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STRENGTH AND BEHAVIOUR OF LIGHTWEIGHT FERROCEMENT-AERATED CONCRETE SANDWICH BLOCKS

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Abstract: Results of an experimental investigation on sandwich blocks fabricated using lightweight aerated concrete encased in a ferrocement box are presented in this paper. The primary variables investigated are the type of wire mesh; chicken and square wire mesh, and number of wire mesh layers in the ferrocement box. The response variables considered include compressive strength, overall unit weight and failure mode. The results are compared with control block specimens made solely of the aerated concrete. The results showed significant increases in compressive strength due to the encasement of aerated concrete. Overall, the unit weight of the sandwich blocks comply with the specifications for lightweight structural components. The ferrocement encasement changes the otherwise brittle failure mode of aerated concrete into a ductile one.

Key words: *Sandwich; ferrocement; aerated concrete; lightweight.*

Abstrak : Kertas kerja ini membentangkan keputusan kajian makmal blok ringan konkrit apit yang diperkukuh dengan jejaring dan teras kekotak simenfero berkekuatan tinggi. Kajian tertumpu kepada kesan penggunaan pelbagai jenis jejaring serta lapisan jejaring bagi menghasilkan kekotak simenfero tersebut. Dua jenis jejaring digunakan; jejaring mata punai, dan jejaring segiempat. Keputusan ujian terhadap kekuatan mampatan, berat keseluruhan unit blok dan mod kegagalan telah diperolehi. Keputusan dibandingkan dengan sampel kawalan yang diperbuat dari blok konkrit tanpa diperkukuh. Hasilnya didapati kekuatan mampatan meningkat dengan ketara bagi sampel yang diperkukuh. Manakala berat keseluruhan unit blok memenuhi piawai bagi komponen struktur ringan. Kesan keseluruhan mendapati bahawa blok yang pada asalnya rapuh bertukar menjadi lebih mulur degan penggunaan kekotak simenfero.

Kata kunci: *Konkrit apit; simenfer;, konkrit berudara; konkrit ringan.*

1.0 Introduction

Structural sandwich panels are frequently used in modern lightweight construction due to their low thermal conductivity and high strength-to-weight ratio (Tat and Qian, 2000; Araffa and Balaguru, 2006). The typical structural sandwich element consists of two thin high strength and high density facings or skins which are adhesively bonded to or encased in a thick core layer made of low strength and low density material (Jorg et al., 2006; Noor Ahmed et al., 2006). The facings or skins consist of homogeneous metallic material or of cement based composites. Cement based composites exhibit much better performance as compared to plain concrete (Noor Ahmed et al., 2005). The common materials used for core are foam, non-metallic honeycombs or cellular concretes. The introduction of new materials such as laminated composites like ferrocement as the facings or skins and low density materials like aerated concrete as the core, presents new possibilities in designing a sandwich system. In this study, this type of composite is referred to as ferrocement-aerated concrete sandwich composite.

Ferrocement is a type of thin walled reinforced concrete commonly consisted of cement mortar reinforced with closely spaced layers of continuous and relatively small wire mesh (ACI, 1997). It has been regarded as a highly versatile construction material having unique properties of strength and serviceability. Its advantageous properties such as strength, toughness, water tightness, lightness, durability, fire resistance and environmental stability can not be matched by any other thin construction material (Naaman, 2000). Ferrocement is a promising composite material for prefabrication and industrialization of the building industry (Noor Ahmed and Salihuddin, 2006). Studies conducted on ferrocement as encasement for structural strengthening (Ong et al., 1992; Waliuddin and Rafeeqi, 1994; Kaushik et al., 1996; Al-kubaisy and Jumaat, 2000; Al-Rifai and Mohammed, 2000; Abdullah and Takiguchi, 2003) have also shown great promise.

Aerated concrete is either cement or lime mortar, classified as lightweight concrete, in which air-voids are entrapped in the mortar matrix by means of suitable aerating agent (Narayanan and Ramamurthy, 2000; Arreshvhina, 2002). These air bubbles are created to reduce the density of the concrete and to provide good thermo-acoustic insulation. However, aerated concrete exhibits low compressive strength and high rate of water absorption (Arreshvhina, 2002). It was reported that, if aerated concrete is encased in ferrocement, the water absorption capacity reduces to about one-fourth of that of the aerated concrete alone (Noor Ahmed et al., 2006). A number of research works, both experimental and analytical, have also been reported (Naani and Chang, 1986; El-Debs et al., 2000; Al-Rifai and Mohammed, 2000) on the use of ferrocement as facing or skin over different lightweight materials for variety of applications. This study is aimed at investigating the feasibility of producing lightweight load-bearing blocks of aerated concrete encased in ferrocement with different type and number of layers of wire mesh. The assessment criteria used include compressive strength, unit weight and failure mode.

2. 0 Experimental Program

2.1 Material

Cement: Ordinary Portland Cement (OPC) of 'SELADANG' brand from Tenggara Cement Manufacturing Sdn. Bhd. was used in this study. The OPC used complies with the Type I Portland Cement as in ASTM C150-92 and BS 12-91 which is same as Malaysian Standard MS 522: Part I-2003.
Ground Granulated Blast Furnace Slag (GGBFS): GGBFS was obtained from YTL Cement Sdn. Bhd. at Pasir Gudang, Johor. The GGBFS used complies with the requirements in ASTM C989-89, which is same as in BS 6699-92.
Fine Aggregate: The sand used for the ferrocement mortar mix complies with the requirements of ASTM C33-92. For aerated concrete core, sand passed through 600 µm sieve was used.
Superplasticizer: The superplasticizer of trade name SIKAMENT NN was used as the chemical admixture. It is type F high range water reducing admixture according to ASTM C 494-92.
Aluminum Powder: The aluminum powder type Y250 was used as the gas-forming agent in producing slag cement based aerated lightweight concrete.
Wire Mesh: Square welded wire mesh, about 1mm diameter and 12mm square grid (Figure 1), and chicken wire mesh (hexagonal) of 0.5mm diameter and 18 mm x 14 mm wire spacing (Figure 2) were used as ferrocement reinforcement. Both are available in the local market.

Figure 1: Square wire mesh

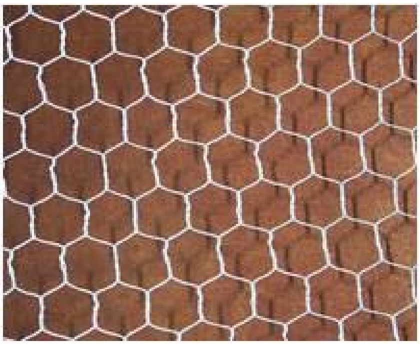

Figure 2: Chicken wire mesh

2.2 Preparation of Specimen and Testing

The experimental study involved casting and testing of 24 block specimens of standard size 400 mm x 200 mm x 100 mm as per the recommendations of MS 1064(2001). The core size of the sandwich specimens was maintained at 376 mm x 200 mm x 76 mm.

Ferrocement box of 12 mm thickness was produced over four sides of the core to fabricate sandwich block of standard size as mentioned above. The specimens were divided into eight batches including the one cast solely with aerated concrete for control specimens. Each batch contains three specimens. Details of the specimens are presented in Table 1. Aerated concrete having design density about 1200 kg/m^3 was adopted as core for all sandwich block specimens including the control specimens. The details of the aerated concrete mix are given in Table 2.

Table 1: Details of block specimens

Sample. No.	Batch Designation	Type of wire mesh	No. of layers	Remarks
1	BC	---	----	Control block made of aerated concrete
2	B0L	---	0	Sandwich block without wire mesh
3	BCW1	Chicken wire mesh	1	Sandwich block with one layer of chicken wire mesh
4	BCW2	Chicken wire mesh	2	Sandwich block with two layers of chicken wire mesh
5	BCW3	Chicken wire mesh	3	Sandwich block with three layers of chicken wire mesh
6	BCW4	Chicken wire mesh	4	Sandwich block with four layers chicken wire mesh
7	BSW1	Square wire mesh	1	Sandwich block with one layer of square wire mesh
8	BSW2	Square wire mesh	2	Sandwich block with two layers of square wire mesh

Table 2: Mix proportions of slag cement based aerated concrete.

Materials	Mix proportion
Binder : Sand (passing through 600µm sieve)	1: 1
Slag Replacement	50%
Water-Dry Mix Ratio	0.23 of total dry mix
Aluminium Powder	0.1% of total dry mix
Superplasticizer	0.55% of total binder

Mortar mix of ratio 1:2 (binder: sand) with w/b ratio adjusted for specific flow value and superplasticizer dosage of 0.2% was used to produce the ferrocement box over aerated concrete. Before casting the ferrocement box, tests were performed to ensure that the flow value of the mortar mix was 136±3%. Noor Ahmed et al (2005) recommended casting of thin ferrocement box by the method of pouring instead of

plastering. A 50% replacement of cement (by weight) by GGBFS was used in both mortar mix and aerated concrete throughout the experimental programme.
The casting of sandwich blocks was carried out in two stages. First, the core of all specimens, except for the control, was cast with dimensions 12 mm less than the overall dimensions along four sides to accommodate 12 mm thick ferrocement box. For aerated concrete, the mould was filled to about 80% of its volume to leave enough room for expansion. The expansion of the mortar took place within 1-2 hours after the casting. However, initial hardening of aerated concrete is achieved within 3-4 hours after casting. Expanded material was later trimmed off to achieve a smooth surface. In the second stage, the core was demoulded on the very next day and wrapped it around for casting of the ferrocement box in single operation.

Table vibrator was used during the casting of the ferrocement box. At the time of casting, three companion cube specimens of size 70.6 mm x 70.6 mm x 70.6 mm were also cast to determine the ultimate compressive strength of ferrocement mortar. All specimens were cured under wet condition for 28 days and tested for compressive strength using TONIPAC 300 testing machine at the Materials and Structures Laboratory of UTM, Malaysia. Before testing, the weight of each specimen was recorded in order to determine the unit weight.

3.0 Results and Discussion

3.1 Compressive strength

Table 3 presents the average compressive strength, for all the specimens. As expected almost all the sandwich specimens showed significant enhancement in compressive strength compared to the control specimen. The compressive strength increases with the number of wire mesh layers except for BCW4 where four layers of chicken wire mesh were incorporated in the ferrocement box.

Table 3: Summary of average compressive strength for the block specimens

Sample. No.	Batch designation	Average compressive strength (MPa)	Increase in compressive strength (% of BC)	Increase in compressive strength (% of B0L)
1	BC	7.7	--	--
2	B0L	10.8	40.3	--
3	BCW1	12.2	58.4	13.0
4	BCW2	13.0	68.8	20.4
5	BCW3	13.7	77.9	26.9
6	BCW4	12.9	67.5	19.4
7	BSW1	15.5	101.3	43.5
8	BSW2	16.4	113.0	51.9

This can be attributed to inadequate compaction of mortar due to reinforcement congestion. Although the compressive strength increases with increasing wire mesh layers, the rate of strength enhancement drops beyond one layer in case of square wire mesh and two layers for chicken wire mesh. This concludes that the appropriate number of mesh layer to obtain the highest compressive strength is one for square wire mesh and two for the chicken wire mesh.

It is also obvious from the table that the enhancement in compressive strength is more significant when sandwich blocks are fabricated with square wire mesh for the ferrocement box. The compressive strength of specimens with one layer of square wire mesh (BSW1) is almost 20% more than the specimens with three layers of chicken wire mesh (BCW3). Thus, square wire mesh is a better option to produce ferrocement-aerated concrete sandwich blocks.

3.2 Unit weight

Before compressive strength tests, all specimens were cleaned and were weighed to calculate the unit weight. Table 4 shows the average unit weight of all the eight batches tested. The values showed higher for specimens with ferrocement encasement. However, the effect of mesh layers on unit weight is insignificant. The unit weight increases by about 29% of the control, when aerated concrete is encased with ferrocement mortar only. Although further increase in unit weight with the incorporation of mesh layers in the ferrocement box was observed, it was very small ranging from 1.7-4% of the sandwich specimens without wire mesh. Therefore, the contribution of steel wire mesh to the unit weight could be ignored in the design of ferrocement-aerated concrete sandwich blocks.

Table 4: Summary of average unit weight of block specimens

Sample. No.	Batch Designation	Average Unit weight (kg/m^3)	Increase in Unit weight (% of BC)	Increase in Unit weight (% of B0L)
1	BC	1205	---	---
2	B0L	1562	29.6	---
3	BCW1	1588	31.8	1.7
4	BCW2	1597	32.5	2.2
5	BCW3	1625	34.9	4.0
6	BCW4	1617	34.2	3.5
7	BSW1	1603	33.0	2.6
8	BSW2	1623	34.7	3.9

It can be noted from Tables 3 and 4 that the enhancements in compressive strength as high as 113% is achieved as compared to 35% increase in unit weight, when two layers of square wire mesh are incorporated in ferrocement box to produce sandwich block. Unit weight is one of the major parameters considered in the design of lightweight structural members. The comparison between the increases in compressive strength and unit weight of respective batches may be noted in Tables 3 and 4.

The average unit weight for all sandwich blocks cast and tested in this study is about 1600 kg/m^3 or about 40% less than the normal weight of 2400 kg/m^3. Thus, looking at the specifications for compressive strength and unit weight of masonry units given in ASTM C90-90, the sandwich blocks fabricated in this study lie in the category of lightweight and load bearing concrete masonry unit.

3.3 Failure mode

Failure mode of all specimens was observed closely during the compressive strength tests. All the control specimens failed in a brittle manner. At the maximum load attained by the specimen, one or more of the surfaces spalled off and the load dropped rapidly before a complete collapse of the specimen. Although the strength of the sandwich block specimens without wire mesh (B0L) was considerably higher than the control (BC), the failure mode of B0L was identical to that of BC. Figures 3 and 4 show the failure of BC and B0L specimens respectively.

Figure 3: BC after failure

Figure 4: B0L after failure

Unlike the brittle, sudden and complete collapse mode of failure for BC and B0L, sandwich specimens with wire mesh showed significant ductile behaviour. At about 60%-80% of the ultimate load, fine cracks appeared at the surfaces of the specimen. Additional cracks were formed and the initial cracks widened with the increase in load leading to the failure of the specimen. In some cases the spalling of concrete in ferrocement box was observed, but the failure occurred due to the cracks in ferrocement box. However, in any case complete detachment between ferrocement box and aerated concrete core was not observed. Thus, almost all the sandwich specimens behaved as composite unit. The load dropped gradually after the failure and the specimen did not collapse completely resulting in a warning period prior to the final collapse. Even after failure, the sandwich specimens were still in a single unit and showed residual strength of 20%-30% of ultimate load. This behaviour of sandwich specimens is attributed to the presence of wire mesh and uniform and close distribution of its wires within the ferrocement box. This is desirable when ferrocement sandwich blocks are considered for structures located in an earthquake prone zone. Adequate ductility and sufficient warning period before complete failure are among the major criteria used for the design of structures under earthquake forces. Figure 10 show the failure modes of typical sandwich blocks after failure.

(a) Block BSW1 (b) Block BSW2 (c) Block BCW3 (d) Block BCW4

Figure 10: Typical specimens after failure

4.0 Conclusions

The following conclusions could be made from the experimental investigations:

- Ferrocement encasement result in significantly higher compressive strength of the sandwich blocks
- Square wire mesh exhibited better performance compared to chicken (hexagonal) wire mesh in terms of compressive strength.
- Although, the compressive strength increases with the increase in wire mesh layers, single layer of wire mesh may be considered as optimum in terms of compressive strength.
- The overall unit weight of ferrocement-aerated concrete sandwich block increases by an average of 33% of the control block because of encasement but it is independent of the number of wire mesh layers.

- Ferrocement encasement over aerated concrete transforms the otherwise brittle failure mode of aerated concrete into a ductile material due to the presence of wire mesh in the ferrocement box.
- The fabricated ferrocement –aerated concrete sandwich blocks tested in this study comply with the specifications of lightweight load bearing concrete masonry units.

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