proportional to the maturity of the concrete with reduction in void and water absorption.

In a research by Tavakoli et al. [23] it was proven that concrete produced with clay bricks as fine aggregate replacement displayed increased water absorption qualities i.e. durability properties of the concrete. Results showed that there was no significant difference between the durability properties of the clay brick and control concrete specimens. However, the brick aggregates negatively affected the durability of reinforced concrete. Results also showed that increase in the content of clay brick aggregate in concrete can minimize corrosion time of reinforcement bars even as the concrete performs better in freezing and thawing. Furthermore, concrete showed reduced stability against chloride iron penetration as a result of high water absorption of the concrete. Adamson et al. [24] observed that the 28 day compressive strength of clay brick coarse aggregate concrete was slightly higher that of the control specimen and displayed increased in workability properties as the amount of clay brick aggregate was increased in the concrete. Mobili et al [25] conducted an investigation on mortar in which natural coarse calcareous aggregate was completely replaced by coarse recycled brick aggregate and coarse recycled concrete aggregate. The result indicated that natural calcareous aggregate can be entirely substituted by recycled aggregates. Even though the obtained mortars displayed more porosity and are more prone to the water capillary absorption than the control specimen, it yielded less stiffness results and less subjected to formation of cracks, less prone to sulphate attack and more permeable to water vapour. Dong et al [26] studied the mechanical properties and microstructures of basalt fibre (BF) reinforced recycled aggregate concrete (RAC). Specimens were tested for mode of failure, tensile and compressive strengths, modulus of elasticity, Poisson's ratio and ultimate strain of the BF reinforced RAC. Test results showed that BF can be used to enhance the mechanical properties of RAC. From the SEM observations of the concrete, it was seen that clusters of BF on the surface of the attached mortar as well as in the pores can promote the microstructure of the interfacial transition zone and also its ductility and strength. Farhangi et al [27] analyzed the characteristics of composite piles made of glass-fiber-reinforced polymer (GFRP) tubes and filled with recycled concrete materials as substitute to nominal steel reinforced piles in bridge foundations. The fibers were orientated at 86^0 and 35^0 in the horizontal and longitudinal directions of the pile, with a segment inclined at 3^0 from the direction of the hoop in the tube placed between the outer and inner layers. It was concluded that the needed bending and axial capacities of piles in different ranges of eccentricities can be achieved by employing the combination of GFRP fiber percentages and tube wall thickness. Thorneycroft et al [28] tried to establish a suitable surrogate for fine aggregate by studying the properties of eleven concrete mixes with respect to two chemical treatments, three categories of particle sizes, three different aspect ratios and five plastic material compositions. The results showed that 10% replacement of fine aggregate by recycled plastic can save about 820 million tonnes of fine aggregate i.e. river sand annually.

Dang et al [29] evaluated the effect of replacing sand aggregates (SA) by recycled brick aggregates (rBA) in different states of moisture (saturated-surface-dry, partial dry, oven dry) at

0%, 50%, and 100%, on concrete's microstructure and durability. It was recorded that replacing SA by rBA increased the water absorption, carbonation, drying shrinkage and water sorptivity but reduced the migration of chloride. When viewed microscopically, the concrete's pore structure was seen to deteriorate as the replacement level increased because of the porous structure of rBA. As a result of the pozzolanic reaction between rBA and cement matrix, crystals of $Ca(OH)_2$ in concrete were consumed producing hydration products that made the interfacial zone denser thereby promoting the adhesion between the cement matrix and rBA. In a bid to enhance the properties recycled brick aggregate concrete (RBAC) Jiang et al [30] introduced fiber-reinforced polymer (FRP) jacketing to provide resistance to corrosion and confinement. Concrete specimens with replacement ratio of RBA (0%, 15%, 30%, 60%, and 100%) and the FRP jacket stiffness (0, 1, 2, and 3 plies) were subjected to monotonic axial compression test. It was found that a high content of RBA reduces the effectiveness of FRP confinement. Liu et al [31] replaced recycled natural sand at 10%, 20% and 30% with sand obtained from sintered clay bricks (SCB) and recycling aerated concrete blocks (ACB) in mortar. The results showed increase in the strength of the mortar as natural sand was replaced by recycled sand from SCB and ACB. In addition, it was noted mortar made with recycled sand from SCB keeps shrinkage while the recycled sand ACB displayed higher shrinkage because SCB and ACB sand particles contain micro-pores which helps them act as internal curing agents thereby improving the microstructure of the interfacial transition zone between the cement matrix and the recycled sand particles. Zhang et al [32] studied the properties of fiber-reinforced concrete made with crushed brick as coarse aggregate replacement. It was concluded that fibers significantly affected compressive and tensile strengths of recycled concrete and also promotes water impermeability but does not affect gas permeability. The inclusion of PP fiber densifies the microstructure of recycled concrete reducing the water absorption by half at PP fiber content of 0.6 kg/m^3 .Chen et al [33] investigated the properties of axially loaded recycled brick aggregate concrete filled steel tubes (RBACFSTs). Replacing 50% recycled coarse aggregate by crushed clay brick led to decrease in compressive resistance up to 3.8%. Crushed clay brick replacement had little effect on the structure as compared to the corresponding effects in the material property tests, due to the confinement effects. Cai et al [34] evaluated the mechanical and durability properties of cement treated permeable concrete incorporated with crushed bricks (CB) and recycled concrete aggregates (RCA) as road base. The cement treated permeable concrete made with CB showed ideal fast-drying and low shrinkage and adequate strength. It was established that 15% addition of CB in weight (CB-15) is acceptable for use in road base concrete with moderate traffic level. Ouda and Gharieb [35] looked into the effects of dolomite-concrete powder (DCP) on alkali-activated brick waste with respect to its microstructure and development of strength. Alkali-activated brick waste was replaced by raw DCP and raw DCP thermally treated at 800 °C for 2 h with a heating rate of 5 °C/min at 0%, 5%, 10%, 15%, 20% and 30% by mass respectively. The experimental results showed that of usage DCP enhances the microstructure of alkali-activated brick waste-based geopolymer and thus it mechanical qualities.

On a general note, results from previous researches have proven that concrete made of clay brick aggregate is practical and cheaper, added to the fact that no remarkable negative effect was recorded. With regards to this project, burnt bricks were recycled in this case by crushing it into coarse particles of different sizes and shapes, say, 20mm, 25mm, 30mm, 50mm, 75mm etc.

which would be used in replacement for gravel aggregates in concrete production. This research work seeks to profess ways and encourage the use of recycled building materials in order to prevent excessive exploration of natural resources used for producing such building materials and make concrete production more economical. The aim of this paper is to investigate the properties of concrete made with crushed bricks as coarse aggregates. To achieve this, the strength properties of the aggregate was tested after which the concrete was tested in fresh and hardened state to evaluate its mechanical and durability properties (such as AIV, ACV, slump, water absorption, compressive strength etc.)

2. Experimental programme

2.1. Materials

2.1.1. Cement

The cement employed for this research was Ashaka brand of ordinary Portland cement and met with BS EN -1 [36] – M32.5 specification. It is the main cement used as binder in the production of concrete and blocks.

2.1.2. Fine aggregates

The fine aggregates were obtained from civil engineering department laboratory of Federal Polytechnic Bauchi, aggregates passing 4.75 mm sieve size were washed with clean water and dried before use. Specific gravity and sieve analysis test were carried out on it.

The results for particle size distribution of aggregates conducted in accordance to BS EN 993-1:1997[37] are presented in Table 1-3 and Figures 1-2.

Table 1
Sieve analysis for fine aggregates.

Sieve size	Weight retained (g)	Percentage retained (%)	Percentage passing (%)	Cumulative % retained
4.75mm	21.00	2.10	97.90	2.10
4mm	52.00	5.20	92.70	7.30
2mm	209.00	20.90	71.80	28.20
1.6mm	300.00	30.00	41.80	58.20
800µm	188.00	18.80	23.00	97.00
630 µm	164.00	16.40	6.60	93.40
400 µm	40.00	4.00	2.60	97.40
Pan	26.00	2.60	0.00	100

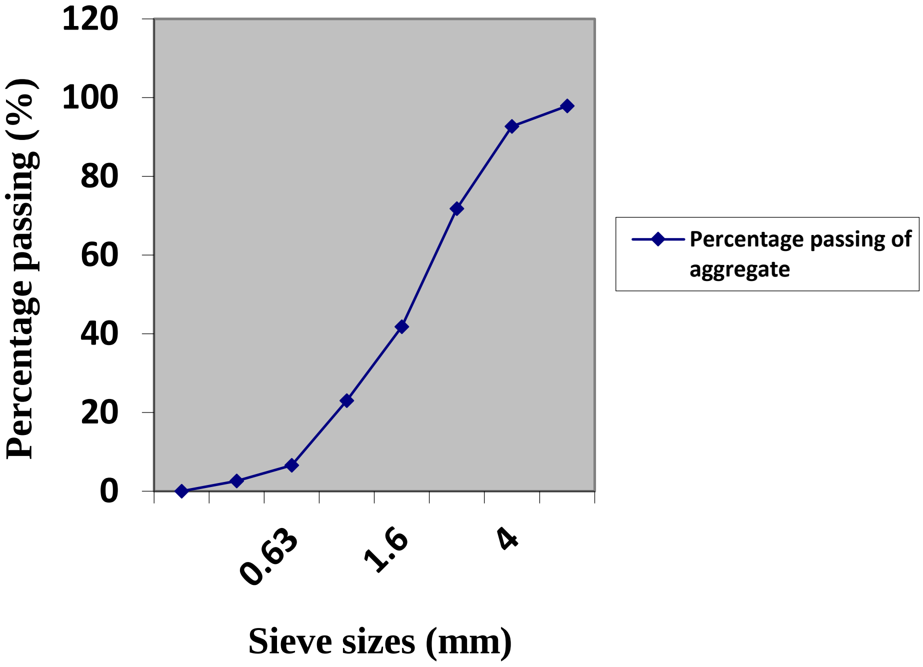

Fig. 1. Sieve analysis graph for fine aggregate.

The results indicate that acquired fine aggregate can be used for construction purpose. As the percentage passing lies within the medium range of grading limit and thus qualifies the sand for use as fine aggregate.

2.1.3. Coarse aggregates

These comprises of crushed quarry rocks from igneous source with maximum size of about 20 mm. These materials were gotten from the department laboratory gravel deposits which were manually sieved using sieve sizes ranging from 37.5 mm to 4.75 mm, the gravel retained on sieve 16 mm to 20 mm size were washed and used. These materials were used to cast the control cubes for comparison.

Table 2
Sieve analysis for coarse aggregates (gravel).

Sieve size	Weight retained (g)	Percentage retained (%)	Percentage passing (%)
37.5mm	0.00	0.00	100.00
25.4mm	0.00	0.00	100.00
19.05mm	328.00	8.20	91.80
12.70mm	1745.00	44.50	47.30
9.50mm	1095.00	27.90	19.40
6.70mm	566.00	14.40	5.00
4.75mm	125.00	3.20	1.80
Pan	63.00	1.80	0.00

2.1.4. Burnt bricks

The burnt bricks were gotten from the environs of Federal Polytechnic Bauchi which had been used over time and were littered all over the school premises, most of the bricks were gotten from rotaract garden and were found to have been exposed to severe atmospheric conditions, broken, removed from position of installation and some were thrown into the drainage. These materials were gathered from various places within the school (The Federal Polytechnic Bauchi) environment for the recycling process. The materials were taken to the laboratory and manually crushed to the required sizes and sieved manually to obtain aggregates ranging between 16mm to 20mm maximum.

Table 3
Sieve analysis for coarse aggregates (crushed bricks).

Sieve size	Weight retained (g)	Percentage retained (%)	Percentage passing (%)
37.5mm	45.00	1.20	98.80
25.4mm	1055.00	28.30	70.50
19.05mm	1000.00	26.80	43.70
12.70mm	605.00	16.20	27.50
9.50mm	282.00	7.60	19.90
6.70mm	242.00	6.50	13.30
4.75mm	209.00	5.60	7.80
Pan	289.00	7.80	0.00

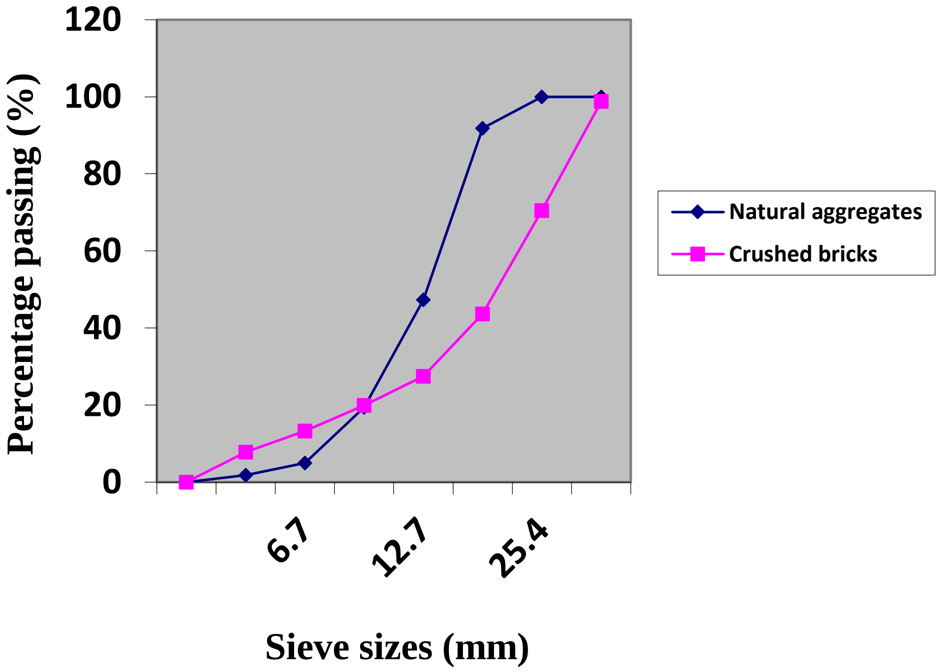

Fig. 2. Sieve analysis graph for coarse aggregate.

The results indicate that natural and coarse aggregate can be used for construction purpose. As the percentage passing lies within the medium range of grading limit and thus qualifies them for use as coarse aggregates.

2.1.5. Water

Tap water from Federal Polytechnic Bauchi was used. Water was added to concrete to activate the cement which binds the mixture together to form a whole compact solid. Water was the last individual ingredients to be added to aggregate mixed with cement. Water for casting of concrete cube was free from impurities such as suspended solids, organic matter and salts which may adversely affect the setting, hardening and durability of the concrete.

2.2. Specific gravity

Table 4 shows test results for specific gravity of concrete constituents conducted in accordance to BS EN 1097-3 [38].

Table 4
Specific gravity of constituent materials.

Materials	Specific Gravity
Sand	2.61
Gravel	2.72
Crushed burnt bricks	2.63
Cement	3.15

The majority of natural aggregates have a specific gravity of between 2.6 and 2.7 for fine aggregates. The specific gravity of sand and gravel was obtained to be 2.61 and 2.72 respectively which falls within the range of values observed by Bowles [39], but that of crushed burnt bricks was obtained to be 2.63 which is still within the specified range of 2.6 to 2.8 [40]. From the result it is noticed that crushed burnt brick has a lower specific gravity compared to gravel which could be as a result of the reduced density of clay it was made from. Bhattacharjee et al. [41] reported a specific gravity of 1.71 for burnt crushed burnt brick.

Duggal [42] observed that specific gravity is a key factor that determines the quality of concrete. Aggregates of low specific gravity may indicate high porosity thereby yielding concrete of low strength and poor durability. Even though Mamlouk and Zaniewski [43] share the opinion that aggregate specific gravity is solely used for concrete mix design as it does not indicate quality. In any case, the specific gravity value and other properties of burnt clay aggregates are interrelated i.e. compressive strength, it can be said that it reflects many properties of the burnt clay aggregates and thus their quality. This concurs with Gambhir [44] conclusion that specific gravity defines aggregate properties and quality; aggregate of high specific gravity will yield harder and stronger concrete.

2.3. Strengths of aggregate

Presented in table are the Aggregate Impact and Crushing values (AIV & ACV) for burnt bricks coarse aggregate.

Table 5
Strength resistance properties of burnt brick coarse aggregate.

Properties	**Values (%)**
AIV	15.68
ACV	23.36

The AIV value is less than 30% and thus falls within the range of limits acceptable as specified by Neville 1981 [45] for wearing surface. BS 882 [46] specifies impact value of aggregate exceeding 45% to be employed in concrete for non-wearing surface. The aggregate impact value of 15.68% for the burnt brick is a reflection of the toughness of the aggregate and the level of its strength to resist impact loading. From BS 812-112 [47] AIV value exceeding 45% denotes aggregate of low impact resistance.

The ACV value of 23.36% is less than the specified range of 25 to 30%. Therefore, the aggregate has an ACV which can be classified as strong aggregates at 23.36% [45]. The value is less than the maximum limit of 45% prescribed in BS 882 [46] and BS 812-110 [48] and hence can be incorporated in concrete applied in areas of non-wearing surface. Even though aggregate crushing value is not directly related to the compressive strength concrete, the test is a pre-requisite guide to the expected compressive strength of the concrete.

2.4. Mix proportion

The British standard BS5328:1976 [49] specified designed mixes in which performance is specified by the user but the mix proportions are determined by the producer of the concrete except that minimum cement content can be laid down. Concrete was designed for characteristics strength of 20 MPa with w/c ratio of 0.47 yielding mix proportion of 1:1.5:3 as illustrated in table 6.

The aggregates gotten from the crushed burnt bricks of 20 mm maximum size were used for the production of concrete, using the crushed bricks as a total replacement for granite or natural aggregates. Table 7 shows total materials for two concrete batches (natural aggregate and bricks) of grade 20 concrete.

Table 6
Mix proportion for concrete grade 20.

Characteristic strength (MPa)	W/C	Water (kg/m^3)	Cement (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	C:FA:CA
20	0.47	184	392	589.33	1176	1:1.5:3

Table 7
Concrete batching for grade 20 concrete (natural aggregate and bricks).

Aggregate type	Concrete volume (m^3)	Cement (kg)	Water (kg)	Fine aggregate (kg)	Coarse aggregate (kg)
Natural aggregate	0.050625	22.05	10.35	33.15	66.3
Bricks	0.050625	22.05	10.35	33.15	66.3

2.5. Experimental tests

The experiments involved conducting identification test on the crushed granite and burnt bricks to ascertain their edibility for concrete ingredient. These tests include sieve analysis, specific gravity, water absorption, density. Artificial aggregate (burnt bricks) was tested for its impact and crushing resistance and fresh concrete mixes were tested for workability, slump and compacting factor. Total of 30 concrete cubes of size 150mm x 150mm x 150mm with mix proportion 1:1.5:3 were casted both for natural coarse aggregates and crushed bricks (15 cubes each) with constant water cement ratio of 0.47. Concrete cubes were tested for compressive strength at ages of 3, 7, 14, 21 and 28 days respectively.

3. Results and analysis

3.1. Properties of fresh concrete

Workability is a measure of the degree of consistency of fresh concrete before final setting [50]. It is of immense importance in calculating and checking the uniformity of improperly mixed batch [51].

Table 6
Fresh concrete properties.

Properties	Natural aggregates	Crushed burnt bricks
Slump	51 mm	46 mm
Compacting factor	0.92	0.813

From the control cube it indicates a medium slump value of 51 mm and a low slump value of 46 mm for fresh concrete made using crushed burnt bricks as coarse aggregates which shows low workability.

From the result shown in table 6, the compacting factor test of fresh concrete made using coarse crushed burnt bricks is lower than that of concrete made using natural aggregate or gravel but still fall within the range of 0.8 as specified by [40], and can be used for road, mass concrete, foundation with highly reinforced section [52].

3.2. Durability properties of concrete

Table 7 shows the water absorption and density of concrete made with crushed burnt bricks as coarse aggregates and gravel. Concrete made with gravel showed maximum water absorption and density of 1.36% and 2488.89 kg/m^3 respectively while concrete made with crushed burnt bricks showed maximum values of 7.83% and 2429.63 kg/m^3 for water absorption and density respectively.

Table 7
Water Absorption properties and Densities of concrete cubes.

Age (days)	Water Absorption (%)		Density (kg/m^3)	
	Gravel	Bricks	Gravel	Bricks
3	3.45	3.10	2488.89	2320.12
7	3.45	3.98	2479.01	2429.63
14	3.22	6.57	2459.26	2424.20
21	1.36	7.02	2439.51	2428.76
28	2.83	7.83	2473.80	2424.07

3.2.1. Water absorption

From the result shown in table 7, it is observed that the rate of water absorption is higher in concrete made using crushed burnt brick as aggregates, while the rate of water absorption is considerable low in concretes made using natural aggregates (gravel). This can be attributed to the increase porosity in the concrete because of the burnt brick aggregates. The water absorption value of 7.83% shown by burnt brick concrete is lower than the allowable maximum of 8.0% for uncrushed bricks [53], meaning the aggregate will show great degree of stability and durability even in wet condition.

3.2.2. Density

The density dropped from 2488.89 kg/m^3 to 2429.63 kg/m^3 with a difference of about 59.26 kg/m^3. Mohammad et al. [54] reported dry compact unit weight of 1653.4 kg/m^3 and 903 kg/m^3 for coarse aggregate (stones) and burnt brick respectively. Implying that reduction in unit weight of the individual aggregates is the major reason for the reduction in density. However, the unit weight of concrete by full replacement of natural occurring aggregate with crushed burnt bricks positions it between normal weight concrete (2200 – 2600 kg/m^3)and light weight concrete (300 – 1850 kg/m^3)[55]. It is thereby classified as medium weight concrete.

3.3. Compressive strength

The compressive strength for all batches for both granite concrete and burnt bricks concrete are shown in Figure 3.

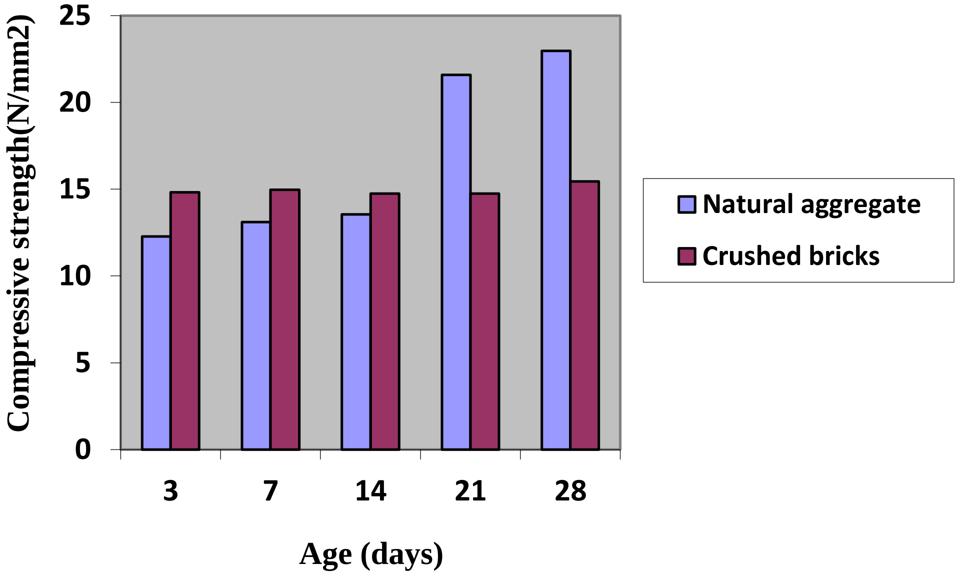

Fig. 3. Compressive Strength of concrete versus Age.

Figure 3 shows that the weight of natural aggregates (gravel) is slightly higher than that of the artificial aggregates which has effect on the weight of concrete produced and also the strength.

The strength of concrete produced and cured at 28 days was found to be 22.97 N/mm^2 which is higher than that of the concrete produced using crushed burnt bricks as aggregates which was found to be 15.45 N/mm^2 cured for the same number of days. The reduction in strength correlates with the studies of Akhtaruzzaman and Hasnat [56] and Brito et al. [57]. The reason for this may be due the effect of crushed brick as an internal curing agent. As bricks are saturated when they are used, considering the absorption properties of bricks and the additional excess water of about 8-23% inside the concrete aside that specified by the water/cement ratio. During the mixing process, the water is inside the bricks and is not available. Hence concrete incorporated with crushed bricks have extra water that could help in cement hydration at later stages and will also not add to the porosity of the concrete nor affect the initial water/cement ratio. This implies that in moderate amount the use of saturated bricks in concrete act as an internal-curing agent for the concrete. However, the water inside the bricks densifies the aggregates by filling the brick pores if it remains inside the bricks and is not used for cement hydration. For this reason, the correct balance between the reduced strength of crushed brick aggregates and its effectiveness as self-curing agent is pivotal to employing it as aggregate in producing concrete. As the amount of crushed bricks in the concrete increases, it loses its advantage as an internal curing agent by augmenting the porosity of the bricks as a result of their porous structure which further deteriorates the pore structure of the concrete. During concrete mixing, the fresh concrete made using crushed burnt bricks as coarse aggregates absorbed more water than the fresh concrete made using natural aggregates (gravel) and table 5 shows that at 28 days of curing water absorption of crushed brick concrete was 7.83% while that of the control specimen was 2.83%. As a result of the pozzolanic reaction between brick aggregates and cement matrix, crystals of $Ca(OH)_2$ in concrete are consumed producing hydration products that densifies the interfacial zone thereby promoting the adhesion between the cement matrix and the brick aggregates, leading to reduction in compressive strength. In addition, specific gravity is the major determinant factor of density of concrete as well as other characteristics of concrete and concrete density is also a major determinant factor of the compressive strength. Concrete made of 100% coarse aggregate replacement showed specific gravity and density of 2.63 and 2429.63 kg/m^3 which are less than that of concrete produced with gravel and sand, this reduced the unit weight of concrete causing the compressive strength of the crushed brick concrete to reduce, and same trend was noticed by Abbas et al [58]. The individual strength properties of the crushed bricks aggregates also affects the overall properties of the concrete, crushed bricks displayed higher impact and abrasion result compared to natural coarse aggregates meaning lesser resistance to loading and lesser concrete strength. The strength properties of the aggregate can be affected by exposure to severe atmospheric conditions like rain, sun, cold, temperature, and humidity, human factors such as indiscriminate dropping, disintegration and trampled upon several times or the bricks may not have been fired to a very high temperature during production. However, the compressive strength of burnt brick concrete is equivalent to grade 15 concrete which qualifies it for use in reinforced concrete with lightweight aggregate [59]. A very interesting results obtained from the strength development of crushed brick concrete up to 28 days, Figure 3 indicates that 28 day strength may not be a good indicator of strength for concrete with 100% crushed bricks as aggregates as increasing the curing age may yield increased compressive strength at 100% replacement.

4. Summary and conclusion

4.1. Summary

In keeping with the commitment of rendering services to the society, the descriptive assessment of recycled burnt bricks as coarse aggregates in concrete production comes into existence. It is generally observed that low recycling of used building materials has contributed to economic downcast and littering of environment. Hence the trend to economic growth should flow through the recycling of used building materials with bodies charged with such responsibility.

4.2. Conclusion

- Crushed burnt bricks showed specific gravity of 2.63 which falls within the specified range of 2.6 to 2.8.
- The aggregate impact value of crushed burnt brick was 15.68% which is a reflection of the toughness of the aggregate and the level of its strength to resist impact loading and falls within the range of limits acceptable for wearing surface.
- Crushed burnt bricks indicated aggregate crushing value (ACV) of 23.36% which is less than the specified range of 25 to 30%. Therefore, the aggregate has an ACV which can be classified as strong aggregates and can be incorporated in concrete applied in areas of non-wearing surface.
- Compacting factor test of fresh concrete made using coarse crushed burnt brick was within the range of 0.8 acceptable for use in road construction, mass concrete, and foundation with highly reinforced section.
- Concrete made with crushed burnt bricks showed maximum values of 7.83% and 2429.63 kg/m^3 for water absorption and density respectively. This classifies the concrete as medium weight concrete and its water absorption show great degree of stability and durability even in wet condition.
- Concrete produced using crushed burnt bricks as 100% replacement for coarse aggregates showed compressive strength 15.45 N/mm^2 at 28 days.
- Increasing the curing age of concrete with 100% burnt clay brick coarse aggregate may increase the compressive strength of the concrete.

5. Recommendations

In view of this research work, I hereby recommend that recycling of burnt bricks as coarse aggregates in concrete production and other used building materials should be encouraged in construction industries. However, care should be taken in selecting materials to be recycled to avoid the usage of materials that has deteriorated beyond recycling to ensure quality of recycled products. The materials to be recycled should be able to give a quality end product to the recyclers. Also, tests should be out on the materials to ascertain their quality and suitability prior to recycling.

From the test carried out, I recommend that concrete made using crushed burnt bricks as coarse aggregates can be used in construction works but care should be taking when using it in water logged area or swampy area.

If these recycling processes are been worked upon and resources put into such companies, the rate of environmental pollution will be reduced, resources saved, it will also save energy, and conserve natural resources as this will promote economic growth, improve standard of living, improve healthy environment for the society at the same time give quality workmanship to the construction industry.

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