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Properties of Bricks Produced With Recycled Fine Aggregate

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***Abstract*—**The main aim of this research is to study the possible use of recycled fine aggregate made from waste rubble wall to substitute partially for the natural sand used in the production of cement and sand bricks. The bricks specimens were prepared by using 100% natural sand; they were then replaced by recycled fine aggregate at 25, 50, 75, and 100% by weight of natural sand. A series of tests was carried out to study the effect of using recycled aggregate on the physical and mechanical properties of bricks, such as density, drying shrinkage, water absorption characteristic, compressive and flexural strength. Test results indicate that it is possible to manufacture bricks containing recycled fine aggregate with good characteristics that are similar in physical and mechanical properties to those of bricks with natural aggregate, provided that the percentage of recycled fine aggregates is limited up to 50-75%.

***Keywords*—**Bricks, cement, recycled aggregate, sand

I. Introduction

IN accordance with conservation efforts, this research focuses on prevention of environmental pollution and considers the elements of sustainable and cost-saving construction projects, especially material usage. According to Reddy and Jagadish [1], selection of materials and technology for construction must meet the needs of consumers and society, without causing negative effects on the environment. Awareness of environmental issues has been growing in recent years, with these issues similarly emphasized in development and construction. Considerable attention should be directed toward reducing the production and release of building materials, such as CO2 (a greenhouse gas), into the atmosphere. In this study, a new alternative concept for brick manufacturing is introduced, in which production involves recycling of waste materials from construction and demolition (C&D) waste—a widely available and extremely cheap resource. In this study, this waste is used as the main material to become recycled aggregates (RAs) to replace natural aggregates in the production of cement and sand bricks.

Cement and sand bricks are a type of bricks that are commonly used in low- and medium-cost housing development and other commercial constructions in Malaysia because they are easy and inexpensive to produce but currently, arise problems plague production of these materials especially in developing areas where manufacturers find it difficult to locate adequate sources due to the shortage of natural aggregate supply. These include the depletion of natural resources in rivers and mining areas, as well as the closing down of some of the mining sand quarries due to rising environmental concerns, compelling the state government to discontinue quarry licensing. As a result, the price of sand has skyrocketed, which in turn affected pricing of cement and sand bricks.

The inventive use of RAs began at the end of World War II when European nations faced problems in rubble material disposal [2]. Subsequently, the most important steps in promoting recycling aggregates published by RILEM Technical Committee 121 [3], which is then followed by a number of researchers around the world. Several studies have shown the possibility of using various types of C&D waste (e.g., waste concrete, bricks, glass, ceramic tiles, and plastic materials) as aggregates in composite concrete [4]–[9]. Unfortunately, there is limited research on the potential of aggregates recycled from C&D waste for use in brick mixture.

Conversely, many studies focus on the use of RAs in the production of concrete and paving blocks. For instance, in a research conducted by Poon et al. [10], a technique for producing concrete bricks and paving blocks from RAs was developed. Their test results showed that 25 and 50% replacements of natural aggregate using recycled aggregates had little effect on compressive strength, whereas a higher level of substitution was reduced compressive strength. They also revealed a satisfactory impact resistance performance of the concrete made of RAs used to produce the paving blocks. Soutsos et al. [11] investigated the use of stone aggregates taken from waste concrete and bricks to replace coarse and fine-stone aggregates. The concrete blocks with 60% replacement of coarse aggregate still presented environmental implications; thus, the use of concrete made with 100% limestone aggregate (which required no increase in cement content) was recommended. Poon and Chan [12] also studied mixing recycled-aggregate concrete and clay bricks broken in the aggregate in the production of paving blocks. Their results showed that the high water absorptive capability of clay brick caused its particles to break down, reducing density, hardness, and strength of the paving blocks produced. However, they also found that paving blocks made with 50% replacement of clay bricks have met the minimum standards required. Debieb and Kenai [5] examined the potential of using crushed brick as coarse and fine aggregates for new concrete. Their findings show that the concrete shares similar characteristics with natural-aggregate concrete prepared with recycled aggregate, with a percentage limited to 25 and 50% for coarse and fine aggregates, respectively.

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This research aims to discover material that can potentially serve as substitute for natural sand in brick making as a way to produce eco-friendly and sustainable building materials. Studies in line with current environmental issues, such as global warming and climate change, call for sustainable development in Malaysia. The country has recently committed itself to adopting a low carbon economy and reducing carbon dioxide emissions by 40% by 2020 [13]. With this study, we intend to promote sustainable development and increase awareness of the implications of construction projects on the environment.

II. Research Methodology

A. Materials

The mixes constituted cement, water, fine natural sand, laterite soil, and recycled fine aggregate. The cement used complies with the Ordinary Portland cement (OPC) according to British Standards Institution [14] specification. In this research, some amount of laterite soil was added during the production of bricks. The laterite soil used in this study works as a binder. The properties of soil with fine grain size can provide give good bond and better composition compared with other matrixes. The physical properties and composition of the soil are shown in Table I. The fine aggregate used in the preparation of the specimens was river sand obtained from a supplier at the Klang area in Selangor. The recycled aggregates used in this study were rubble wall waste sourced from the construction and demolition work in an old shoplot project. The demolition brick wall waste underwent a further process of mechanized crushing and sieving to produce fine aggregate according to the particle size requirements of British Standards Institution [15]. The recycled fine aggregates were not only composed of old cement and sand bricks wall but also contained mortar, a small amount of old concrete, and natural stone. The composition of the recycled fine aggregates is shown in Table II. All the properties of the recycled aggregates and natural were tested according to British Standard methods. The grain size distribution of natural and recycled fine aggregates used is presented in Table III, while their properties are summarized in Table IV. The grain size distribution of the natural and crushed aggregates was comparable. However, the percentage of the recycled fine aggregates was coarser than that of the natural aggregates.

B. Mix Design

TABLE I
PHYSICAL PROPERTIES OF THE LATERITE SOILS

Physical property	Value
Specific gravity	2.66
Liquid limit (%)	63
Plastic limit (%)	32
Plasticity index (%)	31
Activity coefficient	80
Clay (%)	16
Silt (%)	37
Fine sand (%)	56
Coarse sand (%)	6
Moisture content (%)	24

TABLE II
CONSTITUTIONS OF RECYCLED AGGREGATES

Material	Constitution (% by weight)
Clay bricks	79.5
Cement Plaster & Mortar	13.4
Old concrete	4.6
Natural stones	2.5

TABLE III
SIEVE ANALYSIS OF NATURAL SAND AND RECYCLED FINE AGGREGATE

BS test sieve	Percentage passing by weight	
	Natural Sand	Recycled Fine Aggregate
2.36 mm	94.67	67.4
1.18 mm	76.67	43.4
600 µm	48	22.8
425 µm	35.33	17
300 µm	23.33	11.6
212 µm	13.33	7.6
150 µm	8	5
63 µm	1.33	1.4

TABLE IV
PROPERTIES OF THE RIVER SAND AND RECYCLED FINE AGGREGATES

Material	River sand	Recycled fine aggregate
Dry surface density (gm^3)	2.46	2.51
Water absorption (%)	11.3	4.3

To investigate the different effects of recycled fine aggregate on the properties of cement and sand bricks, five groups of mixtures were prepared. The design proportion of the cement and sand bricks was 90% sand, 5% cement, and 5% laterite soil. In this study, a portion of natural sand was replaced by recycled fine aggregate in the production of the brick specimens. The percentages of recycled aggregate used as replacement were 25%, 50%, 75%, and 100% by weight of the natural sand aggregate. One group of bricks had no recycled aggregate added. These bricks served as the control samples, which were used as a guide to compare the performance and properties of concrete containing recycled aggregate. The wastage allowance was 45%, which allowed for wastage in double handling (from hand mixing to pressing machine), error in soil weight, and materials pressing. The total overall quantities for constituent cement, soil, sand and recycled fine aggregate in the bricks were 32.75, 32.75, 294.90 and 294.90 kg, respectively.

Pressing the moisture content of the constituent materials is important. The moisture content of the constituent must be suitable for pressing because if the mixture is liquid, the material will stick to the mould and will not bond and form bricks when dried. Water was added depending on the moisture of the natural sand used. In this research, only the specimen content with 100% recycled fine aggregate was added with water as the moisture content of the recycled fine aggregate was too dry. Water was not added in other mixtures because the natural sand used was wet. When combined with other materials, they became suitable for pressing.

Furthermore, the water cement ratio is important as it influences the strength of the bricks.

C. Preparation of Brick Specimens

The combination of cement and sand bricks produced with recycled fine aggregate was manufactured at the Majpadu Bricks Sdn. Bhd factory in Jalan Kebun, Klang, Selangor. The material was prepared at Universiti Teknologi MARA at Faculty of Architecture, Planning and Surveying Laboratory before it was brought to the factory. Laterite bricks are generally not fired but are hardened through a chemical reaction and mechanical compaction using a pressing machine. The steps involved in cement and sand brick fabrication are mixing, pressing, wrapping, and curing.

i. Mixing of the constituent materials

All the constituent materials were weighed according to the mix design before mixing. The production of bricks samples began with the control samples followed by the mixture content with recycled aggregate. All the constituent materials were shoveled into the mini mixture of the pressing machine and were then mixed together for about 5 min to ensure that all the materials were dispersed evenly in the cement mixture.

ii. Pressing of the bricks

The material was readily mixed in the mini mixture. The bricks were then pressed out and transported by conveyor. The pressure used for pressing the bricks was 9 kN/in². The pressed bricks were moulded with a mould size of 213 mm in length, 101 mm in width, and 63 mm depth.

iii. Curing of the bricks

After pressing, the bricks were stacked on timber palettes and marked according to their percentage of aggregate composition. The bricks were then stored in a sheltered area for 24 h prior to being sprayed with water. The bricks were then stored in open air for 14 days and were allowed to cure for 28 days prior to use in this investigation.

III. RESULTS AND DISCUSSIONS

A. Brick Dimension

Brick dimension is influenced by material content and the density of the constituent materials. The average brick dimension was calculated from ten samples for each group. The brick dimensions evaluated were length, width, depth, area and volume. The average brick dimensions are summarised in Table V. The results show that the standard deviation for average length, width, depth, area and volume for bricks with recycled fine aggregate content was almost zero. It can be summarised that bricks with recycled fine aggregate had a uniform size and surface area similar to bricks with natural aggregate.

TABLE V
THE DIMENSIONS OF BRICKS SPECIMENS

Type Of Batch	Length (mm)	Width (mm)	Depth (mm)	Area (m²)	Volume (m³)
BC – Control	213	101	63	0.0134	0.0014
B1- (25 %)	213	101	63	0.0134	0.0014
B2 – (50 %)	214	101	63	0.0135	0.0014
B3 – (75 %)	214	101	64	0.0137	0.0014
B4 – (100 %)	213	101	63	0.0134	0.0014
Average	213	101	63	0.0135	0.0014
Std. Deviation	0.55	0	0.45	*0.0001*	*0.00001*

B. Bricks Density

The density of brick specimens was calculated by dividing the weight with the volume. In Figure 1 shows that the density of control bricks was 2032.3 kg/m^3. The result showed the density for bricks content with 50% of recycled fine aggregate content slightly increase by 1.7% if compared with control bricks but overall from the chart can be concluded that the average density of cement and sand bricks with recycled fine aggregate are lower compare to control bricks. The most lower can be seen in bricks with 100% of recycled fine aggregate which reduce 3.5% compared control bricks.

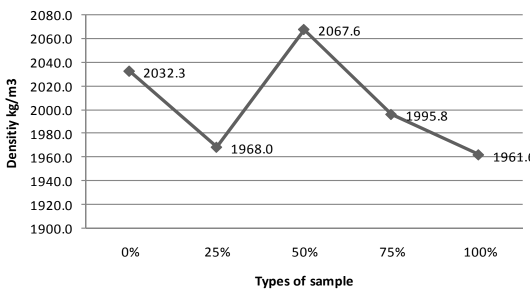

Fig. 1 The average density of cement and sand bricks with recycled fine aggregate

C. Compressive Strength

The compressive strength of a material determines its load-carrying capacity before failure. British Standards Institution [16] states that the compressive strength of bricks should not be less than 7 N/mm^2. The detailed results of the compressive strength of all brick types are illustrated in Figure 2. The results show that the compression strength of the control brick is 12.32 N/mm². The overall findings reveal that the addition of recycled fine aggregate can successfully increase the compressive strength of bricks. The bricks with 50% recycled fine aggregate content show a well gradation between the coarser and finer particles of recycled fine aggregate compared with natural sand. This makes the mixtures more homogenous, providing good interlocking. They show the highest strength at 20.98 N/mm^2, which is 70% greater than that of the control bricks. On the other hand, bricks whose 100% natural sand was replaced with recycled fine aggregate have strength similar to bricks with natural sand.

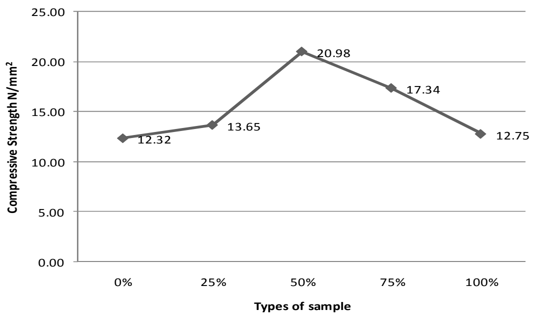

Fig. 2 The average compressive strength of cement and sand bricks with recycled fine aggregate

D. Flexural Strength

The flexural strength of brick is a measure of its ability to resist bending. Flexural strength can be expressed in terms of "modulus of rupture," Figure 3 shows the average modulus of rupture of bricks corresponding to the amount of recycled fine aggregate used. The result indicates that increases in flexural strength occur as the volume dosage rate of recycled fine aggregate increases to 25%, achieving a maximum strength of 5.4 N/mm^2 at 50% recycled aggregate volume. However, a decrease in flexural strength occurs when the recycled fine aggregate volume exceeds 50%. This results in a slightly lower flexural strength compared with the control samples. This is due to the high proportion of coarser aggregate in recycled aggregate. An increase in the dosage volume of recycled fine aggregate likely make the bricks more porous. This causes the aggregates to unbond tightly, creating a void and thus reducing the strength. However, the overall flexural strength of the brick specimens was greater than 2 N/mm^2. For masonry bricks, all the mixes must satisfy the requirements of British Standards Institution [16], with the transverse strength $\geq$ 0.65 N/mm^2.

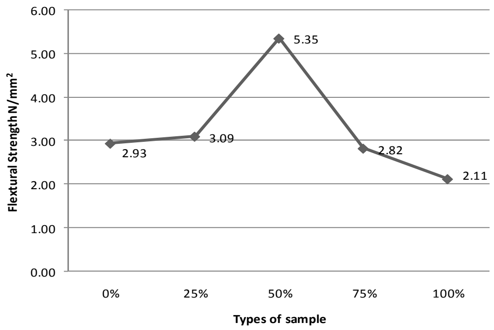

Fig. 3 The average flexural strength of cement and sand bricks with recycled fine aggregate

E. Water Absorption

The water absorption test was carried out to determine the permeability of bricks. The specimens were first dried in an oven for 76 h at 110°C and then later cooled at room temperature before weighing. Afterwards, the specimens were placed inside a curing tank and boiled in water for 6 h. The specimens were removed after being immersed in the tank for 16 h and then weighed. The ratio of water content to the dry mass of bricks determines the quantity of the water absorption of specimens. The result for water absorption and the relationship between water absorption and density are depicted in Figure 4 and Figure 5, respectively. The amount of water absorbed by the bricks composites depends on their void volume and the amount proportion of material present; both these parameters have an effect on density.

From the results, it can be concluded that the water absorption characteristic of cement and sand bricks containing with recycled fine aggregate significantly affected the increased water absorption characteristic of bricks. Only bricks content with 50% recycled fine aggregate show less permeable compare control sample. Thus, one would expect the density to decrease and the water absorption to increase as the recycled aggregate content is increased; the bricks with recycled fine aggregate was more porously than the natural aggregates; their pores are normally discontinuous in a bricks matrix, being completely enveloped by cement paste. This is was due to the physical size, shape and distribution recycled aggregate are more coarser than natural were make the packing of matrix becomes less efficient as the recycled aggregate content is increased, and so void volume increases accompanied by decreased density and increased water absorption. Compare the results in bricks with 50% of recycled fine aggregate shown lower permeability cause of aggregates are bonded tightly, decreasing the pore rate in the brick and increasing its density.

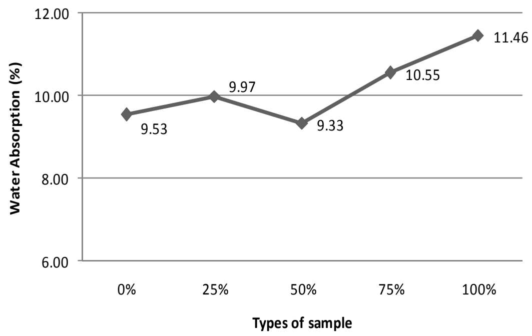

Fig. 4 The average water absorption of cement and sand bricks with recycled fine aggregate

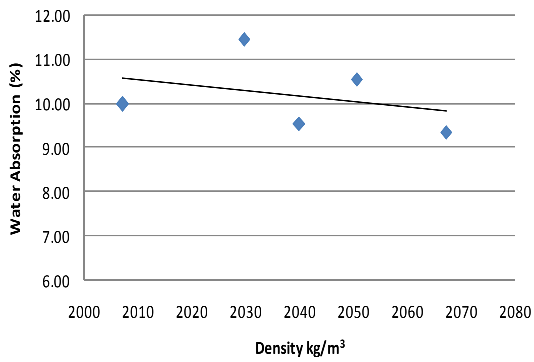

Fig. 5 The relationship between density and water absorption for cement and sand bricks with recycled fine aggregate

F. Drying Shrinkage

The results of drying shrinkage tests are presented in Figure 6. The shrinkage of the control bricks after 28 days was 0.032%. The shrinkage values of the bricks with 50% recycled fine aggregate was shown to be lower than those of the control sample, whereas the shrinkage for bricks with total recycled fine aggregate was shown to have higher shrinkage. Overall the result of drying shrinkage of bricks was lower than 0.06% as required by British Standards Institution [16].

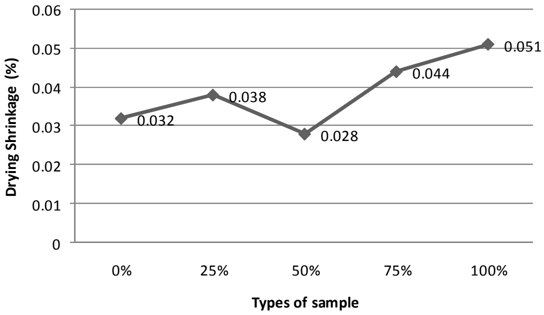

Fig. 6 The average drying shrinkage of cement and sand bricks with recycled fine aggregate

IV. Conclusion

A conclusion can be drawn from the test results that the bricks produced with recycled fine aggregate show a uniform size and surface area similar to bricks with natural aggregate. The replacement with higher recycled fine aggregate can decrease the density of cement and sand bricks.

The test results show that the replacement of natural sand by recycled fine aggregates at the levels of 50% and 75% has good effects on the compressive strength of the bricks. However, having a 100% recycled fine aggregate content reduces the compressive strength compared with that of the control sample. The transverse strength of the specimens increases as the percentage level of the replacement increases to 50%. However, the transverse strength decreases when the percentage of the replacement is more than 50%. The shrinkage and water absorption performances of the bricks are satisfactory.

Overall, recycled fine aggregates produced from demolition waste can be utilised in brick mixtures as a good substitute for natural sand.

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