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TECHNICAL NOTE

INTERPRETATION OF CONCRETE MIX DESIGNS BY SURFACE HARDNESS METHOD

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Abstract: The Structural Health monitoring with Schmidt Rebound Hammer is being widely used by many consultants. The rebound hammer is use for Concrete structures for predicting the service life. The present research work attempted to interpret different Concrete mix designs by Surface hardness method, which gives a test method for structural health assessment by a suitable correlation between Rebound hammer number and Concrete compressive strength. Thus, the objectives of this present research are threefold. First, this research will examine the influence of conditioning such as drying condition on the results of Schmidt hammer test performed on Concrete cubes with different Mixtures proportion. In which W/C ratio, Slump, Grade of concrete, Fine aggregate, Coarse aggregate, Cement content, and Water content under two different conditions such as Slump, and W/C ratio value was varied with constant Compressive strength as in the First case and Compressive strength, and W/C ratio value varied with constant Slump as in the Second case. Seventy-two concrete cubes (100 mm^3) with Grades of concrete ranges from 25 to 40 N/mm^2 were prepared and tested using Schmidt Rebound hammer equipment. The non-destructive test parameters were relate to different Mixtures proportion in ordered to characterize Mix designs. Second, this research will examine the influence of the hardness value on compressive strength. Third, this research will also aims to develop non-destructive charts for different concrete mixtures proportion. Thus, the Schmidt hammer test due to the developed chart gave a better value. This implied that the developed chart was more suitable for normal strength concrete as well as minimising inaccuracy in non-destructive tests.

Keywords: *Concrete, non-destructive testing, Schmidt hammer test, water-cement ratio, grades of concrete, slump, compressive strength*

1.0 Introduction

In order to keep a high level of structural safety, durability and performance of the infrastructure in each country, an efficient system for early and regular structural assessment is urgently required. The quality assurance during and after the construction of new structures and after reconstruction processes and the characterisation of material properties and damage as a function of time and environmental influences is more and more becoming a serious concern. Non-destructive testing (NDT) methods have a large potential to be part of such a system. NDT methods in general are widely used in several industry branches. Aircrafts, nuclear facilities, chemical plants, electronic devices and other safety critical installations are test regularly with fast and reliable testing technologies. A variety of advanced NDT methods is available for metallic or composite materials. In recent years, innovative NDT methods, which are used for the assessment of existing structures, have become available for concrete structures, but are still not established for regular inspections. The purpose of establishing standard procedures for non-destructive testing (NDT) of concrete structures is to qualify and quantify the material properties of in-situ concrete without intrusively examining the material properties. There are many techniques are currently being research for the NDT of materials today. In situ surface hardness testing of materials is an accepted method for strength estimation.

Development of surface hardness testing devices goes back more than 100 years. Hardness research was initialized by the pioneering work of Hertz (Hertz and Reine, 1881). Nevertheless, hardness testing was also the first material testing effort from the 1600s in engineering through scratching hardness-testing (Szymanski and Szymanski, 1989). In situ testing of concrete structures was start in the 1930s. The testing methods at that time covered chisel blow tests, drilling tests, revolver or special design gun shooting tests, splitting tests, pull-out tests, strain measurements from loading tests and the adaptation of the Brinell hardness testing method (Skramtajew, 1938). This latter technique was the most popular in the European testing practice for decades according to its relatively simple and fast operation (Gaede, 1934). Researchers adopted the Brinell method to cement mortar and concrete to find correlations between surface hardness and strength of concrete in the four decades following that Brinell (Brinell, 1901) introduced his ball indentation method for hardness testing of steel (Crepps and Mills, 1923).

The first NDT device for in-place testing of the hardness of concrete was introduce in Germany in 1934, which also adopted the ball indentation hardness testing method; however, dynamic load was apply with a spring impact hammer (Gaede, 1934). Nowadays the most widespread method for the surface hardness testing of concrete is the rebound hammer method that appears in the 1950s through the Schmidt rebound hammer (Schmidt, 1950). In 1950, Ernst Schmidt developed in Switzerland a spring impact hammer of which handling were to be superior to the ball penetration tester devices (Schmidt, 1950). The Rebound surface hardness measurements were to be very popular in the in situ material testing due to the inexpensive testing devices and their relatively simple use. Aim of rebound hammer tests of concrete is usually to find a relationship between surface hardness and compressive strength with an acceptable error. Although, rebound hammer provides a quick inexpensive means of checking the uniformity of concrete, it has serious limitations and these must be recognize. The results are affect by the following factors such as weak and delaminating concrete, smoothness of surface under test, size, shape and rigidity of the specimen, age of specimen, surface and internal moisture condition of the concrete, type of coarse aggregate, type of cement, type of mould, and carbonation of concrete surface. The advantages of using Rebound hammer test are mention below as follows; in which small amount of structure, damage occurs in testing, and usually negligible. It makes possibility of testing concrete strength in structures where cores cannot be drilled, it's an less expensive testing equipment with low power consumption, simple operation doesn't need high consumption of labour, or intensive training, ideally suited for on-site testing, and handy for difficult to access or confined test areas.

The non-destructive testing is a direct method to find in situ compressive strength of concrete (Yüksel, 1995). The advantages of the test were summarized by (Leshchinsky, 1991). The reduction in the labour consumption of testing, decrease in labour consumption of preparatory work, smaller amount of structure damage in testing, lower probability of such structural damage which may cause the need for reinforcement, possibility of testing concrete strength in structures where cores cannot be drilled, and an application of less expensive testing equipment. However, these advantages are of no value if the results are not reliable, representative and as close as possible to the actual strength of the tested part of the structure (Turgut, 2004). The main limitations related to the NDT testing method are anisotropy and heterogeneity of materials, small test conduction area, roughness on the surfaces where the test is applied, test direction, and there have been a number of different empirical equations proposed for different types of materials (Yilmaz, 2009). In order to overcome these limitations, the test results have to be correlated with the outcomes of destructive tests. In reality, the correlation of strength calibration curves is provide and recommended NDT equipment manufacturers for users.

The lower compressive strength concrete will have a low hardness value. However, when two concrete specimens have the same strength and different rigidities, the resulting rebound hammer number values may not equal to each other (Lin, 1999). The amount of energy lost with low-rigidity concrete is greater than that lost with high-rigidity concrete. The reason for this difference may be associated with material parameters such as the amount of coarse aggregate and how aggregate is mix in a concrete mixture affect the concrete rigidity, thus affecting the rebound hammer number value. The study carried out by researchers (Liu, Sue and Kou, 2009] estimates the strength of concrete by conducting the non-destructive test. Study results indicate that the correlation coefficient may reach 0.9622, indicating that the proposed method has referential value. Therefore, engineers may use this comprehensive approach to develop NDTs to determine concrete strength. The concrete test hammer patented by Proceq's Ernst O. Schmidt at the beginning of the 1950's is without a doubt the most widely used NDT instrument worldwide for rapid assessment of the condition of a concrete structure. However, the validity of the method remains a hotly debated topic amongst experts in the NDT field. The researcher (Corbett, 2011) interpreted how recent advances in rebound hammer technology together with extensive research into the various factors that influence the results can improve the rebound hammer method, providing users with more reliable results and reducing doubts concerning the viability of the method.

The reliability of the non-destructive Schmidt hammer test as a means of estimating the compressive strength of concrete is investigate by testing three groups of concrete cube specimens. First group was exposed to cycles of alternate drying and wetting in brackish water, the second group, to continuous immersion in brackish water, and the third (control) group, to normal room condition. The results show that the average Schmidt hammer rebound number for samples in the first and second group is significantly less than that of the third group. It is clear that, the reliability of the Schmidt hammer test was more effective in predicting the reducing effect of exposure to brackish water on the compressive strength of concrete (Kristine Sanchez, and Nathaniel, 2014). The investigation reported by researchers (Tarun, Sankhla and Akash, 2016) is to present study of calibration graphs for Non-destructive testing Equipment, the Rebound hammer and to study the quality of the concrete in existing structures. These Rebound hammer test were then use to test the quality of the concrete of the various structural elements (columns & beams) of single storied newly under constructed building. The use of this method produces results that lie close to the true values when compared with other methods. Correlation between rebound number and strength of concrete structure is established, which can be use as well for strength estimation of concrete structures.

2.0 Research Objectives

The objectives of this research was to examine the influence of conditioning such as Drying condition on the results of Schmidt hammer test performed on Concrete cubes with different Mixtures proportion. In which Slump, and W/C ratio value was vary with constant Compressive strength as in the First case and Compressive strength, and W/C ratio value varied with constant Slump as in the Second case. This research will examine the influence of the hardness value on compressive strength. In addition to that, this research will also aim to develop non-destructive charts for different concrete mixtures proportion. The developed chart was more suitable for normal strength concrete and can be utilised in minimising inaccuracy in non-destructive tests.

3.0 Experimental program

In the present research work, six different mixtures type were prepared in total as per BRE code (Teychenné, Franklin and Erntroy, 1988) standards with a concrete cube of size (100 mm^3). Three of the mixtures type (M1-M3) was concrete cubes (100 mm^3) with a compressive strength (40 N/mm^2), slump (0-10, 10-30, and 60-180 mm) and different w/c (0.45, 0.44, and 0.43). These mixtures type were designate as M1, M2, and

M3. Another three of the mixtures type were concrete cubes (100 mm^3) with a compressive strength (25 N/mm^2, 30 N/mm^2, and 40 N/mm^2), slump (10-30 mm), and different w/c (0.5 0.45, and 0.44). These mixtures type were designate as M4, M5, and M6. The overall details of the mixtures proportion is shown in Table.1-2. Twelve concrete cubes of size (100 mm^3) were casted for each mixture type and overall Seventy-two concrete cubes were casted for six types of concrete mixture. The coarse aggregate used was crush stone with maximum nominal size of 10 mm with grade of cement 42.5 N/mm^2 and fine aggregate used was 4.75 mm sieve size down 600 microns for this research work.

Table 1: (Variable: Slump & W/C value; Constant: Compressive strength)

Mix ID	Comp/mean target stg, N/mm^2	Slump (mm)	w/c	C (Kg)	W (Kg)	FA (Kg)	CA (Kg) 10 mm	Mixture proportions
M1	40/47.84	0-10	0.45	3.60	1.62	5.86	18.60	1:1.63:5.16
M2	40/47.84	10-30	0.44	4.35	1.92	5.62	16.88	1:1.29:3.87
M3	40/47.84	60-180	0.43	5.43	2.34	6.42	14.30	1:1.18:2.63

Table 2: (Variable: Compressive strength & W/C value; Constant: Slump)

Mix ID	Comp/mean target stg, N/mm^2	Slump (mm)	w/c	C (Kg)	W (Kg)	FA (Kg)	CA (Kg) 10 mm	Mixture proportions
M4	25/32.84	10-30	0.50	3.84	1.92	5.98	17.04	1:1.55:4.4
M5	30/37.84	10-30	0.45	4.27	1.92	6.09	16.50	1:1.42:3.8
M6	40/47.84	10-80	0.44	4.35	1.92	5.62	16.88	1:1.29:3.8

4.0 Rebound hammer test

The rebound hammer is one of the most popular non-destructive testing methods used to investigate concrete. Its popularity is due to its relatively low cost and simple operating procedures. The surface of concrete gets harder as concrete gains strength. A low rebound number will indicate that the surface of the concrete is soft and the concrete is weak. A high rebound number will indicate that the concrete is hard and strong. Unfortunately, there is no theoretical relationship between surface hardness and the strength of concrete.

Figure 1: Silver Schmidt hammer test

The application of Schmidt Hammer to the concrete testing is widely accepted and BS: 1881: Part-202:1986 (BS 1881, 1986) explains the standard procedure for the test and correlation between concrete cube crushing strength and rebound number. PROCEQ Company in Switzerland is the renowned manufacturer of non-destructive testing instruments. The latest model PROCEQ Silver Schmidt-a Swiss-made instrument offers unprecedented benefits to users. A number of user-benefits have been incorporate, such as the automatic correction of readings based upon the impact direction eliminating the need to refer to impact direction conversion curves and was use in the present research work as shown above in Fig.1. The rebound hammer reading is very sensitive to local variations in the concrete, especially to aggregate particles near to the surface. It is therefore necessary to take several readings at each test location, and to find their average and thus in the present work, it has decided to take rebound hammer readings at least all three faces of concrete cubes. It is recommended to use these well-accepted instruments for the non-destructive testing of the uniformity of concrete and to measure the surface strength of existing concrete members in situ to control concrete quality and to detect weak spots. The comparative hardness value with their characterization of quality of concrete as represented in Table.3

Table 3: Comparative Rebound hardness value (BS: 1881-Part-202:1986)

Rebound number	*Quality of concrete*
>40	Very good
30-40	Good
20-30	Fair
<20	Poor/delaminated
0	Very

5.0 Results and Discussion

The standard method of determining strength of hardened concrete consists of testing concrete cubes in compression. The quality of entire concrete of a structure cannot be fully assessed by testing a few concrete cubes. The results obtained in testing cubes do not always reflect the actual strength of concrete in construction. In a whole day, concreting work cubes are casted in a few batches, the differences (unintentional and intentional) in the composition is not common, and their compaction and their hardening conditions always differ more or less from those of the structure. In addition, the number of test cubes is generally so small that they can only be consider as random tests. Sometimes, in case of failure of cubes, doubtful concrete cracks, and deterioration of concrete, it becomes necessary to assess the quality and strength of concrete of the structure. Actually the rebound hammer number was influenced by so many factors in which the concrete made of high alumina cement can give strengths up to 100% higher, whereas super-sulphated cement concrete can give 50% lower strength compared to a calibration obtained on Portland cement cubes. Similarly, the Gravel and most crushed rocks give similar correlations, but lightweight aggregates and aggregates with unusual properties require special calibration. Surface and internal moisture condition of the concrete also affects the results.

A wet surface will give rise to under-estimated strength of concrete calibrated under dry conditions. This influence can be considerable and in structural concrete, it is about 10% lower on wet surfaces than on an equivalent dry surface. In very old and dry concrete, the surface will be harder than the interior, giving rebound values somewhat higher than normal. New concrete with moist surface generally has a relatively softer surface, resulting in lower than normal rebound. Surface carbonation of concrete significantly affects the rebound hammer test. In old concrete where the carbonation layer can be up to 20 mm thick, the strength is overestimate by 50%. The concrete test hammer is an excellent tool in the hands of experts. The operation of the hammer is very simple, yet it is not so simple as to entrust this tool to a raw hand for taking readings of a structure. Specialists trained for this purpose must always carry out its operation, calibration, taking readings of a concrete structure, analysis and interpretation of the test data. The obtained rebound hammer number as well as compressive strength is average values taken on three sides of concrete cubes in the present research work with their variation as shown in (Figures.2-7). The variation of average compressive strength with rebound hammer number, standard deviation, and co-relation equation as well as R^2 value are represented in Table.4.

Table 4: Variation of Rebound hammer with Compressive strength

Mix ID	*Comp stg, N/mm²*	*STD*	*RHN*	*STD*	*Co-relation Equation*	*R²*
M1	31.34	5.01	51.10	3.75	$Y=2.6723e^{0.0479x}$	0.9477
M2	32.43	3.58	51.95	2.71	$Y=2.8649e^{0.0466x}$	0.8700
M3	34.48	3.17	53.35	1.85	$Y=2.4599e^{0.0494x}$	0.9691
M4	25.48	2.58	47.14	2.20	$Y=2.6803e^{0.0477x}$	0.9896
M5	31.90	2.42	51.85	1.55	$Y=2.5253e^{0.0489x}$	0.9876
M6	32.12	3.69	51.83	2.63	$Y=2.6381e^{0.0481x}$	0.9884

It is observed from results that, the rebound hammer number was increase with higher compressive strength with different slump value for in case of mixtures type (M1-M3). Whereas in mixtures type (M4-M6), the rebound hammer number was decrease with lower compressive strength, increases with higher compressive strength for constant slump value. The correlation coefficient (R^2) as observed from results that its varied from each other in all mixtures type (M1-M6) which was ranges from 94.77%, 87%, 96.91, 98.96%, 98.76%, and 98.84%. This means that there were an excellent relationship between compressive strength and the rebound number. This also implies that the independent variable (rebound number) is a useful predictor of the dependent variable (Compressive strength).

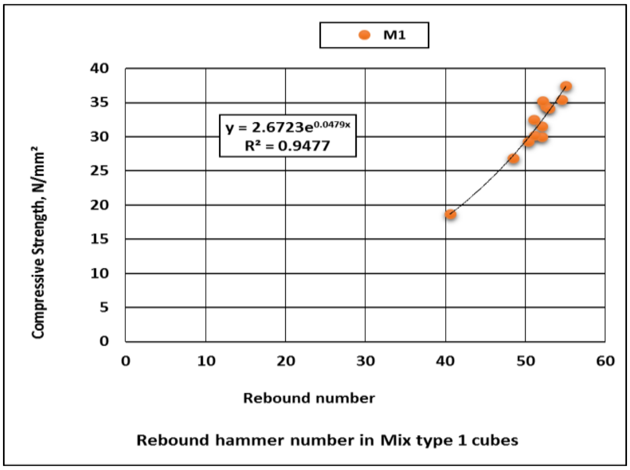

Figure 2: RHN versus compressive strength in M1

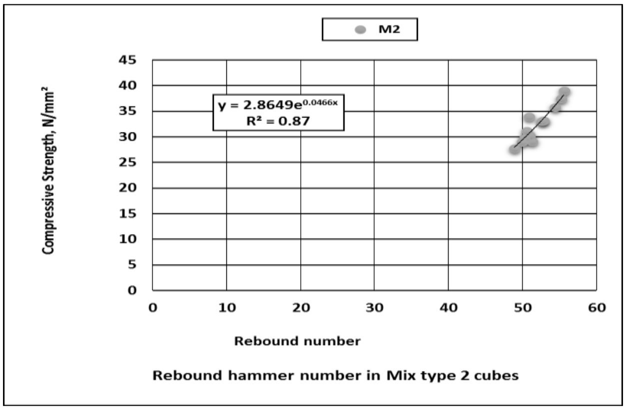

Figure 3: RHN versus compressive strength in M2

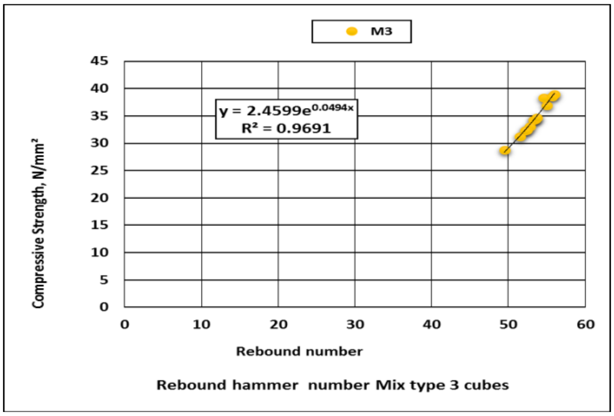

Figure 4: RHN versus compressive strength in M3

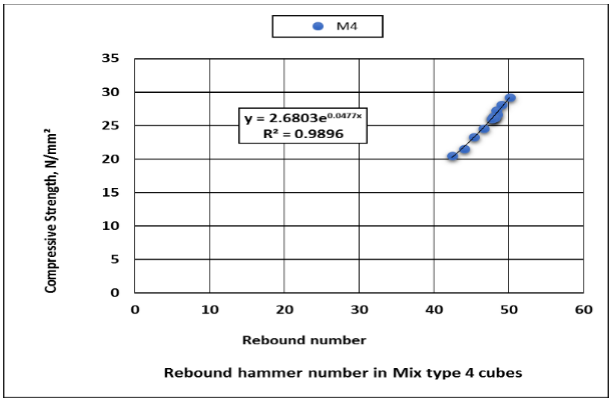

Figure 5: RHN versus compressive strength in M4

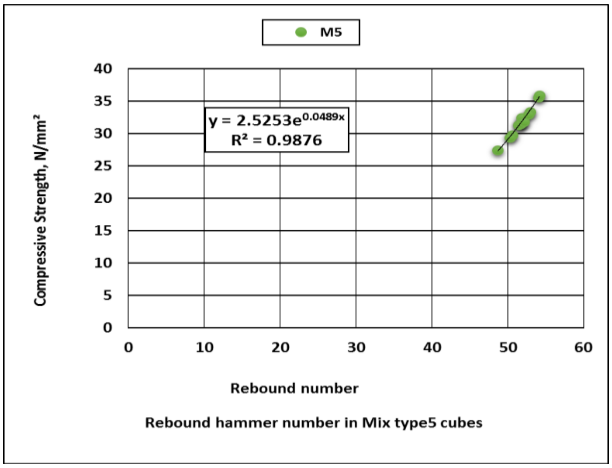

Figure 6: RHN versus compressive strength in M5

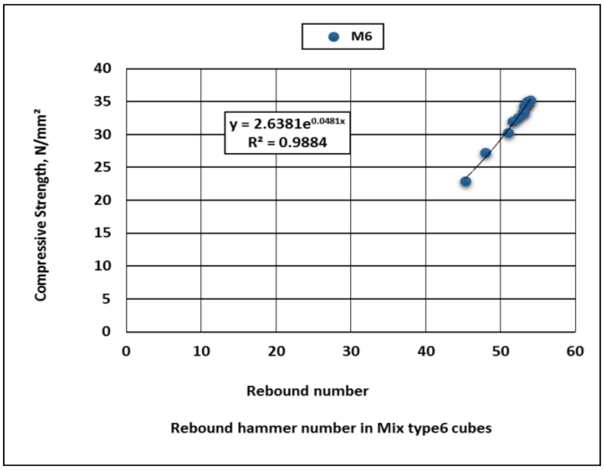

Figure 7: RHN versus compressive strength in M6

6.0 Conclusions

The quality of entire concrete of a structure is not completely assessed by testing a few concrete cubes. The results obtained in testing cubes do not always reflect the actual strength of concrete in construction. In fact, the compaction and their hardening conditions always differ more or less from those of the structure. Sometimes, in case of failure of cubes, doubtful concrete cracks, and deterioration of concrete, it becomes necessary to assess the quality and strength of concrete of the structure. The Rebound surface hardness testing of concrete is one of the most widespread NDT methods for in situ strength estimation of concrete structures. Rebound surface hardness methods are available in the civil engineering testing practice for more than 60 years. However, understanding and modelling of the rebound surface hardness of concrete as a time dependent material property is not available in the technical literature. The following principal conclusions as drawn from this research work:

[1] There is no generalized formula for predicting concrete compressive strength by using non-destructive testing.

[2] The present study puts forward useful mathematical exponential relationships that help the engineer to predict confidently the crushing strength of standard concrete cubes, by measuring the rebound index with Schmidt hammer test. The mathematical expression is applicable for a wide range of concrete strengths.

[3] Schmidt Hammer test results can be influence by many factors such as the characteristics of the mixture, moisture condition, rate of hardening and curing type. Therefore, the correction factors was use to allow this effect for existing concrete.

[4] The use of rebound hammer is suitable to estimate and predict the strength of concrete, which makes engineering judgment quite very easy. In fact, the use of the rebound hammer methods yields more reliable and closer results to the actual strength.

[5] The use of rebound number method produces results that are reliable and close to, the true values as well as an acceptable level of accuracy were achieved for strength estimation of concrete. Hence, the resulting regression model for strength evaluation is use safely for concrete strength estimation for the concrete.

[6] Its confirmed from the results that, higher rebound number results in high compressive strength while low rebound number results in low compressive strength.

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