CERTIFICATION OF APPROVAL

ANALYSIS ON THE INTEGRITY, SURFACE HARDNESS AND POROSITY OF AUTOCLAVED LIGHTWEIGHT CONCRETE

by

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MOHAMMAD HAFIZ HASSAN

ABSTRACT

Autoclaved lightweight concrete is manufactured from sand, lime and cement to which is added a gas-forming agent. Sand is grounded to a required fineness in a ball mill and stored while cement and lime are stored in silos. Water and aluminium powder (gas-forming agent) are then added to the mixture. After mixing, the cement slurry is poured into a mould for few hours before being transported to cutting machine. The final curing of the product takes up to 12 hours under high steam pressure in an autoclave.

In this project, the surface hardness, integrity and also total porosity of autoclaved lightweight concrete are being analyzed using rebound hammer, Ultrasonic Pulse Velocity (UPV) test and porosity test respectively. There are ranges of autoclaved lightweight concrete blocks varying in thickness of 25mm increment from 50mm to 250mm. However, only blocks coded 62100 are chosen for this project which represents length of 600mm, thickness of 200mm and height of 100mm. The results are compared with conventional 150mm concrete samples of 1:2:4 mix that are water and air cured. All samples are evaluated at 7, 28 and 56 days.

Autoclaved lightweight concrete is much inferior compared to water-cured and air-cured conventional concrete in all the three tests performed. For UPV, the average pulse velocity recorded for autoclaved lightweight concrete is approximately half of the value obtained for normal weight concrete. In terms of surface hardness, the values are much better with up to 70% of that exhibited by conventional concrete. Therefore, although the otal porosities are twice more higher than normal weight concrete, these figures are proved to be less significant to the surface hardness of lightweight concrete but yet affecting much of its integrity.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Lightweight concrete is defined as concrete possessing comparatively lower densities than their counterparts that might just range from 490 to 1800 kg/m^3, depending on the type of lightweight aggregates used and the method of production. The latter includes the use of foaming agents, such as aluminum powder, which produces concrete of low unit weight through the generation of gas while the concrete is still plastic. Natural lightweight aggregates include pumice, scoria, volcanic cinders, tuff, and diatomite. Lightweight aggregate can also be produced by heating clay, shale, slate, diatomaceous shale, perlite, obsidian, and vermiculite.

The decrease in density of lightweight concrete is obtained by the presence of voids, either in the aggregate or in the mortar or in the interstices between the coarse aggregate particles. It is clear that the presence of these voids reduces the strength of lightweight concrete compared to normal weight concrete. Because it contains air-filled voids, lightweight concrete provides good thermal insulation and has a satisfactory durability but is not highly resistant to abrasion. Lightweight concrete is a highly workable, low density material which can incorporate up to 50% entrained air.

Pores can make use of their influence on the properties of concrete in various ways. The strength of concretes, as well as that of any brittle material, decreases rapidly with an increase in porosity. Regarding the strength, it is primarily the total volume of the pores that is important while the porosity is influenced by the volume, size and continuity of the pores. The reasons for the rapidity of strength reduction are not only due to the decrease of solid material, but also the decline number of bonds. The utmost of all is that they, the pores, act as stress concentration, where the sharper the pores, the greater will be the stress concentration. The surface is the most permeable and absorptive part of the concrete matrix as compared to the internal microstructure. As a result, porosity gradient exists where the porosity of near surface is higher than that of internal part of concrete. The durability of the whole concrete can be characterized by simply determining the hardness characteristics of the concrete surface, which is considered as the most critical and vulnerable part towards external fluid ingress.

Compared to normal weight concrete, lightweight concrete can significantly reduces the dead load of structural elements, which makes it attractive especially in multi-storey buildings. The use of lightweight concrete with a lower density permits construction on ground with low load-bearing capacity. With lighter concrete, the formwork need withstand a lower pressure than would be the case with normal weight concrete, and also the total mass of materials to be handled is reduced with a consequent increase in productivity. Lightweight aggregate concrete has been shown by test and by performance to behave structurally in much the same manner as normal weight concrete. For properties which differ, the differences are largely those of degree.

The advantages of lightweight concrete are its reduced mass and improved thermal and sound insulation properties, whilst maintaining adequate strength. The insulation value of the heaviest material (crushed shale and clay concrete) is about four times that of ordinary concrete. Most of the lightweight concretes have better nailing and sawing properties than do the heavier and stronger conventional concretes although they fail to hold in some lighter concretes. But still, in other words, lightweight concrete is highly permeable and penetrable which also indicates low surface properties (permeability, hardness etc). In general, lightweight concrete is more expensive than ordinary concrete and more care and attention need to be given during mixing, handling, and placing.

1.2 PROBLEM STATEMENT

Using lightweight concrete can result in significant benefits in term of load bearing elements of smaller cross-section and a corresponding reduction in the size of foundations. Nevertheless, major concern regarding lightweight concrete is the reduction in strength as a result of increasing porosity. Other properties such as surface hardness and the integrity are much affected too as concrete surface is the weakest and critical compared to internal microstructure. An analysis of these properties is therefore inevitable in order to identify their acceptances. However, there is no specific guideline and standard exclusively devoted to lightweight concrete as the tests performed in the study are actually dedicated to normal weight concrete.

1.3 OBJECTIVES

The objectives of this study are:

- To determine the integrity of autoclaved lightweight concrete
- To determine the surface hardness of autoclaved lightweight concrete
- To determine the total porosity of autoclaved lightweight concrete
- To compare the results with conventional concrete

1.4 SCOPE OF STUDY

The scope of study for this final year project covers Non-destructive Test (NDT) namely UPV test, rebound hammer test and porosity test. Samples consist of autoclaved lightweight concrete blocks (62100) and conventional concrete cubes (150mm) are employed. Rebound hammer and UPV test are used to determine the surface hardness and integrity respectively. Whilst for porosity test, cored samples (60mm thickness, 50mm diameter) for lightweight concrete and conventional concrete are used. Meanwhile for conventional concrete, all samples are fixed to 1:2:4 mix with 0.5 water-cement (w/c) ratio. The concrete cube samples are exposed to water and air cured for 7, 28 and 56 days each.

CHAPTER 2

LITERATURE REVIEW / THEORY

2.1 AUTOCLAVED LIGHTWEIGHT CONCRETE

Such concrete is usually cast in working densities ranging from 495 to 650 kg/m^3. Density control is achieved by adding the aluminium powder into the cement and lime mixture, where it reacts with the alkaline elements in the cement and forms a gas. As a result, the liberated gas expands the mixture forming extremely small, finely dispersed air spaces. Unfortunately, reducing the mixture density is accompanied by a reduction in the performances of autoclaved lightweight concrete although it is possible to select a density to satisfy strength requirements and provide increased insulating value at a reduced density.

Table 2.1: Nominal Properties of Autoclaved Lightweight Concrete

Properties	Value	Units
Length	600	mm
Height	200 or 400	mm
Thickness	50 – 250	mm
Nominal Dry Density	490	kg/m^3
Working Density Range	495 – 650	kg/m^3
Compressive Strength, f_{cu}	2.8	MPa
Minimum Compressive Strength, f_m	2.5	MPa
Modulus of Elasticity, E	1500	MPa
Modulus of Rupture, f_{ut}	0.44	MPa
Ultimate Tensile Strength, f_{ut}	0.44	MPa

2.2 NON-DESTRUCTIVE TEST (NDT)

NDT, as a technology, has seen significant growth and unique innovation over the past 25 years. It is, in fact, considered today to be one of the fastest growing technologies from the standpoint of uniqueness and innovation. Recent equipment improvements and modification, as well as a more thorough understanding of materials and the use of various products and systems, have all contributed to a technology that is very significant and one that has found widespread use and acceptance throughout many industries. This technology touches our lives daily. It has probably done more to enhance safety than any other technology, including that of the medical profession. One can only imagine the significant number of accidents and unplanned outages that would occur if it were not for the effective use of nondestructive testing. It has become an integral part of virtually every process in industry, where product failure can result in accidents or bodily injury. It is depended upon to one extent or another in virtually every major industry that is in existence today.

In industry, nondestructive testing can do so much more such as:

- Examination of raw materials prior to processing
- Evaluation of materials during processing as a means of process control
- Examination of finished products
- Evaluation of products and structures once they have been put into service

There are certain misconceptions and misunderstandings that should be addressed regarding nondestructive testing. One widespread misconception is the use of nondestructive testing will ensure, to a degree that a part will not fail or malfunction. This is not necessarily true. Every nondestructive test method has limitations. A nondestructive test by itself is not a universal remedy. In most cases, a thorough examination will require a minimum of two methods: one for conditions that would exist internally in the part and another method that would be more sensitive to conditions that may exist at the surface of the part. It is essential that the limitations of each method be known prior to use. For example, certain discontinuities may be unfavorably oriented for detection by a specific nondestructive test method. It is true that there are standards and codes that describe the type and size discontinuities that are considered acceptable or rejectable, but if the examination method is capable of disclosing these conditions, the codes and standards are basically meaningless.

Another misconception involves the nature and characteristics of the part or object being examined. It is essential that as much information as possible be known and understood as a prerequisite to establishing test techniques. Important attributes such as the processes that the part has undergone and the intended use of the part, as well as applicable codes and standards, must be thoroughly understood as the prerequisite to performing a nondestructive test. The nature of the discontinuities that are anticipated for the particular test object should also be well known and understood.

2.3 ULTRASONIC PULSE VELOCITY (UPV) TEST

Ultrasonic testing is a versatile NDT method which is applicable to most materials, metallic or non-metallic. By this method, surface and internal discontinuities such as laps, seams, voids, cracks, blow holes, inclusions, lack of bond etc. can be accurately evaluated. Ultrasonic testing utilizes high frequency acoustic waves generated by piezoelectric. The resultant acoustic wavelengths in the test material (depend on the ultrasonic wave velocity) are of the order of one to ten millimetres. A highly directional sound beam is transmitted to the test piece through a suitable couplant, usually grease or oil like material.

Since acoustic waves propagate effectively through most structural materials, but are dissipated or reflected by inhomogeneities or discontinuities, measurement of the transmitted and reflected energies may be related to the integrity, which is the function of the material inhomogeneity and defect parameters. Ultrasonic test method provides quantitative information regarding thickness of the component, depth of an indicated discontinuity, size of the discontinuity etc. Pulses are not transmitted through large air voids in such a way if such void lies directly in the pulse path, the instrument will indicate the time taken by the pulses which evade the void by quickest route. So, it is possible to detect large voids when a grid of pulse velocity measurements is made over a region in which these voids are located.

The quantity measured in the techniques is the travel time of stress pulses passing through the concrete under test. If the path length between transmitter and receiver is known, the velocity of the pulse can be computed. It is in the interpretation of the meaning of this velocity and in its use for determining various properties of concrete that agreement is incomplete. The technique is as applicable to in-place concrete as to laboratory-type specimens, and the results appeared to be unaffected by the size and shape of the concrete tested. This, of course, is a highly desirable attribute and makes the pulse velocity techniques most useful. However, the results obtained by the use of this method should not be considered as means of measuring strength.

2.3.1 Factors Affecting UPV Test

It is necessary to measure pulse velocity to a high degree of accuracy since relatively small changes in pulse velocity usually reflect relatively large changes in the condition of autoclaved lightweight concrete. Pulse velocity in concrete is influenced by:

- Path length
- Lateral dimension of tested specimen
- Moisture content
- Presence of reinforcing bar

Influence of path length is negligible provided it is not less than a minimum of 100mm, in which case the heterogeneous nature of the concrete may become important. Physical limitations of the time-measuring equipment may also introduce errors where short path lengths are involved. BS 188 1: Part 203 recommends minimum path lengths of 100mm and 150mm for concrete with maximum aggregate sizes of 20 and 40 mm respectively. For unmoulded surfaces a minimum length of 150 mm should be adopted for direct or 400 mm for indirect readings.

There is evidence (Malhotra, 1976) that the measured velocity will decrease with increasing path length, and a typical reduction of 5% for a path length increase from approximately 3m to 6m is reported. This is because attenuation of the higher frequency pulse components results in a less clearly defined pulse onset. The characteristics of the measuring equipment are therefore an important factor. If there is any doubt about this, it is recommended that some verification tests are performed, although in most practical situations path length is unlikely to present a serious problem.

Shape of specimen will also be negligible provided its least lateral dimension (dimension measured at right angles to the pulse path) is not less than the wavelength of pulse vibrations. Usually, frequency of 50 kHz corresponds to a least lateral dimension of 80mm. Moisture content can have small but significant influence on pulse velocity measurements since velocity increased with increased moisture content, where the influence being more marked for lower quality concrete. Pulse velocity of saturated concrete may be up to 2% higher than that in dry concrete (of same composition and quality) although this figure might be lower for high-strength concrete.

Velocity of ultrasonic pulses traveling in a solid material depends on the density and elastic properties of that material.Pulse velocity is not affected by frequency of the pulse so that the wavelength of the pulse vibration is inversely proportional to this frequency. The higher the frequency, the narrower the beam of pulse propagation but the greater the attenuation (or damping out) of the pulse vibrations. Frequency suitable for concrete ranges from about 20 kHz to 250 kHz with 50 kHz is appropriate for testing of concrete. These correspond to wavelengths ranging from about 200 mm (for lower frequency) to about 16 mm at higher frequency.

Porosity of concrete has significant effect on the UPV test result. It was observed that the decreased of porosity as the concrete matures increase the accuracy in UPV test result. The reason for this is that the presence of void on the path will increase the path length as it goes around the void. Therefore concrete with higher porosity acts like bigger voids. Porosity is expressed as a fraction of volume of voids to the total volume of concrete. As the concrete strengthened, the percentage of porosity decreased due to hydration process.

Analysis of a wave in an extended substance is possible only theoretically because in practice every substance terminate somewhere, it has a boundary. At the boundary, the propagation of the wave is disturbed. If the material concerned borders on an empty space, no waves can go beyond this boundary because the transmission of such a wave always requires the presence of particles of a material. At such a free boundary the wave will return in one form or another. If another material is behind the boundary and adheres to the first material so that energy can be transmitted, the wave can be propagated in it, although usually in a more or less changed in direction, intensity and mode.

2.3.2 UPV Procedure

Direct transmission arrangement should be the priority since it is the most satisfactory where the longitudinal pulses leaving the transmitter are propagated mainly in the direction normal to the transducer face. As a result, it produces maximum sensitivity and provides well-defined path length. UPV indicates time taken for the earliest part of the pulse to reach the receiving transducer, measured from time it leaves the transmitting transducer, when this transducer are placed at suitable points on the surface of the autoclaved lightweight concrete. In order to assess the quality of materials from ultrasonic pulse velocity measurement, it is necessary for this measurement to be of high order of accuracy. This is done by using an apparatus which generates suitable pulses and accurately measures the time of transit time through the material tested. In addition, path length must be measured to enable velocity to be determined from the path lengths and transit times. Slight advantage of careful measurements is that pulse velocity can be measured to within an accuracy of ±2 % which allows a tolerance in the separate measurements of path length and transit time of only a little more than ±1 %.

If transit time remains constant to within ±1% when transducer are applied and reapplied to the concrete surface, it's good indication that satisfactory coupling has been achieved. Since in this study, pulse velocity measurement are made as integrity or quality check, it is advised to keep concrete wet for as long as possible in order to achieve an enhanced value of pulse velocity. This aspect is generally an advantage since it provides an intensive for good curing practice.

Measurements of pulse velocities at points on a regular grid on the surface of a concrete structure provides a reliable method of assessing the homogeneity of the concrete, where size of grid chosen depend on the size of structure and the amount of variability encountered. It is useful to plot a diagram of pulse velocity contours from the results obtained since this gives a clear picture of the extent of the variations. Path length, on the other hand, can influence the extent of the variations recorded because pulse velocity measurements correspond to the average quality of the concrete along the line of the pulse path and also the size of the concrete sample tested at each measurement is directly related to the path length.

2.3.3 Transducer Arrangement

There are three basic ways in which the transducers may be arranged. They are:

- Opposite faces (direct transmission)
- Adjacent faces (semi-direct transmission)
- Same face (indirect transmission)

Since the maximum pulse energy is transmitted at the right angles to the face of the transmitter, direct method is the most reliable from the point of view of transit time measurement. Also, the path is clearly defined and can be measured accurately, and this approach should be used wherever possible for assessing the concrete quality.

This method can sometimes be used satisfactorily if the angle between the transducers is not too great and if the requirement length is not too large. The sensitivity will be smaller, and if these requirements are not met, it is possible that no clear signal will be received because of attenuation of the transmitted pulse. The path length is also less clearly defined due to the finite transducer size but it is generally regarded as adequate to take this from centre to centre of transducer faces.

The indirect method is definitely the least satisfactory, since the received signal amplitude may be less than 3% of that for a comparable direct transmission. The received signal dependent upon scattering of the pulse by discontinuities and is thus highly subjected to errors. The pulse velocity will be predominantly influenced by the surface zone concrete, which may not be representative of the body and the exact path length is uncertain. A special procedure is necessary to account for this lack of precision of path length, requiring a series of readings with the transmitter fixed and the receiver located at a series of fixed incremental points along a chosen radial line.

2.3.4 Evaluating UPV Result

Table 2.2: UPV Test - Acceptance Criteria (Feldman, 1977)

Pulse velocity (m/s)	**General conditions**
Above 4575	Excellent
3660 – 4574	Good
3050 – 3660	Questionable
2135 – 3050	Poor
Below 2135	Very poor

This is probably the most valuable and reliable application of the method in the field. There are many published reports of the use of ultrasonic pulse velocity surveys to examine the strength variations within members. The statistical analysis of results, coupled with the production of pulse velocity contours for a structural member, may often also yield valuable information concerning variability of both material and construction standards. Readings should be taken on a regular grid over the member. A spacing of 1m may be suitable for large uniform areas, but this should be reduced for small or variable units.

Tomsett (Tomsett, 1980) has suggested that for a single site-made unit constructed from a single load of concrete, a pulse velocity coefficient of variation of 1.5% would represent good construction standards, rising to 2.5% where several loads or a number of small units are involved. A corresponding typical value of 6-9% is also suggested for similar concrete throughout a whole structure. An analysis of this type may therefore be used as a measure of construction quality, and the location of substandard areas can be obtained from the 'contour' plot.

The plotting of pulse velocity readings in histogram form may also prove valuable, since concrete of good quality will provide one clearly defined peak in the distribution. Used in this way, ultrasonic pulse velocity testing could be regarded as a form of control testing, although the majority of practical cases in which this method has been used are related to suspected construction malpractice or deficiency of concrete supply. A survey of an existing structure will reveal and locate such features, which may not otherwise be detected. Although it is preferable to perform such surveys by means of direct readings across opposite faces of the member, Tomsett has reported the successful use of indirect readings for comparison and determination of substandard areas of floor slabs (Tomsett, 1979).

2.4 SURFACE HARDNESS AND STRENGTH

The relation between strength and the total volume of voids is not a unique property of concrete but is found also in other brittle materials in which water leaves behind pores: for instance the strength of plaster is also a direct function of its void content (Schiller, 1958). Strictly speaking, strength of concrete is influenced by the volume of all voids in concrete: entrapped air, capillary pores, gel pores and entrained air, if present (Ward, Neville and Singh, 1969).

In addition to their volume, the shape and size of pores are also factors. The shape of the solid particles and their modulus of elasticity also influence the stress distribution and therefore, stress concentration within the concrete. The effect of porosity on the strength of hydrated cement paste has been studied widely. Care is required in translating observations on laboratory-made specimens of neat cement paste into usable information about concrete, but an understanding of the effect of porosity on strength of hydrated cement paste is valuable. There is no doubt that the porosity defined as the total volume of the overall volume of pores larger than gel pores, expressed as a percentage of the overall volume of the hydrated cement paste, is a primary factor influencing the strength of the cement paste.

2.4.1 Rebound Hammer Test

The increase in the hardness of concrete with age and strength has led to the development of test methods to measure this property. Methods based on the rebound principle consist of measuring the rebound of a spring-driven hammer mass after its impact with concrete surface. Schmidt rebound hammer is principally a surface hardness tester with little apparent theoretical relationship between the strength of concrete and the rebound number of the hammer. In this project, electronic digital reading version of Schmidt Rebound Hammer is used where upon testing, it directly displays the surface hardness without referring to the correlation curves as in conventional rebound hammer. The equipment is most suitable for concrete in the 20-60 N/mm^2 strength range.

Rebound hammer is a test based on the principle that rebound of an elastic mass depends on the hardness of the surface upon which it imposes and in this case will provide information about a surface layer of defined as no more than 30 mm deep, as according to according to BS 1881: Part 202: 1986. Result gives a measure of relative hardness of this zone and cannot be directly related to other properties. Empirical correlation (calibration curve) can be established for each concrete between strengths and data obtained from hardness tests. Error can be greater if properties near tested surface differ significantly from deeper portions which might be due to factors such as moisture, carbonation and damaged surface.

The rebound number is influenced primarily by the elastic characteristics of the surface layer of about 25mm of the concrete (Gaede and Schmidt, 1964). Whereas there are theoretical, although approximate numerical relationships between strengths and elastic properties of certain idealized materials (Nicholls, 1976; Akashi and Amaski 1984), these relationships are not applicable to concrete. The main reason for this is that, say, modulus of elasticity of a concrete is controlled primarily by the modulus of elasticity of the aggregate, but its strength is not. Therefore, such theoretical relationships serve only as a basis for the rule of thumb that concretes with higher modulus of elasticity, that is, with higher rebound number, are expected to be stronger. It has also been notice that dry and/or carbonated concretes give higher rebound numbers than wet and/or noncarbonated concretes of the same compressive strength (Petersen and Stall, 1955). Trowelled surfaces also provide higher rebound numbers than screeded or formed finishes. Nevertheless, within limits, an empirical quantitative correlation can be established for each concrete between strengths and the data obtained by the rebound test (Facaoru, 1976).

The test is sensitive to local variations in the concrete; for instance, the presence of large piece of aggregate immediately underneath the plunger would result in an abnormally high rebound number; conversely, the presence of a void in a similar position would lead to a low result. Moreover, the energy absorbed by the concrete is related both to its strength and its stiffness, so that it is the combination of strength and stiffness that governs the rebound number (ACI 228.1R-89, 1994). Because the stiffness of the concrete is influenced by the type of aggregate used, the rebound number is not uniquely related to the strength of concrete.

The plunger must always be normal to the surface of the concrete under test, but the position of the hammer relative to the vertical will affect the rebound number. This is due to the action of gravity to the travel of the mass in the hammer. Thus, the rebound number of a floor is smaller than that of a soffit of the same concrete, and inclined and vertical surfaces yield intermediate values. For this reason, and also because of other factors, which influence the rebound number, the use of 'global' diagrams relating to the hardness number and strength is inadvisable. The correct procedure is to establish experimentally the relation between the rebound number measured on compression test specimens and their actual strength.

Although there seems to be no advantage in taking more than one reading on a spot, it may be noted that the rebound number generally increases with successive repetitions of the test on the same spot (Keiller, 1982). It is recommended by BS 1881: Part 202 (45) to take 12 readings over an area and not exceeding 300 mm square, with the impact points no less than 20 mm from each other or from an edge. The use of grid to locate these points reduces operator bias (Bungey and Millard, 1966). Note also that the rebound number is influenced by the direction of impact because the gravity force on the hammer is added vectorially to the spring force. Correction factors for different impact directions are provided by the manufactures.

Because of local variability in the hardness of the concrete over a small area, the rebound number should be determine at a number of locations in close proximity but according to ASTM C805-85 not closer than 25 mm apart. British Standard BS 1881: Part 202: 1986 recommends testing on a grid pattern with a spacing of 20 to 50 mm within an area not larger than 300 by 300 mm; this reduces the operator bias.

If cubes are used, readings should be taken on at least two vertical faces of the specimen as cast, and the hammer orientation must be similar to that to be used for the in-place tests. The influence of gravity on the mass will depend on whether it is moving vertically up or down, horizontally or on an inclined plane. The effect on the rebound number will be considerable, although the relative values suggested by the manufacturer are likely to be reliable in this instance because this is purely a function of the equipment.

2.5 POROSITY TEST

Total porosity test is aimed to obtain an indication of the durability of concrete. Since autoclaved lightweight concrete has a lower density than its normal weight counterpart, it may, under certain conditions, absorb and retain water. The consequence of water absorption, as a result of porosity, is much greater than expected. The amount of water absorbed by such concrete varies not only with the density of the material, but also with the quality of the mixture ingredients. Most lightweight concrete is only partly saturated and the initial entrance of water is dominated, at least initially, by capillary absorption rather than water permeability.

The movement of water into and out of concrete is an important factor in their performance. The increase in density is the water absorption and may be expressed as a percentage by volume or a percentage of the initial weight or density. Expressing water absorption as a percentage by volume more accurately reflects the effect of sample size, density and the surface area to volume relationship.

CHAPTER 3

METHODOLOGY

3.1 PROJECT PROGRAM

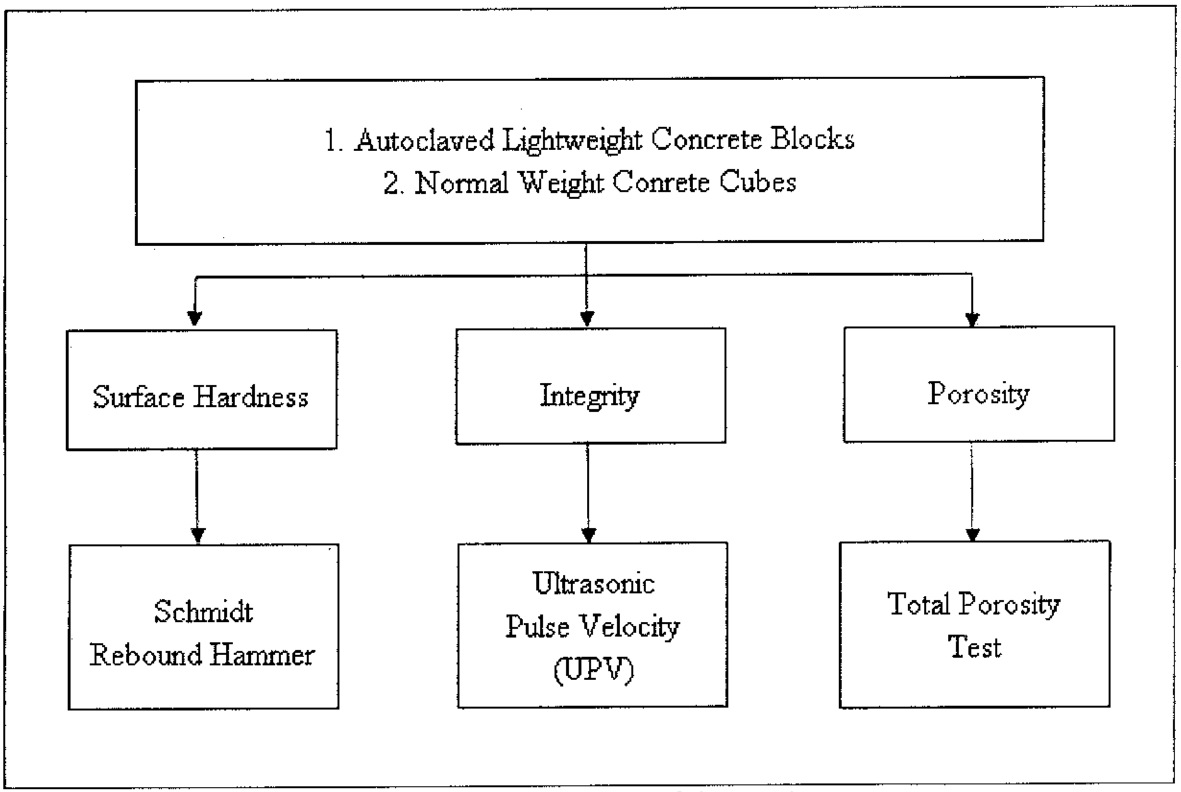


Figure 3.1: General View of the Study

For the purposes of this project, there are three types of tests adopted. First of all is the pulse velocity test that involves the measurement of the velocity of a compressional pulse traveling through the concrete. The second type is the one that is used to estimate surface properties. They are UPV and Schmidt Rebound Hammer respectively. Finally, porosity test is aimed to determine the total porosity of the concrete. All equipments are available in the laboratory and readily to be used at instance. In the other hand, autoclaved lightweight concrete blocks are ordered from the country's sole manufacturer, CSR Building Materials (M) Sdn. Bhd. Meanwhile, concrete test cubes are prepared in the laboratory itself.

3.2 PROJECT TOOLS AND SAMPLES

3.2.1 Basic Tools

Tools and machines involved in running the tests are:

- Ultrasonic Pulse Velocity (UPV) Kit
- Digital Schmidt Rebound Hammer
- Coring Machine
- Vacuum pump
- Desiccator
- Electronic Balance

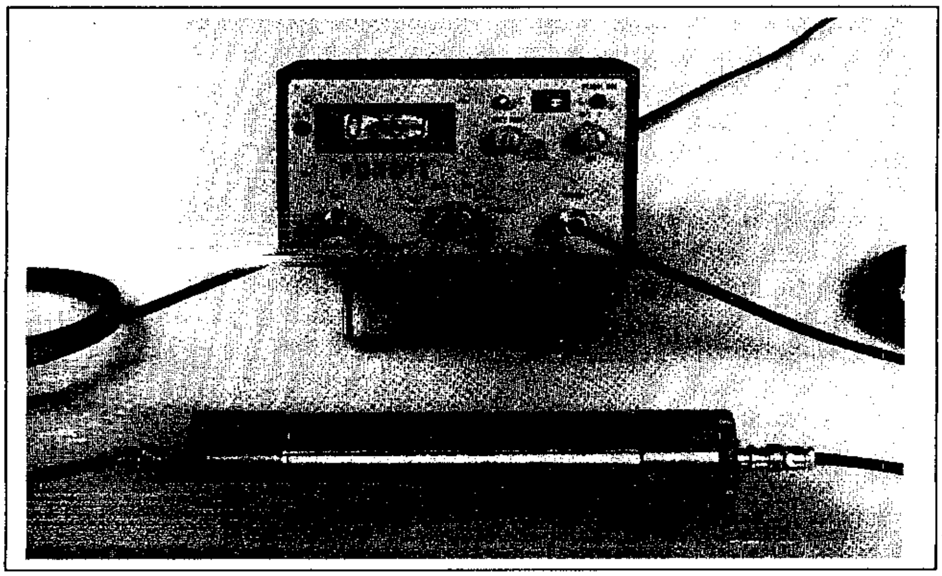
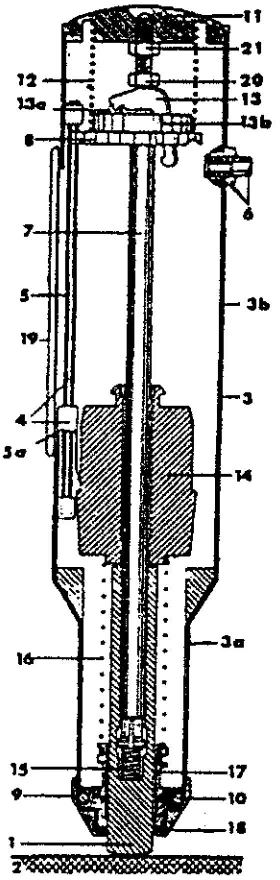


Figure 3.2: Ultrasonic Pulse Velocity (UPV) Kit



No	Name
1	Plunger
2	Concrete Surface
3a	Body Assembly
3b	Body (Lower) Reducer
4	Body (Upper)
5	Indicator Block Assembly
5a	Indicator Block
6	Push Button Assembly
7	Plunger Rod
8	Latch Plate
9	Body Reducer Cap
10	Plunger Bushing Retainer
11	Body End Cap
12	Plunger Return Spring
13	Latch
13a	Latch Spring
13b	Latch Pin
14	Hammer
15	Plunger Springs
16	Hammer Springs
17	Spring Adjuster Collar
18	Felt Washer
19	Indicator Scale Window
20	Adjusting Bolt
21	Adjusting Bolt Nut

Figure 3.3: Schmidt Rebound Hammer

3.2.2 Samples

For autoclaved lightweight concrete blocks, they are 600mm, 200mm and 100mm in length, width and thickness respectively. As for conventional concrete cubes, the dimensions are of equal 150mm and they are water and air cured. The conventional concretes are used for control purpose. The mix proportion is 1:2:4 with water-cement (w/c) ration of 0.5. Two samples from each are used for the use in UPV and rebound hammer test.

In contrast, two cored samples from each of the conventional concrete, water cured concrete cube and air cured concrete cube are used for porosity test. The cores are 50mm in diameter with 60mm thickness.

3.3 PROJECT PROCEDURES

3.3.1 Ultrasonic Pulse Velocity (UPV)

For this test, two blocks of each autoclaved lightweight concrete and concrete test cubes (water and air cured) are prepared. Specimens are kept wet for as long as possible in order to achieve an enhanced value of pulse velocity. The surfaces of the test specimens are ensured to be free from dust or any particles that may interrupt the signal flow between transmitter and transducer. The samples are grounded flat over an area large enough to accommodate transducer face or the area being filled to a level smooth surface with minimum thickness of suitable material.

Prior to testing, the equipment is verified whether it is operating properly and a zero-time adjustment is performed. Coupling agent is applied to the ends of the bar and the transducers are pressed firmly against the ends of the bar until a stable transit time is displayed. The zero reference is adjusted until the displayed transit time agrees with the value marked on the bar in order to avoid entrapped air between the contact surface of the faces of transducers and the surfaces of concrete specimen. The zero adjustment is made by applying coupling agent and the faces of the transducers were pressed together. Microprocessor was used for these instruments to record this delay time which is automatically subtracted from the form subsequent transit time measurements. The length of the shortest direct path from the centre of the faces was measured.

Presently available test equipment limits path lengths to approximately 50 mm minimum and 15 m maximum, depending, partly upon the frequency and intensity of the generated signal. The upper limit depends on surface conditions and characteristics of the interior concrete under investigation. The maximum path length is obtained by using transducers of relatively low vibrational frequencies (10 to 20 kHz) to minimize the attenuation of the signal in the concrete. Meanwhile for shorter path lengths, frequencies of 50 kHz are used to achieve more accurate transit-time measurements and hence greater sensitivity. For autoclaved lightweight concrete, only surface A and C are able to be run with direct transducer arrangement as for surface B, the most appropriate arrangements are semi-direct or indirect method. In order to simplify the study, only direct method is adopted and therefore surface B is put aside. Meanwhile for test cubes, surface A is not included since the condition is not leveled and wavy.

Next is to set suitable pulses and measure the time of their transmission (transit time) through material tested. Distance which the pulses travel in the material (path length) is measured to enable velocity to be determined from the path lengths and transit times. Direct transmission arrangement, or called through-transmission mode is adopted since it's the most satisfactory method. If transit time remains constant to within ±1 % when transducer are applied and reapplied to the concrete surface, it's good indication that satisfactory coupling has been achieved.

3.3.2 Schmidt Rebound Hammer

The instrument is hold firmly so that the plunger is perpendicular to the surface. Gradually, the instrument is pushed towards the test surface until the hammer impacts. If necessary, the button on the side of the instrument is depressed to lock the plunger in its retracted position so that to maintain pressure on the instrument. For autoclaved lightweight concrete, the maximum number of readings depends on the surface area of the faces. For surface A, 12 readings can be obtained while for surface B and C, 4 and 24 readings are managed respectively. In the other hand, due to improper condition of surface A of conventional concrete cubes, they are excluded in the test. No two-impact tests shall be closer together than 25 mm. The impression made on the surface after impact is examined and if the impact crushes ore breaks through a near-surface air void, another reading is taken.

3.3.3 Porosity Test

As similar to UPV and rebound hammer test, the total porosity determination is also conducted for 7, 28 and 56 days. In order to get the core, concrete slabs are done first with required thickness of 60mm.

The cored samples are then placed inside the desiccator for an hour and the vacuum pump is activated to remove all the air/water that trapped inside the concrete voids. After an hour, the desiccator is filled up with water until the entire cored concrete sample contact with water and left for 24 hours (as vacuum pump activated). After a day, the vacuum pump is stopped and the samples are left overnight in the water.

After 24 hours, the samples are removed from the desiccator and water particles at sample surface level are wiped out with dry cloth. The samples are then weight in different ways as follow:

1. W_{sa} – weight of saturated surface dry samples in air
2. W_{sw} – weight of saturated surface dry samples in water

After the sample weighing completed, the samples are put inside the oven with a maintain temperature of 100°C for 24 hours to obtain Wd, weight of oven dry samples. Finally, the total porosity in concrete is obtained from the formula below:

$$P = \frac{W_{sa} - W_d}{W_{sa} - W_{sw}} \times 100$$

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 RESULTS AND FINDINGS

The results for all the tests are presented below according to the ages of the samples; from the 7th day to 56th day accordingly. WCC and ACC indicate water and air cured concrete cubes while ALC represents autoclaved lightweight concrete blocks.

4.1.1 Performance at 7 Days

Ultrasonic Pulse Velocity (UPV)

Table 4.1: UPV Results for Lightweight Concrete Blocks at 7 Days

Sample		ALC 1		ALC 2	
Surface		A	C	A	C
Path Length (mm)		200	100	200	100
Time (μs)	1	102	53	101	55
	2	104	55	103	57
	3	105	53	102	53
	4	102	54	101	55
	5	103	54	101	57
	6	▨	54	▨	53
	7	▨	53	▨	54
	8	▨	52	▨	54
	9	▨	53	▨	56
	10	▨	53	▨	55
	Average	103.2	53.4	101.6	54.9
Velocity (m/s)		1938	1873	1969	1821

Table 4.2: UPV Results for Conventional Concrete Cubes

1:2:4 Mix (Water-cured) at 7 Days

Sample	Surface	Path Length (mm)	Time (μs)					Velocity (m/s)
			1	2	3	4	Average	
WCC 1	B	150	40	38	40	39	39.3	3817
	C	150	39	40	36	37	38.0	3866
WCC 2	B	150	39	38	39	39	39.0	3846
	C	150	38	38	40	39	38.8	3866

Table 4.3: UPV Results for Conventional Concrete Cubes

1:2:4 Mix (Air-cured) at 7 Days

Sample	Surface	Path Length (mm)	Time (μs)					Velocity (m/s)
			1	2	3	4	Average	
ACC 1	B	150	38	39	37	38	38.0	3947
	C	150	38	39	39	39	38.8	3866
ACC 2	B	150	40	42	40	40	40.5	3704
	C	150	39	39	39	39	39.0	3846

Table 4.4: Average UPV Results for 7 Days

Samples	ALC1	ALC2	WCC1	WCC2	ACC1	ACC2
Average (m/s)	1906	1895	3842	3856	3907	3775

Rebound Hammer

Table 4.5: Rebound Hammer Results for Lightweight Concrete at 7 Days

Sample	Surface	Readings				Average (N/mm^2)
ALC 1	A	20.0	20.0	20.0	20.0	21.5
		22.0	22.0	22.0	22.0	
		22.0	26.0	20.0	22.0	
	B	21.0	21.0	21.0	21.0	21.0
	C	20.0	22.0	22.0	20.0	21.0
		22.0	20.0	22.0	20.0	
		20.0	22.0	20.0	22.0	
		20.0	22.0	22.0	20.0	
		22.0	20.0	20.0	22.0	
		20.0	22.0	22.0	20.0	
ALC 2	A	20.0	20.0	24.0	20.0	21.5
		22.0	22.0	22.0	22.0	
		20.0	26.0	20.0	20.0	
	B	20.0	20.0	20.0	20.0	20.0
	C	20.0	20.0	20.0	20.0	21.5
		22.0	22.0	22.0	22.0	
		22.0	26.0	20.0	22.0	
		22.0	20.0	26.0	22.0	
		22.0	22.0	22.0	22.0	
		20.0	20.0	20.0	20.0	

Table 4.6: Rebound Hammer Results for Conventional Concrete Cubes 1:2:4 Mix (Water-cured) at 7 Days

Readings No.	WCC 1				WCC 2			
	B1	B2	C1	C2	B1	B2	C1	C2
1	28	30	24	26	20	22	22	20
2	30	26	28	30	26	24	28	28
3	26	24	26	26	32	22	22	28
4	32	30	24	28	22	26	26	32
5	26	28	24	26	22	28	24	28
6	26	22	24	28	22	24	26	22
7	20	26	20	30	30	20	20	26
8	28	22	22	26	26	22	20	24
9	22	22	24	30	22	28	20	24
Average (N/mm^2)	26.4	25.6	24.0	27.8	24.7	24.0	23.1	25.8

Table 4.7: Rebound Hammer Results for Conventional Concrete Cubes 1:2:4 Mix (Air-cured) at 7 Days

Readings No.	ACC 1				ACC 2			
	B1	B2	C1	C2	B1	B2	C1	C2
1	22	22	22	24	24	26	22	28
2	30	24	28	30	26	34	32	30
3	30	26	32	22	20	30	24	28
4	28	22	28	24	22	28	26	26
5	28	30	32	30	28	32	30	30
6	24	32	28	24	22	30	26	32
7	22	22	22	26	22	30	22	20
8	26	28	28	32	28	32	26	28
9	26	32	24	34	24	30	22	22
Average (N/mm^2)	26.2	26.4	27.1	27.3	24.0	30.2	25.6	27.1

Table 4.8: Average Rebound Hammer Results for 7 Days

Samples	ALC1	ALC2	WCC1	WCC2	ACC1	ACC2
Average (N/mm^2)	21.2	21.0	26.0	24.4	26.8	26.7

Porosity Test

Table 4.9: Porosity Test Results at 7 Days

Sample	Weight (g)			Porosity, P (%)	Average (%)
	Wsa	Wsw	Wd		
ALC 1	59.0	52.8	56.7	37.05	36.30
ALC 2	53.8	47.9	51.7	35.54	
WCC 1	240.0	143.0	230.1	10.21	10.32
WCC 2	261.5	156.0	250.5	10.43	
ACC 1	268.5	161.0	256.7	10.98	11.02
ACC 2	268.5	160.0	256.5	11.06	

4.1.2 Performance at 28 Days

Ultrasonic Pulse Velocity (UPV)

Table 4.10: UPV Results for Lightweight Concrete at 28 Days

Sample		ALC 1		ALC 2	
Surface		A	C	A	C
Path Length (mm)		200	100	200	100
Time (μs)	1	97	51	96	48
	2	97	53	99	50
	3	97	52	98	51
	4	98	53	99	51
	5	96	51	96	51
	6	▨	53	▨	53
	7	▨	54	▨	54
	8	▨	52	▨	52
	9	▨	52	▨	52
	10	▨	53	▨	50
	Avg	97.0	52.4	97.6	51.2
Velocity (m/s)		2062	1908	2049	1953

Table 4.11: UPV Results for Conventional Concrete Cubes

1:2:4 Mix (Water-cured) at 28 Days

Sample	Surface	Path Length (mm)	Time (μs)					Velocity (m/s)
			1	2	3	4	Average	
WCC 1	B	150	42	40	37	38	39.3	3817
	C	150	41	38	38	39	39.0	3846
WCC 2	B	150	40	38	39	39	39.0	3846
	C	150	38	38	40	39	38.8	3866

Table 4.12: Average UPV Results for 28 Days

Samples	ALC1	ALC2	WCC1	WCC2
Average (m/s)	1985	2001	3832	3856

Rebound Hammer

Table 4.13: Rebound Hammer Results for Lightweight Concrete at 28 Days

Sample	Surface	Readings				Average (N/mm^2)
ALC 1	A	18	18	18	20	19.3
		18	20	20	20	
		20	20	20	20	
	B	18	18	18	18	18.0
	C	30	30	30	20	21.3
		20	20	20	20	
		20	20	20	20	
		20	20	20	20	
		20	20	20	20	
		20	20	20	20	
ALC 2	A	18	20	20	20	19.7
		20	20	18	20	
		20	20	20	20	
	B	18	18	18	18	18.0
	C	18	18	18	20	19.3
		20	20	18	20	
		20	20	20	20	
		18	18	20	20	
		20	20	18	18	
		18	20	20	20	

Table 4.14: Rebound Hammer Results for Conventional Concrete Cubes

1:2:4 Mix (Water-cured) at 28 Days

Readings No.	WCC 1				WCC 2			
	B1	B2	C1	C2	B1	B2	C1	C2
1	28	36	22	26	24	26	22	24
2	36	26	26	28	24	26	30	34
3	36	28	30	28	26	26	28	28
4	26	30	26	30	30	28	20	34
5	32	36	24	34	30	26	36	38
6	36	30	30	34	34	34	30	32
7	24	28	26	34	28	20	30	20
8	32	28	24	32	24	24	26	34
9	30	32	22	32	26	30	24	26
Average (N/mm^2)	31.1	30.4	25.6	30.9	27.3	26.7	27.3	30.0

Table 4.15: Average Rebound Hammer Results for 28 Days

Samples	ALC1	ALC2	WCC1	WCC2
Average (N/mm^2)	19.5	19.0	29.5	27.8

Porosity Test

Table 4.16: Porosity Test Results at 28 Days

Sample	Weight (g)			Porosity, P (%)	Average (%)
	Wsa	Wsw	Wd		
ALC 1	59.1	49.8	56.8	24.78	24.61
ALC 2	53.7	45.1	51.6	24.43	
WCC 1	240.0	142.5	231.3	8.92	9.01
WCC 2	261.5	156.0	251.9	9.10	
ACC 1	268.0	160.5	257.5	9.77	10.16
ACC 2	269.0	160.0	257.5	10.55	

4.1.3 Performance at 56 Days

Ultrasonic Pulse Velocity (UPV)

Table 4.17: UPV Results for Lightweight Concrete at 56 Days

Sample		ALC 1		ALC 2	
Surface		A	C	A	C
Path Length (mm)		200	100	200	100
Time (µs)	1	96.5	51.1	101.3	51.0
	2	97.7	51.3	99.8	50.2
	3	96.6	51.4	98.4	49.2
	4	99.4	51.4	99.1	50.4
	5	98.1	51.2	97.6	50.1
	6	▨	52.2	▨	50.8
	7	▨	51.2	▨	51.2
	8	▨	51.0	▨	52.3
	9	▨	53.2	▨	50.4
	10	▨	52.0	▨	51.0
	Avg	97.7	51.6	99.2	50.7
Velocity (m/s)		2047	1938	2016	1972

Table 4.18: UPV Results for Conventional Concrete Cubes

1:2:4 Mix (Water-cured) at 56 Days

Sample	Surface	Path Length (mm)	Time (µs)					Velocity (m/s)
			1	2	3	4	Avg	
WCC 1	B	150	41.4	38.3	36.5	29.4	36.4	4121
	C	150	35.5	36.9	35.7	33.4	35.4	4237
WCC 2	B	150	39.8	54.3	39.8	44.0	44.5	3371
	C	150	47.3	44.1	43.4	39.8	43.7	3432

Table 4.19: Average UPV Results for 56 Days

Samples	ALC1	ALC2	WCC1	WCC2
Average (N/mm^2)	1993	1994	4179	3402

Rebound Hammer

Table 4.20: Rebound Hammer Results for Lightweight Concrete at 56 Days

Sample	Surface	Readings				Avg (N/mm^2)
ALC 1	A	20	20	20	20	20.0
		20	20	20	20	
		20	20	20	20	
	B	18	18	18	18	18.0
	C	18	18	18	18	18.8
		18	18	20	18	
		18	18	20	18	
		20	20	20	20	
		20	20	18	18	
		18	18	20	20	
ALC 2	A	18	18	20	20	19.3
		20	20	18	18	
		20	20	20	20	
	B	18	18	18	18	18.0
	C	20	20	20	20	19.5
		20	20	18	18	
		18	18	20	20	
		18	18	18	20	
		20	20	18	20	
		22	22	20	20	

Table 4.21: Rebound Hammer Results for Conventional Concrete Cubes

1:2:4 Mix (Water-cured) at 56 Days

Readings No.	WCC 1				WCC 2			
	B1	B2	C1	C2	B1	B2	C1	C2
1	30	34	32	26	20	18	24	18
2	36	34	26	34	22	28	30	30
3	30	24	30	32	26	32	28	20
4	26	20	22	30	26	30	22	22
5	36	24	22	32	28	30	32	28
6	38	34	26	34	30	32	30	28
7	22	30	18	30	18	18	18	24
8	28	30	32	28	30	28	22	28
9	30	32	28	26	28	26	26	28
Avg (N/mm^2)	30.7	29.1	26.2	30.2	25.3	26.9	25.8	25.1

Table 4.22: Average Rebound Hammer Results for 56 Days

Samples	ALC1	ALC2	WCC1	WCC2
Average (N/mm^2)	18.9	18.9	29.1	25.8

Porosity Test

Table 4.23: Porosity Test Results at 56 Days

Sample	Weight (g)			Porosity, P (%)	Average (%)
	Wsa	Wsw	Wd		
ALC 1	58.9	52.9	56.6	38.13	37.8
ALC 2	53.5	47.9	51.4	37.44	
WCC 1	240.0	143.0	231.5	8.76	8.8
WCC 2	261.5	155.5	252.1	8.87	
ACC 1	269.0	161.5	257.9	10.33	10.8
ACC 2	270.0	161.5	257.8	11.24	

4.2 DISCUSSIONS AND ANALYSIS

4.2.1 Ultrasonic Pulse Velocity (UPV)

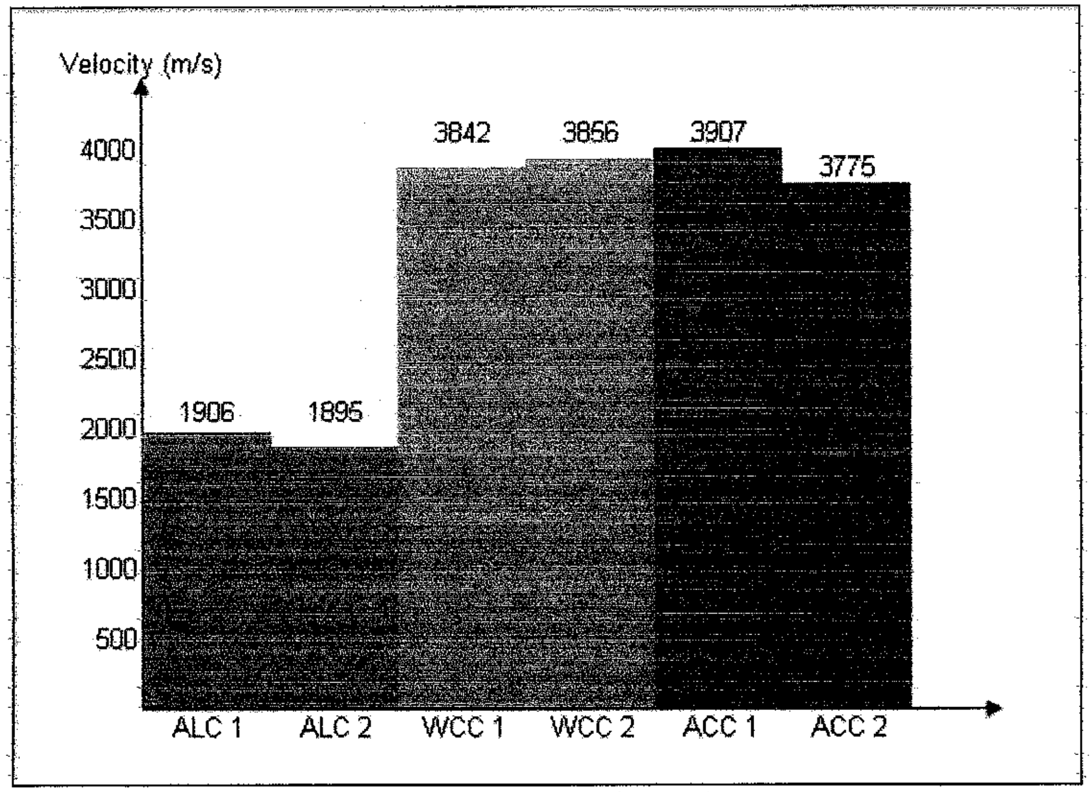


Figure 4.1: UPV Results at 7 Days

At 7 days, the UPV test proved that the autoclaved lightweight concrete largely constituted of air voids that the UPV value decrease to an average of 1900 m/s. In contrast, a more solid and consistent conventional concrete (both water and air cured) exhibit better integrity with recorded velocity of 3849 m/s and 3841 m/s respectively.

The same results are exhibited at 28 and 56 days as the pulse velocities are much higher in normal weight concrete. At 28 days, the velocities recorded are 1993 m/s for autoclaved lightweight concrete while 3844 m/s is recorded in water cured test cubes. Meanwhile, 1993 m/s is recorded for autoclaved lightweight concrete at 56 days and increasing 4179 m/s is obtained for conventional concrete.

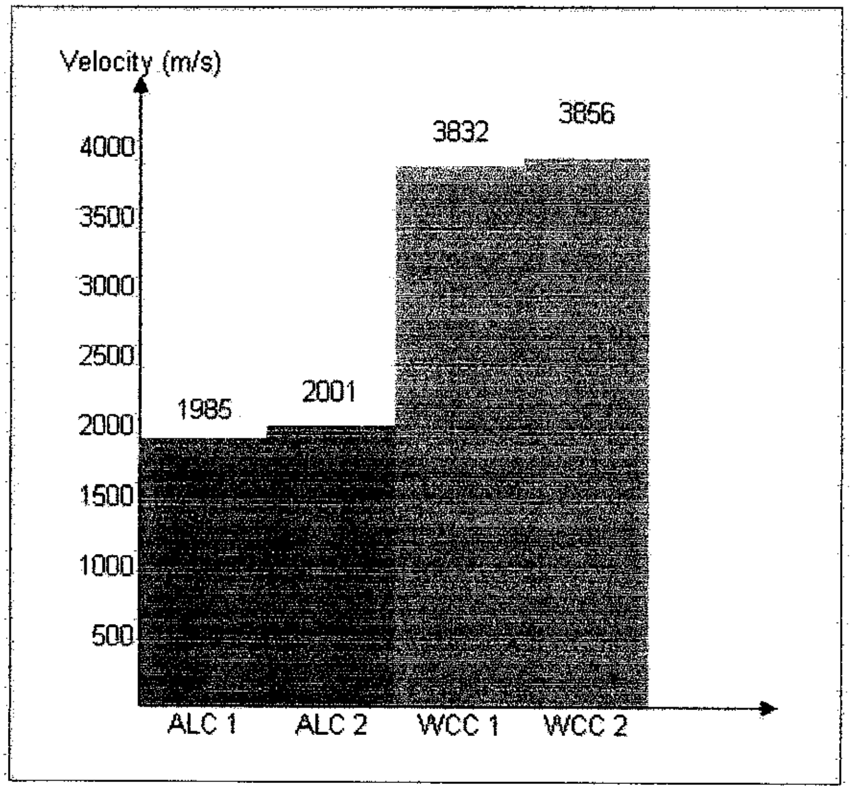


Figure 4.2: UPV Results at 28 Days

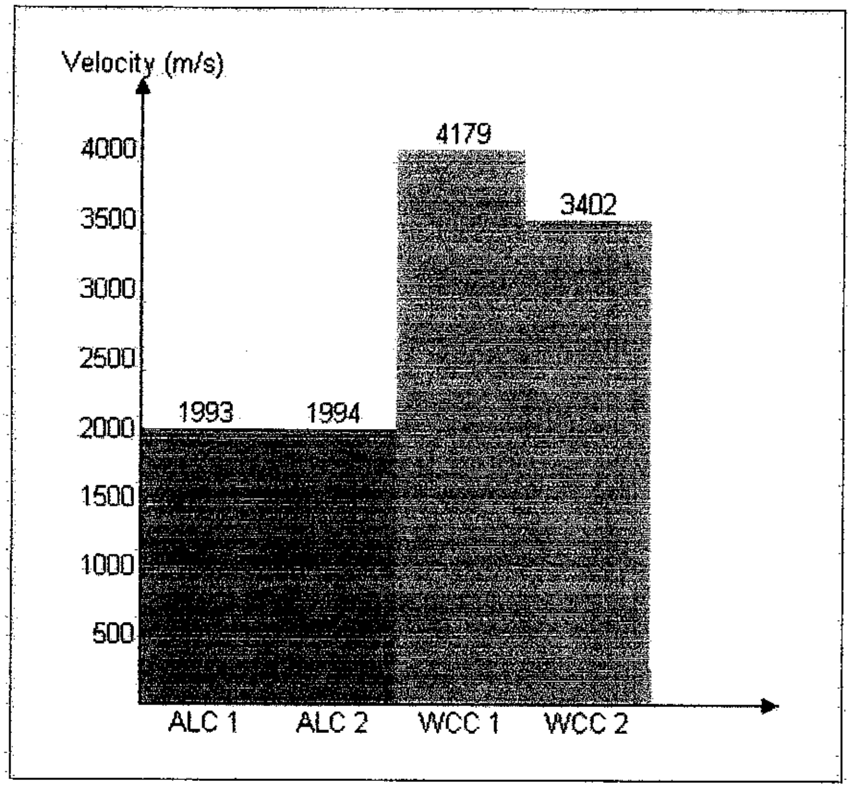


Figure 4.3: UPV Results at 56 Days

Table 4.24: UPV Results of Autoclaved Lightweight Concrete With Respect to Water-cured and Air-cured Conventional Concrete

Age of Sample	Percentage (%)	
	ALC/WCC	ALC/ACC
7 days	$\frac{1900}{3849} \times 100 = 49.36$	$\frac{1900}{3841} \times 100 = 49.47$
28 days	$\frac{1993}{3844} \times 100 = 51.85$	NA
56 days	$\frac{1993}{4179} \times 100 = 47.69$	NA

From Table 4.24, the UPV value for autoclaved lightweight concrete is half of that achieved by normal weight concrete. This is valid for all the 7, 28 and 56 days. This indicates that the time taken for the pulses to reach the receiving transducer (receiver) is longer in lightweight concrete. This is so because the pulses will not be transmitted through air voids as they evade them by the fastest route. However, when there are too many voids, the time taken to reach the receiver is extended.

Based on the acceptance criteria provided in Table 2.2, autoclaved lightweight concrete is categorized as 'Very Poor' since the average pulse velocities recorded is 1962 m/s that is lower than 2135 m/s. In contrast, general condition for normal weight concrete is 'Good' since the value obtain is within the range of 3660 - 4574 m/s.

4.2.2 Rebound Hammer

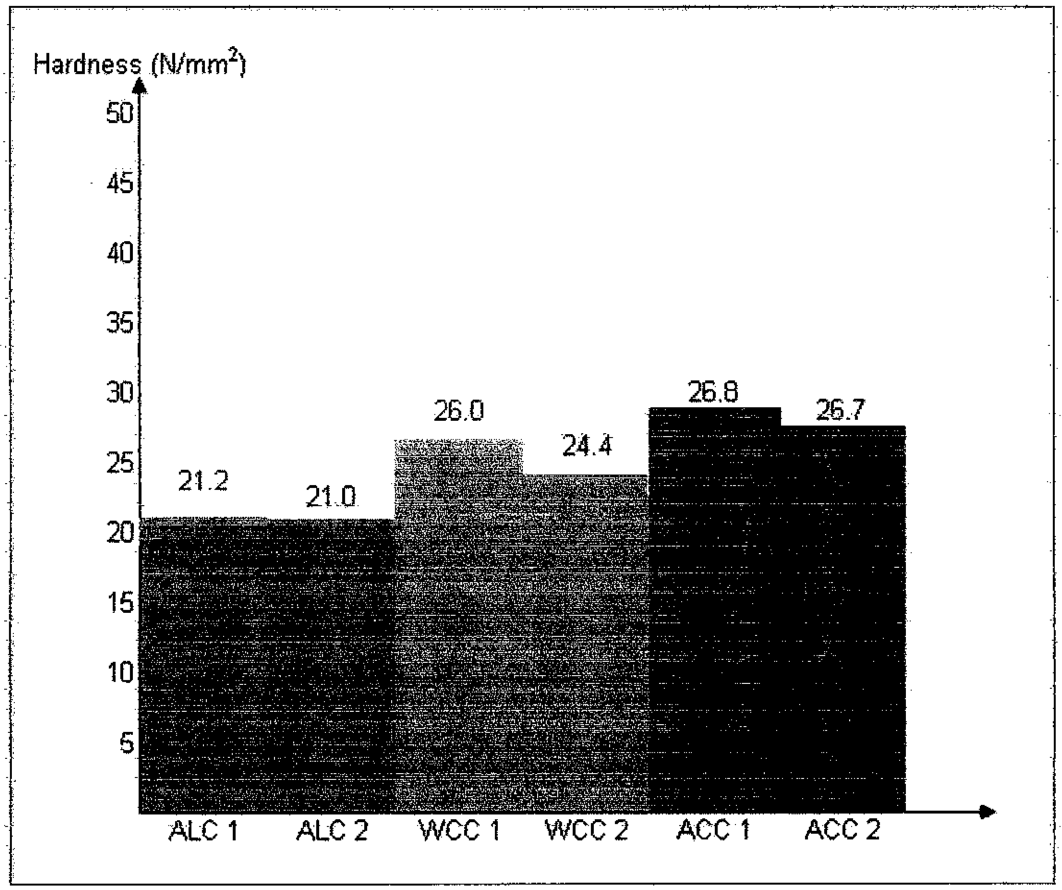


Figure 4.4: Rebound Hammer Results at 7 Days

At 7 days, the rebound hammer test shows that the hardness of autoclaved lightweight concrete is within the same range of that achieved by normal weight concrete test cubes. This is so that the value is 21.1 N/mm^2 as this not differs enough from 25.2 N/mm^2 and 26.7 N/mm^2 recorded by water and air cured samples respectively. However, the results tell us that the surface hardness of porous materials (autoclaved lightweight concrete) are still lower than their counterparts. The same results are exhibited at 28 and 56 days as the surface hardness are much higher in normal weight concrete. At 28 days, the velocities recorded are 19.3 N/mm^2 for autoclaved lightweight concrete while 28.7 N/mm^2 is recorded in water cured test cubes. Meanwhile, 18.9 N/mm^2 is recorded for autoclaved lightweight concrete at 56 days and 27.5 N/mm^2 is obtained for conventional concrete.

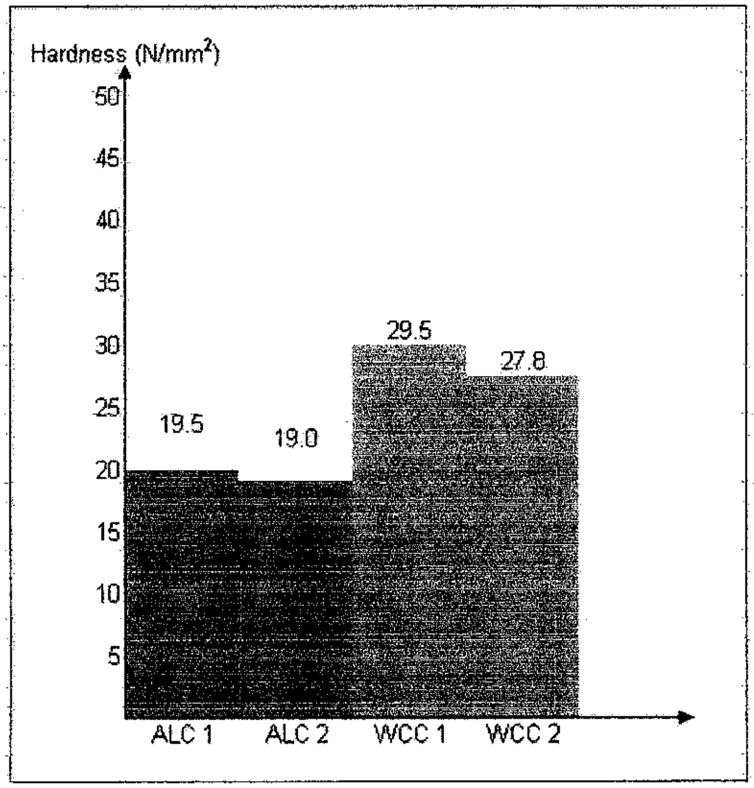


Figure 4.5: Rebound Hammer Results at 28 Days

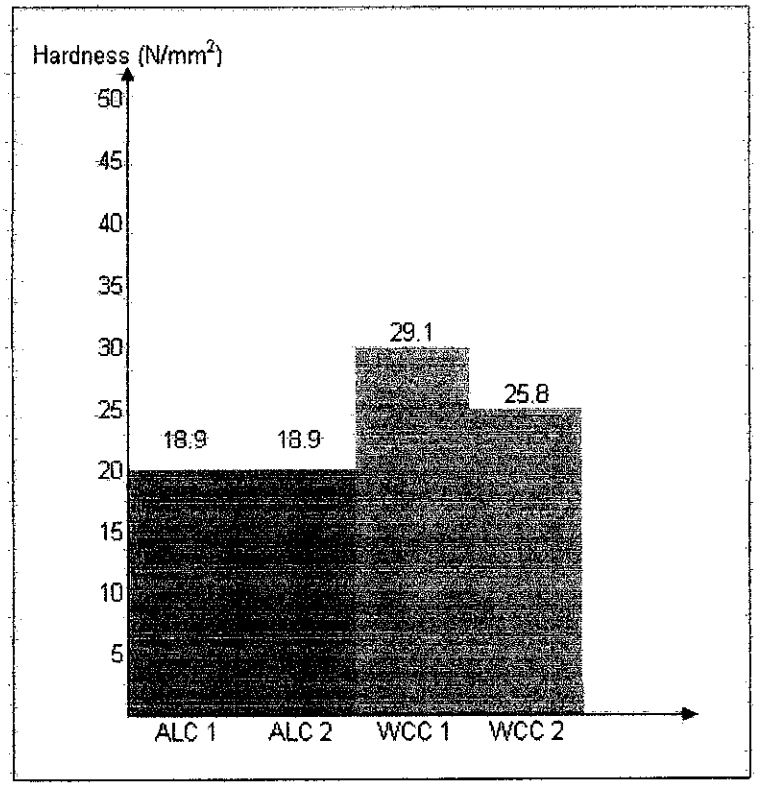


Figure 4.6: Rebound Hammer Results at 56 Days

Table 4.25: Rebound Hammer Results of Autoclaved Lightweight Concrete With Respect to Water-cured and Air-cured Conventional Concrete

Age of Sample	Percentage (%)	
	ALC/WCC	ALC/ACC
7 days	$\frac{21.1}{25.2}$ x 100 = 83.73	$\frac{21.1}{26.7}$ x 100 = 79.03
28 days	$\frac{19.3}{28.7}$ x 100 = 67.25	NA
56 days	$\frac{18.9}{27.5}$ x 100 = 68.73	NA

With respect to UPV test results, surface hardness is far much better in autoclaved lightweight concrete that the values are nearly 70% of that achieved by normal weight concrete. This is valid for the 28 and 56 days, but the percentage obtained on the 7th day might due to errors while operating the test.

The values obtained for surface hardness are mainly determined by the modulus of elasticity, as for autoclaved lightweight concrete is 1500 N/mm^2. This low figure corresponds to the surface hardness for 7, 28 and 56 days. Other factor affecting the surface hardness is the product mass itself.

4.2.3 Porosity Test

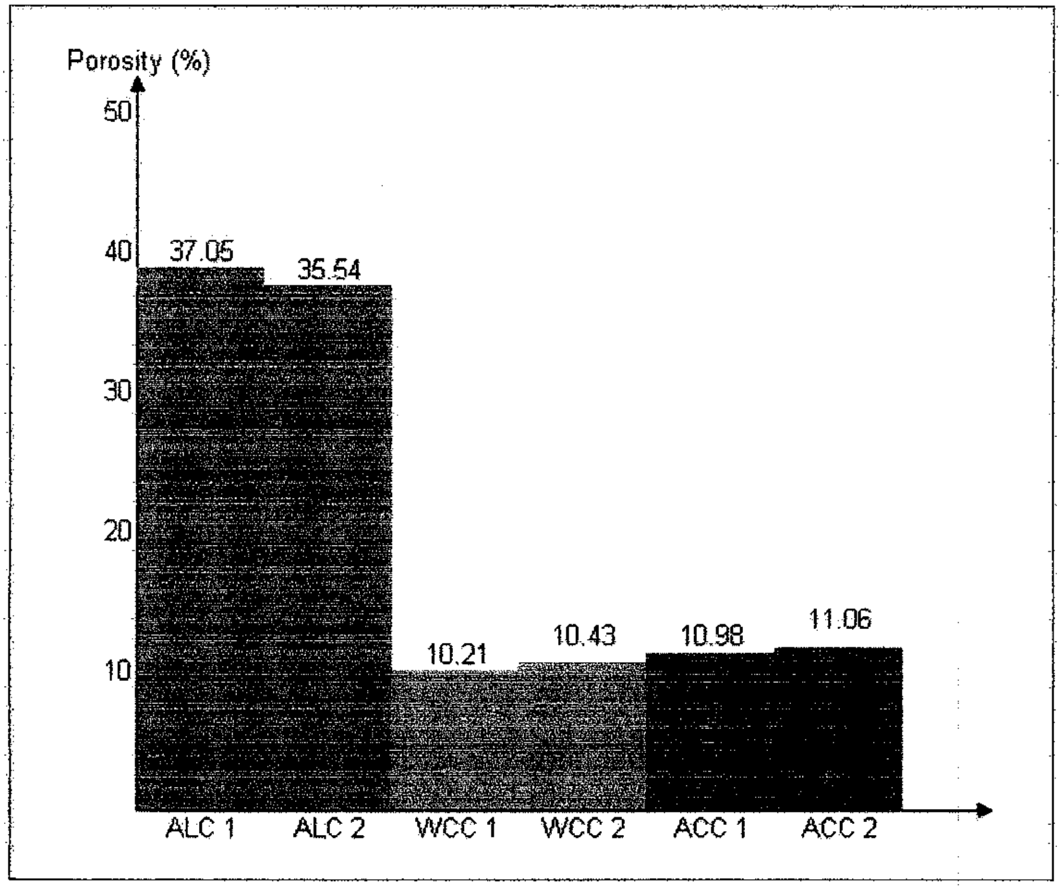


Figure 4.7: Porosity Test Results at 7 Days

At 7 days, the porosity test proved that the autoclaved lightweight concrete cores are totally very porous as the porosity mounted up to an average of 76.3%. In contrast, conventional concrete cores (both water and air cured) exhibit better microstructure with less porosity of 10% and 11% recorded for each water and air cured respectively. The same scenario can be seen on the 28th day as the porosity for lightweight concrete cores is 65% compared to 9% and 10% of that achieved by their normal weight counterparts. Finally, at 56 days, the porosity is maintained above 70% for autoclaved lightweight concrete cores. Meanwhile, the porosities for normal weight concrete cores are 9% and 11% for water and air cured samples respectively.

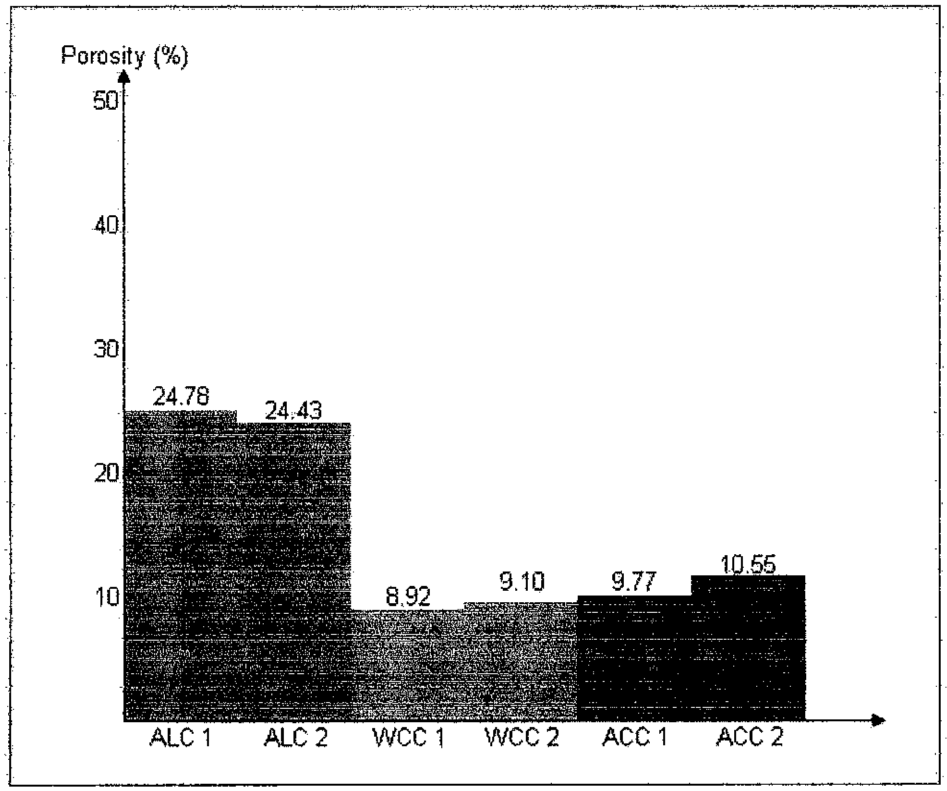


Figure 4.8: Porosity Test Results at 28 Days

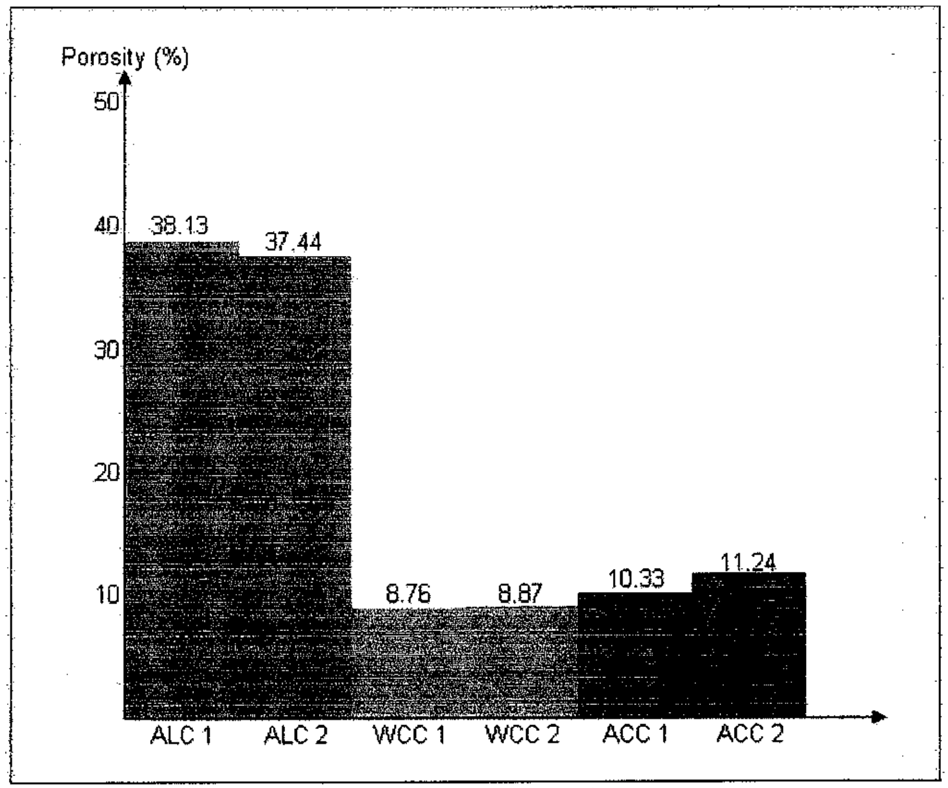


Figure 4.9: Porosity Test Results at 56 Days

Table 4.26: Porosity Test Results of Autoclaved Lightweight Concrete With Respect to Water-cured and Air-cured Conventional Concrete

Age of Sample	Percentage (%)	
	ALC/WCC	ALC/ACC
7 days	$\frac{36.30}{10.32} \times 100 = 351.74$	$\frac{36.30}{11.02} \times 100 = 329.40$
28 days	$\frac{24.61}{9.01} \times 100 = 273.14$	$\frac{24.61}{10.16} \times 100 = 242.22$
56 days	$\frac{37.80}{8.80} \times 100 = 429.55$	$\frac{37.80}{10.80} \times 100 = 350.00$

Apparently, the porosity of autoclaved lightweight concrete is far much higher compared to those obtained by normal weight concrete. The value is up to 4 times higher. The value is however depends a lot on other properties such as absorption rate and permeability too. The samples are also not known whether they are fully saturated or not during the weighing to obtain W_{sa} and W_{sw}. Need to be stressed here that in this study, these properties are not considered in order for simplification.

The porosity values above are not really affecting the surface hardness they still almost 70% of that achieved by normal weight concrete. In other words, 400% increment in porosity will only reduce the surface hardness properties to 70%. However, in terms of integrity, the lightweight concrete is categorized as very poor due to increasing the porosity.

CHAPTER 5

CONCLUSIONS

Autoclaved lightweight concrete is much inferior compared to water-cured and air-cured conventional concrete in all the three tests performed. The integrity of autoclaved lightweight concrete is poor according to the Ultrasonic Pulse Velocity (UPV) acceptance table by Feldman (1977). It is 1962 m/s compared to normal weight concrete of 3847 m/s. Meanwhile, rebound hammer test yielded acceptable surface hardness value of 19.8 N/mm^2 for autoclaved lightweight concrete as normal weight concrete recorded 27.1 N/mm^2. Finally, the total porosity for lightweight concrete is 37.1% compared to 9.4% of conventional concrete.

For UPV, the average pulse velocity recorded for autoclaved lightweight concrete is approximately half of the value obtained for normal weight concrete. In terms of surface hardness, the values are much better with up to 70% of that exhibited by conventional concrete. Therefore, although the total porosity is obviously higher than normal weight concrete, these tremendous values are proved to be less significant to the surface hardness of lightweight concrete but yet affecting much of its integrity.

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APPENDICES

Appendix A – Ultrasonic Pulse Velocity

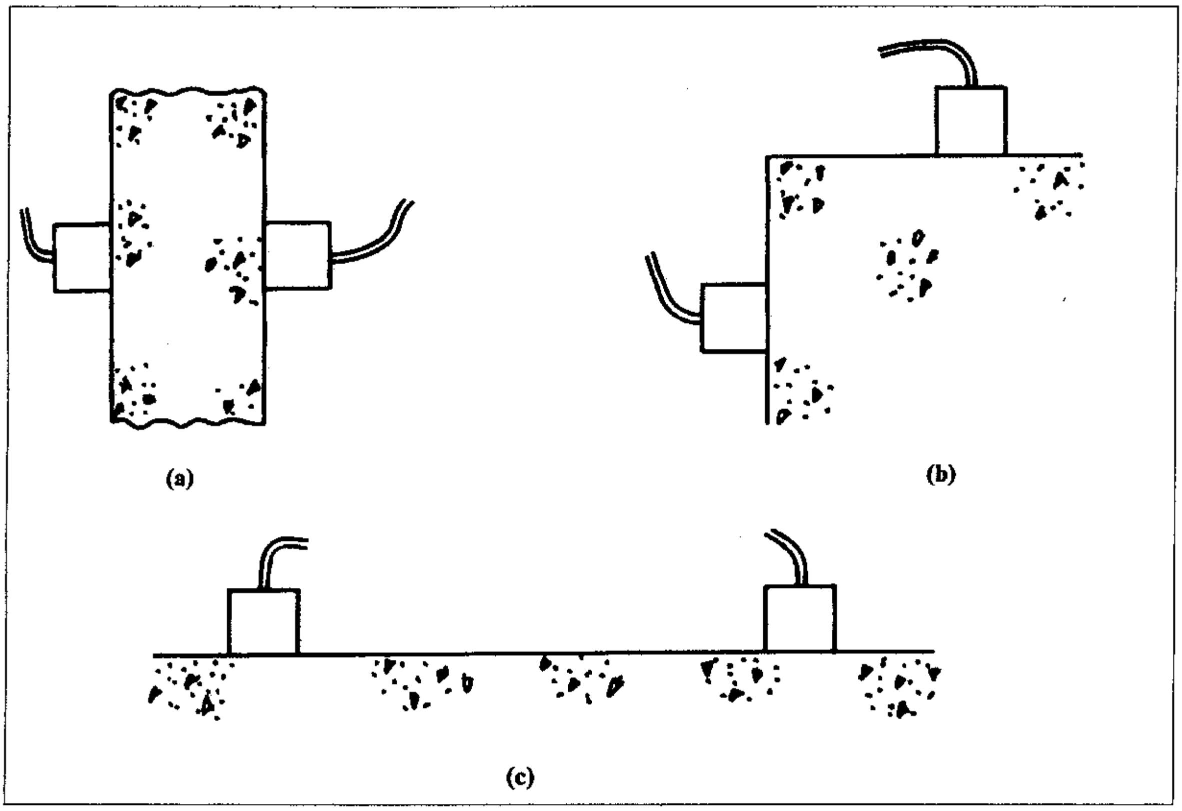

Figure A1: Types of Arrangement (a) Direct, (b) Semi-direct, (c) Indirect (Bungey and Milliard, 1996)

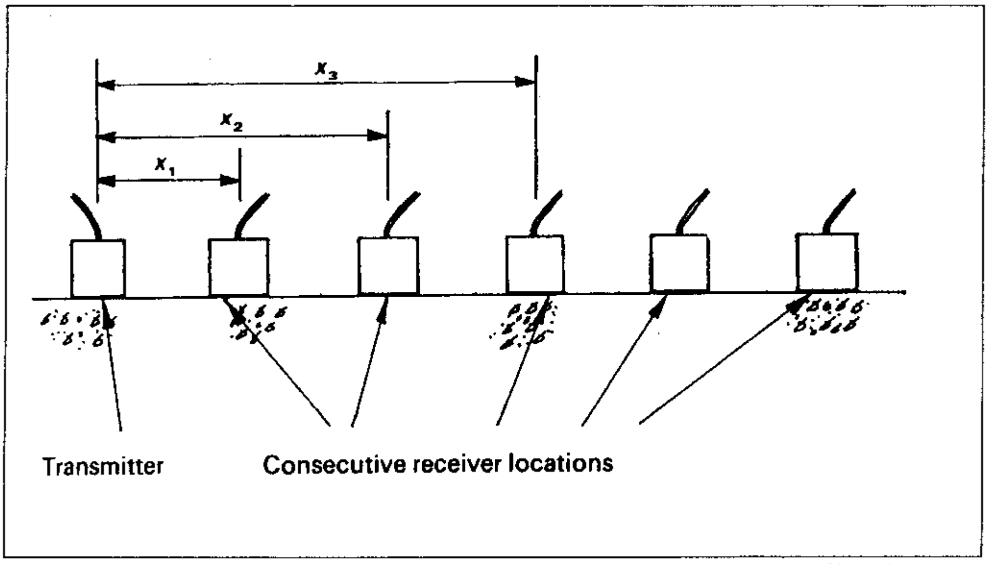

Figure A2: Indirect Transducer Arrangements (Bungey and Milliard, 1996)

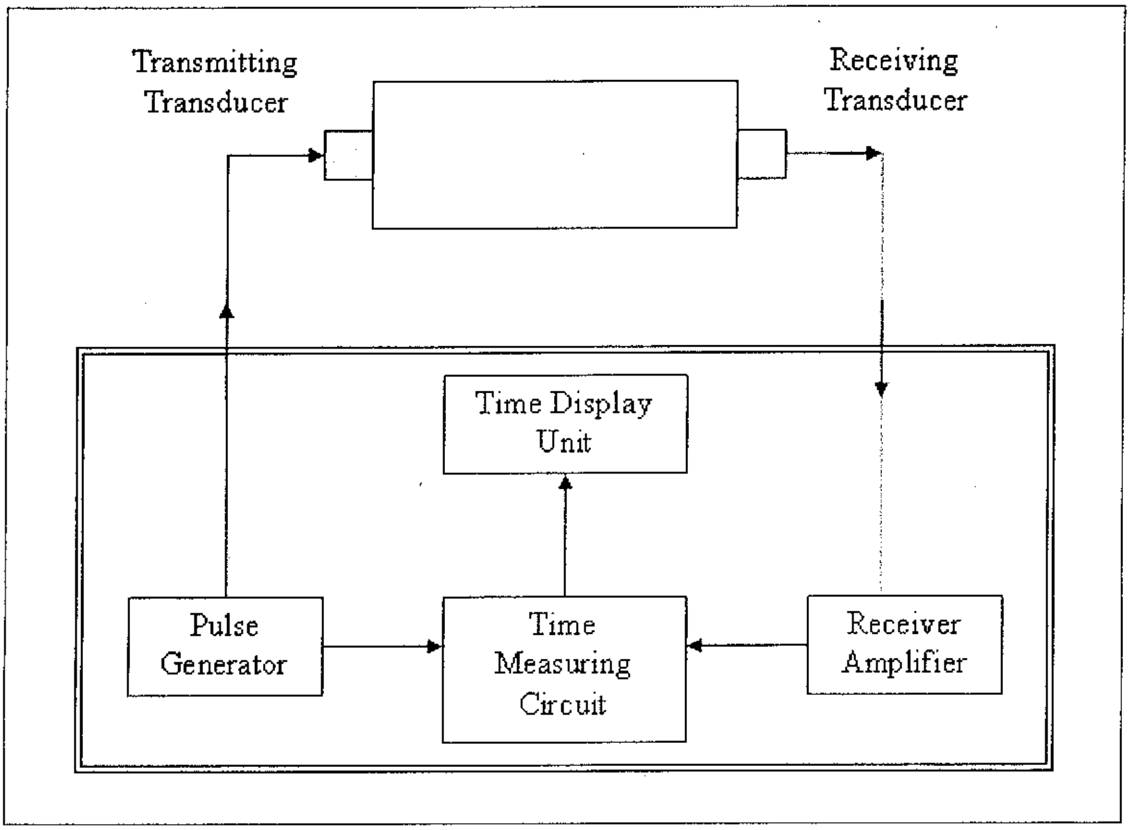

Figure A3: Schematic Diagram of Pulse Velocity Testing Circuit

Appendix B – Manufacturing of Autoclaved Lightweight Concrete

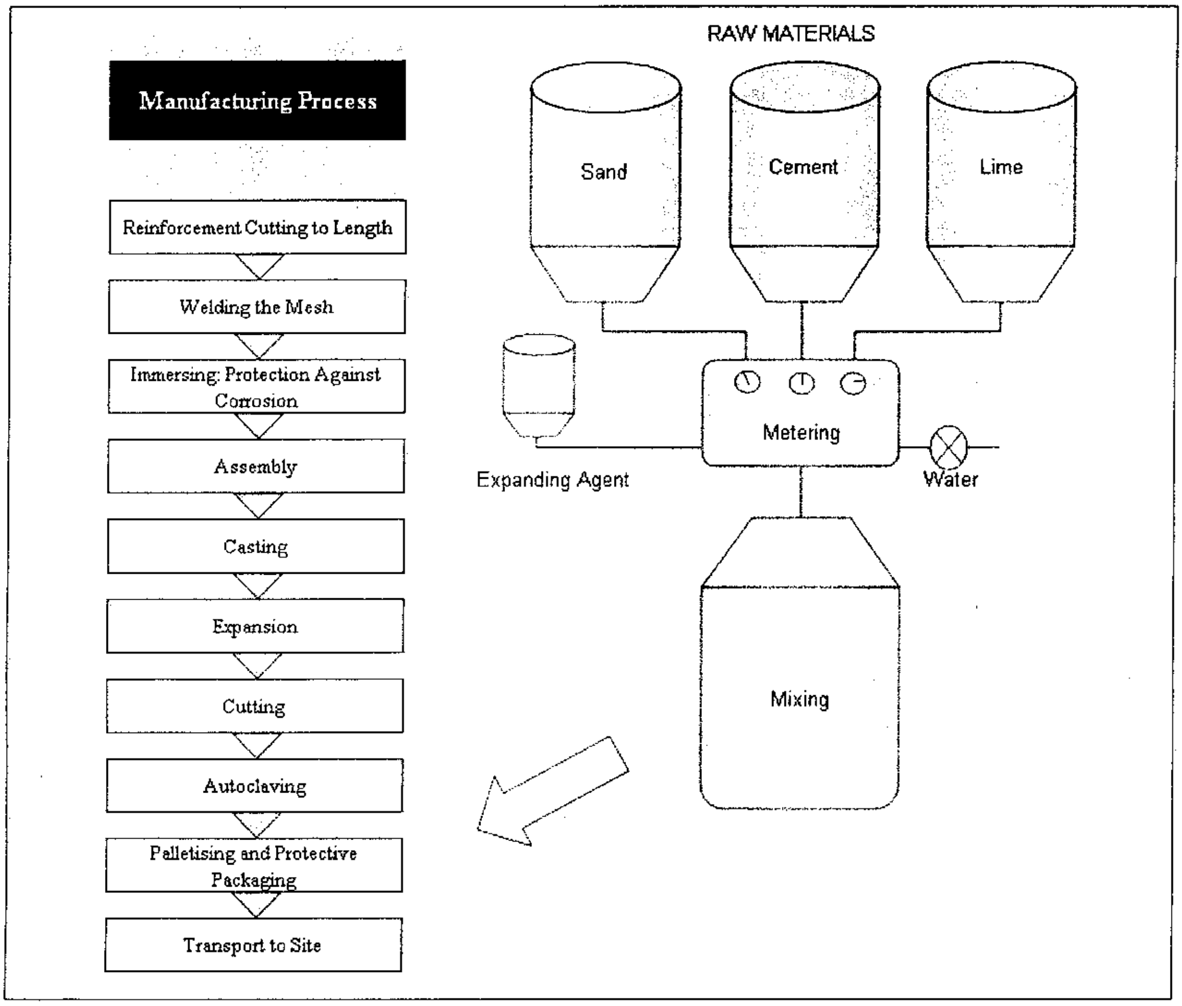

Figure B1: Manufacturing Process of Autoclaved Lightweight Concrete