ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

Schmidt Rebound Hammer Test Correlation Curve for Concrete Produced Using Aggregates in & around Addis Ababa

A Thesis Submitted to School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering (Construction Technology and Management)

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Approved by: Board of Examiners

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Chairperson Signature Date

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Primarily I would like to thank God for keeping me alive to do this research. I would also like to thank Dr. Ephraim Senbetta my advisor and instructor, for his unreserved advice and full support.

I would like to forward special thanks to Hawassa University for giving me this special opportunity to continue my MSc degree. I would also love to give thanks for the Addis Ababa institute of Technology and construction materials laboratory staff members.

Abstract

Among the available non-destructive test methods in concrete testing, the Schmidt hammer test is the most commonly used one in practice. It has been used world-wide as an index test to estimate strength of concrete due to its rapidity and easiness in execution, simplicity, portability, low cost and non-destructiveness. The rebound hammer was constructed and tested extensively at the Swiss Federal Materials Testing and Experimental Institute in Zurich. A correlation was developed between the compressive strength of standard cubes and the rebound number, and this correlation is provided with the instrument. However, as other investigators began to develop correlations between strength and rebound number, it became evident that there was no unique relationship between strength and rebound number.

The main focus of this research is to produce a correlation curve of Schmidt hammer for concretes produced by using aggregates in and around Addis Ababa. The rebound hammer test with the strength correlation curve can be used to estimate concrete strength during construction so that operations that require a specific strength like formwork removal and posttensioning can be performed safely and curing procedures can be terminated. It can also be used to estimate concrete strength during the evaluation of existing structures.

Based on the literature review, the aggregates in the study area were classified. Strength levels, number of replications and the number of Rebound hammer tests at each strength level were determined. After determination of the aggregate classes, strength level and number of replicate, mix design was prepared for two aggregate types based on the ACI method. In accordance with the mix design, samples were casted on 15 cm cube for all strength levels and for the two aggregate types.

After conducting laboratory work and analyzing the data, two correlation curves were generated for concretes produced using aggregates from Bole Lemi and Sululta area with a function of $y = 0.1894x^{1.6031}$ and $y = 0.103x^{1.8224}$ respectively. Comparison between the curve provided along with Schmidt rebound hammer and generated curve was made and for a same compressive strength of a concrete, the generated correlation curve provides a lower rebound number.

Keyword: Non-destructive test, Correlation curves, Schmidt rebound hammer, compressive strength

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List of Abbreviations

ACI	American Concrete Institution
ASTM	American Society for Testing and Materials
BSI	British Standards Institute
ISO	International Standards Organization
ISRM	International Society for Rock Mechanics
MP	Mega Pascal
NDT	Nondestructive Testing
OPC	Ordinary Portland Cement
PPC	Portland Pozzolana Cement
Ppm	Parts Per Million
TMC	Temperature-Matched Curing
UCS	Uniaxial Compressive strength
UTC	Universal Test of Concrete
Var	Variance
γdry	Dry Density
σc	The Uniaxial Compressive Strength of Rock

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Chapter One

Introduction

1.1 Background of the Study

Concrete differs from other construction materials in that it can be made from an infinite combination of suitable materials and its final properties are dependent on the treatment it undergoes after it arrives at the job site. The efficiency of the consolidation and the effectiveness of curing procedures are critical for attaining the full potential of a concrete mixture. While concrete is known for its durability, it is susceptible to a range of environmental degradation factors, which can limit its service life. There has always been a need for test methods to measure the in-place properties of concrete for quality assurance and for evaluation of existing conditions. Ideally, these methods should be nondestructive, so that they do not impair the function of the structure and permit retesting at the same locations to evaluate changes in properties with time.

The Schmidt rebound hammer is principally In-place surface hardness tester (Neville & Brooks, 2010). 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.

Before 1983, ACI 318 required testing of field-cured cylinders to demonstrate the adequacy of concrete strength before removal of formwork or reshoring (Kosmatka S, et al., 2003). Section 6.2.2.1 of ACI 318-83 allowed the use of alternative procedures to test field-cured cylinders. The building official, however, must approve the alternative procedure before its use. Since 1983, ACI 318 has permitted the use of in-place testing as an alternative to testing field-cured cylinders.

Standard-cured cylinders are usually tested for acceptance purposes at an age of 28 days; however, the results of this test cannot be used to determine whether adequate strength exists at earlier ages for safe removal of formwork or the application of post-tensioning. While construction schedules often require that operations such as form removal, post-tensioning, termination of curing, and removal of reshores be carried out as early as possible. To enable these operations to proceed safely at the earliest possible time requires the use of reliable in-place tests to estimate the in-place strength. The need for such strength information is emphasized by several construction failures that possibly could have been prevented had in-place testing been used (Kosmatka S, et al., 2003). In-place testing not only increases safety, but can result in substantial cost savings by permitting accelerated construction schedules.

But if in-place tests are used, a valid relationship between the results of in-place tests and the compressive strength of cylinders must be established.

At present, besides the correlation curve that is provided with the instrument there is no work done to produce a correlation curve for locally used concrete. This deficiency has been obstacle to widespread adoption of Rebound Hammer Test. Therefore, this research presents a correlation curve for concrete produced in and around Addis Ababa.

1.2 Rational of the Research

The main focus of this research is to produce a correlation curve for Schmidt hammer for concrete produced using aggregates quarried in and around Addis Ababa. The rebound hammer test with the strength correlation curve can be used to estimate concrete strength during construction so that operations that require a specific strength like formwork removal and posttensioning can be performed safely and curing procedures can be terminated. It can also be used to estimate concrete strength during the evaluation of existing structures.

Advantage in using the rebound hammer as a means of evaluating concrete to assess the in-place uniformity, to delineate regions in a structure of poor quality or deteriorated concrete, and to estimate in-place strength. The unit is easy to use and a large number of readings can be obtained in a relatively short amount of time. The method is for the most part non-destructive and typically more economical than other methods.

1.3 Objective

The objective of this research is to determine the relationship between the rebound number of Schmidt rebound hammer and the compressive strength of concrete produced using local aggregates in and around Addis Ababa and to determine if the existing correlation curve is applicable to locally produced concrete.

1.4 Scope of the Research

The study targets concrete that is produced in Addis Ababa using aggregate found in and around Addis Ababa.

Since the concrete surface could be damaged by the hammer, Rebound testing should not be carried out on low strength concrete at early ages or when the concrete strength is less than 7 MPa (Neville & Brooks, 2010), accordingly the lower strength class of concrete to be considered in this research is 7 MPa. Also EBCS 2 states the C 15 is the lowest concrete grade to be used for structural purpose therefore for local applications this research targets 15 MPa – 60 MPa strength grade.

The concrete considered for this research is a normal weight concrete. After conducting this research the expected output is a correlation curve which clearly expresses the relationship between the rebound number of Schmidt hammer and the compressive strength of concrete produced using local aggregates in Addis Ababa.

1.5 Methodology of the Study

Literature survey was carried out to review previous studies related to this research, Based on the literature review the aggregates in the study area were classified. Strength levels, number of replications and the number of Rebound hammer tests at each strength level were determined.

After determination of the aggregate classes, strength level and number of replicate, mix design was prepared for C15, C25, C30, C40, C50 and C60 for two aggregate types based on the ACI method. In accordance with the mix design, samples were cast on 15 cm cubes for all strength levels and for the two aggregate types. At the age of 7 and 28 days, hammer test and uni-axial compression test was done on the samples.

The results obtained from experiment are discussed and presented in tables and figures. Finally, conclusions are drawn and recommendations have been forwarded.

Chapter Two

Literature Review

The word concrete comes from a Latin word "concretus" which means to grow together , which implies that it is a composite of different materials (Neville & Brooks, 2010). Concrete, in the broadest sense, is any product or mass made by the use of a cementing medium. Generally, this medium is the product of reaction between hydraulic cement and water.

Concrete has been the most common building material for many years. It is expected to remain so in the coming decades. Much of the developed world has infrastructures built with various forms of concrete. Mass concrete dams, reinforced concrete buildings, pre stressed concrete bridges, and precast concrete components are some typical examples. It is anticipated that the rest of the developing world will use these forms of construction in their future development of infrastructures (Chen & Richard, 2003). It is composed of coarse granular material called aggregate or filler which is embedded in a hard matrix of material (cement or binder with water) binding the aggregates together and filling the space formed between them. When the constituents are mixed with water the concrete solidifies and hardens due to a chemical reaction between the water and the cement called hydration, which finally forms a stone like material by binding the aggregates together.

2.1 Characteristics of Concrete

According to Kosmatka S, et al. (2003) Concrete's versatility, durability, and economy have made it the world's most used construction material. The United States uses about 260 million cubic meters of ready mixed concrete each year. It is used in highways, streets, parking lots, parking garages, bridges, high-rise buildings, dams, homes, floors, sidewalks, driveways, and numerous other applications. Concrete can be engineered to satisfy a wide range of performance specifications, unlike other building materials, such as natural stone or steel, which generally have to be used as they are.

The ability of concrete to be cast to any desired shape and configuration is an important characteristic that can offset other shortcomings.

Good quality concrete is a very durable material and should remain maintenance free for many years when it has been properly designed for the service conditions and properly placed. Of course, proper use of the structure for the intended function can have a significant role. Through choice of aggregate or control of paste chemistry and microstructure, concrete can be made inherently resistant to physical attack, such as from cycles of freezing and thawing or from abrasion and from chemical attack such as from dissolved sulfates or acids attacking the paste matrix or from highly alkaline pore solutions attacking the aggregates. Judicious use of mineral admixtures greatly enhances the durability of concrete.

Additionally Mindess S, et al., (2003) Notes the main advantages of concrete as a construction material are the ability to be cast, being economical, durability, fire resistance, energy efficiency, on-site fabrication and its aesthetic properties, Whereas the disadvantages are low tensile strength, low ductility, volume instability and low strength to weight ratio.

2.2 Constituents of Concrete

Chen & Richard, (2003) States that the constituents of modern concrete have increased from the basic four (i.e. Portland cement, water, stone, and sand) to include both chemical and mineral admixtures. These admixtures have been in use for decades, first in special circumstances, but have now been incorporated in more and more general applications for their technical and at times economic benefits in either or both fresh and hardened properties of concrete.

I. Portland cement

Chen & Richard, (2003) States the name Portland originated from the similarity of Portland cement concrete to a well-known building stone in England found in the area called Portland. Raw materials for manufacturing Portland cement consist of basically calcareous and siliceous material. The mixture is heated to a high temperature within a rotating kiln to produce a complex group of chemicals, collectively called cement clinker.

Briefly, the chemicals present in clinker are nominally the four major potential compounds and several minor compounds (in small percentages, but not necessary of minor importance). The four major potential compounds are nominally (but actually impure varieties) termed as tricalcium silicate ($3CaO.SiO_2$), dicalcium silicate ($2CaO.SiO_2$), tricalcium aluminate ($3CaO. Al2O_3$), and tetracalcium aluminoferrite ($4CaO. Al_2O_3.Fe_2O_3$).

II. Water

ASTM (C1602, 2012) defines sources of mixing water as batch water. Batch water discharged into the mixer from municipal water supply, reclaimed municipal water, or water resulting from concrete production operations.

Almost any natural water that is drinkable and has no pronounced taste or odor can be used as mixing water for making concrete, However, some waters that are not fit for drinking may be suitable for use in concrete. (Kosmatka S, et al., 2003)

Kosmatka S, et al., (2003) additionally points out excessive impurities in mixing water not only may affect setting time and concrete strength, but also may cause efflorescence, staining, corrosion of reinforcement, volume instability, and reduced durability. Therefore, certain optional limits may be set on chlorides, sulfates, alkalis, and solids in the mixing water or appropriate tests can be performed to determine the effect the impurity has on various properties. Some impurities may have little effect on strength and setting time, yet they can adversely affect durability and other properties.

Water containing less than 2000 parts per million (ppm) of total dissolved solids can generally be used satisfactorily for making concrete. Water containing more than 2000 ppm of dissolved solids should be tested for its effect on strength and time of set.

Testing of Water

Potable water need not be tested prior to its use in concrete. ASTM C 94 and the ACI Building Code require tests when the water is not potable. In both standards, water is evaluated based on its effect on the strength of mortar cast in accordance with ASTM C 109.

In addition, ASTM C 94 limits the effect on setting time (measured by ASTM C 191) to not more than one hour earlier nor more than one-and-a-half hours later than a control specimen made with potable water. In ASTM C 94, a mortar specimen made with "questionable" water (i.e., water that "contains quantities of substances which discolor it or make it smell or taste unusual or objectionable or cause suspicion") must produce a 7-day strength equal to at least 90% of the strength obtained with a control specimen produced using potable water.

III. Aggregate

The importance of using the right type and quality of aggregates cannot be overemphasized. The fine and coarse aggregates generally occupy 60% to 75% of the concrete volume (70% to 85% by mass) and strongly influence the concrete's freshly mixed and hardened properties, mixture proportions, and economy. (Kosmatka S, et al., 2003)

Newman, et al. (2003) state natural rock, sands and gravels are by far the commonest source of aggregate worldwide. Artificial and recycled materials account for only a tiny fraction of the total aggregate produced.

Fine aggregates generally consist of natural sand or crushed stone with most particles smaller than 5 mm. Coarse aggregates consist of one or a combination of gravels or crushed stone with particles predominantly larger than 5 mm and generally between 9.5 mm and 37.5 mm (Kosmatka S, et al., 2003)

Functions of the aggregates

Aggregate is the main constituent of concrete. Aggregate properties do influence concrete properties, but by large they do not control the performance of the concrete. The essential requirement is that the aggregate remains stable within the concrete in its exposure conditions. (Newman, et al., 2003) Also adds the choice of aggregates used is often constrained by transport costs. There are three main reasons for mixing aggregate with cement paste to form concrete, rather than using cement paste alone.

- ✓ Aggregate is cheaper than cement, so its use extends the mix and reduces costs.
- ✓ Aggregate reduces shrinkage and creep, giving better volume stability.
- ✓ Aggregate gives greater durability to concrete.

There are clear economic and technical reasons for using as much aggregate and as little cement as possible in a concrete mix.

Properties of aggregates

According to Abebe (2005) The physical properties like specific gravity, porosity, thermal behavior, and the chemical properties of an aggregate are attributed to the parent material. The shape, size and surface texture which are essential for concrete workability and bond characteristics between the aggregate and cement paste are, however, attributes of the mode of production. It is, therefore, essential to understand the mechanical, physical and chemical properties of aggregate and its modes of production in an effort to produce the required quality of concrete at a minimum price.

a) Physical Properties

Roberts, F. L., et al. (1996) states that aggregate physical properties are the most readily apparent aggregate properties and they also have the most direct effect on how an aggregate performs. Commonly measured physical aggregate properties are:

- Gradation and size
- Toughness and abrasion resistance
- Durability and soundness
- Particle shape and surface texture
- Density and specific gravity
- Cleanliness and deleterious materials
- Absorption capacity and moisture content

These are not the only physical properties of aggregates but rather the most commonly measured. Tests used to quantify these properties are largely empirical. The physical properties of an aggregate can change over time.

Gradation and Size

The particle size distribution, or gradation, of an aggregate is one of the most influential aggregate characteristics in determining how it will perform. Gradation helps determine durability, porosity, workability, cement and water requirements, strength, and shrinkage.

Toughness and Abrasion Resistance

Aggregates undergo substantial wear and tear throughout their life. In general, they should be hard and tough enough to resist crushing, degradation and disintegration from any associated activities including manufacturing, stockpiling, production, placing, compaction and consolidation. Aggregates which are not adequately resistant to abrasion and polishing will cause premature structural failure and/or a loss of skid resistance.

Durability and Soundness

Aggregates must be resistant to breakdown and disintegration from weathering (wetting/drying and freezing/thawing). Durability and soundness are terms typically given to an aggregate weathering resistance characteristic.

Particle shape and surface texture

Particle shape and surface texture are important for workability. Aggregates are used as an inexpensive, high-strength material to occupy volume, workability is the major issue regarding particle shape. Rounded particles create less particle-to-particle interlock than angular particles and thus provide better workability and easier compaction. Flat or elongated particles: These particles tend to impede compaction or break during compaction and thus, may decrease strength.

Smooth-surfaced particles: Surfaced particles provide more area to which the cement paste can bond. Thus, rough-surface particles are desirable.

Specific Gravity

Density is the weight per unit of volume of a substance. Specific gravity is the ratio of the density of the substance to the density of water. The density and the specific gravity of an aggregate particle are dependent upon the density and specific gravity of the minerals making up the particle and upon the porosity of the particle.

Cleanliness and Deleterious Materials

Aggregates must be relatively clean when used in concrete. Vegetation, soft particles, clay lumps, excess dust and vegetable matter are not desirable because they generally affect performance by preventing binder-aggregate bonding.

b) Chemical Properties

Aggregates containing reactive forms of silica can react expansively with the alkalis contained in the cement paste. This expansion can cause cracking, surface popouts and spalling. Aggregate chemical properties can change over time, especially after the aggregate is crushed. A newly crushed aggregate may display a different affinity for water than the same aggregate that has been crushed and left in a stockpile for a year.

Alkali-Aggregate Reaction

According to Sidney , et al. (2003) Alkali-aggregate reaction is the expansive reaction that takes place in concrete between alkali (contained in the cement paste) and elements within an aggregate. The most common is an alkali-silica reaction. This reaction can result in map or pattern cracking, surface popouts and spalling if it is severe enough.

c) Thermal properties

According to Shetty (1982) rock and aggregate possess three thermal properties which are significant in establishing the quality of aggregate for concrete construction. They are coefficient of expansion, specific heat and thermal conductivity.

Out of the three, specific heat and conductivity are found to be important only in mass concrete construction where rigorous control of temperature is necessary. Also these properties are of consequence in case of light weight concrete used for insulation purpose. When dealing with the aggregate in general it will be sufficient to deal with only the coefficient of expansion of the aggregate, since it interacts with the coefficient of thermal expansion of cement paste in the body of the set-concrete.

Classification of aggregates

Based on their weight, aggregates are divided into three groups:

1. Heavy aggregates with specific gravity more than four,
2. Normal weight aggregates with specific gravity between 2.4 and 3.0 and
3. Light weight aggregates such as pumice and scoria.

As regards the source, aggregates may be natural or artificial. Natural aggregates are obtained from river beds (sand, gravel) or from quarries (crushed rock) while artificial aggregates are generally obtained from industrial wastes such as the blast furnace slag.

Table 1: Classification of aggregates

Natural	Artificial
Sand, Gravel, Crushed Rock such as • Granite • Quartzite • Sandstone • Basalt	• Broken Brick, • Air-cooled Slag • Sintered fly ash • Bloated clay

Classification Based on the size of aggregate

Shetty, (1982) states that concrete is made with aggregate particles covering a range of sizes up to a maximum size which usually lies between 10 mm and 50 mm; 20 mm is typical. The particle size distribution is called grading. Low-grade concrete may be made with aggregate from deposits containing a whole range of sizes, from the largest to the smallest, known as all-in or pit-run aggregate. The alternative, very much more common, and always used in the manufacture of good quality concrete, is to obtain the aggregate in at least two separate lots, the main division being at a size of 5 mm or No. 4 ASTM sieve. This divides fine aggregate (sand), from coarse aggregate.

Sand is generally considered to have a lower size limit of about 0.07 mm or a little less. Material between 0.06 mm and 0.02 mm is classified as silt, and smaller particles are termed clay. Loam is a soft deposit consisting of sand, silt and clay in about equal proportions.

Classification Based on mineralogy and petrography

Rocks are naturally occurring crystalline, cemented or consolidated materials that form the immediate crust. They are subdivided into types according to mineralogical, petrological and physical characteristics. Almost all natural aggregate materials originate from bed rocks. According to Shetty, (1982) there are three kinds of rocks, namely, igneous, sedimentary and metamorphic.

1. Aggregates from Igneous Rocks

Most igneous rocks make highly satisfactory concrete aggregates because they are normally hard, tough and dense. Therefore, bulk of the concrete aggregates, that are derived, are of igneous origin.

The most widespread of all the igneous rocks are basalts. Basalts are dark colored, fine- Grained extrusive rocks. The mineral grains are so fine that they are impossible to distinguish with the naked eye or even a magnifying glass. Most basalts are volcanic in origin and were formed by the rapid cooling and hardening of the lava flows. Some basalts are intrusive having cooled inside the Earth's interior.

2. Aggregates from Sedimentary Rocks

Igneous rocks or metamorphic rocks are subjected to weathering agencies such as sun, rain and wind. These weathering agencies decompose fragmantise, transport and deposit the particles of rock, deep beneath the ocean bed where they are cemented together by some of the cementing materials. The cementing materials could be carbonaceous, siliceous or argillaceous in nature. At the same time the deposited and cemented material gets subjected to static pressure of water and becomes compact sedimentary rock layer

The quality of aggregates derived from sedimentary rocks will vary in quality depending upon the cementing material and the pressure under which these are originally compressed. Some siliceous sand stones have proved to be good concrete aggregate. Similarly, the limestone also can yield good concrete aggregate.

3. Aggregates from Metamorphic Rocks

Both igneous rocks and sedimentary rocks may be subjected to high temperature and pressure which causes metamorphism which changes the structure and texture of rocks. Metamorphic rocks show foliated structure. Many metamorphic rocks particularly quartzite and gneiss have been used for production of good concrete aggregates.

Classification Based on Shape

Shetty, (1982) states the shape of aggregates is an important characteristic since it affects the workability of concrete. It is difficult to really measure the shape of irregular body like concrete aggregate which are derived from various rocks.

Not only will the characteristic of the parent rock, but also the type of crusher used influence the shape of aggregates.

Table 2: Classification of aggregates based on shape of particles (Shetty, 1982)

Classification	Description	Examples
Rounded	Fully water worn or completely shaped by attrition	River or seashore gravels, desert, seashore and windblown sands
Irregular or Partly rounded	Naturally irregular or partly shaped by attrition, having rounded edges	Pit sands and gravels; land or dug flints; cuboid rock
Angular	Possessing well-defined edges formed at the intersection of roughly planar faces	Crushed rocks of all types; talus; screeds

2.2 Classification of Aggregate in and around Addis Ababa

Abebe, (2005) When revising factors that influence the compressive strength of concrete, he stated, among other things, the quality and proportion of fine and coarse aggregate, the cement paste, the paste-aggregate bond characteristics and Other qualities of concrete such as durability and abrasion resistance are also highly dependent on the aggregate, which in turn depends on strength of parent rock, purity, surface texture, gradation and so on.

On an article published during “Mongolian Concrete Conference” Snell, (June 2012) Briefly pointed out, factors that affect Rebound hammer numbers. He stated, Rebound hammer measures the surface hardness of the concrete, it is important to understand all the items that might affect surface conditions of the concrete and thus, the rebound hammer numbers. These factors include:

1) Smoothness of the surface
2) Size and shape of the concrete sample
3) The rigidity of the test area
4) Age of the concrete
5) Surface moisture
6) Internal moisture (moisture gradient)
7) Coarse aggregates
8) Type of cement
9) Forms used
10) Carbonation
11) Location of the reinforcement
12) Frozen concrete

For these reasons, the user of the rebound hammer must follow exact procedures and use engineering judgment. To illustrate this, table 3 shows how the effects of the coarse aggregates in concrete of the same strength can have on the rebound hammer.

Table 3: Rebound number of concretes of same strength using different aggregate type (Snell, June 2012.)

Concretes of same strength	
Aggregates type	Rebound number
River Rock	40
Granite	37
Limestone	32
Lightweight	31

According to Abebe, (2005) the most commonly available local coarse aggregates around Addis Ababa are obtained from normal weight crushed basaltic stone and lightweight volcanic ash, which are a member of a family of igneous rock (scoria or pumice).Since the scope of this research is normal weight aggregate. The most commonly available normal weight course aggregate around Addis Ababa is basalt.

Aragaw ,(2008) on his research paper "Evaluation of the Suitability of Basaltic Rock as Source of Concrete Aggregate in & Around Addis Ababa City" classifies the basaltic course aggregate in the following manner.

All existing crushed stone aggregate for concrete usages are located on basaltic lithology of five distinctive genetics. 39% of aggregate quarry sites are located in South eastern part of the study area which is composed of Addis Ababa olivine porphyritic basalt, 52% of the quarries are located in Southern parts which is Trachy basalt. The rest 3% and 5% of the aggregate quarry sites are situated in Northern and North western parts of the study area on Addis Ababa aphanitic basalt and Tarmaber basalt, respectively. (Aragaw , 2008)

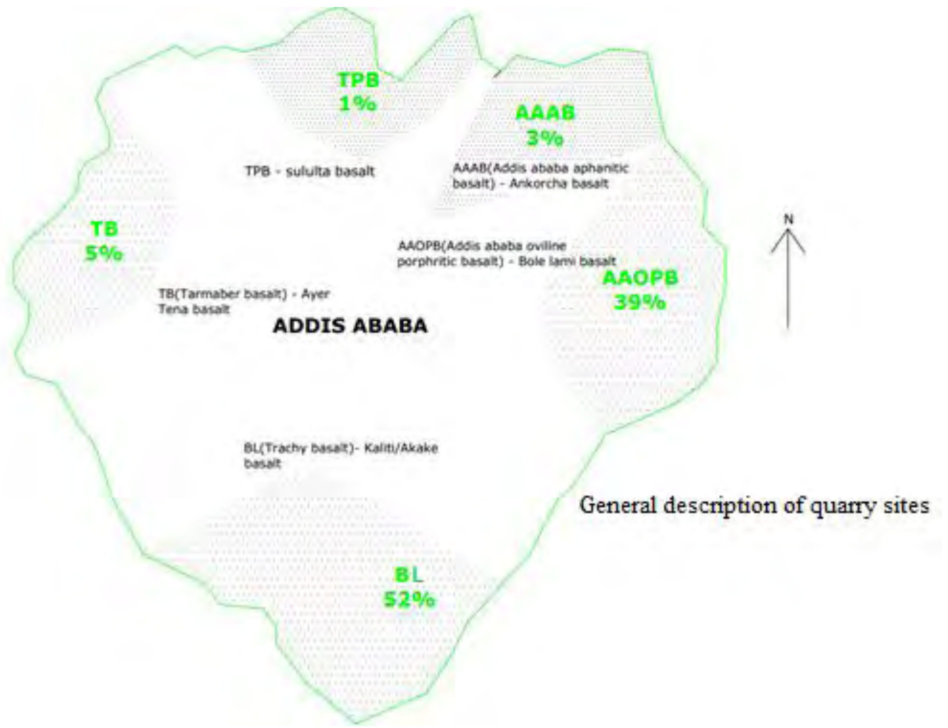


Figure 1: General description on existing quarry sites

In the study area Aragaw , (2008) identified five basalts based on their age, texture and chemical composition of the constituents of the rocks.

1. Bole Lemi Basalt (AAOPB):

This rock is named in various literatures by Addis Ababa olivine porphyritic basalt which is exposed in South East part and North West of the study area.

2. Ankorcha Basalt (AAAB):

This-basalt outcrops around the center of the city and North East of the study area. It is plagioclase, pyroxene and olivine basalt and overlain by the younger ignimbrite from which it is separated by tuffs and agglomerates.

3. Kaliti/Akaki Basalt (BL):

The outcrop of this basalt is located in the southern part of the study area which is majority of quarries situated.

4. Sululta Basalt (TPB):

This-basalt outcrops northern part of the study area this basalt named Tarmaeber basalt in different literature.

5. Ayer -Tena Basalt (TB)

Trachy-basalt to trachy andesite outcrops around Repi & Ayertena, South west of the study area, the basalt outcropped which looks like trachy-basalt but actually it is trachy andasite that contains more feldspar than dark minerals.

Field Rock Strength Test

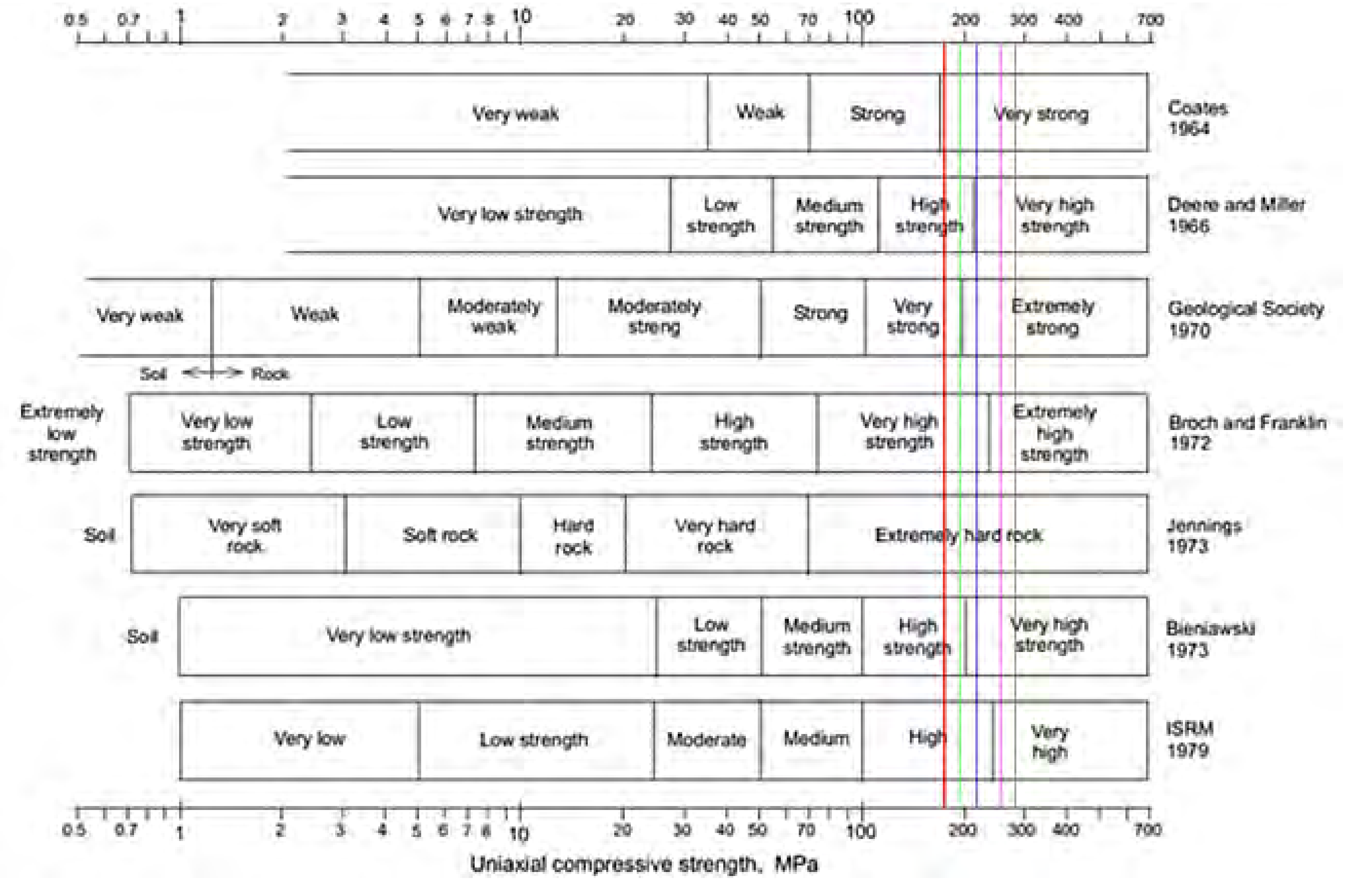
Field rock strength test was estimated using Schmidit hammer (L-type) for fresh and slightly weathered materials of an in situ rock in quarry face on the respective sampled lithology. The test was conducted using ASTM method and the following results were obtained (Table 4).

Table 4: Rebound values, physical properties, and uniaxial compressive strengths (Aragaw , 2008)

Sample Code	R(Rebound Value)		γdry(KN/m^3)	UCS (Mpa)
	Mean	Var.		
AAAB	55.13	8	26.93	195
AAOPB	61.20	10	27.51	285
TB	61.73	13	24.95	220
TPB	54.60	10	28.80	180
BL	58.93	7	27.23	260

The uniaxial compressive strength of rock (σc)

In rock mechanics and engineering geology the classification of rock based on strength is defined in terms of the uniaxial compressive strength. Several classifications based on the compressive strength of rocks have been presented.

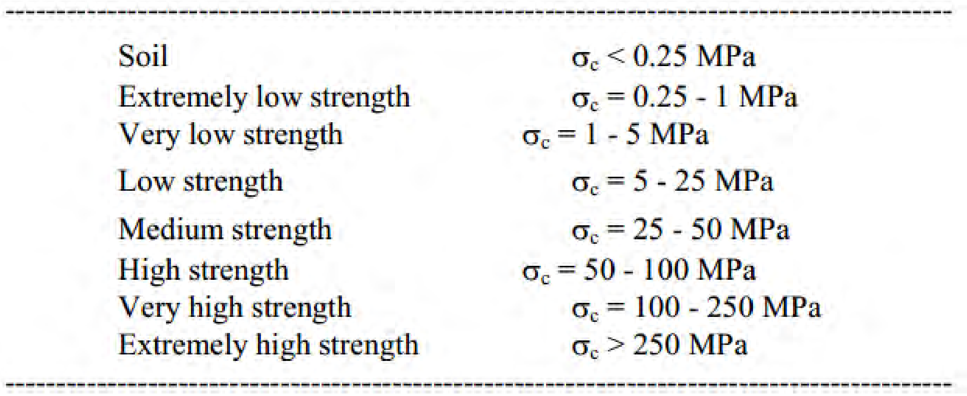


🟥	TPB	180 MPa
🟩	AAAB	195 MPa
🟦	TB	220 MPa
🟪	BL	260 MPa
⬛	AAOPB	285 MPa

Figure 2: Several classifications of the compressive strength of rocks based on (International Society for Rock Mechanics (ISRM), 1978)

International Society for Rock Mechanics (ISRM), Commission on standardization of laboratory and field tests more elaborately states this classification in the following.

Table 5: Classification of the uniaxial compressive strength of rocks (International Society for Rock Mechanics (ISRM), 1978)



Soil	$\sigma_c < 0.25$ MPa
Extremely low strength	$\sigma_c = 0.25 - 1$ MPa
Very low strength	$\sigma_c = 1 - 5$ MPa
Low strength	$\sigma_c = 5 - 25$ MPa
Medium strength	$\sigma_c = 25 - 50$ MPa
High strength	$\sigma_c = 50 - 100$ MPa
Very high strength	$\sigma_c = 100 - 250$ MPa
Extremely high strength	$\sigma_c > 250$ MPa

Based on the above classification the available aggregates in the study area can be classified in the following manner (Table 6).

Table 6: Classification of aggregate in the study area based on the (International Society for Rock Mechanics (ISRM), 1978)

Sample Code	Description	UCS (Mpa)	Classification based on (International Society for Rock Mechanics (ISRM), 1978)
TPB	Sululta Basalt	**180**	Very high strength
AAAB	Ankorcha Basalt	**195**	Very high strength
TB	Ayer -Tena Basalt	**220**	Very high strength
BL	Kaliti/Akaki Basalt	**260**	Extremely high strength
AAOPB	Bole Lemi Basalt	**285**	Extremely high strength

The effect of Strength of aggregate on the strength of concrete

Although it is possible to classify aggregates based on their strength Steven H, et al., (2003) states, the strength of an aggregate does not influence the strength of conventional concrete as much as the strength of the paste and the paste-aggregate bond. Steven H, et al.,(2003) additionally points out the aggregate stress levels in concrete are often much higher than the average stress over the entire cross section of the concrete. In addition to Steven H, et al., (2003), Neville & Brooks, (2010) discusses the compressive strength of concrete cannot significantly exceed that of the major part of the aggregate contained therein, although it is not easy to determine the crushing strength of the aggregate itself. A few weak particles can certainly be tolerated; after all, air voids can be viewed as aggregate particles of zero strength.

Considering the data given above about the types of basalt aggregates in and around Addis Ababa and the relationship with the strength class of concrete considered under this research (I.e. 15-60 Mpa), the basalt type may not significantly affect the strength of the concrete class considered. But as it can be seen in Table 1 concrete of the same strength can have different rebound number because of deferent aggregates used. Therefore, classifying the basaltic aggregate in to two sub classes will be sufficient for this research. Strength of the aggregates vary from 180 to 285 MPa.

Table 7: Classification of aggregate in the study area

Aggregate strength class	Aggregate name
Very high strength	Sululta Basalt **(TPB)**
	Ankoarcha Basalt(**AAAB)**
	Ayer -Tena Basalt **(TB)**
Extremely high strength	Kaliti/Akaki Basalt **(BL)**
	Bole Lemi Basalt **(AAOPB)**

2.3 Testing of Hardened Concrete

The proof of concrete quality is field performance under actual loading and environmental conditions. But before concrete experiences much of this exposure, it’s necessary to determine its acceptability and make projections about its long-term performance. These judgments are based, in part, on the results of tests performed on hardened concrete. Standardized tests are available for:

- Estimating mechanical properties, such as compressive, tensile, or flexural strength
- Estimating stiffness or elasticity

- Indicating concrete durability factors, such as permeability or resistance to freeze-thaw, scaling, and abrasion

Other useful, but nonstandard tests can estimate cement content and water-cement ratio and be helpful in diagnosing problems, such as poor mixing, re-tempering, or inadequate curing and protection. Due to the scope of the research the primary focus of discussion will be on the Tests for strength of concrete using the standard cylinder test and the rebound hammer.

2.3.1 Concrete Strength Testing

Based on Lamond & Pielert, (2006) the most common concrete property measured by testing is strength. There are three main reasons for this. First, the strength of concrete gives a direct indication of its capacity to resist loads in structural applications, whether they are tensile, compressive, shear, or combinations of these. Second, strength tests are relatively easy to conduct. Finally, correlations can be developed relating concrete strength to other concrete properties that are measured by more complicated tests. Caution should be exercised, however, when strength is used to estimate other properties based on empirical correlations. When a non-strength property is of primary interest, that property should be measured directly.

2.3.2 Nature of Concrete Strength

Reaction of cement with water forms hardened cement paste, which binds together coarse and fine aggregate to form a solid mass. Hardened paste consists of poorly crystallized hydrates of various compounds, referred to collectively as gel, crystals of calcium hydroxide, un-hydrated cement, and air voids (Neville & Brooks, 2010).

Lamond & Pielert, (2006) States Concrete can be considered as a two-phase composite, consisting of cement paste and aggregate, and its behavior under load is a result of the interaction of the two phases and the interfacial regions between them. Failure of concrete occurs as a result of the development of a network of micro-cracks that grow in length with increasing load to the point where the concrete cannot support further load (Figure 3). The coarse aggregate particles act as inclusions that can both initiate and arrest crack growth. The latter feature is beneficial in reducing the brittleness of concrete.

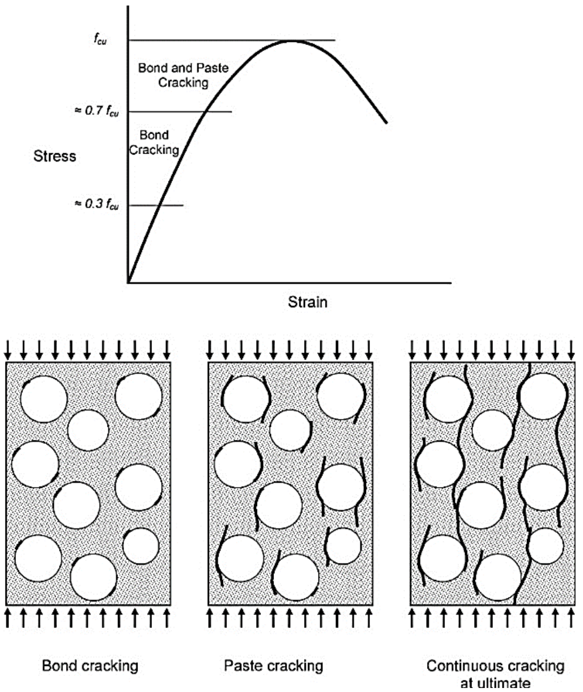


Figure 3: Stress-strain curve of concrete in compression and stages of micro cracking (Lamond & Pielert, 2006)

Neville & Brooks, (2010) explains the nature of crack development as load is progressively applied as follows, before external load is applied to concrete, fine cracks exist in concrete at the interface of coarse aggregate and cement paste due to mechanical property differences and the occurrence of shrinkage or thermal strains. These pre-existing micro cracks are responsible for the low tensile strength of concrete. As external load is applied, existing micro cracks are stable up to about 30% of the ultimate load, at which point interfacial cracks begin to increase in length, width, and quantity. When 70–90 % of the ultimate strength is reached, cracks penetrate into the bulk paste leading to continuous larger cracks until the concrete cannot support additional load.

The shape of the compressive stress-strain curve of concrete is related to the formation and growth of micro cracks. The process of micro cracking and its relationship to the stress-strain curve. Up to about 30 % of the ultimate strength, the stress-strain curve is linear. When existing interfacial micro cracks begin to propagate, the curve starts to deviate from linear behavior; deviation from linearity increases as more interfacial cracks are formed. When micro-cracks penetrate into bulk cement paste, deviation from linearity increases at a faster rate. As ultimate strength is approached, interfacial and bulk paste micro cracks join to form continuous cracks parallel to the direction of loading. At some point, the extent of cracking is so great that the concrete cannot support additional load, and subsequently the stress required for additional strain decreases (Neville & Brooks, 2010).

Based on the above micro cracking process, it is clear that the ultimate strength of concrete is related strongly to the strength of the cement paste.

2.3.3 Preparation of Test Specimens

Concrete strength tests are conducted on both molded specimens and specimens cut from existing structures. Although testing procedures are similar, the significance of the information obtained can be quite different depending on specimen preparation and handling prior to testing. Following are brief descriptions of current standard procedures for preparing test specimens up to the time of testing. (Lamond & Pielert, 2006)

Molded Specimens

Current ASTM test methods for measuring strength call for specimens in the shape of cylinders or beams. Preparation of these specimens in the field is governed by ASTM Practice for Making and Curing Concrete Test Specimens in the Field (C 31/C 31M), and under laboratory conditions by ASTM Practice for Making and Curing Concrete Test Specimens in the Laboratory (C 192/C 192M). ASTM Test Method for Compressive Strength of Concrete Cylinders Cast in Place in Cylindrical Molds (C 873) provides procedures for obtaining cylinders cast and cured in concrete slabs. ASTM C 873 involves cylinders that are cast in special molds placed within a structural slab, so that the cylinders receive curing identical to that of the surrounding concrete in the structure until the time of test. Specimens made according to ASTM C 873 will be referred to as push-out cylinders.

ASTM C 192/C 192M specifies procedures for preparing test specimens in the laboratory and is generally used in research and mixture proportioning studies. This procedure is considered to be the “ideal” condition for specimen preparation, and will produce the most consistent results due to the high degree of control involved.

Specimens given curing similar to that of the structural component are used to indicate the in-place strength of concrete prior to form removal or application of construction loads. Even though efforts are made to provide equivalent curing to both the concrete in the structure and the molded specimens, differences in strength are expected due to differences in consolidation and early-age temperature histories. Push-out cylinders (ASTM C 873) are also used to determine in-place concrete strength, but the curing of push-out cylinders is more like that of the structure than for molded specimens stored on the structure according to ASTM C 31/C 31M.

Another technique to estimate the in-place strength is to use the temperature-matched curing (TMC) technique. In a temperature-matched curing system, thermocouples inserted into the concrete mass monitor the temperature rise as it cures and control the temperature of specimens placed in a water bath or in molds with heating elements. In effect, the ambient temperature surrounding the concrete specimens matches the temperature history of the concrete mass as it cures. Such a curing system could also be used to follow a pre established temperature history of a structural element. It has been found that temperature-matched curing allows for the best estimation of in-place strength.

Specimens from Existing Structures

Generally, drilled cores or sawed beams are obtained when doubt exists as to the strength of the concrete as placed. This can be due to low strength test results during construction or signs of distress in the structure. Also, cut specimens are useful if strength information is required for older structures or if service loads are to be increased above original design levels. All other factors being equal, the strength of these specimens is most likely to be representative of the strength of the concrete in the structure. Cutting of these specimens is, however, costly, and the drilling or sawing processes may introduce variables affecting strength test results.

Procedures for obtaining strength test specimens from existing hardened concrete are specified in ASTM Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete (C 42/C 42M). Drilled cores can be tested either in compression or splitting tension, and sawed beams are tested in flexure. In addition to placing dimensional requirements on specimens, ASTM C 42/C 42M requires that test specimens be comprised of intact, sound concrete, as free of flaws as the particular construction will allow.

Although the concrete in drilled or sawed specimens is more likely to be representative of that in the structure than molded specimens, one must be aware of various factors that are likely to affect the strength of the concrete samples thus obtained. Excess voids in a particular concrete sample, due to poor consolidation, will cause strength reductions. Further, the process of drilling or sawing of specimens may cause some damage that may affect strength test results, and this factor may become more pronounced as the ratio of cut surface to specimen volume increases .The resultant strength reductions have been reported to be greater in higher-strength concretes.

The loading to which the concrete member has been subjected may also affect the measured core strength. Cores taken from highly stressed regions, where micro cracking is likely to have occurred, have lower strength than those from unstressed regions (Lamond & Pielert, 2006).

2.3.4 Compressive Strength Test Procedures

Compressive strength testing of molded concrete cylinders prepared according to ASTM C 31/C 31M or C 192/C 192M is specified in ASTM Test Method for Compressive Strength of Cylindrical Concrete Specimens (C 39/C 39M).

Testing procedures for cores (C 42/C 42M) and push-out cylinders (C 873) also refer to ASTM C 39/C 39M for measuring compressive strength. All of these standards specify tolerances on specimen geometry, end conditions, and specimen moisture condition at time of testing. In addition, if the end condition tolerances are not met by the concrete specimens, the test methods require grinding or sawing of the ends to meet the requirements, or capping with bonded caps according to ASTM Practice for Capping Cylindrical Concrete Specimens (C 617) or with unbonded elastomeric caps (to be described) according to ASTM Practice for Use of Unbonded Caps in Determination of Compressive Strength of Hardened Concrete Cylinders (C 1231). (Lamond & Pielert, 2006)

2.3.5 Factors Affecting Compressive Strength

According to Lamond & Pielert, (2006) the following are the major factors affecting the compressive strength test.

Effect of Specimen End Conditions

ASTM C 39/C 39 M states that the ends of cylindrical specimens to be tested must not depart from perpendicularity with the specimen axis by more than 0.5° (approximately 1 mm in 100 mm), and that the ends must be plane to within 0.050 mm).

The purpose of specifying end condition requirements of planeness and perpendicularity is to achieve a uniform transfer of load to the test specimen. Surface irregularities will lead to local concentrations of stress even in specimens that are capped to meet the planeness requirements. In general, specimen ends that do not meet the specified requirements prior to capping cause lower strength test results, and the degree of strength reduction increases for higher-strength concretes.

Effect of Specimen Size

It is commonly accepted that as specimen size increases, the measured concrete strength and the variation in test results decrease. The magnitude of the size effect decreases with increasing specimen diameter. The reasoning behind the size effect is that the strength of a concrete specimen will be governed by the weakest part of that specimen, and that the probability of the occurrence of large flaws increases as specimen size increases.

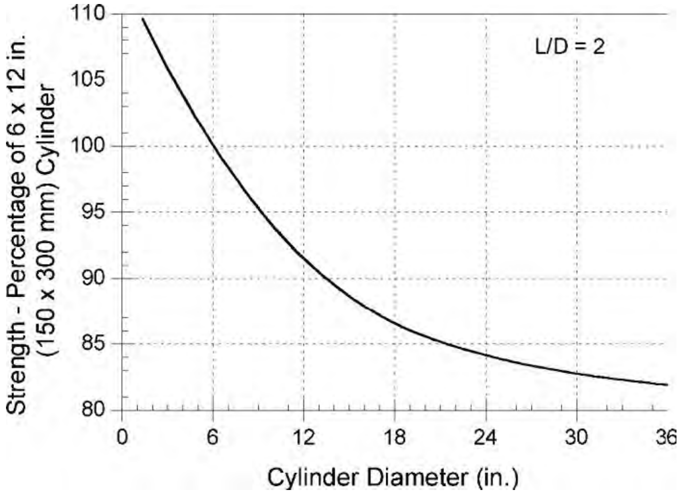


Figure 4: Effect of cylinder size on measured compressive strength (Lamond & Pielert, 2006)

Effect of Diameter-Aggregate Size Ratio

Current specifications for molded specimens and push-out cylinders require that the minimum specimen dimension be at least three times the Nominal Maximum Size Aggregate. For molded specimens, larger-sized aggregates may be removed by hand picking or by wet sieving so that smaller specimen dimensions may be used. It has been reported, however, that the practice of removing larger aggregate sizes from concrete will result in higher compressive strengths.

For drilled cores, the preferable condition is that the core diameter is at least three times the maximum nominal aggregate size used in the concrete placement. This condition may be relaxed by the specifier of tests provided the core diameter is at least twice the maximum size of coarse aggregate (Lamond & Pielert, 2006).

Effect of Specimen Moisture Condition

The moisture condition of the specimen at the time of testing can have a significant influence on measured strengths. In general, specimens have 5–20 % lower compressive strengths when tested in a moist condition than they would if tested in a dry condition. The higher strength of dry specimens is attributed to increased strength of secondary bonds within the paste structure. It has been postulated that as a specimen dries, the outer surface attempts to shrink, thereby inducing lateral compression on the specimen interior, which increases its apparent compressive strength. A specimen that is wetter in the outer region will have lower compressive strength (Lamond & Pielert, 2006).

Effect of Loading Direction versus Casting Direction

Molded concrete cylinders are tested parallel to their casting direction. Beams and drilled cores, however, may be tested either parallel or perpendicular to the casting direction, depending on the circumstances involved.

In general, specimens tested in the same direction as cast will yield higher strengths than those tested perpendicular to it. The difference in measured strength is attributed to the occurrence of weak paste-aggregate interfaces aligned perpendicular to the casting direction due to water gain under coarse aggregate particles. Cores tested parallel to the casting direction may have about 8 % higher strengths than those tested perpendicular to the casting direction (Lamond & Pielert, 2006).

Effect of Loading Rate

The measured strength of concrete specimens increases as the rate of loading increases. The dependence of ultimate strength on loading rate is thought to be related to mechanisms of creep and micro cracking. This would appear to be in agreement with the observation that when subjected to a sustained load of approximately 75 % of its ultimate capacity obtained using ASTM C 39/C 39M, concrete will eventually fail with no further load application (Lamond & Pielert, 2006).

2.4 Non Distractive Testing Of Concrete

According to Nawy G, (1997) there is no standard definition for nondestructive tests as applied to concrete. For some people, they are tests that do not alter the concrete. For others, they are simply tests that do not impair the function of a structure, in which case the drilling of cores is considered to be a NDT test. For still others, they are tests that do less damage to the structure than does drilling of cores.

In the inspection and testing of concrete, the use of Nondestructive testing (NDT) has been making slow but steady progress since the 1950s (Lamond & Pielert, 2006). The slow development of these testing methods for concrete is due to the fact that, unlike steel, concrete is a highly non-homogenous composite material, and most concrete is produced in ready-mixed plants and delivered to the construction site. The in-place concrete is, by its very nature and construction methods, highly variable, and does not lend itself to testing by traditional NDT methods as easily as steel products.

Notwithstanding the preceding, there has been considerable progress in the development of NDT methods for testing concrete in recent years. A number of these methods have been standardized by ASTM International, the International Standards Organization (ISO), and the British Standards Institute (BSI).

Lamond & Pielert, (2006) subdivides tests that are identified generally as nondestructive into two main types, the first type includes those identified as sonic and pulse velocity tests and the Sonic and pulse velocity tests, which involve the determination of the resonant frequency and the measurement of the velocity of a compressional pulse traveling through the concrete, also included in this category are stress wave tests for locating the flaws or discontinuities that may be present, or measuring the thickness of concrete.

Second type includes those tests that are used to estimate strength properties this include the surface hardness, penetration, pullout, maturity, pull-off, and combined methods. Some of these methods are not truly nondestructive because they cause some surface damage that is generally insignificant.

2.4.1 Methods to Estimate In-Place Strength

In-situ/nondestructive tests may not be considered as replacements for the standard cylinder test, but should be considered as additional techniques. When performed in conjunction with standard core tests, they can provide additional information and reduce the number of cores required for testing.

Lamond & Pielert, (2006) point out unless comprehensive correlations have been established between the strength parameters to be predicted and the results of in-situ/nondestructive tests, the use of the latter to predict strength properties of concrete is not recommended.

As tried to outline in the above discussions there are different methods to determine the in place strength of concrete. Since the main focus of this thesis is on the surface hardness method only an overview of other in place methods are given.

Ultrasonic pulse velocity testing

Ultrasonic pulse velocity testing, mainly used to measure the sound velocity of the concrete and hence the compressive strength of the concrete. A pulse of longitudinal vibrations is produced by an electro-acoustical transducer, which is held in contact with one surface of the concrete under test. When the pulse generated is transmitted into the concrete from the transducer using a liquid coupling material such as grease or cellulose paste, it undergoes multiple reflections at the boundaries of the different material phases within the concrete. A complex system of stress waves develops, which include both longitudinal and shear waves, and propagates through the concrete. (Khan, 2002)

Measurement of the velocity of ultrasonic pulses of longitudinal vibrations passing through concrete may be used for the following applications:

- Determination of the uniformity of concrete in and between members
- Measurement of changes occurring with time in the properties of concrete
- Correlation of pulse velocity and strength as a measure of concrete quality.
- Determination of the modulus of elasticity and dynamic Poisson's ratio of the concrete.

Penetration resistance or Windsor probe test

Penetration resistance or Windsor probe test, used to measure the surface hardness and hence the strength of the surface and near surface layers of the concrete. The Windsor probe, like the rebound hammer, is a hardness tester, and its inventors claim that the penetration of the probe reflects the precise compressive strength in a localized area is not strictly true. However, the probe penetration does relate to some property of the concrete below the surface, and, within limits, it has been possible to develop empirical correlations between strength properties and the penetration of the probe. (Khan, 2002)

Pullout Test

A pullout test, by using a dynamometer and a reaction bearing ring, measures the force required to pull out from concrete a specially shaped insert whose enlarged end has been cast into the concrete. Because of its shape, the insert is pulled out with a cone of the concrete. The concrete is simultaneously in tension and in shear, and the generating lines of the cone are defined by the key dimensions of the insert and bearing ring. The pullout force is then related to compressive strength by means of a previously established relationship. (Lamond & Pielert, 2006)

Maturity Method

It is well known that the compressive strength of well-cured concrete increases with time. However, the increase in strength is governed by many factors other than curing time, the most important being the concrete temperature and the availability of moisture. The combined effect of time and temperature has been studied by several investigators. Maturity functions are mathematical expressions that convert the temperature history of concrete to an index indicative of its strength development. (Lamond & Pielert, 2006)

Permeation method

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 of water 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.

2.4.2 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 and cracking.

According to Khan, (2002) 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.

Khan, (2002) specifies the typical situations where non-destructive testing may be useful 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
- 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 helping 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
- Monitoring long term changes in concrete properties

It stated in ACI 228.1R-03 before 1983, ACI 318 required testing of field-cured cylinders to demonstrate the adequacy of concrete strength before removal of formwork or reshoring. ACI 318-83 allowed the use of alternative procedures to test field-cured cylinders. The building official, however, must approve the alternative procedure before its use. Since 1983, ACI 318 has permitted the use of in-place testing as an alternative to testing field-cured cylinders provided there are sufficient correlation data (ACI 318R).

Architects/Engineers in evaluating the uniformity and relative concrete strength in-place, or for selecting areas to be cored." ACI 301-99 states in Paragraph 1.6.6.1 that the results of in-place tests "will be valid only if the tests have been conducted using properly calibrated equipment in accordance with recognized standard procedures and acceptable correlation between test results and concrete compressive strength has been established and is submitted. ACI 301-99, however, restricts the use of these tests in acceptance of concrete by stating that: "Nondestructive tests shall not be used as the sole basis for accepting or rejecting concrete," but they may be used to "evaluate" concrete when the standard-cured cylinder strengths fail to meet the specified strength criteria.

2.5 Schmidt Rebound Hammer Test

In 1948, Ernst Schmidt, a Swiss engineer, developed a device for testing concrete based upon the rebound principle (Malhotra, 1976, 1991). As was the case with earlier indentation tests, the motivation for this new device came from tests developed to measure the hardness of metals. In this case, the new device was an outgrowth of the Scleroscope2 test, which involves measuring the rebound height of a diamond-tipped hammer, or mass, that is dropped from a fixed height above the test surface. (ACI 228.1R-03 , 2009)

Figure 5: Typical section view of rebound hammer

2.5.1 Fundamental Principle

Nawy G, (1997) explains 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 have attempted to establish a correlation between the hammer rebound number and the hardness as measured by the Brinell method.

2.5.2 Equipment for Schmidt/Rebound Hammer Test

The Schmidt rebound hammer is shown in Fig.6 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 7. 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 to 100. The rebound distance is recorded as a "rebound number" corresponding to the position of the rider on the scale.

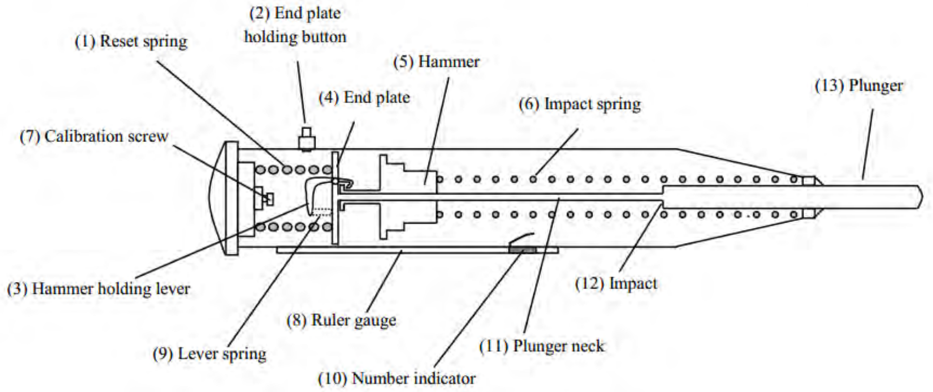


Figure 6: Details of an L type Schmidt hammer (Journal of Mining & Environment)

2.5.3 General Procedure for Schmidt Rebound Hammer Test

The method of using the hammer is explained on (ACI 228.1R-03 , 2009) by the help of Figure 6. 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. The plunger is then held perpendicular to the concrete surface and the body pushed towards the concrete (Figure 6b). This movement extends the spring holding the mass to the body.

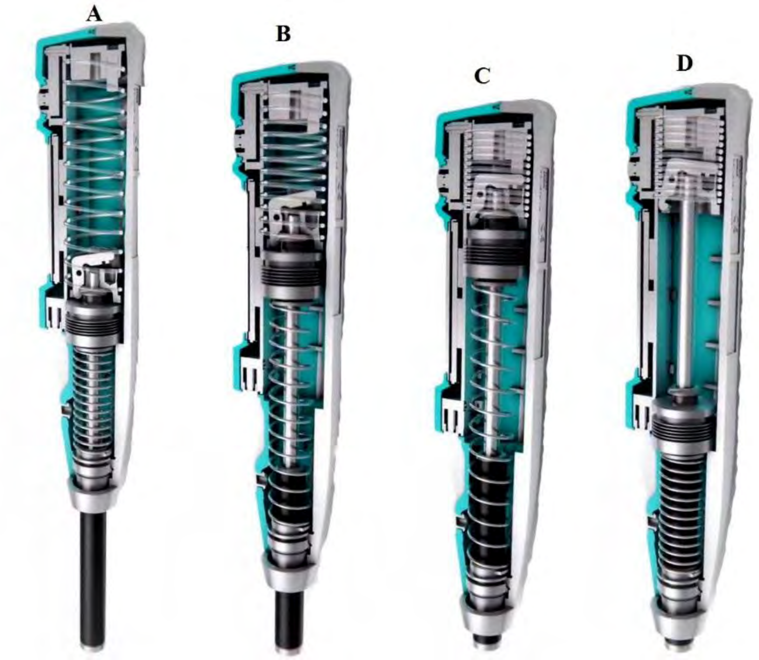


Figure 7: Cutaway schematic view of the Schmidt rebound hammer, ACI 228.1R-03, 2009

When the maximum extension of the spring is reached, the latch releases and the mass is pulled towards the surface by the spring, Figure 7c. The mass hits the shoulder of the plunger rod and rebounds because the rod is pushed hard against the concrete, Figure 7d. 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.

2.5.4 Applications of Schmidt Rebound Hammer Test

The hammer can be used in the horizontal, vertically overhead or vertically downward 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. (Khan, 2002)

Additionally Khan, (2002) points out, even if 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.

2.5.5 Factors Affecting Rebound Number

(IS 13311-2, 1992) Explains the standard procedure for test and correlation between concrete cube crushing and strength rebound number. The rebound numbers are influenced by a number of factors like types of cement and aggregate, surface condition and moisture content, age of concrete and extent of carbonation of concrete.

i. **Influence of Type of Cement:**

   Concretes made with high alumina cement can give strengths 100 percent higher than that with ordinary Portland cement. Concretes made with super sulphated cement can give 50 percent lower strength than that with ordinary Portland cement (IS 13311-2, 1992).

ii. **Influence of Type of Aggregate**:

   Different types of aggregate used in concrete give different correlations between compressive strength and rebound numbers. Normal aggregates such as gravels and crushed rock aggregates give similar correlations, but concrete made with lightweight aggregates require special calibration.

iii. **Influence of Surface Condition and Moisture Content of Concrete:**

   The rebound hammer method is suitable only for close texture concrete. Open texture concrete typical of masonry blocks, honeycombed concrete or no-fines concrete are unsuitable for this test. All correlation assume full compaction, as the strength of partially compacted concrete bears no unique relationship to the rebound numbers. Trowelled and floated surfaces are harder than moulded surfaces, and tend to overestimate the strength of concrete. A wet surface will give rise to underestimation of the strength of concrete calibrated under dry conditions. In structural concrete, this can be about 20 percent lower than in an equivalent dry concrete.

iv. **Influence of Curing and Age of Concrete**:

   The relationship between hardness and strength varies as a function of time. Variations in initial rate of hardening, subsequent curing and conditions of exposure also influence the relationship. Separate calibration curves are required for different curing regimes but the effect of age can generally be ignored for concrete between 3 days and 3 months old.

v. **Influence of carbonation of concrete surface:**

Influence of carbonation of concrete surface on the rebound number is very significant. Carbonated concrete gives an over estimate of strength which in extreme cases can be up to 50 percent. It is possible to establish correction factors by removing the carbonated layer and testing the concrete with the rebound hammer on the un-carbonated concrete.

2.6 Rebound Hammer Number Correlation Curve

The rebound hammer was constructed and tested extensively at the Swiss Federal Materials Testing and Experimental Institute in Zurich. A correlation was developed between the compressive strength of 150mm standard cubes and the rebound number, and this correlation was provided with the instrument. However, as other investigators began to develop correlations between strength and rebound number, it became evident that there was not a unique relationship between strength and rebound number (Nawy G, 1997). The current recommended practice [ASTM C 805, ACI 228.1R, 1995] is to develop the strength relationship using the same concrete and forming materials as will be used in construction. Without such a correlation, the rebound hammer is useful only for detecting gross changes in concrete quality throughout a structure.

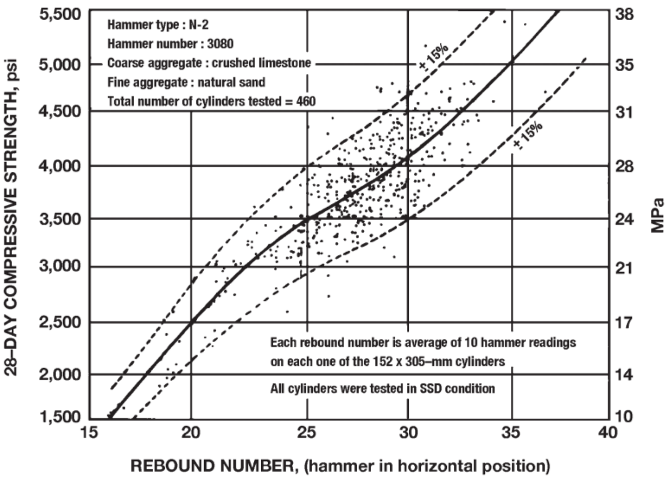


Figure 8: Typical correlation curve for limestone aggregate (Khan, 2002)

2.7 Standardization of Rebound Test Method

ASTM Test Method for Rebound Number of Hardened Concrete (C 805) was revised in 2002; the significance and use statement of the test method as given in ASTM C 805-02 is as follows: (Lamond & Pielert, 2006)

i. This test method is applicable to assess the in-place uniformity of concrete, to delineate regions in a structure of poor quality or deteriorated concrete, and to estimate in-place strength development.
ii. To use this test method to estimate strength requires establishing a relationship between strength and rebound number. The relationship shall be established for a given concrete mixture and given apparatus. The relationship shall be established over the range of concrete strength that is of interest. To estimate strength during construction, establish the relationship by performing rebound number tests on molded specimens and measuring the strength of the same or companion molded specimens. To estimate strength in an existing structure, establish the relationship by correlating rebound numbers measured on the structure with the strengths of cores taken from corresponding locations.
iii. For a given concrete mixture, the rebound number is affected by factors such as moisture content of the test surface, the method used to obtain the test surface (type of form material or type of finishing), and the depth of carbonation. These factors need to be considered in preparing the strength relationship and interpreting test results.
iv. Different hammers of the same nominal design may give rebound numbers differing from 1 to 3 units. Therefore, tests should be made with the same hammer in order to compare results. If more than one hammer is to be used, perform tests on a range of typical concrete surfaces so as to determine the magnitude of the differences to be expected.
v. This test method is not intended as the basis for acceptance or rejection of concrete because of the inherent uncertainty in the estimated strength.

Chapter Three

Material Preparation and Mix Design

To produce acceptable quality of concrete, it is important to make physical characteristic tests on materials used for the investigation before any concrete experiments are carryout. So, this chapter elaborates concrete making materials used for the research and their physical test results conducted for the experiment, mix design and proportion.

3.1 Material Preparation

In order to produce appropriate mix design for the concrete production, the physical characteristics of concrete making materials (cement, fine aggregate, coarse aggregate, water and admixture) used for the research were examined.

Cement Used For the Experiment

The cements used for this particular research are

- ✓ Ordinary Portland cement (OPC) produced as per CEM-I-42.5 for high strength concrete
- ✓ Portland Pozzolana cement (PPC) CEM-IV-32.5 for normal strength concrete

Dangote Cement PLC was used throughout the experiment.

Aggregate Used for the Experiment

The importance of using the right type and quality of aggregates cannot be overemphasized. The fine and coarse aggregates generally occupy 60% to 75% of the concrete volume (70% to 85% by mass) and strongly influence the concrete's freshly mixed and hardened properties, mixture proportions, and economy. Coarse aggregates consist of one or a combination of gravels or crushed stone with particles predominantly larger than 5 mm and generally between 9.5 mm and 37.5 mm. In addition aggregates should be clean, hard, strong, and durable and graded in size to achieve utmost economy from the paste. Therefore, to judge the quality of the aggregate physical characteristics tests have to be conducted. So, in this research the following physical testes are performed on the properties of fine and coarse aggregate.

Gradation of Aggregates Used for the Experiment

Sieve Analysis is a procedure for the determination of the particle size distribution of aggregates using a series of square or round openings stating with the largest. It is used to determine the grading of aggregate and the fineness modulus, an index to the fineness and coarseness and it is after this analysis is carried out that aggregates are described as well graded, poorly graded, uniformly graded, gap graded, etc. each of the above aggregate categories has close association with a range of quality of concrete produced using the aggregate.

Fine Aggregate

Natural sand commonly known as Langano sand, which is extracted from Langano area found in Oromia region about 140 km from Addis Ababa was used to prepare the concrete samples. In addition to this, all fine aggregate which was retain on 9.5mm sieve size were no longer relevant, and all the passing fine aggregate were used for experimentation. Then, the following tests were conducted for fine aggregates.

Table 8: Gradation for fine aggregate

Sieve size	Weight of Sieve (gm)	Wt. Of sieve and retained (gm)	Weight Retained (gm)	Percentage Retained (%)	Cumulative Coarser (%)	Cumulative Passing (%)	Upper limit (%)	Lower limit (%)
9.5	585	585	0	0.00	0.00	100.00	100.00	100.00
4.75	567	567	0	0.00	0.00	100.00	100.00	95.00
2.36	415	457	42	8.40	8.40	91.60	100.00	80.00
1.18	354	458	104	20.80	29.20	70.80	85.00	50.00
0.6	326	490	164	32.80	62.00	38.00	60.00	25.00
0.3	304	407	103	20.60	82.60	17.40	30.00	10.00
0.15	460	537	77	15.40	98.00	2.00	10.00	2.00
Pan	254	264	10	2.00	100.00	0.00	0.00	
					F.M 2.80			

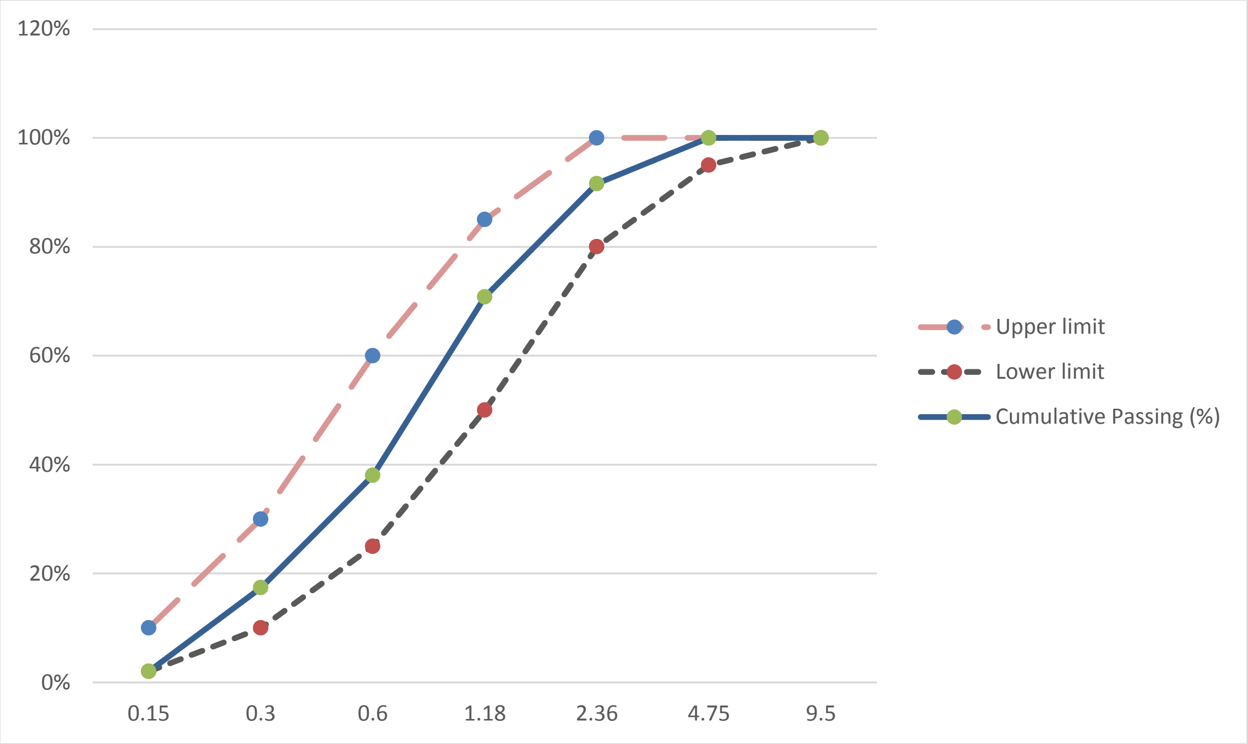


Figure 9: Gradation of fine aggregate

Coarse Aggregate

The coarse aggregate used for this research was basaltic crushed rock from two different locations one is from Sululta area and the other one is from Bole Lemi area. The following tests were conducted for coarse aggregates.

Table 9: Gradation of coarse aggregate for Bole Lemi Area

Sieve size	Weight of sieve(gm)	Wt. of sieve and retained (gm)	Weight Retained (gm)	Percentage Retained (%)	Cumulative Coarser (%)	Cumulative Passing (%)
25	1170	1340	170	8.46	8.46	91.54
19	1400	1960	560	27.86	36.32	63.68
12.5	1165	1930	765	38.06	74.38	25.62
9.5	1175	1490	315	15.67	90.05	9.95
4.75	1180	1320	140	6.90	97.01	2.99
Pan	735	795	60	2.99	100.00	0.00

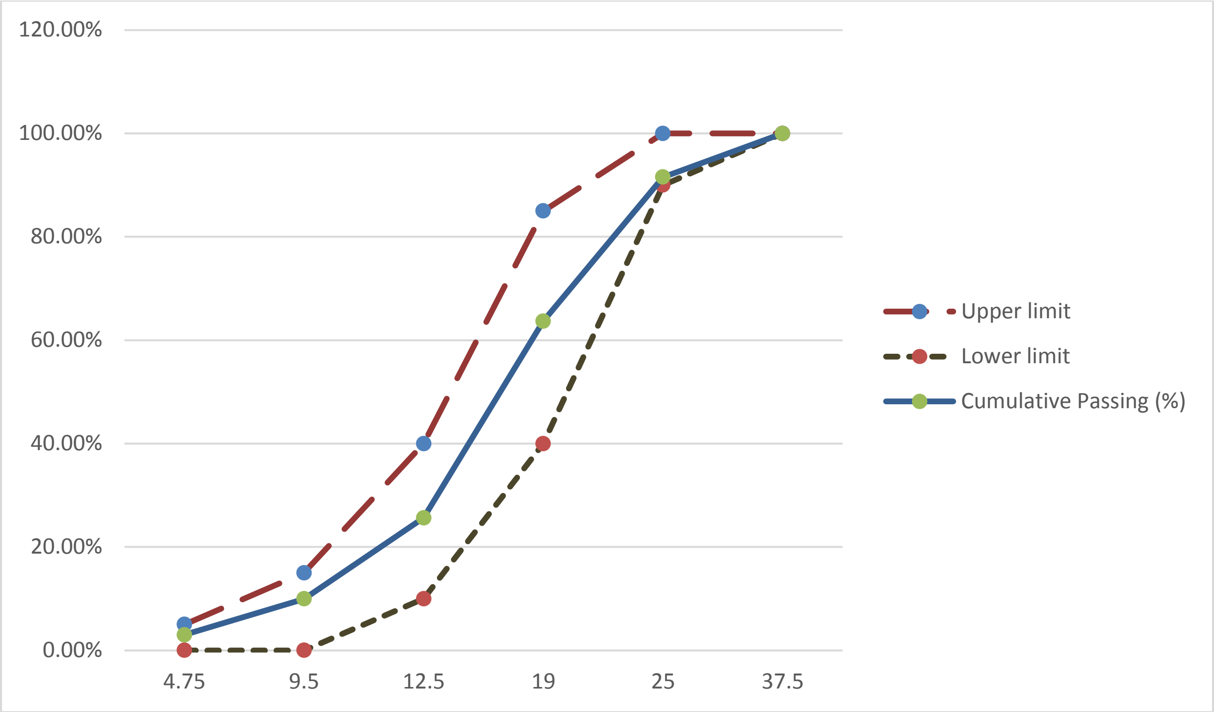


Figure 10: Gradation of coarse aggregate for Bole Lemi Area

Table 10: Gradation of coarse aggregate for Sululta Area

Sieve size	Weight of	Wt. Of sieve and Retained (gm)	Weight Retained (gm)	Percentage Retained (%)	Cumulative Coarser (%)	Cumulative Passing (%)
25	1170	1345	175	8.77	8.77	91.23
19	1400	2287	887	44.46	53.23	46.77
12.5	1165	1331	166	8.32	61.55	38.45
9.5	1175	1879	704	35.29	96.84	3.16
4.75	1180	1214	34	1.70	98.55	1.45
Pan	735	764	29	1.45	100.00	0.00

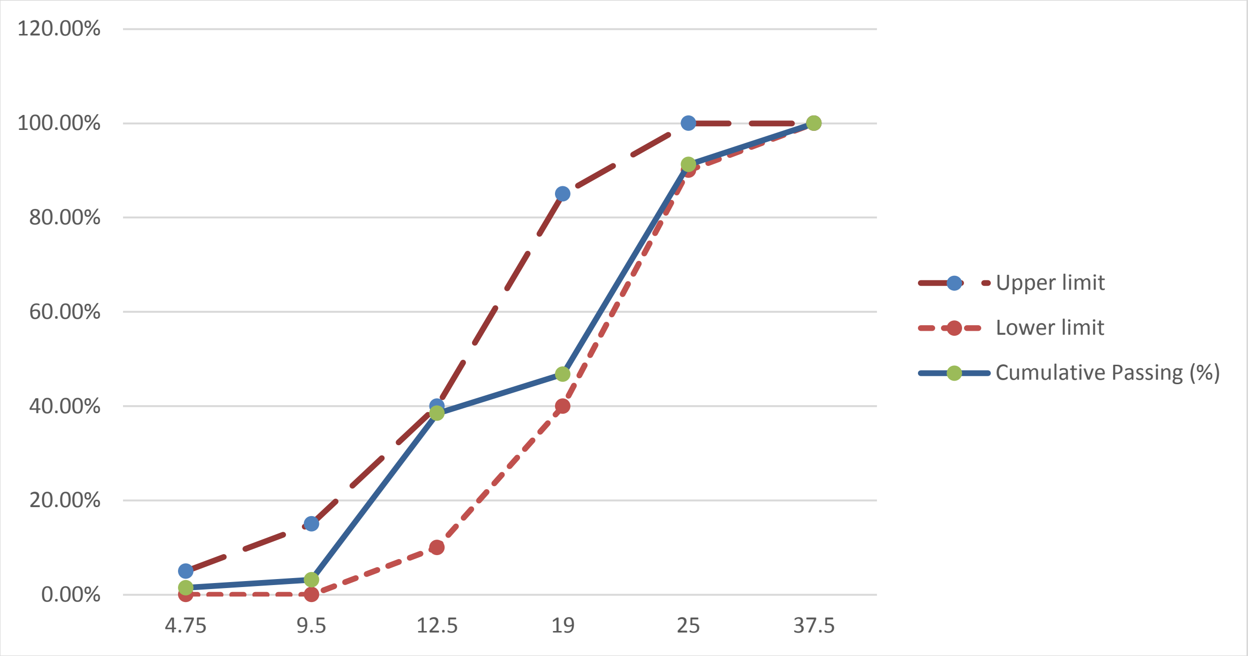


Figure 11: Gradation of coarse aggregate for Sululta Area

Physical Test for Aggregate

Aggregates make up the largest volume of material used in concrete. The aggregates must be clean, properly graded, hard, strong, durable, and free from chemicals or coatings of clay or other foreign materials that may inhibit the bond between the cement and aggregate. Testing must be performed to make sure that the aggregate meets all these criteria. The following tests as shown in table 11 were conducted on the aggregates to be use for the research.

Table 11: Physical test for aggregate

No	**Physical test for Aggregate**		**Results**		
			Bole Lemi	**Sululta**	**Fine aggregate**
1	Silt content				6.00%
2	Fineness modulus				2.80
3	Bulk density(kg/m3)		1581	1642	
4	Specific gravity	Bulk specific gravity	2.82	2.96	
		Bulk specific gravity(SSD)	3.07	2.90	
5	Absorption capacity		2.80%	3.80%	
7	Moisture content		0.45%	3.89%	

Water Used For the Experiment

Mixing water used in this research was water found in the laboratory, potable water supplied by the Addis Ababa Water and Sewerage Authority.

3.2 Concrete Mix Design and Materials Proportion

Based on the (ACI 211.1-91) "Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete" for the normal strength concrete and (ACI 211.4R) "Guide for selecting and proportions for high strength concrete", (ACI 363 R -92) "Report on high strength concrete" for the high strength concrete different mix designs were prepared. The following table presents the result form the mix design process for detail the mix design is attached in the annex.

Table 12: Material proportion for Bole Lemi aggregate

Aggregate Type	Bole Lemi			
Strength Class	C15			
W/C Ratio	0.64			
Materials	Cement	water	Fine aggregate	Course aggregate
Quantities per m^3	303.9	114.1	958.5	1101
Aggregate Type	Bole Lemi			
Strength Class	C25			
W/C Ratio	0.50			
Materials	Cement	water	Fine aggregate	Course aggregate
Quantities per m^3	384.0	148.1	878.6	1101
Aggregate Type	Bole Lemi			
Strength Class	C30			
W/C Ratio	0.45			
Materials	Cement	water	Fine aggregate	Course aggregate
Quantities per m^3	424.7	150.1	838.0	1101
Aggregate Type	Bole Lemi			
Strength Class	C 40			
W/C Ratio	0.40			
Materials	Cement	water	Fine aggregate	Course aggregate
Quantities per m^3	437.5	142.6	628.6	1094
Aggregate Type	Bole Lemi			
Strength Class	C50			
W/C Ratio	0.31			
Materials	Cement	water	Fine aggregate	Course aggregate
Quantities per m^3	553.1	146.6	549.8	1094
Aggregate Type	Bole Lemi			
Strength Class	C60			
W/C Ratio	0.45			
Materials	Cement	water	Fine aggregate	Course aggregate
Quantities per m^3	700.0	151.6	449.6	1094

Table 13: Material proportion for Sululta aggregate

Aggregate Type	Sululta			
Strength Class	C15			
W/C Ratio	0.64			
Materials	Cement	water	Fine aggregate	Course aggregate
Quantities per m^3	303.9	143.2	977.2	1137
Aggregate Type	Sululta			
Strength Class	C25			
W/C Ratio	0.50			
Materials	Cement	water	Fine aggregate	Course aggregate
Quantities per m^3	384.0	147.2	897.3	1137
Aggregate Type	Sululta			
Strength Class	C30			
W/C Ratio	0.45			
Materials	Cement	water	Fine aggregate	Course aggregate
Quantities per m^3	424.7	149.2	856.6	1137
Aggregate Type	Sululta			
Strength Class	C40			
W/C Ratio	0.40			
Materials	Cement	water	Fine aggregate	Course aggregate
Quantities per m^3	437.5	142.8	624.8	1154
Aggregate Type	Sululta			
Strength Class	C50			
W/C Ratio	0.32			
Materials	Cement	water	Fine aggregate	Course aggregate
Quantities per m^3	553.1	146.7	545.9	1154
Aggregate Type	Sululta			
Strength Class	C60			
W/C Ratio	0.25			
Materials	Cement	water	Fine aggregate	Course aggregate
Quantities per m^3	700.0	151.7	445.8	1154

Chapter Four

Experimental Programs and Discussions

Based on the research objective and the stated methodology laboratory experiment were conducted to generate two correlation curves.

- A correlation curve for concrete produced using aggregates from Bole Lemi area
- A correlation curve for concrete produced using aggregates from Sululta area

Based on the defined concrete grades and the classified aggregate types the number of 15 cm cube samples used in this thesis is stated in the following table.

Table 14: Sample size

Aggregate types with Strength classes							Total number of sample
Bole Lemi Aggregate	C15	C25	C30	C40	C50	C60	72 sample
Sululta Aggregate	C15	C25	C30	C40	C50	C60	

4.1 Concrete Production and Tests

The following steps and the discussed laboratory tests were conducted to generate the correlation curve.

1. Prepared a mix design based on ACI followed
2. Materials
   - Aggregate collected from both sites per the required quantity
   - Cement PPC for the normal strength and OPC for the high strength concrete used
   - River Sand collected as per the required quantity
   - Water; tap water was used from the lab
3. Proportion the materials as per the mix design before mixing

Photo 1 Proportioned materials

4. Mixing process
    - Mixed using the labs mixer
    - Slump checked after mixing
    - Small vibrator used to vibrate the casted concrete in the molds

Photo 2 Mixing process

- Surface of the concrete smoothed after vibration, labeled with IDs (s-sululta ,c-15 concrete class)

Photo 3 Labeled concrete sample

- Concrete left in the lab to dry for 14 hrs.

Photo 4 Drying concrete

- Mold removed by the next day and the concrete socked in water.

Photo 5 Curing concrete

4.2 Compressive Strenght Test and Hammer Test

To generate the correlation curve for the Schmidt rebound hammer test the results of both compressive strength test and the rebound value from the hammer test is needed. Therefore On the 7th and 28th day Schmidt rebound hammer and compression strength test was conducted on the cubes

a) Schmidt rebound hammer test.

   Test done following ASTM C 805, 11 readings taken from each cube

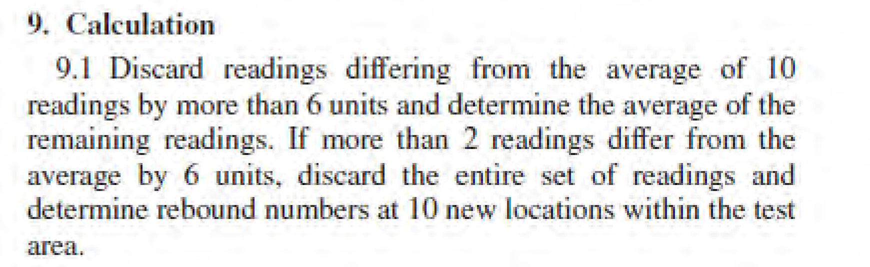
   The following conditions were considered while testing

   - Cube was supported to restrict movement

- Care was taken not to hit one place twice using Schmidt rebound hammer.
- Time was taken to dry the samples
- Result was recorded in automated excel sheet to check data constancy as per ASTM C 805

b) Compression strength test: conducted on 3 cubes for each strength class after taking the Schmidt rebound hammer test.

An excel format was prepared when collecting data for the hammer readings to be as per the ASTM C 805, 11.



9. Calculation

9.1 Discard readings differing from the average of 10 readings by more than 6 units and determine the average of the remaining readings. If more than 2 readings differ from the average by 6 units, discard the entire set of readings and determine rebound numbers at 10 new locations within the test area.

ASTM C 805, 11.

The excel traces the data collected as per the code

MIN

- Searches for the lowest value from the 11 readings & subtracts it from the average (RN)
- If < 6 ok if not make correction as per the code
- Formula (=RN-MIN(_ _:_ _)

MAX

- Same procedure but checks for the upper value
- Formula (=MAX(_ _:_ _) - RN)

RN

Calculates the average of the 11 readings

Table 15: Sample data collection sheet

		1	2	3	4	5	6	7	8	9	10	11	RN	Mpa	MIN	MAX
BOLE	cube 1	15	12	14	12	18	14	16	14	16	14	14	14.45	13.71	2.45	3.54
BOLE	cube 2	16	16	18	18	20	16	20	20	18	20	18	18.18	13.68	2.18	1.81
BOLE	cube 3	14	16	14	18	16	16	14	14	14	18	16	15.45	20.55	1.45	2.54

4.3 Test Results

In the following tables a summary of the test results for the compressive strength test and Schmidt rebound hammer test is presented

Table 16: 7th day Schmidt rebound hammer test and compressive strength test results for aggregates from Bole Lemi

Aggregate type	Bole Lemi																	
Date of test	7th day strength																	
Strength level	C15			C25			C30			C40			C50			C60		
UCT result(MPA)	12.13	9.18	11.40	18.93	21.01	15.53	19.34	26.61	11.77	33.12	28.61	27.63	34.46	33.39	33.79	31.69	33.71	29.57
Average UCT			10.90			18.49			19.24			29.78			33.88			31.65
Average Rebound value	15.73	13.00	12.36	18.55	19.45	17.00	17.09	19.27	18.36	23.64	23.27	21.36	19.55	26.64	28.27	30.55	30.09	26.73

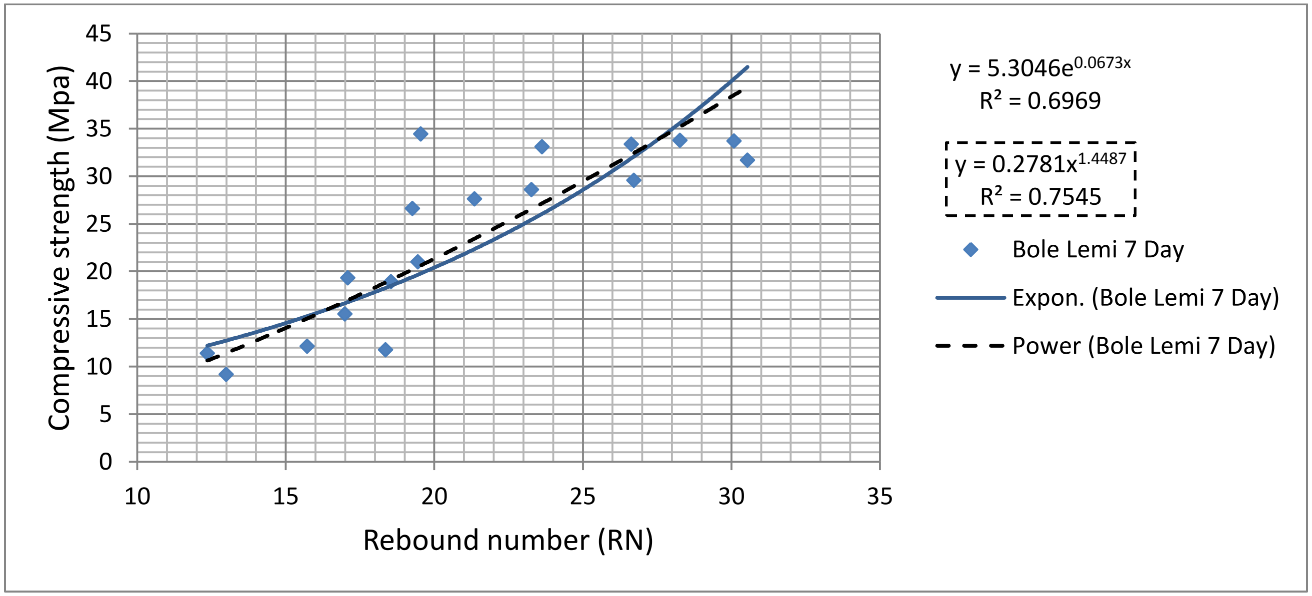


Figure 12: Test result (7 day)

Table 17: 7th day Schmidt rebound hammer test and compressive strength test results for aggregates from Sululta

Aggregate type	Sululta																	
Date of test	7th day strength																	
Strength level	C15			C25			C30			C40			C50			C60		
UCT result	9.95	11.15	9.95	13.63	16.78	15.30	16.80	16.60	17.15	19.80	28.16	23.76	34.60	29.50	24.58	35.89	32.99	31.35
Average UCT			10.35			15.23			16.85			23.91			29.56			33.41
Average Rebound value	14.45	11.73	15.82	17.36	15.09	14.55	17.09	16.73	18.00	24.00	20.91	23.45	20.55	20.91	19.09	26.55	25.45	24.55

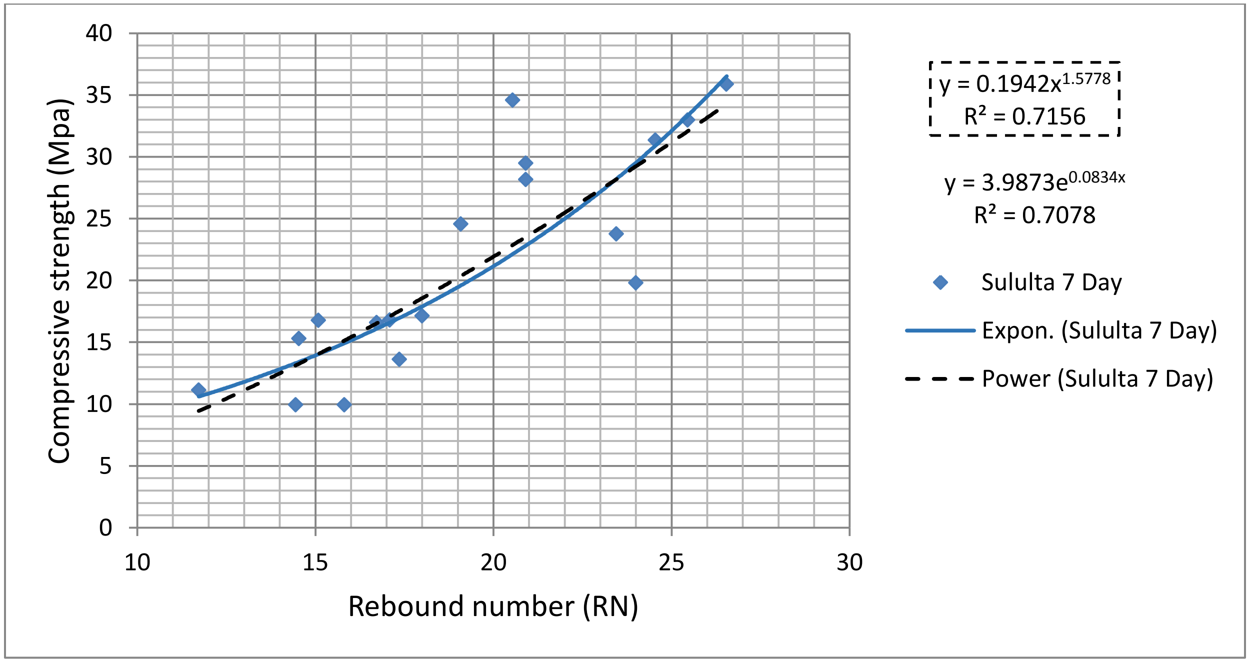


Figure 13: Test result (7 day)

Table 18: 28th day Rebound hammer and UTC test results for aggregates from Bole Lemi

Aggregate type	Bole Lemi																	
Date of test	28th day strength																	
Strength level	C15			C25			C30			C40			C50			C60		
UCT result	13.71	13.68	20.55	27.79	19.82	23.92	32.74	31.03	31.52	34.66	46.99	47.33	46.36	40.03	41.23	56.81	53.64	56.08
			15.98			23.84			31.76			42.99			42.54			55.51
Average Rebound value	14.45	18.18	15.45	20.55	19.27	20.91	19.45	20.55	21.27	28.82	27.36	26.73	28.73	29.09	30.73	32.18	31.64	30.91

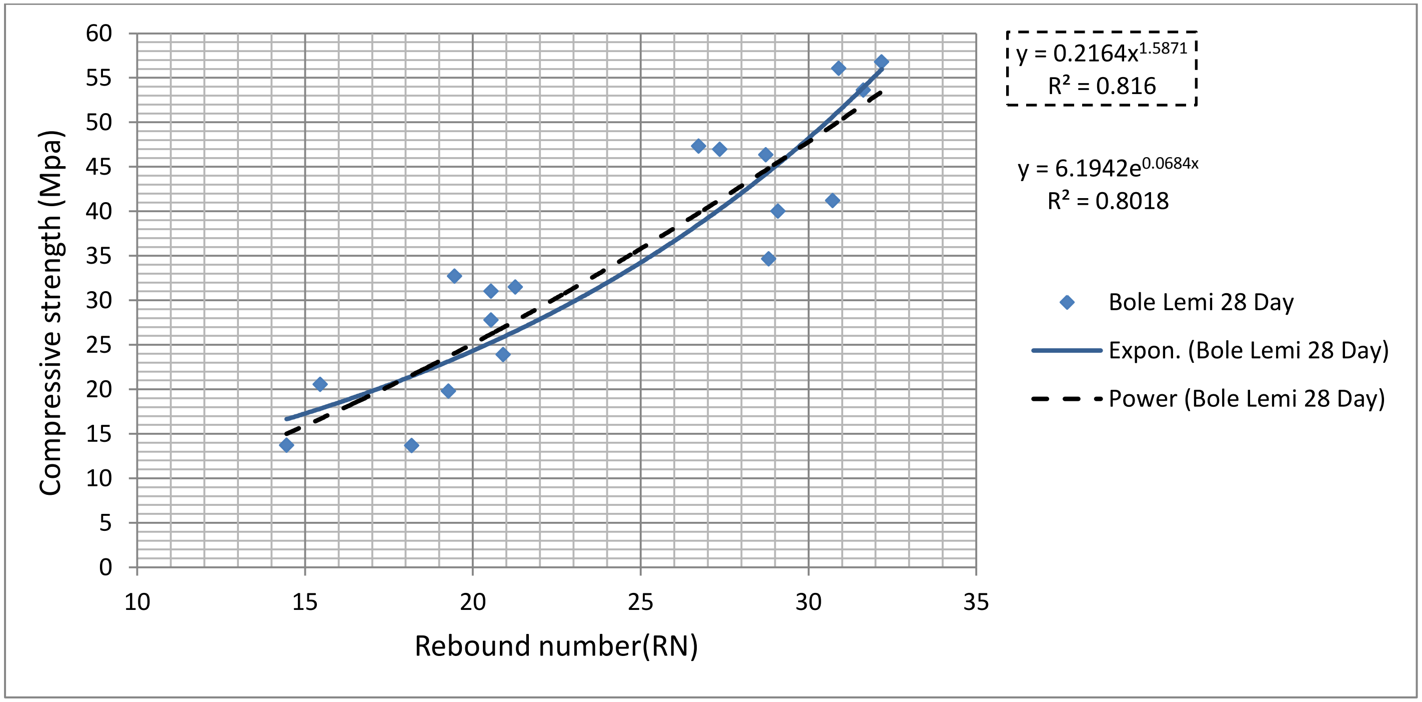


Figure 14: Test result (28 day)

Table 19: 28th day Rebound hammer and UTC test results for aggregates from Sululta

Aggregate type	Sululta																	
Date of test	28th day strength																	
Strength level	C15			C25			C30			C40			C50			C60		
UCT result	15.96	14.96	15.67	24.33	19.43	24.83	27.48	32.34	31.56	44.55	42.70	38.42	52.33	55.60	53.02	51.98	58.68	56.01
			15.53			22.86			30.46			41.89			53.65			55.55
Average Rebound value	15.45	15.45	15.09	20.91	17.09	18.36	18.91	21.36	21.82	24.73	24.36	26.36	28.36	28.09	31.82	31.09	31.55	31.64

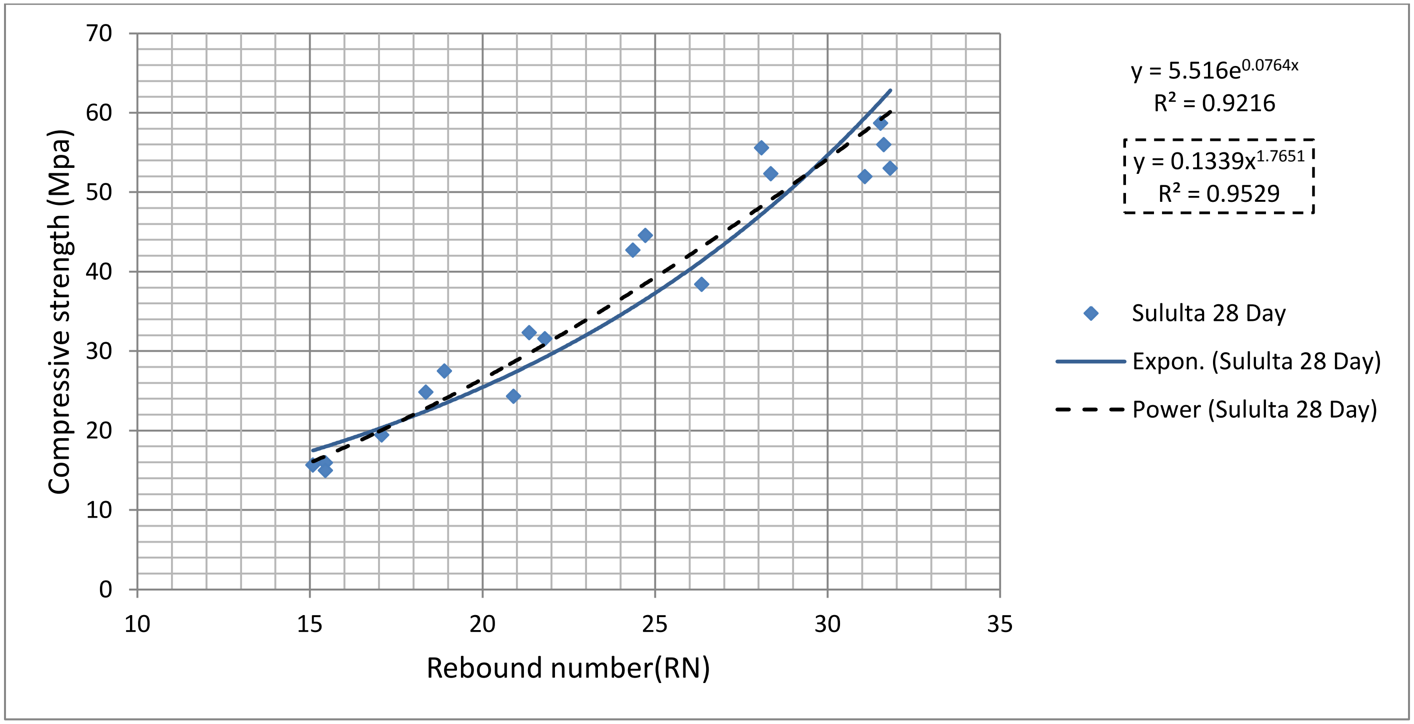


Figure 15: Test result (28 day)

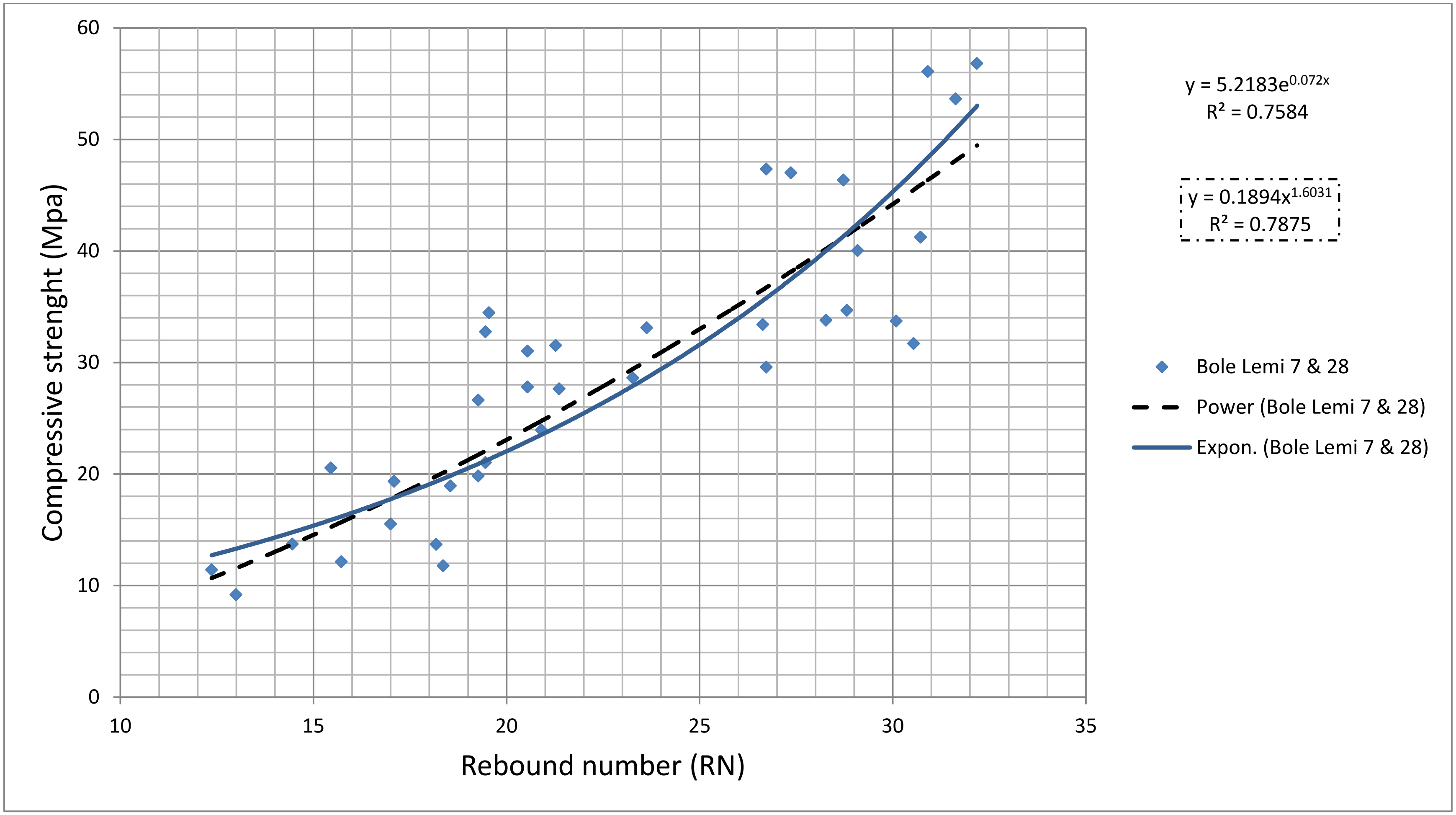


Figure 16: Rebound hammer correlation curve for concrete produced using Bole Lemi aggregate

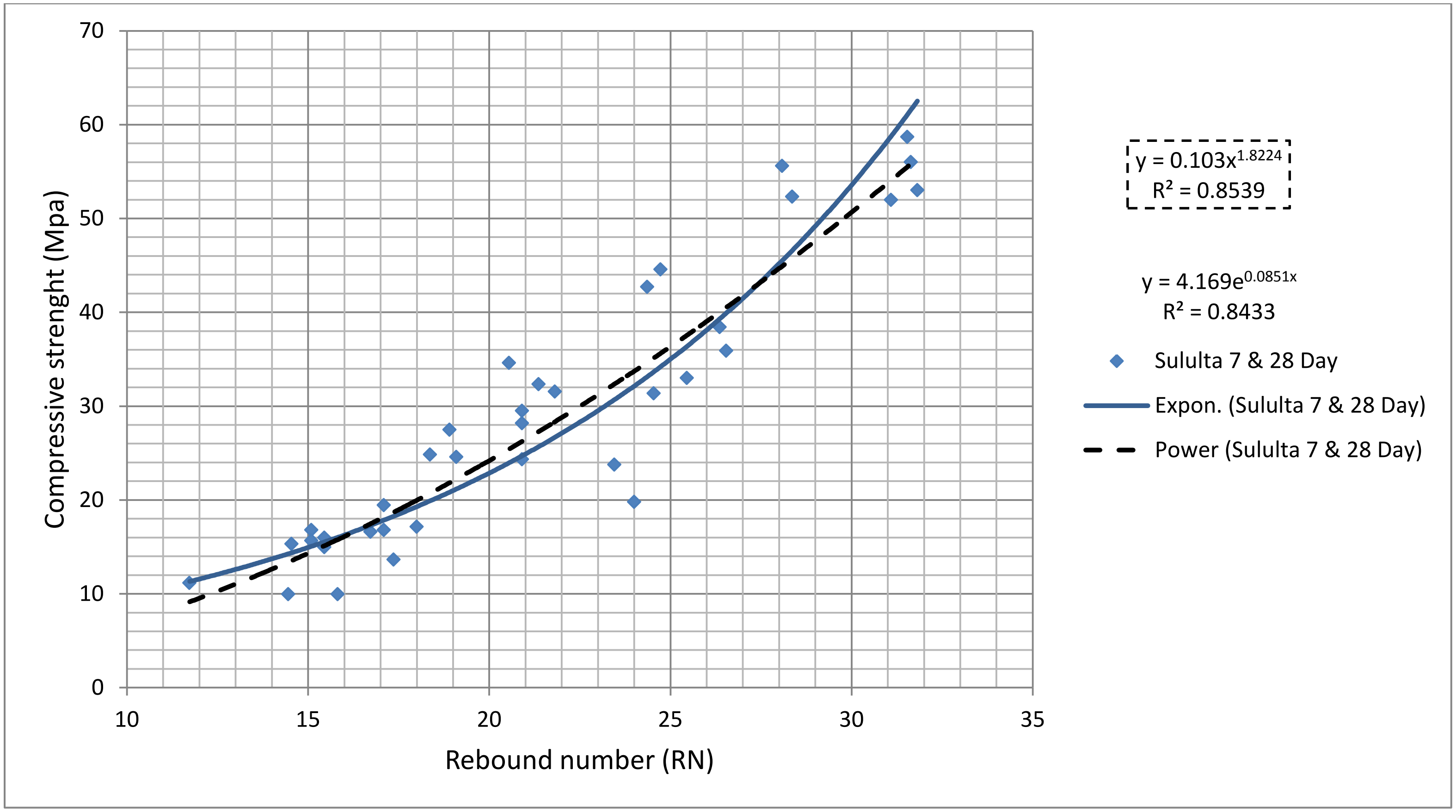


Figure 17: Rebound hammer correlation curve for concrete produced using Sululta aggregate

As it can be seen from the above correlation curves the coefficient of determination which is defined as

“Coefficient of determination (R$^{2)}$

The *coefficient of determination* is a measure of how well the regression line represents the data.

If this percent is less than 100%, then the difference between 100% and the coefficient of determination tells what percent of the variation is determined by something other than the regression line.

If $r^2 = 0.82$, then 82% of the variation is determined by the regression line, and 18% of the variation is determined by some other factor or factors.

The best fit function for the correlation curve is the curve with high R^2 value; R^2 is higher for the power function which is indicated by dotted line in the illustrated graphs, therefore the Rebound hammer correlation curves for concrete produced using aggregates in the Bole Lemi and Sululta area is presented in the following pages.

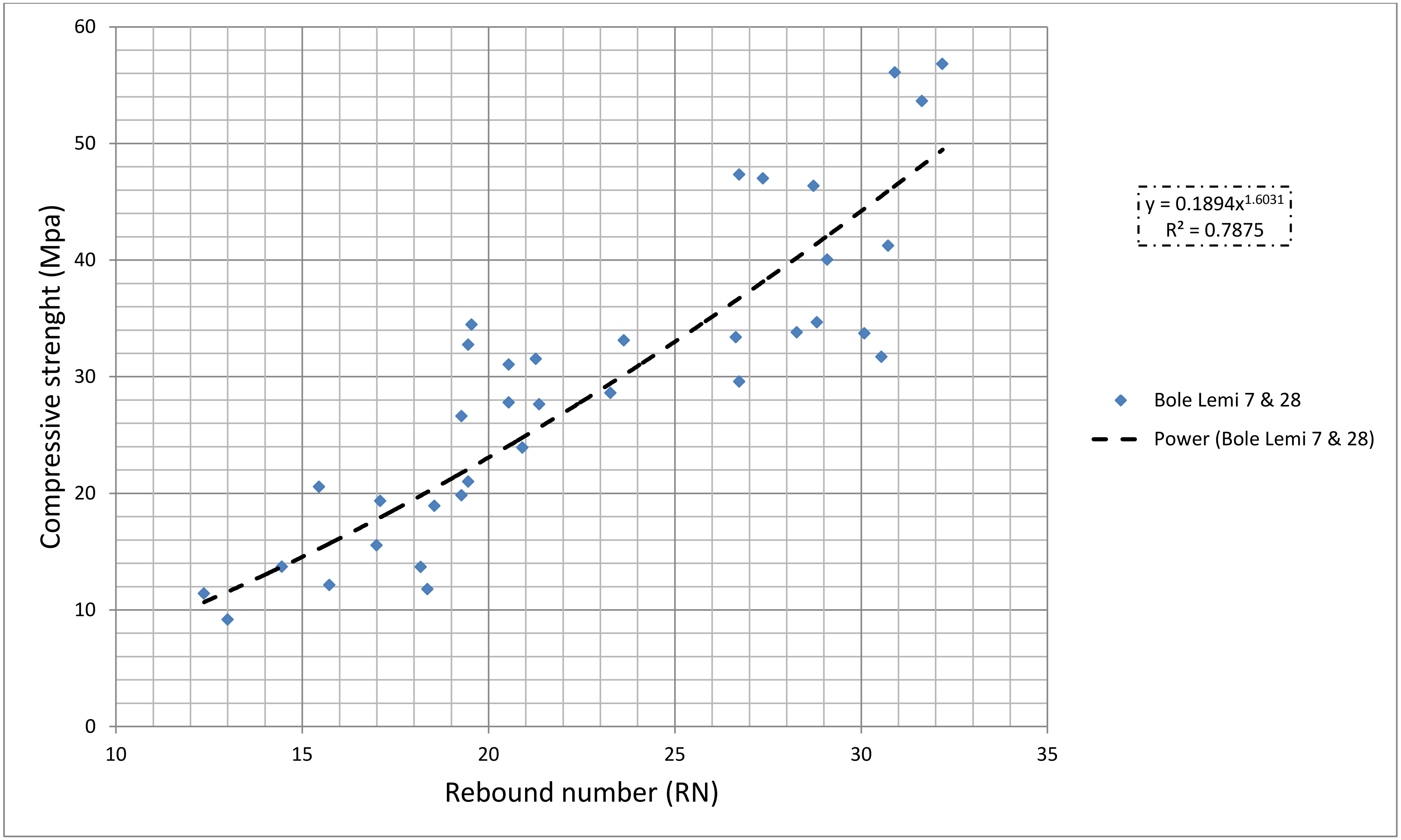


Figure 18: Rebound hammer correlation curves for concrete produced using aggregate found around Bole Lemi area

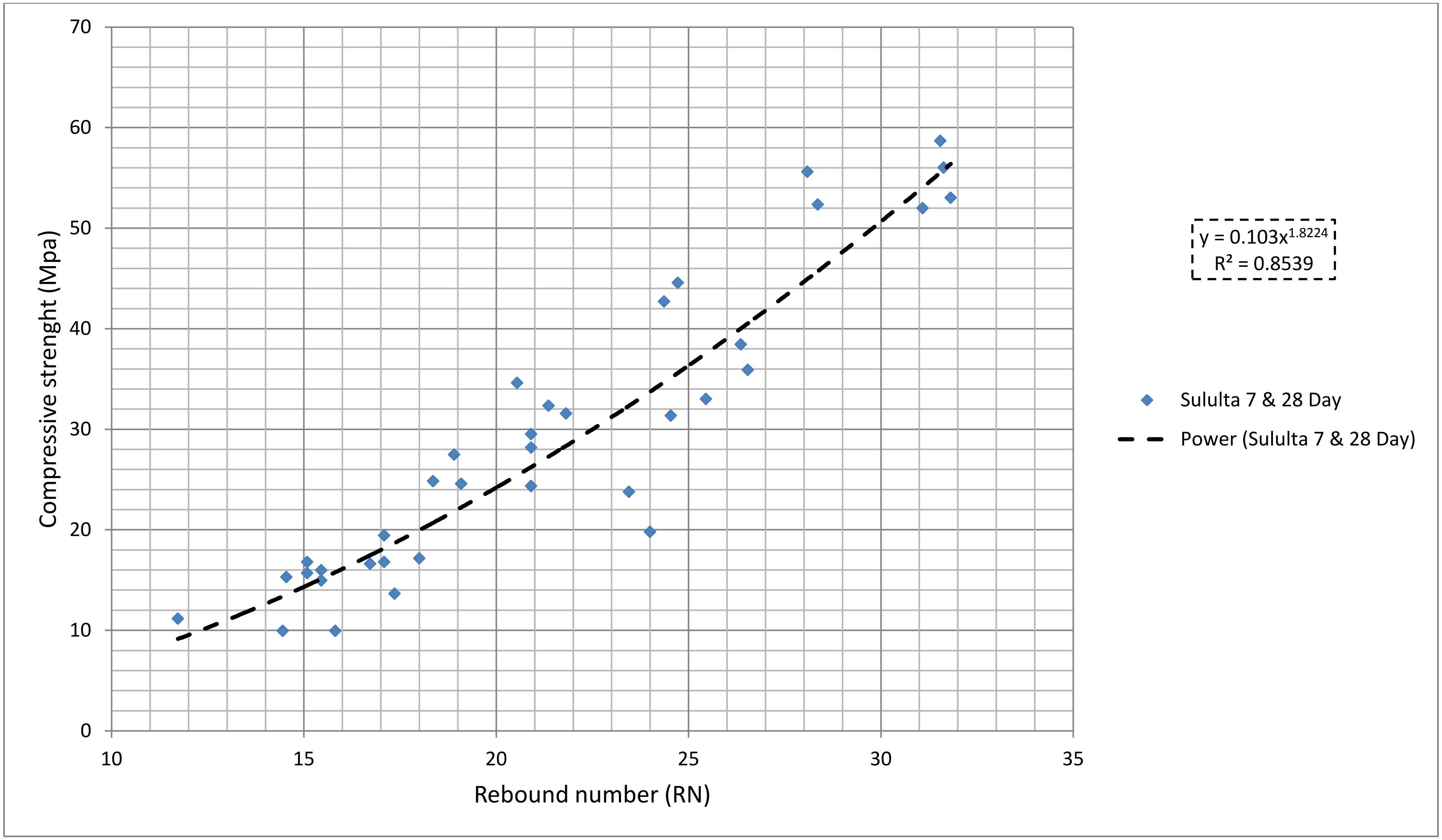


Figure 19: Rebound hammer correlation curves for concrete produced using aggregate found around Sululta area

4.3 Comparison of the Generated Correlation Curves

A comparison between the generated correlation curve and the curve provided along with Schmidt rebound hammer is shown in the following figures.

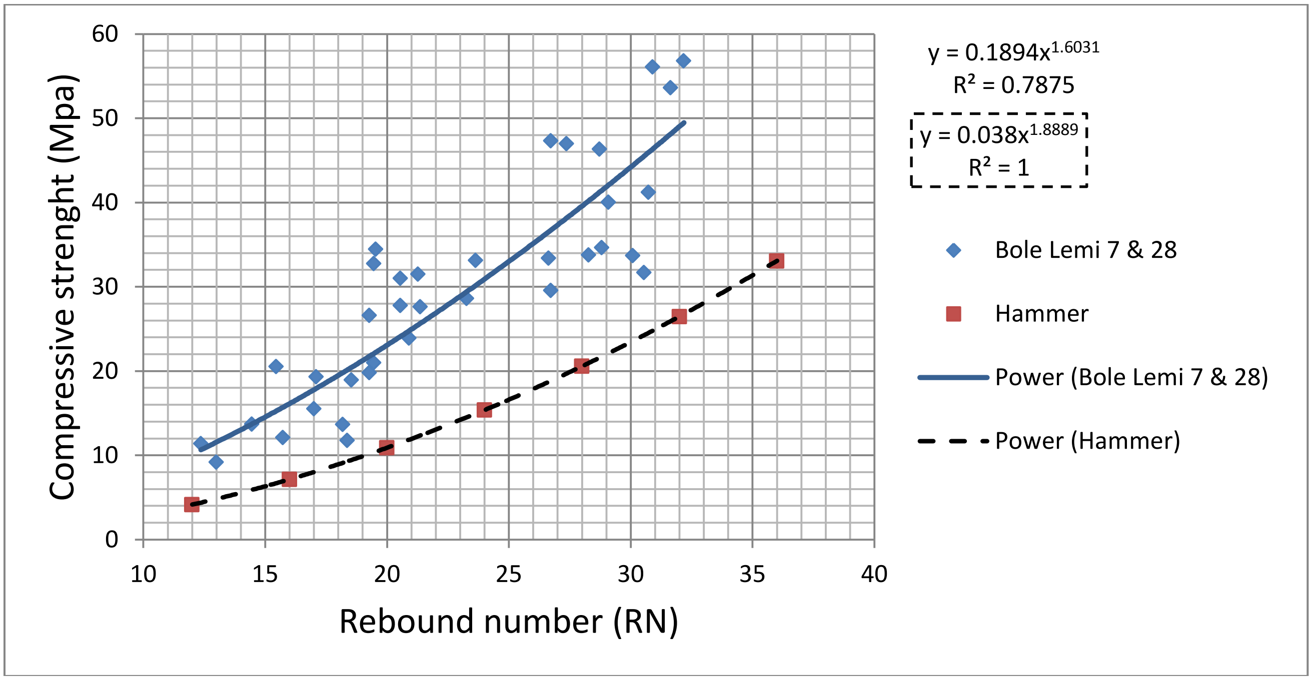


Figure 20: Comparison with the correlation curve provided with the equipment

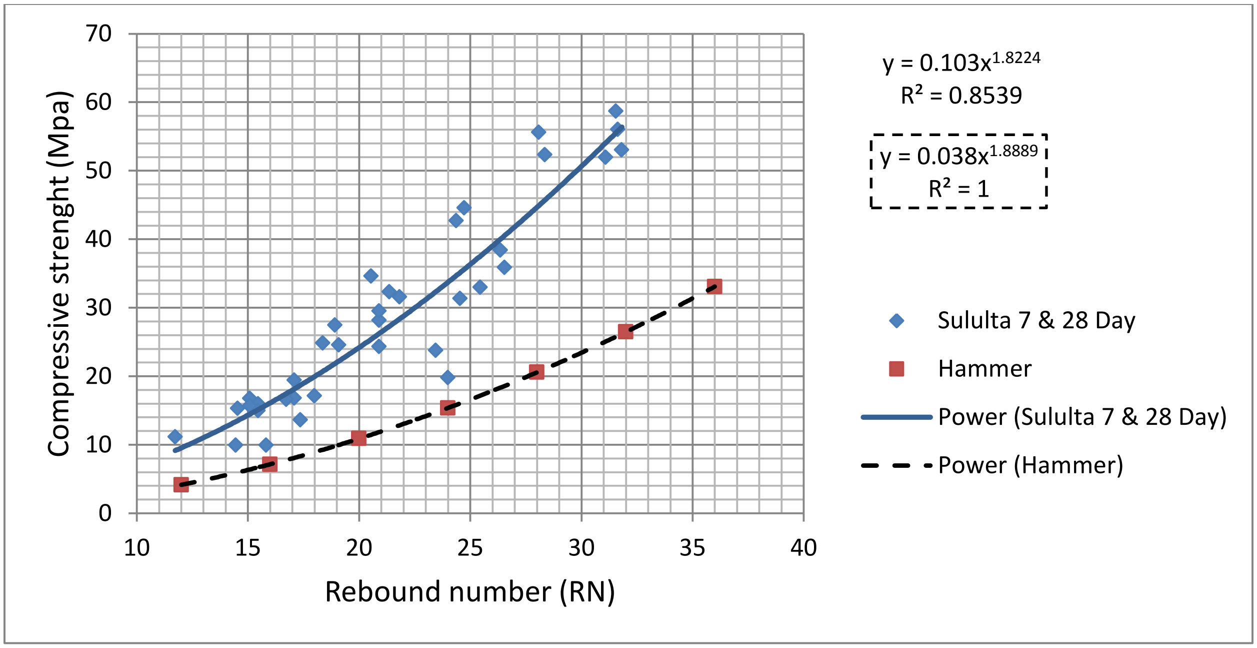


Figure 21: Comparison with the correlation curve provided with the equipment

It is clear that for a given compressive strength, the generated correlation curve provides a lower rebound number.

Correlation curve comparison for normal strength and high strength concrete

Under this section comparison is made between the rebound hammer correlation curve made for normal strength and high strength concrete. As per ACI 318(2002) a concrete having a compressive strength greater than 40 MPa is known as high strength concrete.

Table 20: Compressive strength and Schmidt rebound hammer results

Normal strength class							High strength class					
		Sululta		Bole Lemi					Sululta		Bole Lemi	
7th	class	RN	MPA	RN	MPA		7th	class	RN	MPA	RN	MPA
	C15	14.45	9.95	15.73	12.13			C40	24.00	19.80	23.64	33.12
		11.73	11.15	13.00	9.18				20.91	28.16	23.27	28.61
		15.82	9.95	12.36	11.40				23.45	23.76	21.36	27.63
	C25	17.36	13.63	18.55	18.93			C50	20.55	34.60	19.55	34.46
		15.09	16.78	19.45	21.01				20.91	29.50	26.64	33.39
		14.55	15.30	17.00	15.53				19.09	24.58	28.27	33.79
	C30	17.09	16.80	17.09	19.34			C60	26.55	35.89	30.55	31.69
		16.73	16.60	19.27	26.61				25.45	32.99	30.09	33.71
		18.00	17.15	18.36	11.77				24.55	31.35	26.73	29.57
28th	C15	15.45	15.96	14.45	13.71		28th	C40	24.73	44.55	28.82	34.66
		15.45	14.96	18.18	13.68				24.36	42.70	27.36	46.99
		15.09	15.67	15.45	20.55				26.36	38.42	26.73	47.33
	C25	20.91	24.33	20.55	27.79			C50	28.36	52.33	28.73	46.36
		17.09	19.43	19.27	19.82				28.09	55.60	29.09	40.03
		18.36	24.83	20.91	23.92				31.82	53.02	30.73	41.23
	C30	18.91	27.48	19.45	32.74			C60	31.09	51.98	32.18	56.81
		21.36	32.34	20.55	31.03				31.55	58.68	31.64	53.64
		21.82	31.56	21.27	31.52				31.64	56.01	30.91	56.08

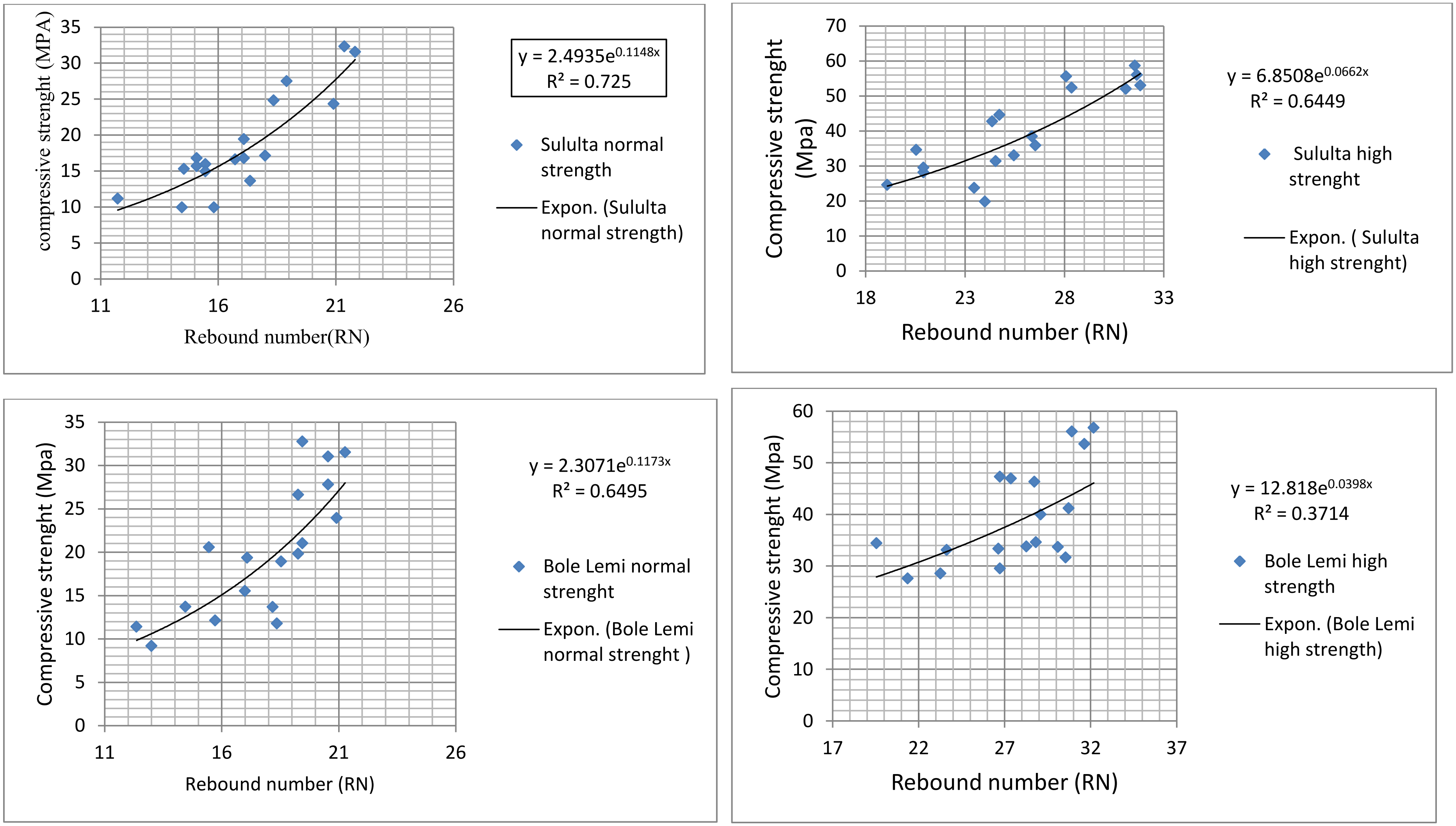


Figure 22: Correlation curve comparison for normal strength and high strength concrete

Based on the above data a correlation curve is produced. Comparing the coefficient of determination (R^2) of the normal and high strength concrete curves it can be seen that the Schmidt rebound hammer correlation curve has a lower coefficient of determination for high strength concrete. This indicated that the rebound hammer test is more effective tool for normal strength concrete class.

Chapter Five

Conclusions and Recommendations

5.1 Conclusions

According to the observed test results

- The correlation between rebound hammer and compressive strength for concrete produced using coarse aggregate located in Bole Lemi area can be expressed by the function $y = 0.1894x^{1.6031}$ with coefficient of determination $R^2 = 0.7875$
- The correlation between rebound hammer and compressive strength for concrete produced using coarse aggregate located in Sululta area can be expressed by the function $y = 0.103x^{1.8224}$ with coefficient of determination $R^2 = 0.8539$
- Compared with the existing correlation curve provided with the equipment, the generated correlation curve for both concrete types shows a correlation curve with lower rebound number for fixed compressive strength.
- As observed from the lab tests the rebound hammer test is influenced by the aggregate type, mix design (w/c ratio) and moisture condition.
- When compared between normal and high strength concrete rebound hammer test is more effective tool for determination of strength in normal strength concrete class.
- It's also observed that, movement of the concrete under test also severely affects the test results for the rebound number.

5.2 Recommendations

- This research paper covers for concrete produced in and around Addis Ababa, for wide use of this testing method in Ethiopia, it is recommended to produce a correlation curve for concrete produced using different materials all over the country.
- As it can be seen from the comparison between the generated correlation curve and the curve provided along with Schmidt rebound hammer the values differs, therefore for accurate use of this test method, it is recommended to produce a curve based on the mix design that is going to be used for the specific work.
- This research covers correlation relationships between compressive strength and the rebound number of concrete cubes casted in the laboratory. For existing structures it is recommended to take a drilled sample and prepare a correlation curve based on the samples & use the curve along with the Schmidt rebound hammer to determine strength at different places in the same structure.

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