# THE POTENTIAL OF BOTTOM ASH AS FINE AGGREGATE REPLACEMENT IN CONCRETE

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## ABSTRACT

Bottom ash is one type of the solid residues by products produced from coal power generating plants. The purpose of this study was to enable the practical use of this material as an alternative to the existing building material. Direct use of this material with a large quantity, will provide a solution to dispose of this material, and the possibility as alternative materials in construction. The study was conducted to investigate the effect of replacing the bottom ash as fine aggregate (sand) in concrete on compressive strength and total porosity. Study was carried out by the sand replacement ratio of 25%, 50% and 100%. The control parameter is water-cement ratio at 0.46 and workability on 30 – 60 mm. Slump test have been conducted on wet concrete to evaluate the workability of concrete and the compressive strength is determined at the age of seven, 14 and 28 days of hardened concrete cube sample size of 150 mm. Meanwhile, for total porosity was measured with hardened concrete cube of 70 mm at 60 days age. The replacement of bottom ash on the sand in the concrete resulted in a decrease of slump test and compression test. The test results also showed porosity of concrete with bottom ash is higher than the control concrete. The analysis also showed that the compressive strength is inversely proportional to the porosity, which is the increment of porosity; it will reduce the compressive strength of concrete.

# ABSTRAK

Abu dasar relau adalah sejenis pepejal hasil sampingan yang diperolehi daripada loji janakuasa tenaga arang batu. Tujuan kajian ini adalah untuk membolehkan bahan ini praktikal digunakan sebagai bahan alternatif pembinaan yang sedia ada. Penggunaan langsung bahan ini dengan kuantiti yang besar, akan memberi satu penyelesaian masalah kepada pelupusan bahan ini, malah juga berkemungkinan kepada penggunaan bahan alternatif baru sebagai bahan dalam pembinaan. Kajian ini dijalankan untuk mengkaji kesan penggantian abu dasar relau sebagai agregat halus (pasir) dalam konkrit ke atas kekuatan mampatan dan jumlah keliangan. Kajian dijalankan dengan penggantian nisbah pasir sebanyak 25%, 50% dan 100%. Parameter kawalan adalah air-simen yang sama pada nisbah 0.46 dan kebolehkerjaan pada 30 – 60 mm. Ujian runtuhan kon telah dijalankan ke atas konkrit basah bagi menilai kebolehkerjaan konkrit, dan kekuatan mampatan ditentukan pada umur tujuh, 14 dan 28 hari daripada sampel kiub konkrit keras bersaiz 150 mm. Manakala kiub konkrit keras bersaiz 70 mm digunakan untuk ujian keliangan. Penggantian abu dasar relau ini terhadap pasir di dalam konkrit menghasilkan penurunan dalam ujian runtuhan kon dan ujian mampatan. Keputusan ujian juga menunjukkan jumlah keliangan konkrit adalah lebih tinggi berbanding konkrit kawalan. Analisis juga meunjukan bahawa kekuatan mampatan berkadar songsang dengan jumlah keliangan, di mana peningkatan jumlah keliangan akan mengurangkan kekuatan mampatan konkrit.

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| | | |
|---|---|---|
| A | - | Surface Area |
| ACAA | - | American Coal Ash Association |
| ACI | - | American Concrete Institude |
| $Al_2CO_3$ | - | Aluminum Oxide |
| ASTM | - | American Society for Testing and Material |
| BS | - | British Standard |
| c | - | Cohesion Intercept |
| $C_2S$ | - | Dicalcium Silicate |
| $C_3S$ | - | Tricalcium Silicate |
| CaO | - | Calcium Oxide |
| $Fe_2O_3$ | - | Ferric Oxide |
| FGD | - | Flue gas desulfurization |
| JBA | - | Jabatan Bekalan Air |
| $K_2O$ | - | Potassium Oxide |
| MgO | - | Magnesium Oxide |
| Mm | - | Millimeter |
| MPa | - | Mega Pascal |
| MS | - | Malaysian Standard |
| MW | - | Mega Watt |
| $Na_2O$ | - | Sodium Oxide |
| P | - | Ultimate Compressive Load |
| $P_2O_5$ | - | Phosphorus Pentoxide |
| S | - | Shear Strength |
| $SiO_2$ | - | Silica |
| $SO_3$ | - | Sulphur Trioxide |
| $TiO_2$ | - | Titanium Oxide |

| | | |
|---|---|---|
| TNB | - | Tenaga Nasional Berhad |
| UMP | - | Universiti Malaysia Pahang |
| Ws | - | Weight of Saturated Dry Samples in Air |
| Wd | - | Weight of Oven Dry Samples in air |
| Wb | - | Weight of Buoyancy balance |
| $\varphi$ | - | Angle of Internal Friction |
| $\sigma$ | - | Normal Stress |

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

Concrete is a mixture of various materials, consist of cement, fine aggregate, coarse aggregate and water which has emerged as a dominant construction material for the infrastructural and building needs. Concrete is probably the most extensively used construction material in the world. It is only second to water as the most heavily consumed substance with about six billion tones being produced every year.

Waste material has gained attention among researchers as replacement to natural aggregate or cement in concrete making. The sense of using waste materials in concrete not only of the economic factor but the more significant aspect is to protect the environment since more solid waste are produced day by day. There are also some other benefit can expected to be gained in term of quality in concrete by using aggregate from waste products such as sustainability in construction.

Durability of concrete has been as interest in research field since the durability problem has largely affecting concrete for a long term performance. Repair work due to weakening of concrete also imposed considerable expense and economic impact due to the repair works has been a great concern.

To be durable, the concrete mass must have high resistance to access of external damaging agent which would consequently lead to the breakup of the hardened mass. To have such resistance, the durability of the concrete should be of primary design concern along with strength design criteria.

Coal is one of the world's most important sources of energy, fuelling almost 40 percent of electricity worldwide. In many countries this figure is much higher: Poland relies on coal for over 97 percent of its electricity; South Africa for 92 percent; China for 77 percent; and Australia for 76 percent (Joseph, 2005). Coal was introduced as a raw material for power generation since 1988 in Malaysia. The existing coal-fired power plants in Malaysia are Kapar (1,600 MW) commissioned in 1988-1999 and TNB Janamanjung (2,100 MW) commissioned in 2003. Looking at the electricity generation mix, the percentage of coal remains stable at an average of 8.6 percent from 1993-2000 and increased slightly to 12 and 14.1 percent in 2001 and 2002 respectively. However, in 2003, the percentage increased tremendously from 14.1 percent to 24.6 percent of coal in the electricity generation mix due to the commissioning of Janamanjung power plant. According to Joseph (2005), with the two more new constructed coal-fired power plants, Jimah and Tanjung Bin, coal consumption is expected to increase from 10 million tonne to 19 million tonne in year 2010. Malaysia imports about 70 percent of its total coal requirements from Indonesia, other will be imported through bulk carriers from mines in China, Australia, South Africa, and elsewhere as the need arises.

Two types of ash, fly ash of 80 percent and bottom ash of 20 percent are produced at coal power plant. Most of them are being dumped as the waste disposal site near the factory. This will pollutes the environment and it is creating a disposal problem because a large space of dump yard is required. Lignite coal fly ash can be used as partial replacement of cement and is considered to be a medium value added usage. Lignite bottom ash consists mainly of calcium carbonate and silica.

It is expected that bottom ash can be used as fine aggregate replacement in making concrete when natural sand is expensive to long carrying distance and has high clay content. Utilization of bottom ash as fine aggregate should be studied to alleviate the environmental problem.

Bottom ash [normally recognized as coal combustion residues (CCRs) from pulverized fuel power stations] has been categorized as solid garbage. But, CCRs are increasingly being regarded as a useful substitute material resource. They had an appearance similar to dark gray coarse sand, and its particles are clusters of micron-sized granules, up to 10mm in diameter (60%-70% smaller than 2 mm. 10%-20% smaller than 75 microns).

Fly ash and bottom ash possess properties that give them several productive uses as construction materials, and more than 70 percent of the ash remains unused (ACAA, 1998). The majority of unused coal ash is disposed off in landfills or mined out areas of coal mines prior to their reclamation. Basically, it is applications and potential applications that include the cement and concrete industries, production of synthetic aggregates and zeolites, backfill and embankment materials for highway construction, stabilization of engineered soils for construction purposes, and improvement of soils behaviour for agriculture and horticulture. The geotechnical, geochemical and mineralogical properties of the coal combustion products may vary from individual sample depending on the type of raw materials, feedstock handling and inflammation condition.

In this study, bottom ashes from Tanjung Bin (Pontian, Johor) were used. Basically, the Tanjung Bin power plant comprises of 3 power-generating units, each with a nominal net capacity of 700MW. The type and origin of coal burned, boilers type, degree of pulverization, firing conditions in the furnace and ash handling practices will affects the characteristics on physical, mechanical and chemical of bottom ash (Huang, 1990).

Although there are a lots of studied related to the properties of coal ash, but the investigation about the local coal ash is very limited. Therefore, it is necessary to provide the information based on the laboratory and field education of the locally available coal ash particularly the bottom ash for potential construction uses.

## 1.2 Problem statement

The growing demand for electricity resulted in the construction of many coal-fired power plants. As the consumption of coal by power plants increases, so does the production of coal by product such as fly ash and bottom ash. While the use of coal increases, waste issues associated with coal production are tempted more and more thoughtfulness. Malaysia is very serious about environmental issues and it has cause the stringent control about the emission standards on the new projects for coal power (Joseph, 2005). Even though there is no report about the production of coal ash annually in Malaysia, but theoretically, there is about 10% of total weight of the coal burned produces ash (Huang, 1990).

Disposal of unused coal ash is costly and places a considerable burden on the power industry, and finally transferred to the electricity consumer. In addition, the disposing of ash in landfills contributes to the ongoing problem of diminishing landfill space in the Malaysia. And at the same time, ash disposal may pose an environmental hazard.

Previously, most of the available research had been focusing on the properties of fly ash since fly ash accounts for a larger portion (approximately two-third) of the total coal ash produced than bottom ash does (ACAA, 1998). Nevertheless, some of the studies showed that the engineering properties of most bottom ash were more favourable than those of traditional highway material and has the capability to improve asphalt pavement performance when used to substitute a portion of the aggregate in asphalt mixes.

Changeability of bottom ash is a latency problem because of the variability in type and origin of coal burned, boiler types, degree of coal pulverization, firing conditions in the furnace and ash handling practice (Huang, 1990). There is a requirement for a systematic manner to estimate locally available bottom ashes for potential construction utilization because even bottom ash produced from unitary source can be entirely difference depending on the operating conditions and procedures.

The using of bottom ash as alternative measures to replace the natural sand in concrete production. Therefore, Malaysia has a great potential to turn its abundant supply of electrical by coal industry by products into value added products especially in construction material. The conventional method of burning these residues often creates environmental problems, which generates air pollution and it is prohibited by the Environment Protection Act. In abiding by the regulations, these residues are becoming expensive to dispose. Nevertheless, looking on the brighter side of things, extensive research has provided an alternative way of optimizing the usage of coal residues based into value added product in construction industry.

## 1.3 Objectives

The main objectives for this research are:

i. To determine the optimum content of bottom ash as a substitute for fine aggregate (sand) in concrete;
ii. To evaluate the mechanical properties (compressive strength) of concrete containing bottom ash from power plant as sand replacement in concrete;
iii. To study the porosity of concrete containing bottom ash.

## 1.4 Scope of research

In this research, this project focused on the effects of different bottom ash percentage on the workability, compressive strength and porosity of concrete containing bottom ash as fine aggregate replacement. There are the limitations of this project:

1. The percentage of bottom ash in this study is 0% as the control, Meanwhile 25%, 50% and 100% were used to replace the fine aggregate.
2. Water-cement ratio of 0.46 was used in concrete mixture.
3. The concrete slump was about 30–60mm.
4. The size of specimens was 150x150x150mm each for compressive test and 70x70x70mm for porosity test.
5. The size of aggregates was used was 20mm and is in accordance to MS30: Part 2 (1995).
6. Cubes were tested at the age of 7, 14, 28 and 60 days.
7. Concrete workability was tested on fresh concrete using slump test method.
8. Compressive strength and porosity were tested in hardened concrete.
9. Concrete with characteristic strength of $30N/mm^2$ at 28 days was used in this study.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Concrete properties

Concrete has relatively high compressive strength, but significantly lower tensile strength, and as such is usually reinforced with materials that are strong in tension which is often for steel. The elasticity of concrete is relatively constant at low stress levels but a start decreasing at higher stress levels as matrix cracking develops. Concrete has a very low coefficient of thermal expansion, and as it matures concrete shrinks. All concrete structures will crack to some extent, due to shrinkage and tension. Concrete which is subjected to long-duration forces is prone to creep. Tests can be made to ensure the properties of concrete correspond to specifications for the application. The density of concrete varies, but is around 2,400 $kg/m^3$.

### 2.1.1 Strength

As mention before, concrete has relatively high compressive strength, but significantly lower tensile strength. It is fair to assume that a concrete sample's tensile strength is about ten to fifteen percent of its compressive strength.

As a result, concrete would almost always fail from tensile stresses and even when loaded in compression. The practical implication of this is that concrete elements subjected to tensile stresses must be reinforced with materials that are strong in tension.

Reinforced concrete is the most common form of concrete. The reinforcement is often steel and rebar. Structural fibers of various materials are available. Concrete can also be prestressed which reducing tensile stress using internal steel cables named tendons, allowing for beams or slabs with a longer span than is practical with reinforced concrete alone. Inspection of concrete structures can be non-destructive if carried out with equipment such as a Schmidt hammer, which is used to estimate concrete strength.

The ultimate strength of concrete is influenced by the water-cement ratio, the design constituents, and the mixing, placement and curing methods employed. All things being equal, concrete with a lower water-cement ratio makes a stronger concrete than that with a higher ratio. The total quantity of materials can affect strength, water demand, shrinkage, abrasion resistance and density. All concrete will crack independent of whether or not it has sufficient compressive strength.

In fact, high Portland cement content mixtures can actually crack more readily due to increased hydration rate. As concrete transforms from its plastic state, hydrating to a solid, the material undergoes shrinkage. Plastic shrinkage cracks can occur soon after placement but if the evaporation rate is high they often can actually occur during finishing operations, for example in hot weather or a breezy day. In very high-strength concrete mixtures the crushing strength of the aggregate can be a limiting factor to the ultimate compressive strength. In lean concretes which with a high water-cement ratio, the crushing strength of the aggregates is not so significant.

### 2.1.2 Expansion and shrinkage

Concrete has a very low coefficient of thermal expansion. However, if no provision is made for expansion, very large forces can be created, causing cracks in parts of the structure not capable of withstanding the force or the repeated cycles of expansion and contraction.

As concrete matures it continues to shrink, due to the ongoing reaction taking place in the material, although the rate of shrinkage falls relatively quickly and keeps reducing over time. This is for all practical purposes concrete is usually considered to not shrink due to hydration any further after 30 years.

The relative shrinkage and expansion of concrete and brickwork require careful accommodation when the two forms of construction interface. Because concrete is continuously shrinking for years after it is initially placed, it is generally accepted that under thermal loading it will never expand to its originally placed volume. Due to its low thermal conductivity, a layer of concrete is frequently used for fireproofing of steel structures.

### 2.1.3 Cracking

Concrete cracks due to tensile stress induced by shrinkage or stresses occurring during setting or use. Various means are used to overcome this. Fiber reinforced concrete uses fine fibers distributed throughout the mix or larger metal or other reinforcement elements to limit the size and extent of cracks. In many large structures joints or concealed saw-cuts are placed in the concrete as it sets to make the inevitable cracks occur where they can be managed and out of sight.

### 2.1.3.1 Shrinkage cracking

Shrinkage cracks occur when concrete members experience restrained volumetric changes as a result of drying, autogenously shrinkage or thermal effects. Restraint is provided either externally or internally. Once the tensile strength of the concrete is exceeded, a crack will develop. The number and width of shrinkage cracks that develop are influenced by the amount of shrinkage that occurs. The amount of restraint present and the amount and spacing of reinforcement provided. These are minor indications and have no real structural impact on the concrete member.

### 2.1.3.2 Tension cracking

Concrete members may be put into tension by applied loads. This is most common in concrete beams where a transversely applied load will put one surface into compression and the opposite surface into tension due to induced bending. The portion of the beam that is in tension may crack. The size and length of cracks is dependent on the magnitude of the bending moment and the design of the reinforcing in the beam at the point under consideration. Reinforced concrete beams are designed to crack in tension rather than in compression. This is achieved by providing reinforcing steel which yields before failure of the concrete in compression occurs and allowing repair and evacuation of an unsafe area.

### 2.1.4 Concrete testing

#### 2.1.4.1 Mechanical test

Concrete is typically sampled while being placed, with testing protocols requiring that test samples be cured under laboratory conditions which are standard cured. Additional samples may be field cured for non-standard for the purpose of early 'stripping' strengths. That is, form removal and evaluation of curing, but the standard cured cylinders comprise acceptance criteria. Concrete tests can measure the "plastic" for unhydrated properties of concrete prior to, and during placement. As these properties affect the hardened compressive strength, the properties of workability, temperature, density and age are monitored to ensure the production and placement of 'quality' concrete. Tests are performed per ASTM International.

Compressive strength tests are conducted using an instrumented hydraulic ram to compress a standard cylindrical or cubic sample to failure. Tensile strength tests are conducted either by three-point bending of a prismatic beam specimen or by compression along the sides of a standard cylindrical specimen.

#### 2.1.4.2 Durability test

Learning to determine the preservation needs for a stage performance to be achieved or that is required is said to be the durability of the development in relation to its features.

Increase durability characteristics of concrete, especially for high-strength concrete is very important to consumers and may be more important than the proceedings of a high strength. Resistance is associated with the identification of a concrete other than strength such as resistance against carbonation, porosity, diffusion and corrosion resistance.

The strength of a structural element is influenced by the strength in the area of concrete cross section restraining the load applied. Durability of concrete elements controlled by the main surface area. Durability of concrete is defined as the ability to maintain the physical characteristics and in safe condition for the service structures. Therefore, concrete should be durable and able to work across a variety of moderate to extreme environments, including the weather, chemical attack, scratches, frost and fire in the external or internal.

Preservation requirements of the standard are directly to the durability of concrete is not specified in the united state. The durability of standard design should be improved in the early to determine the level of performance on the perimeter or use. For the time being, the researchers are looking for the best alternative methods to determine the needs of preserving the rationale for achieving levels of performance characteristics needed appropriate. Factors that protect the concrete is reinforced concrete and prestressed concrete. Besides that, the concrete cover also protects the entry of moisture and air is needed. In addition, the permeability also affects the durability of concrete.

## 2.2 Concrete material

### 2.2.1 Cement

Cement is a material which has a sticky and wet adhesion while and then solidify and harden and bind the solid into a solid object. Cement can be classified into two types of hydraulic cement and cement not hydraulic. Hydraulic cement can solidify and harden when reacting with water such as Portland cement, consisting of silicate and aluminates. They do not have exposure to drying air. But it can harden despite being immersed in water. Not a hydraulic cements, nor may solidify and harden in the water as it needs air to the reaction such as lime.

Each type of cement is different in terms of composition and particle fineness. In general, use of cement containing quantities tricalcium silicate ($C_3S$) levels more quickly achieve the strength and have a major impact on the early strength of concrete from cement containing calcium silicate ($C_2S$) high.

### 2.2.2 Aggregate

Aggregate quality can affect the strength and durability of concrete. Aggregate selection suitable for construction purposes requires an understanding of the properties of aggregates. These attributes can be known through the experiments, experiments as determined by the standard codes.

Aggregate is divided into two main parts of fine aggregate and coarse aggregate. Nominal size is less than 5mm sand and gravel aggregates are stones that have nominal size larger than 5mm. Coarse aggregate can be obtained from natural sources or synthetic. Natural resources generally were from the granite and limestone (BS812: Part 1:1975). Groupings were used for the construction of comparative density of normal and stone aggregates typically are in the range of 2500-2700 kg/m$^3$.

Artificial aggregates can be obtained from industrial waste. Steel ball for weight concrete, clinker or slag concrete products of combustion to lightweight. Lightweight aggregates generally have low strength and the aggregate weight of a high strength. Nominal size commonly used is the 10mm, 20mm and 40mm. The maximum size depends on the type of construction such as a compact arrangement of reinforcement and building a thick or thin.

Aggregate strength also affected many of the characteristics of concrete such as concrete strength, deformation, durability, volume, specific gravity, transparency, and chemical reactions. Aggregate strength is usually higher than the strength of the concrete will be designed.