EVALUATION OF STRENGTH RELATIONS IN FOAMED AERATED CONCRETE CONTAINING PULVERIZED BONE (PB) AS A PARTIAL REPLACEMENT OF CEMENT

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Abstract:

The focus of this paper is on the results of investigation conducted to find strength relationships in foamed aerated concrete in which cement has been partially replaced by pulverized cow bone by weight, up to 20 % at interval of 5 %. Concrete beam specimens of dimension 150 x 150 x 750 mm were used for the modulus of rupture test, while cylinder specimens 150 x 300 mm were used for the splitting tensile strength test. Compressive tests were carried out using 150 x 150 x 150 mm cube specimens. The results showed that (i) both the ratio of splitting tensile strength to compressive strength, and modulus of rupture to compressive strength were decreased with an increase in the replacement of cement with pulverized cow bone, (ii) both the ratio of splitting tensile strength to compressive strength, and modulus of rupture to compressive strength increased with curing ages. Also, the expressions relating splitting tensile strength and the modulus of rupture with compressive strength of foamed concrete containing pulverized bone as partial replacement of cement yielded results that compared well with the experimental data.

1 Introduction

Recent works by [1-4] have showed the suitability of pulverized bone as substitute for cement in the production of foamed aerated concrete. However, attention is yet to be given to the development of relations between the compressive strengths and the tensile strength. Developing a relationship between the compressive strength and the tensile strength (flexural and splitting) is very important in the design of structural concrete. Firstly, it is important while designing plain concrete structures such as dams. Also, highway pavements and airfield slabs are designed on the principle that depends on the flexural strength of concrete. Thus, tensile strength rather than compressive strength is important in the design of these structures. Furthermore, the knowledge of tensile strength is useful to estimate the load under which cracking will develop [5]. This is due to the influence of tensile stress on the formation of cracks and its propagation in the tension region of the reinforced concrete flexural member. Shear, torsion and other actions also exert tensile stresses on the particular section of a concrete member. In most

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cases, member behavior changes upon cracking. However, the importance of relationship between compressive and tensile strength expressed in terms of ratio from the perspective of its usefulness in other areas should not be overstated / overestimated. For example, in Bortolloti studies, to express material constants defining the failure envelope for intact rock under triaxial compression, the ultimate values in uniaxial tension as well as in Johnston's strength criterion were stressed by [6]. But assessment of the tensile strength either from the modulus of rupture or splitting test is difficult to obtain for the purpose of control and compliance [7]. Therefore, compressive strength, which is easily measured, is used as an indirect means to assess the flexural strength (obtained as modulus of rupture) and the tensile strengths of concrete. Many researchers have recently developed useful relations between tensile strength and compressive strength on normal weight concrete [8-10, 6, 11-14]. There are also relations for and to concrete blends [15-18]. However, there are extremely few literatures showing expressions relating compressive strength to tensile strength in foamed aerated concrete. The expressions developed by [19] were on Lightweight aggregate aerated concrete in which lightweight aggregates were manufactured; 'Leca' of different grades were used. Developing strength relations for foamed aerated concrete is important for many reasons. Firstly, it is inevitable since foamed aerated concrete is gradually becoming a structural material. And secondly, foamed aerated concrete is used on highways where the emphasis is on flexural strength. Field compliance and control definitely require that the flexural strength be related to the compressive strength which is easily measured on site. Foamed aerated concrete is produced using wastes with pozzolanic properties as partial replacement of cement or/and sand. One of such pozzolans is pulverized cow bone – agro-based wastes – which has only recently been found suitable as partial replacement of cement in the production of strong and low-cost foamed aerated concrete up to 20 % replacement level [2-4]. There is thus a compelling need to go further to develop useful relations between compressive strength and tensile strength to aid the users. Earlier work by [3] discussed compressive and tensile strengths behavior of foamed aerated concrete with pulverized cow bone, but the emphasis was neither on the development of relationships between them, nor on the intention to emphasize the ratios between them. Thus, the aim of this is to develop expressions relating the splitting strength to compressive strength and flexural strength to compressive strength in foamed aerated concrete in which cement has been partially replaced with pulverized bone up to 20 % by weight, and subsequently compared with expressions developed for similar concrete in some national codes by researchers with a view to providing useful guide to designers.

2 Experimental investigation

2.1 Materials

Two types of binder were used: namely ordinary Portland cement and pulverized bone. The Portland cement was produced in accordance with [20] and classified as CEM I or CEM II and described as grade 42.5. The pulverized bone was obtained from bones generated as waste from a government-controlled abattoir at Oko-Oba, in Agege Local government of Lagos State, Nigeria. The bones were dried after they had been separated from all the muscles, flesh, tissues, intestines and fats. The dried bones were then ground or pulverized through a grinder into powder, and the fraction passing through 150 μm was later packaged in bags and stored in cool place. It was used as a partial replacement of cement up to 20 % as determined from preliminary investigations [2]. The sand used was obtained from dredged sand from the River Ogun at Ibafo town in Ogun State of Nigeria, and treated to meet the requirements of [21, 22]. In addition, all particles size greater than 2.36 mm were sieved out in order to improve the flow and the stability of the foamed concrete [23]. The foaming agent (surfactants), a protein-based foaming agent (Lithofoam), found by [24, 25] to produce more stable, smaller, and stronger bubble structure which resulted in higher strength foamed concrete compared to synthetic foaming agents, was used for this project. It was sourced from Germany. The dilution ratio for the surfactant consists of one-part surfactant to 25 parts of water. The water used for this work is potable tap water. This is crucial when using a protein-based foaming agent because organic contamination can have an adverse effect on the quality of the foam, and hence the concrete produced.

2.2 Mix proportions

Since available literature from the works by many researchers [26, 27] shows that foamed aerated concrete with structural value can be obtained in the reported a density range of 1400 – 1900 kg/m^3, but for this work, a target plastic density of 1600 kg/m^3 was adopted. Density is the main criterion for design purpose in foamed concrete technology. The designed density provided the basis of evaluating the relationships between the compressive and tensile strengths of the foamed concrete so produced, with and without pulverized bone as partial substitute for cement. Mixes were designed and produced to achieve the required density following the procedure adopted by [23]. From the results from trial mix, and by using the expression suggested by [23], the following mix design parameters, the following mix proportions were adopted: (i) binder (cement and pulverized bone) /sand ratio of 1: 3, (ii) water/Binder (cement and pulverized bone) ratio of 0.5, (iii) foaming agent dilution of 1: 25, (iv) curing methods are by water and air (at room temperature) at 7, 14, 21, 28, 60, and 90 days. In addition, 125 grams of foam concentrate was designed for 50 kg of sand. The mix without pulverized bone served as the control. The replacement of cement by weight, with pulverized bone in the mix was at interval of 5 % up to 20 %. The mix constituent proportions are shown in Table (1).

Table 1. Mix constituent proportions for the foam concrete mixes [3]

% PB*	Binder (kg/m^3)		Sand (kg/m^3)	Water for base mix (kg/m^3)	Foam concentration	
	Cement	PB*			Mixing water (kg/m^3)	Foam (g/m^3)
0	25.00	0.00	75	12.50	4.688	187.5
5	23.75	1.25	75	12.50	4.688	187.5
10	22.50	2.50	75	12.50	4.688	187.5
15	21.25	3.75	75	12.50	4.688	187.5
20	20.00	5.00	75	12.50	4.688	187.5
*PB – Pulverized bone						

2.3 Experimental investigation

The following tests were conducted on the foamed aerated concrete specimens.

2.3.1 Density test

The wet density of the foamed concrete was determined according to [28].

2.3.2 Compressive strength test

Compressive strength was measured at 7, 14, 21, 28, 56 and 90 days essentially in accordance with [29]. The specimens were subjected to water-curing. The water-cured specimens were then tested at saturated state (immediately after removal from curing tank). The strength characteristics of each cube specimens were determined with 600 kN Avery Denison Universal Testing Machine at a loading rate of 120 kN/min. Three specimens for each of the curing ages were tested to failure by crushing, and the average failure load was recorded. The average failure load of the three specimens was then divided by the area of the specimens to obtain the compressive strength.

2.3.3 Tensile strength

According to [5, 19], it is impossible to maintain the applied load truly axial with the direct method of assessing the tensile strength so that indirect method of splitting cylinders and loading beam to failure in flexure was used instead. The strength thus determined is known as splitting tensile strength and modulus of rupture, respectively. In this work, splitting tensile test and modulus of rupture tests were used to assess the tensile strength of the foamed aerated concrete.

Splitting strength test

The splitting tensile strength test was carried out on the foamed concrete in accordance with the provision of [30] and [31] for lightweight concrete The specimens were 150 x 300 mm cylinders. They were water-cured for 7 days, followed by air curing under ambient condition until the day of testing. The tests were carried out by compressing the cylinder on its sides. The splitting strengths were determined with 600 kN Avery Denison Universal Testing machine at a loading rate of 120 kN/min until failure. The splitting tensile strength (T_s) is then calculated as follows:

$$T_s = \frac{2P}{\pi l d}, \quad (1)$$

where, T_s = splitting tensile strength (N/mm^2), P = maximum applied load (in Newtons) by the testing machine, l = length of the specimen (mm), and d = diameter of the specimen (mm).

Modulus of rupture

The flexural strength of foamed concrete was determined by using a simply supported unreinforced beam subjected to a third point loading configuration as shown in Fig. 1. The beam specimens were produced, prepared and tested in accordance with the provisions of [32, 33]. The text specimens were 150 x 150 x 750 mm beams. The specimens were loaded at a constant rate of 12 N/min until failure. The maximum tensile stress reached at the bottom of the fibre of the test beam is known as the modulus of rupture (M_r). Thus the Modulus of Rupture (M_r) is calculated as:

$$M_r = \frac{PL}{bd^2}, \quad (2)$$

where, M_r is modulus of rupture (MPa), P is maximum applied load (N), L = span (mm), b = average width of the specimen at the failure (mm) and d = average depth of the specimen at the failure (mm).

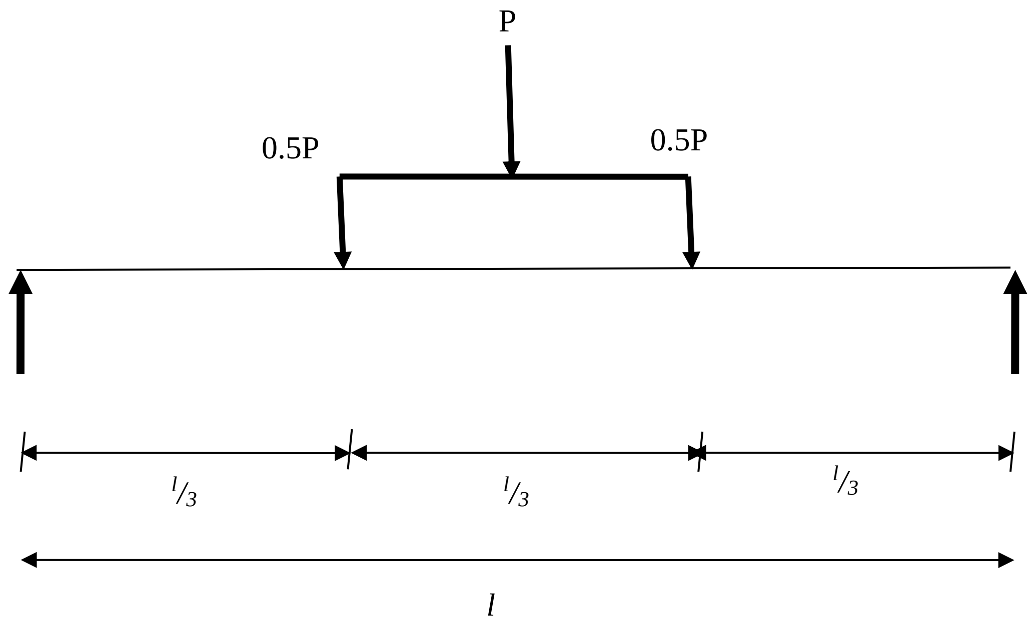

Figure 1. Structural configuration for third point loading.

3 Results and discussion

3.1 Density

The results of the wet density of specimens for this investigation are: 1638.28 kg/m^3, 1629.19 kg/m^3, 1599.71 kg/m^3, 1589. 89 kg/m^3, and 1573.68 kg/m^3 respectively for 0, 5, 10, 15, and 20 % cement replacement with pulverized cow bone. The standard deviations respectively were 35.23 -, 38.15 -, 45.45 -, 39.89 - , and 40. 89 kg/m^3. These values were within the range defined for lightweight concrete [34, 35] of which foamed aerated concrete is one. The importance of producing foamed aerated concrete with densities within the prescribed limit is a step further to achieving one of the objectives of this work, which excludes the normal concrete density range so that the following results could be considered as valid.

3.2 Development of strengths relations

3.2.1 Evaluation of strength ratios

The ratios of splitting tensile strengths to compressive strengths (hereafter as "α") and modulus of rupture to the compressive strengths (hereafter as "β") at the different levels of cement replacement with pulverized bone for 28, 60, and 90-day curing age, are shown in Table 2, 3, and

Table 2. The strengths ratios strength at 28-day curing

PB (%)	Compressive strength, f_c (N/mm^2)	Splitting strength, f_s (N/mm^2)	Ratio α = f_s/f_c	Modulus of rupture f_r (N/mm^2)	Ratio β = f_r/f_c
0	15.93 (13.12) ± 0.51	1.84 ±0.04	0.14	2.81 ± 0.07	0.22
5	15.01 (12.10) ± 0.40	1.66 ±0.10	0.14	2.58 ± 0.05	0.21
10	14.21 (11.91) ± 0.20	1.58 ±0.07	0.13	2.21 ± 0.00	0.19
15	13.87 (11.62) ± 0.29	1.32 ±0.04	0.12	2.05 ± 0.02	0.18
20	13.00 (11.03) ± 0.83	1.11 ±0.00	0.10	1.89 ± 0.09	0.17
NB: figures in parentheses are the equivalent cylinder strength value, and the following figures are the standard deviations.					

In this analysis, the cube compressive strengths have been converted into cylinder compressive strength (in parenthesis) by multiplying the cube compressive strength by 0.85 because the expression of relation between flexural tensile and compressive strengths is mainly based on cylinder specimen [9].

Table 3. The strengths ratios at 60-day curing

PB (%)	Compressive strength, f_c (N/mm^2)	Splitting strength, f_s (N/mm^2)	Ratio α = f_s/f_c	Modulus of rupture f_r (N/mm^2)	Ratio β = f_r/f_c
0	17.26 (15.27) ± 0.51	2.56 ± 0.05	0.17	2.91 ± 0.04	0.19
5	16.98 (14.17) ± 0.40	2.01 ± 0.05	0.14	2.70 ± 0.05	0.19
10	16.01 (13.41) ± 0.20	1.91 ± 0.02	0.14	2.52 ± 0.03	0.19
15	14.99 (12.47) ± 0.29	1.71 ± 0.09	0.14	2.30 ± 0.06	0.18
20	14.67 (12.39) ± 0.83	1.61 ± 0.00	0.13	2.11 ± 0.00	0.17
NB: the figures in parenthesis are the equivalent cylinder strength value, and the figures following are the standard deviations					

Table 4. The strength ratios at 90-day curing

PB (%)	Compressive strength, f_c (N/mm^2)	Splitting strength, f_s (N/mm^2)	Ratio α = f_s/f_c	Modulus of rupture f_r (N/mm^2)	Ratio β = f_r/f_c
0	18.25 (15.26) ± 0.33	2.68 ± 0.03	0.18	2.94 ± 0.00	0.19
5	17.68 (14.18) ± 0.28	2.39 ± 0.00	0.17	2.82 ± 0.03	0.20
10	16.88 (14.01) ± 0.03	2.14 ± 0.02	0.15	2.75 ± 0.03	0.20
15	15.96 (12.46) ± 0.64	1.91 ± 0.07	0.15	2.69 ± 0.00	0.22
20	14.88 (12.10) ± 0.23	1.79 ± 0.00	0.15	2.66 ± 0.00	0.22
NB: the figures in parentheses are the equivalent cylinder strength value, and the following figures are the standard deviations					

It can be observed from Tables 2, 3 and 4 that the ratio of splitting tensile strength to compressive α, decreases by increasing the levels of cement replacement with pulverized bone considered at the curing ages. This is in agreement with observation by [5, 19] that the ratio of the two strengths depend on the compressive strength of the concrete. This behavior is thus to be expected considering the fact of reduction in compressive strengths of the specimens with an increase in the percentage level of cement replacement with pulverized bone recorded for this work. It can also be observed from Tables 2 – 4 that the ratio increases with curing days. For example, the maximum values of 0.14, 0.17 and 0.18 were recorded respectively at 28-, 60-, and 90 days of curing, while the minimum values of 0.10, 0.13, and 0.15 were also recorded for the same curing regime. This is in agreement with [5] quoting Saul (1960) that after one month, the ratio increased with time for concrete of low compressive strengths. This is because the presence of air voids in foamed concrete lowers the compressive strength of the concrete more than the tensile strength. The improved splitting strength to compressive strength ratios at higher curing ages can also be attributed to the combined effects of pozzolanic activities of pulverized cow bone and lower strength characteristics of foamed aerated concrete. Pozzolans are noted for delayed reactivity at early stages. In the work [36], it was suggested that strength developed and that 56 days of curing should be used as the characteristic strength of foamed aerated concrete instead of 28 days of curing, which is specified in design. These results agreed with the recommendations by [3]. The ratio of the modulus of rupture to the compressive strength β also followed the same pattern as that of the ratio of splitting tensile strength to compressive strength. However, the numerical recorded values were higher than those of the ratio of splitting tensile strength to compressive strength. This is obviously due to the higher modulus of rupture. This fact is in agreement with works of researchers [16, 37]. Generally, the higher ratio of splitting tensile to compressive strength was recorded in this work when compared with normal weight concrete, which is about 10 % [35], and which is typical of lightweight concrete characterized by lower compressive strength [5].

3.2.2 Numerical relationships between the compressive strength and tensile strength

In other to obtain numerical relationships between: (i) the splitting tensile strength and compressive strength and (ii) between the modulus of rupture and compressive strength, a statistical model of the form in the equation 3 was adopted:

$$f_t = A f_c^{B}, \qquad (3)$$

where, f_t is the tensile strength, f_c is the compressive strength, while A and B are non-dimensional coefficients. The adoption of the power equation of the form of the equation 3 is to allow a comparison with other expressions that relate tensile strength to compressive strength in concrete usually expressed in the similar form.

3.2.2.1 Numerical relationship between compressive strength and splitting tensile strength

The relationships between the compressive strength and splitting tensile strength of specimens at all the replacement levels of cement with pulverized cow bone are represented by a scatter plot using the data in Tables 1 – 3, as shown in Fig. 2.

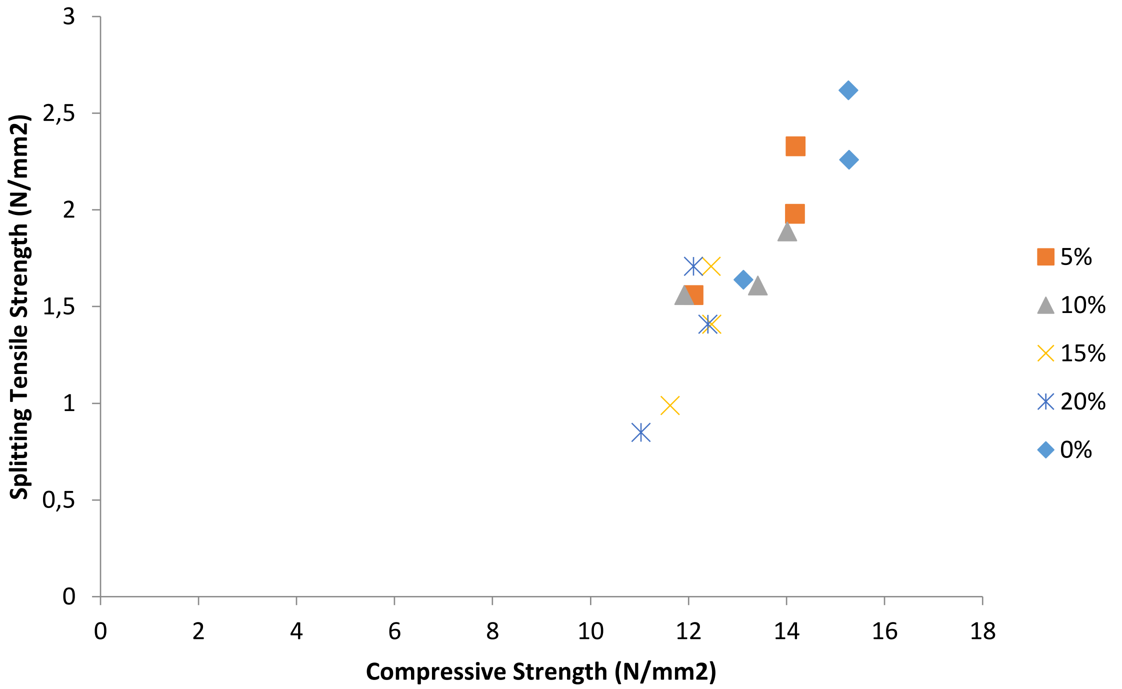

Figure 2. Relationship between the compressive strength and splitting tensile strength at all replacement levels.

Thus by using the power regression analysis, the following expressions (equations 4 - 8), represent the relationships between the splitting tensile strengths and the compressive strengths for 0, 5, 10, 15, and 20 % respectively, for cement replacement with pulverized cow bone.

$$f_{st} = 0.002 f_c^{2.61}, \quad R^2 = 0.9024 \quad (0\ \%) \tag{4}$$

$$f_{st} = 0.01 f_c^{2.03}, \quad R^2 = 0.8702 \quad (5\ \%) \tag{5}$$

$$f_{st} = 0.75 f_c^{0.32}, \quad R^2 = 0.8424 \quad (10\ \%) \tag{6}$$

$$f_{st} = 0.0000002 f_c^{6.39}, \quad R^2 = 0.7994 \quad (15\ \%) \tag{7}$$

$$f_{st} = 0.000003 f_c^{5.25}, \quad R^2 = 0.7112 \quad (20\ \%) \tag{8}$$

where, f_c = cylinder compressive strength, and f_s = splitting tensile strength. The correlation coefficients (R^2) were: 0.9024, 0.8702, 0.8424, 0.7994, and 0.7112 respectively for 0, 5, 10, 15, and 20 % cement replacement levels with pulverized cow bone. It is also to be noted that the correlation coefficient was decreased with an increase in the levels of replacement of cement with pulverized bone. However, the least R^2 value of approximately 0.71 obtained at 20 % replacement, which was the highest, means 71 % of the test data correlated to the regression equation.

3.2.2.2 Numerical relationships between the compressive strength and modulus of rupture

The relationship between the compressive strength and the modulus of rupture at all the replacement levels is represented using the data in Table 1 - 3, in a scatter plot shown in Fig. 3. Using the statistical line of best fit, the following expressions represent the relationships (the equations 9 – 13) for 0, 5, 10, 15, and 20 %, respectively.

$$f_m = 1.77 f_c^{0.17}, \quad R^2 = 0.9179, \quad (0\ \%) \tag{9}$$

$$f_m = 2.20 f_c^{0.06}, \quad R^2 = 0.8383, \quad (5\ \%) \tag{10}$$

$$f_m = 0.85 f_c^{0.41}, \quad R^2 = 0.8098, \quad (10\ \%) \tag{11}$$

$$f_m = 0.80 f_c^{0.45}, \quad R^2 = 0.7319, \quad (15\ \%) \tag{12}$$

$$f_m = 0.36 f_c^{0.75}, \quad R^2 = 0.6776, \quad (20\ \%) \tag{13}$$

where, f_c = cylinder compressive strength, and f_m = modulus of rupture.

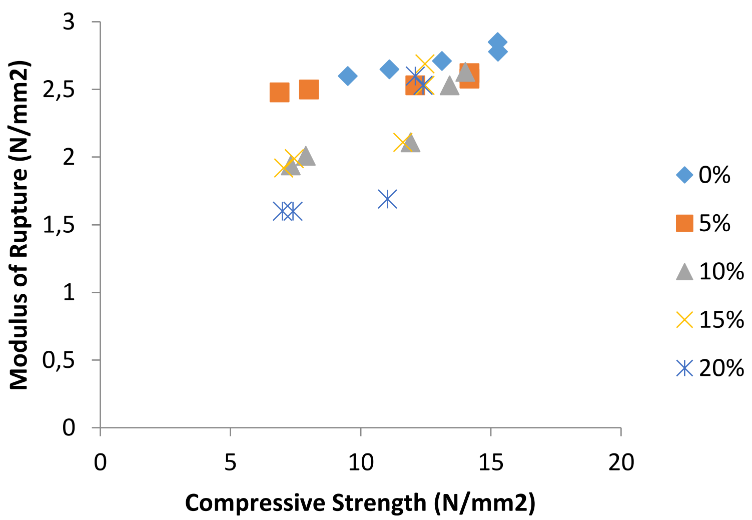

Figure 3. Relationship between the compressive strength and the modulus of rupture.

The correlation coefficients (R^2) obtained for the modulus of rupture were 0.9179, 0.8383, 0.8098, 0.7319, and 0.6776 respectively for 0, 5, 10, 15, and 20 % cement replacement levels with pulverized cow bone. Although, by replacing cement with pulverized bone, the values of R^2 are decreased as are the values of splitting tensile strength, the least value of about 0.68 shows that about 68 % of the test data correlates to the regression equation at the highest replacement value. The reduction of the correlation coefficient with an increase in the levels of cement replacement with pulverized bone is not unconnected with progressive reduction in strength that accompanied higher replacement values.

3.3 Comparison of results of this work with other researchers

The accuracy and applicable ranges of the equations 4 – 13 were examined by comparing relations from other researchers and institutions for lightweight aggregate concrete which is of comparable strength with foamed aerated concrete using the 28 day test data. For foamed concrete, being a relative new emerging structural material, extremely few equations are available expressing the strength relations. Few expressions relating the splitting tensile strength to compressive strength by [38, 39, 19] are given respectively in the equations 14, 15 and 16.

$$f_{st} = 0.23 f_c^{0.67}, \quad (14)$$

$$f_{st} = 0.48 f_c^{0.50}, \quad (15)$$

$$f_{st} = 0.18 f_c^{0.84}, \quad (16)$$

where, f_{st} is the splitting tensile strength (in N/mm^2) and f_c is the cylinder strength, but cube strength in [38] expression of the equation 14. Also, the expressions relating the modulus of rupture to compressive strength by the same researchers are given in the equations 17, 18, and 19 in the same order:

$$f_m = 0.45 f_c^{0.67}, \quad (17)$$

$$f_m = 0.54 f_c^{0.50}, \quad (18)$$

$$f_m = 0.30 fc^{0.81}, \quad (19)$$

where, f_m is the modulus of rupture (in N/mm^2) and f_c is the cylinder strength, but the cube strength in [37] expression of the equation 17. The values obtained from all these equations are presented in Tables 5 and 6. The percentage increase and decrease are in parentheses. For the control specimens, the values of the splitting tensile strength obtained by using the expression derived from the present study and that expressed in [39] compare well with test data being within the 10 % tolerance [23]. However, the values from [19, 35] seemed to underestimate the value of the splitting tensile strength. The values of the splitting tensile strength using the equations developed by/in [19, 38] compare well with cement replacement values of up to 10 % but overestimated it beyond 10 %. The expressions shown in [39] compare well with the experimental data up to 15 % cement replacement with pulverized bone, while the expressions developed in this study agree well with the experimental data up to 20 % cement replacement with pulverized bone.

Table 5. Comparison of compressive strength and splitting tensile strength expressions of researchers and bodies

PB in the mix (%)	Experimental data	This study	Sin [19]	FIP [38]	ACI [39]
0	1.84	1.66 (9.79)	1.56 (15.20)	1.47 (20.00)	1.74 (5.43)
5	1.66	1.58 (4.81)	1.45 (12.65)	1.41 (15.06)	1.67 (- 0.60)
10	1.58	1.56 (1.27)	1.44 (8.86)	1.36 (13.92)	1.66 (- 5.06)
15	1.32	1.28 (3.03)	1.41 (- 6.81)	1.34 (- 1.51)	1.64 (- 24.24)
20	1.11	0.89 (19.81)	1.35 (-21.62)	1.28 (- 15.31)	1.59 (- 43.24)

Table 6. Comparison of compressive strength and modulus of rupture expressions of researchers and bodies

PB in the mix (%)	Experimental data	This study	Sin [19]	FIP [38]	ACI [39]
0	2.81	2.74 (2.49)	2.41 (14.23)	2.88 (-2.49)	1.96 (30.25)
5	2.53	2.56 (0.40)	2.26 (10.67)	2.76 (- 9.09)	1.88 (25.69)
10	2.21	2.35 (- 6.33)	2.23 (- 0.91)	2.66 (- 20.36)	1.86 (15.84)
15	2.05	2.41(- 17.56)	2.19 (- 6.83)	2.62 (- 27.81)	1.84 (10.24)
20	1.89	2.18 (- 15.34)	2.10 (- 11.11)	2.51 (- 32.80)	1.79 (5.29)

The values of the modulus of rupture for the control samples obtained from the expression developed in this study and that developed by [38] compared well with the experimental data, with the tolerance that is less than 10 % [23]. Pulverized bone used as replacement for cement, the values of which are beyond 5 %, the expression in [35] overestimates the modulus of rupture, while the expression in [38] largely overestimates all replacement values. No noticeable pattern was developed by/in [19], the expression which relates the modulus of rupture to the compression strength. However, the expressions developed in this study agreed with experimental data up to 15 % of the replacement of cement with pulverized bone but beyond it, the values are overestimated.

3 Conclusions

Based on the results obtained from this investigation, the following conclusions can be made:

- the ratio of splitting tensile strength to compressive strength, as well as the modulus of rupture to compressive strength is decreased with an increased replacement of cement with pulverized cow bone;
- the ratio of splitting tensile strength to compressive strength, and the modulus of rupture to compressive strength are increased with curing ages;
- the expressions relating the splitting tensile strength to the compressive strength agreed well with similar expression developed by ACI, and yielded reliable values for the splitting tensile strength of foamed concrete containing pulverized bone up 15 % as partial replacement of cement by weight;
- the expressions relating the modulus of rupture to the compressive strength agreed with similar expression developed by FIP, and they yielded reliable values for the modulus of rupture of foamed concrete containing pulverized bone up 10 % as partial replacement of cement by weight.

The newness of foamed concrete as a structural concrete material and the emergence of pulverized bone as a potential pozzolanic material (a recent effort) have accounted largely for the paucity of literature in this area. Thus, more research work is needed covering wide range of structural issues that are needed to make their usage acceptable before any expression can be confidently proposed with certainty for the various relationships.

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