
Performance of Concrete Containing Ground Granulated Blast Furnance Slag as Cement Replacement

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This thesis deals with an investigation on the performance of concrete containing ground granulated blast-furnace (GGBF) slag, as a partial cement replacement. Tsets were conducted on concrete in which 0, 40, and 60 percent (by weight) of ordinary Portland cement, was replaced by BBGF slag. Water-cementitious (w:c) ratio of 0.4 was used for all mixes. Concrete moist cured at 20° C, 27° C, cured at site, and sured in sea-water were tested at ages between three days and one year for compressive strenght. The results also showed that with increasing age, the compressive strenght of concrete increases. This is due to the combined effect of the decrease in volume of large pores and partial pore blocking resulting from the cement replacement material.

Key Words: Strenght, Curing, Slag, Temperature.

Introduction

Concrete is the most popular material. Compared with other construction materials, it possesses many advantages including low cost, availability of raw materials, adaptability, easy to form in accordance with architectural consideration, lowty essentially stems from the careful design of the mix, the accurate proportioning of its constituents, adequate compaction and proper curing after placing. Low permeability is a vital factor in the resistance of concrete to attack from external sources. Some types of cement are more resistant to certain chemical agents than others, and cement replacement materials may offer a greater degree of resistance. Other essentials are impermeability, a minimum amount of shrinkage, cracking, cavitation and surface wear. In short concrete should be durable (Englinton, 1987).

In addition, the quality of concrete is also governed by the impermeability of the cement and fine aggregate part of the mix. The coarse aggregate plays little part, provided that it is not so porous as to provide a channel for the ingress of aggressive solutions. It is also suggested by a number of researchers that the transition zone contributes to the increase in permeability of concrete (Englinton, 1987).

The chief factor controlling the permeability of the fine fraction is the amount of water used in relation to the cement content of the mix, that is, the water-cement ratio. The amount of water required in any one mix depends on a number of factors, such as surface area and absorbent properties of the aggregate. but for the production of durable concrete it should be kept as low as possible. No more should be used in the mix than is necessary to ensure that all aggregate particles

are completely covered by the cement paste, that the cement and fine aggregate mortar fills the voids between the coarse aggregate, and that the concrete is fluid enough to be placed and compacted while remaining coherent.

As mentioned earlier, curing is a critical factor governing the strength and durability of concrete. This means, the prevention of loss of water during the early stages of the hydration of the cement by providing the concrete with a moist environment, either by applying water to the surface or by covering on the surface with appropriate material.

The chemical reaction between alkalis in cement and reactive aggregate that causes expansion in concrete was first recognized by Stanton in 1940. The reaction between alkalis and aggregates is relatively slow and occurs internally, as opposed to the external chemical attack such as sulfates and chloride salt. Although most structural failure due to the alkali aggregate reaction in the 1930s and 1940s occurred within 1 to 10 years, in some structures the deterioration did not occur until after 15 to 20 years (Mindess and Young, 1981). These failures were characterised by extensive map cracking, frequently accompanied by gel exuding from cracks, popouts, and spalling.

Many researchers (Mangat et al, 1995, Dhir et al, 1996) reported that the use of GGBF slag in concrete is beneficial in inhibiting chemical attack, reducing heat of hydration, increasing denseness and inhibiting alkali-aggregate reactivity. These attributes present GGBF slag as a potentially useful mineral admixture from the standpoint of improving the quality of concrete construction. However, the data regarding of the long term effect of GGBF slag in concrete is very limited, especially in Asian countries.

Objective of Study

The main objective of this research investigation are as follows :

1. To investigate the engineering properties of concrete containing different percentage levels of cement replacement with GGBF slag cured under different curing temperatures.
2. To evaluate the effect on the strength development of concrete containing different percentage levels of cement replacement with GGBF slag cured under different curing temperatures.

Importance of Study

1. The research findings will contribute to the knowledge regarding the use of GGBF slag as a cementitious material in terms of the future reference and the potential improvements to the properties of concrete.

To provide more information on the production of good quality concrete containing different levels of cement replacement with GGBF slag cured under different curing temperature.

Scope of Investigation

This experimental work is aimed at assessing the influence of the following parameters :

1. The concrete containing different percentage levels of cement replacement by 0%, 40% and 60% with GGBF slag using water-cement ratio value of 0.4
2. The engineering properties of concrete containing partial replacement of the above were

investigated. The a chosen properties are compressive strength, The properties of concrete cubes cured between one days to one year at curing temperature of 20oC and 27oC (except for the first 24 hours) were monitored.

Literature Review

Introduction

There is a wide variety of cements used in the building and construction industries. The chemical composition of these cements can be quite diverse, but by far the greatest amount of concrete used today is made with Portland cement. This chapter will discuss the composition of Portland cements, engineering properties and microstructure of hardened concrete to resists chemical composition, durability indicators of concrete, the concrete exposed to sea water, and also a review on GGBF slag performance in concrete.

Portland Cement

ASTM C 150 (1992) defines Portland Cement as a hydraulic cement produced by pulverising clinkers consisting essentially of hydraulic calcium silicates, usually containing one or more of the forms of calcium sulfate as an interground addition. Clinkers are 5 to 25 mm diameter nodules of a sintered material which is produced when a raw mixture predetermined compositions is heated to high temperature.

Hydraulic cements are defined as cements that not only harden by reacting with water but also form a water resistant product. Cement derived from calcination of gypsum or carbonates such as limestone are nonhydraulic because their products of hydration are not resistant to water. Lime mortars that were used in ancient structures built by Greeks and Romans were rendered hydraulic by the addition of pozzolanic materials which reacted with lime to produce a water resistant cementitious product (Mehta, 1986).

Compared to gypsum and lime cements, Portland cement and its various modifications are the principal cements used today for making structural concrete. This is because Portland cement is truly hydraulic, it does not require the addition of a pozzolanic material to develop water-resisting properties (Mehta, 1986).

The raw materials used in the manufacture of Portland cement consist mainly of lime, silica, alumina and iron oxide. These compounds interact with one another in the kiln to form a series of more complex products, and, apart from small residue of uncombined lime which has not had sufficient time to react, a state of chemical equilibrium is reached. However, equilibrium is not maintained during cooling, and the rate of cooling will affect the degree of crystallisation and the amount of amorphous material, known as glass, differ considerably from those of crystalline compounds of a nominally similar chemical composition. Another complication arises from the interaction of the liquid part of the clinker with the crystalline compounds already present (Neville, 1995).

In addition to the main compounds listed in table 2.1, there exist minor compounds, such as MgO , TiO_2 , Mn_2O_3 , K_2O and Na_2O ; they usually amount to not more than a few per cent of the weight of cement. Two of the minor compounds are of interest: the oxides of sodium and potassium, Na_2O and K_2O , known as alkalis (although other alkalis also exist in cement). They have been found to react with some aggregates, the products of the reaction causing disintegration of

concrete, and have also been observed to affect the rate of the gain of strength of cement. (Neville, 1995).

Four compounds are usually regarded as the major constituents of cement, they are listed in Table 2.1 together with their abbreviated symbols.

TABLE 2.1.

Main Compounds of Portland Cement (Boque composition)

Name of compound	oxide composition	Abbreviation
Tricalcium aluminate	3CaO. Al ₂ O ₃	C ₃ A
Tetracalcium aluminoferrite	4CaO. Al ₂ O ₃ . Fe ₂ O ₃	C ₄ AF

Cement is a complex mixture of compounds and the characteristics of these compounds are influenced by the raw materials, fuel and manufacturing process. the performance of cement depends not only on the chemistry, but also on the way compounds are formed during the manufacturing process. It is possible for two cements with virtually identical compositions to behave very differently in terms of strength development and other properties.

The Boque chemical compounds mentioned above are seldom pure and the degree and type of impurities in the cement compounds can have a significant bearing on their properties. Calculation from chemical analyses show that most cements are made up from the four compounds. Around 70 percent of ordinary Portland cement consists of calcium silicate compounds, which provide the main strength giving compound. Alite (C₃S) is the principal silicate compound in Portland cement. On mixing with water, hydration begins quickly, the calcium silicate hydrates formed providing a substantial contribution to strength at early ages. Dicalcium silicate or belite (C₂S) hydrates to give similar products, but contributes to strength much more slowly (Soroka, 1979).

The two most important minor compounds are tricalcium aluminate (C₃A) and tetracalcium aluminoferrite (C₄AF). C₃A alone reacts very rapidly with water but in the presence of sulphate in solution (derived from calcium sulphate) the reaction is controlled by a layer of ettringite-crystalline calcium sulphoaluminate hydrate-formed on the C₃A grains. C₄AF reacts slowly in lime water, and this compound contributes little strength (Corish, 1985).

Durability of Concrete

Definitions

A long service life is considered synonymous with durability. Since durability under one set of conditions does not necessarily mean durability under another, it is customary to include a general reference to the environment when defining durability. According to ACI Committee 201(1991), durability of hydraulic-cement concrete is defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration. Durable concrete will retain its original form, quality, and serviceability when exposed to its environment.

Durability is generally equated with the quality of the concrete, but the word quality is a very subjective one. Insufficient durability of concrete structures has become a serious problem in many parts of the world. Whereas analytical methods exist to evaluate the load carrying capacity of concrete structures on the basis of materials parameters such as compressive strength and modulus of elasticity, such methods and materials parameter are not available for the evaluation of the durability of concrete structures (Schonlin and Hilsdorf, 1987).

No material is inherently durable, as a result of environmental interaction the microstructure and consequently the properties of material change with time. A material is assumed to reach the end of service life when its properties under given conditions of use have deteriorated to an extent that the continuing use of the material is ruled either unsafe or uneconomical. (Mehta, 1986).

Important of Concrete Durability

The most commonly occurring causes of durability related problems with concrete are acid attack, sulfate attack, freeze-thaw cycles, abrasion or wear, corrosion of reinforcing steel (rebar) and the presence of reactive aggregates. In all cases, the susceptibility of the concrete to deterioration and the rate of deterioration are directly related to the presence of aggressive solutions or water and the porosity and permeability of the concrete as well as the presence of cracks (Senbentta and Malchow, 1987).

Transport properties of concrete are important and deserve thorough investigation as they significantly influence the durability of concrete. Water, carbon dioxide gas, and chloride ions are considered to be primal substances degrading the integrity of concrete structures. These are as a result of their transport through and subsequent with cement hydrates and embedded steel reinforcement. Low permeability of concrete is important to water retaining or submerged structures. Concrete above ground and exposed to the atmosphere should have a low gas permeability so as to prevent carbonation that results from the penetration of carbon dioxide gas into the concrete. In addition, lower gas permeability can be desirable for concrete structures confining radioactive waste materials so as to reduce the risk of emission of radiation. For the case of concrete structures in marine and other-severe environments, chloride permeability which can be used to predict service performance of concrete needs to be understood in relation to the corrosion of steel reinforcement embedded in the concrete cover. (Sugiyama, et al, 1996)

Various properties related to the pore structure within the aggregate particles, such as absorption, porosity, pore size, and pore distribution or permeability, may be indicators of potential durability problems when the aggregates are used in concrete which will become saturated and freeze in service, it is the coarse aggregate particles with relatively high porosity and absorption values (ACI 201, 1991)

Fine aggregate is generally not a problem since the particles are small enough to be below the critical size for the rock type and the entrained air in the surrounding paste can provide an effective level of protection (Gaynor, 1967)

The presence of durability problems may be caused either by the environment to which the concrete is exposed or by internal causes within the concrete itself. The external causes can be physical, chemical or mechanical. They may be due to weathering, occurrence of extreme temperatures, abrasion, electrolytic action, and attack by natural or industrial liquids and gases. The extent of damage produced by these agents depends largely on the quality of the concrete. Nonetheless extreme conditions any unprotected concrete will deteriorate (Neville, 1995)

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The internal causes are the alkali-aggregate reaction, volume changes due to the differences in normal properties of aggregate and cement paste, and above all the permeability of the concrete. The last-named largely determines the vulnerability of concrete to external agencies, so that in order to be durable concrete must be relatively impervious (Neville, 1995).

It has been well established for many years that freezing and thawing action in the temperate regions of the world can cause severe deterioration of concrete. Increased use of concrete in countries having hot climates during recent decades has drawn attention to the fact that deleterious chemical processes such as corrosion and alkali-aggregate reactions are aggravated by high temperatures. Also, the combined effects of cold winter and hot summer exposures should receive attention in proportioning and making of durable concrete. (ACI 201, 1991)

Freezing and thawing damage is a serious problem. The mechanisms involved are now fairly well understood. The damage is greatly accelerated, particularly in pavements, by the use of deicing salts, often resulting in severe scaling at the surface. Fortunately, concrete made with good quality aggregates, a low water-cement ratio, and proper air void system, which is allowed to develop proper maturity before being exposed to severe freezing and thawing, will be highly resistant to such action (ACI 201, 1991)

Sulfates in soil, ground water, or sea water will be resisted by using suitable cementitious materials and a properly proportioned concrete mixture which has been subjected to proper quality control.

The most outstanding technical benefit of incorporating mineral admixtures in concrete is improved durability of the concrete to various types of chemical attack, mainly due to its reduced permeability arising from a pore refining process. But these concrete are also sensitive to temperature and moisture conditions, and need early and longer moist curing than that for normal Portland cement concrete.

Most fly ashes and natural pozzolans when used as admixtures have little effect on the durability of concrete provided that the air content, strength, and moisture content of the concrete are similar. However, a suitable investigation should be made before using unproved materials. Fly ashes and natural pozzolans should conform to ASTM C 618 (1992). GGBF slag should conform to ASTM C 989 (1992). In continental European countries (Belgium, the Netherlands, France, and Germany) blast-furnace slag cement have been used successfully for over a century in concrete exposed to severe freezing and thawing environments, including marine exposures. (ACI 201, 1991)

Curing Condition

Curing is the maintaining of a satisfactory moisture content and temperature in concrete during its early stage so that desired properties may develop. The strength and durability of concrete will be fully developed only if it is cured (Samir et. al, 1988). Therefore, curing practices shown is such as to keep concrete as nearly saturated as possible until originally water-filled space has become filled with hydration products. The necessity for curing arises from the fact that

hydration of cement can take place only in water-filled capillaries. For this reason a loss of water from concrete due to evaporation, in addition to the self-desiccation which is caused by the consumption of water during hydration, must be prevented and be replaced by water from outside (Samir et. al, 1988).

Adequate curing is essential for the proper strength development of normal concrete. It is known that adequate curing is of even greater importance for concrete containing pozzolans such as silica fume, fly ashes, rice husk ash and cementitious material such as GGBF slag and is subjected to hot and dry environments immediately after casting. Because of the low early strength and partly because of the anticipated poor performance due to lack of adequate curing in actual construction practices, the use of pozzolans and concrete as structural materials were restricted (Ramezaniapour, 1995)

The chemical process of hardening continues at a diminishing rate for an indefinite period, as long as moisture is present and the temperature is favourable. Early age, effective curing for a practical period is an essential operation for the adequate and uniform development of a cementitious binding matrix. Not only does it increase the compressive strength of concrete, but improves the requisite qualities of impermeability, abrasion-resistance and general dimensional stability (Gowripalan et. al, 1990)

Durability of concrete is improved by moist curing, through a decrease in permeability and absorption . Nevertheless, fresh concrete that is exposed to the weather must, when necessary, be protected against the possibility of frost action. The retarded rate of evaporation of moisture from air-entrained concrete is conducive to incipient curing, although effective curing in general virtually ceases at a relative humidity below 85 percent.

Neville, 1995 agreed that no loss in strength results from delay of curing for mixes with high water cement ratio, but high strength concrete should be cured at an early age as partial hydration may take the capillaries discontinue and on renewal of curing, water would not be able to enter the interior of the concrete and resume hydration. Premature surface drying may cause crazing or cracking of the surface since concrete has not attained sufficient strength to resist the tensile forces developed as the result of rapid moisture loss. It is important that there be no interruption in the availability of water during the early curing period, to avoid volume changes due to alternate wetting and drying.

In order to obtain good concrete the placing of an appropriate mixture must be followed by adequate curing in a suitable environment during the early stages of hardening. Curing problems are exaggerated when concreting in hot weather due to both higher concrete temperatures and increased rate of evaporation. The durability, strength, and other characteristics of concrete in hot climates are thus critically dependent on its treatment during the first few weeks from the moment it is compacted. Inadequate curing can negate all the earlier care taken in mixture design and concreting operations, and can also lead to serious defects such as plastic shrinkage cracking and excessive drying shrinkage (Austin at. Al, 1992)

Blended Cement

Blended cements are ordinary Portland cements with which pozzolanic material such as calcined clays and shales are blended by intergrinding with the Portland cement clinker. Cost saving was probably the original reason for the development of blended Portland cement. However, the impetus to rapid growth in the production of blended cement in many countries of Europe and Asia came as a result of energy-saving potential. Also, in certain respects, the blended

cements perform better than Portland cement. Presently, the production of slag cements represents nearly 22 per cent of the total cement production of West Germany, and the production of pozzolan cements represents about one-third of the total cement produced in Italy. In the United States the production of blended cements is still in the infancy, there is a growing interest to use pozzolanic (e.g., fly ash) and cementitious materials (e.g., ground granulated blast furnace slag) as mineral admixtures in concrete.

Blended cements contain - in addition to Portland clinker and calcium sulphate a latent hydraulic component such as granulated blast-furnace slag, or a pozzolanic component such as natural pozzolona, low-lime fly ash, burnt clay or an indifferent component such as limestone.

The strength development and ultimate strength of Portland-blast furnace slag cement depends - in addition to clinker quality and fineness- mainly on the quality (i.e. hydraulic reactivity) and amount of slag added. The effect of slag composition on reactivity has been extensively studied. It is generally accepted that the cementing properties of slag are linked to the presence of a glass phase in the material, even though a perfect vitrification is not desired. The reactivity of glass phase is not constant and depends to a great extent on its composition. In general the more basic the slag is, the greater is its hydraulic activity in the presence of alkaline activators including clinker. On the other hand, the response to sulphate activators depends mainly on the alumina content of the slag. At a constant basicity the strength of the resultant cement increases with increasing content of Al_2O_3 in the GGBF slag. MgO contents up to 8-10% may have little influence on strength, while Fe_2O_3 and MnO affect the reactivity and thus the strength adversely.

From economic, technological and ecological points of view, cement replacement materials have an undisputed role to play in the future of the construction industry. Small amounts of inert fillers have always been acceptable as cement replacements, but if the fillers have pozzolanic properties, they impart not only technical advantages to the resulting concrete but also enable largest quantities of cement replacement to be achieved. Many of these mineral admixtures are industrial by products, and correctly considered as waste, so that the resulting benefits in terms of energy savings, economy, environmental protection and conservation of resources are substantial

GGBF slag in Concrete

The historical Development of GGBF slag

Ground granulated blast-furnace (GGBF) slag is a by product in the manufacture of pig iron. It consists of lime, silica, alumina, and minor amounts of magnesia, iron oxide, and alkali oxides. When molten slag is rapidly quenched by water or a combination of water and air, it solidifies in a non crystalline state. The water-quenched product is called granulated slag, and the product resulting from water-air quenching is palletised slag. The use of GGBF slag as a cementitious material dates back to 1774 when Lorient made a mortar using GGBF slag in combination with slaked lime (Mather, 1957).

The first recorded production of Portland blast-furnace slag cement was in Germany in 1892; the first United States production was in 1896. Until the 1950's, GGBF slag was used in production of cement or as a cementitious material in two basic ways: as a raw material for the manufacture of Portland cement, and as a cementitious material combined with Portland cement, hydrated lime, gypsum, or anhydrite (Lewis, 1981).

Since the late 1950's, use of GGBF slag as a separate cementitious material added at the concrete mixer with Portland cement has gained acceptance in South Africa, Australia, the United

Kingdom, Japan, Canada, and the United States (ACI 226.1R, 1987). Separate grinding of GGBF slag and Portland cement, with the material combined at the mixer, has two advantages over the interground blended cements: 1) each material can be ground to its own optimum finesses and 2) the proportion can be adjusted to suit the particular project needs (ACI 226.1R, 1987).

GGBF slag has been available in UK blends with OPC as Portland blast-furnace cement (PBFC) of up to 65% replacement for over 60 years, and also as low heat PBFC, when between 50% and 90% slag is permitted. During the past 20 years or so when widely used as a separate material, levels of between 30% and 60% direct replacement of OPC are common. Higher replacement levels of up to 75% are often used for concrete forming massive sections in order to control thermal properties. GGBF slag has also been used in secant pile construction when up to 85% replacement has been successfully incorporated (Miller, 1993).

Malaysian Standard (MS) 1387 (1995) and British standard (BS) 6699 (1992) are specifications for ground granulated blast-furnace slag on its own. There are two Malaysia Standard and three British Standards relating to cements in which GGBF slag is Component. They are:

- MS 1389 : 1995 and BS 146: Part 2: 1973 *Portland Blast-Furnace cement*.
This cement is a combination of Portland cement and granulated blast-furnace slag with up to 65 per cent slag. This standard was first issued in 1923.
- MS 1388: 1995 and BS 4246: part 2: 1974: *Low heat Portland blast-furnace cement*. This cement is also a combination of Portland cement and granulated slag, but with between 50 and 85 per cent slag.
- BS 4248: 1974: *Supersulphated cement*. This cement is a combination of ground blast-furnace cement, calcium sulphate and Portland cement and has very high chemical resistance (nb, supersulphated cement is currently not readily available)

Hydraulic reactivity of GGBF slag

The hydration product that is formed when GGBF slag is mixed with Portland cement and water is essentially the same as the principal product formed when Portland cement hydrates, i.e., calcium-silicate hydrate (CSH) (ACI 226.1R, 1987)

In the hydration of Portland cement, the tricalcium aluminate phase reacts instantly upon adding water, and the sulfate and hydroxyl ions activate the subsequent hydration of both calcium silicates, alite, and belite. When GGBF slag is mixed with water, initial hydration is much slower than Portland cement or alkali salts are used to increase the reaction rate. Hydration of GGBF slag in the presence of Portland cement depends largely upon breakdown and dissolution of the glassy slag structure by hydroxyl ions released during the hydration of the Portland cement. The hydration of the GGBF slag consumes calcium hydroxide and uses it for additional calcium silicate hydrate formation (ACI 226.1R, 1987).

The clarification of the basic principles of slag hydration makes it possible to identify the primary factors that in practice will influence the effectiveness of the uses of GGBF slag in hydraulic cement (MS 1387 : 1995 / BS 6699 : 1992). These factors are:

- a. composition and manufacture of the GGBF slag.
- b. fineness of the GGBF slag and Portland cement.
- c. glass content of the GGBF slag.
- d. compressive strength of the GGBF slag and Portland cement.
- e. initial setting time of the GGBF slag and Portland cement.
- f. soundness of the GGBF slag and Portland cement.

g. temperature during the early phases of the hydration process.

Due to the complexity of the influencing factors, it is not surprising that earlier attempts to relate the hydraulic quality of GGBF slag to a simplified chemical module, such as :

a. The GGBF slag shall consist of at least two-thirds by mass of the sum of CaO, MgO and SiO₂

$$b. \frac{\text{CaO} + \text{MgO}}{\text{SiO}_2} \geq 1$$

$$c. \frac{\text{CaO}}{\text{SiO}_2} \leq 1.4$$

Failed to provide adequate evaluation criteria for practice. The complexity of the reaching system therefore suggests that direct performance evaluations of workability, strength characteristics, and durability are the most satisfactory measures of the effectiveness of GGBF slag use. The ASTM C 989 (1992) recommends that the GGBF slag activity index to be taken as a basic criterion for evaluating the relative cementitious potential of GGBF slag. Furthermore, proportioning for particular performance requirements should be based on tests of concrete including the same materials to be used in the work.

At the moment, there are no specific mix proportioning methods designed for slag concrete. The material is used as a direct replacement of cement by weight, at proportioning of 25 to 70 per cent by mass of the total cementitious content, and then current proportioning techniques for concrete made with Portland cement or blended cement are followed. Generally, when GGBF slag fineness is of the same order of magnitude as Portland cement, the compressive strength of concrete containing GGBF slag is lower than of a control concrete without GGBF slag, particularly at early ages and at replacement levels of 50 percent and above (Swamy et. al, 1990)

Rheology of Concrete Containing GGBF slag

The present of GGBF slag in the mix improves workability and makes the mix more mobile but cohesive. This is the consequence of a better dispersion of the cementitious particles which are smooth and absorb little water during mixing (ACI 226, 1987)

The types and characteristics of commonly used mineral admixtures are covered by several recent publications (Austin et. al, 1993, Malhotra, 1993, Dhir et. al, 1996).

Both pozzolanic and cementitious mineral admixtures are characterised by fine particle size (high specific surface), and either total absence of crystallinity (glassy structure) or poor crystallinity. Whereas the particle size plays an important role in determining the rheological characteristics of fresh concrete mixtures such as cohesiveness, bleeding, and the workability. The fine particle size of mineral admixtures are not only superior pozzolans on account of their high reactivity, but owing to their high surface area (about 400 to 600 m²/kg blaine surface area) are also very effective in controlling the bleeding tendency in freshly place concrete mixtures. Mixtures with excessive bleeding would produce a weak transition zone; microcracking in the transition zone increases the permeability and reduces the durability of concrete.

Portland blast-furnace slag cement consist of a blend of Portland cement and slag. During

the hydration process, the Portland cement component hydrates initially and the calcium hydroxide formed during the hydration of Portland cement then reacts with the slag to form stable compounds, which results in significant reduction of the size of large pores in the cement paste. Compared to concrete of the same strength made without slag, the effect of the slag is to lower the heat of hydration, reduce permeability, and increase sulfate resistance.

The proportioning techniques for concrete incorporating slag are similar to those used in proportioning concrete made with Portland cement or blended cement. However, due to high proportions of GGBF slag commonly used, allowances should be given for and Portland cement (3.15). Due to the greater solid volume and the higher fineness of GGBF slag, more coarse aggregate may be used without a loss of workability.

Strength Development of Concrete Containing GGBF slag

Due to a blend of Portland cement and GGBF slag contains more silica and less lime than Portland cement alone, hydration of the blended cement produces more C-S-H and less lime than Portland cement alone. The resulting microstructure of the hydrated cement paste is dense. However, the initial hydration of GGBF slag is very slow because it depends upon the breakdown of the glass by the hydroxyl ions released during the hydration of the Portland cement. In a manner similar to blended cements containing pozzolanas, reaction of GGBF slag with calcium hydroxide takes place (Neville, 1995).

The initial rate of hydration of concrete containing GGBF slag is slower than that of concrete without GGBF slag is slower than that of concrete without GGBF slag, but the strength development at later ages is greater. The extent to which GGBF slag affects strength is dependent on the slag activity index of the particular GGBF slag, percentage of replacement of the cement, the water/cementitious ratio, the physical and chemical characteristics of the Portland cement, and curing conditions (Austin et al., 1992).

Hwang and Lin (1986) reported that GGBF slag may be used to replace the major portion of cementitious material when the early strength is not emphasized. However the early strength may be achieved by further grinding of the GGBF slag, high temperature curing, or using low water-cementitious ratio whenever it is appropriate.

Effect of Curing on Porosity, Permeability and Absorption

As with OPC concrete, curing is important if the full potential is to be achieved. Concrete sets and hardens through the hydration reaction between cement and water. Strength and other aspects of durability which depend on the degree of hydration are adversely affected when concrete is allowed to dry out at early ages and hydration is prematurely arrested. Most vulnerable are thin sections exposed to drying conditions during the first few days after casting. There is little effect on the thick sections or more mature concrete. Because GGBF slag hydrates more slowly than OPC, it is potentially more susceptible to this effect (Higgins and Uren, 1991).

Gowripalan et al. (1990) have recently reviewed the effect of the method and duration of curing on porosity, permeability and water absorption of concrete made with OPC and GGBF slag. They reported that concrete containing 70% GGBF slag had a lower porosity when cured at 35°C in comparison with specimens cured at 21°C, which illustrates the potential advantage of using cement replacements in hot climates.

Curing temperature can significantly increase the strength of concrete containing GGBF slag at early stages. When the curing temperature gets as high as 80°C, it may have a negative

effect on the strength (Hwang and Lin, 1986).

Prolonged moist curing of concrete containing GGBF slag is particularly important because the initial low rate of hydration results in a system of capillary pores which allows the loss of water under drying conditions. If this happens, continuing hydration cannot take place. Japanese recommendations (1988) for curing may be of interest; these are shown in Table 2.6.

TABLE 2.6.

Japanese Recommendation for Moist Curing of Concrete Containing different Percentages (by Mass of Total Cementitious Material) of GGBF slag.

Air Temperature (°C)	Minimum period of moist curing (days) at GGBF slag content of (per cent)		
	30 to 40	40 to 55	55 to 70
≥ 17	5	6	7
10 to 17	7	8	9
5 to 10	9	10	11

Oxygen permeability measurements have some practical significance because the availability of oxygen is one of the factors controlling corrosion of steel reinforcement in concrete. The importance of curing is apparent from oxygen permeability test results where near surface oxygen permeability of non cured concrete can be eight to ten times that of well cured (Gowripalan et. al, 1990).

In a study of high strength concrete incorporating GGBF slag, Nakamura et al. (1986) reported that substitution of 40% of Portland cement by an equal mass of GGBF slag significantly increased both the static and dynamic moduli of elasticity of concrete at age of 91 days. This result can be explained by noting that the modulus of elasticity is much more dependent on the transition zone than is the compressive strength.

Furthermore, tests performed on specimens of the same age showed that the 40% GGBF slag cement concrete was less permeable and more durable to cycles of freezing and thawing than a comparable Portland cement concrete. These improvement can also be attributed to the changes in the transition zone.

The use supplementary cementitious materials like GGBF slag in concrete construction is wide spread due to the economic, technical and environmental benefits of these materials. However concrete made with GGBF slag was reported to be sensitive to lack of curing (Haque and Chulilung, 1990).

Water absorption can be used to compare different methods of curing, provided that the same conditioning is adopted for all specimens. The results will depend mainly on the volume of capillary pores and pore size distribution. Increasing the duration of water curing from one day to three days reduces water absorption considerably for mixes with slag exposed to hot environments. The effect is not so significant in the case of OPC mixes (Wainwright et. al, 1985).

The most acknowledged property of blended cement is the difference in rates of gain in

both initial and longer term strength, these being due to the differences in hydration chemistry of GGBF slag. Some general observations regarding as follows; a) the higher replacement level of GGBF slag produce lower strength at early age; b) latent strength beyond 28 days are increased again depending on the quantity of GGBF slag present; c) early strength with GGBF slag replacement can be dependent on the reactivity of the source of the slag; d) the temperature to which an in-situ concrete element reaches during hydration can have a bearing on the strength of concrete (Miller, 1993).

Ramezaniapour (1995) reported that the reduction in the moist curing period produced lower strengths, higher porosity and more permeable concretes. The strength of concrete containing GGBF slag appears to be more sensitive to poor curing than the control concrete. He also reported that concrete incorporating GGBF slag increased the resistance to chloride ions and produced concrete with very low permeability.

Khatri et. al, (1997) have reviewed the effect of curing on water permeability made with specimen containing 65% GGBF slag and 7% silica fume and were tested at 7 and 28 days cured at various curing regimes. They reported that twenty-eight days intermittent curing was found to be as effective in reducing permeability as 7 days of continuous moist curing for all types of binder examined. As expected, 28 days of continuous moist curing gave the lowest coefficient of permeability. The results also found that the coefficient of permeability decrease with increasing strength.

There is no significant effect of carbonation on concrete containing GGBF slag. Because of the small amount of calcium hydroxide present in the hydrated cement paste, carbon dioxide does not become fixed near the surface of the concrete so there is no pore-blocking formation of calcium carbonate. Consequently, at early ages, the depth of carbonation is significantly greater than in concrete containing Portland cement only (Day, 1995). On the other hand, the low permeability of well-cured concrete containing GGBF slag prevents a continuing increase in the depth of carbonation (Bakker, 1985). For this reason, except when the GGBF slag content is very high, there is no increased risk of corrosion of steel reinforcement through a reduction in the alkalinity of the hydrated cement paste. (ACI 226, 1987).

Summary

GGBF slag have a extensive history of successful use and have been found to provide considerable durability benefits. Many beneficial effect using the GGBF slag in concrete was presented, it is clear that its advantages are in the improvement of properties and microstructure characteristic concrete such as the former including low heat, high resistance to the penetration chloride, reducing permeability, alkali-silica reaction (ASR) protection and long term strength.

Due to the hydration of GGBF slag in combination with OPC is generally a two stage process, and because GGBF slag hydration tends to lag behind that of the OPC component's hydration, slag concrete are likely to be more susceptible to poor or inadequate curing conditions than will concrete containing only OPC. However, there are on the effects of curing concrete containing GGBF slag, especially detailed information on the engineering implication of mix proportioning and adequate curing with special reference to strength development, permeability, absorption and porosity.

The review also reveals the need for more investigation to be carried out using GGBF slag as partial cement replacement in concrete. Limited published reports are available on the use of GGBF slag cured in tropical climate countries. Its potential contribution to concrete durability is not properly understood.

Thus it is clear the study on the use GGBF slag in concrete has to be encouraged. Three major engineering properties and a microstructure characteristic to be investigated in the study of the effects of partial replacement of cement by GGBF slag, are strength, permeability, absorption and porosity.

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Materials, Manufacture, Curing and Testing Procedure

Introduction

This chapter deals with the preparation of the raw materials (such as cement, fine aggregate, coarse aggregate, and admixtures), material physical properties as well as the technique employed for the manufacture, and the preparation of the test specimens. All the testing procedure involved in the investigation are outlined.

Material for Concrete Specimens

Aggregates

The fine and coarse aggregates were local natural sand and crushed gravel, respectively. A coarse aggregate with a nominal size of 20 mm and a zone 2 fine aggregate grading (BS 882 : 1983) were used throughout. The results of the sieve analysis of the fine aggregate and coarse aggregate are shown in Fig. 3.1. Each point on the curve represents the average of three analyses. It can be seen that the curve lies within the grade M fine aggregate and 20 mm nominal size for coarse aggregate.

Cement

The ordinary Portland cement was used "CAP SELADANG" produced by Tenggara Cement Manufacturing Sdn. Bhd., Johor, Malaysia. The physical properties and chemical analysis of which are given in Table 3.1.

GGBF slag

GGBF slag from APMC was used. The chemical composition of the GGBF slag is also shown in Table 3.1.

Superplasticizer

This research used a CONPLAST 2000 superplasticizer at 0.7 % volume by weight of cement content as chemical admixture that was produced by Fosroc Expandite Sdn. Bhd., Pulau Pinang, Malaysia.

TABLE 3.1.**Average of physical properties and chemical analysis
of cementitious materials**

Description of test	Portland cement Cap " SELADANG"	GGBF slag
Physical Tests		
Specific gravity	3.28	2.90
Surface area (m ² /kg)	314	420
Chemical analysis (per cent)		
Silica dioxide (SiO ₂)	20.20	28.2
Aluminium oxide (Al ₂ O ₃)	5.7	10.0
Ferric oxide (Fe ₂ O ₃)	3	1.8
Calcium oxide (CaO)	62.58	50.4
Magnesium oxide (MgO)	2.60	4.6
Sulphur trioxide (SO ₃)	1.80	2.2
Sodium oxide (Na ₂ O)	0.16	0.14
Potassium oxide (K ₂ O)	0.87	0.6
Loss on Ignition (LOI) *	2.70	0.2

(*) This consists of moisture and CO₂. High values are often an indication of poorly stored cements. The usual limit is 3.0 percent maximum with higher values for cements containing pulverised fuel ash (Corish, 1985)

Determination of Compressive Strength*Specimen Preparation and Curing*

The mix proportions comprising of cement, GGBF Slag, coarse aggregate, fine aggregate and water for each batch of casting are shown in Table 3.2. The table shows the total weight of mix proportion for 1 m³ of concrete. The volume of concrete mix were adjusted according to the volume of specimens required per mix. Plate . 3.1. show the mixer used in this research.

TABLE 3.2**Mix proportions of concrete incorporating GGBF slag**

Types	W/C	Cement (Kg)	GGBFS (Kg)	water (Kg)	fine aggregate (Kg)	coarse aggregate (Kg)
Slag- 0 % (S - 0)	0.4	525	0	210	670	1005
	0.5	420	0	210	712	1068
Slag-40 % (S - 40)	0.4	315	210	210	670	1005
	0.5	252	168	210	712	1068
Slag-60 % (S - 60)	0.4	210	420	210	670	1005
	0.5	168	252	210	712	1068

100 mm cube specimens were casted in steel moulds. Placement was done in two layers, with each layer compacted by hand for 25 drops. Immediately after compaction, the excess concrete was removed and the top surface was levelled and smoothed using a trowel. In order to reduce evaporation, the exposed top of the cubes were covered using wet gunny sacks. The specimens were demoulded after 24 hours and marked for later identification followed by immediate curing in water at 20°C and 27°C. These specimens were tested for 3, 7, 14, 28, 60, 120, 180 and 365 days. The long side the cylinders specimens were cast for permeability, absorption and porosity tests. Plate 3.2 and 3.3 shows the specimen casted in cubes and cylinders and specimen curing tank.

Testing procedure

Compression tests were performed using TONIPACT 3000 testing machine operating at a constant loading rate of 0.3 KN/s (BS 4551: 1980). The testing arrangement are as shown in Plate 3.5. The specimens which were cured in water were removed from the container and covered with wet tissue cover to retain the moisture before testing. The ends were dried and placed in the testing machine at room temperature in saturated state.

The water cored specimens were tested at 3, 7, 14, 28, 60, 120, 180 and 365 days. The specimens immersed in sea water and exposed at air were tested at the age of 28, 180 and 365 days.

Test Results and Discussion**Introduction**

The development of cement and concrete capable of resisting chemical attack has been the subject of research and development for many years. It is most essential for concrete to be cured adequately to benefit the utmost potential with regards to strength and durability. The curing becomes even more important if the concrete contains supplementary cementing materials such

as GGBF slag.

This chapter reports the results of research investigation in which the performance of concrete containing GGBF slag was studied under two curing temperatures. These include moist curing at temperature of 20°C and 27°C, with water-cement ratio of 0.4. All results will be presented in the form of tables and graphical plots.

Compressive Strength

The results of compressive strength investigation described in section 3.3 on concrete specimens containing 0, 40 and 60% GGBF slag moist cured at 20°C and 27°C are shown in Table 4.1 and Fig. 4.1. Tests were performed on concrete at specimen ages ranging between three days and one year.

TABLE 4.1

The compressive strength values of concrete moist cured at 20°C and 27°C, w/c = 0.4

Mix	Curing	Compressive strength (MPa)							
		3-d	7-d	14-d	28-d	60-d	120-d	180-d	1-yr
Control	27°	35.90	43.40	50.70	56.50	61.30	65.00	66.43	69.55
S - 40	20°	26.63	42.25	49.20	53.85	62.60	67.28	71.20	75.23
S - 40	27°	31.55	42.50	47.80	55.15	58.12	64.30	70.45	74.20
S - 60	20°	24.82	35.40	44.30	50.76	56.60	60.30	64.37	65.75
S - 60	27°	31.82	41.57	47.4	54.80	58.20	62.30	65.87	68.54

At three days, the highest strength of 35.9 MPa is obtained for control concrete (concrete without GGBF slag moist cured at 27°C). This is followed by concrete containing 40% GGBF slag moist cured at 20°C, 27°C and specimen with 60% GGBF slag moist cured at 27°C at strength values of 26.63, 31.55 and 31.82 MPa respectively.

The lowest value of 24.82 MPa is for concrete with 60% GGBF slag moist cured at 20°C. The results indicate that the specimens moist cured at 27°C achieve higher strength values than those moist cured at 20°C. However, there is no clear relationship between replacement level of GGBF slag on the strength development of concrete.

At 28 days, the control concrete achieves the highest strength value of 56.50 MPa. This is followed by concrete incorporating 40% slag moist cured at 27°C, 60% GGBF slag concrete moist cured at 27°C and 20°C at strength values of 55.15, 54.8 and 53.85 MPa respectively. The lowest compressive strength value at 28 days is 50.76 MPa for 60 % GGBF slag concrete moist cured at 20°C. The figures shows that initial rate of hydration of GGBF slag is slower than that of Portland cement. The figures also indicate that up to 28 days of age the control specimen is the most superior in strength achievement. The results also indicate that irrespective of replacement level of GGBF slag, the 27°C moist cured specimens achieve higher strength value than those moist cured at 20°C. Table 4.1 also shows that the specimen moist cured at 20°C shows higher strength value for lower GGBF slag replacement level. However, at 27°C there is comparable strength development for both replacement levels.

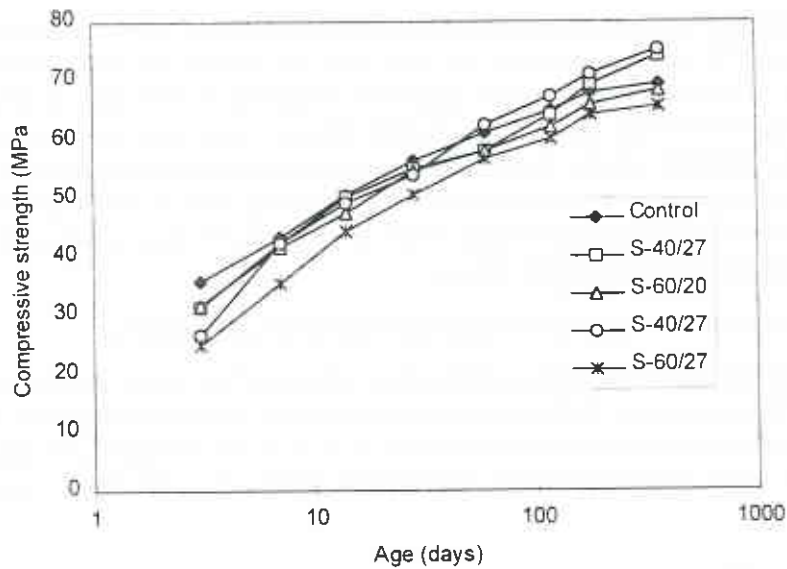


Fig. 4.1 Compressive strength development of moist cured concrete, $w/c = 0.4$

At one year, the concrete incorporating 40% GGBF slag moist cured at 20°C achieves the highest strength value of 75.23 MPa. This is followed by concrete incorporating 40% GGBF slag moist cured at 27°C, control concrete, and concrete containing 60% GGBF slag moist cured at 27°C at strength value of 74.2, 69.55 and 68.54 MPa, respectively. The lowest compressive strength values of 65.75 MPa is given by specimen containing 60% slag moist cured at 27°C. The results show that lower replacement level of GGBF slag produce higher strength values, irrespective of curing temperatures. The results indicate that there is no significant effect of temperature strength on achievement for all specimens beyond 120 days.

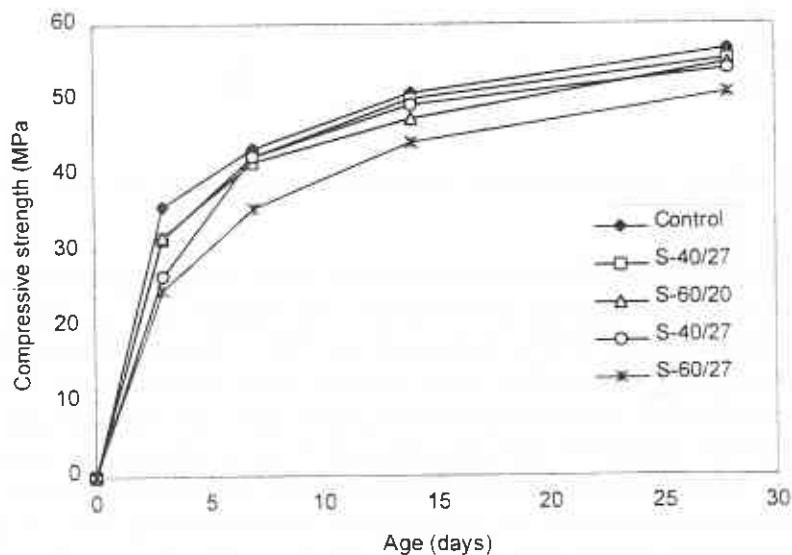


Fig. 4.2 Early age compressive strength development of moist cured concrete $w/c = 0.4$

The compressive strength development of concrete at various replacement levels of GGBF slag moist cured at 27°C are shown in Fig. 4.2. At 3 days the control specimen obtains the highest strength value in comparison with concrete specimen containing GGBF slag. At 28 days concrete sample containing 40% GGBF slag exhibits higher strength value than sample containing 60% GGBF slag. However, these are still lower than strength value is given by the control sample. The highest strength value is given by the specimens incorporating 40% GGBF slag at one year. The figure also indicates that the optimum replacement level of GGBF slag in concrete is about 40% GGBF slag (based on one year strength results).

The contribution of GGBF slag to Strength Development in Concrete

The curing temperatures for this investigation consists of two types namely, water curing at 27°C and 20°C. The results show that the compressive strength value increases with increasing age. The specimens with water-cementitious ratio value of 0.4 incorporating GGBF slag moist cured at 20°C, and 27°C show that the optimum replacement levels of GGBF slag in concrete is about 40%..

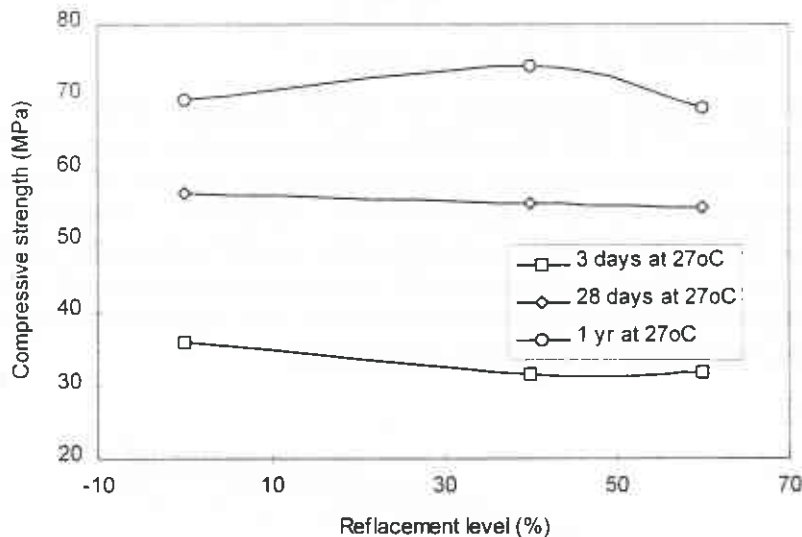


Fig. 4.3 Compressive strength development of concrete at various replacement levels of GGBF slag moist cured, $w/c = 0.4$

At three days, the results indicate that the specimens cured at higher temperature produce higher strength values. However, these are still lower than the strength value of control concrete. Other researchers (Ramezaniapour (1995), Kobuku et. Al (1989), Chern and Chan (1989)) found that concrete containing GGBF slag produce lower strength values in comparison with control concrete, but that under elevated curing temperatures (greater than 20°C) the strength of GGBF slag concrete continues to increase at later ages (beyond 28 days) whereas the corresponding OPC concrete strength is constant or decreases at same condition. It also been reported (Austin et al., 1992) that the initial rate of hydration of slag cement is slower than that of Portland cement, but the strength development at later ages is greater. Neville (1985) also reported that initial hydration of GGBF slag is very slow because it depend upon the breakdown of the glass by the hydroxyl ions released during the hydration of the Portland cement. The reaction of GGBF slag

with calcium hydroxide takes place in a manner similar to blended cements containing pozzolanas.

At one year, specimens with water-cementitious ratio of 0.4, the highest strength values is given by concrete containing 40% GGBF slag moist cured at 20°C. There is clear effect of curing temperatures on strength development. The optimum replacement levels of GGBF slag in concrete is about 40% (based on one year strength results). The results show that higher replacement level of GGBF slag could not produce higher strength value. Robin et. al (1992) point out that in the hot arid conditions some of the moist cured slag mixes produced higher 28 days strength than the OPC mix; the best of replacement levels studied was the 50% GGBF slag in mix (three GGBF slag concrete are 0, 30, 50 and 70% cement replacement were investigated).

Summary

The initial rate of hydration of GGBF slag in concrete is slower than that of Portland cement, but the strength development development at later ages is greater. Generally concrete at all replacement levels of GGBF slag behaves in a similar manner to the plain concrete control with regard to the effects of curing temperature. The rate of strength development, the magnitude of the maximum highest strength development attained, and the time of its attainment is highly dependent on the slag activity index, the physical and chemical characteristics of the Portland cement, curing temperature, curing condition, and water-cementitious ratio in concrete.

The strength values of concrete containing GGBF slag at early ages tend to be lower in comparison with the control, particularly at higher replacement levels of GGBF slag in concrete. At early ages, the specimens containing GGBF slag cured at higher temperature produce higher strength value.

Conclusion and Recommendations

Conclusion

1. Generally concrete at all replacement levels of GGBF slag behaves in a similar manner to the plain concrete control with regard to the effects of curing temperature. The rate of strength development, the magnitude of the maximum highest strength development attained, and the time of its attainment is highly dependent on the curing temperature, curing condition, water-cementitious ratio in the concrete.

The strength values of concrete containing GGBF slag at early ages tend to be lower in comparison with the control, particularly at higher replacement levels of GGBF slag in concrete because it depend upon the breakdown of the glass by the hydroxyl ions released during the hydration of the Portland cement. At early ages, the specimens containing GGBF slag cured at higher temperature produce higher strength value.

3. The optimum replacement levels of GGBF slag is 40%, this is based on one year results. Strength development of concrete using GGBF slag will depend on a large number factors including the properties and proportions of the GGBF slag, the Portland cement, and other concrete ingredients, and also curing temperatures.

The maximum compressive strength value achieved by specimen incorporating 40% slag cured in water at 20oC, with water-cementitious ratio value of 0.4. This result also higher than control concrete. However there is comparable performance with both specimens.

Recommendation and Suggestion in Future Study

Though progress has been made in the used of supplementary cementing materials, there are a number of areas that used need additional research. Thses include the following; optimation of the amount of materials as cement replacement in concrete: developing a compressive strength data base on GGBF slag concrete with defferent water-cementitious ration: studying long term performance in marine environment: studying the effect of behavior of concrete mechanisms of attack on concrete surfaces, and determining the effects of early of age curing.

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Aktivitas Bakterisida Pada Ekstrak Cabai Kecil dari Berbagai Varietas (*Capsicum frutescens*)

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*A laboratory experiment was conducted to measure the strength of the inhibitory effect and the lethal dose of hot chili extract (*Capsicum frutescens*) on *Escherichia coli*. For this purpose, chili extract from three different varieties (White, Hot, and Bara) were used in respectively 0 percent, 5 percent and 10 percent (v/v) concentration. The bactericidal activity was determined by culturing *E. coli* and was then measured with spectrophotometer. Then, the research decided its lethal dose by measuring the total bacteria in the nutrient medium added with chili extract with the highest inhibitory effect.*

The result shows that the Bara, White, and Hot chili extracts have bactericidal activities with LD 1%, 5%, and 5% respectively. It is the Bara which has the highest capability of killing bacteria or the inhibitory factor.

Pendahuluan

Cabai (*Capsium* sp) dalam kebiasaan masyarakat Jawa, dijadikan bahan ramuan obat tradisional. Daun cabai sangat mujarab untuk mengobati luka maupun gangguan pencernaan. Cabai rawit (*C. frutescens*) dapat menyembuhkan sakit tenggorokan karena kaya akan vitamin A. Rasa panas yang ditimbulkan oleh cabai dapat dimanfaatkan untuk menggantikan fungsi kayu putih, sehingga dapat mengurangi pegal-pegal, rematik, sesak napas dan gatal-gatal (Makfoeld, 1983; Setiadi, 1992; Sugeng, 1984).

Cabai mengandung zat *capsicol* dan *capsaicin* (minyak atsiri oleoresin). Pada umumnya, minyak atsiri berperan sebagai bakterisida dan fungisida yang sifat penghambatannya spesifik. Beberapa jenis minyak atsiri digunakan sebagai bahan antiseptik internal atau eksternal, bahan analgesik, haemolitik, sebagai sedatif dan stimulan untuk obat sakit perut (Guenther, 1990). Karena senyawa yang terdapat di dalam cabai diduga dapat berperan sebagai bakterisida. Hal ini didukung hasil penelitian Astuti (1996) yang menunjukkan bahwa ekstrak cabai kecil mempunyai efek penghambatan terbesar terhadap pertumbuhan bakteri *Escherichia coli* dengan LD 50 = 1%, bila dibandingkan dengan ekstrak cabai Hijau dan cabai Merah dengan LD 50 = 6% - 15%.

Rasa pedes yang ditimbulkan oleh cabai dimanfaatkan sebagai penyedap makanan dan dapat menimbulkan nafsu makan (Makfoeld, 1983; Setiadi, 1992; Sugeng, 1984). Menurut Frazier dan Westhoff (1978), rempah-rempah yang ditambahkan pada pengolahan makanan umumnya bertujuan untuk memberi rasa dan aroma yang spesifik pada produk, sebagai pengawet alami atau antioksidan. Selain itu rempah-rempah juga digunakan sebagai bahan obat-obatan, kosmetika, wangi-wangian dan industri kimia lainnya (Guenther, 1987). Frazier (1978) menduga bahwa rempah-rempah dapat dijadikan agen antimikrobia yang dapat digunakan untuk adanya zat