Experimental study on compressive strength of Interlocking Hollow Block System (IHBS) using fly ash

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Abstract. Interlocking Hollow Block System (IHBS) is a reasonable solution for conventional block masonry due to its structural ability and building capability. In addition, economic and ecological building of brickwork can be achieved by incorporating fly ash into IHBS. The main aim of the research is to produce interlocking compressed hollow block that satisfy the standard requirement as in Eurocode 6. The study is essentially divided into 2 phases, block production and block compression testing. This paper studies on the compressive strength of interlocking hollow clay block with various compositions including laterite soil, cement, sand and fly ash. The optimum mix design is achieved with minimum compressive strength of 7 MPa, which comply with the standard BS 5628-1:1992 Code of practice for Use of masonry – Part 1: Structural use of unreinforced masonry. Test result on addition of fly ash revealed that the optimum fly ash content was 2% with the highest compressive strength of 10 MPa. The results of this study show that the proposed block mixture meets the standard strength requirements and the structural performance of the masonry block is improved by adding fly ash into the mix design.

1 Introduction

Bricks are among the most significant building materials in residential development. Brick manufacturing and steel materials quality have been improved to be sustainable and environmentally friendly [1]. The idea of interlocking masonry has been grown considerably over the past several decades in construction applications and development. This was due to its high productivity rate, efficiency and low requirement of manpower in manufacturing and implementation sectors [2, 3].

Interlocking Hollow Block System (IHBS) was invented to produce a sustainable, low-cost and eco-friendly construction materials. IHBS is used to build low-cost houses with

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load bearing masonry system. Compressive strength is an important data for designing houses using IHBS. The material used to produce IHBS are laterite soil, sand, cement, and water. IHBS are different with conventional clay brick as IHBS contain cement and produce by compressed method. The cement in IHBS allows strength improvement because the presence of cement and water develop hydration reaction and improve the bonding between the clay soil and other materials. C_3S and C_2S in the cement react with water generating C-S-H silicate gel. The hydration products of the cement occupy the void in the mixture as well as improve the hardness of its structure by establishing a significant number of strong connections in the soil, which improves the compressive strength [4].

A lot of researchers studied on the mechanical properties of interlocking compressed clay brick. The majority of them concentrate on boosting their strength and durability. However, the strength of the brick still needs to give extra attention and should comply with the standards. Standards such as BS 5628-1:1992, MS 76:1972, ASTM C 109, ASTM C 67, EN 772-1:2000, EN 1052-1:2009, and BS 3921-1985 can be used to determine the compressive strength of interlocking brick [5]. This paper presents the mix design for IHBS to obtain the average compressive strength. The aim of this paper is to get the optimum mix design and the effects of fly ash of the compressive strength of IHBS. Eurocode 6 does not set the minimum strength for bricks. Therefore, the data from BS 5628-1:1992 [6] is used where the minimum compressive strength is 7 N/mm^2 at 28 days [6].

2 IHBS mix design

This section presents the mix design for the proposed IHBS block which are design by weight of the materials. The details of the material composition are shown in Table 1. Mix design 1 to 4 investigate the effects of cement and laterite content in the block, while Mix 5 to 7 will look into the effects of fly ash. The IHBS sample will be tested for the compressive strength at 14 days and 28 days.

Table 1. Composition proportions of IHBS

Mix	Cement (%)	Laterite Soil (%)	Sand (%)	Water cement ratio	Fly ash (%)
Mix 1	15	53	32	0.6	0
Mix 2	17	53	30	0.6	0
Mix 3	20	48	32	0.6	0
Mix 4	20	56	24	0.6	0
Mix 5	19	56	24	0.6	1
Mix 6	18	56	24	0.6	2
Mix 7	16	56	24	0.6	4

3 Methodology

3.1 Materials

The materials used to produce interlocking hollow clay block were laterite soil, sand, cement, water and fly ash. Laterite soil is comprised of clay and iron. These elements are important to the strength of IHBS. The laterite soil will become soft when the water content is high, while it becomes hard when exposed to a higher environmental temperature continuously. [7]. The laterite soil was air dried and stored in a container after crushing and sifting. This is to ensure that the particle size of the laterite soil is suitable to be used to produce IHBS and the water content will not affect the mix proportion.

Sand as the fine aggregates and should be sufficiently fine which passes through 2.36 mm of sieve as well as clean and free from any organic matter. Ordinary Portland Cement (OPC) was the binding agent and a good stabilizer in interlocking hollow clay brick manufacturing because it possesses adhesive qualities, which bind minerals and particles with each other.

The water used must be free from organic or sulphate contaminants. The presence of contaminants will influence the process of hydration during hardening. Water also necessary for optimum hydration of cement during curing. Fly ash is residuals from electric power plant coal combustion so it is a waste material and available based on supplier. The fly ash used in this study was collected from Tanjung Bin Power Plant in Johor. By utilizing fly ash, the waste material can be rid of in a sustainable way because it will require the power plant a disposal cost of the fly ash as it is a fine waste material and will caused pollution if not properly disposed. Therefore, most of the plant will provide the fly ash for free. Fly ash has the cementitious properties similar to cement and lime. For that reason, various researchers concentrate on the utilization of fly ash as replacement for cement in concrete production.

3.2 Production of interlocking hollow clay block

The block is produced at Makmal Kerja Raya Malaysia (MKRM), Construction Research Institute of Malaysia (CREAM), Construction Industry Development Board (CIDB), Kuala Lumpur. The interlocking hollow clay block were manufactured by using hydraulic compression machine with the mould size of 300 mm × 150 mm × 100 mm as shown in Figure 1. The air-dried laterite soil was crushed by using crusher to obtain the suitable particle size. On the other hand, the sand has been filtered by using 2.36 mm sieve. All laterite soil, sand, cement, fly ash and water materials were weighed by weighting scale according to the mix proportions. The materials were combined thoroughly in a mixer for 5 minutes and water was added gradually using spray bottle in order to avoid formation of lumps. Before the mixture is poured into the compression machine, the steel mould must be cleaned and greased to prevent the block from sticking on the mould. The mixture was then poured into the mould and distribute uniformly. It was then compacted by using the hydraulic jack. The compressed blocks were then removed from the mould and measured for dimension check. Curing was performed by water spraying over the blocks every 24 hours for 3 days. This is to avoid quick drying that would result in shrinkage and cracking. Figure 2 shows an overview of the interlocking hollow clay block production.

Fig. 1 Hydraulic compression machine

Fig. 2. Interlocking hollow clay block production a) Crushing of laterite soil; b) Sieving of sand; c) Weighing of laterite soil; d) Weighing of sand; e) Weighing of cement; f) Weighing of water; g) Dry mixing of soil, sand and cement; h) Addition of water; i) Pouring mixture into mould; j) Mixture compression; k) Watering the IHBS; l) Curing of IHBS

3.3 Compressive strength test

The compression test of the interlocking hollow clay block was conducted using Universal Testing Machine (UTM). The width W_1, width W_2, length L_1, and length L_2 was measured using the digital calliper. The label of dimension for IHBS sample is shown in Figure 3. The weighing balance was used to weigh the IHBS samples and then the IHBS samples were placed in the compression machine. The top and bottom surface of the IHBS is covered with steel plates of size 400 mm × 200 mm × 20 mm to ensure the load distribute evenly across the block. The IHBS sample and steel plate were centred with respect to the lower plate. In the configuration menu, the width and length of IHBS is entered and loading rate is set to 0.6 MPa/s.

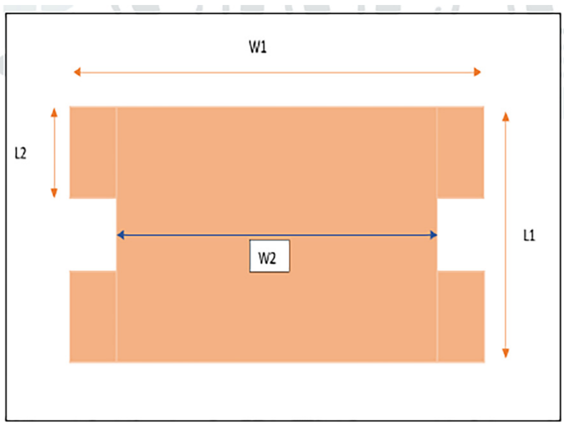

Fig. 3. Dimension of IHBS

4 Result and discussions

There are total of 42 blocks were produced and the dimension of each block is measured. A comparison between designed dimension and actual dimension of the IHBS sample are shown in Table 2. Based on the comparison in Table 2, all the actual dimensions are in good agreement with the designed dimension. This shows the consistency of the produced block and no shrinkage occurs during the curing process. The accuracy of the actual dimension is in the range of ±0.95mm for W1, ±1.16mm for W2, ±1.24mm for L1, ±0.82mm for L2 and ±2.03mm for H.

Table 2. IHBS dimensions

Dimension	Max Size (mm)	Min Size (mm)	Average (mm)	Standard deviation	Designed Dimension (mm)
W1	300.95	299.45	300.31	0.37	300.00
W2	261.16	259.59	260.23	0.34	260.00
L1	151.24	149.92	150.54	0.27	150.00
L2	40.82	39.99	40.36	0.23	40.00
H	100.81	97.97	98.94	0.65	100.00

The compression test results for the IHBS sample are shown in Table 3. The results showed that all IHBS samples achieved the minimum compressive strength of 7 MPa at 28 days, which comply with BS 5628-1:1992. For mix design without fly ash, it was observed that the highest average compressive strength of the block is 8.16 MPa in mix 4 and the lowest was 7.18 MPa in mix 2, which have a difference of 13.6% in compressive strength. This may be due to the higher cement content in mix 4 by 3%. The higher in cement content resulting more C-S-H gel formation in the block during hydration process and lower block porosity. Formation of C-S-H gel fill the voids in the block resulting in higher compressive strength. On the other hand, with addition of fly ash the highest compressive strength is obtained with Mix 6 or average compressive strength of 10.12 MPa. Based on the results obtained, the optimum percent of fly ash content was 2% and the strength has increased by 24% as compared to Mix 4. The fly ash does not contribute to the strength of the block when the fly ash content was 1% and the strength reduced when the fly ash content 4%. The previous study shows that the results have been reported that optimal fly ash content is 10% [8]. From Table 3, the average weight of IHBS sample is in the range of 7.23 to 7.64 kg while the density of IHBS sample is in the range of 1716 kg/m^3 to 1833 kg/m^3.

Table 3. Compressive strength of IHBS block samples

Mix	Max Strength (MPa)	Min Strength (MPa)	Std Dev	Max Density (kg/m³)	Min Density (kg/m³)	Max Average Strength (MPa)	Min Average Strength (MPa)	Max Weight (kg)	Min Weight (kg)
1	7.44	6.87	0.29	1833.67	1716.55	10.12	7.18	7.64	7.23
2	7.35	6.86	0.28						
3	8.65	7.25	0.70						
4	9.32	7.00	1.64						
5	8.83	7.25	0.82						
6	10.86	9.4	0.73						
7	8.2	7.82	0.20						

Figure 4 compares the strength of IHBS between 14- and 28-days. Based on the results, the difference between the compressive strength is in the range of 80% to 98% for Mix 1 to Mix 4, while for Mix 5 to Mix 7 the difference is in the range of 72% to 94%. As compared to normal concrete mix design, the strength of concrete should achieve 90% of the design strength at 14-days and full strength at 28-days. However, based on this study the strength development of IHBS is not similar as compared to normal concrete as the difference between 14- and 28-days can vary up to 28%. This may be due to the hydration process in IHBS take longer duration, which can be determine in longer duration for future study.

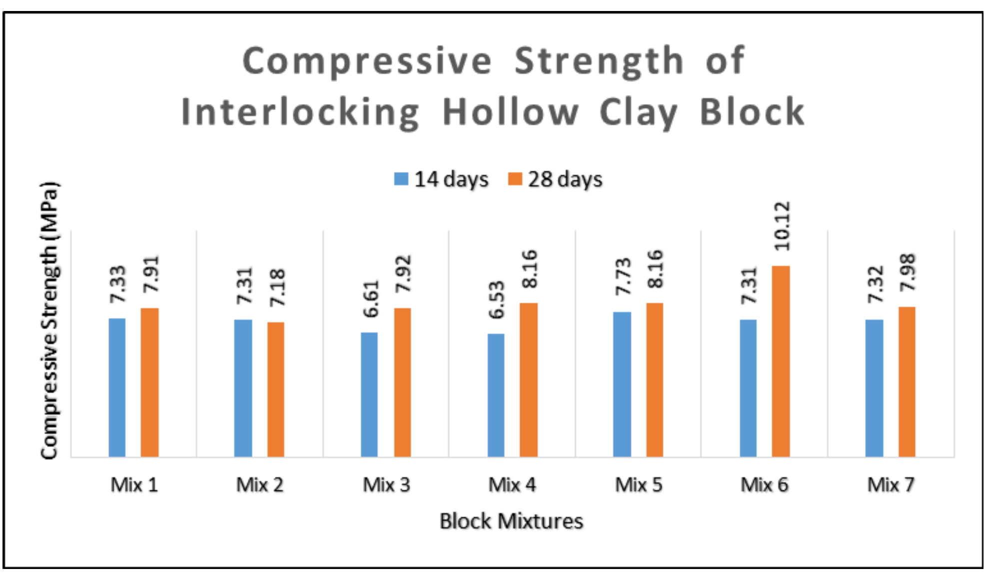

Fig. 4. Comparison of average compressive strength of IHBS block samples for 14 and 28 days

5 Conclusion

Several conclusions can be drawn from this study as follow:
1. The dimension of the IHBS is consistent with the designed dimension, where the difference is in the range of ±0.82 to ±2.03mm
2. The compressive strength of all IHBS sample comply with the minimum strength requirement as in BS 5628 or 7 MPa for load bearing element. The highest compressive strength is achieved in mixture Mix 6 with fly ash and Mix 4 without fly ash.
3. The optimum fly ash content is achieved in Mix 6 or 2% fly ash content.

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