An Evaluation of Concrete Compressive Strength Using Computer Tomography Scan Method

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ABSTRACT

Compressive strength represents a basic standard by which the quality of concrete is assessed. However, in view of the inherent shortcomings of the compressive strength test, current trend is towards performance oriented test using Non Destructive Methods, NDT. This is a report on a research carried out on the assessment of concrete strengths using computer tomography (CT) scan method. First, a preliminary investigation of the various properties of the materials used for the production of concrete samples was carried out. Concrete samples were then prepared, cured and subjected to computer tomography (CT) scan test at the end of the following curing periods: 1, 3, 7, 14, 21, 28 and 56 days. Samples were then subjected to compressive strength test. Results showed compressive strength is related to the Hounsfield value by a correlation of 0.863. Correlation test, multiple regression analysis and graphs were used to analyze the results. Part of the conclusion drawn from the analysis is that CT scan is good in evaluating concrete strength. It was recommended that where CT scan is used, the following equation can be used to determine that compressive strength, $y = 5.6 + 0.00711X_t$.

KEYWORDS: Concrete, Non-destructive testing, Computer tomography scan, Compressive strength, Quality.

INTRODUCTION

Concrete is the most widely used construction material all over the world and is second only to water as the most utilized substance in the world. According to Mehta and Monteiro (2006), concrete benefits mankind more effectively than any construction material. The quality of concrete in any building project, therefore, determines, to a large extent, the quality of building production in terms of the performance of such structure, production cost and delivery time.

However, there are too many variables in the environmental conditions and workmanship that affect its quality (Garba et al., 2004; Neville, 2007; Gupta and Gupta, 2008; Neville and Brooks, 2010). The constituents of a good and bad concrete may be exactly the same; it is only the knowledge and skill of the producer often without additional cost of labour which are responsible for the difference. Unfortunately, according to Neville (2007), the engineer often knows less about the concrete of which the structure is made than about other popular manufactured construction materials, like steel. This means that there exists the need to take measures throughout the entire stages of production of concrete so as to ensure the production of qualitative concrete; quality control. Testing is an inseparable part of quality control. This explains the reason why there is always a provision for testing of concrete in any large-or medium-sized building or civil

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engineering project, and money is set aside for that. It is often necessary to test concrete structures after concrete has hardened in order to determine whether or not the structure is suitable for its designed use. Ideally, such testing should be conducted without damaging the concrete. In view of the many shortcomings associated with the compressive strength test, there exists the need for a viable alternative. Non-destructive testing seems to be the right choice. According to Shetty (2009), NDT is now considered as a powerful method for evaluating existing concrete structures with regard to their strength and durability apart from assessment and control of quality of hardened concrete. Gambhir (2006) noted that there is now a switch-over to performance oriented test through the use of non-destructive method. This, perhaps, explains the reason why Akkaya et al. (2002) noted that the evaluation of mechanical properties of concrete by non-destructive techniques is one of the most challenging tasks in modern civil engineering.

Furthermore, the increasing age of reinforced concrete structures all over the world has led to the growing need for reliable tools for concrete degradation assessment. Also, studies of micro-structure property relationships are at the heart of modern material science. In other words, there is a demand for modelling of material properties on a meso-scale rather than on the macro-scale only (Reinhardt, 2002). As such, tools are needed that allow close examination into a material rather than onto a surface only; molecular analysis.

MATERIALS AND METHODS

Materials

The materials used in the experiment are: cement, fine aggregates, coarse aggregates and water. Preliminary tests were carried out on these materials so as to establish preliminary test results and obtain appropriate parameters. The various tests undertaken were as follows:

Cement

The type of cement used for the study was Ordinary Portland Cement, OPC, manufactured and recently supplied by the Dangote Cement Company. Various tests were undertaken so as to ensure compliance with the relevant standards. These tests were carried out on the cement used in accordance to the Nigerian Industrial Standards: NIS 11 (1974), NIS 445 (2003), NIS 447 (2003), NIS 455 (2003) and British Standards BS 12 (1996) and EN 197-1 (2000). Setting time test, as well as soundness and consistency tests were undertaken in a concrete laboratory at the Department of Civil Engineering, Ahmadu Bello University, Zaria, Nigeria.

Chemical analysis of the cement samples was also carried out at the Center for Energy Research and Training, CERT, Ahmadu Bello University, Zaria, Nigeria.

Fine Aggregates

Fine aggregates used in this research work were clean and air - dried river sand obtained from Samaru – Zaria. It was sieved with a 5 mm B5 112 (1971) sieve, so as to remove impurities and larger aggregates. Before fine aggregates were used, they were subjected to sieve analysis. This was undertaken in accordance to BS 933-Part 1 (1997). Other properties of fine aggregates that were investigated include: specific gravity on oven-dried basis, apparent specific gravity and water absorption. These tests were carried out in accordance to the following British Standards: BS 812 (1990), BS 882 (1992) and BS 933 (1997).

Coarse Aggregates

Coarse aggregates used were crushed granite stones obtained from a single quarry site along the Zaria-Sokoto road. Sieve analysis was carried out on the coarse aggregates used in the experiment in accordance to BS 933- Part I (1997).

Other properties of coarse aggregates that were investigated include: specific gravity on oven-dried basis, apparent specific gravity and water absorption.

These tests were undertaken in accordance to the following British standards: BS 812 (1990), BS 882 (1992) and BS 933 (1997).

Water

Water used for mixing was clean, fresh water, free from injurious oils, chemicals and vegetable matter or other impurities.

Equipment Used

In the course of carrying out the various experiments, certain equipment were used. Details of the types of equipment used are presented in Table 1.

Table 1. Types of tests and description of equipment used

Type of Test	Description of Equipment/Device Used
Compressive strength	Universal compressive testing machine, produced by Saml Denison & Son, Ltd., Houslet Foundry, Leeds, England, U.K.
Computer tomography scan	Nix high speed computer tomography scanner manufactured by clinical equipment company in 2004.

PRODUCTION AND TESTING OF CONCRETE SPECIMEN

Trail Mix

A trail mix was carried out in order to determine the most suitable water-cement (W/C) ratio and compaction method. An absolute volume method of batching with a nominal mix ratio of 1:2:4 and three (3) different W/C ratios of 0.4, 0.5 and 0.60 were used. The samples were tested to destruction after 7days.

Final Mix Design

The final mix design entails the use of absolute volume batching with a nominal mix of 1:2:4 and a water-cement ratio of 0.50 to determine the proportion of each constituent to be used in the production of concrete samples. Mixing machine, a horizontal rotary drum mixer, and manual compaction method were employed in the production of pieces of 150 mm x 150 mm x 150 mm concrete cubes. Details of the materials needed for a batch of 6 concrete cubes are presented in Table 2.

Table 2. Quantity of materials required for a batch of 6 concrete cubes

S. No.	Types of Material	Quantity of Material Required (kg)
1	Cement	7.09
2	Sand	15.50
3	Coarse Aggregates	30
4	Water	3.25

Computed Tomography Scan - (CT Scan)

The test was carried out at the Department of Radiology, Ahmadu University Teaching Hospital, Zaria, Nigeria. Samples of concrete cubes were subjected to CT scan after each required curing period. Also, two 150 mm x 300 mm concrete cylinders were produced and three (3) steel reinforcement pieces were put in one cylinder whereas four (4) pieces were placed in the other cylinder. The procedure is as follows:

The sample was removed from the curing tank, dried and weighed. It was, then, placed in the CT scan machine/device. Brain protocol was used for the test. Using AX IAL scan, with 2 mm slice thickness, a scanogram was taken for the sample as the base which allows to plan so as to get the next series scan. The series scans were used to obtain images of internal structure of the concrete. The radiation exposure factor used was 120 kVp with standard time of 300 MAs. The images of concrete samples produced by the CT scan were then used to:

1. Determine the Hounsfield values.
2. Calculate the density of the concrete samples using the processed CT scan images by obtaining the readings using densitometer from such images.

Determination of the Hounsfield Values

The Hounsfield values were obtained directly from the computer by placing the cursor of the computer on the image, and the Hounsfield values were immediately displayed at the left hand side of the image, as shown in Figure 1.

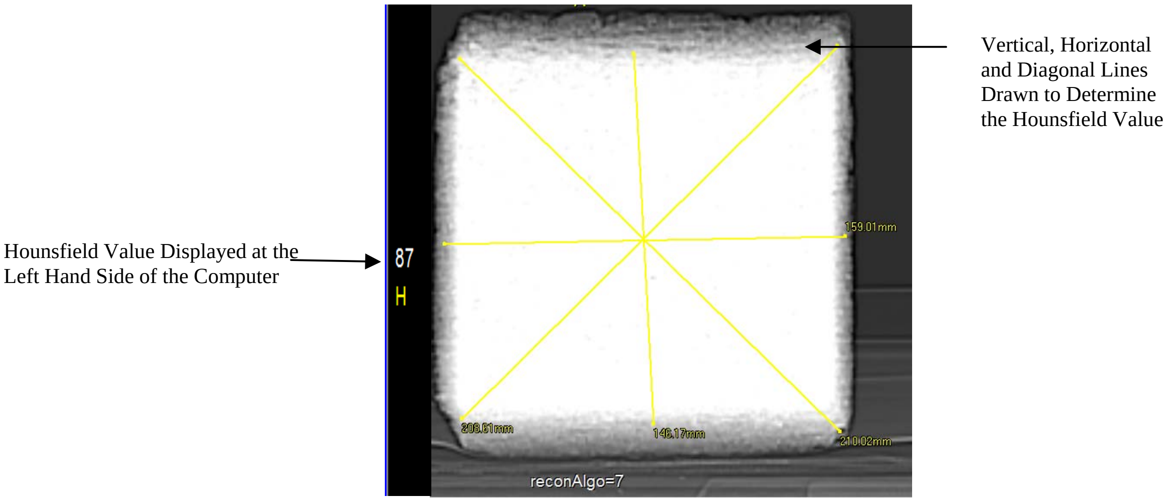

Figure (1): Determination of the Hounsfield Value from the Computer

Determination of Density from Images of Concrete Samples on the Films Developed

The images from the film produced by the CT scan were used to determine the density. The summary of the procedure is as follows:

An instrument used for the determination of density, called densitometer (type X), was used. The unit was switched on, a digital readout was displayed. Then, the probe-tip of the unit was placed against the light source to be used, and slight forward pressure was applied. The density reading of the film, including the base fog, is now displayed on the Digit-X. The unit was kept at right angles to the light source at all times during measurement. After each reading, the probe tip was removed from the source and the zero buttons were pressed so that the instrument would display 0.00. The same procedure was repeated for all readings. At least 2 minutes were given before taking readings on a new film.

Compressive Strength Test

The aforementioned NDT procedures (ultrasonic pulse velocity test, rebound hammer, determination of radiation attenuation coefficient of concrete cube and CT scan), were followed by the destructive compression test. A Universal Compression Testing Machine with a capacity of 3000kN was used for that purpose.

Compressive strength of concrete specimens was determined by placing, one after the other, 150 mm x 150 mm x 150 mm concrete cubes centrally in between the platens of the testing machine. The concrete sample was placed in such a way that the axis of the specimen is aligned with the axis of the loading device. There was no packing used in between the bearing surface of the machine and the specimen. Concrete cubes were then subjected to increasing load and pressure applied to the samples, until the specimen failed. Load was applied without jerking or shock. The rate of loading was 0.233 MPa per second. The test was undertaken at the Concrete Laboratory, Department of Civil Engineering, Ahmadu Bello University, Zaria, Nigeria.

RESULTS OF CT SCAN OF CONCRETE SAMPLES

Hounsfield Values and Readings Obtained from the Processed X - Ray Images

The Hounsfield values were recorded directly from the CT scan images obtained directly from the computer. The other results were determined from the processed CT scan images on the processed CT scan films. Details of the results are presented in Tables 3 and 4.

Table 3. CT scan number from the images of concrete samples in the computer

Age (Days)	Weight (kg)	C.T. Scan Number (Hounsfield)	Average	Standard Deviation
1	8.20	1647,1579,1781,1588,1605,1472,1576,1489,1615,1771	1612.3	101.6
3	8.10	1959,2021,2124,2697,2515,2035,2746,2907,2743,2339	2408.6	356.9
7	8.25	3089,2213,3278,3369,2263,2454,2893,3415,3089,2400	2846.3	471.1
14	8.20	2901,2540,2459,2867,3342,3496,3668,3147,3104,2243	2976.7	464.4
21	8.20	3030,3577,3318,3580,2836,2346,3006,2788,3527,2371	3037.9	463.1
28	8.15	3432,3435,3967,2212,2364,3334,3614,3168,3272,3064	3186.2	535.9
56	8.30	2167,3091,3638,3030,2132,2274,3008,2220,2112,2235	2590.7	547.5

A total of ten readings were recorded for each of the samples tested. The average of the results and the standard deviation were calculated.

Table 4. Readings from processed CT scan images using densitometer

Age (Days)	Weight (kg)	Reading from processed CT Scan images	Average	Standard Deviation
1	8.20	0.01,0.05,0.07,0.02,0.01,0.04,0.02,0.08,0.23,0.26	0.08	0.09
3	8.10	0.16,0.06,0.21,0.03,0.06,0.10,0.04,0.35,0.38,0.68	0.21	0.27
7	8.25	0.29,0.46,0.45,0.25,0.10,0.06,0.34,0.16,0.33,0.25	0.25	0.13
14	8.20	1.02,0.51,0.46,0.04,0.42,0.07,0.37,0.01,0.23,0.26	0.34	0.29
21	8.20	0.07,0.26,0.23,0.01,0.23,0.61,0.71,0.69,0.13,0.50	0.34	0.26
28	8.15	0.08,0.04,0.58,0.91,0.45,0.86,0.29,0.43,0.38,0.01	0.40	0.32

Table 5. Hounsfield values from the images of concrete samples in the computer and densitometer readings from processed CT scan images

Curing days	Weight	CT Scan No. (*Hounsfield Value*)	Readings from Processed CT Scan Images	Compressive Strength (N/mm^2)
1	8.20	1612.3	0.08	18.89
3	8.10	2408.6	0.21	20.00
7	8.25	2846.3	0.25	23.56
14	8.20	2976.7	0.34	24.89
21	8.20	3037.9	0.34	29.33
28	8.15	3186.2	0.40	30.89

CT scan numbers ranged from 1612.30 to 3186.20. The density obtained from the densitometer readings ranged from 0.08 to 0.40.

RESULT OF CT SCAN TEST

Relationship between Hounsfield Value, Densitometer Readings and Compressive Strength

Correlation test was used to analyze the results of CT scan test and compressive strength test. Result of the correlation test is summarized in Table (6).

Table 6. Correlation of compressive strength against Hounsfield value, densitometer reading and weight

	Hounsfield Value	Densitometer Reading	Weight
Compressive Strength	0.863**	0.207	0.283

Note: * *Correlation is significant at 0.05 level.*
** *Correlation is significant at 0.01 level.*

There is direct correlation of 0.863 between the compressive strength and the CT scan number (Hounsfield value). When this value is compared to the maximum value (1.0), it is seen that such a relationship is a strong one, though not perfectly linear (direct relationship). This means that 86% of the Hounsfield values are directly related to compressive strength.

Regression analysis was also used to analyze the results considering the compressive strength as the independent variable and the Hounsfield value of the concrete sample as the dependent variable, meaning that the equation that can be used to predict compressive strength (y) given the Hounsfield value, is especially considering the fact that R square is 74.5% .The equation is as follows:

$$y = 5.6 + 0.00711X_1$$

where: y = Characteristic strength.
X_1 = Hounsfield value.

It follows that when the CT scan is used, quite apart from the examination of the internal structure, it can be used to predict the compressive strength which is the most important index for gauging the quality of concrete.

Additionally, a formula for assessing the characteristic strength of concrete cubes was determined. The formula is as follows:

$$C = 0.008\ N$$

where: C = Characteristic strength.
N = CT scan number.

The two formulae obtained from the regression analysis and the graph of characteristic strength of concrete cubes against the CT scan number were used to convert the CT scan test result into the characteristic strength. Thereafter, the values determined were used to plot three graphs. These graphs are:

i. The graph of concrete cube characteristic strength obtained from the destructive (compressive strength) test.
ii. The graph of CT scan test results converted into characteristic strength using the formula obtained from the regression analysis ($y=5.6+0.00711X_1$).
iii. The graph that was plotted using the result of comparative analysis of concrete characteristic strength and RAC test results ($C=0.0408R$).

In case of densitometer readings, there is a linear correlation of 0.207, but it is a weak correlation. But, when the densitometer readings are compared with the weight, the result of analysis shows that there is an inverse correlation of -0.592. However, as regards to the relationship between Hounsfield value and weight, there is a very weak correlation of 0.126.

Regression analysis was also used to analyze the results considering the compressive strength as the independent variable and the Hounsfield value of the concrete sample as the dependant variable. The constant, the intercept, is given as 46.450 and the level of significance is 0.051 which is slightly greater than 0.05; while the slope is - 103 and the level of significance is 0.308 which is much higher when compared to 0.05. This means that the equation that can be used to predict compressive strength (y) given the Hounsfield value, is:

$$y = 46.450 - 403X_1$$

where y = Compressive Strength.

X_1 = Hounsfield value.

It follows that when CT scan is used, quite apart from the examination of the internal structure, it can be used to predict the compressive strength which is the most important characteristic of concrete.

The readings obtained from the processed CT scan images were also converted into the compressive strength by analyzing the concrete cube compressive strength and the test result of CT scan. The compressive strength obtained and the concrete cube compressive strength are shown in Table 8.

Table 7. Characteristic strength obtained from CT scan results using the formulae derived from the analysis

Age	Regression Analysis (*y=5.6+0.00711X*)	From Graph (*C=0.008N*)	Concrete Cube Characteristic Strength
1	17.06	12.90	18.89
3	22.73	19.27	20.00
7	25.84	22.77	23.86
14	26.76	23.81	24.89
21	26.87	24.30	29.33
28	28.25	25.49	30.89

Table 8. Compressive strength obtained from readings from processed CT scan images using the formula derived from regression analysis

Age	Regression Analysis (*y = -78.5122+381.86X*)	Concrete Cube Compressive Strength
1	47.96	18.89
3	1.68	20.00
7	16.95	23.86
14	51.32	24.89
21	51.32	29.33
28	152.74	30.89

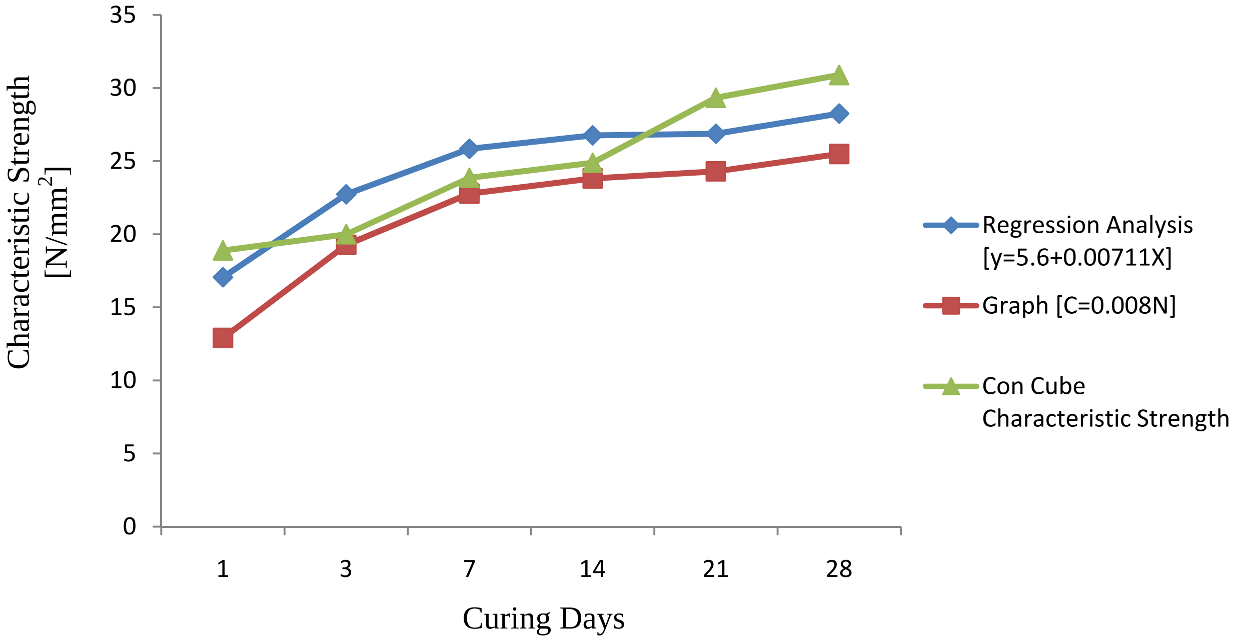

Figure (2): Characteristic strength obtained from CT scan results using the formulae derived from the analysis

Looking at Figure 2, it can be noted that, although the three graphs are not exactly the same, they are very close to each other assuming similar form. This is particularly so in case of the two graphs drawn from the result of analysis of the CT scan test result and the characteristic strength. This again confirms an important observation made earlier, stating that the CT scan result can be used to determine the strength of concrete.

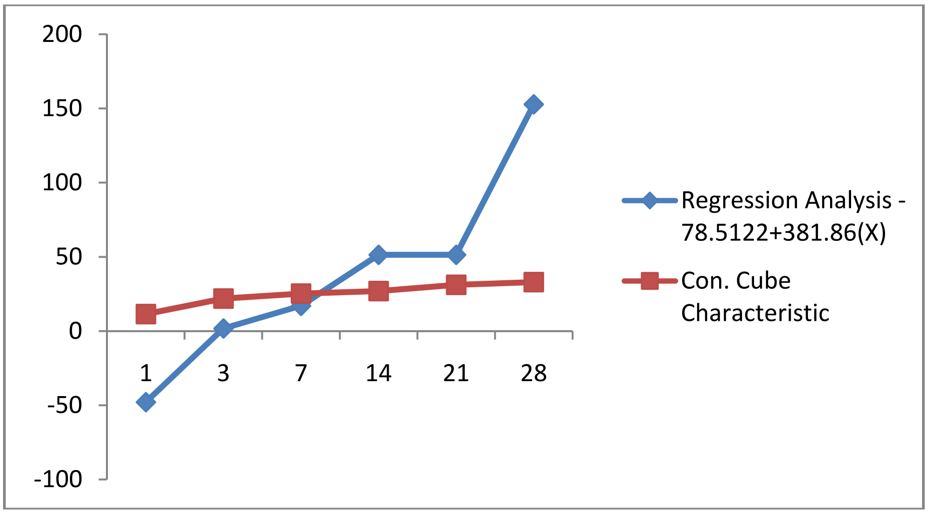

Figure (3): Result of processed CT scan image converted into strength and concrete cube characteristic strength

Figure 3 shows the graph of the result of processed CT scan image converted into strength using regression analysis equation and the graph of concrete cube characteristic strength. Looking at the two graphs, it will be noted that they are at variance to each other. This implies that the regression equation cannot give an accurate estimate of characteristic strength of concrete.

CONCLUSIONS

After carrying out experiments, observations, analysis and discussion on the CT scan test method, the following conclusions can be drawn.

1. There is a relationship between the weight, and hence the density of concrete, and the Hounsfield value is 0.126.
2. The Hounsfield value (also known as CT scan number) is directly related to the characteristic strength. The value of such correlation is 0.863.
3. The equation that can be used to predict characteristic strength (y) given the Hounsfield value, is:

   $y = 5.60 + 0.00711X_1$.

   where y = characteristic strength.
   X_1 = Hounsfield value.
4. The readings of the densitometer obtained from the processed CT scan film have a weak correlation of 0.207 with the compressive strength and an inverse relationship of - 0.592 with the weight of the concrete sample.
5. The regression equation obtained from densitometer reading from the processed CT scan image cannot give an accurate estimate of characteristic strength of concrete cubes.
6. The densitometer instrument is not suitable for determining the compressive strength and density of concrete samples from the processed CT scan

images of the concrete samples.

7. In this study, the physical aspect; like the size, number and nature of voids noted in the CT scan test, seems to give more meaningful information on its relationship with compressive strength than the chemical analysis using AAS and XRF.

RECOMMENDATIONS

Based on the results of the study, the following recommendations are made:

1. Where CT scan is used to examine concrete, it is suggested that the following equation can be used to determine the characteristic strength of concrete:

$$y = 5.60 + 0.00711X_1$$

where: y = Characteristic strength of concrete.
X_1 =CT scan number.

2. A joint research should be undertaken between physicists, civil engineers/builders, mechanical and electrical engineers to study the possibility of designing and fabricating a portable device that uses the principle of CT scan machine which can be used for examining the internal structure of concrete, detecting concealed reinforcement bars, examining the internal condition of concrete,... etc.

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REFERENCES

Akkaya, Y., Voigt, T., Subramaniam, and Shah, S.P. (2003). "Non-destructive measurement of concrete gain by an ultrasonic wave reflection method". Materials and Structures Journal, 36 (8), 507 – 514.

British Standard, BS 12. (1996). “Portland Cement”. BSI, Linfordwood, Milton Keynes MK14 6LE, U.K.

British Standard, BS 882: 109. (1992). “Aggregates from Natural Sources for Concrete”. BSI, Linfordwood, Milton Keynes MK14 6LE, U.K.

British Standard, BS 933: 1. (1997). “Determination of Particle Size Distribution – Sieving Method”. BSI, Linfordwood, Milton Keynes MK14 6LE, U.K.

British Standard, BS 812: 109. (1990). “Method for Determination of Moisture Content of Aggregate”. BSI, Linfordwood, Milton Keynes MK14 6LE, U.K.

British Standard, BS 1881: 124. (1988). “Methods of Analysis of Hardened Concrete”. BSI, Linfordwood, Milton Keynes MK14 6LE, U.K.

British Standard, BS 112. (1971). “Determination of Properties of Fine Aggregate”. BSI, Linfordwood, Milton Keynes MK14 6LE, U.K.

Gambhir, M.L. (2006). “Concrete Technology.” Second Edition, Tata McGraw Hill, New Delhi, India.

Garba et al. (2007). “An Investigation into the Practice of Mixed Design of Concrete in the Nigerian Construction Industry.” Journal of Environmental Technology. ATBU Bauchi –Nigeria.

Gupta, B.I., and Gupta, A. (2008). “Concrete Technology.” Standard Publishers-Distributors. New Delhi, India.

Mehta, K.P., and Monterio, P.J.M. (2006). “Concrete: Microstructure, Properties and Materials.” McGraw Hill, Ltd., California, U.S.A.

Neville, A.M. (2007). “Properties of Concrete". Addison Wesley Longman, Ltd., Edinburgh Gate, Harlow Essex CM 20 2JE, England.

Neville, A.M., and Brooks. (2010). “Concrete Technology.” Second Edition, Addison Wesley Longman, Ltd., Edinburgh Gate, Harlow Essex CM 20 2JE, England.

NIS 013. (1974). "Specification for aggregates from natural sources for concrete". Suite 1, 24 Greenville Estate Badore, Lekki-Ajah, Lagos, Nigeria.

NIS 014. (1974). "Methods for the sampling and the testing of minerals aggregate, sand and filler". Suite 1, 24 Greenville Estate Badore, Lekki-Ajah, Lagos, Nigeria.

NIS 447. (2003). "Methods of testing cement-determination of setting time and soundness". Suite 1, 24 Greenville Estate Badore, Lekki-Ajah, Lagos, Nigeria.

NIS 455. (2003). "Methods of testing cement-taking or preparing samples of cement". Suite 1, 24 Greenville Estate Badore, Lekki-Ajah, Lagos, Nigeria.

Reinhardt, H.W., and Grosse, C.U. (1999). "Setting and Hardening of Concrete Continuously Monitored by Elastic Waves." http://www.ndt.net/article/grossel/grossel.htm: Retrieved 2009.

Reinhardt, W.W., Grosse, C., and Herb, A. (2000). "Ultrasonic Monitoring of Setting and Hardening of Cement Mortar- a New Device." Materials and Structures, 33 (233).

Shetty, M.S. (2009). "Concrete Technology: Theory and Practice." S. Chand and Company, Ltd., Ram Nagar, New Delhi 110 055, India.