THE ACCURACY OF MICRO-CORE COMPRESSIVE TEST TO PREDICT THE STRENGTH OF CONCRETE

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ABSTRACT

In-situ compressive strength of concrete is the process of quality control of concrete. The methods widely accepted for determining the compressive strength of concrete in existing structures is concrete core test. In this study, the idea is replacing the standard core with micro-core in concrete core test. The objective of this study is to compare the compressive strength for both standard core and micro-core. According to international standards and recommendations, the most suitable diameter for testing in laboratory is 100 mm diameter. However, drilling core concrete sample on such rather large size cores may cause hazardous in many cases. In this regard, the estimate strength of concrete in structures may be gained from compression test of core having the diameter less than 100 mm. As it is not always safe to drill cores of 100 mm diameter, utilizing smaller diameters is more practical. Micro-cores have many advantages such as can be drilled in-situ with very light equipment that can greatly reduced costs and less damage to the structure. This paper examines the results of the in-situ compressive strength tests applied on 100 mm and 25 mm diameter drilled from slab specimen. The results were analyzed using linear regression analysis and detailed statistical analysis.

ABSTRAK

Kekuatan mampatan konkrit in-situ adalah proses kawalan kualiti konkrit. Kaedah yang diterima secara meluas untuk menentukan kekuatan mampatan konkrit dalam struktur sedia ada adalah ujian teras konkrit. Dalam kajian ini, idea menggantikan teras standard dengan teras mikro di dalam ujian teras konkrit. Objektif kajian ini adalah untuk membandingkan kekuatan mampatan bagi kedua-dua teras standard dan teras mikro. Mengikut piawaian antarabangsa dan cadangan, diameter yang paling sesuai untuk ujian di makmal ialah 100 mm. Walau bagaimanapun, menggerudi sampel teras konkrit untuk teras saiz yang agak besar boleh menyebabkan berbahaya dalam banyak kes. Dalam hal ini, anggaran kekuatan konkrit dalam struktur boleh diperolehi daripada ujian mampatan teras yang mempunyai diameter kurang daripada 100 mm. Kerana ia tidak sentiasa selamat untuk menggerudi teras berdiameter 100 mm, menggunakan lebih kecil diameter lebih praktikal. Teras mikro mempunyai banyak kelebihan seperti boleh digerudi in-situ dengan peralatan sangat ringan yang mana ia boleh mengurangkan kos dengan banyak dan kurang kerosakan kepada struktur. Kertas kerja ini mengkaji keputusan ujian kekuatan mampatan in-situ yang diuji ke atas 100 mm dan 25 mm mikro-teras yang digerudi dari spesimen papak. Keputusan telah dianalisis dengan menggunakan analisis using linear regression analysis dan detailed statistical analysis.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

The construction in Malaysia is growing in the early 1990s in conjunction with the development of mammoth project. The Vision 2020 has launched by government to envision that Malaysia will be a fully industrialised country by the year 2020. The government has invested heavily in the infrastructure of the Kuala Lumpur metropolitan area to achieve Vision 2020. The modernisation is designed to propel Malaysia into the digital age and position it as a hub for high technology businesses in Southeast Asia.

Concrete are most widely used in construction that commonly made by mixing Portland cement with aggregate (sand and crushed rock) and water. Kumar and Paulo (2006) stated today the rate at which concrete is used is much higher that it was 40 years ago. It is estimated that the present consumption of concrete in the world is of the order of 10 billion tonnes (12 billion tons) every year. The structural elements can be formed into a variety of shapes and size. That because freshly made concrete is a plastic consistency. Plastic consistency which permits the material to flow into prefabricated formwork. After a number of hours, concrete has solidified and hardened to a strong mass.

At present, the methods widely as a basis of quality control is compression testing of cubes and it represents the potential strength of the concrete used. The main parameters determining the qualities of concrete are its compaction, composition and curing. In this case, composition of concrete going into the cubes and that going into the structure is the same. Limaye, B. R. (2002) stated that the methods of compaction and curing may be usually are different for the cubes and the structural members. This is why the results obtained on cubes may not truly represent the quality of concrete in the structure.

During construction, the test is usually performed for quality is by testing standard specimens (cubes or cylinders) made from the same batch that is used in the construction. However, there are many objections to this procedure due to many factors between laboratory and in-situ conditions. One of the objection is the results from the standard specimen tests might not represent the actual properties of concrete in a structure. To solve this problem, other methods are used to do in-situ core testing which is accepted as reliable and gives useful results since the cores are mechanically tested to destruction.

On the basis of results obtained from tests on cores drilled from structure, the strength level of the concrete in the structure can be determined. The decisive factor in determining the quality of the concrete is the strength level. The strength level is an appropriate criterion, it is important to determine the actual strength of concrete. In order to estimate the quality of the concrete, it is required to drill and test large number of core cylinder samples. For the core cylinders are to be used for compression test, British and American standards stated that the core is at least three times the nominal maximum aggregate size.

According to the international standard, it is recommended that a minimum diameter of 100 mm should be used for compression test. However, core cylinders are having diameter smaller than 100 mm is permitted when the core is intended to be used for determination of in-situ strength of concrete. Since it is not always possible to drill core which small diameter, researchers and practitioners are often forced to utilize 38 mm or 1.5 inch diameter cores (micro-cores).

Micro-cores are offer many advantage such as can be drilled in-situ with very light and easy to wield equipment. That also gives benefit in greatly reduced costs for the core test. Compared to other non-destructive methods, micro-core testing offers one significant advantage in that the estimate of average concrete strength in-situ is obtained directly from an analysis of the results of compression tests performed on the concrete being considered (Indelicato, F., 1997).

However, the result of this test should be interpreted carefully. It is because the result of core strength are affected by many factor such as size of diameter use for testing, length to diameter ratio (l/d) and also the moisture condition of the core specimens. The most important for this test is diameter of the core because that plays an important role in the evaluation of core strength results.

What is more important, the damage of the structure becomes virtually negligible and this test is can possible to be classified as a non-destructive method by using this micro-cores. In this respect, micro-core testing brings together the advantages of classical core tests and those offered by non-destructive methods.

1.2 Problem Statement

One of the problems to estimate of in-situ concrete strength is most frequently encountered whenever it is necessary to assess the bearing capacity of a structure. Therefore, research in this field has been very active and has led to the development of a wide variety of destructive and non-destructive methods.

The standard method, involving the use of compression tests on cylindrical specimens obtained from cores drilled in-situ from concrete structures, this method are as the safest method, despite the fact that the results obtained are always influenced by a great number of parameters which may result in considerable interpretation errors. According to the most common international standards and recommendations currently in force, in fact, the minimum core diameter is generally fixed at 100 mm or 4 inch with the fact that the drilling of holes may weaken the structural elements in which they are made. This means that core drilling may prove hazardous were core drilling is mostly applied to structures whose concrete strength is being questioned.

Since to drill cores of 100 mm diameter is does not always prove possible, experimenters are often forced to utilize smaller diameters, but the small diameter of core is harder to assess the result correctly and to translate core strength into the corresponding strength values as would be obtained on standard specimens, such as the cubes specified by many existing standards.

1.3 The objective of Study

The aim of this study has been to develop and compare methods for the in-situ estimation of core strength by testing and comparing specimens of different diameters. In this experimental investigation, the in-situ compressive strengths of 25 mm diameter micro-cores and 100 mm diameter standard core were investigated.

The strength values measured on standard cores and miro-cores produced from the same concrete mixes were then used to work out the correlation curves and the relative confidence intervals. The results and the relationships obtained were compared and analysed to assess their validity for the estimate of the cube strength of existing structures.

1.4 The Scope of Study

The concrete sample of grade G25, G30, and G35 will be prepared and cast to form a concrete slab. The size of concrete slab is 700 mm x 700 mm x 300 mm. After age of concrete of 28 day, the slab will be drill to take six concrete core samples for both diameter sizes. There are two sizes of concrete core diameter; 100 mm (4 inch) and 25 mm (1 inch). The length to diameter ratio (l/d) of the concrete core should be 2:1. For the 100 mm diameter concrete core sample, the length is 200 mm and for the 25 mm, the length is 50 mm.

In order to accomplish the aims and the objective of this research, laboratory work will be done. The concrete core sample will be test by using concrete compression test machine. The scope is related to the material and equipment that involve in this study and fulfil the requirement according to standard BS 1881: Part

116:1983: Concrete Compression Test and ASTM C42/C42M–11: Standard Test Method for Obtaining and Testing Drilled Cores. BS EN 12348:2000+A1:2009: Core Drilling Machines on a Stand.

1.5 Significant of Study

Although the construction industry in this country is grown following the market required but concrete micro-core test is not be used for the commercial to determined the concrete strength. The application in construction area especially in Malaysia is still cannot be determined. Therefore, by conducting this study the concrete micro-core test can be further investigated and contribute to expand the use of this test.

Besides, the study can help to promote the new alternatives to determine the concrete strength in construction industry. Therefore concrete micro-core test has a big potential to bring about economic, financial benefit and safety. Finally, the data obtained during this research can be applied or use as a reference in future research to improve the outcome obtained.

1.6 Conclusion

This chapter has discuss more to the introduction for this whole study. The objective for this study has already clearly stated to compare the core strength between standard cores and micro-cores. This research is required because of the standard core that usually use for estimate of in-situ concrete strength is faced many problem such as could damage the structure and not suitable to core the samples in certain areas.

Therefore, the research of core test using micro-cores was conducted to find the relative between standard cores and micro-cores. Micro-core offer many advantages such as greatly reduce the cost and can be classified as a non-destructive method. For this research, three grade of concrete were used, grade G25, G30 and G35.

The scope is related to the material and equipment that involve in this study and fulfil the requirement according to standard BS 1881: Part 116:1983: Concrete Compression Test and ASTM C42/C42M–11: Standard Test Method for Obtaining and Testing Drilled Cores. BS EN 12348:2000+A1:2009: Core Drilling Machines on a Stand.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Recently, concrete is a very important material and widely used in construction industry. Concrete is one of the single most environmentally friendly construction products available. According to Kayne, R. (2011) are define that concrete is a masonry material that uses cement to bind together crushed stone, rock and sand. Concrete has a high compressive strength, built-in-fire resistance, durability and low maintenance. Although concrete is very strong, it requires reinforcement if used as a building material because of its poor tensile strength, or ability to withstand the horizontal forces or sway buildings must endure from wind or earthquakes (Kayne, R., 2011).

Quality of concrete is related to the quality of material that used to mix it. If materials have a high quality, the concrete also will have a high quality (Lomborg, 2001). The strength of concrete is affect by the age of concrete. According to Lomborg (2001) state that concrete grows stronger with increase of age. Kadir Kilinc et al. (2010) said that the actual strength of concrete in the structure is a random variable which is affected by many factors such as the age of the concrete, the compaction quality, curing, and the size and type of the load-bearing member.

Today, there are many testing conducted to determine the strength of the concrete. In-situ methods are most widely accepted used for determined the compressive strength of the concrete. According to Kadir Kilinc et al. (2010) state that core testing is one of the widely accepted methods for assessing in-situ strengths.

Testing for standard core can be classified as destructive test method. For the standard core test can be classified as destructive method. This method is an expensive and time consuming procedure. However, according to many researchers, this test is reliable and give the useful result on determine the concrete strength.

For face that problem, many researchers conduct the experimental to reduce the size of concrete core and it is call micro-cores. There are many advantages for using micro-cores for the testing. According to Kadir Kilinc et al. (2010) the micro-core is greatly reduced cost and less damage for structure. The statistical characteristics of micro-cores on the other hand are not understood completely.

2.2 Concrete Material

Concrete are most widely used in construction that commonly made by mixing Portland cement with aggregate (sand and crushed rock) and water. Concrete is define as a composite construction material that composed of aggregate (coarse aggregate generally made of crushed rock or gravel and fine aggregate such as sand), cement (commonly used Portland cement) and water. According to Kumar and Paulo (2006), today the rate at which concrete is used is much higher that it was 40 years ago. It is estimated that the present consumption of concrete in the world is of the order of 10 billion tonnes (12 billion tons) every year.

Freshly made concrete is a plastic consistency that permits the material to flow into prefabricated formwork. By using concrete, the structural elements can be formed into variety of shape and size. After a number of hours, concrete has solidified and hardened to a strong mass.

2.2.1 Cement

In the most general sense of the word, cement is a binder, a substance that sets and hardens independently, and can bind other materials together. Cement is made from limestone, calcium, silicon, iron and aluminium, plus lesser amounts of other ingredients.

Blackledge (1999) stated that cement consists of a mixer of oxides of calcium, silicon and aluminiums. Portland cement is the most common type of cement in general usage. It is a basic ingredient of concrete, mortar and plaster. The water and cement paste hardens and develops strength over time. According to Kayne, R. (2011) said that when water is added to cement, a chemical process occurs as it hydrates, allowing it to harden.

2.2.2 Aggregates

Aggregate is granular material such as sand, gravel, crushed stone, blast-furnace slag, and lightweight aggregates. The most mined in the world is aggregate. Aggregate is A recent report (ACI Committee E-701, 2007) highlighted the aggregate are usually occupies approximately 60 to 75% of the volume of concrete. Aggregate properties significantly affect the workability of plastic concrete and also the durability, strength, thermal properties, and density of hardened concrete. By using aggregate the concrete much stronger, with the aggregate acting as the type of reinforcement.

Aggregate also increase the lifetime of the concrete and make the concrete more durable. All aggregate is divided into two types; fine and coarse aggregates. Both fine and coarse aggregates are used to make up the bulk of a concrete mixture. Sand, natural gravel and crushed stone are mainly used for this propose.

Kumar and Monteiro (2006) stated that fine aggregate is defined as material that will pass a No. 4 sieve and will, for the most part, be retained on a No. 200 sieve or it lower than 5 mm. Fine crushed aggregate will pass through a No. 4 sieve but will be stopped by a No. 200 sieve during the aggregate screening process or sieve analysis. The purpose of the fine aggregate is to fill the voids in the coarse aggregate and to act as a workability agent. For increased workability and for economy as reflected by use of less cement, the fine aggregate should have a rounded shape.

Properties of the coarse aggregate affect the final strength of the hardened concrete and its resistance to disintegration, weathering and other destructive effect. When put through a separator or aggregate washer, coarse crushed aggregate will pass through a 3 inch (7.62 cm) sieve but will not go through a No. 4 sieve. According to Kumar and Monteiro (2006) that defined coarse aggregates are particles greater than 4.75 mm, but generally range between 9.5 mm to 37.5 mm in diameter.

2.2.3 Water

Water is important element in making concrete. The quality requirement of the water is depend on the types of the use. Natural water that drinkable and has no pronounced taste or odor are usually used as mixing water for concrete. Excessive impurities in mixing water is affect on setting time and concrete strength and also may cause efflorescence, staining, corrosion of reinforcement, volume instability, and reduced durability.

According to ASTM C 1602 stated that the potable water is most suitable use in mixing concrete. In construction, the portable water is widely used as mixing water in concrete. The mixing water in freshly mixed concrete has three main functions; (1) it reacts with the cement powder, thus producing hydration, (2) it acts as a lubricant, contributing to the workability of the fresh concrete; and (3) it secures the necessary space in the paste for the development of hydration products. A recent report (Sandor Popovics, 1992) stated that the amount of water needed for adequate workability is practically always greater than that needed for complete hydration of the cement.

2.3 Properties of Concrete

During hydration and hardening, concrete needs to develop certain physical and chemical properties. Gambhir (2004) said that the hardening is caused by chemical reaction between water and cement and it continues for a long time, and consequently the concrete grows stronger with age.

Concrete sets faster or slower according to how much gypsum is added to the mixture. According to Kayne, R. (2011) state that set time of concrete can be accelerated by adding calcium chloride, or retarded by adding sugar. Among others qualities, mechanical strength, low moisture permeability, and chemical and volumetric stability are necessary.

2.3.1 Workability

The American Concrete Institute (ACI 116R-00, 73) describes workability as that property of freshly mixed concrete or mortar that determines the ease with which it can be mixed, placed, consolidated, and finished to a homogenous condition. The Japanese Association of Concrete Engineers defines workability as that property of freshly mixed concrete or mortar that determines the ease and homogeneity with which it can be mixed, placed, and compacted due to its consistency, the homogeneity with which it can be made into concrete, and the degree with which it can resist separation of materials. Workability is the amount of useful internal work necessary to produce full compaction (Neville, 1981).

According to Koehler, E. P. and Fowler, D. W. (2003), workability depends not just on the properties of the concrete, but also on the nature of the application. A very dry concrete mixture may seem to have very low workability when it is, in fact, appropriate for the given application. Workability which is an important property of concrete that were affects the rate of placement and the degree of compaction concrete. Reductions in both strength and durability of concrete are because of not inadequate compaction. Therefore, the testing of workability of concrete is required to make sure the in-situ concrete achive a good quality. According to Ben Sabaa and Rasiah Sri Ravindrarajah (1999), the fundamental characteristics to define the workability include viscosity, cohesion, mobility, stability, compactability, pumpability and finishability. There are three testing for workability of concrete that most national and international standard used, slump test, the compacting factor test and the vebe test, and that is depending on the degree of workability by measuring one or more of the characteristics of concrete.

2.3.2 Strength

The compressive strength can be defined as its ability to resist compression. Tensile strength is defined as ability to resist stretching, bending or twisting. The compressive strength of concrete is very high but tensile strength of concrete is low. Consequently, concrete which must resist a good deal of stretching, bending, or twisting such as concrete in beams, girders, walls, columns, and the like must be reinforced with steel. Concrete that must resist only compression may not require reinforcement. The most important factor controlling the strength of concrete is the water-cement ratio, or the proportion of water to cement in the mix.

2.3.2.1 Compressive Strength

Compressive strength is the capacity of a material to withstand axially directed pushing force. Noguchi (2000) define the compressive strength of a material is that value of unaxial compressive stress reached when the material fails completely. When a specimen of material is loaded in such a way that it extends, it call tension. On the other hand, if the specimen compress and shortens, it were call compression. When the limit of compressive strength is reached, materials are crushed. Concrete can be made to have high compressive strength. The compressive strength of concrete is the most common performance measure used by the engineer in designing building and other structure.

The compressive strength is usually obtained experimentally by means of a compressive test. The value compressive strength is often measure on a universal testing machine (UTM). The result of compressive strength test is primarily used to determine that the concrete mixture as delivered meets the requirement of the specific strength. Compressive strength, which is the most important concrete parameter, depends on a number of factors: type and proportion of ingredients, strength level, position of concrete in a structure, type and size of the structure, compactness, curing and age (Kadir Kilinc et al., 2010).

2.3.2.2 Flexural Strength

Flexural strength is one measure of the tensile strength. It is the ability of a beam or slab to resist failure in bending. Flexural testing is use to determine the flexure or bending properties of a material. Stonton and Bloem (1999) stated that the flexural strength is expressed as modulus of rupture (MR) in psi. Flexural MR is about 12% to 20% of compressive strength.

According to Diamaruya (1997), the tensile strength of a material is the maximum amount of tensile stress that it can be subjected to before failure. It has long been known that concrete materials have a low tensile strength compared to their compressive strength. Since concrete is inherently weak in tension, it has been used as a compressive member material in most structures.

2.3.3 Durability

Tumatar, J. F. (2010) define durability of concrete as the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties. Concrete required degrees of durability that depending on the properties desired and exposure environment.

The ultimate durability and life of concrete is depend on concrete ingredients, their proportioning, placing and curing practices, the service environment, and interactions between them. The inferior durability of concrete may be caused by environment condition. The environment condition that can effect the durability of concrete is temperature, moisture and physical, chemical and mechanical factors. The problem on durability of concrete related to environment condition is steel corrosion, delamination, cracking, carbonation, sulfate attack, chemical attack, scaling, spalling, abrasion and cavitation.

2.3.4 Shrinkage

Shrinkage of concrete is the time-dependent strain measured in an unloaded and unrestrained specimen at constant temperature. Some high strength concretes are prone to plastic shrinkage, which occurs in the wet concrete, and may result in significant cracking during the setting process. This cracking occurs due to capillary tension in the pore water. According to Deshpande, S. et al. (2007) said that shrinkage is a reduction in volume, and in concrete, it is mainly caused by the loss of water. In most cases, shrinkage is measured by monitoring longitudinal strain.

Gilbert, R. I. (2001) state since the bond between the plastic concrete and the reinforcement has not yet developed, the steel is ineffective in controlling such cracks. Silica fume concrete, low water content and the use of such concrete in elements such as slabs with large exposed is the factor that can cause this problem.

The Shrinkage leads to cracking when tensile stresses due to restrained volume contraction exceed the tensile strength of concrete is called shrinkage cracking. Shrinkage can be classified based on the state of concrete and the causes of volume change. There are three types of shrinkage; plastic shrinkage, chemical shrinkage and drying shrinkage.

2.3.4.1 Drying Shrinkage

After hardening, concrete begins to shrink as water not consumed by cement hydration leaves the system. This is known as drying shrinkage. According to Tarr, S. M. et al. (2008), water above that necessary to hydrate cement is required for proper workability and finishability – the water is called "water of convenience".

Drying shrinkage is the reduction in volume caused principally by the loss of water during the drying process. Gilbert, R. I. (2001) describes chemical (or endogenous) shrinkage results from various chemical reactions within the cement paste and includes hydration shrinkage, which is related to the degree of hydration of the binder in a sealed specimen.

Concrete shrinkage strain, which is usually considered to be the sum of the drying and chemical shrinkage components, continues to increase with time at a decreasing rate. Gupta, S.M. (2009) state that drying shrinkage occurs after the concrete has already attained its final set and a good portion of the chemical hydration process in the cement gel has been accomplished. Moisture loss causes volume changes based on three mechanisms that result in changes in capillary stress, disjoining pressure, and surface free energy (Deshpande, S. et al., 2007).

2.3.4.2 Plastic Shrinkage

Plastic shrinkage occurs during the first few days after fresh concrete is placed and due to loss of moisture from fresh concrete. According to Deshpande, S. et al. (2007), this loss may in be in form of surface evaporation or moisture loss to the subgrade, for slabs on the ground. During this period moisture may evaporate faster from the concrete surface than it is replaced by bleed water from layers of the concrete mass. Gupta, S.M. (2009) describes paste of rich mixes such as high strength/performance concrete, will be more susceptible to plastic shrinkage than normal concrete.

2.3.4.3 Chemical Shrinkage

Autogenous Shrinkage (also known as chemical shrinkage) is a volume change that occurs without moisture loss to the surrounding environment. It occurs when water in cement paste is consumed by the hydration reactions, and results due to self desiccation of the concrete. This type of shrinkage mainly occurs in the mixes with low water-cement (w/c) ratios and may be increased by the use of reactive pozzolans. According to Deshpande, S. et al. (2007), for the concretes with w/c ratios of 0.42 and greater, autogenous shrinkage is normally small and can be considered as a part of drying shrinkage.

2.4 Concrete Core Test

Concrete core testing is used to test the strength of concrete for building construction. In-place concrete core testing may be required when samples obtained during construction fail to meet safety standards. According to Mustafa, T. et al. (2005) describes that method consists of expensive and time consuming operations, cores give reliable and useful results since they are mechanically tested to destruction.

2.4.1 Standard Core

According to international standards, it is recommended the minimum size of diameter core is generally fixed at 100 mm. Kadir Kilinc et al. (2010) stated that British and American standards recommended that a minimum diameter of 100 mm should be used according to the international standards. Mustafa, T. et al. (2005) said both ASTM and British Standards (BS) specify a minimum core diameter of 100 mm providing that the diameter of the core is at least three times larger than the maximum aggregate size in concrete mixture. However, to drilling the core in rather large size can be hazardous in many cases.

2.4.2 Micro-core

Micro-cores are offer many advantage such as can be drilled in-situ with very light and easy to wield equipment. By using micro-core, the possibility of cutting reinforcing bars is lower and a smaller hole is left for consequent repair in the case of small diameter cores during drilling operation. The damage of the structure becomes virtually negligible and this test is can possible to be classified as a non-destructive method by using this micro-cores. Kadir Kilinc et al. (2010) describes by using this technique is that damage to the structure becomes virtually negligible and core testing can be classified as a non-destructive method.