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Physical and mechanical properties of self-compacting concrete containing superplasticizer and metakaolin

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Physical and mechanical properties of self-compacting concrete containing superplasticizer and metakaolin

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Abstract. The development of concrete technology shows a variety of admixtures in concrete to produce special concrete. This includes the production of self-compacting concrete which is able to fill up all spaces, take formwork shapes and pass through congested reinforcement bars without vibrating or needing any external energy. In this study, the main objective is to compare the physical and mechanical properties of self-compacting concrete containing metakaolin with normal concrete. Four types of samples were produced to study the effect of metakaolin towards the physical and mechanical properties of self-compacting concrete where 0%, 5%, 10% and 15% of metakaolin were used as cement replacement. The physical properties were investigated using slump test for normal concrete and slump flow test for self-compacting concrete. The mechanical properties were tested for compressive strength and tensile strength. The findings of this study show that the inclusion of metakaolin as cement replacement can increase both compressive and tensile strength compared to normal concrete. The highest compressive strength was found in self-compacting concrete with 15% metakaolin replacement at 53.3MPa while self-compacting concrete with 10% metakaolin replacement showed the highest tensile strength at 3.6MPa. On top of that, the finishing or concrete surface of both cube and cylinder samples made of self-compacting concrete produced a smooth surface with the appearance of less honeycombs compared to normal concrete.

1. Introduction

Due to the high demand and increasing applications of concrete, concrete technology is developing rapidly and many types of concrete have been studied to increase the quality and its properties. One of the achievements of concrete technology is the production of self-compacting concrete. This type of concrete is considered to have a very high workability due to its flow able properties. As a result, the concrete can be placed and compacted without needing any vibration medium as well as external energy. This vibration or compaction primarily aims to minimize the entrapped air in fresh concrete in order to obtain a homogenous mix with no cavities or honeycombs [9]. Due to its flowable properties, this type of concrete can also slip through congested reinforcement bars and take any shape of the formwork [13].

In terms of strength, the inclusion of metakaolin was introduced as a cement replacement and it is believed to increase the strength of concrete in both compress and tensile state [1]. Metakaolin is a type of mineral admixture and is also known as calcined clay. It is a very fine material and is produced by heating up kaolin until 800^{o}C [12]. It has been reported that the use of metakaolin in concrete can increase the strength of mixtures especially during the early ages [1].

2. Self-Compacting concrete

Self-compacting concrete (SCC) can be defined as concrete which can flow and be compacted with its own weight, able to pass the space in between the reinforcement bars to fill up the formwork and stabilize its material composition at the same time [12,18-22]. It was first developed in Japan during the late 1980's [2]. In Japan, SCC has become the standard concrete mixture [16].

Various tests associated with self-compacting concrete include slump flow test, J-ring test, L-box test etc. The slump flow test is used to assess the flow ability and the flow rate of self-compacting concrete in the absence of obstructions [5,19,23-24]. The J-ring test is used to assess the passing ability of self-compacting concrete to flow through tight openings including spaces between reinforcing bars and other obstructions without segregation or blocking [7,25]. The L box test is used to assess the passing ability of self-compacting concrete to flow through tight openings including spaces between reinforcing bars and other obstructions without segregation or blocking. There are two variations; the two-bar test and the three-bar test. The three-bar test simulates more congested reinforcement [6].

There are 3 properties that differentiate self-compacting concrete from normal concrete which are flowing ability, passing ability and resistance to segregation [2]. Three properties which make self-compacting concrete different from normal concrete are as follow:

2.1. Flowing ability

A higher flowing ability of concrete shows its ability to fill up every space in the formwork.

Table 1. Classes of slump flow.

Class	Slump flow (mm)
SLF 1	550 – 650
SLF 2	660 – 750
SLF 3	760 – 850

2.2. Passing ability

The ability of concrete to fill up the formwork and pass through the congested reinforcing bars.

Table 2. Classes of passing ability.

Class	Step height (mm)
PJ 1	≤ 10 to 12 bars
PJ 2	≤ 10 to 16 bars

2.3. Resistance to segregation

The ability of material inside the concrete to remain mixed and not separated between each material.

Table 3. Classes of resistance to segregation.

Class	Sieve segregation (%)
SR 1	≤ 20
SR 2	≤ 15

3. Experimental program

The experimental program in this study consist of metakoalin, materials preparation and testing method.

3.1 Metakoalin

Many efforts have been made to minimize the use of cement as a binder in concrete production. Concrete containing metakaolin has been claimed to possess enhanced engineering properties that are comparable to silica fume concrete [7].

Metakaolin is a type of mineral admixture and is generally known as calcined clay. It is an ultrafine material produced by the dehydroxylation of a kaolin precursor upon heating in the temperature range of 700^{o} - 800^{o}C [15]. Metakaolin enhances the strength and durability of concrete through three primary actions which are the filler effect, the acceleration of ordinary Portland cement hydration and the pozzolanic reaction with calcium hydroxide [11]. In addition, the inclusion of metakaolin can increase the resistance to acids and sulphates, reduce porosity, reduce oxygen permeability, reduce chloride ion diffusivity, prevent or minimize the risk of alkali-silica reaction and reduce the unsightly effect of efflorescence [4].

The main characteristics of metakaolin are its high reactivity with calcium hydroxide, Ca(OH)2, and its ability to accelerate cement hydration [3]. Due to these characteristics, the addition of metakaolin in concrete can increase its strength especially during the early ages [14].

Table 4. Chemical composition comparison between metakaolin and OPC.

Chemical	Metakaolin	OPC
SiO_2	20.69	51.6
Al_2O_3	4.72	41.3
Fe_2O_3	3.06	4.64
CaO	63.76	0.09
MgO	2.08	0.16
TiO_2	-	0.083
SO_3	2.92	-
K_2O	0.61	0.62
Na_2O	0.26	0.01

3.*2 Material preparation*

The cement used in producing the concrete was Ordinary Portland Cement (OPC) from Tasek Cement brand. The aggregate used was uncrushed aggregate type with nominal size of 20mm and should be oven dried first to avoid any changes in water cement ratio. The sand used should also be dried first. The water used is normal pipe water.

In terms of admixture and material to be studied, superplasticizer was used to increase the workability of concrete. The superplasticizer used was Darex Super 20 as shown in Figure 1(b). Metakaolin shown in Figure 1(a) was used marked by the company as KM5CL which is the finest particle size available.

Four batches of self-compacting concretes were produced and another sample of normal concrete should be used as a control sample. For each batch of self-compacting concrete, different percentages of metakaolin were used as cement replacement (0%, 5%, 10% and 15%). Cube mould size of 150 x 150 x 150mm was used for the compressive strength test [7-10] whereas cylinder mould size of 150mm x 300mm was used for tensile strength test [11] in accordance to British Standards.

(a) (b)

Figure 1. (a) Metakoalin (b) Superplasticizer (Darex Super 20).

3.3 Testing method

In the testing method, all tests were conducted according to British Standards. The slump flow test was used to assess the flowability and the flow rate of self-compacting concrete in the absence of obstructions shown in figure 2(c). It is based on the slump test described in BS EN 12350-2. The result is an indication of the filling ability of self-compacting concrete. T500 time is a measure of the speed of flow and an indication of the relative viscosity of the self-compacting concrete [4].When the cone is withdrawn upwards, the time from commencing upward movement of the cone to when the concrete has flowed to a diameter of 500 mm is measured; this is known as t500 time. The largest diameter of the flow spread of the concrete and the diameter of the spread at right angles to it are then measured and the mean is the slump-flow [4]. In addition, the compressive strength and tensile strength tests should follow as described in BS EN 12390-3 and 6.

(a) (b) (c)

Figure 2. Testing method of compressive test (a), tensile test (b), slump flow test (c).

4. Results and discussion

4.1. Slump flow test

Four type of samples of self-compacting concrete with differ percentages of metakoalin have been tested using this method.

Table 5. Diameter and SF value for each sample.

Type of sample	D1 (mm)	D2 (mm)	SF (mm)
SCC + 0% Metakaolin	600	596	598
SCC + 5% Metakaolin	589	586	588
SCC + 10%Metakaolin	571	575	573
SCC + 15%Metakaolin	560	567	564

4.2. Compressive test

From the figure 3, shown the results of slump flow with differ percentages of metakoalin for self-compacting concrete produced, the slump flow recorded are in class SLF 1 where the flow is between 550-650mm.

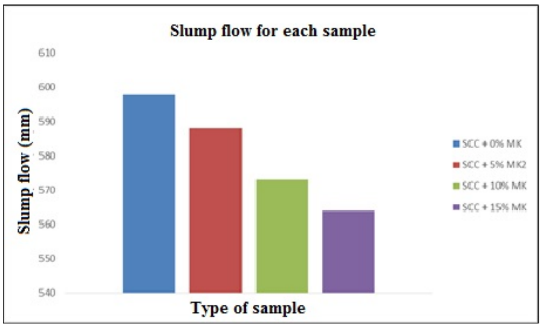

Figure 3. Result slump flow.

From figure 4, there is no significant difference between 2 types of normal concrete and self-compacting concrete in terms of compressive strength at 28 days. The difference recorded is only 3.1% where the recorded strength of normal concrete was 44.8MPa whereas the recorded strength of SCC was 43.8MPa.

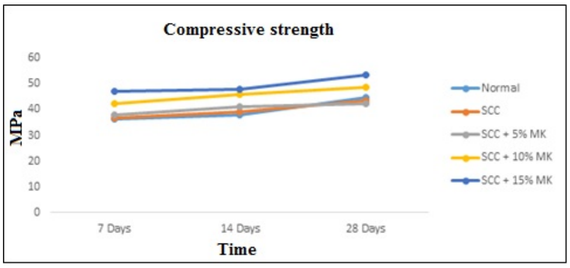

Figure 4. Development of compressive strength for each sample until 28 days.

When the effect of metakaolin in SCC was compared, the highest compressive strength recorded was SCC + 15% metakaolin sample where its strength at 28 days was 53.3MPa while the lowest strength recorded was SCC + 5% metakaolin. However, the difference between normal concrete and SCC + 5% was low, that is a difference of only 5% (2.3MPa). The 28 days strength recorded for SCC + 10% metakaolin was 48.6MPa.

In terms of early strength development, it can be said that the inclusion of metakaolin in concrete increases the early strength of the concrete as all 3 samples of concrete with metakaolin showed high early strength until day 14 as compared to normal concrete and SCC without metakaolin.

4. 3 Tensile strength

From figure 5, shown the significant difference between normal concrete and self-compacting concrete. Normal concrete recorded the lowest tensile strength and its value was nowhere near any of the samples.

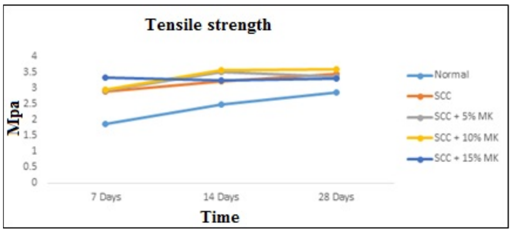

Figure 5. Development of tensile strength for each sample until 28 days.

The biggest difference between normal concrete and self-compacting concrete was recorded when the age of concrete was 7 days with a difference of 35.2% (1.02MPa) and the difference decreasesover time. In terms of the usage of metakaolin, self-compacting concrete + 10% metakaolin produced the highest tensile strength of 3.6MPa at 28 days and the data plotted for this sample is consistent with increasing tensile strength over time.

Overall, the inclusion of metakaolin increases the tensile strength of concrete with 10% of metakaolin showing the optimum result. However, the addition of superplasticizer also increases the tensile strength compared to normal concrete.

5. Conclusion

In conclusion, the addition of metakaolin in concrete helps increase its strength. In terms of compressive strength, the higher inclusion of metakaolin increases the strength linearly. However, the inclusion of metakaolin in concrete reduces the workability of concrete. In order to counter the problem, superplasticizer is used in concrete to produce self-compacting concrete. The usage of superplasticizer in concrete doesn't have any effect on compressive strength. It does, however, help to increase the tensile strength of concrete.

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