

Experimental Investigation of Sandwich Panels with Different Types of Coarse Aggregate

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Abstract

Concrete sandwich panel [CSP] is an innovative structural construction system. It is two or more layers of concrete separate by lightweight layers. The present work, the one-way sandwich panels are comprised of two lightweight concrete layers, between them a layer of cork, the dimensions of the slabs were (1100mm total length \times 400 mm width \times 90mm thickness). The outer concrete layers were connected by steel bar in the shape of truss. An experimental program was carried out on four slabs, one of them was solid slab while the three other slabs were sandwich slabs. The main variable of this study was the type of coarse aggregate which used in the outer concrete layers. The slabs have been tested as a simply support span under two points load. Experimental results proved that the using of sandwich panels will have enhanced many properties such as toughness, ductility and maximum value of deflection, in addition to the main benefit is a total weight reduction. The differ in the type of coarse aggregate considerably influences the structural behavior of the panels.

Keywords: Sandwich panel, Light-weight concrete, Clay crushed- bricks.

1. Introduction

Sandwich panels generally consists of two layers of any strong material, in that work it was concrete and separated by a low density material such as cork [1],[2],[3],[4],[5]. The chosen of materials which used in the outer layer is a major factor affecting the behavior of the panels[6]. The structural constraint of the outer wythes was its ability for resisting the applied loads and resist fire. The sandwich panels under flexural loads can be designed as a full composite panel, non-composite panel or partially composite panel, full composite panel was strong and stiff [7]. Benayoune et. al. [2] studied experimentally and theoretically the flexural behavior of concrete sandwich composite panel. The tested six slabs included two slabs with dimensions (2000* 750) mm, two slabs with dimensions (1500 *1500) mm, while the other two slabs with dimensions (1000*500) mm. CSP was consisted of two reinforced concrete layers with 40 mm thickness, and one polystyrene layer in the middle with 40 mm thickness. A square welded steel BRC mesh of 6 mm bar diameter with 100 * 100 mm openings was used as the longitudinal and transverse reinforcement for the two concrete wythes. While continuous truss-shaped connectors, with 250 mm spacing, were used, to tie the inner and the outer concrete wythes so that the panels act as a composite structural unit. The shear connectors were manufactured of steel bars with 6 mm diameter. It was bowed to zigzag- shape, the height for all bent was 90 mm. The shear connectors and wire mesh were connected to form continuous truss shape shear connector. For all tested slabs, the first crack appears at the load about of (55 to 60 %) of the ultimate load. The finite element results were compared with the experimental tests results. The load capacity improves with increasing in the number of shear connectors, the ultimate load was :20 kN, 25.16 kN, 29.75 kN for shear connector numbers 2, 3 and 4; respectively. The results indicated that failure mode and pattern of cracks for sandwich panels are similar to the failure mode and pattern of cracks for solid panels. Dawood, [8]studied concrete sandwich units (wall and slab). the tests were conducted on ten slabs and ten walls. The variables of the study were: the inner layer thickness, the concrete layer strength, and type of lightweight aggregate utilized in the inner concrete layer), dimensions of slabs were (1200 mm * 400 mm), the total thickness was variable between (40/50/60) mm depending on the inner lightweight layer thickness. The second variable was compressive strength for traditional concrete in the outer wythe, fcu was variable between (28/39.3/49.7). Three types of lightweight aggregate which used in the inner concrete layer: polystyrene, sawdust, porecilenite. The results showed that the reference slabs load capacity increased when the thickness was increased. Mohamad et al., [6] studied the structural behavior of recycled aggregate in concrete sandwich slabs tested under flexural load. Different recycle aggregate percentages were used as coarse aggregate in the concrete. The percentages of replacement were; exactly :25% / 50% / 75% and 100%. The results indicated that the percentage of Recycle Aggregate RA used has a minor effect on the mechanical properties of RAC but quite a major effect on the structural behavior of sandwich slabs under flexure. The first crack progresses approximately at 48 – 67 % of the failure load followed by panels failed with excessive cracks in the concrete bottom wythe. Also, it was observed that the flexural strength of the slabs with recycling aggregate concrete decreased with the percentage of RA increase in the concrete. Joseph et al., [9] carried out a research on the behavior of concrete sandwich slabs subjected to four-point bending with varying the thickness of slab, mesh size, with or without either shear resistant ribs or traditional steel rebar's (in addition to the wire mesh) in the lower concrete layer. Panel dimensions were (3000 * 1220 *100 or 150) mm (Length * Width * Thickness), cube compressive strength of self- compacting concrete that used to cast the concrete layers was 45.9 N/mm² and flexural tensile was 4.3 N/mm².the Thickness of each layer was 25 mm. The results of the tests show that all slabs act as composite panel till failure occurred, and the behavior of sandwich panels is similar to solid reinforced concrete one way panels. Cracking behavior in terms of a number of cracks and crack spacing of concrete sandwich panels is similar to that of Ferro cement cracking behavior owing to the presence of wire mesh.

From the previous researches, it is clear that studies on sandwich slabs are still limited and there is a weakness. Most of concrete wythes in the sandwich panels were made of conventional concrete. So these sandwich panels are strong but they have lower strength over weight ratio. Therefore, further investigation on using both lightweight concrete in the wythes and polystyrene core layer was required. Investigate the influence of using different types of lightweight coarse aggregate on the structural behavior of panel.

2. Experimental Work

The experimental investigation conducted one solid conventional slab with normal weight concrete and three sandwich slab, the coarse aggregate which used in the outer concrete layers of sandwich slabs were (normal coarse aggregate, clay crushed bricks, Attapulгите) with maximum size 10 mm. All slabs were tested under two points load. All slabs were one-way action and have same total dimensions (1100 × 400 × 90) mm. Sandwich panels involve of two concrete wythes with 3 cm thickness, separate them cork layer with a 3 cm thickness as shown in Figure 1.

(RN) refer to the conventional solid panel with normal weight concrete reinforced with longitudinal steel bars $\text{Ø}6 @ 150 \text{ mm}$, this panel considered as a control slab for comparison.

(SN-C45), (SB-C45), (SA-C45) are sandwich panels with normal weight, clay crushed brick, Attapulгите coarse aggregate in the outer concrete layers and steel truss shear connectors included angle for each bent was 45° was continuing along the length of span.

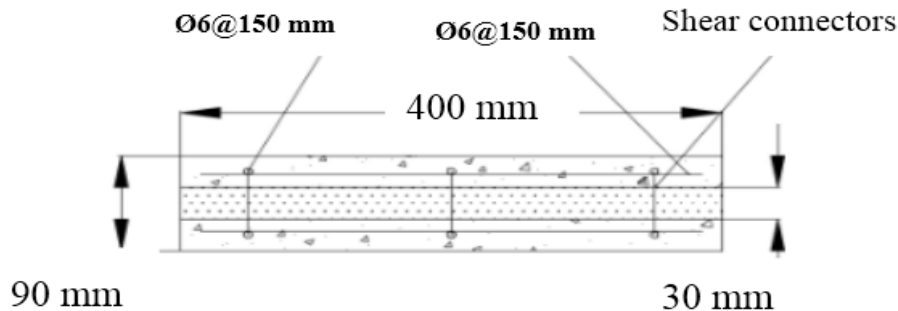


Figure 1: Cross Section Details of the Sandwich Slabs.

2.1 Materials

The materials which used in the current study were:

- Portland cement resistance to sulfate (Type V). The physical and chemical properties tests result conform to the specification No.5 1984.
- Normal-weight, natural sand was used for concrete mixes. The sieve analysis and sulfate content of it were within the limits of Iraqi Specification No. 45/1984.
- Normal-weight coarse aggregate within a maximum size of 10 mm.
- Clay crushed bricks within a maximum size of 10 mm and bulk density of 805 kg/m^3 was used as light weight aggregate.
- Attapulгите: lightweight aggregate obtained from crushing Attapulгите rocks, Attapulгите is a fibrous silicate which has rather large a surface area and acidic characteristics that make the clay more useful as an adsorbent and catalyst. Attapulгите introduced by Carrol 1970 as: $\text{Si}_8\text{Mg}_5\text{O}_{20}(\text{OH})_2 \cdot (\text{OH}_2)_4 \cdot 4\text{H}_2\text{O}$. Firstly, the Attapulгите rocks were crashed into smaller sizes by hammer, then the Attapulгите was screen out by sieve series according to ASTM C330-05 specifications. The prepared raw material was located in three loose layers spread on a strand and placed in a furnace each layer was approximately 110–130 mm, and then was fired by gas as shown in Plate 1. The increasing rate of the temperature was $5^\circ\text{C}/\text{min}$, and when the furnace temperature reached the required degree (1100°C), the sample was kept for half hour soaking time according to
- **Hyperplast PC 200** was used as high Performance Super-Plasticizer Concrete Admixture.
- Reinforcement steel mish with 6 mm diameter bars with spacing of 150 mm deformed steel reinforcement, yield strength of 533 MPa, placed in center of the concrete layers.
- Water for washing, casting and curing for all the specimens.
- Shear connectors, the outer concrete layers were connecting together by steel truss shear connector of 4mm diameter deform bars bent with inclined angle 45° . As shown in Plate 2.



Plate 1: Furnace of Burning

The concrete mix proportion for the normal weight concrete and the lightweight aggregate concrete was (1:2.1:1.2) with water/cement ratio = 0.4 and with super plasticizer 0.5 % weight of cement. The panels were removed from the formwork after 24 hours, and then submerged in water for 28 days.



Plate 2: Shear Connectors

2.2 Tests Procedure

All panels were tested as a simply supported panel under two points load which applied at L/3 from supports. All panels have been tested by using (1000kN) capacity universal testing machine, as illustrated in Plate (3). At the center of the panel, deflection was measured at mid-span by LVDT with 100-mm. At loading was zero, first reading of LVDT was recorded, then load was increased gradually while deflection was recorded until failure occurs. The tests were conducted in the Civil Engineering Department at the structures laboratory in Kerbala University.



Plate 3: Loading System of the Tested Panels.

3. Result and discussion:

3.1 The Load-Deflection Behavior.

Load- deflection illuminated the structural behavior. The following part displays clearly the load vs. vertical deflection curves, the area under the curves (toughness), ductility index, different in the total weight for all tested slabs. The solid and sandwich slabs tests have been conducted under the condition of load control of 3 kN increments. Table (1) shows the total weight, ultimate loads and deflection of panels, and a comparison with a reference RN slab, as given below.

Table 1: Failure Loads and Maximum Deflection of Tested Panels.

| Specimen symbol | Total weight of panels kg | Ultimate load kN | Max. Deflection mm | Different in the total weight compared with RN slab % | Different in ultimate load compared with RN slab % |
|-----------------|---------------------------|------------------|--------------------|---|--|
| RN | 94.5 | 33 | 11 | - | - |
| SN-C45 | 65 | 30 | 13.5 | -31.12 | -9.09 |
| SB-C45 | 57.4 | 27.84 | 22 | -39.26 | -15.63 |
| SA-C45 | 55.7 | 25.89 | 23.42 | -41.06 | -21.54 |

From table 1, it can be noticed that:

- 1) The main benefit of using sandwich form was increasing the ratio of strength/ weight as compared with the solid panel, for same type of coarse aggregate used in concrete mix, **SN-C45** slab shows increasing in the strength/ weight by about **32.1 %** than **RN** slab. Also, the toughness, ductility index will have increased by about **25.11%,2.27%**; respectively. As shown in Figure 2. While the total weight and the flexural load capacity will have reduced **31.2%, 9.09%** as compared with the total weight and ultimate strength of the **RN** slab.

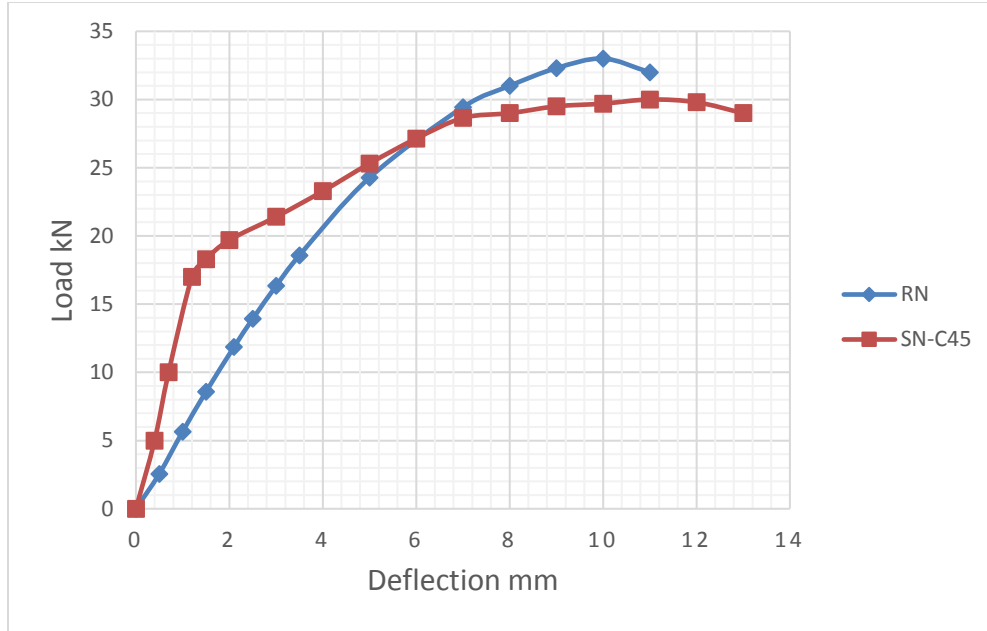


Figure 2: Load Deflection Curves for the RN &SN-C45 Slabs.

- 2) When using clay crushed bricks in concrete mix in the outer wythes of concrete slab panels, the toughness, ductility index will have increased by about **92.75%**, **42.82%**; respectively. As shown in Figure 3. While the total weight and the flexural load capacity will have reduced **39.26%**, **15.63 %** as compared with the total weight and ultimate strength of the **RN** slab.

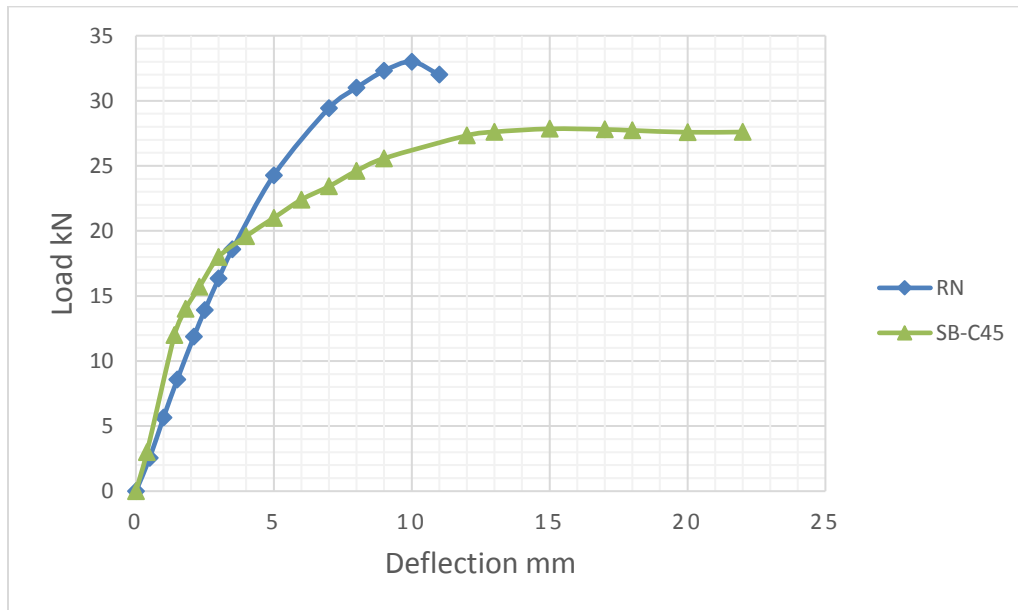


Figure 3: Load Deflection Curves for the RN &SB-C45 Slabs.

- 3) The area under the curve and ductility index will have increased by about **79.97%**, **41.9%**; respectively, when using Attapulgite as a coarse aggregate in the outer concrete wythe (**SA-C45** slab) as compared with **RN** slab, as exhibited in Figure 4. While the total weight and the flexural load capacity will have reduced **41.05%**, **21.54 %** as compared with the total weight and ultimate strength of the **RN** slab.

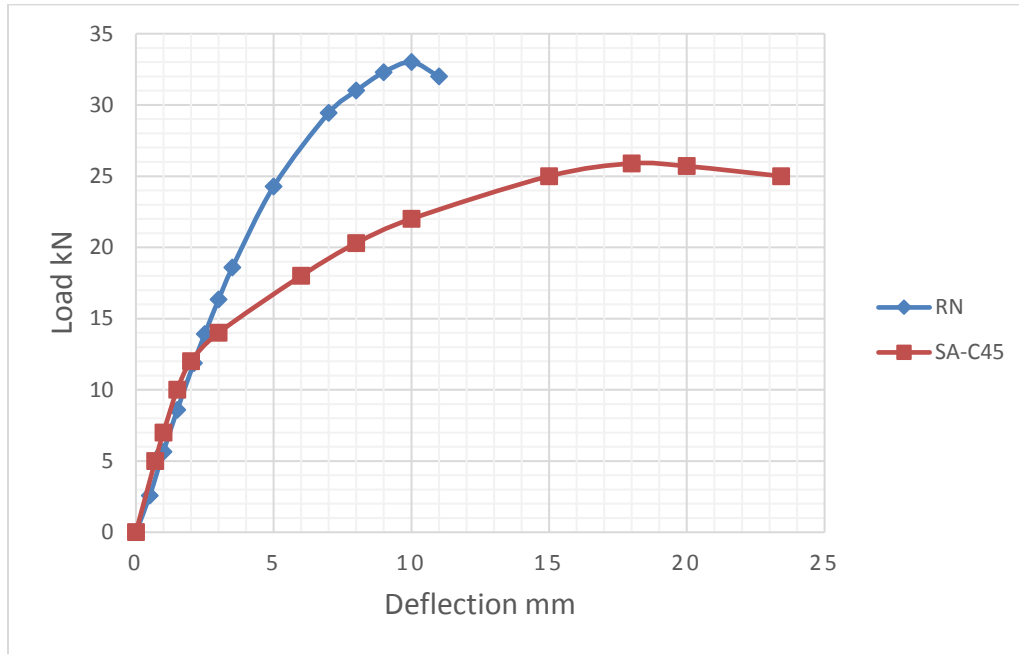


Figure 4: Load Deflection Curves for the RN & SA-C45 Slabs

3.2 Crack Pattern

Plate (4) displays cracks pattern which appeared in the bottom face of the lower concrete layer. All panels showed flexural cracks that developed along the panel width. Small cracks appeared in the upper concrete layer. Larger crack focused at right under the applied loads, despite the maximum bending moment was at the mid-span. Behavior of sandwich panels was similar to the previous researches. All sandwich panels proved to be ductile panel more than solid conventional panel. The failure in all concrete sandwich panel was due to the tension in steel the in the lower concrete layer except solid panel which failed due to concrete crushing.

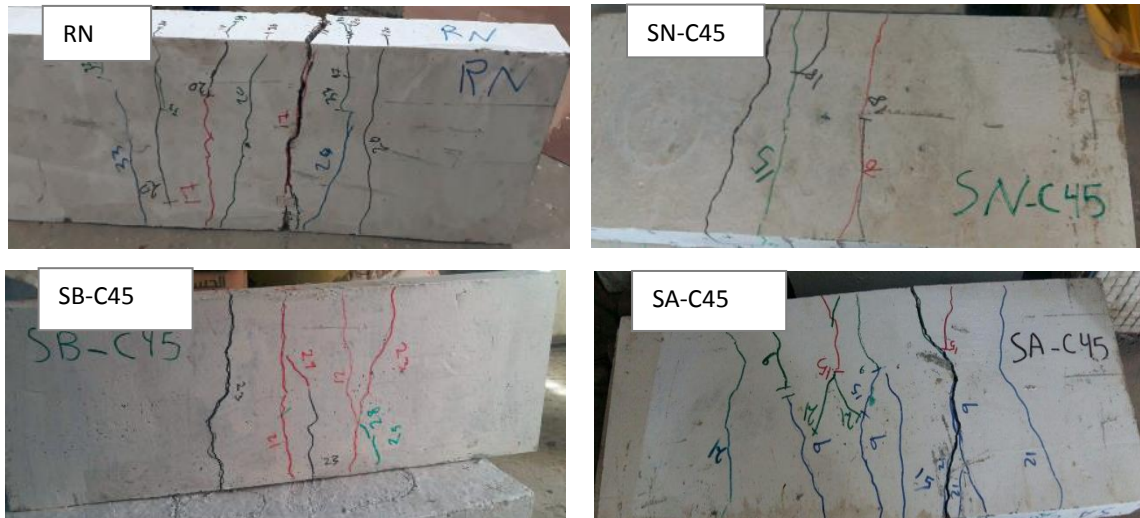


Plate 4: Cracks Distribution of the Different Tested slabs

4. Conclusions:

1. The differ in the type of coarse aggregate significantly affects the structural behavior of the panels.
2. The **SB-C45** slab shows enhancement in the toughness, ductility and maximum value of deflection when compared with the **SN-C45** slab. Also, total weight will decrease by about **11.7%**.
3. The **SA-C45** slab exhibits enhancement in the toughness, ductility and maximum value of deflection when compared with the **SN-C45** slab. While total weight will have reduced by about **14.31%**.
4. The **SB-C45** slab shows an increment in the in the toughness and ductility when it is compared with The **SA-C45** slab while maximum value of deflection will decrease by about **6.06%**.
5. The **SA-C45** slab exhibits decreasing in the total weight and failure load by about **3.13%, 7%** as compared with the **SB-C45** slab.

Conflicts of Interest

The author declares that they have no conflicts of interest.

5. Reference

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التحري العملي للالواح الساندويجية بأنواع مختلفة من الركام الخشن

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الخلاصة :

تمثل الالواح الساندويجية الخرسانية شكل انشائي مبتكر يتكون من طبقتين او أكثر من الخرسانة مفصولة بطبقة خفيفة الوزن .في العمل الحالي ، الالواح الساندويجية تتكون من طبقتين من الخرسانة الخفيفة الوزن بينهما طبقة من الفلين ، تربط الطبقتين الخرسانية الخارجية بواسطة قضيب حديدي على شكل قفص .البرنامج العملي يتكون من اربعة سقوف ، واحد منها يكون سقف صلد بينما السقوف الثلاث الأخرى هي سقوف ساندويجية. المتغير الرئيسي للدراسة الحالية كان نوع الركام الخشن المستخدم في طبقتنا الخرسانة الخارجية . فحست الالواح بوضعية بسيط الأسناد تحت تأثير خطين من الحمل المسلط . بينت النتائج العملية ان استخدام السقوف الساندويجية يحسن الكثير من الخواص مثل المتانة والليونة والقيمة العظمى للهطول.بالأضافة الى الفائدة الرئيسية وهي تقليل الوزن الأجمالي للالواح ، وكذلك اختلاف انواع الركام الخشن يؤثر بشكل كبير على التصرف الانشائي للالواح .

الكلمات الدالة: الألواح الساندويجية، الخرسانة خفيفة الوزن، مكسر الطابوق الطيني.