بسم الله الرحمن الرحيم

Sudan University of Sciences & Technology

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Evaluation of the Relationship between Destructive and Non-destructive Testing for Concrete

تقويم العلاقة بين الإختبارات الإتلافية واللاإتلافية للخرسانة

A thesis submitted for the partial fulfillment for the requirement on the degree of M.Sc in Civil Engineering

(Construction Engineering)

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الآيـــــة

قال تعالي:

بسم الله الرحمن الرحيم

﴿إِنَّ فِي خَلْقِ السَّمَاوَاتِ وَالْأَرْضِ وَاخْتِلَافِ اللَّيْلِ وَالنَّهَارِ وَالْفُلْكِ الَّتِي تَجْرِي فِي الْبَحْرِ بِمَا يَنفَعُ النَّاسَ وَمَا أَنزَلَ اللَّهُ مِنَ السَّمَاءِ مِن مَّاءٍ فَأَحْيَا بِهِ الْأَرْضَ بَعْدَ مَوْتِهَا وَبَثَّ فِيهَا مِن كُلِّ دَابَّةٍ وَتَصْرِيفِ الرِّيَاحِ وَالسَّحَابِ الْمُسَخَّرِ بَيْنَ السَّمَاءِ وَالْأَرْضِ لَآيَاتٍ لِّقَوْمٍ يَعْقِلُونَ﴾

صدق الله العظيم

سورةالبقرة – الآية (164)

Dedication

To my lovely parents even now and more forever.

To my husband and my sons.

To my family.

To my friends.

To all whom I love.

Acknowledgement

In preparing this thesis, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts.

In particular, I wish to express my sincere appreciation to my main Thesis supervisor, **Dr. Ali Hussein Mohammed Ali** for encouragement, kind help and guidance.

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Extend thanks and utmost respect and appreciation to my friends, Engineer Amal Hamid , and Engineer Zienab Mustafa , who stood next to me in my career Scientific.

Finally, I would like to take the opportunity to thank my parents and family for having supported me through the all project and studies.

Abstract

The research aims to evaluation of a relationship between two devices used to test the compressive strength of concrete, one of the concrete destructive tests [Crushing machine] and the other of non-destructive tests [Schmidt hammer] and finding equation between the test results between the two devices to help site engineers to estimate the value of compressive strength for existing buildings.

A number of [36] concrete cubes were used for the tests, divided into [18] cubes with a compressive strength of 25 MPa and the other [18] cubes with a compressive strength of 40 MPa. The tests were carried out for concrete ages 7, 14, and 28 days after treatment by immersing in water. The Schmidt hammer test was carried out in the vertical direction on the loading of the pressure machine and then the pressure test was performed on the pressure test machine. Finally, the results were analyzed using the Excel program and compared the convergence of compressive resistance between the two devices.

The more accurate equation in concrete grade 25 in 28 days is

$Y = .057x^2 - 2.713x + 58.9$ and regression

$R^2 = 0.986$, the relationship between Schmidt hammer strength and crushing machine strength controlled by quadratic equation.

The more accurate equation in concrete grade 40in 28 days is

$Y = -0.0072x^3 + 0.988\,x^2 - 45.178x + 714.42$ and regression

$R^2 = 0.9808$, the relationship between Schmidt hammer strength and crushing machine strength controlled by cubic equation.

ملخص البحث

يهدف البحث إلى إيجاد تقييم علاقة ما بين جهازين يستخدمان لإختبار مقاومة إنضغاط الخرسانة ، أحدهما من الإختبارات الإتلافية [ماكينة الضغط للخرسانة] والجهاز الآخر من الإختبارات غير الإتلافية [مطرقة شميدت] وإيجاد معادلة بين الجهازين لمساعدة مهندسي المواقع في تقدير قيمة مقاومة الكسر الخرسانة للمباني المبنية مسبقا.

تم إستخدام عدد [36] مكعب خرساني للإختبارات ، مقسمة إلي [18] مكعب لها مقاومة إنضغاط 25 ميقاباسكال والأخرى [18] مكعب مقاومة إنضغاطها 40 ميقاباسكال. وأجريت الإختبارات لأعمار الخرسانة 7، 14، 28 يوم بعد معالجتها بالغمر في الماء. و تم إجراء إختبار مطرقة شميدت في الإتجاه الرأسي على إتجاه تحميل ماكينة الضغط ومن ثم إجراء إختبار الضغط على ماكينة إختبار الضغط. وتمت عملية التحليل للنتائج بإستخدام برنامج الإكسيل و مقارنة مدى تقارب نتائج مقاومة الضغط للجهازين. اكثرالمعادلات دقة بالنسبة لمقاومة الضغط 25 ميقا باسكال تحكم بالمعادلة من الدرجة الثانية

$$Y = 0.057x^2 - 2.713x + 58.9$$

وكان عمرالخرسانة 28 يوم ، وجد الارتباط $R^2 = 0.986$

كانت العلاقة بين نتائج ماكينة الضغط والمطرقة بالنسبة لمقاومة الضغط 40 ميقاباسكال تحكم بالمعادلة من الدرجة الثالثة

$$Y = -0.0072x^3 + 0.988\,x^2 - 45.178x + 714.42$$

وكان عمر الخرسانة 28 يوم وجد الإنحدار $R^2 = 0.9808$

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INTRODUCTION

CHAPTER ONE

INTRODUCTION

1.1 : Background

From the results of this research it is intended to obtain a statistical relationship between the concrete compressive strength test and the Schmidt Hammer test.

Concrete is the most commonly used construction material in structures. Determination of compressive strength has become the most important concern of researchers since its usage and usually regarded as the main criteria to judge the quality of concrete**.**

There are many test methods to assess the strength of concrete in situ, such as non-destructive tests methods (Schmidt Hammer and Ultrasonic Pulse Velocity…etc). These methods are considered indirect and predicted tests to determine concrete strength at the site. These tests are affected by many parameters that depending on the nature of materials used in concrete production. So, there is a difficulty to determine the strength of hardened concrete in situ precisely by these methods. In this research, Schmidt Hammer test is used to assess the concrete compressive strength.

1.2: Research problem Statement

The quality of concrete in the existing building is often low, In the case of low compressive strength results, non-destructive tests such as impact rebound hammer is performed to check these results. This clearly shows the need for appropriate correlations for concrete made with local materials and under local environmental conditions. This study needs to propose appropriate simplified correlations between compressive strength test and impact rebound hammer test for concretes .

1.3: Research Significance

This research helps and enables engineers in approximately estimating values of compressive strength for the concrete of the constructed buildings.

1.4: Research Question

- Is the hammer test appropriate for estimating the cube strength.

1.5: Research Objectives

The main objective of this study is to find an acceptable equation that can be used to measure the compressive strength from the Schmidt Hammer test for normally cured concrete. The secondary objectives are the following:

- To know the different types of testing for Non-destructive testing.
- To know the factors affect the hammer test.

1.6: Research Methodology

The study consisted of a laboratory evaluation of hardened concrete to measure compressive strength and rebound hammer test of concrete cube samples.

In this study the experimental program as follow:

- Mixed design from local materials will be prepared in concrete laboratory.
- Cast 36 concrete cubes.
- Immersed In water tank for curing.
- Measuring the rebound number for cubes.

- Crush in 7 , 14 and 28 days.
- Measuring the compressive strength for cubes
- Analyzing the results and comparative between the two results.

1.7: Outline of Research Content

This research constitutes five main parts. Each part deals with a section of the study but chapters are linked in their targets.

Chapter one: contains a brief description of the research problem, the objective of the study, the methodology and outlines for the thesis.

Chapter two: reviews the concepts of rebound hammer test, the compressive strength, the equipments used and the methods that can be followed to read the rebound hammer test. And finally review the most famous published equation's authors how work in finding the relation between the compressive strength and the rebound hammer test.

Chapter three: describes the experimental work and the devices that are developed in this study to compare rebound hammer test with the compressive strength test.

Chapter four: present the results and discussion of these results and their applications to the field conditions are also presented in this chapter.

Chapter five: gives summary and conclusions of the current work and the recommendations for future work.

Appendices.

CHAPTER TWO

LITERATURE REVIEW

CHAPTER TWO

LITERATURE REVIEW

2.1: Introduction

Non-destructive testing (NDT) is defined as the course of inspecting, testing, or evaluating materials, components or assemblies without destroying the serviceability of the part or system. The purpose of NDT is to determine the quality and integrity of materials, components or assemblies without affecting the ability to perform their intended functions. Non-destructiveness ought not to be confused with non-invasiveness. Testing methods that do not affect the future usefulness of apart or system are considered to be non-destructive even if they consist of invasive actions. For example, coring is a common NDT method that is employed to extract and test specimens from concrete components in order to determine the properties of in-situ concrete. Coring alters the appearance of the component and marginally affects its structural integrity. If done correctly, coring maintains the serviceability of the structural component and is thus considered to be non-destructive [1].

Recent development in concrete is high strength concrete, which is mixture of cement, sand, aggregate, water and admixtures. The compressive strength of concrete is its one of the most valuable property. To determine compressive strength of concrete is a major task of engineers/researchers for existing concrete structures. There are two aspects of determination of compressive strength of concrete which are destructive tests (DT) and nondestructive tests (NDT). The DT of concrete is not always appropriate method to find compressive strength of concrete and concrete structures because it affects the durability and lifespan of concrete. Hence, the NDT method is only one predominant method to find the strength of existing concrete and concrete structures, and to judge the quality of concrete. The NDT method is direct and easy tool to find in situ compressive strength of concrete. The NDT test methods include rebound hammer, ultrasonic pulse velocity test, penetration test, radiography test, sonic integrity tests etc. There are two distinct areas in civil engineering works where it has to be relied on NDT for practical and theoretical purposes. The first ones are the old monumental structural systems like ancient temples and edifices. The second ones are the buildings which are coming up so fast in the urban areas as the result of burgeoning housing industry, which badly needs quality control for mass safety and security of the people [2].

The properties, characteristics and qualities of these two groups of structural systems can be quickly and systematically recorded, if the tests performed are NDT ones. However, for the reliability of these results and records can be proven only if the relationship between these tests and the DT which are more realistic and reliable but not always possible has been established. The relationship between the two types of tests which the research work is to establish will provide a series of vital data and solve a series of problems in assessment of the properties, characteristics and vulnerability of the standing structural systems [3]. However, none of these tests can be used independently to yield reliable quantitative results. Out of these NDT test methods, combination of two or more NDT yields results of acceptable levels. For instance, in case of a historical monument, which is already standing for hundreds of years or in case of a structural system which has already been constructed but requires verification of the properties, and characteristics of its material, elements or the system as a whole, the DT is not the best method to apply.

Destructive testing explores failure mechanisms to determine the mechanical properties of material such as yield strength, compressive strength, tensile strength, ductility and fracture toughness. NDT methods explore indications of properties without reaching component or assembly failures. Extensive attempts and advancements have been made to develop NDT methods capable of indicating mechanical, acoustical, chemical, electrical, magnetic, and physical properties of materials. One of the earliest documented attempts of NDT dates to the 19th century where cracks were detected in railroad wheels by means of acoustic tap testing [4]. More sensitive, reliable and quantifiable NDT methods have expansively emerged in recent years. NDT methods have materialized as a response to the need for structural damage detection and prevention. The extensive use of NDT is driven by economics and safety. In a pre-emptive attempt to eradicate the problems associated with structural deterioration, novel in-site testing techniques have been invented to allow for the assessment of concrete during the construction, commissioning and servicing lifecycle stages of a structure. The major factors that influence the success of a 7 non-destructive survey are depth of penetration, vertical and lateral resolution, and contrast in physical properties, signal-to-noise ratio and existing information about the structure [5].

The understanding of material properties and the key issues associated with their application in structural engineering is imperative for the success of any NDT method. The steps to choosing an adequate NDT method are [6];

- Understanding the physical nature of the material property or discontinuity to be inspected;
- Understanding the underlying physical processes that govern the NDT method
- Understanding the physical nature of the interaction of the probing field with the test material
- Understanding the potential limitations of available NDT technology;
- Considering economic, environmental, regulatory and other factors.

There is a wide range of NDT methods which are used by the civil and structural engineering industry.

While there appears to be ample technical literature regarding NDT of concrete, there is a lack of collaboration between civil engineers, NDT researchers and specialists.

2.2: Importance and need of non-destructive testing

It is often necessary to test concrete structures after the concrete has hardened to determine whether the structure is suitable for its designed use. Ideally such testing should be done without damaging the concrete. The tests available for testing concrete range from the completely non-destructive, where there is no damage to the concrete, through those where the concrete surface is slightly damaged, to partially destructive tests, such as core tests and pullout and pull off tests, where the surface has to be repaired after the test. The range of properties that can be assessed using non-destructive tests and partially destructive tests is quite large and includes such fundamental parameters as density, elastic modulus and strength as well as surface hardness and surface absorption, and reinforcement location, size and distance from the surface. In some cases it is also possible to check the quality of workmanship and structural integrity by the ability to detect voids, cracking and delimitation.

Non-destructive testing can be applied to both old and new structures. For new structures, the principal applications are likely to be for quality control or the resolution of doubts about the quality of materials or construction. The testing of existing structures is usually related to an assessment of structural integrity or adequacy. In either case, if destructive testing alone is used, for instance, by removing cores for compression testing, the cost of coring and testing may only allow a relatively small number of tests to be carried out on a large structure which may be misleading. Non-destructive testing can be used in those situations as a preliminary to subsequent coring

Typical situations where non-destructive testing may be useful are, as follows:

- Quality control of pre-cast units or construction *in situ*.
- Removing uncertainties about the acceptability of the material supplied owing to apparent non-compliance with specification.
- Confirming or negating doubt concerning the workmanship involved in batching, mixing, placing, compacting or curing of concrete.
- Monitoring of strength development in relation to formwork removal, cessation of curing, pre stressing, load application or similar purpose.
- Location and determination of the extent of cracks, voids, honeycombing and similar defects within a concrete structure.
- Determining the concrete uniformity, possibly preliminary to core cutting, load testing or other more expensive or disruptive tests.
- Determining the position, quantity or condition of reinforcement.
- increasing the confidence level of a smaller number of destructive tests
- Determining the extent of concrete variability in order to help in the selection of sample locations representative of the quality to be assessed.
- Confirming or locating suspected deterioration of concrete resulting from such factors as overloading, fatigue, external or internal chemical attack or change, fire, explosion, environmental effects.
- Assessing the potential durability of the concrete.
- Monitoring long term changes in concrete properties.
- Providing information for any proposed change of use of a structure for insurance or for change of ownership.

2.3: Non-Destructive Testing Methods

2.3.1: Surface hardness methods

Non-destructive surface hardness methods are noninvasive procedures that investigate strength characteristics of material. The two categories that define concrete surface hardness techniques are indentation methods and rebound methods. These methods attempt to exploit empirical correlations between strength properties of concrete and surface hardness as measured by indentation or rebound. Originating in the 1930 (Jones, 1969), indentations methods are no longer common in the civil engineering industry, whereas rebound methods are frequently applied to investigate concrete strength characteristics with reference to standard guidelines on testing and interpretation. The most commonly used surface hardness procedure is the standard rebound hammer test. The test was developed in 1948 by Swiss engineer Ernst Schmidt and is commonly referred to as the Schmidt Rebound Hammer (Kolek, 1969). Upon impact with the concrete surface, the rebounded hammer records a rebound number which presents an indication of strength properties by referencing established empirical correlations between strength properties of concrete (compressive and flexural) and the rebound number.

The fundamental understanding of impact and rebound relates to the theory of wave propagation. A compression wave is propagated when the surface of the concrete is disturbed by the plunger (σi). The reaction force propagates a reflected compression wave through the plunger (σr). The ratio of the wave amplitudes (σr/ σi) is found to be proportional to there bound number which could be empirically correlated to compressive and flexural strength
(Akashi &Amasaki, 1984).

Operation of the Standard Rebound Hammer requires less mechanical skills as compared to other methods of NDT. A visual examination of the concrete surface should be conducted prior to the test in order to identify a smooth surface suitable for testing.

The test can be conducted in any directional angle where calibration charts are used to mitigate the different effects of gravity Fig.(2.1): The hammer is pressed against the concrete surface until a spring loaded mass is released causing the plunger to impact against the surface and rebound a distanced measured by a slide indicator as shown in Fig. (2.2): The measured distance is referred to as the rebound number.

Fig.(2.1):NDT of concrete by Schmidt Rebound Hammer.

(As adapted from http://www.ntu.edu.sg/)

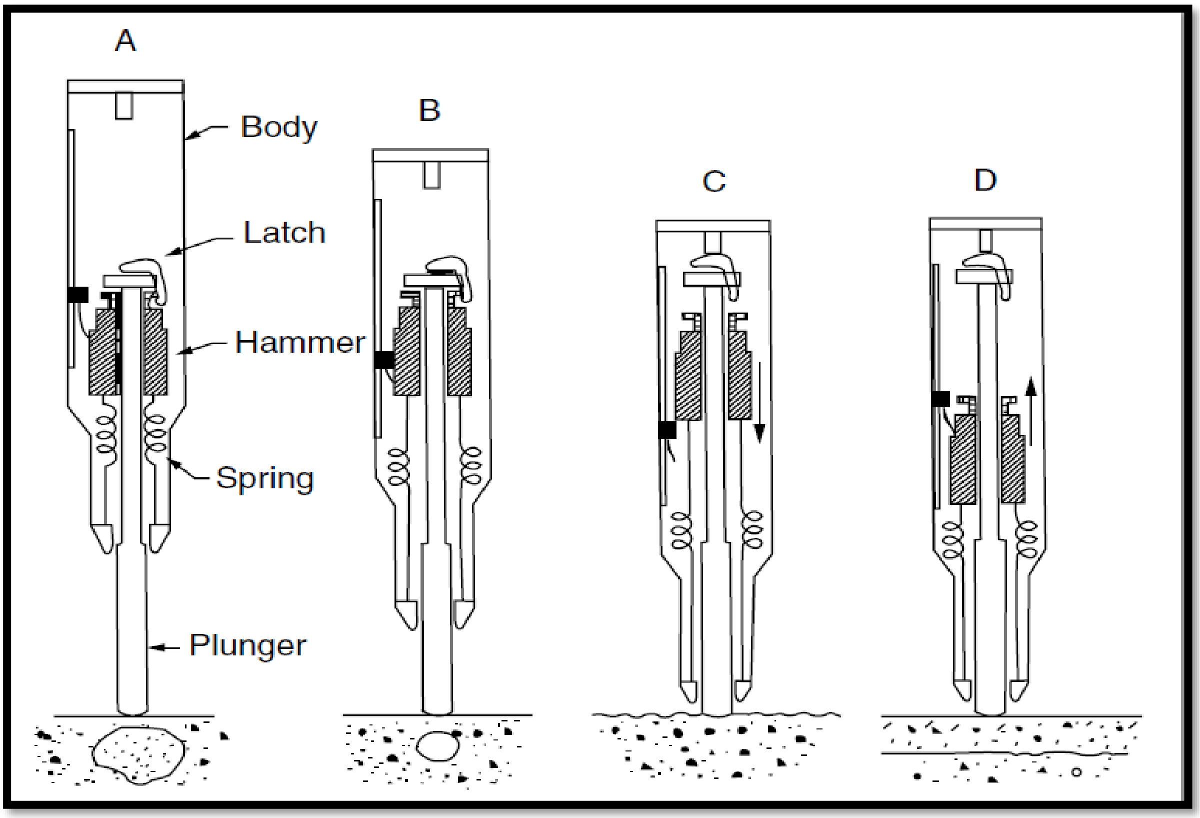

Fig. (2.2): Schematic diagram of Schmidt rebound hammer procedures. (Malhotra, 2004)

Empirical correlations are provided by the manufacturer to relate the rebound number to concrete strength properties; however, the testing conditions of the manufacturer might be dissimilar to the conditions present. Therefore, it is recommended to conduct a test-specific correlation procedure where a number of concrete cylinders ranging in strength are prepared and tested by both Standard Rebound Hammer and compression-testing machine. The results of the two tests are then integrated into a simple regression analysis model which yields an empirical correlation by means of ordinary least squares. The following publications present standard guidelines for the application and interpretation that govern the standard rebound test:

- ASTM C 805: Standard Test Method for Rebound Number of Hardened Concrete;
- BS EN 12504-2:2012: Testing Concrete in Structures Non-destructive Testing

2.3.1.1: Determination of Rebound Number

The Standard Rebound Hammer provides a simple, easy and inexpensive method to estimate concrete strength properties. However, the results of the test on concrete are affected by various factors such as smoothness of the surface, geometric properties of the test specimen, age of the test specimen, surface and internal moisture conditions of the concrete, type of coarse aggregate, type of cement, type of mold and carbonation of the concrete surface (Malhotra, 2004). Strength estimation from rebound readings of specimens similar to correlation curve specimens are achieved within an accuracy of 15%to 20% (Concrete Institute of Australia, 2008). It is therefore recommended that the standard rebound hammer test be used as a method of testing variability of strength properties between concrete samples rather than as a substitute for standard compression testing.

2.3.2: Penetration resistance method

Penetration resistance methods are invasive NDT procedures that explore the strength properties of concrete using previously established correlations.

These methods involve driving probes into concrete samples using a uniform force. Measuring the probe's depth of penetration provides an indication of concrete compressive strength by referring to correlations. Due to the insignificant effect of the penetration resistance methods on the structural integrity of the probed sample, the tests are considered to be non-destructive despite the disturbance of the concrete during penetration.

The most commonly used penetration resistance method is the winds or probe system. The system consists of a powder-actuated gun, which drives hardened allow-steel probes into concrete samples while measuring penetration distance via a depth gauge Fig.(3): The following publications present standard guidelines for the application and interpretation that govern penetration testing:

- ASTM C 803-02: Standard Test Method for Penetration Resistance of Hardened Concrete;
- BS 1881-207 Testing Concrete – Recommendations for the assessments of concrete strength by near-to-surface tests.

The penetration of the Windsor probe creates dynamic stresses that lead to the crushing and fracturing of the near-surface concrete Fig. (2.4): A cone shaped zone develops upon penetration, which encompasses fracturing and is resisted by the compression of the adjacent concrete. The resistance is empirically correlated to probe penetration depth; however, empirical relationships provided by manufacturers often yield unsatisfactory results. Therefore, test-specific correlation procedures should be conducted utilizing penetration methods and compression-testing machine in order to achieve more accurate correlation charts.

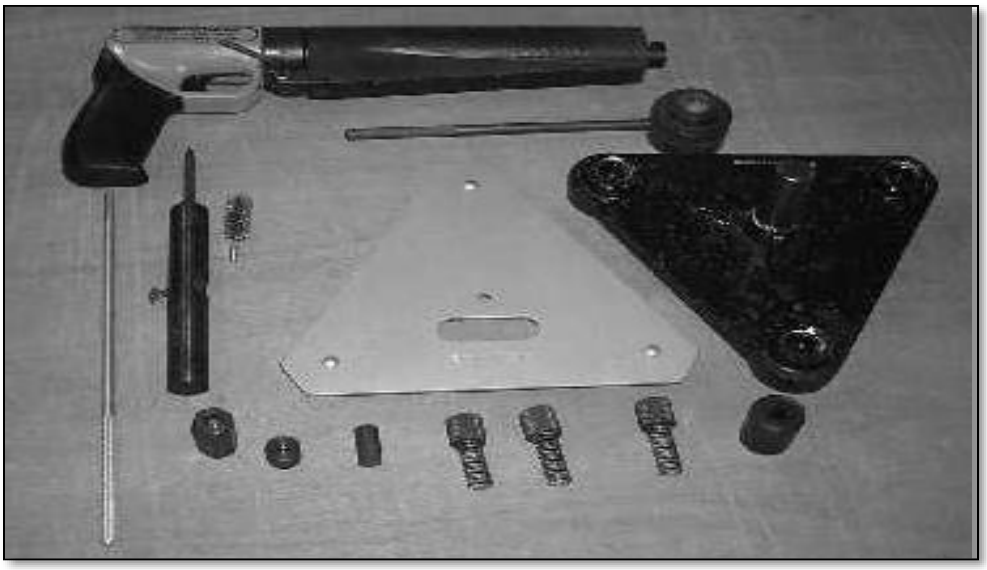

Fig.(2.3): Components of the Windsor Probe System

(As adapted from http://www.ntu.edu.sg/).

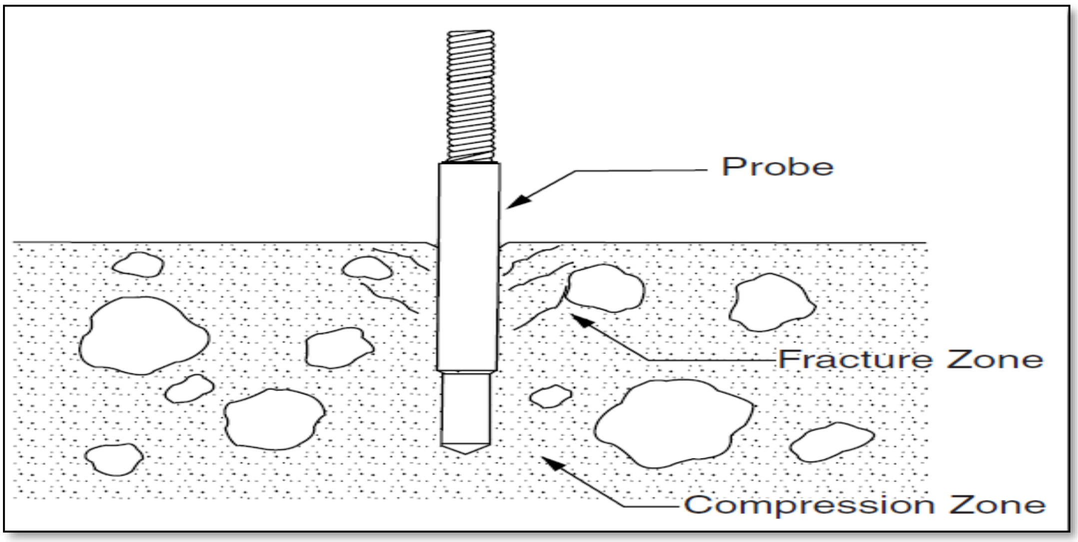

Fig.(2.4): Schematic diagram of typical concrete failure mechanism during probe penetration (Malhotra &Carette, 2004)**.**

The factors that contribute to within-test variability are attributable to operator error, equipment error, size of aggregates and the heterogeneous nature of concrete (Malhotra & Carette, 2004). The most significant factor that affects within-test variability is aggregate size. For example, a 5% coefficient of variation is expected for testing samples of 20mmaggregate size; whereas, a 14% coefficient of variation is expected for samples of 55mm aggregate size(Concrete Institute of Australia, 2008). Nevertheless, variations in the estimated early strength of concrete are low to moderate, which provides a reasonable degree of accuracy and certainty for the removal of formwork in concrete constructions. Additionally, the numbers of factors contributing to within-test variability are fewer than those of other NDT procedures such as surface hardness methods. The Winds orprobe system is quick, cheap and simple to operate. As with surface hardness methods, the penetration resistance methods do not yield absolute values of strength and must therefore be used as a method of testing variability of strength properties between concrete samples.

2.3.3:Pull-out resistance methods

Pull-out resistance methods measure the force required to extract standard embedded inserts from the concrete surface. Using established correlations, the force required to remove the inserts provides an estimate of concrete strength properties. The two types of inserts, cast-in and fixed-in-place, define the two types of pull-out methods. Cast-in tests require an insert to be positioned within the fresh concrete prior to its placement. Fixed-in-place tests require less foresight and involve positioning an insert into a drilled hole within hardened concrete.

Pull-out resistance methods are non-destructive yet invasive methods which are commonly used to estimate compressive strength properties of concrete. The most commonly used pull-out test method is the LOK test developed in 1962 by Kierkegarrd-Hansen (Kierkegaard-Hansen, 1975). The test requires an insert embedment of 25mm to insure sufficient testing of concrete with coarse aggregates (Fig.2.5). The force required to remove the insert is referred to as the "lok-strength", which in other pull out resistance methods is referred to as the pull-out force.

The following publications present standard guide lines for pull-out resistance testing:

-ASTM Standard C 900-13a: Standard Test Method for Pullout Strength of Hardened Concrete;

-BS 1881-207 Testing Concrete – Recommendations for the assessments of concrete strength by near-to-surface tests.

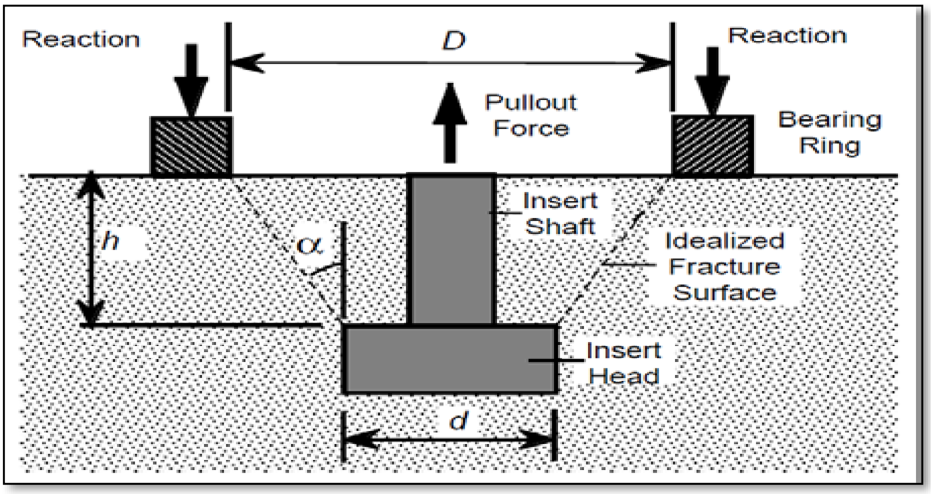

Fig.(2.5): Schematic diagram of typical pull-our resistance methods

(Carino, 2004)

The pull-out force is resisted by normal stresses and shear stresses acting on the insert surface. The non-uniform three-dimensional state of stress initiates a concrete failure mechanism, which lacks a consensus in its understanding. Analytical and experimental studies have attempted to gain under standing of the fundamental failure mechanism and have been successful in presenting substantial correlations between pull-out force and compressive strength (Bickley, 1982; Keiller, 1982). The average value for the coefficient of variation for the pull-out test has been found to be around 8% (Carino, 2004).The factors that affect result variability are maximum aggregate size, cement mortar percentage, type of insert and depth of embedment (Concrete Institute of Australia, 2008). These factors can be mediated by conducting test-specific correlation charts which match in characteristics with the expected concrete samples of interest.

2.3.4: Pull-off resistance method

The pull-off test is an in-situ strength assessment of concrete which measure the tensile force required to pull a disc bonded to the concrete surface with an epoxy or polyester resin. The pull-off force provides an indication of the tensile and compressive strength of concrete by means of established empirical correlation charts.

The most commonly used pull-off test is the 007Bond Test. The test consists of a hand operated lever ,bond discs, an adjustable alignment plate, and force gauges Fig.(2.6).The disc is bonded to the concrete surface by a high strength adhesive and is attached to the hand operated lever by a screw. After leveling the adjustable alignment plate, tension force is applied by the lever and measured by the force gauge Fig.(2.7). The pull-off tensile strength is calculated by dividing the tensile force at failure by the disc area and is used to determine the compressive strength of concrete by using previously established empirical correlations. The following publications present standard guidelines for pull-off resistance testing:

- ASTM D 4541-109e1: Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers;
- BS 1881-207: Testing Concrete – Recommendations for the assessments of concrete strength by near-to-surface tests.

Fig. (2.6):A typical setup of pull-out resistance NDT methods (Adapted from http://www.ndtjames.com).

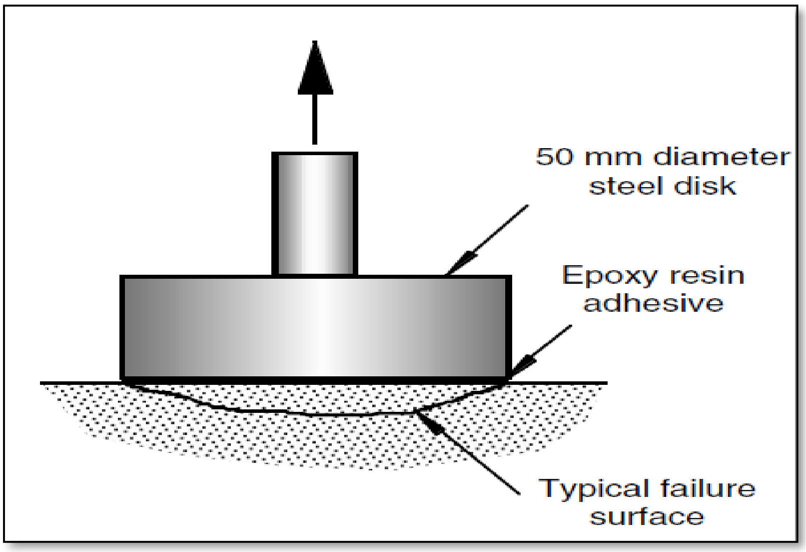

Fig.(2.7): Schematic diagram of pull-out resistance NDT methods (Henderson, Basheer, & Long, 2004).

The main advantage of pull-off test methods is that they are simples, quick and could be used to test a wide range of construction settings. A significant limitation is the curing time required for the adhesive, which is generally around 24 hours. Another limitation relates to the human error in surface preparation which may cause the adhesive to fail.

The results for tensile strength are often within20% of the true tensile strength (Concrete Institute of Australia, 2008). The factors that most contribute to the variability of results are the size and type of coarse aggregates (Henderson, Basheer, & Long,2004). It is recommended to develop correlation charts using samples that match testing conditions and to conduct the test several times using different sized disks in order to increase confidence by repeatability.

2.3.5: Resonant frequency test method

Resonant frequency methods are non-invasive non destructive tests that are conducted to determine material properties by measuring their natural frequency of vibration. The two categories of resonant frequency methods are resonant frequency by vibration and resonant frequency by impact .The natural frequency of a vibrating structural member is a function of its dimensions, dynamic modulus of elasticity and density. Therefore, measuring either the transverse or longitudinal natural frequency of vibrations of a structural member of know dimensions and material allows the determination of its modulus of elasticity (Eq. 1 & 2)(Rayleigh, 1945). It should be noted that the following equations were determined according to homogenous ,isotropic and perfectly elastic systems. The conditions are not met in the testing of in-situ concrete ;however, the equations still provide an accurate estimate of material properties.

$$N = (m^2 k / 2\pi L^2)\sqrt{E}/d \text{.............................. (2.1)}$$

$$F_4 = (4\pi^2 2L^4 N^2 d)/(m^4 k^2) \text{.......................... (2.2)}$$

where; E = dynamic modulus of elasticity; d = density of the material; L = length of the specimen; N =fundamental flexural frequency; k = radius of gyration; and m = a constant (4.73 for the fundamental mode of vibration).The system comprises of an oscillator which generates mechanical vibrations and sensors that detect the vibrations (Fig. 2.8). The three most commonly used sensors are displacement sensors, velocity sensors and accelerometers.

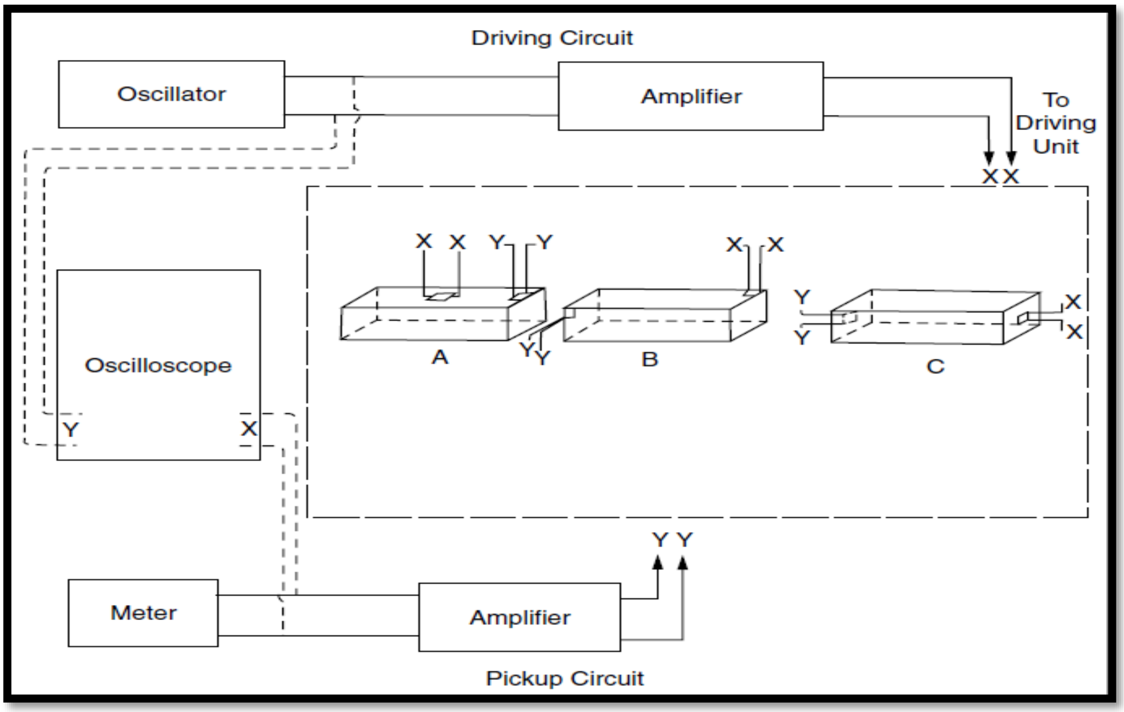

Fig.(2.8): Schematic diagram of a typical apparatus for the forced resonance method showing driver and pickup positions for the three types of vibration. (A) Transverse resonance. (B) Torsional resonance. (C) Longitudinal resonance. (Adapted from ASTM C 215-85).

The standard guideline on testing and interpreting resonant frequency methods is ASTM Standard C215-85: Standard Test Method for Fundamental Transverse, Longitudinal and T orsional Frequencies of Concrete Specimens. The dynamic modulus of elasticity provides an indication of the mechanical integrity of structural components. Dynamic modulus of elasticity is generally higher than the static modulus of elasticity, which is the recommended parameter in design calculations. The factors affecting resonant frequency and dynamic modulus of elasticity are the concrete mix proportions, aggregate properties ,structural specimen size and curing conditions These factors should be taken into account when testing structural elements that are dissimilar to the conditions outlined in ASTM C215-85. Never the less,resonant frequency methods provide an excellent means for studying the effects of extreme temperature changes and loading.

2.3.6: Maturity test method

The maturity method is a NDT technique for determining strength gain of concrete based on the measured temperature history during curing. The maturity function is presented to quantify the effects of time and temperature. The resulting maturity factor is then used to determine the strength of concrete based on established correlations. The maturity method has various applications in concrete construction such as formwork removal and post tensioning.

Temperature versus time is recorded by means of thermocouples inserted into fresh concrete (Fig.9). The measured time history could be used to compute a maturity index which provides a reliable estimate of early age concrete strength as a function of time (Saul, 1951) . The standard guideline on the testing and interpretation of the maturity method is ASTM C 1074-11: Standard Practice for Estimating Concrete Strength by Maturity Method.

Fig. (2.9): Maturity test apparatus with thermocouple(Adapted from http://www.humboldtmfg.com).

The factors that lead to variability in testing are aggregate properties, cement properties, water cement ratio and curing temperature (Concrete Institute of Australia, 2008). Before attempting to estimate in-situ strength of concrete, laboratory testing on concrete samples of similar characteristics must be performed in order to develop the correct maturity function while minimizing the effect of the aforementioned factors. Temperature probe locations must be carefully selected to measure a representative temperature of the entire concrete section.

2.3.7: Permeation test method

The permeability of aggressive substances into concrete is the main cause for concrete deterioration. Permeability represents the governing property for estimating the durability of concrete structures. Permeation tests are non-destructive testing methods that measure the near-surface transport properties of concrete.

The three categories of measuring concrete permeability are:

- Hydraulic permeability which is the movement ofwater through concrete;
- Gas permeability which is the movement of air through concrete;
- Chloride-ion permeability which involves the movement of electric charge. The measuring of chloride penetrability is the most commonly used non-destructive method that provides an indication of concrete permeability through established correlations. The standard guideline on the application and interpretation of chloride penetrability is ASTM C 1202: Standard Test Method for Electrical Indication of Concrete’s Ability to Resist. The test involves coring a standardized cylinder from the in-situ concrete. The sample is then trimmed, sealed with an epoxy coating from two sides, saturated in water and then placed in asplit testing device filled with a sodium chloride solution with an applied

voltage potential (Concrete Institute of Australia, 2008). The charge passing through the concrete is then measured where:

- a value of between 100 and 1000 Coulombs represent slow permeability
- a value greater than 4000 Coulombs represents high permeability

2.3.8: Ultrasonic pulse velocity method

Ultrasonic pulse velocity methods involve propagating ultrasonic waves in solids while measuring the time taken for the waves to propagate between a sending and receiving point. The features of ultrasonic wave propagation can be used to characterize a material's composition, structure, elastic properties, density and geometry using previously established correlations, known patterns and mathematical relationships. This non-invasive technique is also used to detect and describe flaws in material as well as their severity of damage by observing the scattering of ultrasonic waves. The basic technique of ultrasonic pulse velocity methods involve the transformation of a voltage pulse to an ultrasonic pulse and back by a transmitting and receiving transducer respectively. The transmitting transducer is placed onto the concrete surface and is allowed to transmit an ultrasonic pulse through the specimen medium. The ultrasonic pulse travels through the concrete specimen and is detected by a receiving transducer at the opposite end which transforms the ultrasonic pulse to a voltage pulse (Fig. 2.10). Knowing the distance between the two points, the velocity of the wave pulse can be determined. The velocity of the ultrasonic pulse provides a detailed account of the specimen under investigation.

The following publications present standard guidelines for ultrasonic pulse velocity testing:

- ASTM C 597: Standard Test Method for Pulse Velocity Through Concrete.

- BS EN 12504-4:2004 Testing Concrete. Determination of Ultrasonic Pulse Velocity.

Fig.(2.10): Ultrasonic pulse velocity test apparatus(Adapted from http://www.controls-group.com).

The factors contributing to the variability of ultrasonic pulse velocity methods as applied to concrete are aggregate properties, cement type, water cement ratio, admixtures and age of concrete (Naik, Malhotra & Popovics, 2004). Additionally, embedded reinforcement in the pulse path may have a significant effect on the measurements of pulse velocity(Concrete Institute of Australia, 2008). By taking these factors into account during analysis, ultrasonic pulse velocity methods are excellent means for investigating the uniformity and durability of concrete in a simple and inexpensive manner.

2.3.9: Impact-echo method

The impact-echo system is a recent development of ultrasonic methods which involves the measuring of concrete thickness and integrity using one surface. The test is also applied to determine the location of cracking, voids and delimitation. It is based on monitoring the surface motion of concrete resulting from a short-duration mechanical impact. Specifically, the test measures the amplitude of reflected shockwaves to detect flaws in concrete. The impact-echo system uses an electro mechanical transducer to generate a short pulse of ultrasonic stress waves that propagates into concrete plate-like structures. The different materials of different densities and elastic properties will reflect the stress pulse at their boundaries. The reflected pulse travels back to the transducer, which also acts as a receiver. An oscilloscope displays the received signal and the round trip travel time of the pulse is measured electronically. The distance of the reflecting interface can be determined by knowing the speed of the stress wave. The standard guideline on the application and interpretation of the impact-echo method is ASTM C 1383 - 04: Standard Test Method for Measuring the P-Wave Speed and the Thickness of Concrete Plates Using the Impact-Echo Method.

The factors that affect the detection of a flaw within concrete are: the type of the flaw and its orientation, the depth of the flaw and the contact time of the impact (Carino N. , 2001). The impact-echo method proves to be a reliable method for locating a variety of defects in concrete structures. As with most methods for flaw detection in concrete, experience is required to interpret impact-echo test results.

2.3.10: Corrosion of reinforcement method

Corrosion of steel is an inevitable electrochemical and thermo dynamical reaction which occurs spontaneously due to metallurgical characteristic of iron.

Corrosion of steel reinforcement in concrete requires the loss of passivation, presence of moisture and/or the presence of oxygen. These conditions are often satisfied in concrete structures where corrosion can only be delayed or slowed down by preventative measures and techniques. The resulting iron oxides have unique chemical, electrical, magnetic and electrical properties which could be exploited in order to determine the extent of reinforcement corrosion by means of NDT.

Non-destructive methods of testing reinforcement corrosion require the use of a half-cell system and high-impedance voltmeters (Fig. 2.11). This system is capable of detecting the current flow of ion migration through the concrete between anodic and cathodicsites by measuring the resultant equipotential lines (Elsener, Müller, Suter, &Böhni, 1990). The concrete functions as an electrolyte and the risk of corrosion may be related empirically to the measured potential difference that leads to corrosion.

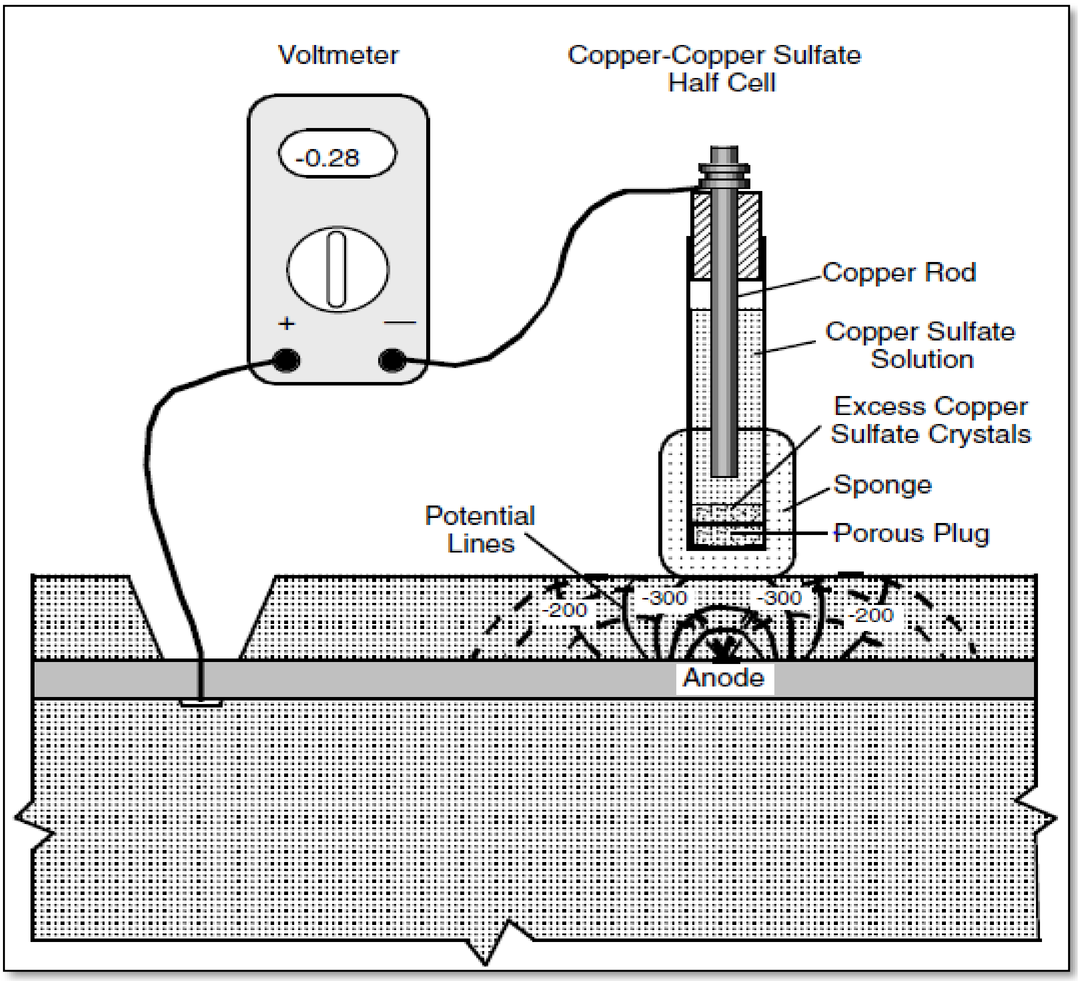

Fig. (2.11): Schematic drawing of half-cell apparatus (Carino,2004).

The standard guideline on application and interpretation of reinforcement corrosion testing is ASTM C 876 - 91: Standard Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete. The conditions for the successful testing are exposure and electrical continuity of reinforcement in the test area. According to ASTM 876, there is a:

- 90% probability of active corrosion if negative potential is more than -350mV;
- 90% probability of no corrosion if negative potential is less than -200mV;

Uncertainty in corrosion if negative potential is between -350mV and -200mV.

The half-cell potential test is a useful technique to locate likely active areas of corrosion. It is recommended hat potential surveys be supplemented with tests for carbonation and soluble chloride ion content for more accurate results.

2.3.11: Qualification and certification

The qualification and certification of NDT personnel for the inspection of concrete is not commonly covered by the qualification and certification schemes presently established in most countries. Usually such schemes are based on the requirements of the International Standards Organization (ISO) 9712 “The qualification and certification of NDT Personnel” and cover the use of methods such as ultra-Sonic’s, radiography, eddy current testing and surface methods tests to inspect essentially homogeneous materials such as metals. The growing interest in the use of NDT for the inspection of concrete may result in a demand for certification in the future.

2.4: Schmidt Rebound Hammer Test

2.4.1: Fundamental Principle

The Schmidt rebound hammer is principally a surface hardness tester. It works on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges. There is little apparent theoretical relationship between the strength of concrete and the rebound number of the hammer. However, within limits, empirical correlations have been established between strength properties and the rebound number.

Further, Kolek has attempted to establish a correlation between the hammer rebound number and the hardness as measured by the Brinell method.

2.4.2: Equipment for Schmidt/Rebound Hammer Test

The Schmidt rebound hammer is shown in Fig. (2.1). The hammer weighs about 1.8 kg and is suitable for use both in a laboratory and in the field. A schematic cutaway view of the rebound hammer is shown in Fig. (2.2). The main components include the outer body, the plunger, the hammer mass, and the main spring. Other features include a latching mechanism that locks the hammer mass to the plunger rod and a sliding rider to measure the rebound of the hammer mass. The rebound distance is measured on an arbitrary scale marked from 10 to100. The rebound distance is recorded as a “rebound number” corresponding to the position of the rider on the scale.

2.4.3: General Procedure for Schmidt Rebound Hammer Test

The method of using the hammer is explained using Fig. (2.2). With the hammer pushed hard against the concrete, the body is allowed to move away from the concrete until the latch connects the hammer mass to the plunger, Fig.(2.2a).

The plunger is then held perpendicular to the concrete surface and the body pushed towards the concrete, Fig. (2.2b). This movement extends the spring holding the mass to the body. When the maximum extension of the spring is reached, the latch releases and the mass is pulled towards the surface by the spring, Fig.(2.2c).The mass hits the shoulder of the plunger rod and rebounds because the rod is pushed hard against the concrete, Fig.(2.2d). During rebound the slide indicator travels with the hammer mass and stops at the maximum distance the mass reaches after rebounding. A button on the side of the body is pushed to lock the plunger into the retracted position and the rebound number is read from a scale on the body.

2.4.4: Applications of Schmidt Rebound Hammer Test

The hammer can be used in the horizontal, vertically overhead or vertically down ward positions as well as at any intermediate angle, provided the hammer is perpendicular to the surface under test. The position of the mass relative to the vertical, however, affects the rebound number due to the action of gravity on the mass in the hammer. Thus the rebound number of a floor would be expected to be smaller than that of a soffit and inclined and vertical surfaces would yield intermediate results. Although a high rebound number represents concrete with a higher compressive strength than concrete with a low rebound number, the test is only useful if a correlation can be developed between the rebound number and concrete made with the same coarse aggregate as that being tested. Too much reliance should not be placed on the calibration curve supplied with the hammer since the manufacturer develops this curve using standard cube specimens and the mix used could be very different from the one being tested.

A typical correlation procedure is, as follows:

(1) Prepare a number of 150 mm × 300 mm cylinders (or 150 mm3 cube specimens)

Covering the strength range to be encountered on the job site. Use the same cement and aggregates as are to be used on the job. Cure the cylinders under standard moist-curing room conditions, keeping the curing period the same as the specified control age in the field.

(2) After capping, place the cylinders in a compression-testing machine under an initial load of approximately 15% of the ultimate load to restrain the specimen. Ensure that cylinders are in a saturated surface-dry condition.

(3) Make 15 hammer rebound readings, 5 on each of 3 vertical lines 120° apart, against the side surface in the middle two thirds of each cylinder. Avoid testing the same spot twice .For cubes, take 5 readings on each of the 4 molded faces without testing the same spot twice.

(4) Average the readings and call this the rebound number for the cylinder under test. Repeat this procedure for all the cylinders.

(5) Test the cylinders to failure in compression and plot the rebound numbers against the compressive strengths on a graph.

(6) Fit a curve or a line by the method of least squares.

A typical curve established by Zoldners for limestone aggregate concrete is shown in Fig. (2.13). This curve was based on tests performed during 28 days using different concrete mixtures.

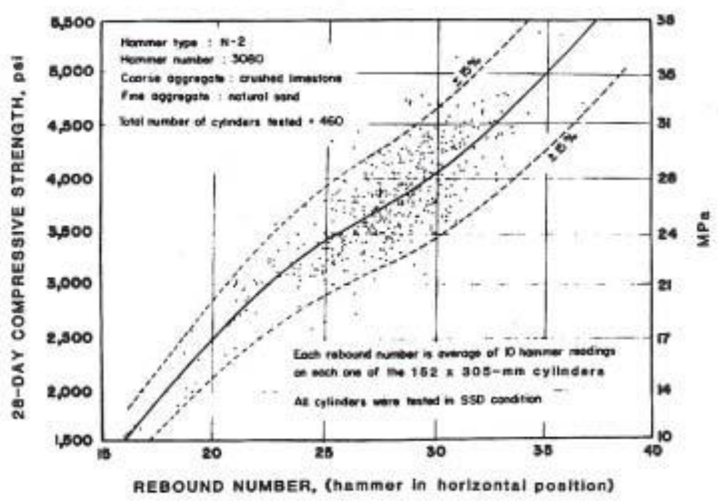

Fig. (2.12): Relationship between 28-day compressive strength and rebound number for limestone aggregate concrete obtained with Type N-2 hammer.

2.4.5: Range and Limitations of Schmidt Rebound Hammer Test

Although the rebound hammer does provide a quick, inexpensive method of checking the uniformity of concrete, it has some serious limitations. The results are affected by:

2.4.5.1: Smoothness of the test surface.

Hammer has to be used against a smooth surface, preferably a formed one. Open textured concrete cannot therefore be tested. If the surface is rough, e.g. a trowelled surface, it should be rubbed smooth with a carborundum stone.

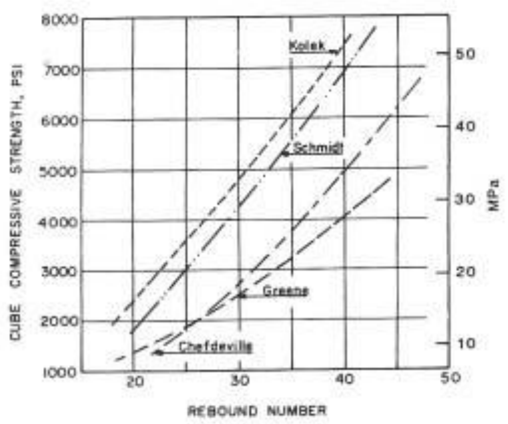

Fig. (2.13): Correlation curves produced by different researchers.

(Greene curve used Type N hammer; others used Type N-2).

2.4.5.2: Size, shape and rigidity of the specimen

If the concrete does not form part of a large mass any movement caused by the impact of the hammer will result in a reduction in the rebound number. In such cases the member has to be rigidly held or backed up by a heavy mass.

2.4.5.3: Age of the specimen

For equal strengths, higher rebound numbers are obtained with a 7 day old concrete than with a 28 day old. Therefore, when old concrete is to be tested in a structure a direct correlation is necessary between the rebound numbers and compressive strengths of cores taken from the structure. Rebound testing should not be carried out on low strength concrete at early ages or when the concrete strength is less than 7 MPa since the concrete surface could be damaged by the hammer.

2.4.5.4: Surface and internal moisture conditions of concrete

The rebound numbers are lower for well-cured air dried specimens than for the same specimens tested after being soaked in water and tested in the saturated surface dried conditions. Therefore, whenever the actual moisture condition of the field concrete or specimen is unknown, the surface should be pre-saturated for several hours before testing. A correlation curve for tests performed on saturated surface dried specimens should then be used to estimate the compressive strength.

2.4.5.5: Type of coarse aggregate

Even though the same aggregate type is used in the concrete mix, the correlation curve scan be different if the source of the aggregate is different. An example is shown in Fig. 4.5where correlation curves for four different sources of gravel are plotted.

Fig. (2.14). shows the considerable difference that can occur between correlation curves developed for different aggregate types.

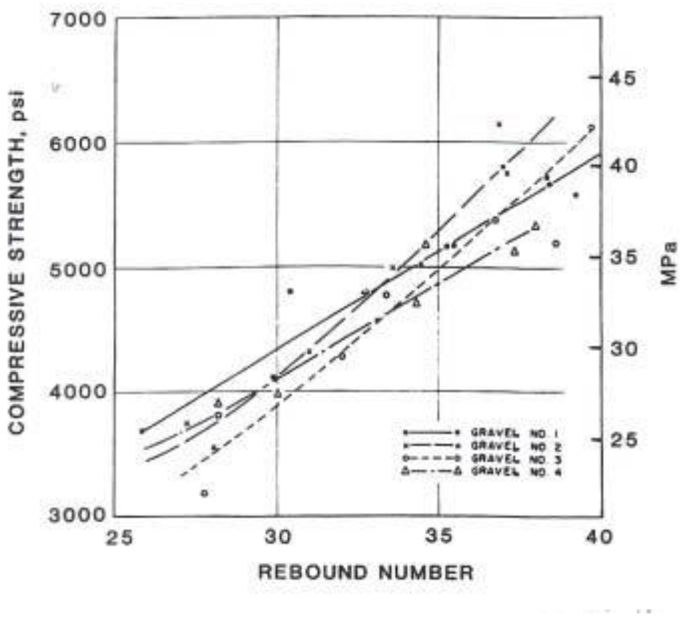

Fig. (2.14): Effect of gravel from different sources on correlation curves. (Carino, 2004).

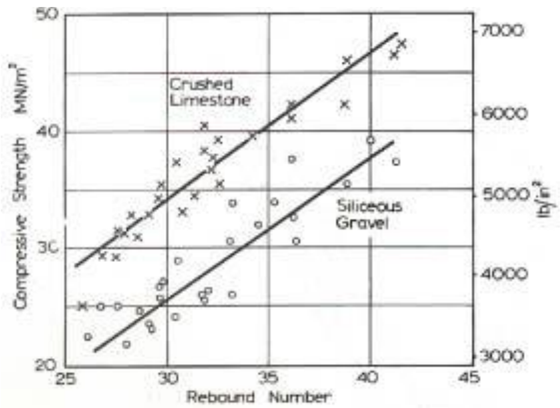

Fig. (2.15): Comparison between correlation curves for crushed limestone and siliceous. (Carino, 2004).

2.4.5.6: Type of cement

High alumina cement can have a compressive strength 100% higher than the strength estimated using a correlation curve based on ordinary Portland cement. Also, super sulphated cement concrete can have strength 50% lower than ordinary Portland cement.

2.4.5.7: Carbonation of the concrete surface

In older concrete the carbonation depth can be several millimeters thick and, in extreme cases, up to 20 mm thick. In such cases the rebound numbers can be up to 50% higher than those obtained on an un carbonated concrete surface.

CHAPTER THREE

EXPERIMENTAL PROGRAM

Chapter Three

Experimental Program

3.1: Introduction

The research aimed to obtain a simple correlation plot used by engineers who work on-site. Samples were made from ordinary Portland Cement and aggregate of local natural sources. Various concrete mixes were used to prepare the standard cube specimens (15×15×15) cm^3 in the laboratory to compare with Schmidt Hammer and crushing machine.

Cube specimens were cured in to water at 7, 14, 28days and rubbed with a dry cloth to obtain a surface dry sample. Two opposite faces of the cubes were prepared for the Schmidt Hammer test when drying was completed. The specimens were placed in the testing machine and slight load was applied. Afterwards, a fixed amount of energy is applied by pushing the hammer against the test surface according to the ASTM C 805 (1993) and TS 3260 (1978).

Each of the two opposite faces of cubes was impacted to get at least 18readings to illustrate the sensitiveness of the test to the presence of aggregate and voids immediately underneath the plunger

3.2: laboratory work

3.2.1: Preliminary tests

(1) Standard tests of cement:

- Setting time test (initial & final setting time).
- Compressive strength test.

The result of cement tests are shown in Table (3.1).

Ordinary Portland cement (Atbara) was used throughout experimental program. Its physical properties were determined according to BS-12-1996; sufficient cement was reserved to avoid changing reference cement.

Table (3.1): Results of cement Test

Test	Results	Requirements of BS 12-1996
Consistency	29.0%	26 -32%
Setting Time		
a) Initial	2 hrs	Not less than 60 min (-15 min)
b) Final	3 hrs: 10 min	Not more than 10 hrs.
Compressive Strength		
a) 2days		Equal or Greater than 10 N/mm^2
1	17.6 N/mm^2	
2	17.2 N/mm^2	
3	17.32 N/mm^2	
b) 28 days		Equal or Greater than 42.5 N/mm^2
1	45.6 N/mm^2	
2	44.1 N/mm^2	
3	46.2 N/mm^2	

(2) Standard tests for fine aggregate:

- Sieve analysis.
- Silt content

The following Table (3.2) represents the sieve analysis of fine aggregate.

Table (3.2): Fine Aggregate Sieve Analysis

Sieve No mm	Retained (g)	Percentage retained	Percentage Passing	BS Zone 2 BS 882
4.75	93	4.7	95.3	89-100
2.36	163	8.2	87.1	65-100
1.18	332	16.7	70.4	45-100
0.6	347	17.5	52.9	25-80
0.3	792	39.9	12.99	5-48
0.15	180	9	3.93	0-5
0.075	63	3.2	0.76	
pan	14	0.7	0	
T.wi	1984 g			

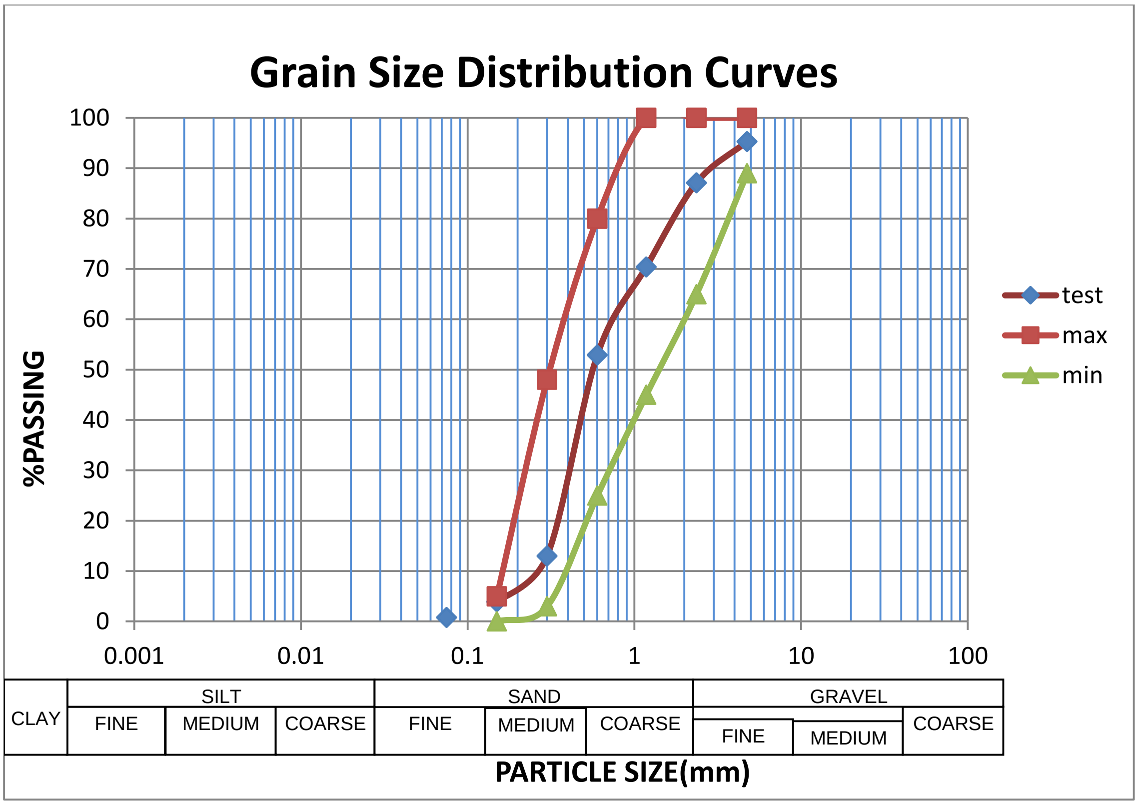

Fig. (3.1): Grain Size of fine Aggregate Test

Locally available natural sand passing through 10 mm sieve and retained on 0.15 mm sieve fin**e** aggregate (zone-II) confirming BS 882.

3.2.2: Results of Silt Content

Silt content in fine aggregate should not be more than 3% of the total weight of sand according to the (BS882) [12]. Sample of sand weighted and washed and after that dried in furnace and the percentage of loss weight calculated, found the silt content in fine aggregate about (2) %.

Table (3.3): Physical Properties of Coarse aggregate 20mm

Physical properties of Aggregates		
	Sample1	Sample2
Specific gravity	2.7	2.7
Absorption	1.5	1.42

3.2.3:Results of Coarse Aggregate Test

The following Figure and Table represent the sieve analysis and grain size distribution curve of coarse aggregate.

Table (3.4): Grading of Coarse aggregate 20mm

Sieve No mm	**Retained (g)**	**Percentage retained**	**Percentage Passing**	**BS 882**
25	0	0	100	100
19	156	5.2	94.8	90-100
12.5	1257	42.2	52.6	40-80
9.5	584.5	19.63	32.9	30-60
4.75	678.5	22.8	10.14	0-10
Pan	302	10	0	
Total				**2978g**

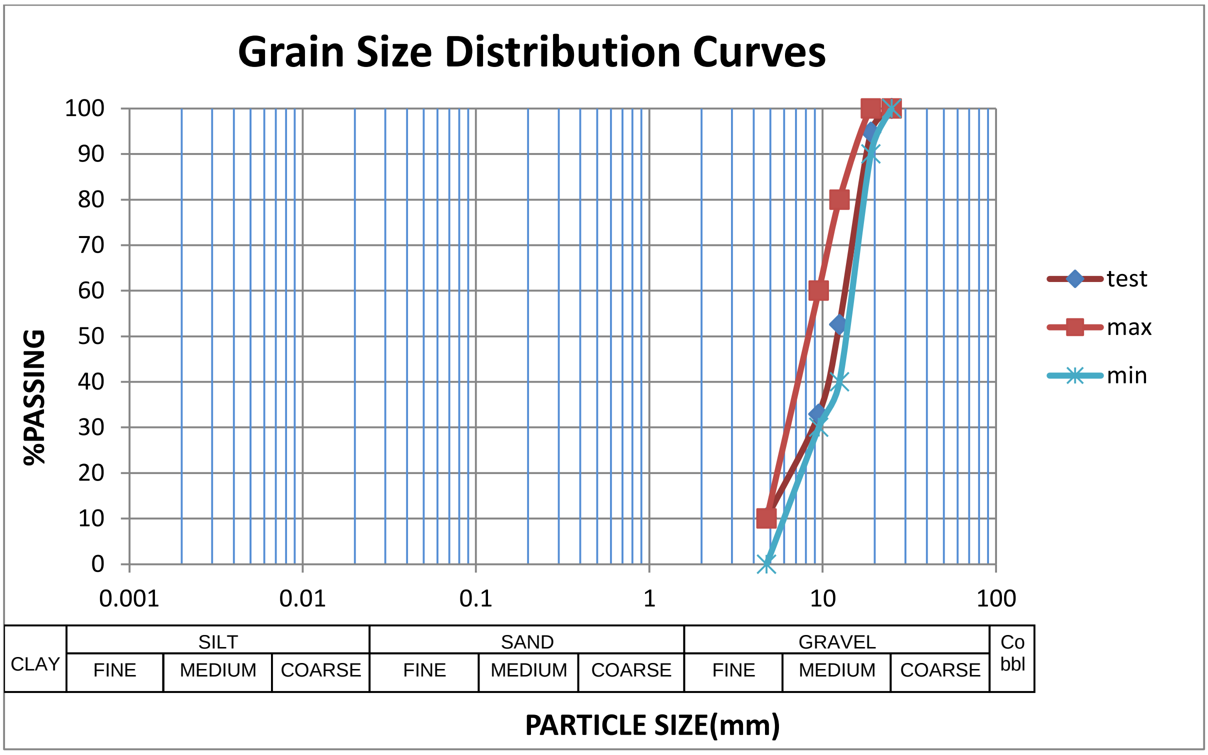

Fig. (3.2): Grain Size of Coarse Aggregate Test.

It is clear that the grading of coarse aggregate is well graded and the grading of fine aggregate is classified as zone 2 according to BS882, 1992.

3.2.4: Testing program

In this study the testing program is as followed:

1- Mixed design from local materials which prepared in concrete laboratory.
2- Casted [36] concrete cubes.
3- Casting 18 cubes with C25and other 18 with C40.
4- Measuring the rebound number for tested cubes.
5- Record the result of rebound hammer test.
6- Crushed cubes on 7, 14 and 28 days.
7- Record the results of compressive strength for cubes.
8- Analyzing the results and recording notifications.

3.3: Concrete mix designs

Concrete mix design can be defined as the procedure by which, for any given set of concrete, the proportion of the constituent materials are chosen so as to produce a concrete with all the required properties for the minimum cost.

Image 1: Concrete Mixing

Image 2: Concrete Cubes Finishing

3.4: Required concrete properties

The basic requirements for concrete are conveniently considered at two stages in its life. In its hardened state (in the completed structure) the concrete should have adequate durability, the required strength and also the desired surface finish.

In its plastic state, or the stage during which it is to be handled and compacted in its final form, it should be sufficiently workable for the required properties in its hardened state to be achieved with the facilities available on site.

This means that:

i. The concrete should be sufficiently fluid to be able to flow into and fill all parts of the form work, into which it is placed.
ii. It should do so without any segregation or separation, of the constituent materials while being handled from the mixer or during placing.
iii. It must be possible to fully compact concrete when placed in position.
iv. It must be possible to obtain the required surface finish.

If concrete does not have the required workability in its plastic state, it will not be possible to produce concrete with the required, properties in its hardened state.

3.4.1: Durability

Adequate durability of exposed concrete can frequently be obtained by ensuring full compaction, an adequate cement content and a low water-cement ratio, all of which contribute to producing a dense, impermeable concrete. Moreover, other factors affecting durability are:

3.4.1.1: Aggregate

Aggregates constitute about 75% of the volume of concrete, so their properties have a large influence on the properties of the concrete [7].

Aggregates are granular materials, most commonly natural gravels and sands or crushed stone. The choice of aggregate is important particularly for concrete wearing surface and where improved fire resistance is required. Aggregate having high shrinkage properties should be used with caution in exposed concrete.

Durability is not a readily measured property of the hardened concrete. However, for a correctly designed concrete mix any increase in the water – cement ratio on site, the associated reduction in durability will be accompanied by a reduction in concrete strength. The latter can be determined quite easily using control specimens and for this reason the emphasis in control testing is on the determination of concrete strength.

3.4.2: Strength

The strength of the concrete is frequently an important design consideration particularly in structural applications where the load carrying capacity of a structural member may be closely related to the concrete strength. This will usually be the compressive strength although occasionally the flexural or indirect tensile strength may be more relevant. The strength requirement is generally specified in terms of a characteristic strength coupled with a requirement that the probability of the strength falling below it shall not exceed a certain value. An understanding of the factors affecting concrete strength on site, and of the probable variations in strength, is essential if such specifications are to have any real meaning at the mix design stage.

Difference in strength can also occur owing to variation in the quality of cement but the principal factor affecting the strength is the water cement ratio in the concrete mix. Once a suitable mix has been obtained the workability can be assessed quite satisfactorily by an experienced mixer operator, with periodic control tests of the workability. However, human error will inevitably result in some variation in the water – cement ratio either side of the desired value.

Any variation in mix proportion or significant changes in the aggregate grading will affect the quantity of water needed to maintain the required workability and this too will result in variation in the water – cement ratio and hence in concrete strength [8].

3.4.3: Compressive strength

The compressive strength of concrete is taken as the maximum compressive load it can carry per unit area. Concrete strength of up to $60N/mm^2$ can be achieved by selective use of the type of cement, mix proportion, method of compaction and curing conditions. Concrete structures, except for road pavement, are normally designed on by steel reinforcement.

In the United Kingdom a 150 mm cube is commonly used for determining the compressive strength. The test specimen should be cured in water and crushed immediately after it has been removed from the curing tank [8].

The compressive strength of concrete is primarily dependent on the following:

1- Curing: duration, moisture content, temperature.

2- Age at testing.

3- Shape and size of specimen (Cube or cylinder).

4- Testing procedure (applied load rate & moisture condition).

Compressive strength is considered as an index to assess the overall quality of concrete and it is generally assumed that an improvement in the compressive strength results in improvement of all other properties. Hence strength investigations are generally centered on compressive strengths [9].

3.4.4: Workability

The ease of placing, consolidating, and finishing freshly mixed concrete and the degree to which it resists segregation is called workability. Concrete should be workable but the ingredients should not separate during transport and handling.

The degree of workability required for proper placement of concrete is controlled by the placement method, type of consolidation, and type of concrete. Different types of placements require different levels of workability.

Factors that influence the workability of concrete are:

1. The method and duration of transportation.
2. Quantity and characteristics of cementations materials.
3. Concrete consistency.
4. Grading, shape, and surface texture of fine and coarse aggregates.
5. Water content and water – cement ratio.
6. Admixtures.

3.4.5: Water – Cement ratio

Water cement ratio gives the compressive strength of concrete at a given age. The lower the water – cement ratio, the greater is the compressive strength and vice versa [7].

3.5: Laboratory Investigation

The following subsections present the details of the materials used in the production of concrete cube and the related testing and specifications.

3.5.1: Aggregates

Aggregate are those parts of the concrete that constitute the bulk of the finished product. They comprise 60-80% of the volume of the concrete and have to be so graded that the entire mass of concrete acts as a relatively solid, homogeneous and dense. There are two types of aggregate:

Natural water that is drinkable (Water that is safe to drink is safe to use in concrete) [8].

3.6: Slump cone test

The slump test is the most commonly used method The slump test is suitable for slumps of medium to high workability, slump in the range of 60 – 180 mm.

3.7: Testing of hardening concrete

3.7.1: Hammer strength

ASTM C805, "Standard Test Method for Rebound Number of Hardened Concrete" and BS 1881: Part 202 (1986), summarizes the procedure as "A steel hammer impacts, with a predetermined amount of energy, a steel plunger in contact with a surface of concrete, and the distance that the hammer rebounds is measured." The device consists of a plunger rod and an internal spring loaded steel hammer and a latching mechanism. When the extended plunger rod is pushed against a hard surface, the spring connecting the hammer is stretched and when pushed to an internal limit, the latch is released causing the energy stored in the stretched spring to propel the hammer against the plunger tip. The hammer strikes the shoulder of the plunger rod and rebounds a certain distance. There is a slide indicator on the outside of the unit that records the distance traveled during the rebound. This indication is known as the rebound number.

ASTM C805 states that this method is applicable for the following uses:

- To assess the in-place uniformity of concrete regions in a structure of poor.

- Quality or deteriorated concrete.
- To estimate in-place strength if a correlation is developed.

Table (3.5): Quality of concrete from rebound values

Average rebound	Quality of concrete
> 40	Very good
30 - 40	Good
20 - 30	Fair
< 20	Poor and / delaminated
0	Very poor and/ or delaminated

After prepared the cubes the test hammer was first used while kept in a vertical position to test opposite cube surfaces. Finally, destructive testing was carried out for the same cubes to obtain its crushing strengths using standard compression testing machine.

3.7.2: Compressive Strength of Concrete

Concrete cubes of (150×150×150 mm) dimension were casting for compressive strength. They have tested for compressive strength after 7, 14, and 28days of water curing. The compressive strength was determined according to BS 1881: Part 116, 1986.

3.7.3: Procedure of Compressive strength test:

- After finishing all other tests, the specimens (cubes) are ready for Compressive Strength Test.
- Each specimen to be fixed in the compressive machine in order to applied load on it.
- The load is applied gradually.
- Failure load of the specimen is recorded.

CHAPTER FOUR

RESULTS PRESENTATION AND DISSCUSSION

Chapter four

Results Presentation and Discussion

4.1: Introduction

In this study, the destructive and non-destructive tests were performed on totally 36cubes divided in to18 cubes of grade25and ones of18grade40.By using excel software to study the correlation between rebound index and crushing strength of a standard concrete cube for both situations under consideration.

Simple relationships were determined and correlated between non-destructive testing (NDT) named as Schmidt rebound hammer test and concrete destructive compression test. The Schmidt rebound hammer is principally a surface hardness tester with an apparent theoretical relationship between the strength of concrete and the rebound number of the hammer. Schmidt hammer was applied in vertical positions.

Table (4.1): Results of compressive strength test (C25)using crushing machine

Age	Weight of cube (kg)	Compressive strength (N/mm^2)	Average (N/mm^2)
7days	8.061	26.5	24.65
	8.089	20.2	
	8.093	23.4	
	8.134	27.3	
	8.582	29.8	
	8.282	20.7	
14days	8.080	28.6	27.18
	8.125	23.4	
	8.334	28.6	
	8.021	28.5	
	8.206	24.5`	
	8.176	29.5	
28days	8.322	30	31.17
	8.017	33.42	
	7.961	28.66	
	8.284	32.32	
	8.174	28.67	
	8.080	34	

This is results of compressive strength test (C25).in7days the average was 24.6,in 14 days the average was 27.1 and in 28days the average was 31.7 .

Table (4.2):Results of compressive strength test (C40) using crushing machine.

Age	Weight of cube (kg)	Compressive strength (N/mm^2)	Average (N/mm^2)
7days	8.080	25	27.91
	8.334	28.4	
	8.021	29.5	
	8.206	25.6	
	8.176	30	
	8.190	29	
14days	8.310	39.78	35.58
	8.102	40.72	
	8.170	33.99	
	8.410	31.6	
	8.210	34.4	
	8.090	33	
28days	8.373	42.71	46.22
	8.332	44.65	
	8.311	48.63	
	8.204	48.11	
	8.430	49	
	8.427	44.27	

This is results of compressive strength test (C40).in7days the average was 27.9,in 14 days the average was 35.5 and in 28days the average was 46.2 .

Table (4.3): Results of compressive strength(C 25)using hammer test.

Age	Weight of cube (Kg)	Compressive strength(N/mm^2)	Hammer strength
7 days	8.061	26.5	29
	8.089	20.2	20
	8.093	23.4	26.3
	8.134	27.3	26
	8.582	29.8	30
	8.282	20.7	18
14days	8.080	28.6	30
	8.125	23.4	26.8
	8.334	28.6	29
	8.021	28.5	30
	8.206	24.5	26.6
	8.176	29.5	31.5
28days	8.322	30	31
	8.017	33.42	34.4
	7.961	28.66	30
	8.284	32.32	34
	8.174	28.67	29.5
	8.080	34	35

Table (4.4): Results of compressive strength (C40)using hammer test.

Age	Weight of cube (Kg)	Compressive strength(N/mm^2)	Hammer strength
7days	8.080	25	29
	8.334	28.4	30
	8.021	29.5	32
	8.206	25.6	31.5
	8.176	30	34
	8.190	29	32
14 days	8.310	39.78	41
	8.102	40.72	40
	8.170	33.99	34.5
	8.410	31.6	34
	8.210	34.4	44.2
	8.090	33	35
28 days	8.373	42.71	41
	8.332	44.65	44
	8.311	48.63	49.4
	8.204	48.11	50
	8.430	49	50.4
	8.427	44.27	44.5

4.2: Summary of tests Results

The hammer test was first used while kept in a vertical position to test opposite cube surfaces been placed in horizontal direction, and then kept in a horizontal position to test opposite cube surfaces been placed vertical direction. Finally, destructive testing was carried out for the same cubes to obtain its crushing strengths using standard compression testing machine.The tests results for both positions are given in Tables (4.9).

Table (4.5): Comparison of compressive strengths between Crush machine and hammer strength

Age	Hammer result (C25)(MPa)	Crushing machine (C25) (MPa)	Hammerresult (C40) (MPa)	Crushing machine (C40) (MPa)
7 days	29	26.5	29	25
	20	20.2	30	28.4
	26.3	23.4	32	29.5
	26	27.3	31.5	25.6
	30	29.8	34	30
	18	20.7	32	29
14 days	30	28.6	41	39.78
	26.8	23.4	40	40.72
	29	28.6	34.5	33.99
	30	28.5	34	31.6
	26.6	24.5	44.2	34.4
	31.5	29.5	35	33
28 days	31	30	41	42.71
	34.4	33.42	44	44.65
	30	28.66	49.4	48.63
	34	32.32	50	48.11
	29.5	28.67	50.4	49
	35	34	44.5	44.27

4.3: Data Analysis

Samples of Grade25analysiswas conducted using excel software to study the correlation between rebound index and crushing strength of a standard concrete cubes for both positions under consideration. Figures (4.3), (4.4), (4.5), (4.6), (4.7), (4.8), (4.9), (4.10), (4.11) showed these relationships.

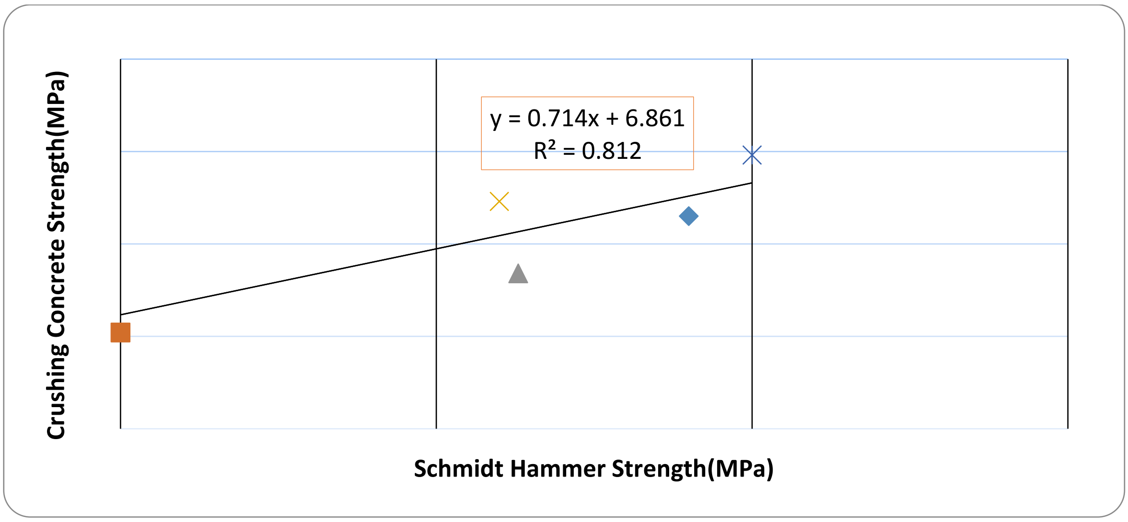

Fig.(4.1): Rebound numbers and strength relation of C25 age 7day.

(Linear Equation)

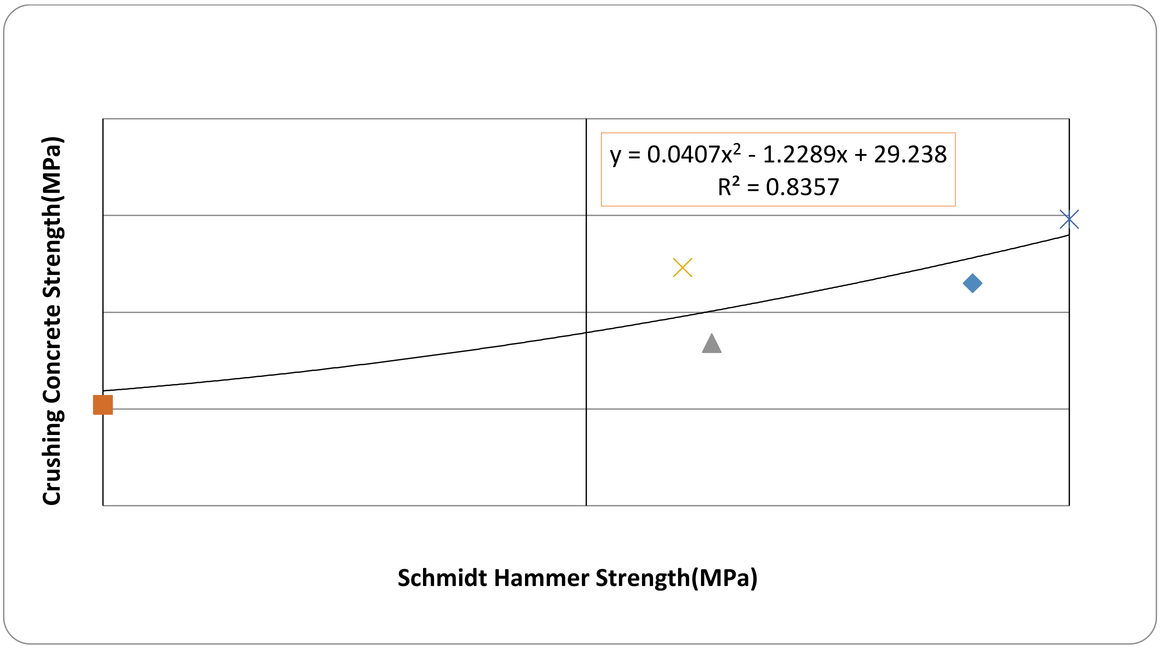

Fig. (4.2): Rebound numbers and strength relation of C25 age 7days.

(Quadratic Equation)

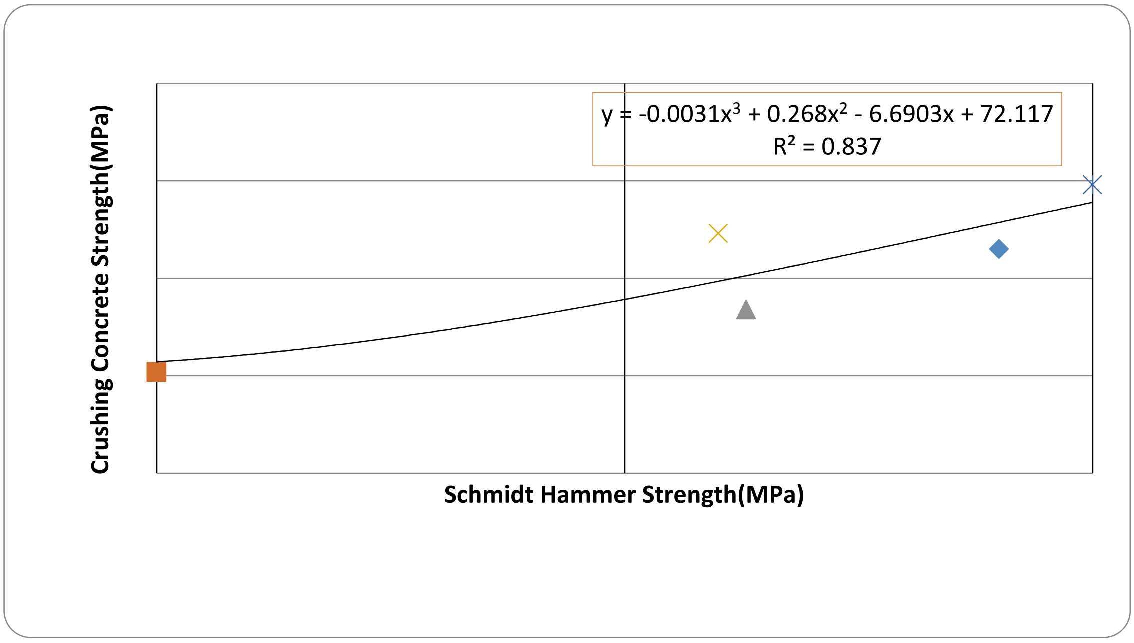

Fig.(4.3): Rebound numbers and strength relation of C25 age 7days.

(Cubic Equation)

- For concrete C25 in age 7days, there is no significant difference between the linear, quadratic and cubic equation in term of regression. The regressions values are 0.812,0.835and .837 respectively in the correlation between hammer test results and compressive strength test.

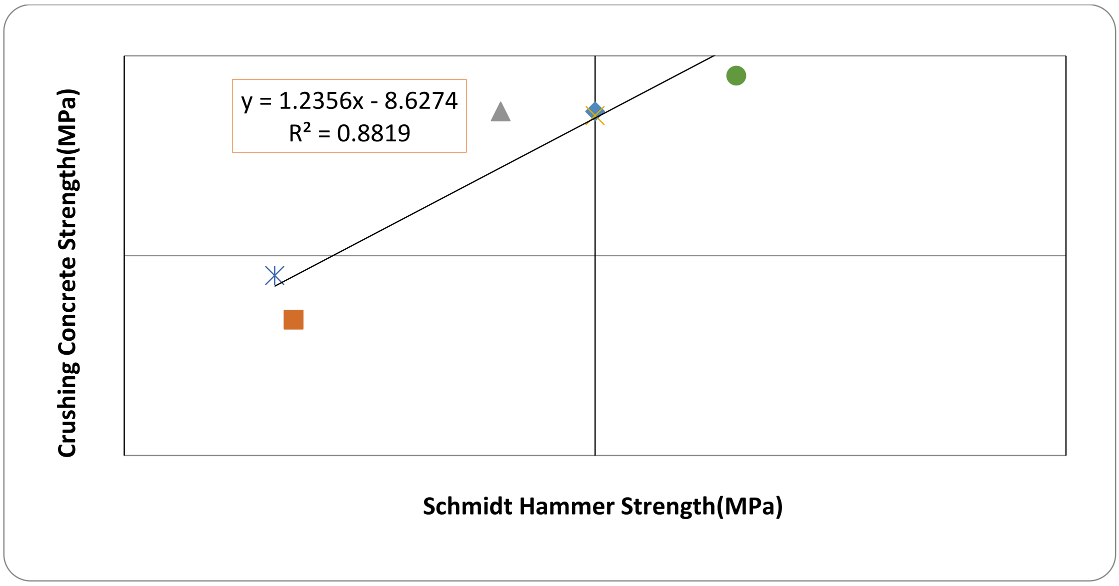

Fig. (4.4): Rebound numbers and strength relation of C25 age 14days.

(Linear Equation)

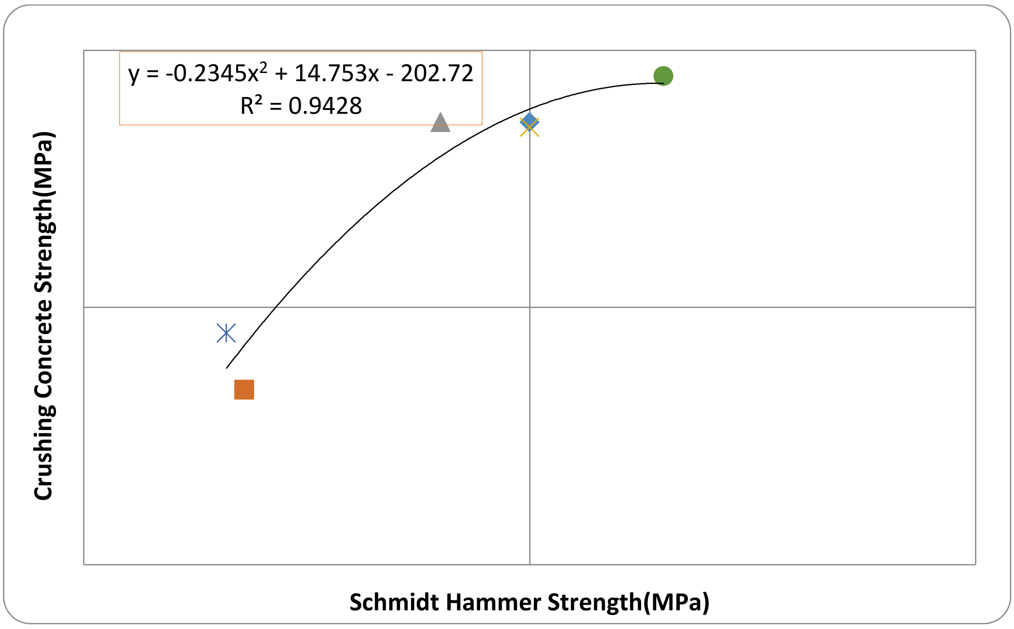

Fig .(4.5): Rebound numbers and strength relation of C25 age 14days.

(Quadratic Equation)

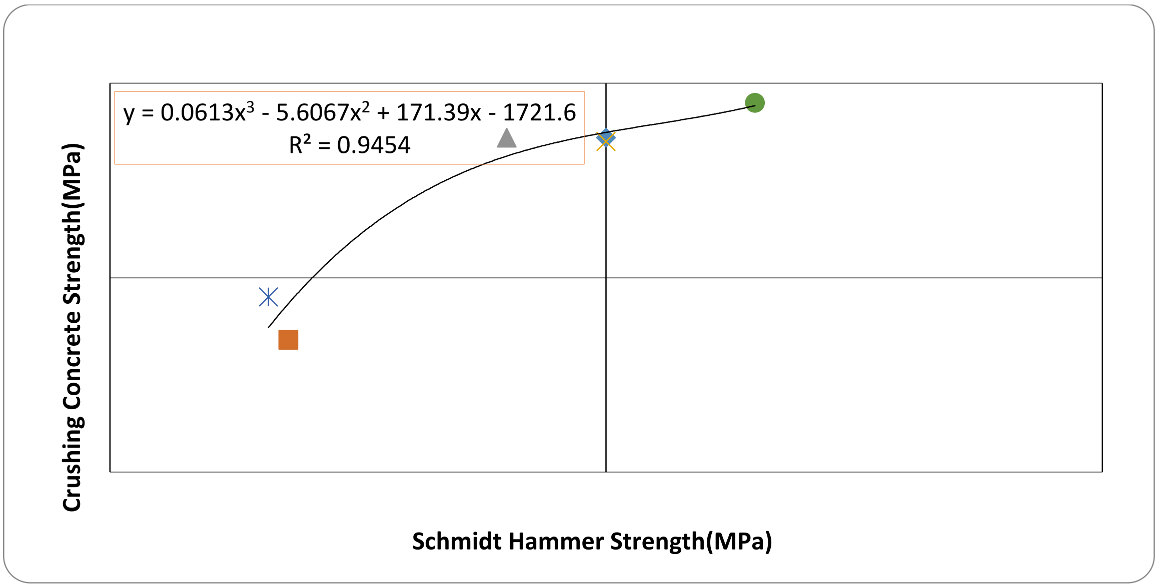

Fig.(4.6): Rebound numbers and strength relation of C25 age 14days.

(Cubic Equation)

- For the concrete C25in age 14 days. Observed that the regression values in quadratic and cubic all most typical 0.942 and 0.945respectively.and no significant difference in linear equation which is 0.881. In the correlation between hammer test results and compressive strength test.

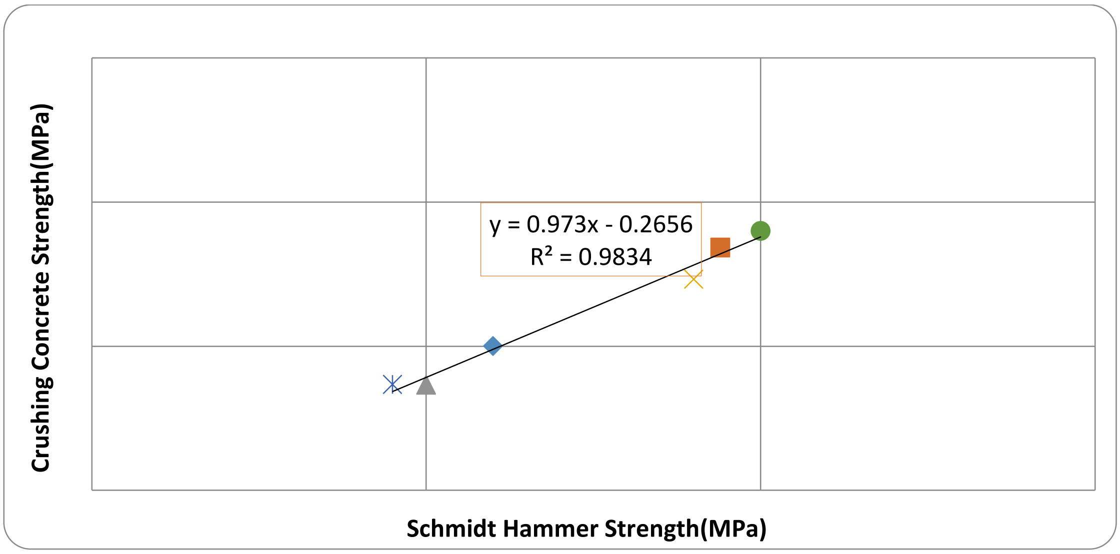

Fig .(4.7): Rebound numbers and strength relation of C25 age 28days.

(Linear Equation)

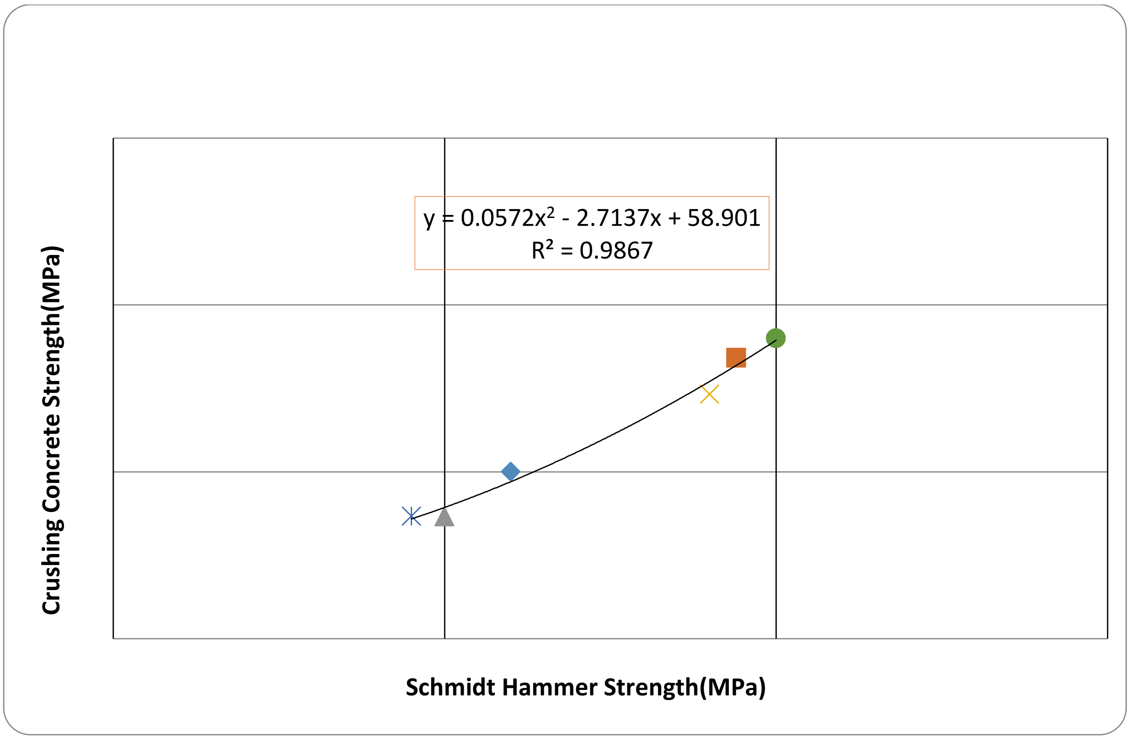

Fig (4.8): Rebound numbers and strength relation of C25 age 28days.

(Quadratic Equation)

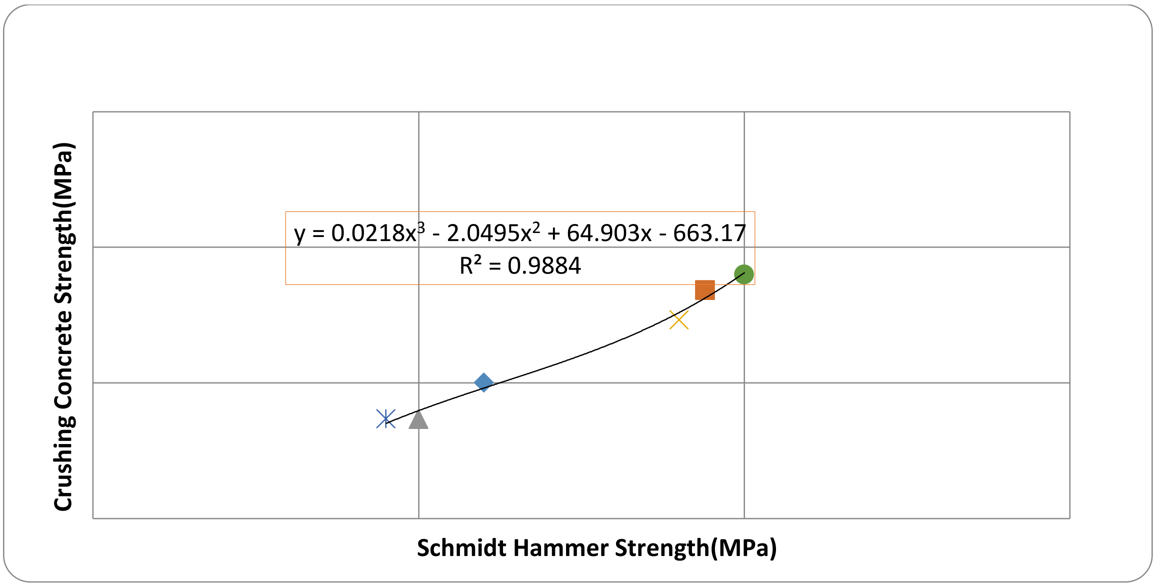

Fig. (4.9): Rebound numbers and strength relation of C25 age28days.

(Cubic Equation)

- For the concrete C25in age 28days, noticed that a linear, quadratic and cubic equation in term of regression are all most typical 0.983, 0.983and .986 respectively in the correlation between hammer test results and compressive strength test.

Table (4.6): Correlation between Crushing machine and Schmidt Hammer in Vertical direction Linear Relation(C25).

Age	Hammer result(C25)(MPa)	Crushing machine (C25)(MPa)	With respect to rebound strength F_{cu} (MPa) Predicted Linear Relation	Difference %	Average %
7days	29	26.5	27.5	3.7	5.7
	20	20.2	21.1	4.4	
	26.3	23.4	25.6	9.4	
	26	27.3	25.4	6.9	
	30	29.8	28.2	5.3	
	18	20.7	19.7	4.8	
14 days	30	28.6	28.42	0.6	2.2
	26.8	23.4	24.4	4.2	
	29	28.6	27.1	5.2	
	30	28.5	28.4	0.3	
	26.6	24.5	24.4	0.4	
	31.5	29.5	30.3	2.7	
28days	31	30	29.8	0.6	0.85
	34.4	33.42	33.2	0.6	
	30	28.66	28.9	0.8	
	34	32.32	32.8	1.4	
	29.5	28.67	28.4	0.9	
	35	34	33.7	0.8	

- For the concrete grade 25In age 7days,14days and 28 days the average of difference was 7.8, 0.05and 0.13 respectively. There are differences between the actual compressive strength produced by crushing machine and the predicted compressive strength by linear equation.

Table (4.7): Correlation between Crushing Machine and Schmidt Hammer in vertical direction Quadratic Equation (C25).

Age	Hammer result (C25)(MPa)	Crushing machine (C25)(MPa)	With respect to rebound strength F_{cu} (MPa) Predicted Quadratic Equation	Difference %	Average %
7days	29	26.5	27.2	2.6	2.6
	20	20.2	20.67	2.3	
	26.3	23.4	24.6	5.1	
	26	27.3	20.5	2.4	
	30	29.8	29.6	0.6	
	18	20.7	20.08	2.9	
14 days	30	28.6	29.2	2	1.8
	26.8	23.4	24.5	4.7	
	29	28.6	28.2	1.3	
	30	28.5	29.2	2.4	
	26.6	24.5	24	2	
	31.5	29.5	29.7	0.6	
28days	31	30	29.5	1.6	0.9
	34.4	33.42	33.02	1.1	
	30	28.66	28.8	0.4	
	34	32.32	32.5	0.5	
	29.5	28.67	28.4	0.9	
	35	34	33.7	0.8	

- For the concrete grade 25, the average of differences between actual compressive strength produced by crushing machine and the predicted compressive strength by quadratic equation are 2.6 in 7 day ,1.8 in 14 days and 0.9 in 28 days.

Table (4.8): Correlation between Crushing machine and Schmidt Hammer in Vertical direction Cubic Equation (C25).

Age	Hammer result (C25)(MPa)	Crushing machine (C25)(MPa)	With respect to rebound strength $F_{cu\ (MPa)}$ Cubic Equation	Difference %	Average %
7days	29	26.5	30.3	1.4	2.2
	20	20.2	21.5	0.6	
	26.3	23.4	26.9	1.4	
	26	27.3	26.6	2.5	
	30	29.8	31.6	6	
	18	20.7	21.0	1.4	
14days	30	28.6	28.9	0.1	1.5
	26.8	23.4	26.9	1.3	
	29	28.6	29.7	3.7	
	30	28.5	28.8	1	
	26.6	24.5	25	2	
	31.5	29.5	29.8	1	
28days	31	30	30.5	1.6	2.1
	34.4	33.42	33	1.2	
	30	28.66	29	1.1	
	34	32.32	34	5.1	
	29.5	28.67	29	1.1	
	35	34	35	2.9	

- For the concrete grade 25 In age 7 days, 14 days and 28 days .the average of difference was 2.2, 1.5and 2.1 respectively .there are differences between the actual compressive strength produced by crushing machine and the predicted compressive strength by cubic equation.

4.4:Samples of grade 40

Figures (4.12),(4.13),……(4.20) showed the correlation between rebound index and crushing strength of a standard concrete cube for the both position under consideration.

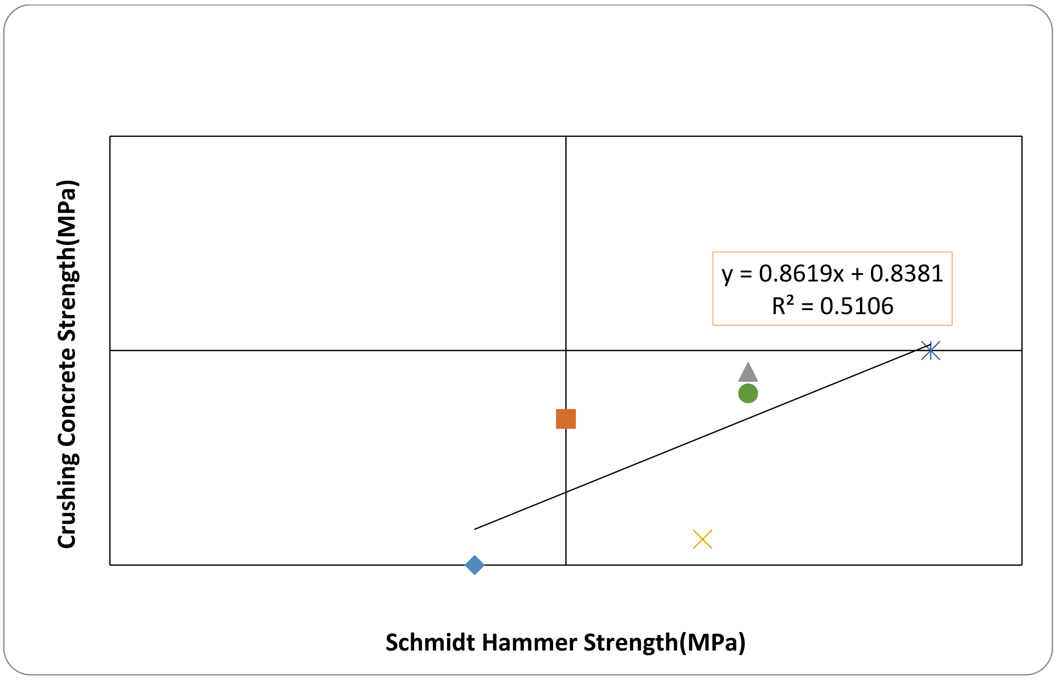

Fig. (4.10): Rebound numbers and strength relation of C40 age7days.

(Linear Equation)

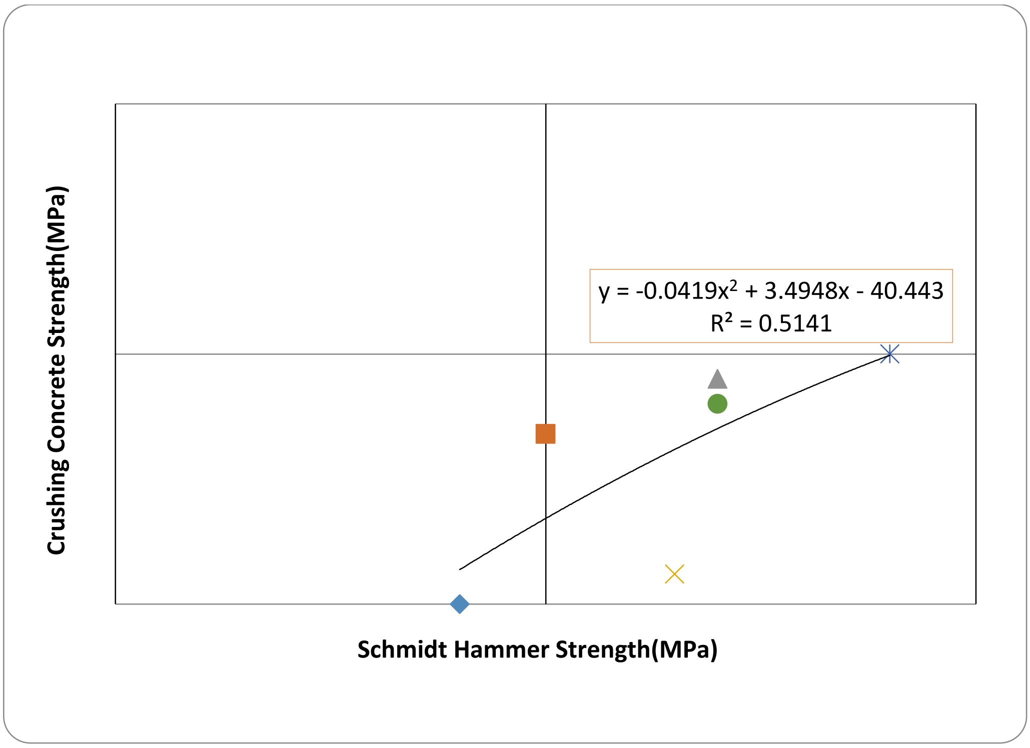

Fig. (4.11): Rebound numbers and strength relation of C40 age7days.

(Quadratic Equation)

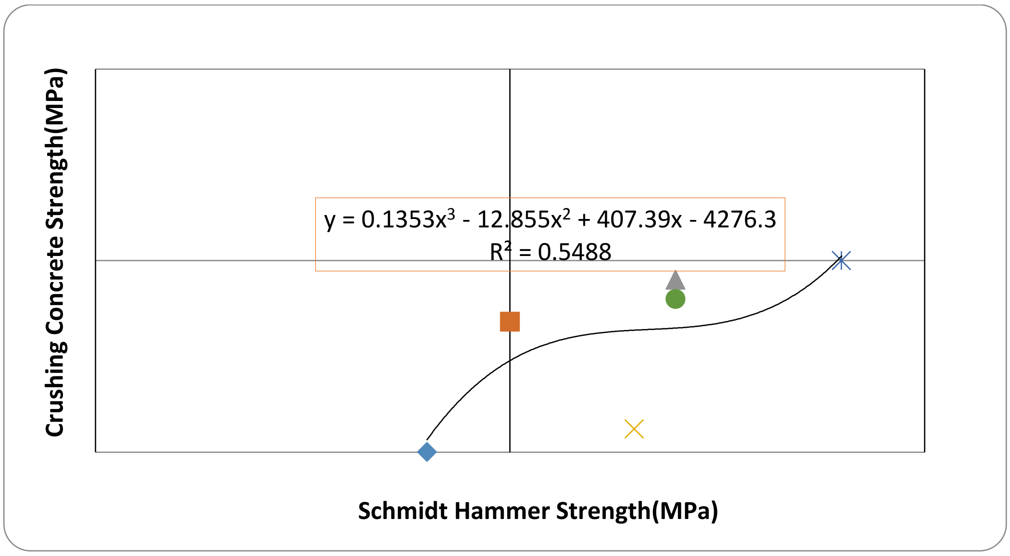

Fig. (4.12): Rebound numbers and strength relation ofC40 age 7days.

(Cubic Equation)

- For the concrete C40in age 7 days. There is no significant difference between the linear, quadratic and cubic equation in term of regression .the regressions values are 0.51, 0.514 and 0.548 respectively in the correlation between hammer test results and compressive strength test.

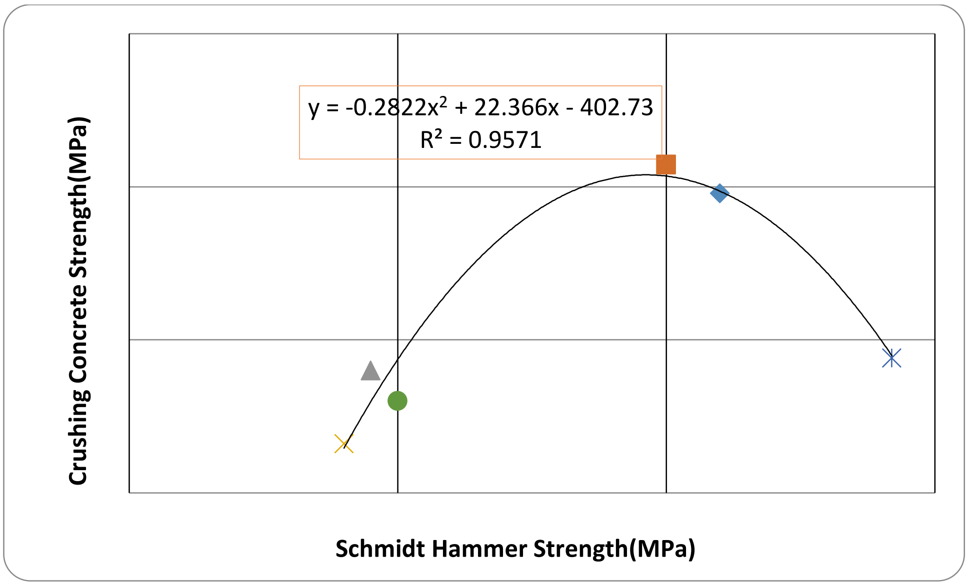

Fig. (4.13): Rebound numbers and strength relation of C40 age 14days.

(Linear Equation)

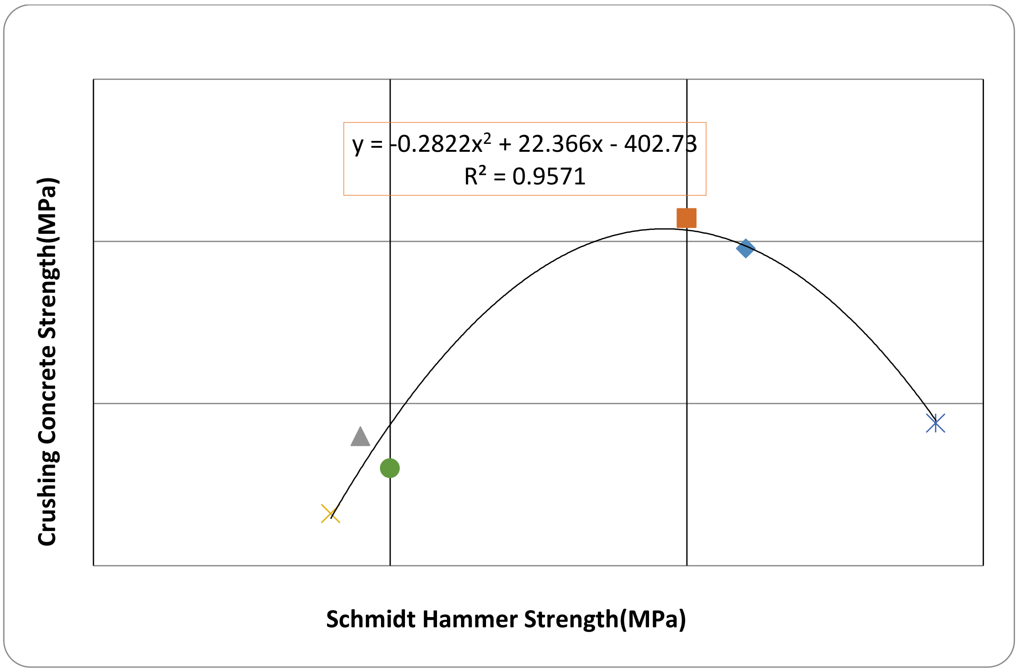

Fig. (4.14): Rebound numbers and strength relation of C40 age 14days.

(Quadratic Equation)

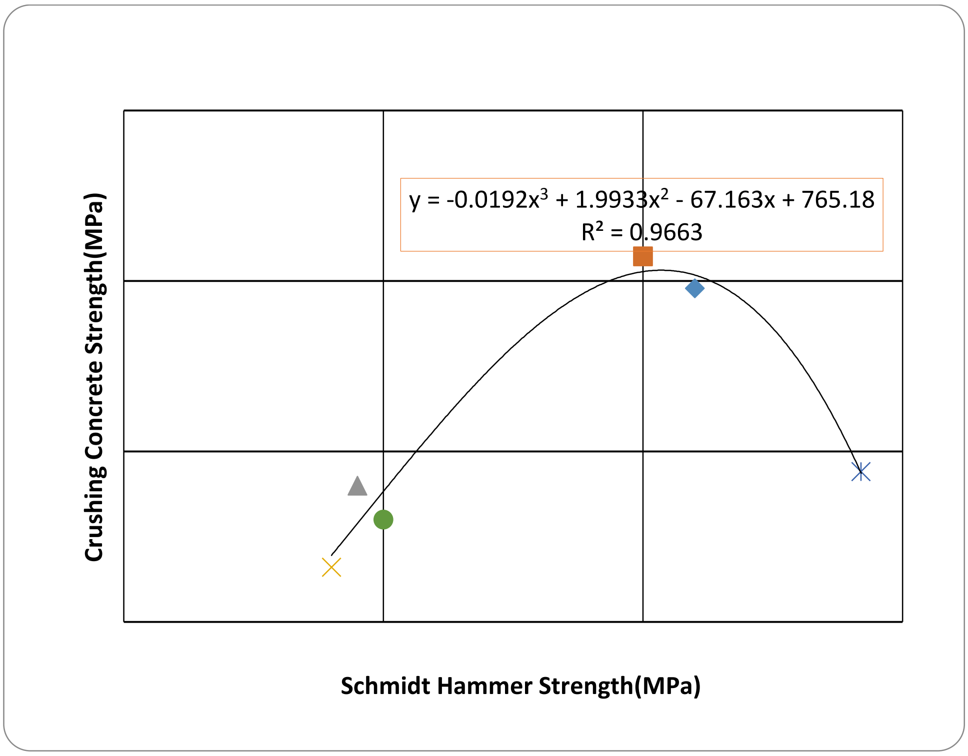

Fig. (4.15): Rebound numbers and strength relation of C40 age 14days.
(Cubic Equation)

- For the concrete C40in age 14 days. Observed that the regressions values in liner quadratic and cubic all most typical 0.95, 0.95 and 0.966 respectively. And no significant difference in linear equation which is 0.881. In the correlation between hammer test results and compressive strength test.

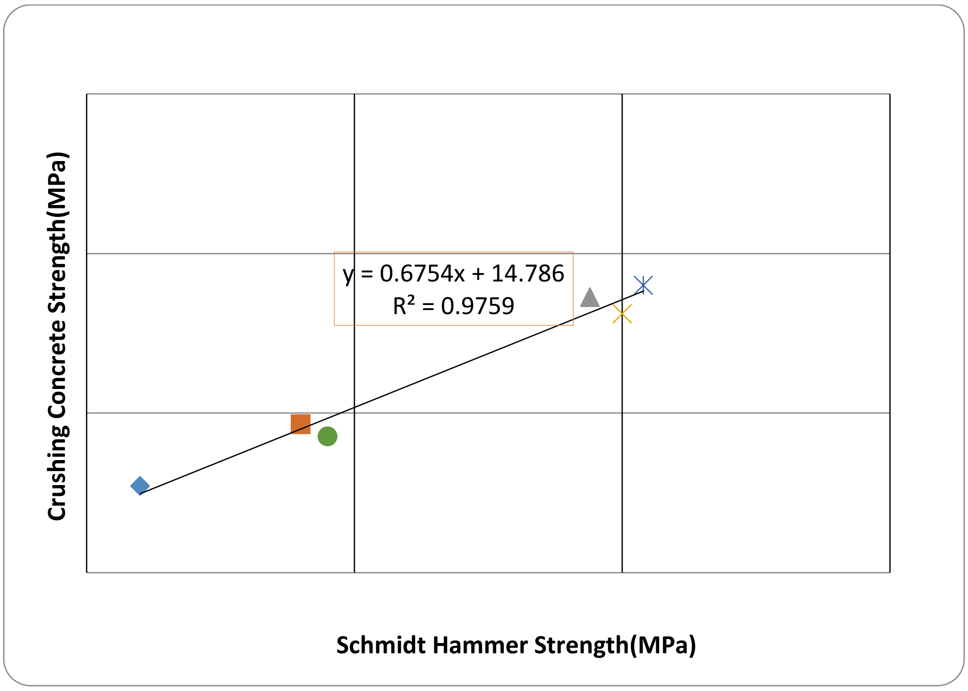

Fig. (4.16): Rebound numbers and strength relation of C40 age 28days.

(Linear Equation)

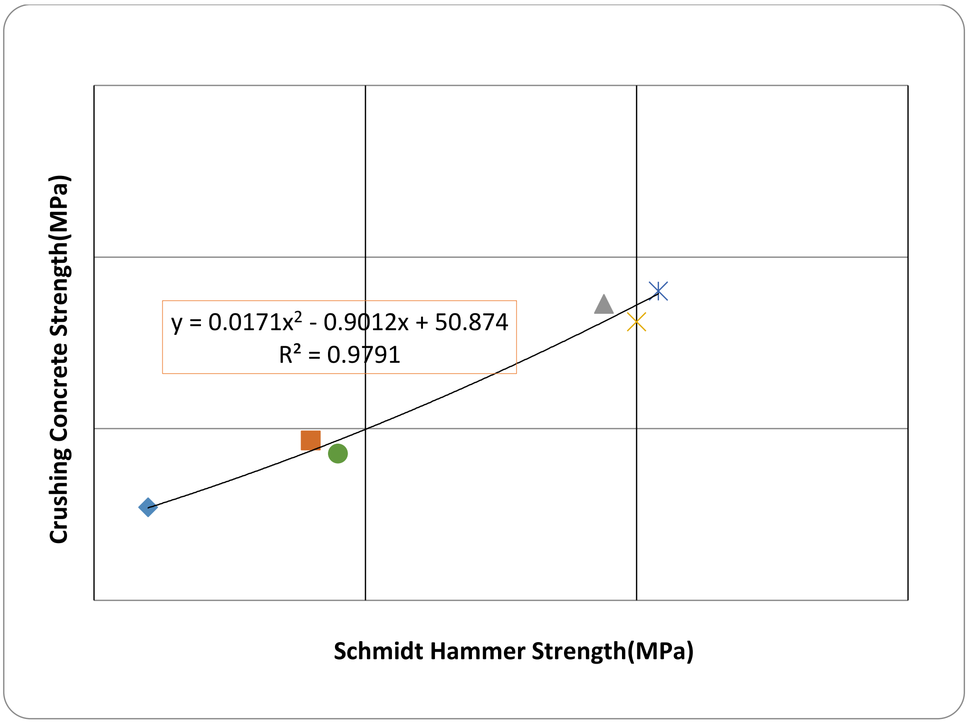

Fig. (4.17): Rebound numbers and strength relation of C40 age 28days.

(Quadratic Equation)

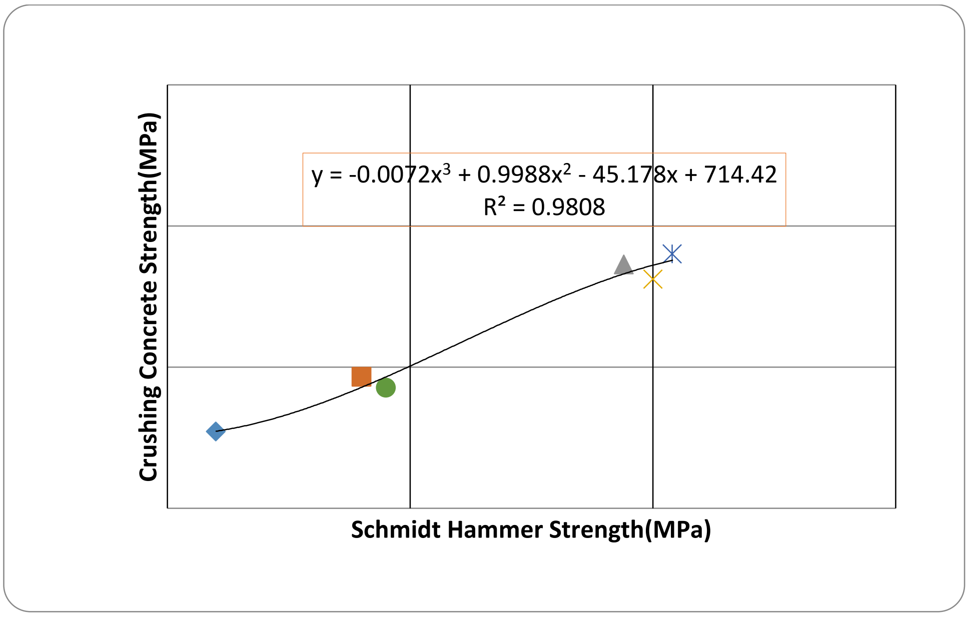

Fig. (4.18): Rebound numbers and strength relation of C40 age 28days.

(Cubic Equation)

- For the concrete C40 in age 28 days. Noticed that a linear, quadratic and cubic equation in term of regression values are all most typical 0.975, 0.979 and 0.980 respectively in the correlation between hammer test results and compressive strength test

Table (4.9): Correlation between Crushing machine and Schmidt Hammer in Vertical direction for linear regression(samples C40).

Age	Hammer result (C40)(MPa)	Crushing machine (C40)(MPa)	With respect to rebound strength F_{cu} (MPa) Linear Relation	Difference %	Average %
7days	29	25	25.8	3.2	4
	30	28.4	26.6	6.3	
	32	29.5	28.3	4	
	31.5	25.6	27.9	8.9	
	34	30	30.1	0.3	
	32	29	28.3	2.4	
14 days	41.0	39.78	37.0	6.9	6.4
	40.0	40.72	36.5	10.3	
	34.5	33.99	33.7	0.8	
	34.0	31.6	33.4	5.6	
	44.2	34.4	38.6	12.2	
	35.0	33	33.9	2.7	
28days	41	42.71	42.4	0.7	0.75
	44	44.65	44.4	0.5	
	49.4	48.63	48.1	1	
	50	48.11	48.5	0.8	
	50.4	49	48.8	0.4	
	44.5	44.27	44.8	1.1	

- For the concrete grade 40 in age 7 days, 14 days and 28 days, the average of difference was 4.0, 6.4 and 0.75 respectively. There are differences between the actual compressive strength produced by crushing machine and the predicted compressive strength by linear equation.

Table (4.10): Correlation between Crushing machine andSchmidt Hammer in Vertical direction for Quadratic regression(C40).

Age	Hammer result (C40)(MPa)	Crushing machine (C40)(MPa)	With respect to rebound strength F_{cu} (MPa)	Difference %	Average %
			Quadratic Equation		
7 days	29	25	26.4	5.6	4.3
	30	28.4	27.4	3.5	
	32	29.5	29.3	0.6	
	31.5	25.6	28.9	12	
	34	30	30.9	3	
	32	29	29.3	1	
14 days	41.0	39.78	40.0	5.5	3.2
	40.0	40.72	40.5	5.4	
	34.5	33.99	33.0	2.9	
	34.0	31.6	31.5	0.3	
	44.2	34.4	34.6	0.5	
	35.0	33	34.4	4.7	
28 days	41	42.71	42.5	0.4	.76
	44	44.65	44.1	1.2	
	49.4	48.63	47.8	1.7	
	50	48.11	48.3	0.3	
	50.4	49	48.6	0.8	
	44.5	44.27	44.4	0.2	

- For the concrete grade 40,the average of differences between actual compressive strength produced by crushing machine and the predicted compressive strength by quadratic equation are 4.3 in 7 days ,3.2 in 14 days and 0.76 in 28 days.

Table (4.11): Correlation between Crushing machine and Schmidt Hammer in Vertical direction for Cubic Equation regression (C40).

Age	Hammer result C40)(MPa)	Crushing machine (C40)(MPa)	With respect to rebound strength F_{cu} (MPa) Cubic Equation	Difference %	Average %
7 days	29	25	21.3	1.4	1.8
	30	28.4	23	1.9	
	32	29.5	22.8	2.2	
	31.5	25.6	23	1	
	34	30	23.6	2.1	
	32	29	22.8	2.1	
14 days	41.0	39.78	52.2	3.1	2.7
	40.0	40.72	51.5	2.6	
	34.5	33.99	40.0	1.7	
	34.0	31.6	38.7	2.2	
	44.2	34.4	49.5	4.3	
	35.0	33	41.3	2.5	
28 days	41	42.71	57.6	3.4	4.7
	44	44.65	62.7	4	
	49.4	48.63	74.6	5.4	
	50	48.11	75	5.5	
	50.4	49	76.7	5.6	
	44.5	44.27	63.7	4.3	

- For the concrete grade 40 in age 7 days, 14 days and 28 The average of difference was 1.8, 2.7 and 4.7 respectively .there are differences between the actual compressive strength produced by crushing machine and the predicted compressive strength by cubic equation.

The more accurate equation in concrete grade 25 in 28 days is

$Y = .057x^2 - 2.713x + 58.9$

and regression $R^2 = 0.986$, the relationship between Schmidt hammer strength and crushing machine strength controlled by quadratic equation.

where y=compressive strength , x=hammer test.

The more accurate equation in concrete grade 40 in 28 days is

$Y = -0.0072x^3 + 0.988\,x^2 - 45.178x + 714.42$

and regression $R^2 = 0.9808$, the relationship between Schmidt hammer strength and crushing machine strength controlled by cubic equation.

where y=compressive strength , x=hammer test.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

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5.1: CONCLUSIONS

At present stage the hammer tests are suitable only for estimating the compressive strength within the specified range of the target object preliminary assessment.

The correlation among the strength values obtained by destructive and NDT test methods on laboratory-made concrete has been established. Schmidt Hammer test method has been used as a non-destructive test and crush machine (compressive strength test) as destructive. The following principal conclusions have been drawn:

- The Presents study puts forward a useful mathematical linear nonlinear relationship (quadratic and cubic) that help the engineer to predict confidently the crushing strength of standard concrete cubes, by measuring the rebound index by means of Schmidt hammer. The mathematical expression is applicable

5.2: Recommendations

The correlation among the strength values obtained by destructive and NDT test methods on laboratory-made concrete has been established. Schmidt Hammer test method has been used as a non-destructive test and compressive strength test using crushing machine as destructive test. The following principal recommendation from the study has been drawn:

1. The use of rebound hammer test method on concrete cubes is suitable to estimate its strength. Direct use of rebound hammer demonstrates high variations, which makes engineering judgment quite difficult. The Schmidt Hammer method could only be used as a reliable instrument to calculate the compressive strength.

2. The rebound hammer test should always be performed at least with one equipment and the results should be close enough so that the most probable one from them can be adopted.
3. Conducting further studies in this field for improving accurate relationship between hammer test and compressive strength of concrete of higher strengths.
4. Evaluate the equation by using concrete with adding addition's.
5. Evaluate the equation by using high strength concrete.

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APPENDICES

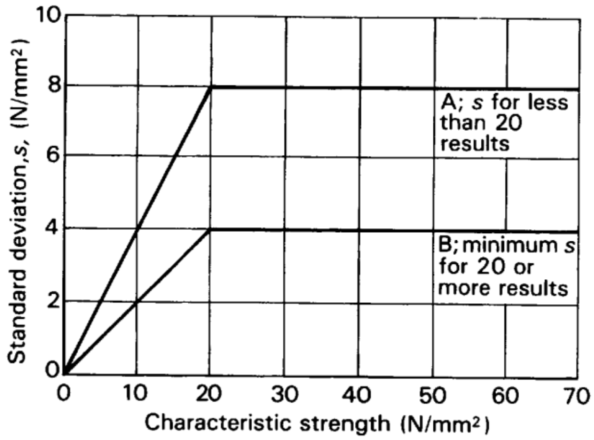

Figure 3
Relationship between standard deviation and characteristic strength

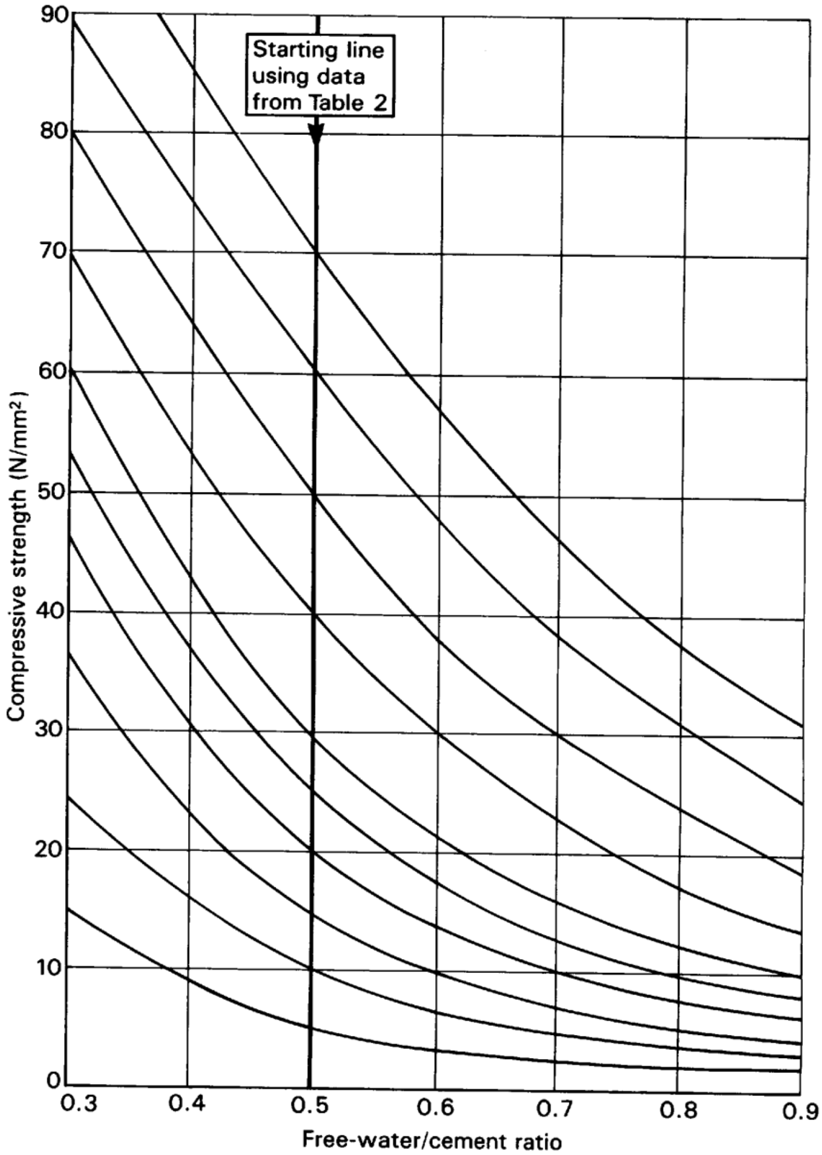

Figure 4
Relationship between compressive strength and free-water/cement ratio

Table 2 Approximate compressive strengths (N/mm^2) of concrete mixes made with a free-water/cement ratio of 0.5

Cement strength class	Type of coarse aggregate	Compressive strengths (N/mm^2) Age (days) 3	7	28	91
42.5	Uncrushed	22	30	42	49
	Crushed	27	36	49	56
52.5	Uncrushed	29	37	48	54
	Crushed	34	43	55	61

Throughout this publication concrete strength is expressed in the units N/mm^2.
1 N/mm^2 = 1 MN/m^2 = 1 MPa. (N = newton; Pa = pascal.)

Table 3 Approximate free-water contents (kg/m^3) required to give various levels of workability

Slump (mm)		0–10	10–30	30–60	60–180
Vebe time (s)		>12	6–12	3–6	0–3
Maximum size of aggregate (mm)	Type of aggregate				
10	Uncrushed	150	180	205	225
	Crushed	180	205	230	250
20	Uncrushed	135	160	180	195
	Crushed	170	190	210	225
40	Uncrushed	115	140	160	175
	Crushed	155	175	190	205

Note: When coarse and fine aggregates of different types are used, the free-water content is estimated by the expression:

$$\tfrac{2}{3} W_f + \tfrac{1}{3} W_c$$

where W_f = free-water content appropriate to type of fine aggregate
and W_c = free-water content approporiate to type of coarse aggregate.

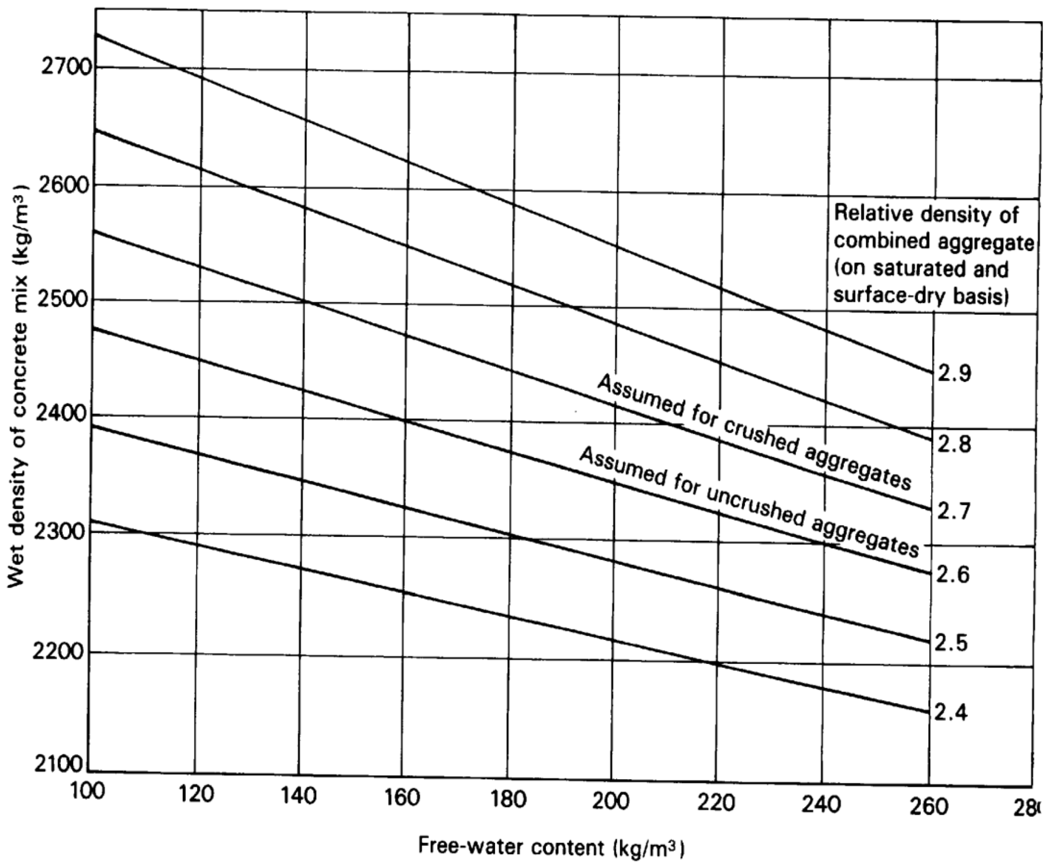

Figure 5 Estimated wet density of fully compacted concrete

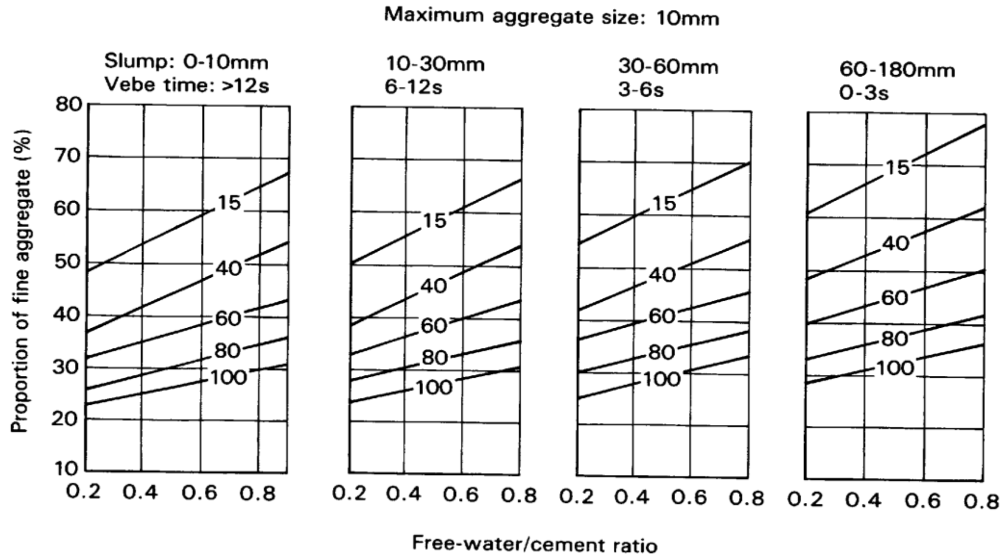

Figure 6 Recommended proportions of fine aggregate according to percentage passing a 600 μm sieve

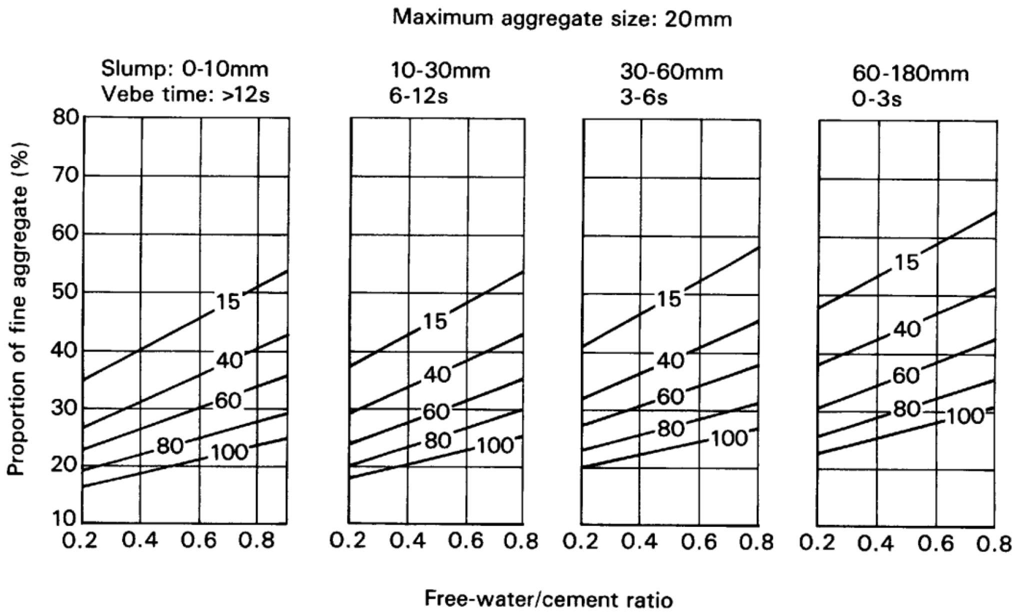

Figure 6 (continued)

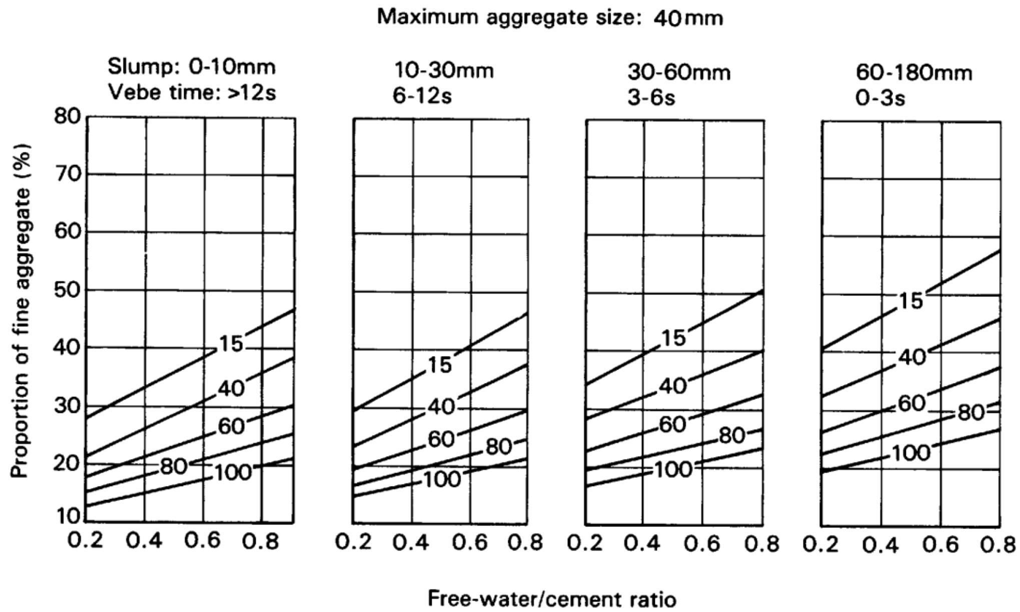

Figure 6 (continued)