Direct Research Journal of Engineering and Information Technology
Vol. 9 (7), Pp. 285-292, August 2022
ISSN 2354-4155
DOI: https://doi.org/10.26765/DRJEIT16716303
Article Number: DRJEIT16716303

http://directresearchpublisher.org/drjeit/

Full Length Research Paper

Assessment of Compressive Strength of Concrete using Atomic Absorption Spectrometry and X-Ray Fluoroscopy in Selected Construction Projects Within Federal Polytechnic Kaura Namoda Zamfara State

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Received 9 July 2022; Accepted 30 July 2022; Published 11 August 2022

ABSTRACT: One of the most serious difficulties experienced in building construction is the use of poor construction materials, which causes structural collapse in the Nigerian construction sector, resulting in the loss of life and property. This is an assessment of concrete production in selected construction projects at federal Polytechnic Kaura Namoda using atomic absorption spectrometry and X-ray fluoroscopy technologies. Because of differences in compaction, curing, and workmanship, tests done on standard hardened concrete specimens from new concrete frequently mislead the genuine grade of concrete actually utilized in the project. Modern compliance testing methods include atomic absorption spectrometry and X-Ray fluoroscopy. It was accomplished by laboratory experimentation and careful examination of contract documents, with a focus on mix design/specification. The information acquired from the document was then used to create concrete samples (control sample). Renal samples of actual concrete used were collected at random, cured, and subjected to atomic absorption spectrometry and X-ray fluoroscopy after 1, 3, 7, 14, 21, 28, 56, and 90 curing days, respectively. The identical samples were compressed strength tested to destruction. Elemental analysis using the AAS method traced eleven elements. Samples were generated from the concrete specimen and submitted to elemental analysis using Atomic Absorption Spectrometry, AAS, and X-Ray Fluoroscopy, XRF. These are: Fe, Ca, mg, Zn, Ca, Mn, K, Na, Cd, and Cr. While XRF method determined eight elements. These are: Ai, Si, Ca, K, Na, Ti, Fe and Mn. According to the study's findings, zinc, copper, manganese, potassium, and Cd have a positive association. The correlations are as follows: 0.281, 0.023, 0.485, 0.434, and 0.023. As a result, they all have a direct relationship. However, the correlations are not significant because all of the factors are much below 1.0. This demonstrates that these elements cannot directly give an idea of compressive strength; additionally, the study demonstrates that non-adherence to the correct steps of concrete production, such as the use of the incorrect water/cement ratio and the use of a crude method of batching, were identified as common problems in concrete production. Checklist was prepared on the right method of concrete production and used to assess how concretes were produced. It was also found that the average compressive strength of concrete produced on two construction projects as 10.47 N/mm^{2}and 6.96 N/mm^2 did not attain the minimum strength required at 28 days which is 21 N/mm^2 by the BS 1881, (1983b) part 116, while the concrete produced on another sites has a strength of 20.01N/mm^2 at 28 days which is close to the specification of BS 1881 and the controlled sample average strength of concrete at 28 days was 23.79N/mm^2 which is within the range specified by the BS 1881 part 116 (1983b).Based on the results obtained, the compressive strength of concrete collected from sites was less than the control specimen by 14% hence it was recommended that 14% should be added to the estimated design strength as a factor of safety to take care of the problems of the handling of the concrete materials and other construction inaccuracies. Government and professional bodies should make concerted effort in enforcing National Building Code.

Keywords: Concrete, atomic absorption spectrometry, X-ray fluoroscopy, production, quality

INTRODUCTION

One of the serious problems facing the construction industry in Nigeria is structural failure, Adenuga (2008) in Olufemi (2015) reported that over 136 reported cases of collapsed building occurred in Nigeria between 1974 and 2008. Result of investigation revealed that the use of defective construction materials is one of the major cause of structural failure (Emeka, 2019). Concrete is the most widely used construction material, not only in Nigeria, but all over the world. According to Dahiru (2010) twice as much concrete is used in construction around the world than other construction materials-including wood, steel, plastic and aluminum. Thus, any discussion on structural failure would not be complete without reference to concrete. (Dahiru, 2010). However, unlike most other prominent construction material like steel, which is produced under carefully controlled conditions, with even the properties determined in a laboratory and clearly described in a manufacturer's certificate, the quality of concrete is subject to variation from the one designed or specified. Concrete's constituents are handled and subsequently mixed together to give certain required quality/properties, these include compressive strength, workability, durability and good cohesion. It is certain that when these requirements are not met, failure may occur (Okekere, 2007). To guide against failure, there is the need for quality control which according to Gambhir (2006) is a corporate, dynamic programme to ensure that all aspects of materials, equipment and workmanship are well looked after. Quality control is therefore, conformity to the specifications. The owner will have no right to expect anything more than what is in the specification. The builder, on the other hand knows that anything less than what is in the specification will not be acceptable to the client. International Atomic Energy agency. IAEA (2002) defined quality control as the controls applied to each production stage to produce a qualitative product.

Conforming to standards, according to Gambhir (2006), is the most feasible approach of quality control. Testing concrete is a major and very important step in quality control. Because compressive strength is the most important property of concrete, which is used to assess most other properties of concrete, compressive strength is used as a quality index by not only design and control engineers, but also professional Builders. McCosh (1997), Gupta and Gupta (2008), Ede (2010), Shetty (2009), and Neville and Brooks (2010) The majority of the concrete used in Nigeria's building industry is in-situ cast concrete. Furthermore, there is substantial evidence that improper treatment of constituent materials and final products before to placement may be to blame for the manufacture of inferior concrete. This necessitates an improvement in the management of concrete and its constituent ingredients. Furthermore, it is not only desired but also required that design and control engineers understand the quality of concrete produced on site so that they may have a solid picture of the level of departure from the specifications given in the contract agreement. This will aid in arriving at a realistic estimate of allowance (Factor of safety) that should be included in concrete design and specification to guide against failure. This explains why several academics, including Garba et al. (2004), Okekere (2007), Dahiru (2010), Emeka (2011), Ede (2010), and Sadiku (2010), worked on the topic of concrete production in Nigeria (2011). According to Okekere (2007), there are contradictions in the results of many concreting researches, largely because researchers were unable to simulate site conditions in the laboratory, leading some experts in hot weather concreting to conclude that the results of concrete production studies are far from conclusive (Okekere, 2007). This necessitates the development of yet another loom for the study of concrete production. This is especially significant given the construction industry's dynamic nature. Ede's previous results may no longer be applicable at this time (2010). In addition to the fact that the materials for good and terrible concrete may be the same, the difference in quality is due to the individual generating the concrete's familiarity, dexterity, and experience. This is a report on the evaluation of concrete production in selected construction projects at Federal Polytechnic Kaura Namoda Zamfara State, with an emphasis on atomic absorption spectrometry and X-ray fluorescence.

In order to achieve the desired goal, the following steps were followed:

Study the handling process and the workers producing concrete.

To determine the quality of concrete as specified by contract document with special reference to structural design, specification and Bills of quantities.

To Study contract documents, the handling process and caliber of workers especially level of supervision and the commitment exhibited by the workers towards the achievement of good quality concrete during concrete production.

To use the information so obtained, from step 1, 2, and 3 to produce control samples of concrete and determine the quality of concrete produced on site, with emphasis on atomic absorption spectrometry and X-ray fluoroscopy.

To compare the quality of concrete in selected construction projects within federal polytechnic Kaura Namoda. and the one produced in laboratory.

METHODOLOGY

The methods used can be summarized under the following headings:

Field survey and study of contract documents

Studying the contract documents to come up with the actual quality of Concrete specified.

(i) Site visit to observe the concrete practices. – Especially handling process.
(ii) Structured interview and interaction with the supervisors of concrete production.

Experimental programme

In view of the fact that researchers have undertaken studies on various aspects of concrete production in

Nigeria, this paper made an attempt to report on not only the quality of concrete produced but to examine effort made in solving the observed problems of concrete production. For instance, problems due to high temperature and high relative humidity, etc. To achieve the desired objective, three construction sites were selected for that purpose. These construction sites are located within the Federal Polytechnic Kaura Namoda, were included in the study. Contract documents for such projects were studied. So as to know the quality of concrete specified in the contract document, for projects under study. This was then used to produce a control sample. Also, the actual concrete produced in these sites under study, were randomly collected and their compressive strengths were determining by using Atomic Absorption Spectrometry, AAS and X-Ray Fluoroscopy, XRF. The study was confined to medium and Large sized projects; for the fact that recent study revealed that structural failure is more pronounced in buildings from five storey down wards (Dahiru, 2011).

MATERIALS AND METHODS

The study used cement, fine aggregate, coarse aggregate, and ready-mixed concrete from Federal Polytechnic Kaura Namoda.

Cement

The cement used for the experiment was Ordinary Portland Cement, OPC, manufactured and recently supplied by Sokoto cement. It conforms to the relevant Nigerian and British standards.

Fine aggregates

Fine aggregates used in this research work were clean and air - dried river sand obtained from Zamfara state. It was sieved with a 5mm BS 112 (1971) sieve, so as to remove the impurities and larger aggregates. Before the fine aggregate was used; it was subjected to sieve analysis. This was undertaken in accordance to the BS 933 Part 1 (1997).

Coarse aggregates

The coarse aggregate used were crushed granite stones from single quarry obtained from Zamfara State, Nigeria.

Harmful impurities

The aggregates were inspected in order to determine whether they contain harmful impurities in such a form or quantity that can adversely affect the properties of concrete. The result of the inspection showed that no such impurities were present.

Test samples

Ready mixed concrete was collected from the actual concrete sample produced and used for the construction of buildings at the sites under study. The samples were prepared in 150mm x 150mm x 150mm cubes, cured and subjected to compressive strength tests and analysis using Atomic Absorption Spectrometry, AAS and X-Ray Fluoroscopy, XRF. after each curing day. Then a control sample was produced using the specification contained in the Contract documents. This is in order to compare the samples produced at each site with one specified in the contract document. A total of 12 concrete cubes (150mm x 150mm x150mm) were produced and used as control sample for this experiment. While 36 concrete cubes were obtained from the sites considered this was because in all the sites considered the specifications were the same.

Study of the concrete production

Documents

These consist of Bills of Quantities, Specifications, article of agreements and conditions of contract which were under the custody of the contractor and were carefully studied and used for this study.

Caliber of operatives producing the concrete

There were encounters with the personnel assigned to produce concrete. In order to determine the quality of the labour force engaged for concrete manufacturing on these locations.

Method and quality of supervision of concrete production

Part of the research entails close study of concrete production on the selected sites. This was undertaken by, personally, visiting the sites and making a close observation of the nature, quality of materials, method of batching, mixing and time of mixing concrete, etc. The way and manner in which the aforementioned activities were carried out, were noted and then compared with a prepared checklist on the right procedure of undertaking these activities as enunciated by experts. The quality and extent of supervision was also investigated.

Method of assessing concrete production

Thirty (30) of the main variables that should be considered in the production of high quality concrete were utilized as a checklist, and points were assigned to each factor based on the degree of conformance to the defined standard. The following is the grade: Excellent (5), Very Good (4), Good (3), Fair (2), Poor (1) The following were used to grade concrete manufacturing in the locations examined for the overall assessment: 150 - 129 - Excellent, 120 - 91 - Very Good, 90 - 61 Good, 60 - 31 - Fair, 30 - 0 Poor. In evaluating concrete output at the sites evaluated, personal judgment, attentive observation, and supervisor responses were used.

Test procedures

In addition, the research includes a careful examination of the internal structure of concrete samples, elemental analysis, and their impact on the compressive strength of concrete. The elemental analysis utilizing AAS and XRF methods is not intended to explore chemical transformations, but rather to investigate the link between elements in a given mix and compressive strength. Concrete compressive strength testing was performed in the Department of Civil Engineering Technology Laboratory, Federal Polytechnic Kaura Namoda Zamfara State, in conformity with the relevant requirements, particularly the British Standards. Because the most significant properties of fresh and hardened concrete are workability and compressive strength, respectively. The following tests were carried out. Crushed compressive strength test samples were used to prepare test samples for Atomic Absorption Spectrometry (AAS) and X-Ray Fluoroscopy (XRF). All experiments were conducted in compliance with British Standards and other pertinent documentation.

Assessment of workability

Slump test was used to assess the workability of the fresh concrete sample used for the experiment.

Compressive strength test

The compressive strength was carried out followed by using Atomic Absorption Spectrometry, AAS and X-Ray Fluoroscopy, XRF. of concrete sample from the chosen construction sites were determined.

Cube density test

Density of concrete samples were determined

RESULTS AND DISCUSSION

Presentation of results

The results of the compressive strength test for the controlled one was obtained from contract documents and the samples obtained from the three sites considered are given below. From the (Table 1) concrete at the age ranging from 7 days to 28 days at controlled level which is specified in the contract documents has strength ranging from 15.51N/mm^2 to 21.00N/mm^2 while those obtained from various sites have an average compressive strength ranging from 5.83N/mm^2 to 20,01N/mm^2 it can also be observed that the compressive strength in site 3 is close to the one specified in the contract documents while site 1 and 2 are less than that of the controlled one (contract documents) this represent 14% of compressive strength which is far below the requirements and provision of contract documents, it is also an indication that the quality of concrete produced by the contractors in the various sites does not conforms to standards as specified in the contract documents.

Atomic Absorption Spectrometry (AAS) Test

The experiment was carried out at the National Animal Production Research Institute (NAPRI) Shika - Ahmadu Belle University, Zaria. The steps observed are as follows: The sample for analysis was weighed and grounded in an agate mortar. A binder (PVC dissolved in Toluene) is added to the sample, carefully mixed and pressed in a hydraulic press into a pellet. The pellet is located in the sample chamber of the spectrometer and voltage (30KV maximum) and a current (1mA maximum) was applied to produce the X-rays to excite the sample for a present time (l0mins in this case). The spectrum from the sample was then analysed to determine the concentration of the element in the sample. The test was carried out at the end of 1, 3, 7, 14, 21, 28, 56 and 90 curing days. Result of AAS test shows the number of elements traced and the quantity of each, in a particular curing day. As observed in (Table 2), AAS test traced up to ten elements. However, Cr was not seen in the 1st, 3rd and 90th curing day's tests.

The X-Ray Fluorescence Spectrometry - (XRF)

The experiment was carried out at Ahmadu Bello University's Centre for Energy Research and Training (CERT). Following the destruction of the concrete cube sample (compressive strength test), the concrete sample specimen was subjected to elemental analysis using the X-ray fluorescence spectrometry, the XRF test Mini Pal, which is a compact energy dispersive X-ray Spectrometry designed for such tests, was used. A PC running the proprietary Mini Pal analysis software controls the system. Mini Pal Version 4 type PW 4030 X-ray Spectrometry was utilized for this investigation. It is an energy dispersive microprocessor-controlled analytical equipment developed for the detection and measurement of elements in samples (solids, powders, and liquids) ranging from sodium to uranium. The result of concrete sample prepared and subjected to the XRF test is presented in the (Table 3). Result of the X – Ray Fluoroscopy test shows that eight (8) elements were traced however the Mn was given in ppm.

Table 2: Atomic absorption spectrometry, AAS test results.

Curing Days	%Fe	%Ca	%mg	%Zn	%Cu	%Mn	%K	%Na	%Cd	%Cr
1	0.36	4.97	0.33	0.0019	0.000	0.002	0.20	0.80	0.00	
3	0.42	5.31	0.32	0.031	0.00	0.008	0.09	0.50	0.00	
7	3.76	0.389	0.765	0.006	0.0006	0.260	0.280	0.0008	0.0004	0.000
14	2.67	0.348	0.765	0.033	0.0006	0.230	0.300	0.0008	0.0004	0.000
21	2.67	0.439	0.539	0.009	0.000	0.240	0.300	0.0008	0.0000	0.405
28	2.64	1.500	0.543	0.009	0.000	0.331	0.290	0.0002	0.0000	0.405
56	3.99	0.394	0.769	0.0030	0.000	0.220	0.290	0.0003	0.0000	0.405
90	0.40	4.58	0.33	0.039	0.00	0.006	0.08	0.67	0.00	

Table 3: Result of the X – Ray Fluoroscopy, XRF, test.

	Compound						
Curing Days	**Ai**	**Si**	**Ca**	**K(%)**	**Na**	**Ti**	**Fe**
1	5.695	29.538	9.228	2.821	0.309	0.414	1.982
3	6.55	41.4	0.55	27.94	0	0.734	12.06
7	4.332	28.534	13.848	2.620	0.309	0.243	1.809
14	3656	24.454	11.463	1.869	0.371	0.229	1.940
21	4.984	27.599	11.718	0.35	206.964	0.388	2.110
28	4.794	26.917	13.881	1.811	0.337	0.222	1.751
56	1.329	9.923	6.848	1.423	0.249	0.074	0.959
90	1.356	12.930	11.005	1.095	0.423	0.087	2.504

(ppm)								
Curing Days	1	3	7	14	21	28	56	90
Mn	134.897	0.085	143.977	530.064	207.964	99.553	5.854	16.907

Table 4: Correlations of compressive strength against compounds.

Elements	Fe	Al	Na	Si	Ti	Mn	Ca	K
Compressive Strength	0.422	-0.719*	0.98*	-0709*	0.599	0.485	-511	0.434

Note: * Correlation is significant at the 0.05 level

The highlights of the results are as follows:

The X-ray image of concrete sample taken using exposures factors of: Voltage – from 60 -110 kV, Current – 5 – 200MA and time - 0.2 - 5.0 seconds were not clear.

Elemental analysis using Atomic Absorption Spectrometry, AAS, method, traced ten elements. These are: Fe, Ca, mg, Zn, Ca, Mn, K, Na, Cd, and Cr. However, Cr was not seen at the 1st, 3rd and 90th days of curing. While the X – Ray Fluoroscopy, XRF determined eight elements. These are: Ai, Si, Ca, K, Na, Ti, Fe and Mn. But Mn was presented in ppm – particles per million.

Result of the elemental analysis using AAS shows that up to ten elements were determined. Although the result has no clearly defined pattern - as it can be seen from the graph in (Figure 1). The number of elements traced using AAS elemental analysis method is higher than the XRF method. Figure 1 shows the results of the analysis. Zinc, copper, manganese, potassium, and Cd all have a positive correlation with each other. The correlations are as follows: 0.281, 0.023, 0.485, 0.434, and 0.023. So, there is a direct link between all of them. But the correlations do not mean much because all of the parts are well below 1.0. This shows that these parts cannot tell you much about the compressive strength on their own. But for the fact that there are certain chemicals that are very harmful to the concrete, it can be inferred from this result that these test methods can be used to study concrete that is exposed to aggressive environment most especially the tracing of those elements in the concrete sample - possibly with their concentrations (Table 4).

However, the use of these tests - AAS and XRF to assess or at least understand the relationship between the elements and compressive strength is very difficult especially when the two graphs in (Figures 1 and 2) are analyzed. There seems to be no any defined pattern that the percentages of elements take. Thus it relatively easier to make meaning from the physical aspect, at least based on this study, than the chemical.

Practical application of the result of this research

The result of this study can be applied to many situations some of them are:

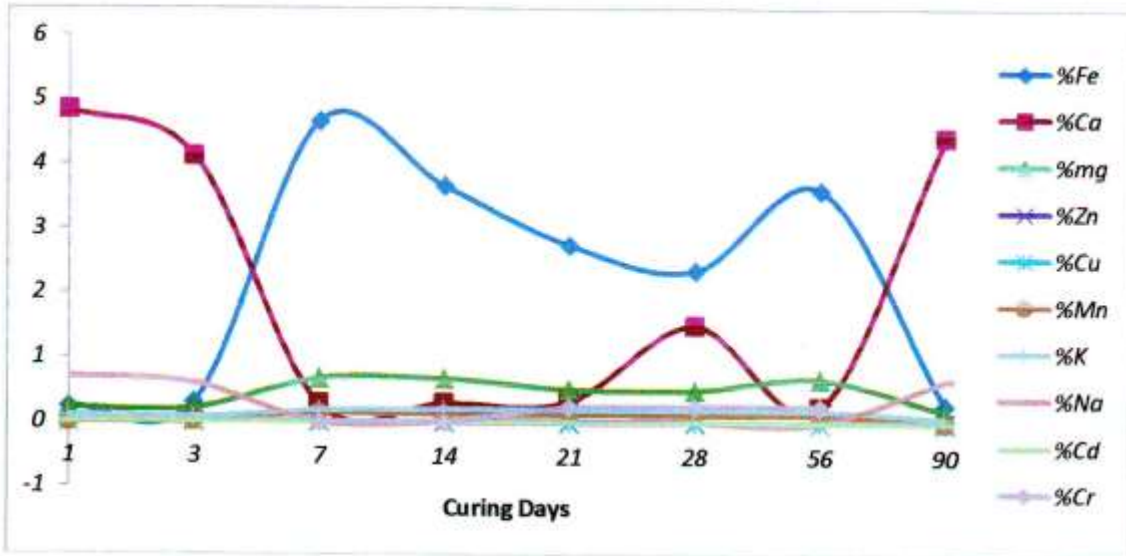

Figure 1: Relationship between Result of AAS test and compressive strength test.

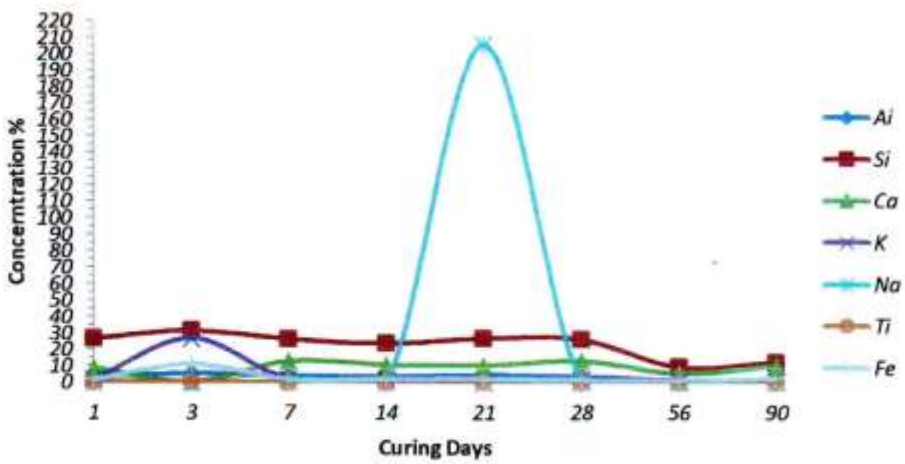

Figure 2: Result of X-ray Fluoroscopy, XRF, test showing the relationship between elements and compressive strength.

Engineering evaluation: In an engineering evaluation, concrete reinforcements and placement information may be required to establish the load carrying capacity of required to establish the load carrying capacity of such structured element or the condition of concrete/reinforcement.

Evaluation of structural integrity: Assessment of structure where such a structure is damaged by fire, blast, overload, etc or situation where a major work is to be carried out in an existing building for example where there is a major extension work, conversion or there would be change of usage of such structure or where the structure is to be purchased/sold.

Building survey: As a multi-disciplinary work, building survey requires the input of an engineer, in the appraisal of the structural integrity of building and evaluation of safety of structure. The compressive strength of concrete which is an important index for assessing the quality of concrete in structural elements can also be assessed by using this study.

Monitoring Concrete Exposed to Aggressive Environment: Now that environmental pollution is increasing, most especially in urban areas and industrial atmosphere, and the use of concrete is gradually being extended to more hostile environment, leading to chemical attack. Also, elemental analysis such as AAS and XRF can be used to study the extent of its exposure to aggressive chemicals.

Study of the internal structure of concrete: Result of this research may be used to study the internal structure of concrete specially to monitor the condition of such concrete. Especially considering the fact that in recent times, emphasis is made on molecular analysis of concrete in the study of concrete element.

Summary

In this study two methods of testing were used to test concrete sample so as to examine the possibility of evaluating compressive strength. The highlights of the results are as follows:

Elemental analysis using Atomic Absorption Spectrometry, AAS, method, traced ten elements. These are: Fe, Ca, mg, Zn, Ca, Mn, K, Na, Cd, and Cr. However, Cr was not seen at the 1^{st}, 3rd and 90^{th} days of curing. While the X - Ray Fluoroscopy, XRF determined eight elements. These are: Ai, Si, Ca, K, Na, Ti, Fe and Mn. But Mn was presented in ppm - particles per million.

Conclusion

After carrying out the experiments, observations, analysis and discussions, on the Testing of concrete, the following conclusions were drawn:

1. There is an inverse relationship between Ca, Na, Al, K, Si, Fe and the compressive strength of concrete sample.
2. There is no agreement as regards to the concentrations or pattern that the elements traced by the two methods - AAS and XRF as it is very difficult to be used to assess (or predict) the strength of concrete.
3. The number of elements that were analyzed by AAS is higher than the ones analyzed by XRF and XRF seems to give more information about the concentration, hence, it may be more suitable for elemental analysis of concrete exposed to aggressive chemicals.
4. In view of the many elements traced by those two methods, AAS and XRP, they can serve as a means of studying the condition of concrete exposed to aggressive environment.

Recommendations

Based on the result of the study, the following recommendations were made:

1. An in-depth study should be carried out on the exposure factors to be used for the radiography of concrete with thickness up to 150mm or above.
2. Where only UPV test method is to be in testing Concrete, it is recommended that the following equation should be used:
y = l51-3.26Xi Where: y = Concrete cubes characteristic strength X_1 = UPV test result
3. If rebound hammer is to be used, it is suggested that Ikybilowing equation should be used: y =19.8 +1.35 X_1 Where: y = Concrete cube characteristic strength X_1 = Rebound hammer test result. For more accurate result, rebound hammer should be combined with UPV test method. In testing concrete. It is recommended the following formula should be used: to determine the characteristic strength: y = 45.80 + 0.88 X]-1.31 X_2 Where: y = Concrete cube characteristic strength X_1 = Rebound hammer test result X_2= UPV test result.
4. Detailed investigation should be carried out on the influence of radiation on the compressive strength of concrete such study should take into cognizance the type of cement, aggregate size/type grade of concrete, etc.
5. If Radiation Attenuation Coefficients (RAC) of concrete is to be used for assessing the compressive strength, the following formula should be used: y = -21.40 + 0.198Xi
Where: y = Compressive Strength X_1 = Radiation Attenuation coefficient.
6. Another research should be carried out on ways of improving method of testing the compressive strength of concrete using radiation attenuation coefficient. The scope of the study should be widened so as to examine the influence of factors like cement, aggregate size/thickness of the specimen, type of radiation source, etc.
7. The use of elemental analysis such as XRF, AAS, should be used to study the durability of concrete most especially the influence of aggressive environment on the durability of concrete, in view of the fact the results of those tests can trace many elements in the concrete.
8. For the fact that emphasis is made on molecular analysis of concrete in recent years which calls for tools to be used to study concrete at micro level, it is suggested that CT scan test should be used for such purpose.
9. A joint research should be undertaken between physicist, 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, detection of concealed reinforcement bars, examination of internal condition of concrete, etc.
10. A research should be carried out using CT scan so as to see the possibility of monitoring concrete structure exposed to aggressive environment. In view of the fact that currently engineers/designers pay more attention to durability issues owing to the fact that the use of concrete has been extended to a hash and hostile areas.

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