# OPTIMIZATION OF AGGREGATE'S PACKING DENSITY IN THE STRENGTH'S IMPROVEMENT OF OPC CONCRETE

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## ABSTRACT

The purpose of this study was to determine the optimum packing density, workability and the strength of the concrete. Mix of concrete is made from OPC and granite aggregates, sand and water with different quantities of aggregates. Simulation graph are made in advance to determine the quantity of aggregates required for each mix. Diameter of the aggregates used for each mixture is between 20mm, 14mm, 10mm, and 5mm. The mixing is done as normal concrete with different aggregates for each diameter. The workability test of the concrete will be done after the mix is done to determine whether the concrete reaches the design was done which is a drop of 100cm. If the drop of concrete did not reach 100cm, the workability of concrete is not exceeded desired design and mixing must be performed again by adding the amount of water as the mixture is too dry. Mixture is left for 24 hours before being released from the box shape and cured. For this study, the concrete cured in a pool filled with water. Strength tests will be carried out at 1, 7, and 28 days. The results of the tests conducted, the strength of concrete is made to achieve the design of 30Mpa for each cube.

Keywords: Aggregates, OPC , Concrete, Workability , Curing process.

# ABSTRAK

Tujuan kajian ini adalah untuk menentukan ketumpatan pembungkusan konkrit yang paling optimum serta kebolehkerjaan konkrit tersebut serta kekuatan yang diperolehi. Bancuhan konkrit adalah diperbuat daripada OPC dan batu baur granit, pasir dan juga air dengan kuantiti batu baur yang berbeza. Graf simulasi diperbuat terlebih dahulu bagi menentukan kuantiti batu baur yang diperlukan bagi setiap bancuhan. Diameter batu baur yang digunakan untuk setiap bancuhan adalah diantara 20mm, 14mm,10mm , dan 5mm. Proses bancuhan adalah dilakukan seperti bancuhan konkrit biasa dengan jumlah batu baur yang berbeza untuk setiap diameter. Ujian kebolehkerjaan konkrit akan dilakukan selepas bancuhan dibuat untuk menentukan adakah bancuhan konkrit itu mencapai reka bentuk yang telah dilakukan iaitu penurunan sebanyak 100cm. Jika penurunan tidak mencapai 100cm, kebolehkerjaan konkrit adalah tidak melepasi rekabentuk yang diinginkan dan bancuhan mesti dilakukan semula dengan menambah jumlah air kerana bancuhan terlalu kering. Bancuhan dibiarkan selama 24jam sebelum dikeluarkan daripada kotak bentuk dan diawet. Bagi kajian ini, konkrit diawet didalam kolam berisi air. Ujian kekuatan akan dijalankan pada 1,7,dan 28 hari. Hasil daripada ujian yang dijalankan, kekuatan konkrit adalah mencapai rekabentuk yang dibuat iaitu sebanyak 30Mpa untuk setiap kiub.

Kata kunci : Batu baur, OPC, konkrit, kebolehkerjaan, proses pengawetan

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OPC – Ordinary Portland Cement

ASTM – American Society for Testing and Materials

SHRP – Strategic Highway Research Program

FKASA – Fakulti Kejuruteraan Awam & Sumber Alam

Ordinary Portland cement

# CHAPTER 1

# INTRODUCTION

## 1.0 BACKGROUND OF STUDY

Aggregate is a material that was used in construction. It is include sand, gravel, crushed stone, slag, recycled concrete, and geosynthetic aggregate. Aggregate mining is the most widespread mining in the world. It is a component from composite material like concrete and asphalt concrete and it is function as reinforcement to add the strength for all composite material. Aggregate is an important materials that commonly used in construction. Proper use of aggregate size is required for the types of specific construction. So that, the uses of aggregate is important on the construction and country development. All of the construction type will use aggregate in their concrete work.

Concrete formed from a mixture of water, cement, and aggregate. The mixture of this material has their own design mix to make sure the concrete strength is suitable for their uses of concrete. Common concrete mix ratio that was use on the construction is 1:2:4 which are aggregate: cement: sand. Improper concrete mix can cause the decreases of concrete workability. Therefore, the aggregate packing density in the concrete mixture will be study in this research to fine the most strength concrete.

The most inexpensive component of Portland cement concrete is an aggregate, except for water. Typically, cement which is the most expensive component is responsible for about 60 percent of the total cost of material. The paste, which is cement plus water, is the part of concrete which is produce shrinkage, heat generation, although durability problem and at the same time is the element that fills aggregate voids action.

Nowadays, the most important parameter that affects the concrete achievement is aggregate packing density. The aggregate packing density can be determined directly by measuring the bulk density of concrete. To increase the strength of the resulting concrete, used of aggregate must be matched and apart from strength, an increase in the packing density of continuous materials will also improve the overall performance of concrete. To increase the strength of concrete, cement patch will be less inclined to reduce the time of placement.

The aggregate size distribution is followed as required recommended for the certain type of construction. The aggregate size distribution also known as aggregate gradation which is adjusted for the minimum way results or voids space level for some desirable achievement's (Animesh Das). In this study, the particle size distribution was state to achieve. Particle size distribution was determined by the sieve analysis process. In this study, the aggregate will be sieve from size 20, 10, 5, 2.36 until fine aggregate.

The strength of the concrete material is actually come from the better packing density in their aggregate packing. The voids in the concrete material can reduce the strength of concrete mix. In this research, the strength of the concrete mixture will be test and also the porosity of concrete. The strength of the specimen will be test by compressive strength machine while the porosity test will be test by buoyancy balance machine. Before that, the workability of concrete specimen will be determined by slump test.

The dimension for this concrete specimen is 100mmx100mmx100mm. The material of this mixture is ordinary Portland cement (OPC) type one, fine aggregate, coarse aggregate and also water. This material will be mix according to the five mix design material. The design mix material for this research is distinguished by their particle size of distribution. First design mix is as delivered, and the other four is well graded simulation 1, 2, and 3.

## 1.1 PROBLEM STATEMENT

Concrete strength is contributed by material composition and material quality. Generally, water cement ratio is used as the basic element to desire concrete strength. However, aggregate is also playing important role in defining concrete quality. Coarse aggregate with proper gradation play an important role in workable concrete producing. It is also to ensures the aggregates sample contained all of aggregate standard fractions in a required proportion like the sample contained a minimum voids. Poor gradation of aggregate will be affecting concretes performance in transmitting load. Therefore, this study is proposed to optimize the loading transfer mechanism through optimum packing density by simulating the particle size distribution.

## 1.2 OBJECTIVE OF STUDY

The general objective of this study is to investigate the compressive strength of concrete by the optimum packing density to produce high strength concrete with design mix proportion. The specific objectives of this study were:
The objective of this study is:

1. To determine the workability of concrete with various packing density of aggregate.
2. To determine the compressive strength and porosity of concrete with various packing densities of aggregate.
3. To determine the optimum packing density of aggregates that can contribute to the improvement of concretes properties.

## 1.3 SCOPE OF STUDY

This study is discussing on the concrete strength and concrete porosity. The uses of aggregate size are from 20, 14, 10, and 5. Type of cement using is type 1 which is named as ordinary Portland cement (OPC). This study is to determine the optimum packing density to produce good concrete strength and test on compression as well as flexural. Five types of design mix are prepared for this study which is difference at the particle distribution size. Coarse aggregate is granite type, and fine aggregate is river sand. The dimension of the specimen is 100×100×100mm. A total of 36 cube is use to determine the compressive test and 10 cube is use to determine the porosity of the concrete. For compressive strength test, no of test day is 1,7,28 while the porosity test is 1, and 28 day which will be performed at the concrete laboratory of Civil Engineering (FKASA lab). These concrete mixtures containing 380kg/m³ of OPC, 205kg/m³ of water, 725kg/m³ of fine aggregate, 1090kg/m³ of coarse aggregate.

## 1.4 SIGNIFICANCE OF STUDY

The study is conducted to determine optimum aggregate packing density to produce good concrete strength using the optimum packing density. Aggregate acts as reinforcement of concrete mixture using different particle size distribution to produce optimum quality of concrete. Denser the concrete is packed, will give the higher strength of concrete. The aggregate packing density is a direct impact on the ability of the mixture to send and distribute the load.

# CHAPTER 2

# LITERATURE REVIEW

## 2.0 INTRODUCTION

The purposed of this chapter is to study and analysed the previous study that has been done earlier by using journal, article, research paper and also thesis. This chapter will review more detail regarding aggregate packing density, aggregate, concrete and the model use for packing density.

Particle packing density, is defined as the ratio of the amount of solid particles, for large volumes occupied by the particles, are the basic parameters that govern the properties of many materials made of particles. Because of the concrete is also made largely of particles, the properties affected by the density of packing of solid materials. In the modern concrete technology, the optimization of aggregate packing density is become as a key strategy. For the example, the amount of will increase for the same paste volume, the higher paste volume will be defined from it (Leo Gu Li, 2013).

## 2.1 MATERIAL

The material used for this study was referred by previous research to compare the best material that can be used to complete the study. Knowledge from the previous research about their material used is important for this study because to know about the suitable material that can be used and the fact of the material used. Otherwise, a good material comes from a good research that was study by previous research and the best result were come out. Other than that, a way to handle the material can be carried out to get the best result and to ensure the result is perfect.

### 2.1.1 Aggregate

The structure and the characteristic of aggregate especially the shape, grade, surface, and texture is considered as an important factor affecting the development of the framework of aggregate (Huanan Yu). The aggregate packing density also has significance effect by the rheological properties of concrete mixes. The workability and compatibility of concrete was improved by the dense particle packing also reducing the paste consumption, thereby provide the significant cost saving as well (Kwan and Mora, 2001).The function of aggregate in this study is to pack the minimum void ratio, the higher void contains; it will lead to requirement of mixing water. It is usually found near riverbed for crushed aggregate and the course aggregate usually use 20mm nominal maximum size. (R.srinivarsan, 2010).

There have two important reasons to increase the aggregate amount of the aggregate in the concrete mix. First of all, since the cost of aggregate is more lower than cement, for the concrete volume unit, increasing quantity of aggregate means a decreasing quantity of cement, so it's a reduction in concrete producing cost. The second one is a unit volume of concrete an increase in the amount of aggregate which results in a decrease in cement content, leads to a decrease in the most of durability problems of hardened concrete caused by cement. It is also known that the increasing of concrete shrinkage is related with the increasing of cement content. The aggregate was reducing shrinkage and crack thereby providing greater volume stability (Arum).

Since up to approximately 80 percent of the total volume of concrete consists of aggregate, aggregate significantly affect the performance of fresh and hardened concrete and have an impact on the cost effectiveness of concrete (Hudson, 1999). Aggregate characteristics of shape, texture, and grading influence workability, finishibility, bleeding, pumpability and segregation of fresh concrete and affect strength, stiffness, shrinkage, creep, density, permeability, and durability of hardened concrete.

Construction and durability problem has been reported due to poor mixture proportioning and variation on grading ( Lafrenz, 1997 ).

As mentioned by Ahmad Shayan (2011) "Among concrete ingredients, the aggregate phase forms the largest proportion by moth mass and volume. Consequently, the properties of the aggregate can significantly influence the performance of the concrete. For this reason, concrete aggregates specifications in various countries include many test to ensure that the aggregates with poor properties are excluded from use in concrete. The aggregate forms the main skeleton of concrete and its function to provide strength and volume stability to the concrete mass. Many natural rocks have inherent strength properties well above that required for most concrete products. Therefore, the strength of the aggregate is usually more than sufficient when it is produced from unweather or even slightly weathered rock sources. Ahmad Shayan (2011).

As mentioned by Pedro, the characteristic of aggregate has a significant effect on the behaviour of hardened and fresh concrete. This effect will change continuously as a function of particle size, and the following classification will be made according to common practice which is the material retained in the N4 sieve will be considered coarse aggregate, the material passing no.4 sieve and retained in the no.200 sieve will be considered as fine aggregates and material passing no. 200 sieve will know as hereinafter microfine. This classification table will show in table 2.1 below. The impact of some particle characteristics on the performance of concrete is different for microfines, fine and coarse aggregate as well as the characterization required for each test sections (Pedro and David, 2004).

**Table 2.1** : Classification of Aggregate

| Aggregate fraction | Size range |
|---|---|
| Coarse | Retained in No.4 |
| Fine | Passing N0.4 – Retained in No.200 |
| Microfines | Passing No.200 |

**Source** : Pedro and David, 2004

"The aggregate characteristics of shape, texture and grading have significance effect on the performance of fresh Portland cement concrete. Its blend with well-shaped (spherical and cubical), rounded and smooth particles, require less cement and water for a given slump than blend with flat, elongated, angular, and rough particles. At the same time, uniform flat particle size distributions that have proper amounts of each size, results result in aggregate blend with high packing density and in concrete with low water demand for a given slump (Pedro and David, 2004).

From the previous research, "the aggregate occupy about 80 percent of the volume of typical concrete mixtures, and their characteristics have a definitive impact on the performance of fresh and hardened concrete. The study was mainly concerned about the geometric characteristics, the shape, texture and grading, and the amount and type of microfines, as well as these effect the workability that is assessed by means of the slump cone and the flow table of the fresh concrete and their effect on the compressive and flexural strength of hardened concrete. The results show that the shape and texture play an important role on the performance of fresh concrete, particularly in slump and flow table test (Pedro and David, 2004).

#### 2.1.1.1 Aggregate shape

Shape is related to three different characteristics, sphericity, form and roundness. Sphericity is a measure of how nearly equal are the three principal axes or dimension of a particle. Form is the measure of the relation based on ratios between the three dimensions of a particle based on ratios between the proportions of the long, medium, and short axes of the particle. Form also called "shape factor" is used to distinguish between particles that have the same numerical sphericity. However, different definitions exist that not necessarily correlate. Besides sphericity and shape factor, two more parameters have been defined in order to describe the shape of aggregates better the elongation factor and the flatness factor. (Pedro and David, 2004).

## 2.2 AGGREGATE GRADATION

A particle size distribution of aggregate is significantly affects some of concrete like a packing density, aggregates voids content, consequently, workability, segregation, durability, and other characteristics of concretes. The uniformly distributed of mixture will produced a better workability than the gap-graded mixture. The higher slumps could be achieved with gap-graded mixtures. There are some properties of hardened concrete are also affected by grading. The distributed mixtures are generally leads to the higher density and less permeability. Fine and coarse aggregate should uniformly grade. If the fine aggregate is to coarse, a bleeding, segregation and harness will be produced. But, if the aggregate is too fine, the demand of water will be increased (Pedro and David, 2004).

As mentioned from the previous research, the grading of aggregate is also play an important role to get the best result for the strength and workability. From Pedro and David research, the results of their study show that the mixture with the same grading show that the slump and flow of mixtures increased with the packing density of aggregates and that the super plasticizer dosage required to reach the target slump decreased with the packing density of aggregates. For mixtures with the same amount, of microfines, differences due to grading as high as 100 percent were found. A side from slump or flow the effect of grading on placebility and finishibility was observed (Pedro and David, 2004).

A workable concrete is come from a good aggregate gradation. "The coarse aggregate grading requirement of ASTM C 33 permits a wide range in grading and a variety of grading size (Table 2.1). the grading of maximum size of aggregate can be varied over a moderate range without appreciable effect on cement and water requirement of a mixture if the proportion of fine aggregate to total aggregate produces concrete of good workability. A mixture proportion should be change to produce workable concrete if wide variations occur in the coarse aggregate grading" (Wilson & Kosmatka).

**Table 2.2:** Grading requirements for coarse aggregate ASTM C 33

| Size number | Nominal size, sieves with square openings | Amounts finer than each laboratory sieve, mass percent passing | | | | |
|---|---|---|---|---|---|---|
| | | 100mm | 90mm | 75mm | 63mm | 50mm |
| 1 | 90 to 37.5mm | 100 | 90 - 100 | - | 25 - 60 | - |
| 2 | 63 to 37.5mm | - | - | 100 | 90 - 100 | 35 -70 |
| 3 | 50 to 25.0mm | - | - | - | 100 | 90 - 100 |
| 357 | 50 to 4.75mm | - | - | - | 100 | 95 - 100 |
| 4 | 37.5 to 19mm | - | - | - | - | 100 |
| 467 | 37.5 to 4.75mm | - | - | - | - | 100 |
| 5 | 25.0 to 12.5mm | - | - | - | - | - |
| 56 | 25.0 to 9.5mm | - | - | - | - | - |
| 57 | 25.0 to 4.75mm | - | - | - | - | - |
| 6 | 19.0 to 9.5mm | - | - | - | - | - |
| 67 | 19.0 to 4.75mm | - | - | - | - | - |
| 7 | 12.5 to4.75mm | - | - | - | - | - |
| 8 | 9.5 to 2.36mm | - | - | - | - | - |

**Source:** Wilson & Kosmatka

### 2.2.1 Type of aggregate gradation properties

The aggregate size distributions are classified as uniformly graded, well graded and gap-graded aggregate. Aggregate gradation is typically presented in a graphical form in which percentage of aggregate passing a sieve size is plotted in an arithmetic scale.

## 2.3 PACKING DENSITY

Each of aggregate combination packing density can be measured by weighing with aggregates on one litre container and consolidated for two minutes vibrating table (De Larrad and Sedran, 1994). When the container is filling by the weight of aggregate, performance optimization of concrete is mainly a matter of improving the packing density of its granular skeleton (Wong, 2007). Several orders to investigation have applied and developed particle packing models such as Anderson, Powers, Aim and Goff. Toufar et al derived model based on linear packing. (Mohammed and Pusch).

### 2.3.1 Packing of Aggregate

From the value of aggregate packing density it was determined the different combination of aggregate in each series, the maximum packing density and the optimal distribution of the particle fractions was identified. The degree of aggregate contact and interlocking is a function of aggregate size and contributed to increasing the packing density with the aggregate size, as packing density depends on this factors ( Vinod.P and Lalu Mangal, 2012).

The characteristic of an aggregate have a significant effect on the behaviour of the hardened and fresh concrete. Although these effects of aggregate characteristics will change continuously as a function of particle size, the following classification will be made according to the common practice such as the material retained in the N4 sieve will be considered coarse aggregate, material passing no.4 sieve and retained in the no.200 sieve will be considered fine aggregate, and material passing no.200 will be called hereinafter micro fines. The effect of some particle characteristics on the performance of concrete is different for micro fines, fine and coarse aggregates as well as the characterization tests required for each of these fractions (Pedro and David, 2003).

There are three fundamental relationships for concrete mixture proportioning, there the concrete strength, rheology behaviour of cement paste, slump of concrete mixture, the optimal aggregate proportioning and the workability of concrete. In the mixture proportioning, and the properties of high performance concrete, these criteria are completely define and being quantified with corresponding models. The comprehensive modelling of concrete workability and rheological behaviour is not possible without detailed knowledge of the arrangement of aggregate particle, packing degree and characteristic of porosity (Adil and Konstantin, 2008).

The proportioning of the coarse and fine aggregates in the concrete cement has the important effect on the properties of both hardened and fresh concrete. Some of guides are providing to determine the optimal gradation of coarse and fine aggregate for the concrete mixing using a set of tables. In the tables, is either based on very empirical approaches or on the model of computer for packing theoretical of particles spherical which including their specific gravity and their size. Otherwise, the cement concrete is using these tables to help to produce more workable mix better hardened consolidation concrete with the decreasing of permeability and the improvement of the durability. Such tables are for instance given in the SHRP-C-334 guide (Anderson & Johansen, 1993).

### 2.3.2 Voids of Aggregate

From the previous research, the table below shows the aggregate ratios void saturation with the coefficient correlation coefficients from the linear regression both with and without zero intercept. It is also mean that the values of aggregate void saturation ratios with coefficients of a variation from the final mix proportions are given. The mean values from the linear regression through the origin as expected. Saturation voids of aggregates value obtained without going through zero are lower and with slightly correlation improvement. More conservative is using values based on zero interception correlation improvement (Stefan and Bard, 2007).

| Ratio | Regression | | | | Mean | |
|---|---|---|---|---|---|---|
| | Zero interc. | $R^2$ | No zero | $R^2$ | Mean | C. of V. |
| $K'$ | 1.20 | 0.85 | 1.18 | 0.85 | 1.20 | 5% |
| $K''$ | 1.14 | 0.82 | 1.01 | 0.84 | 1.15 | 5% |
| $K_{app}'$ | 1.01 | 0.79 | 0.79 | 0.86 | 1.02 | 6% |
| $K_{app}''$ | 0.96 | 0.68 | 0.67 | 0.84 | 0.97 | 7% |

**Figure 2.1:** Aggregate ratios void saturation

"The voids in an aggregate are considered to be most important mix design parameter which affects the durability, of concrete mix. This has traditionally been addressed during mix design by meeting a minimum voids in the mineral aggregate requirements, based solely upon the nominal maximum aggregate size without regard to other significant aggregate-related properties (Wang, Li and Qu, 2009). From the previous research by Mohammed and Pusch, mentioned that the Danish software 4C program from Danish technologies institute, the europack based on the modified Toufar model. These programs are good opportunities for engineers to find an optimum combination of mix constituents for obtaining a minimum void ratio. By adopting one or several mathematical models, for determining the void ratio and combining them that one can obtained the composition that gives the minimum porosity and permeability and maximum slump. One can hence optimize the properties of both freshly prepared and hardened concrete (Mohammed and Pusch, 2011).

The variations of voids ratio and the solid concentration with the obtained ratio during wet packing test of typical aggregate are plotted in figure below. From curves plotted, there was an optimum ratio, called basic water ratio, at which voids that reached a minimum value and solid concentration reached maximum value. The similarities of void ratio and solid concentration with ratio were obtained for the other aggregate samples tested. In the other case, the maximum solid concentration so determined was ticking as the packing density of the aggregate sample tested. It also should be noted that the basic water ratio is not necessarily equal to the minimum void ratio because the entrapped air can caused the air ratio to be non-zero when the minimum voids ratio occurs. Hence, the basic water ratio should not to be mistaken as minimum amount of water needed to fill up the voids (Kwan and Fung, 2011).

# CHAPTER 3

# RESEARCH METHODOLOGY

## 3.0 INTRODUCTION

The experimental procedure, used material, preparation, of material, and apparatus, regarding this study is discussed further in this chapter. This research focus on toughness and compressive strength of concrete and the optimum aggregate packing density to use in the concrete mixture. The test was held to determine the strength and the porosity of the concrete mix. The objective was to provide the optimum aggregate packing density in concrete mix. The effective cost concrete results in a mixture was contain aggregates with an optimum particle size of distribution which yield the high packing density which is contain low voids, the minimum quantity of cement and desirable slump, workability and placebility.

The mix design was held starting from 5$^{th}$ February until 13$^{th}$ March including the curing process and testing process. For testing age, the test was doing on the 1$^{st}$ day, 7$^{th}$ day and 28$^{th}$ day for compressive strength. For porosity test, testing age is on the 1$^{st}$ and 18$^{th}$ day. The experimental process mostly done at FKASA Concrete laboratory but the porosity testing process was held on FKASA Highway laboratory.

## 3.1 EXPERIMENTAL PLANNING

First step for start this project is the title choose for this study. After the title was selected, the objective of this study will be defined. This study is carried out investigate the optimum aggregate packing density in the conventional concrete. The strength of the concrete is also can be determine compared without packing density and with packing density. Figure 3.1 shows the research methodology flowchart in this study.

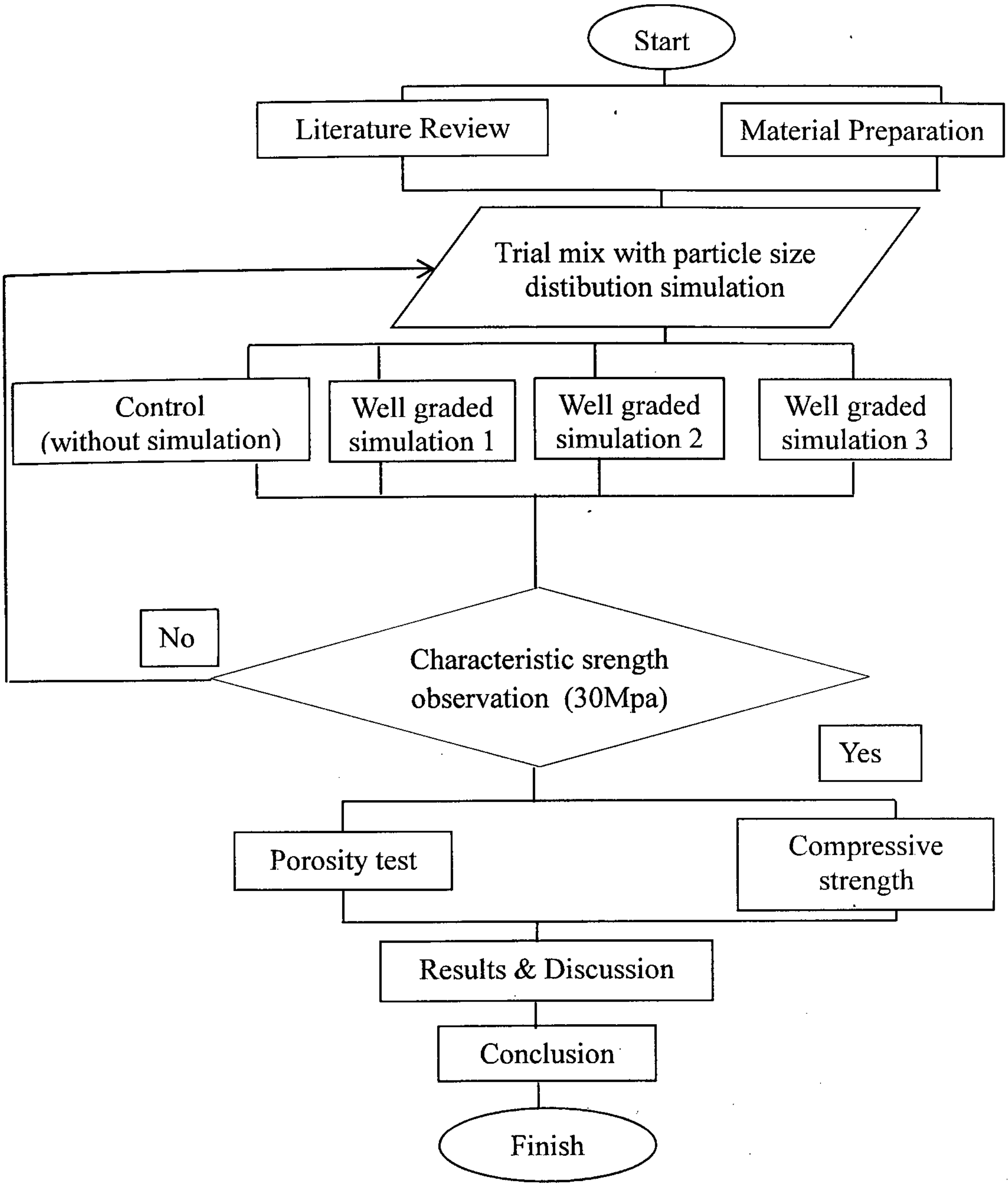


**Figure 3.1:** Flow Chart

The material preparation for this study has been conducted according to the study and objective needed. There has 4 design concrete mixes for this study and the