IMPACT RESISTANCE OF LATERIZED CONCRETE

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ABSTRACT

Resistance to impact and other suddenly applied loads is now recognized as one of the significant properties of normal concrete. Results of tests on normal concrete have shown that the introduction of steel or fibre reinforcement into the cement matrix has a significant effect on the impact resistance of the concrete. The addition of fibre is known to improve many of its properties such as fatigue, toughness, flexural strength and strain capacity. Tests are reported on the impact resistance of plain laterized concrete, on fibre-reinforced laterized concrete and the effect of thickness is also investigated. For all three areas investigated the percentage of sand by weight of the total fine aggregate was varied in steps of 25% up to a maximum of 100% corresponding to normal concrete. For the fibre-reinforced laterized concrete the fibre content was varied from 0.5% to a maximum of 5 percent. For the effect of thickness variation on impact resistance, the thickness of specimen was varied from an initial thickness of 50.8mm and in steps of 12.72 mm to a maximum thickness of 88.92 mm. The impact resistance of laterized concrete was found to increase with thickness. The impact strength increased with percentage increase in fibre content only at a laterite content of 25 per cent. For higher percentages of laterite content, the impact resistance does not increase throughout with percentage increase in fibre content. But there is an optimum value of fibre content above which there was a decrease in impact strength as fibre content in the cement matrix was increased. The impact strength of the laterized concrete was also found to vary with the laterite content in the cement matrix.

INTRODUCTION

Experience has shown that a material with high compressive strength can be very brittle and may easily fail due to impact, whereas a material which is more resilient but with less compressive strength can have a higher impact resistance. Until just over a decade ago the concrete and material industry lacked an acceptable impact test that demonstrates the relative brittleness, resilience, impact resistance and toughness of concrete and similar construction materials.

The picture has since changed as a simple portable and practical test has been developed (Schrader, 1978) to determine the impact resistance of concrete and similar construction materials. The same test also checks fatigue because it applies a load repeatedly to the test specimen instead of making it to fail with one massive blow. The number of blows that a standard size ball must be dropped a standard distance to make the first visible crack appear is taken as a measure of the impact resistance.

The American Concrete Committee on fibre-reinforced concrete (ACI, 1978) has also suggested the use of a drop hammer test to evaluate the impact resistance of concrete. The tests are to be conducted by dropping a 4.54kg hammer repeatedly from a height of 457mm to a hardened steel ball resting on a cylindrical specimen of 152.5mm diameter and 63.5mm height. The number of blows required for the first visible crack to appear was considered to be an indication of the impact resistance of the material.

The Charpy impact and rotating impact machine methods have also been widely used to measure the impact resistance of fibre-reinforced concrete specimens. In the Charpy test method a three - point beam specimen is struck at the centre by a pendulum. By knowing the height of the pendulum before and after impact and assuming that all energy lost by the striker is absorbed in breaking the beam specimen, one can calculate the energy absorbed due to the impact loading. Using this test method, Shah & Baehr (Shah and Boehr, 1977) observed that the impact resistance of glass fibre-reinforced concrete specimens is ten times greater than unreinforced concrete specimens. Johnson (Johnson, 1974) also observed a ten-fold increase in Charpy impact resistance when mortar specimens were reinforced with steel fibres.

Present Investigation

The method used in this investigation is a modified form of that recommended by the ACI committee 544 report. The size of the specimen and the diameter of the ball used are slightly different from those specified in the ACI committee report. The steel ball has a diameter of 50.8mm against a diameter of 63.5mm specified in the ACI committee report and the height of drop of the hammer to the test specimen is 425mm against 457mm specified in the ACI committee 544 report (Figures 1a, b and c). But the weight of the hammer is 4.54kg, the same as that specified in the ACI committee report. The number of blows required for the first visible crack to appear is considered to be the impact resistance of the material.

MATERIAL AND TESTING PROCEDURE

Materials

The materials used in this investigation are: cement, fine and coarse aggregates, water and fibre reinforcement. Ordinary Portland cement with properties conforming to the requirements of BS 12 [1970] was used. The fine aggregate consisted of sand and laterite. The laterite used has a particle size range of 4.75-0.063mm (particles passing through sieve with aperture 4.75mm but retained on sieve with aperture 0.063mm). The sand used is clean, sharp river or pit sand free from clay, loam, dirt, organic or chemical matter of any description and is sand passing through 4.75mm zone of British Standard test sieves. The coarse aggregate is crushed rock having particle size between 20.00mm and 5.00mm. The water is potable water, which is fresh, colourless, odourless and tasteless water that is free from organic matter of any type. In this study deformed steel fibre chips with lengths varying from 15mm-25mm were used. The fibre chips were the waste product of the metal fabrication laboratory of the University of Lagos.

Preparation of Test Specimens and Testing Procedure

The moulds for the concrete specimens used in this investigation were cut from 150mm diameter PVC pipes.

The percentage of sand by weight of the total fine aggregate was varied in steps of 25% up to a maximum of 100 percent corresponding to normal concrete. A total of 12 laterized concrete specimens were made for each proportion of laterite in the cement matrix. The same number of cube specimens was also made for the compressive strength test. Impact resistance and compressive strength tests were carried out on the specimens and cubes at ages 3, 7, 14 and 28 days. For the compressive strength tests, the testing procedure described in BS 1881: part 4 (1970) was followed. All the cubes were cured by full immersion in water right from the moment they were removed from the moulds until the day for the testing when they were removed from the curing water- tank and sun- dried before being tested for strength. The weight of each specimen as well as cube was determined and recorded prior to the testing. The Avery universal testing machine was used for the exercise.

TEST RESULTS AND DISCUSSION

Impact Resistance of Plain Laterized Concrete

The results are presented in both tabular and graphical forms. In the graphical presentation the impact resistance (indicated by the number of blows), is plotted against percentage laterite content in the cement matrix. The exercise was carried out using 3 water/cement ratios, namely, 0.6; 0.65 and 0.70 (Figure 2). In the tabular presentation the results are shown in Tables 1 and 2. Table 1 shows the impact strength test results for the laterized concrete specimens prepared using 3 different mix proportions, namely 1:2: 4, 1:11/2:3 and 1:1:2 but at a constant water cement/

ratio of 0.65. Table 2 on the other hand shows the test results for a new set of laterized concrete specimens manufactured with a constant mix proportion of 1:2:4 but with 3 different water/cement ratios, namely, 0.6, 0.65 and 0.7.

Density of Laterized Concrete

It has been established that the density of laterized concrete compares favourably with the density of normal concrete. This can readily be seen by a careful examination of the results presented in Tables 1 and 2. This result confirms the result of previous work (Balogun and Adepegba, 1984) that laterized concrete is not a structural lightweight concrete.

Compressive Strength

It is an established fact that plain normal concrete exhibits higher strength characteristics than plain laterized concrete. In line with the results of previous work (Balogun and Adepegba, 1984) the compressive strength of laterized concrete was found to increase as the proportion of sand in the cement matrix increased.

The results also show that for 1:2:4 mixes at a water/cement ratio of 0.65 the compressive strength values were generally higher than those for 0.6 and 0.7 water/cement ratios. This agrees with the result of previous work [8], which recommended a water/cement ratio of 0.65 for structural laterized concrete.

Impact Resistance

The number of blows required to produce the first tensile crack in the test specimen is normally taken as a measure of its impact resistance. ACI Committee 544 defines ultimate failure, in terms of the number of blows required to open the cracks in the test specimen sufficiently and to cause the fractured pieces to touch at least 3 of the 4 positioning lugs in the base plate (Figure 1b).

At a constant water/cement of 0.65, the 1:11/2:3 mix generally gives higher impact resistance values than the 1:2:4 and 1:1:2 mixes. Also at a water/cement ratio of 0.65 and 1:2:4 mix, the impact resistance falls as the laterite content in the cement matrix increases. At a water/cement ratio of 0.60, the higher impact resistance values are obtained for laterite contents up to 75 percent, beyond which the highest impact resistance values are obtained at a water/cement ratio of 0.60.

At a low water/cement ratio, laterized concrete is stiff due to lack of sufficient water for mixing, particularly for high laterite content in the cement matrix. The stiff laterized concrete has poor workability and low impact resistance. At low water/cement ratio, plain normal concrete has the higher impact strength. As the water/cement ratio increases however, laterized concrete compares favourably with plain normal concrete especially in the region of up to 75 percent laterite content in the fine aggregate.

It is also observed that as the percentage of the laterite content in the cement matrix increases there is a corresponding decrease in the impact resistance of the laterized concrete and this is irrespective of the mix being considered.

Mode of Failure

The mode of failure of concrete under a repeated falling weight test depends on a number of factors such as the following:

(i) The strength of aggregate;
(ii) The matrix strength; and
(iii) The aggregate matrix bond strength.

Other factors are the test boundary conditions and the type of specimen. The predominant mode of failure with plain concrete specimens is a tensile failure through the coarse aggregate although local crushing and shearing also occur in the region where the falling weight impacts the surface. In the test being reported here using plain laterized concrete specimen, the specimens failed by breaking into 3 pieces. The failure in all cases was brittle and it occurred through the granite aggregate particles.

Impact Resistance of Fibre-Reinforced Laterized Concrete

The results are presented in graphical form. The graphs show the plot of impact resistance (indicated by the number of blows) against the concentration of fibre-reinforcement for different strengths of laterized concrete as determined by the percentage of the fine laterite in the cement matrix. (Figures 3-6)

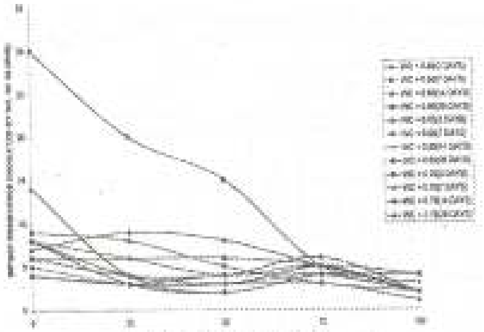


Fig. 2: Plot of Impact Resistance Against Percentage Laterite Content in the Cement Matrix (1:2:4 Mix)

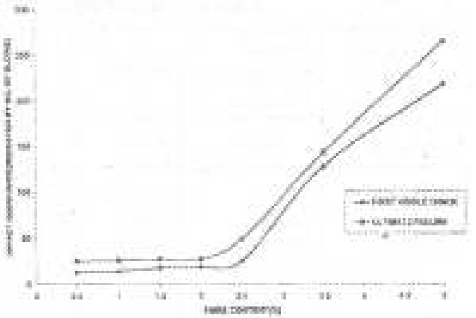


Fig. 3: Variation of Impact Resistance with Fibre Content (25% Laterite Content)

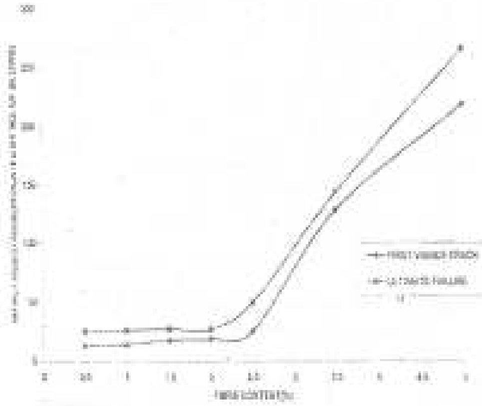


Fig.4: Variation of Impact Resistance with Fibre Content (25% Laterite Content)

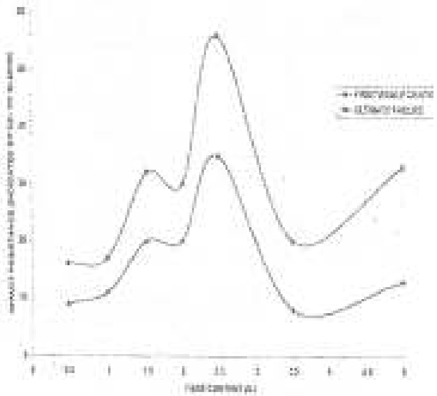


Fig. 5: Variation of Impact Resistance with Fibre Contnt (65% Laterite)

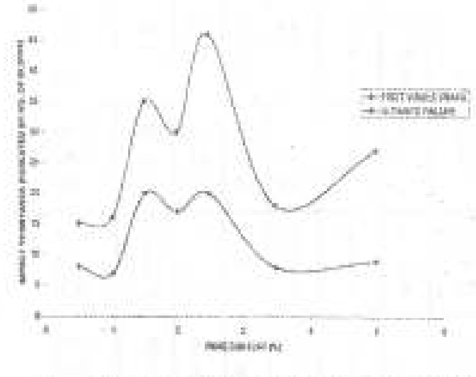


Fig. 6: Variation of Impact Resistance with Fibre Content (100% Laterite Content)

Compressive Strength

It has been established that laterized concrete
not a structural lightweight concrete as the dens
of laterized concrete compares favourably wi
that of normal concrete. The results show th
the compressive strength of fibre-reinforc
laterized concrete is higher than that of pla
laterized concrete. The results also indicate th
the density increases with increases in the fib
reinforcement content in the cement matrix. It
interesting to observe that laterized concrete w
25 percent laterite content gives high
compressive strength values than even norm
concrete.

Table 1: Impact-Energy Test Results for Laterized Concrete at 28 Days

Laterized Concrete: Percentage Laterite Content	28 Day Compressive Strength	Density	No. of Blows To Cause First Crack				No. of Blows To Cause Ultimate Failure				Water/ Cement Ratio	Standard Mix
	N/mm²	Kg/m³	1	2	3	Ave	1	2	3	Ave		
'A' 0% Laterite	25.47	2548.1	13	8	13	11	29	23	33	28	0.65	1:2:4
	26.49	2595.6	23	50	30	34	33	64	46	47		1:11/2:3
	27.96	2488.9	57	18	37	37	76	31	50	52		1:1:2
'B' 25% Laterite	24.19	2518.5	45	25	107	58	58	37	132	75	0.65	1:2:4
	27.86	2539.3	11	25	17	17	25	35	29	30		1:11/2:3
	29.73	2370.4	15	25	20	20	25	43	44	37		1:1:2
'C' 50% Laterite	23.51	2548.1	8	10	17	12	23	25	30	26	0.65	1:2:4
	32.80	2447.4	30	47	27	34	41	55	48	48		1:11/2:3
	33.15	2370.4	7	7	14	9	27	22	25	25		1:1:2
'D' 75% Laterite	15.55	2311.1	4	7	5	5	16	15	14	15	0.65	1:2:4
	27.02	2497.8	23	7	105	78	40	22	217	93		1:11/2:3
	32.89	2400.0	11	10	17	13	26	22	24	24		1:1:2
'E' 100% Laterite	17.77	2429.6	6	5	4	5	17	18	50	28	0.65	1:2:4
	20.00	2388.1	2	7	4	4	9	11	15	12		1:11/2:3
	26.04	2388.1	30	8	16	18	43	22	29	31		1:1:2

Table 2: Impact-Energy Test Results for Laterized Concrete at 28 Days (1:2:4 Mix)

Laterized Concrete: Percentage Laterite Content	28 Day Compressive Strength	Density	No. of Blows To Cause First Crack				No. of Blows To Cause Ultimate Failure				Water/ Cement Ratio
	N/mm²	Kg/m³	1	2	3	Ave	1	2	3	Ave	
'AA' 0% Laterite	33.36	2637.0	10	31	29	23	47	43	42	45	0.60
	26.23	2592.6	5	9	5	6	19	19	15	18	0.65
	22.00	2597.5	14	11	16	14	23	19	24	22	0.70
'BB' 25% Laterite	21.13	2456.0	6	4	20	10	14	20	32	19	0.60
	26.64	2563.0	9	6	4	6	16	15	10	14	0.65
	11	2528.4	4	4	4	4	12	8	14	11	0.70
'CC' 50% Laterite	15.7	2291.4	12	4	18	15	19	10	30	25	0.60
	26.25	2503.7	5	6	7	6	16	17	15	16	0.65
	11	2513.6	3	3	3	3	10	11	13	11	0.70
'DD' 75% Laterite	6.0	2148.1	4	6	5	5	13	14	15	14	0.60
	16.28	2380.2	4	6	6	5	13	14	14	14	0.65
	16.00	2242.0	5	5	6	5	17	16	16	16	0.70
'EE' 100% Laterite	0.98	1703.7	1	2	2	2	4	7	8	8	0.60
	4.04	2123.5	2	2	2	2	7	8	6	7	0.65
	15.0	2232.1	5	4	3	4	13	13	18	15	0.70

Impact Resistance

From the results obtained, two factors are emphasized which are observed with almost all types of impact tests. The first one is that large variations occur in the number of blows required to produce the first crack among test specimens of the same mix and this happens to both plain and fibre-reinforced laterized concrete specimens. For example, 12, 6 and 7 blows were recorded for the first visible crack for the three samples of plain-laterized concrete and 29,25 and 11 blows for the three samples of fibre-reinforced laterized concrete. These differences reflect the randomness of cracking in concrete, the occurrence of weak sections in any concrete elements, the non-uniformity of fibre distribution and the obvious limitations of the type of impact tests such as the drop weight tests. Secondly such variations also occur in the number of blows sustained at ultimate failure but to a much lesser degree.

Mode of Failure under Impact

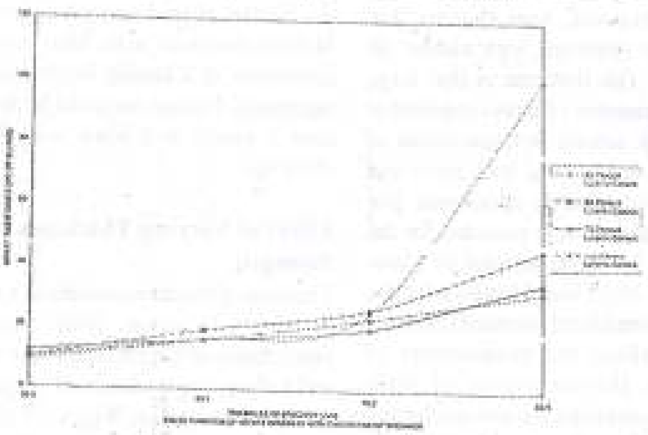
As for the plain laterized concrete, the mode of failure observed with fibre-reinforced concrete specimens is a tensile failure through the coarse aggregate. Failure occurred by breaking into more than 3 pieces and some wide cracks were also observed.

Effect of Varying Thickness on Impact Strength

The impact resistance results in terms of the number of blows to cause first crack for different percentages of laterite content in the cement matrix and for varying thickness of specimen are shown in Table 3. The graph (Figure 7) shows a plot of the impact resistance against the thickness of the laterized concrete specimen for each proportion of the laterite content in the cement matrix (28-day values only have been used).

Table 3: Impact Resistance Of Plain Laterized Concrete Specimens (4 Different Thicknesses)

Age of Laterized Concrete Specimen (Days)	Impact Resistance (No. of Blows) Thickness of Specimen (mm) 50.8	63.5	76.2	88.9	Percentage Laterite Content
3	11	12	14	23	25
7	12	23	20	61	
14	8	15	18	53	
28	9	16	25	101	
3	10	11	12	19	50
7	9	9	13	17	
14	13	20	22	30	
28	10	19	26	46	
3	8	11	12	20	75
7	10	13	14	23	
14	9	14	16	30	
28	12	16	20	35	
3	12	14	15	18	100
7	11	13	16	33	
14	12	18	20	46	
28	10	16	23	32	



GENERAL DISCUSSION

The falling weight test is a simple and practical test carried out under rather arbitrary conditions. Consequently they can only give an indirect assessment of the impact strength of plain and fibre-reinforced concrete. The failure definition specified in the falling weight test method recommended by the ACI Committee 544 Report is arbitrary. What's more, a rigid base supports the test specimen. In practice however, support conditions of both the plain and fibre-reinforced concrete elements are likely to be markedly different from those adopted in the test. Consequently the mode of failure and the impact resistance may be quite different from those observed.

It will therefore be difficult to generalize the results obtained in this investigation. In addition, the results cannot be interpreted as absolute values of inherent energy absorption characteristics of the material unless it will be possible to quantify the energy dissipation in the various supports used in the test method. It is also instructive to observe that the effects of scaling and modelling are not yet known, and since real elements are likely to be much larger than the test specimens used, it is very doubtful if the obtained results can be translated into prototype behaviour.

In spite of the obvious limitations enumerated above, the test method used in this investigation appears to take into account the properties of the cement matrix, the properties of the fibre and the nature of the interfacial bond between the aggregate and the matrix as well as between the fibre and the matrix. In conclusion, the test appears to provide a reasonable qualitative assessment of the impact strength of both plain and fibre-reinforced laterized concrete.

CONCLUSIONS

The main conclusions derived from this investigation are as follows:

1. Plain laterized concrete is inferior to plain normal concrete as far as density and compressive strength are concerned.
2. The modes of failure in the laterized concrete specimens are essentially the same as in plain concrete specimens and they are brittle failure occurring through the granite aggregate particles.
3. Large variations in the number of blows required to initiate first crack and in some cases to cause ultimate failure are observed. In some cases differences of over 100 percent are recorded.
4. The modes of failure of fibre-reinforced laterized concrete specimens are the same as for fibre-reinforced normal concrete specimens.
5. The compressive strength of the laterized concrete increased with the increase in the steel fibre-reinforcement content in the

mix only at a laterite content of 25 per cent as well as with increases in the sand content in the fine aggregate in the cement matrix.

6. The results show that even with a fibre content of only 0.5%, substantial increases in the impact strength and energy absorption can be achieved over those of plain laterized concrete. At high fibre content the results show that there is a more substantial increase in the impact resistance than at low fibre concentration.

7. There is an optimum value of fibre content above which there was a decrease in impact strength as fibre content in the cement matrix increased.

8. The presence of granite under the steel ball markedly affected the results of the tests in the sense that the presence of the granite under the ball increased substantially the number of blows to initiate the first crack in the test specimen and even to cause ultimate failure.

9. The impact resistance of the laterized concrete specimens increased as the thickness of the specimens increased.

10. In spite of the limitations of the drop test used in this investigation, the test adopted here offers a good assessment of the impact resistance of both plain and fibre-reinforced laterized concrete.

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