Development of Self Consolidating Concrete (SCC) Using Crushed Waste Clay Brick as Alternative Aggregate

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Abstract. In housing construction, concrete are materials that will be used extensively to produce a wall structure that accommodates the load. However, the problem is the cost of producing by using natural resources, as it is a major mineral is difficult to find sufficient natural aggregate supply sources since high demand. Therefore, the lack of natural aggregate and its increasing demand leads to an alternative to be developed to replace the natural aggregate. This study investigated the effect of utilization of waste clay brick in Self Compacting Concrete (SCC) on its properties and performance. The waste clay brick (WBS) was replaced as fine aggregate in SCC from 10\% to 30\%. As the amount of waste clay brick in SCC increases, its workability and also Ultrasonic Pulse Velocity (UPV) quality decreases while the water absorption increases. The highest average compressive strength achieved was 43.3 MPa and for splitting tensile strength was 12 MPa respectively; both at 25\% of WCB replacement. All test results showed that the optimum percentage to replace waste clay brick in SCC is 25\% and it has the potential to be replaced as fine aggregate in SCC.

Keywords: self-compacting concrete; waste clay brick; alternative aggregate; compressive strength and splitting tensile strength.

1.0 INTRODUCTION

Self-Compacting Concrete (SCC) is new kind of concrete at first made in Japan in 1988 which literally can flow between reinforcement bars without blockage of coarse aggregate. SCC is concrete that can be compacted to every corner of the mould, essentially with its own weight and without the need for vibration compaction. In addition, SCC has introduced construction materials to meet workability and better strength by using natural aggregate. However, the problem is the cost of production using natural resources, as it is a major mineral it is difficult to find adequate natural aggregate supply sources since high demand. Therefore, the price of natural resources such as rock has increased, which in turn affects the price [1].

In Japan, after the Second World War, numerous structures are developed from crushed waste clay brick in view of low-cost and rapidly constructed buildings [2]. With the accelerating of urban development and improvement, very large amount of Waste Clay Brick (WCB) were produced from demolition of old buildings and structures which generally changed into strong waste contributing to...
construction garbage. Those demolition waste produced can be recycled as raw material for manufacturing of new concrete. New concrete mixture containing recycled brick aggregates can be produced. Using this type of aggregate in construction promotes the development of eco-friendly concrete and encourages the concept of sustainable production, which is receiving greater attention nowadays. The manufacturing of different types of concrete with WCB has been carried out lately. Lightweight concrete produced with 25% substitution of waste clay brick showed the highest compressive strength of 25 MPa with density of 1647 kg/m$^3$ [3]. The use of crushed clay brick aggregate as a 100% replacement of coarse natural aggregate in normal concrete has been studied and found that it is not suitable due to weak properties crushed clay brick aggregate. SCC made with 12.5% and 37.5% GCB showed higher compressive strength in presence of SCC admixture at 28 days. The use of 30–40 mass % of GCB in self-compacting concrete will produce a good quality concrete [4]. Increasing the curing time also causes the strength of concrete with 10% or 20% WCB similar to ordinary one [5]. 30% of recycled clay brick powder substitution improves the strength of grade 30 concrete, and water permeability and water absorption reduced efficiently [6].

Substitution of kaoline waste (KW) up to 15% showed virtually identical porosity and water absorption values with the control concrete with no increase or decrease. Rate of water absorption of concrete mixtures with 5% and 10% KW were almost identical or lower than that of the control mixture. Crushed brick concrete absorbs more water than crushed stone concrete.

The workability of the concrete is also affected by the WCB percentages. Replacing 0%-100% of clay bricks gave different slump flow for each percentage. The workability decreases gradually from 79cm to 68cm as the clay brick replacement rate increased from 0% to 40% [7]. KW percentages of 0% (control concrete), 5%, 10%, 15%, 20% and 25% were used as replacement for cement. The splitting tensile strength values ranged from 2.64 to 3.56 MPa, respectively. The trend in the variation of compressive, flexural and splitting tensile strength will be similar [8].

2.0 EXPERIMENTAL PROCEDURE

2.1 Raw Materials
Waste clay brick (WCB) was taken from construction sites in Kangar where the clay bricks were left as solid waste. These clay bricks sample constitutes mainly of SiO$_2$, Al$_2$O$_3$, Fe$_2$O$_3$, CaO, SO$_3$, MgO, and Na$_2$O, K$_2$O as traces. This clay brick was crushed manually into coarse aggregate sizes and then crushed by using crushing machine into the sizes of fine aggregates. Different percentages of waste clay brick was used to replace fine aggregate in SCC which are 10%, 15%, 20%, 25% and also 30%. Based on EFNARC standard, locally available graded crushed dolomite aggregates (magnesium carbonate and calcium carbonate) with a normal maximum size of 20mm and natural sand with 4.75mm maximum size was used. Particles size less than 0.125mm i.e.125 microns size was considered as fines which go under the category of powder [9]. Superplasticizer of Polycarboxylate Self-Compacting Admixture- Master Glenium ACE-8109 (TYPE A) was used in this study.

2.2 Mix Design
Concrete mix design is important in determining their relative quantities of raw material required to achieve the desired strength of 30MPa. Three different water/cement ratios (0.4, 0.5 and 0.8) proposed at the beginning of this study for normal self-consolidating concrete (SCC) and normal SCC were made with these water/cement ratios to determine the optimum water/cement ratio. Standard workability of 600mm-800mm is not achieved when water/cement ratio of 0.4 is used, so water/cement ratio of 0.5 was selected since it’s giving higher compressive strength and better workability.

2.3 Mix Proportions
The amount of coarse aggregate and fine aggregates used in this study is 860 kg/m$^3$ and 1290 kg/m$^3$ respectively. Portland cement of amount 420 kg/m$^3$ was used with water cement ratio of 0.5. Superplasticizer of 11% from the volume of cement was added. Crushed waste clay brick was used to
replace fine aggregate at 10%, 15%, 20%, 25% and 30%. For each percentage, about 9 concrete cubes and 3 cylinders were casted to be tested and a total of 45 concrete cubes and 15 cylinders were made.

2.4 Mixing and Casting
All the batches were mixed well for a total time of 10 minutes. The materials were placed into the mixer by following sequence: first with course aggregates and fine aggregates then followed by WCB (ratio of 0.10, 0.15, 0.20, 0.25 and 0.30) together with cement for about 5 minutes. After that initially 85% of water amount was poured into the mixture and the mixture was mixed again for 1 to 5 minutes. The remaining water was added together with the superplasticizer and then poured into mixture. After workability test, the fresh concrete was casted as fast as possible to prevent segregation. The cubes size of 100x100x100 mm was casted for compressive test and cylinder of size 300x100mm for splitting tensile test. Water curing was carried out in this study.

2.5 Testing and Analyzing
The slump (workability) test was conducted according to ASTM C1611 (Slump Flow standard for SCC) by using flipped cone method. The recommended diameter is in range of 600-850mm [10]. The water absorption and density was carried out based on ASTM C642-06 in hardened concrete [11]. Average density for a normal SCC will be 2400 kg/m³ based on EFNARC standard [9]. The quality of concrete was determined by Ultrasonic Pulse velocity test according to BS 1881 part 203-1986 [12]. Cube SCC specimens were used to determine the compressive strength according to BS 1881-116 1983 [13] at 7 & 28 days while splitting tensile strength test was performed according to BS 1881-117 [14] at 28 days with cylindrical samples with packing strips of width 15±2mm, thickness 4±1mm and length greater than the length of line of contact with specimen. The failure mode of the concrete cube was analyzed according to BS EN 12390: 2009 [15].

3.0 RESULTS AND DISCUSSION

3.1 Density Test
The density of normal SCC concrete of normal is about 2400 kg/m³ based on EFNARC standard [9]. Density varies depending on the materials used which are waste clay brick, aggregates, admixtures and also air entrapped. Density increases gradually as the percentage of waste clay brick in SCC increased. All SCC containing waste clay brick are in the category of high density (more than 2600 kg/m³) due to dense packing of the SCC in the presence of waste clay brick which acts as filler besides fine aggregate. The character of rough surface and high hygroscopicity will form a microtubule or micropore system which improves the cohesiveness between aggregate and cement, increases the compactness of hardened concrete [16].

3.2 Workability
Control SCC has the highest and better workability compared to SCC containing waste clay brick. The workability of SCC containing waste clay brick decreases as the percentage of waste clay brick increases. The smallest slump was obtained at 30% of WCB which indicates the peak percentage with average value of 657.33mm. Further increasing of waste clay brick in SCC may worsen the workability. The usage of superplasticizer (Glenium) based on ASTM C494-TYPE A [17]; water reducing admixture had given it a good workability even with lesser water intake.

The shape and texture of waste clay brick in SCC also influenced the workability where it produces high adhesion between the cement matrix and particles. The stability of fresh SCC was identified by evaluating visually the distribution of the coarse aggregate within the concrete mass after the spreading of the fresh concrete has stopped and rated with Visual Stability Index (VSI) [18] values range from 0 to 3. By observation, all the SCC containing of waste clay brick have the VSI value of 1; stable with no presence of segregation and slight bleeding. Figure 1 shows the workability of SCC samples.
3.3 Water Absorption
This test was done by measuring the water content in a surface-dry concrete sample after been soaked in water for 24 hours and again after it was oven dried. The average water absorption increases as the percentage of waste clay brick in SCC increases. When contain of clay brick in SCC increased, more water was absorbed due to the porous characteristic of clay brick. This can be explained as total voids in the concrete sample increases as the amount of waste clay brick increases. More voids in concrete samples absorb more water thus causing higher water absorption capacity [19].

3.4 Ultrasonic Pulse Velocity
Pulse velocity measurements were made on concrete cube in three different phases which are direct, semi-direct and indirect. Control SCC has higher UPV values compared to SCC containing waste clay brick. UPV value increases with decreasing concrete unit weight, thus with increasing pore volume in SCC. This proved that the role of waste clay brick in SCC is not limited to fine aggregate only but also as filler because it occupies the pore within the particles and improves the particle packing [7] claims that the strength of concrete can be increased if the brick is used in small portion or also as filler when the the UPV values of a normal SCC ranges from 3.30 km/s to 4.88 km/s [20]. The UPV results of SCC samples in this study is shown in Figure 2.

3.5 Compressive Strength
The testing machine was set according to BS1881-115 [21]. All the samples have achieved 60% of the designed strength (30MPa) in 7 days which are within 16-18MPa. The compressive strength increases
gradually as the percentage of waste clay brick increased from 10% to 25%. This indicates that the optimum percentage for replacing fine aggregate with waste clay brick is about 25% and more than that could affect its strength and quality. The superplasticizer worked well in achieving higher strength by reducing the water usage in mix. The compressive strength of control SCC and SCC containing waste clay brick is shown in Figure 3.

![Compressive strength of Control SCC and SCC containing WCB in 7 and 28 days](image)

**Figure 3.** Compressive strength of Control SCC and SCC containing WCB in 7 and 28 days

### 3.6 Modes of failure of Cubes

For compressive test, the failure is divided into two types of cracks which are explosive cracks and tensile cracks. SCC samples with WCB percentage from 10% to 25% undergo explosive cracks pattern and only SCC sample containing 30% WCB showed tensile crack. Replacement of 30% WCB or more is not likely suitable for SCC while 25% WCB is the optimum replacement for SCC. Figure 4 shows the crack pattern of normal SCC and SCC containing WCB.

![Crack pattern of cube samples](image)

**Figure 4.** Crack pattern of cube samples; a) Control SCC sample undergone explosive cracks pattern, b) SCC containing 0% - 25% WCB samples undergone explosive cracks pattern and c) SCC containing 30% WCB samples undergone tensile crack pattern.

### 3.7 Splitting Tensile Test

The tensile strength increases as the percentage of waste clay brick in SCC increased up to 25% and it started to decrease slowly when the percentage of waste clay brick further increased to 30%. Control SCC have lower splitting tensile compared to waste clay brick SCC as shown in Figure 5. Waste clay brick improves the strength of SCC by pozzolanic reaction where reaction products (C-S-H) are produced and precipitated in some open pores. Waste clay brick plays an important role as nucleation sites for the early reaction products of C-H and C-S-H, which in turn increases the hydration process of cement clinkers in SCC especially C3S and the compressive strength, is increased [20].
3.8 Modes of Failure of Cylinders
Waste clay brick replacement of from 0% to 25% provides a good splitting surface for the cylinder samples. All the samples except samples with 30% waste clay brick replacement had split well into half without any defects (TYPE A of pure interfacial failure) while only samples with 30% waste clay brick experienced partially failure on surface line of cylinder causes only a part of the cylinder to crack (Type C with substratum failure). Figure shows the interfacial failure of SCC and also SCC containing WCB.

3.9 Correlation of Compressive and Splitting Tensile Strength
The trend line in Figure 7 shows that correlation of compressive strength and splitting tensile strength with equations of y=1.2851x+26.787 with R² value of 0.9185. Both compressive and splitting tensile strength is directly proportional to the percentage of waste clay brick replacement as fine aggregate in SCC.
3.10 Coloration of SCC samples
With no waste clay brick replacement, the interior color of SCC seems to be whiter or light brownish. The interface color of SCC becomes darker consequently as the percentage of waste clay brick replacement increases. SCC containing waste clay brick is more reddish and darker than the normal SCC due to the presence of clay brick. Figure 8 shows the coloration of SCC samples in this study.

![Figure 8. Colorations of SCC samples from lighter to darker begin with containing 0% - 30% WCB](image)

4.0 CONCLUSION
The best workability was obtained for control SCC with average value of 708.7mm which is within the required range of 600mm-850mm. The workability decreases as the amount of WCB in SCC increases. Mineral admixtures such as WBS which is cheap in cost could be used in SCC to increase the workability of the concrete mix and also to improve the mechanical properties and durability of concrete [22]. The average highest value of compressive strength and splitting tensile strength obtained from the test are 43.4 MPa and 12Mpa respectively; both at 25% replacement of waste clay brick. In the study of [4] stated that the compressive strength of concrete made of crushed clay brick concrete are increased 75-80% of normal concrete at 28days. Further increasing of WBS to 30% replacement decreases it’s both compressive and splitting tensile strength. The production of the SCC containing waste clay brick provides good structural performance as normal SCC and also contribute to a reduction in fine aggregate requirement thus decreasing the cost. The WBS is more suitable to be replaced as fine aggregate in concrete compared as course since some of previous finding recently
showed replaced WBS in SCC as coarse aggregate claimed that the compressive strength decreases as the percentage of waste clay brick increases [7; 23; 24].

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