Journal of Engineering and Development, Vol. 17, No.4, October 2013, ISSN 1813- 7822

Structural Behavior of Composite Sandwich Slab Panels

Asst. Prof. Dr. Waleed A. Waryosh
Civil Engineering Department
College of Engineering
AL- Mustansiriya University
Baghdad, Iraq

Lec. Dr. Yaarub G. Abtan
Civil Engineering Department
College of Engineering
AL- Mustansiriya University
Baghdad, Iraq

Mohammed Hussin Ali Dawood
College of Engineering
AL- Mustansiriya University

Abstract :

Concrete sandwich panel [CSP] is a relatively new and innovated form of construction. In the present study, it is consisting of a layer of light weight concrete [L.W.C], sandwiched between two outer layers of reinforced concrete which are connected together by truss reinforcement as shear connectors. An experimental study was conducted on ten slab panels, with three variables were investigated (thickness of the inner wythe, the strength of the outer wythe, and the type of light weight aggregate which used in the inner wythe) .When one of these variables was varied, the other two variables remain constant. The slab panels were tested as simply support under two point loads. The results, that obtained from the experimental program, indicated that the strength of the reference slab panels increased when the thickness was increased. This behavior can be seen when the thickness of the inner wythe for sandwich slab panels was increased. The strength was decreased when the concrete strength of the outer wythes increase for sandwich slab panels. The strength of the sandwich slab panel with the sawdust, which used as aggregate in the inner wythe, was greater than the strength of sandwich slab panel with polystyrene (styropor) or porcilenite. The maximum deflection and maximum slip for sandwich slab panel depend on the thickness of the inner wythe, the concrete strength of the outer wythes and the light weight aggregate which used in the inner wythe.

التصرف الانشائي لالواح السقوف الساندويجية المركبة

أ.م.د. وليد عواد ورپوش
م. د. يعرب كاظم عبطان
محمد حسين علي داوود

الخلاصة :

تمثل الالواح الخرسانية الساندويجية شكل انشائي جديد ومبتكر نسبيا. تدور الدراسة الحالية حول الخرسانة خفيفة الوزن المحصورة بين طبقتين من الخرسانة المسلحة ومربوطة سويا بواسطة روابط قصية الشكل (shear connectors).

يتضمن البرنامج العملي في الدراسة الحالية عشرة نماذج من الالواح . في هذه الدراسة تم اعتماد ثلاث متغيرات (سمك الطبقة الداخلية ، مقاومة الانضغاط لخرسانة الطبقتين الخارجيتين، نوع الركام الخفيف الوزن الذي يستخدم في الطبقة الداخلية). فحصت النماذج بوضعية بسيط الاسناد،تحت تاثير نقطتين من الحمل المسلط في الثلث الوسطي.

بينت النتائج التي تم استحصالها من الفحوصات العملية انه كلما يزداد السمك للنماذج المرجعية تزداد المقاومة،كذلك تزداد المقاومة كلما يزداد السمك للطبقة الداخلية بالنسبة للنماذج الساندوجية. تقل المقاومة عند زيادة مقاومة الخرسانة للطبقات الخارجية للنماذج الساندويجية. بالنسبة للنماذج الساندويجية فان المقاومة تزداد عند استخدام نشارة الخشب كركام خفيف الوزن للطبقة الداخلية بدلا من الفلين (polystyrene) اوالحجر الخفيف الوزن (porecilinite). التشوة الاقصى وقيمة الانزلاق للنماذج المركبة الساندويجية يعتمد على سمك الطبقة الداخلية، مقاومة الانضغاط لخرسانة الطبقتين الخارجيتين، نوع الركام خفيف الوزن المستخدم في الطبقة الداخلية.

1. Introduction :

In civil engineering construction, the objective of using or selecting any material is to make full use of its properties in order to get the best performance for the formed structure. The merits of a material are based on factors such as availability, structural strength, durability and workability. Methods of improving material utilization can be classified into two categories. The first is to select appropriate materials mixed and the second dispersed to form a new product with desired properties, thus resulting in a composite material. Light weight concrete sandwich panel unit is a relatively new and innovated form of construction, it is consisting of layer of light weight concrete [LWC], sandwiched between two layers of reinforced concrete which are connected to the light weight concrete [LWC] by shear connectors. The main advantage of the shear connectors is to give the strength and to connect the three concrete layers together and also act as transverse shear reinforcement. The main advantage of the system is increased bearing load, good insulations panels, easier to handle, material and labor cost reduction**,** quick and easy installation. Sandwich panels were introduced in the construction industry more than 40 years ago [1], and many researchers were studied this type of system [2-12].

2. Experimental Work

2.1 Experimental Program

The experimental work consists of casting and testing three reference and seven sandwich slab panels. The specimens were divided into four groups; each group consisted of three specimens. All specimens were tested under flexural load (two point loads). The variables investigated in this study were the effect of inner wythe thickness of the sandwich panel, the effect of compressive strength of outer wythes and the effect of type of light weight aggregate (polystyrene, sawdust and porecilinite). These types of materials were used as course aggregate in the inner wythe of sandwich specimens. To provide good bond and to improve the composite action between the outer reinforced concrete and the inner light weight concrete, shear connectors were used in the shape of truss connectors. Also, this type of connection is used to transfer normal and shearing forces between the three concrete layers. All specimens detail can be found in **Table (1).**

Table (1): Properties of specimens

Group No.	Slab* No.	Inner wythe thickness (mm)	Total thickness (mm)	Aggregate for the inner wythe	Concrete strength for the outer wythe fcu (Mpa)	Weight of specimen (Kg)
G1	S1	reference	40	reference	28	54.67
	S2	reference	50	reference	28	61.3
	S3	reference	60	reference	28	75.7
G2	S4	10	40	polystyrene**	28	53.1
	S5	20	50	polystyrene	28	55
	S6	30	60	polystyrene	28	62.7
G3	S5	20	50	polystyrene	28	55
	S7	20	50	polystyrene	39.3	56
	S8	20	50	polystyrene	49.7	59.5
G4	S5	20	50	polystyrene	28	55
	S9	20	50	sawdust	28	54.8
	S10	20	50	porecilenite	28	51.2

*** All slabs have same dimensions of length and width of (1200× 400mm).**
**** Styropor**

2.2 Materials

Ordinary Portland Cement (Type I), was used in this study. The physical properties and chemical test results for the used cement conform to the specification No.5 1984 [13]. The grading and the sulfate content of natural sand, from (Al-Ukhaidher) region in Iraq, which was used for concrete mixes, were within the limits of Iraqi specification No. 45\1984 [14]. For normal weight concrete, crashed gravel from (AL-Nebaee) region with maximum size of 10mm was used. However, crushing porcilinite [15] rocks with maximum size of 14mm and density of 830 Kg/m^3 (from Alrutba region in Iraq) and polystyrene (styropor) [16] with density of 20 Kg/m^{3}and sawdust with density of 1900Kg/m^3 were used in this study as light weight aggregate. The grading of normal and light weight aggregate was conforms to the Iraqi standard specification No. 45/1984[14] The maximum size of cellular polystyrene formed from polystyrene and sawdust material was 4.75mm and 2.36mm, respectively. The mix proportions for concrete with normal and light weight aggregate (precilenite aggregate) was (1:1.5:3) with w/c=0.37 and with w/c=0.45, respectively. However, for concrete with polystyrene and sawdust as aggregate, the proportion mix was (1:1.5:0.02) with w/c=0.4 and (1:1.5:0.15) w/c=0.5, respectively. All the concrete sandwich slab panels were reinforced with two layers of deformed steel reinforcement, consisting of 6mm diameter bars with spacing of 150mm and yield strength of 460MPa, placed centrally through the outer wythes panel thickness. The outer wythes connecting to the inner wythe by truss shear connector of 4mm diameter plain bars **(Figure1)** with shear strength of 10 kN. After 48 hours from casting, the specimens were stripped of water from the formwork and completely immersed potable water for a period of 28 days.

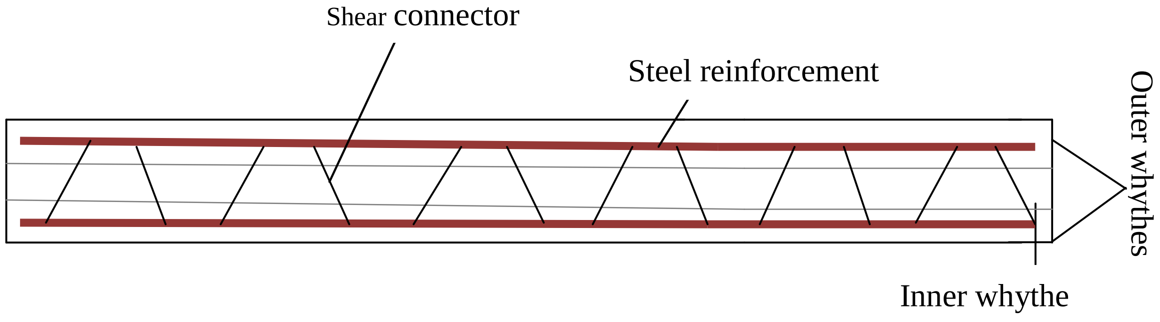


Fig. (1): Sandwich panel unit.

2.3 Test Procedure and Measurements

The specimens were tested over a simply supported span of (1200mm), where two point loads were applied at L/3 from supports. The slabs were tested using (3000kN) capacity universal testing machine, as shown in Figure (2). Dial gauge of (0.01mm) was used to determine the deflection at mid-span. End slip was measured at top and bottom layer at each end of specimens by using dial gauges of (0.01mm). Figures (3 and 4) show the loading arrangement. At zero loading, initial readings of dial gauges were recorded, then load was increased gradually and its reading in steps while deflection and end slip measurements were recorded simultaneously until failure occurs (defined as the highest capacity beyond which loading drops). The test was carried out in the structures laboratory in the Civil Engineering Department, Al-Mustansiriya University.

Fig. (2) Universal testing machine (8551 M. F. L. system)

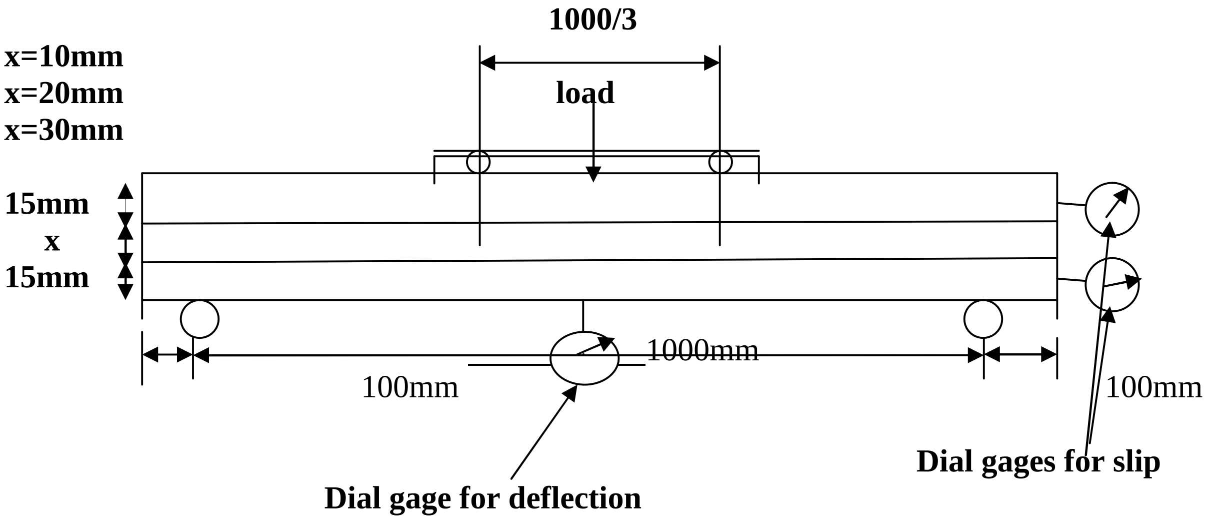


Fig.(3) Schematic diagram for testing panel.

Fig. (4): Arrangement before testing panels.

3. Result and discussion :

3.1 Failure Loads

The failure loads of tested reference and sandwich slab panels are listed in Table (2) and a comparison between the results, dependent on the considered variables, is given as following:

Table (2) Flexural Failure Load Results

Group	Specimen*	Total thickness (mm)	Inner wythe thickness (mm)	Outer wythes thickness (mm)	Light weight aggregate used in the inner wythe	Compressive strength of the outer concrete wythe (Mpa)	Failure load kN
Group (1)	S1	40	30	15	reference	28	32
	S2	50	20	15	reference	28	37.5
	S3	60	10	15	reference	28	40.5
Group (2)	S4	40	10	15	polystyrene	28	19
	S5	50	20	15	polystyrene	28	23
	S6	60	30	15	polystyrene	28	24
Group (3)	S5	50	20	15	polystyrene	28	23
	S7	50	20	15	polystyrene	39.3	21
	S8	50	20	15	polystyrene	49.7	17.5
Group (4)	S5	50	20	15	polystyrene	28	23
	S9	50	20	15	sawdust	28	29
	S10	50	20	15	porecelinite	28	15.5

* **All slabs have same dimensions of length and width of (1200× 400mm).**

From the above table can be noticed that:

1) The ultimate strength of the reference slab panels was increased about 41% from the ultimate strength of the sandwich slab panels when the thickness was increased.
2) When the outer concrete strength wythes was increased from 28Mpa to 49.7Mpa, the flexural strength decreased about 24%. Different in the density between the wythes was reduced the bond between these layers resulting in slip of the wythes , thereby, the material failed without reaching its full load capacity then panels fail due to separation of these wythes.
3) Flexural strength was increased by using the sawdust in concrete mix in the inner wythe of concrete slab panels, while this value was decreased by using the polystyrene (styropor) and porecelinite.

3.2 Load-Deflection Behavior

The structural behavior is normally explained by using a load versus deflection diagram. This section, graphically, shows the load versus central deflection for both the reference and sandwich slab panels. The reference and sandwich slab panels tests were carried out under the condition of load control of 2kN increments. Table (3) shows the maximum central deflection for all slab panels. Figures (5 to 8) show the structural behavior for all slab panels. In order to compare the structural behavior of the panels accurately, each figure will represent three panels with one variable and the other parameters are constant. First group (G1) represents the reference slab panels, while the groups (G2, G3 and G3) represent the sandwich slab panels.

Table (3) Maximum slip and central deflection of the slab panels

specimens	Max. deflection (mm)	Max. slip of the upper wythe (mm)	Max. slip of the lower wythe (mm)
S1	18	reference	reference
S2	17.5	reference	reference
S3	13	reference	reference
S4	17	0.64	1.1
S5	18	0.78	1.3
S6	20.1	1.03	2.6
S7	12.5	0.9	1.4
S8	9.5	1	1.55
S9	19.5	0.65	0.69
S10	6.6	1	1.4

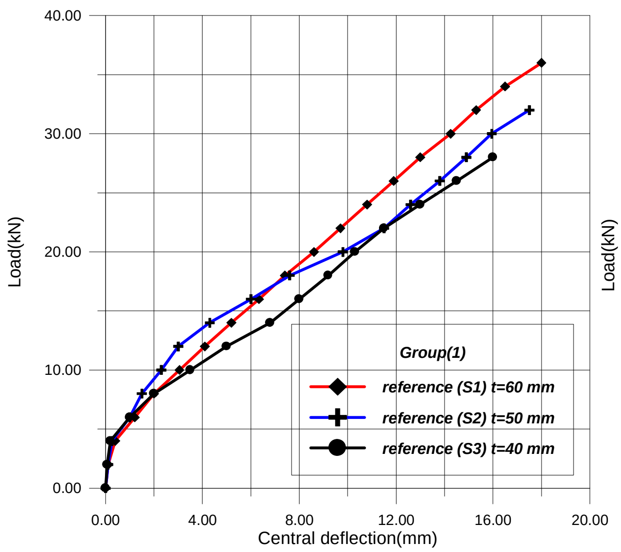


Fig. (5) Load- Central deflection curve for Group (1)

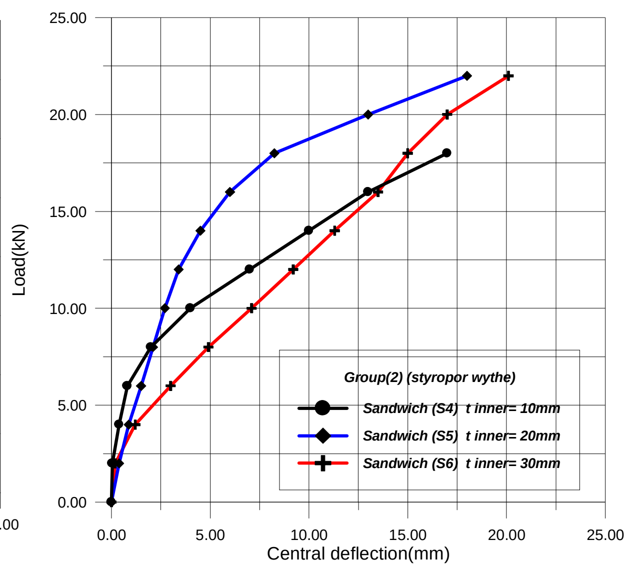


Fig.(6) Load-Centdeflection curve for Group (2)

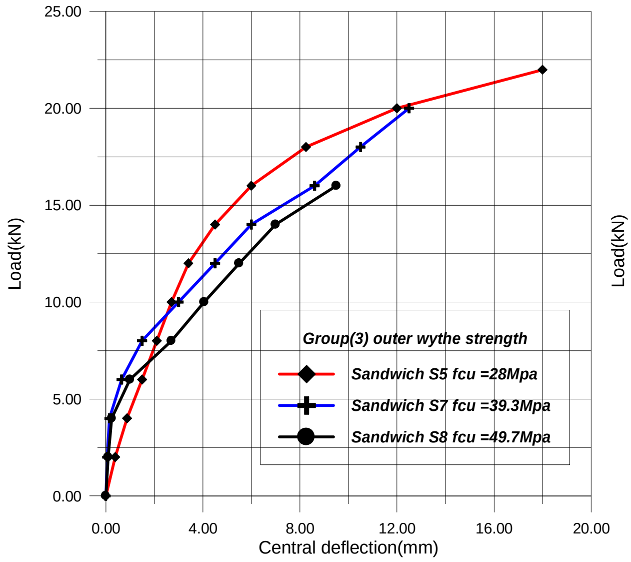


Fig.(7) Load-Central deflection curve for Group(3)

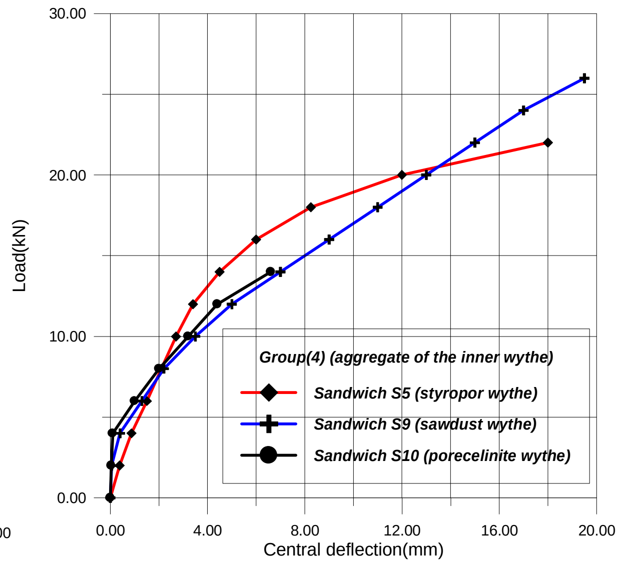


Fig.(8) Load-Central deflection curve for Group(4)

The test results, plotted in the above figures, can be summarized by the following points:

1) **Figure (5)** explains the behavior of reference specimens [G1], load-deflection curve of reference slab panels (S1) panel shows a non-linear curve at initial loading (3 to 5) kN, and then followed by a linear behavior up to failure. While (S2andS3) show a non-linear behavior up to failure load. The figure also explains that the stiffness of the slab was increased with increasing its thickness.

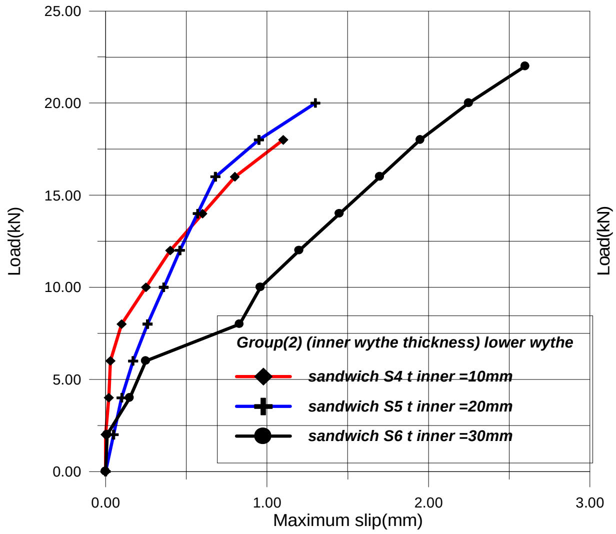
2) **Figure (6)** explains the behavior of group [G2]. From this figure it can be seen (S4) panel had a linear behavior at initial loading (6 to 7)kN and then followed by a non-linear behavior up to failure load .(S5) panel shows a linear behavior from initial load up to the loading (12to 13)kN, then followed by a non-linear behavior up to failure load. While (S6) shows a linear behavior up to failure load. This difference in behavior is due to the change in stiffness of the specimens due to changing the thickness of inner wythe. For comparison with the behavior of group (G1), the maximum deflection for G2 was greater than the maximum deflection for G1. This may be due that the G2 exhibited more ductile failure behavior with respect to the reference panels in G1.

3) **Figure (7)** shows that the (S5and S8) panels had a linear behavior from initial load to the loading (12 to 13)kN, then followed by a non-linear behavior up to failure. While (S7) panel shows a linear behavior at initial loading (3 to 4)kN and then followed by a non-linear behavior up to failure
.

4) **Figure (8)** explains the behavior of group (G4). It shows that the (S5) panel had a linear behavior form initial load to the loading (12 to 13)kN and then followed by a non-linear behavior up to failure. (S9) panel shows a linear curve up to failure load.(S10) panel shows a linear curve from initial load to the loading (4 to 4.5)kN and then followed by a non-linear behavior up to failure. For comparison, with the behavior of group (G1), the maximum deflection for G4 was greater than the maximum deflection for G1. This may be due to that the G2 have more ductility than the reference panels G1.

3.3 Load-Slip Curves

The maximum slip between the two outer concrete wythes and the inner light weight concrete wythe was measured. The values of maximum slip are shown in Table (3), and Figures (9 to 14).



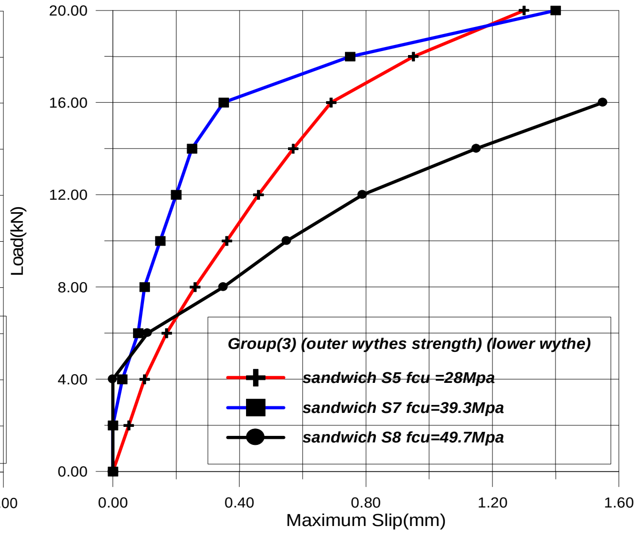
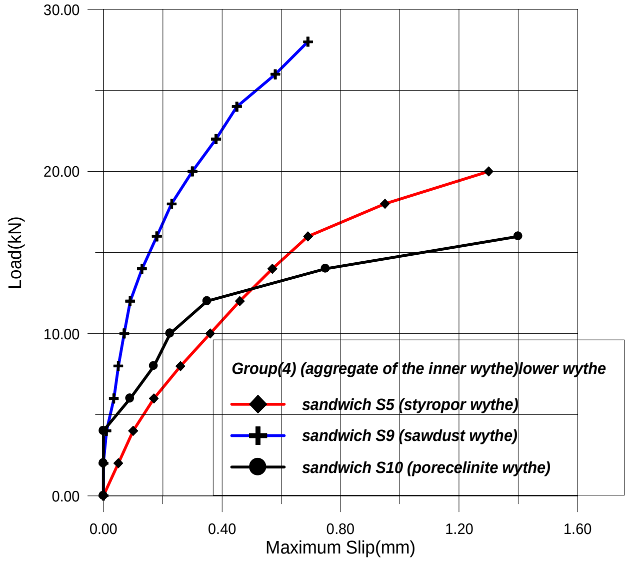


Fig.(9): Load-Maximum Slip curve of the curve of the lower wythe for Group(2) Group(3)

Fig.(10): Load-Maximum Slip lower wythe for



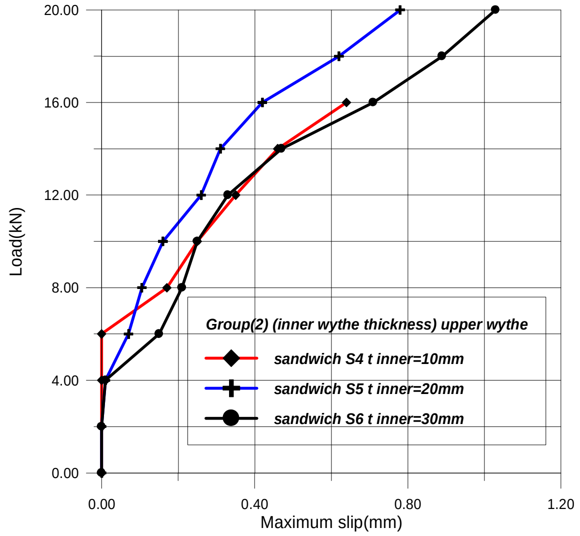
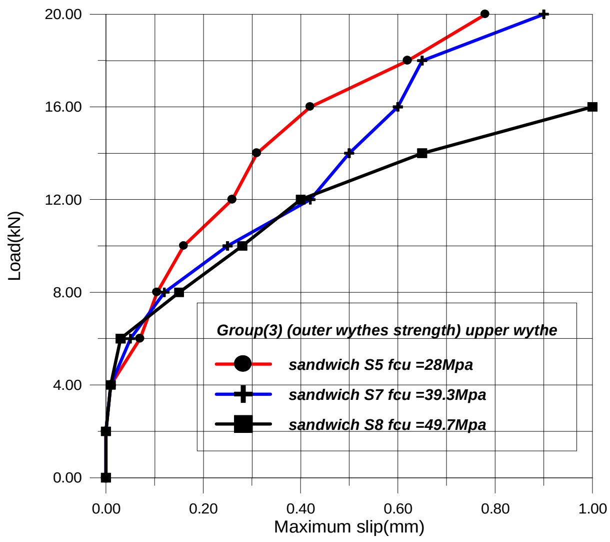


Fig.(11) Load-Maximum Slip curve of the of the lower wythe for Group(4) Group(2)

Fig.12) Load-Maximum Slip curve upper wythe for



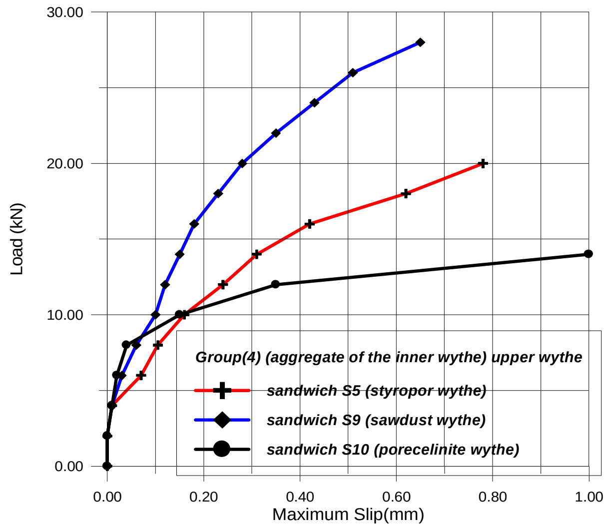


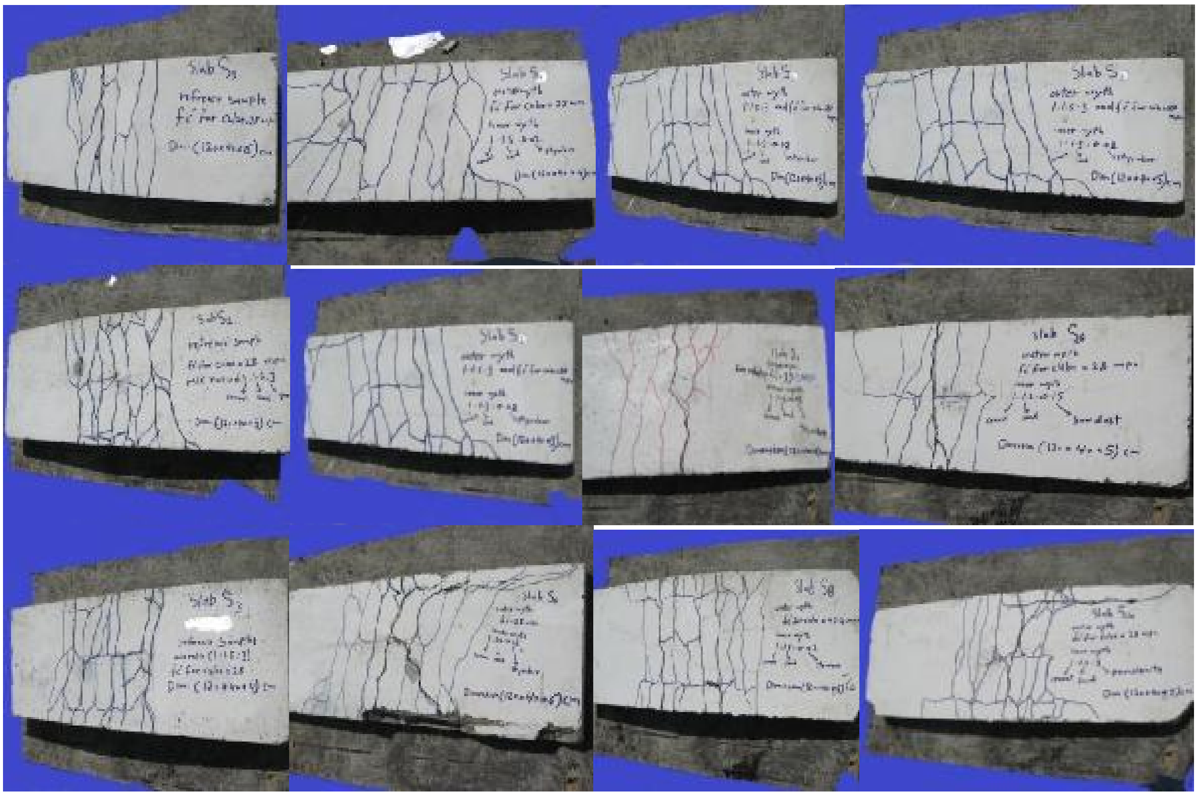
Fig.(13) Load-Maximum Slip curve of the upper wythe for Grou(3)

Fig.(14) Load-Maximum Slip curve of upper wythe for Group(4)

1) **Figures (9and 12)** show the maximum slip of the lower wythe of the specimens for different thickness of inner wythe. From this figure, it is clear that the slip becomes larger when the thickness of the inner wythe was increased. This may be due to that the bond at the interface between the wythes was decreased when the thickness of the inner wythe was increased. Also, different in density between the wythes reduced the bond between these layers, thereby increased the slip.
2) **Figures (10and 13)** show the maximum slip of the lower wythe of the specimens. It is clear that the slip was increased when the concrete strength of the outer wythes was increased. This tendency is attributed to the fact that density of the concrete increases with increasing its compressive strength. This difference in the density between the wythes may reduce the bond between the interface of the wythes. So the slip between the wythes was increased.
3) **Figures (11 and 14**) show the maximum slip of the lower wythe of the specimens. The maximum slip was increased when changing the type of light weight aggregate which used in the inner wythe (sawdust, polystyrene, porecelinite), respectively. This explains that the connection between the interface of the wythes was depend on the type of lightweight aggregate.
4) **From Figures (9to 14),** it can be seen that the maximum slip of the lower wythe for all groups in the sandwich slab panels was greater than the maximum slip of the upper wythe. This can be explained that when the load was applied [two point load] on the specimens, the tension zone will develop in the lower wythe, and the cracking of concrete along the slab at location of the lower wythe, therefore, the maximum slip in the lower wythe becomes more than the upper wythe, see **Table (3).**

3.4 Crack Pattern

The crack patterns observed on the tension faces of the slab panels are shown in Figures (15 to 18). All these photographs were taken after failure of the panels marking the visible cracks as lines when possible.



Fig(15)Crack pattern for Group (G1) **Fig(16) Crack pattern for Group (G2)** **Fig(17)Crack pattern for Group (G3)** **Fig(18)Crack pattern for Group (G4)**

It can be noticed that all panels exhibited horizontal cracks and perpendicular to the loading direction in the middle one third of the panels while cracks occurred near the support in the panels S4,S5,S6 and S10.

3.5 Failure Mode

In the present study, all the slab panels were failed by bending. In this type of failure, the panel deflected in a single curvature in the vertical direction of the panels and continue to deflect until the failure occurred by flexural mechanism. It is noticed that the line of failure lies near the center of the panels. Generally, the failure mode of the concrete slab panels was affected by thickness of the inner wyrthe, concrete strength of the outer wythes and type of the light weight aggregate of the inner wythe.

4. Conclusions :

Depending on the test results of the experimental program, the following conclusions were obtained:

- Flexural strength was increased with increasing the thickness of the panels, since panel stiffness increased with its thickness.
- Flexural strength was increased when using sawdust as light weight aggregate in the inner wythe instead of polystyrene (styropor) and porcelenite. This may be related such that the connection at the interface between the wythes was increased when using this type of light weight aggregate.
- The maximum central deflection was decreased when increasing the concrete strength of the outer wythes. This can be explained that the outer wythes became more brittle with the increase its concrete strength.
- Different in the density between the wythes was reduced the bond between these layers resulting in slip of the wythes, thereby, the material failed without reaching its full load capacity, so, panels failed due to the separation of these wythes.
- The maximum slipwas increased when increasing the concrete strength of the outer wythes, which is related to the large different in density between the inner and the outer wythes.

References

1. **Bush, T. D., and Zhiqi, Wu., " Flexural Analysis of Prestressed Concrete Sandwich Panel with Truss Connectors", PCI Journal, September-1998,pp. 76-86.**
2. **Kabir, M. Z., "Structural Performance of 3-D Sandwich Panels Under Shear and Flexural Loading", Sharif University of Technology, October- 2005, pp.1.**
3. **Rudolf, Michael, and Sami, H.,"Structural Behavior of Insulated Precast Prestressed Concrete Sandwich Panels Reinforced with CFRP Grid," North Carolina State University, Raleigh, North Carolina 2008, pp.1.**
4. **Papanicolaou, C. G. and Triantafillou, T. C., "Analysis and Minimum Cost Design of Concrete Sandwich Panels under out-of-plane Loading", University of Patras, Greece, Department of Civil Engineering,2004,pp.1-17.**
5. **Benayoune, Samad, Abang Ali and Trikha, D. N. , "Response of Pre-Cast Reinforced Composite Sandwich Panels to Axial Loading", University of Kuala Lumpur, MFI, Section 14, JLN Teras Jernang, 43650 B.B. Bangi, Selangor, Malaysia, Department of Civil Engineering, KUiTTHO, Malaysia, Received 1 April 2005;pp.1-9.**

6. **James, R., Mackechnie and Thorbjorg Saevarsdottir, "New Insulating Precast Concrete Panels", Canterbury University, Private Bag 4800, SB07, New Zealand, 2007, Paper number: 065, pp. 1- 11.**

7. **Hany, N. Maximos and Wilast, A., "Behavior and Design of Composite Precast Prestressed Concrete Sandwich Panels with NU-Tie", University of Nebraska – Lincoln, Final Report, March 2007,pp.1-28.**

8. **Frankl, B.A., "Structural Behavior of Insulated Precast Prestressed Concrete Sandwich Panels Reinforced with CFRP Grid", Athesis submitted to the Graduate Faculty of North Carolina State University, 2008.**

9. **Sumadi, S.R, and Memon, N.A., "Development Of Lightweight Ferrocement Sandwich Panels for Modular Housing and Industralized Building System", A thesis submitted to the University Technology, Malaysia, RESEARCH VOTE NO: 73311,2008.**

10. **Dong, Y., Feng, S., Xia, C., and Gui, L., "Dynamic Behaviour of Concrete Sandwich Panel under Blast Loading", China University of Mining & Technology, Beijing, China-100 083, Vol. 59, No. 1, January, 2009, pp. 22-29.**

11. **Bush, T.D., and Stine, G.L.,"Flexural Behavior of Composite Prestressed Sandwich Panels", PCI JOURNAL, 39.2 (1994): pp.112-121.**

12. **Husain, M.H, Zain, and Wasan, "Thermal Analysis of High Performance Lightweight Concrete Sandwich Panels", Tech. Journal, Vol.28, No.21, 2010, University of Technology, 2010, pp. (1-19).**

13. **Iraqi Specification No. 5, "Portland Cement ", Baghdad, 1984.**

14. **Iraqi Specification No. 45, "Natural Sources for Gravel that is Used in Concrete and Construction", Baghdad, 1984.**

15. **ASTM C33-03, "Standard Specification for Concrete Aggregates".**

16. **www.abshar foam properties.htm**