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Load Deflection and Ultimate Strength Properties of Sandwich Lightweight Foamed Concrete Panels

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Authors' contributions

This work was carried out in collaboration between all authors. Author AOR designed the study, performed the statistical analysis, wrote the protocol, managed the literature searches and wrote the first draft of the manuscript. Authors OJA and OOA managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

The interaction that exists between two wythes of concrete, inner and outer, goes a long way to establish the structural behavior of the whole components and particularly, lightweight foamed concrete sandwich panel. Precast concrete sandwich panel (PCSP) has become a household name since it has been utilized in the construction of structural shell in some building types. This research investigated the load deflection of six different lightweight foamed concrete panels. The six panels were produced using a foamed concrete mix of the same density and the mechanical properties of the mix were tested. Each panel consists of two withes (facings) made of lightweight foamed concrete and polystyrene was used as the core and the insulation layer. Mild steel wire mesh of 6mm sizes was used as reinforcement in three of the panels while 9mm diameter high yield steel was used in the remaining three panels. The reinforcement in both facing was tied together using shear and bend to an angle of 45^0.End crushing of the panels was avoided using concrete capping. An axial load test was conducted, the load deflection, mode of failure and crack patterns of the panels was observed. The result also revealed that panels with concrete capping deflect along with

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their Wythe in the same directions and small deflection was recorded in panels with concrete capping. Cracking modes in panels reinforced with 6mm mild steel were controlled by material failure while those in panels with 9mm high yield steel, cracks was only observed at the lower part of the capping.

Keywords: Sandwich concrete; lightweight foamed concrete; shear connector; ultimate strength and load deflection.

1. INTRODUCTION

Foamed concrete is a lightweight aerated concrete produced through the mixture of sand, water and cement to produce paste which is mixed with pre-formed stable foam from foam generator. It is a type of concrete that can be designed to have any density within 300-1850 kg/m^3 dry density [1].

Sandwich concrete technology has gained more ground for the past decades. The technology has been in use for the past 40years although confined to aerospace applications. But by 1960, several alternative uses were discovered, such applications in automobile and shipbuilding industries, refrigerator storage and building construction.

Advancement in the utilization of this machinery was observed in structural insulated panels (SIP) when it was utilized for the construction of refrigerated storages, automobiles, buildings and different operation processes in the shipping sector, especially for ship construction [2]. During the initial age of SIP, concrete panels were made as a non-load bearing structure of a building usually called a cladding panel. This is made-up of two broad layers of concrete, one internal layer and external layer; these layers are also called wythes [3]. But in North America, precast concrete sandwich panels (PCSPs) were adopted as system of building that is practicable for over fifty decades [4]. Unfortunately, the utilization of these PCSPs cannot be ascertained by the committee of Precast/Prestressed Concrete Institute of America [5]. The panels, concrete inner and outer wythes were intended as non-load bearing and load bearing structures respectively, and insulation material were used to divide the two Wythe [6]. The PCSP'S behavior, structurally, relies on the stiffness of the mechanical shear connectors and the strength. In order to meet up with the stiffness and strength needs, the shear connector must have adequate strength that can spur composite action, hence, permit sufficient transfer of shear as well as complete composite behavior between the two wythes of the concrete [7]. It has been established that the properties and capability of concrete composite panel decrease over a particular period and it does not continue. It relies considerably on the strength of the shear connector's across the panel life time [8]. It was observed that the most significant and effective shear connector is steel truss-shaped type used for the connection of concrete wythes together. This is because, it was proved that, it permit the shear forces to be transferred completely, hence, bending that occurs between the wythes. Meanwhile, the thermal behavior of the sandwich concrete panels is controlled by the credibility of the provided insulation, while the buckling process of the panel can be resisted by the concrete wythes' strength [9-11].

Afterwards in the decades, this model of sandwich panel application was made and developed [12-15]. Apart from this, it was observed that several types of shear connection can be utilized in the production of sandwich panels that are composite in compositions. Specifically, Gara et al. [15] made use of horizontal steel connectors to incorporate sandwich wall panels by connections in order to achieve a semi-composite behaviour. In another development, a continuous type of steel truss connector was utilized to bind the two wythes of the concrete of PCSP, therefore, the research study outcome revealed an incomplete composite action, especially at the critical state, yet it was reported as the most effective structural type of shear connection for PCSP [16]. A different type of hybrid shear truss connector was proposed by Einea [13] and classified as composites and non-composites shear connectors. Although, the shear connector type improves the thermal conductivity performance of the concrete by means of high control attained through the design of materials (such as fiber reinforced plastic bars). Likewise, in other research, truss girder shear connector in a longitudinal orientation was used and the results presented a partial composite behaviour, [9].

Researchers and developers' interest in sandwich panels has been growing recently which cause the rise in searching for adequate and efficient practicable products. However, the significant advantage of PCSPs is similar in all respects to that of precast solid wall panels but they are different by method and style of construction. It is on record that researchers and stakeholders in building and Infrastructure materials are more comfortable with some of the properties of PCSP relative to insulation efficiency, walls' energy performance and structural efficiency [16-19]. Initially, PCSP was designed to function as a structure that is energy efficient in the formation and method. As years pass by, PCSP advanced in its application as wall bearing due to its ability to uphold loads that are transferred through various building elements to the building foundation [11]. There are several benefits of PCSP wall features and this includes, among others, very fast construction, high durability, aesthetic architectural appearance and minimum cost of maintenance. These unique and influential features of PCSP panels were advanced to enhance the recent components system of buildings and the constructions [4,5&20]. Sandwich panels, according to Noor et al [21], offer a high strength-to-weight ratio resulting in a significant structures self-weight reduction. The elements' self-weight of high density itself accounts for the larger portion of the overall structures' loads by the adoption of a suitable approach outcomes in the minimization of cross-section element, foundation size, the cost and the earthquake damages as the earthquake forces that will impact the buildings and other structures are proportional its mass.

There are different Sandwich panels available for use, such as honeycomb core, web core, corrugated or truss core, encased core and foam or solid core as mentioned and described by Cheng [22]. Contemporarily, Sandwich have been widely used in many various industries in the aerospace industry, ship building industry, civil and infrastructure industry industries among others. Although, the usage varies from one ranges to the other which includes, among others, snow skis, kaya platforms, platform tennis paddles, racing boats, auto racing cars and also as infrastructural materials such as bridge construction as established by Davalos et al. [23] that sandwich products was successfully implemented in several bridge projects.

Benefits of sandwich concrete materials are numerous, especially when compared to normal weight concrete for instance, sandwich component materials has a good thermal insulation because of the thick cellular core and this makes it a suitable external construction material as established by Bottcher and Lange [24]. Lightweight characteristics of sandwich structures give it structural advantages in a situation where weight reduction is the ultimate target of design [25]. Hence it can be utilized for construction of buildings in a soil with poor load bearing capacity, [26]. This also gives it a distinct advantage above traditional structural sections because it offers high stiffness as well as high strength to weight ratio [27,28].

The ambiguous features of PCSP based on non-linearity of its' material, the unpredictable impact and responsibility of the shear connectors as well as the interaction that exist between different type of components has triggered research into verification of all the outlined observation by performing experiments to explore it by the mere analytical method. In the meantime, the experimental investigation with valid information is still a handful on sandwich panel construction due to the cost implications of the materials which are necessary for full scale experimental investigation in comparison to small scale testing models [29]. Recently, the existing PCSP products are manufactured as a heavy system whereby the performance face challenges in construction of houses, especially in the peat type of soil. Apart from this, the foundation engineers failed to offer a sufficient load bearing foundation to uphold the overall dead loads of superstructures. Therefore, the need for a proper and adequate optional composite material likes lightweight foamed concrete panels (LFCP) to be produced.

Lightweight foamed concrete has been in existence since 1920 and its applications have been limited to non-structural as well as non-load bearing use. Such uses as backfilling, road embankments, and road based thermal insulation, trenches filling and building blocks.

Lightweight foamed concrete was categorized as lightweight concrete with a structure that is cellular which formed air voids in paste or mortar by means of using adequate and sufficient foaming agent. Usually, it is produced by mixing cement mortar or paste with different produced foaming agent of high flowability, exceptional insulation properties and low density. A wide range of densities can be achieved by mean of adequate foaming agent dosage control (For instance, densities can range from 400 to 1800 or even 1900 kg/m^3, at times), hence, lightweight foamed concrete can be produced to meet the requirement of different construction applications and structures in terms of elements, insulation requirement, acoustic desires, filling grades and partition studs and boards [30,31]. Researchers that specialized in concrete have come up with lightweight foamed concrete utilizing fly ash binder replacement partially and the result proved satisfactorily to loading behaviour structurally, Jones and Mc Carthy [32]. According to another research study, the most crucial parameters for good properties of lightweight foamed concrete such as good workability, density, mechanical strength and cost effectiveness are adequate cement/filler ratio, water/cement ratio, [33]. Kearsley [34] described foamed concrete as a lightweight building material that can be used for many structures if the strength is optimized and the cost is far more effective using waste products such as ash. Foamed concrete can either be a cement paste or mortar generally categorized as lightweight concrete whereby there is an entrapped air voids in mortar as provided by adequate foaming agent, [35]. It possesses some properties such as high flowability, lesser aggregate consumption, controlled low strength, low self-weight and excellent thermal insulation properties.

2. OBJECTIVES

The major objective of this research paper is to investigate the suitability of lightweight sandwich concrete panel for structural applications in civil and building construction industry targeting at the specific requirement that must be met if this material is to be used as an Industrial Building System. Requirements such as strength, ultimate strength capacity and its composite action under load application. Design factors that contribute to the absolute strength and composite action, like slenderness ratio, orientation and type of the shear connector used, were investigated. The achievable degree of completeness is determined by the capacity of the shear connectors to transfer the applied load which depends on the diameter of the connector used and its orientation.

3. EXPERIMENTAL PROGRAMMES

3.1 Materials

3.1.1 Cement and fly ash

The chemical composition of the cement and fly ash used in the experiment are shown in Table 1 and the constituents of the materials to produce lightweight foam concrete. Ordinary Portland cement type I comply to ASTM C150 [36], sourced locally in Penang state of Malaysia, was used as received and the chemical and physical compositions of the cement are shown in Table 3.1. The fine aggregates used was fine river sand finer than 300microns and of specific gravity of 2.52 and comply with BS 882 [37]. Class F fly ash conforming to ASTM C618 [38].The fly ash was used as a cement substitute at 10% contained. The foam was produced using a protein foaming agent, Noraite PA-1 of 80kg/m^3 density and in ratio of 1:30 mixing dilution with water as specified by the manufacturer. A Porta PM-1 foam generator was used to generate the foam with a density of 80kg/m^3.

3.1.2 Mix proportioning

Mix proportioning guidelines of ASTM C796 [39] which is peculiar to cement slurry was used and modified to suit the production of the foam concrete used for this study with a target density range between 1500kg/m^3 - 1600kg/m^3 density.

The mixing procedure consists of the cleaning of the laboratory mixer, get the excess water drain, then add a quarter of the measured mix water, after which the fine sand and the cement were added, allowed the materials to mix for a few minutes before the addition of the fly ash and the mix water, permit all the materials to blend together until considerable slurry is attained. The preformed foam was incorporated into the base mix by means of the foam generator nozzle based on the estimated amount of the flow rate per seconds. The fresh lightweight foamed concrete's density was checked against the target density, between 1500 kg/m^3 - 1600kg/m^3.This is the process that was observed for all the mix proportions used in this study. And the recorded ambient temperature was in the range of 44.9^{0}C and 55^{0}C and relative humidity is within 40% and 47%. All samples were cast and cured until testing ages. The mix proportion is shown in Table 2 and the grain size is shown in Fig. 1.

3.2 Methods

After mix, the density of the base mix was tested in accordance with BS EN 12350 Part 6 [40] and the slump was also measured in compliance with BS EN 12350 Part I [41]. It was conducted after the stable foam was blended into cement and sand mortar mix. Meanwhile the compressive strength test was done using BS 1881: Part 116 [42]. Cube size specimens were used. The flexural strength of the specimen was performed in line with ASTM C293 [43] while the drying shrinkage was done in alignment with what was stipulated ACI 209.2R-08 [44]. The modulus of elasticity test was conducted on the specimen according to the standard outline in BS 1881; Part 121 [45] while water absorption test was done in compliance with ASTM C642-97 [45].

3.2.1 Design and fabrication of the LFCP

In this study, the sandwich panels used and tested is six specimens consist of two facings made of lightweight foamed concrete and polystyrene as the core. The Panels wyths thickness is fixed at 40mm. A varied gap range from 25mm to 70mm was used such as to obtain a varied wall thickness of between 100mm to 150mm. Square welded mild steel wire mesh was used as reinforcement both longitudinally and transversely in the facings of all the panels. This was strengthened by tying up with steel shear connectors. The shear connector was designed to prevent facings buckling and to be well strengthened. The effect of orientation on the load bearing capacity was controlled with the arrangement of the wire mesh, 45^0 diagonal orientation was avoided in the arrangement of the wire mesh, [34,35]. Full composite action is achieved by providing sufficient horizontal shear transfer between facings because this exhibit, plane section behavior throughout its entire depth at all locations along its span. The slenderness ratio was in the range 14.56 to 19.97. All the panels were designated LFCP and count from 1 to 6. Details of the panel design are shown in Table 3.

The concrete cover is 15mm for all panels; the reinforcement is 6mm diameter mild steel @ 200mm center to center for LFCP 1-3 and 9 mm diameter high yield steel @ 200mm center to center for LFCP 4-6. While the shear steel connector is 6mm mild steel placed in diagonal orientation. Both inner and outside facing were made of Lightweight foamed concrete with a target wet density of between 1500 kg/m^3 and 1600kg/m^3 to achieve a target compressive strength range of between 9MPa and 12MPa for all the panels. The mix proportion ratio adopted for the foamed concrete is 1:2 of cement to sand. While fly ash is used as a cement substitute at 15% of the weight of the binder. Before the casting of the main specimen for the study, trial test was done in the laboratory and the observed best result was eventually used for the panels as shown in Table 3.

3.2.2 Casting of LFCP

The fabrication of formwork's and the arrangement of the reinforcement bars for the 6 panels is shown in Fig 1 and Fig. 2 Shows the arrangement of reinforcement in concrete capping. This makes the difference in the reinforcement arrangement to cater for uneven distribution of transfer loads.

In the reinforcement arrangement, BRC of 6mm sizes was attached to the 6mm steel truss connectors while another BRC was joined to the edges. The whole reinforcement arrangement was placed inside the formwork. The casting was then done by pouring prepared foamed concrete into the formwork until the required thickness is attained. The Polystyrene was cut and positioned at the edge of the already cast lower facings as well as between the steel shear connectors as shown in Fig. 3a. The casting is finished up with the casting of the second facings which is the upper facing, Fig. 3b. This same procedure was followed for all panel specimens that contain 9 mm steel bars.

Meanwhile, the reinforcement bars used on the specimens were all tested in the laboratory using UTM and the reinforcement bar properties are shown in Table 4.

4. LABORATORY STRUCTURAL TESTS

The Panel testing under axial load was done using a Torsee's Universal testing machine Rat 50T of 50tonne (490.3325kN) capacity strength. The panels were pinned at the top and bottom using supports. The surface strain measurement was achieved through 8 numbers of strain gauges attached to the surfaces of the panels in a well-arranged manner for accuracy and then connected to a data logger to record the vertical strain reading. Linear Voltage Displacement Transducer is used to measure the horizontal displacement, and this was attached to the center position of the panel but on the opposite sides of the panel. This is likewise connected to the data logger reader.

At the commencement of the loading, a test of all set up the instrument was made to check the functionality by applying 1kN and then gradually increased at approximately 25kN until the failure of each specimen panels. Strain and deflection values were recorded by the data logger at each load stage. The crack patter was observed in the cause of loading. The test setup is shown in Fig. 4.

Table1. Chemical composition of Portland cement and fly ash (wt. %)

Material	SiO_2	Al_2O_3	FeO_3	CaO	MgO	SO_3	Na_2O	K_2O	Loss on Ignition
Cement	21.89	5.3	3.34	53.27	6.45	3.67	0.18	0.98	3.21
Fly ash	53.9	33.5	3.70	4.70	1.30	0.1	0.7	0.7	0.8

Note- the Blaine surface area (m^2/kg) for fly ash is 350 and the relative humidity is 2.2%

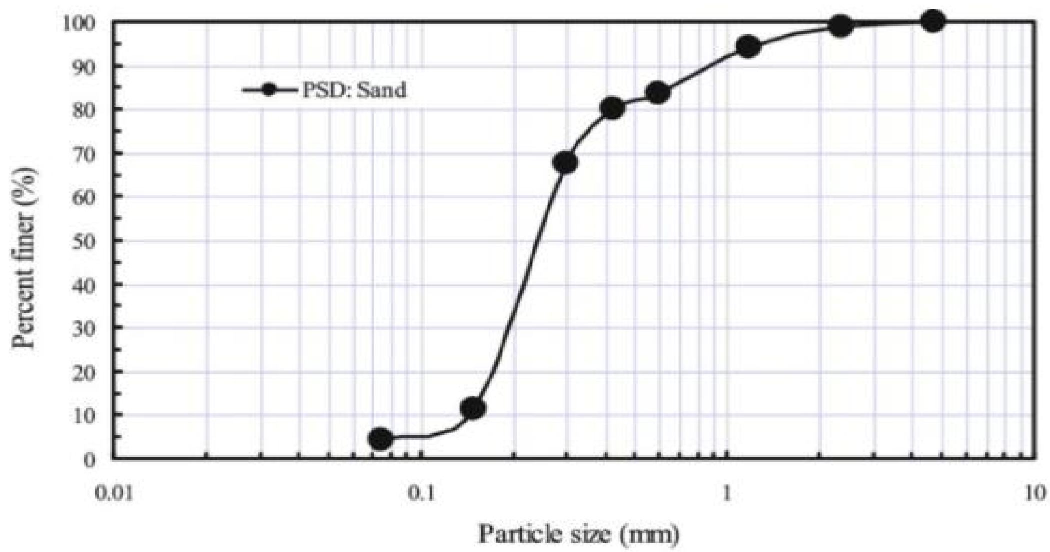

Fig. 1(a). Grain size of fine sand

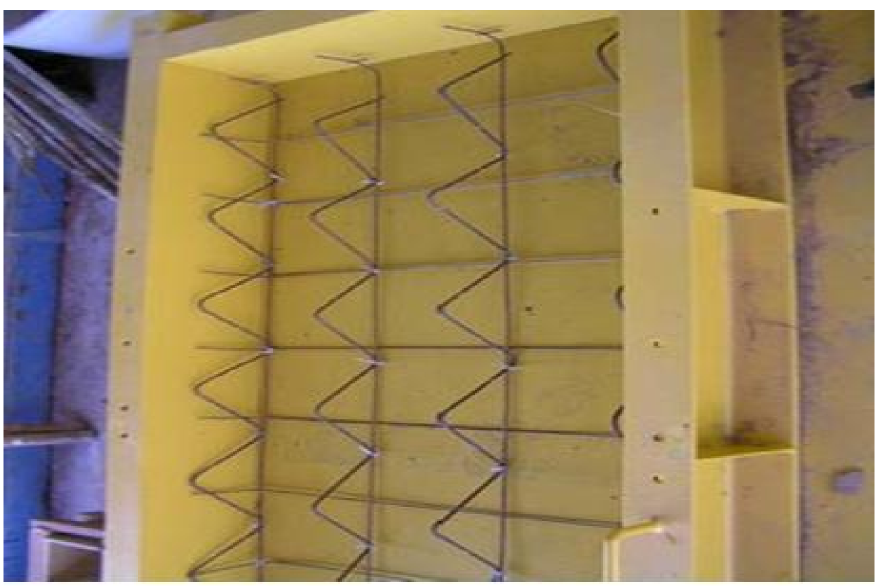

Fig. 1(b). Reinforcement arrangement of 6 mm mild wire mesh steel

Table 2. Mix proportions of the materials

Mix	Sand (kg)	Cement (kg)	Fly Ash (kg)	Water (kg)	Water cement ratio	Foam volume	Foam %	Target density	Actual density obtained	Slump
RTM 1600	58.44	24.68	2.74	9.85	0.30	13litres	25.11%	1600	1610	200mm

Table 3. Shows the detail of the panel design

Specimen	Dimension	Slenderness ratio	Facing thickness	Core thickness
LFCP 1	2500x850x125	19	40mm	50
LFCP 2	2500x850x150	14.66	40mm	70
LFCP 3	2500x850x100	19.97	40mm	25
LFCP 4	2000x850x100	18.6	40mm	25
LFCP 5	2500x850x150	17	40mm	40
LFCP 6	2500x850x125	16.9	40mm	40

Table 4. Shows reinforcement bar properties

Reinforcement	YieldStressσy (MPa)	Tensile Strength, σt (MPa)	Strain at Failure	Es (KN/mm^2)
6mm connectors	516	543.10	0.0480	198.42
9mm bars	557	624.68	0.1941	203.58

Fig. 2. Reinforcement arrangement of high yield steel 9mm steel and the connector

Fig. 3. Shows the lower facings, the polystyrene and the connector's arrangement

5. RESULTS AND DISCUSSION

5.1 Compressive Strength

The compressive strength of the foamed concrete was taken before the casting of the panels using cubes modes of 100mmx100mm cubes and it was shown that the compressive strength at 10% replacement of the binder was not as high as the control experiment but higher than any other percentage substitute of fly ash content and the reason might be as a result of the foam percentage and the pozzolanic action of fly ash which was not fully utilized till the test age of 28days and this was as confirmed by Alonge and Mahyuddin [46]. The fly ash mechanism is embedded in the pozzolanic nature of the cementitious materials hence the reduction in the foam volume used and the consequent reduction in the pore volume in the mix and pore uniform distribution. Fly ash in the mix produces a good binder without the merging of the pore structures. The result of this is the uniform distribution and coating on each of the bubbles present, according to Nambiar and Ramamurthy [47]. It was observed that at 10% binder substitute, the sustainability and the strength was not compromised. The compressive strength achieved at 28days was 10.53MPa and this is about 14.3% higher than the samples with 20% content of fly ash during the trial mix. Table 5 shows the compressive strength for all the testing day.

5.2 Flexural Strength

The flexural strength of the base mix used in the foamed concrete was tested using a prism specimen of 100mmx100mmx500mm size and tested with four-point lead ELLE international testing machine. The result shows 3.57N/mm^2 which fall within the range of the established standard ratio of flexural strength to compressive strength of cellular concrete of 0.25-0.35, as quoted by Ramamurthy et al. [48]. This result would have been better than this if fibers, especially Polypropylene have been used as was reported through a study by Keasley and Mostert [49] that the use of Polypropylene fibers improve the flexural and tensile strength performance of foamed concrete, provided it does not have adverse effect on the fresh concrete behavior and self-compaction.

5.3 Drying Shrinkage

The drying shrinkage of the foamed concrete used was measured. It was observed that the shrinkage was lower due to the presence of fly ash and fine aggregates which restrain shrinkage better than when fly ash or other cementitious materials was used as filler rather than when used as cement replacement. The presence of fly ash due to its adamant particles in the course of hydration process may likely be the cause. The result shows that it was about 1250microstrain within 28days.

5.4 Modulus of Elasticity

The Lightweight foamed concrete's modulus of elasticity was tested, and it was observed to be corresponding to the strength of the foamed concrete. The test was conducted in accordance to ASTM C469, a total number of 12 cylinders of (150 x 300) mm were tested at different ages. It was observed to be higher and this may be due to the interlocking of fine aggregates used in the base mix. See Table 6 for details. This result corresponds to the study done by Ramamurty et al. [48] which affirmed that foam concrete with the incorporation of fly ash as fine aggregates is observed to have lower modulus of elasticity compare to foam concrete with incorporation of sand. This is as a result of the high quantity of fine aggregates in sand mix compare to mix with fly ash incorporation, which consists of no aggregates but paste.

5.5 Water Absorption

The water absorption property of foamed concrete is basically spurred by phases of the paste and not every artificial pores take part in the water absorption process since they have no connections, Alonge and Mahyuddin [46] and Kearsley and Wainright [50]. The water absorption of the base mix used in this study was tested and it was found that the water absorption was low which may be as a result of the presence of fly ash though in small percentage quantity. The uniform distribution of pore structures of the fly ash makes a remarkable difference in the water absorption. See Table 7 for details.

5.6 Failure Mode and Crack Pattern

Panels LFCP1- LSCP 6 was subjected to axial load using Torsee's Universal testing machine RAT 50T, and the typical crack patterns is shown in Fig. 5 and 6. It was observed that the failure mode in panels LFCP 1- LFCP 3 was majorly dictated by the material failure specifically the 6mm reinforcement bars. The panels failed prematurely from local buckling noticeable near the supports and the load deflection curve revealed that both facings deflected apart from each other with the rear facings having higher deflection than the front facing hence lack of cohesion (non-composites). This may likely be as a result of lower compressive strength of the panel's lightweight foamed concrete of low strength and lack of evenly distributed load of the means of an arrangement of the reinforcement which is not having sufficient capacity to bear and distribute the loads evenly. This is the general result as the same mix was used for all the panels except that the differences in the reinforcement sizes compared to that of panels LSCP 5and 6 that have higher diameter reinforcement sizes and capping. In LFCP 4, LFCP 5 and LSCP 6, the crack pattern was a little different due to the presence of 120mm thickness concrete capping at both ends. The normal concrete capping was of 45MPa strength.

The result of this when the LFCP 4, LFCP 5 and LFCP 6 was subjected to axial load shows that the capping act effectively in the prevention of premature cracking near the loading and support areas as observed in LFCP1-LSCP4 and this also compliment and strengthened the panels against any early cracking. The first crack loads are shown in Table 6 along with ultimate strength capacity.

5.7 Ultimate Strength Capacity

When all the panels were subjected to ultimate strength test, it was clearly shown that the ultimate strength achieve has a corresponding with the Compressive strength of the lightweight foamed concrete used as the facings in the panels and also the slenderness ratio of the panels. The slenderness ratio, proportion and the core thickness make the great difference since the same foamed concrete mix of same compressive strength was used as the base mix. Table 6 Shows the Ultimate Strength Capacity, Maximum deflection and First Crack load of panels.

5.8 Load Deflection

Fig. 7a-7f displays the analysis of the load deflection of the Six panels. At initial loading, the trend of deflection of LFCP 1- LSCP 3 shows out of plane deflection curve and this indicates very minor load deflection, but at the loading point of 55kN, LFCP1, LFCP 2 and LFCP 3 was observed to show some cracking. The increase in loading resulted in a corresponding increase in mid-depth displacement value. The obvious sign in the curve is the movement of both facings away from each other. Both the rear and the front facing curve tend to move in both negative and positive directions. The indication is that the facings of the panel both deflected in a different direction till the maximum load was achieved.

Meanwhile, the load deflection curve of LFCP4, LFCP 5 and LSCP6 facings was observed to be smaller deflection at the early stage of loading. Although the facings was observed to move in the opposite direction, however the panels buckled at the later stage where it was revealed by the LVDT that the front facings tend to move towards the same direction as that of rear facings of the panels. This was the trends of the deflection until the maximum load was achieved. The indication of this is that the concrete caps of the panels at the ends have a significant result in the improved performance of the LFCP panels 4, 5 and 6, in which certain degree of composites was achieved unlike LFCP1-LFCP3.

Fig. 4 Test setup

Table 5. Shows the compressive strength of the base mix

Base Mix	Compressive Strengths (MPa)		
	7days	14days	28days
LFCP 1600-10FA	8.6	8.8	10.5

Table 6. Shows the details of the Properties of Foamed Concrete used as based mix

Mix	f_{cu} (MPa)	f_t(MPa)	E_c (kN/mm^2)	Water Absorption(%)	WetDensity (Kg/mm)	Dry Density (Kg/mm)
LFCP 1600	10.5	3.57	10.67	0.087	1680	1602

Table 7. Shows the ultimate strength capacity, maximum deflection and first crack load of panels

Specimen	Dimension	Slenderness ratio	Core thickness	Ultimate Strength Capacity, Fcu (kN)	Maximum deflection(mm)	First crack load (kN)
LFCP 1	2500x850x125	17.85	50	36.5	12.76	8.30
LFCP 2	2500x850x150	14.66	70	41.5	14.54	10.6
LFCP 3	2500x850x100	19.97	25	33.4	11.23	7.51
LFCP 4	2000x850x100	18.6	25	32.7	10.78	6.98
LFCP 5	2500x850x125	17	40	39.2	13.88	9.20
LFCP 6	2500x850x125	16.9	40	38.3	12.98	8.91

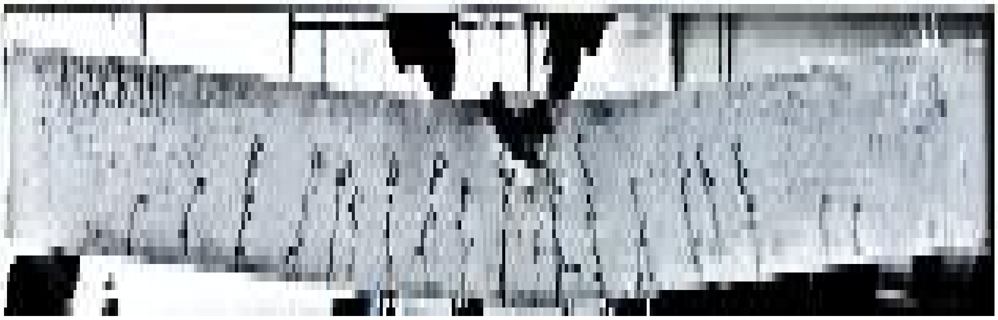

Fig. 5. Typical crack patterns of LFCP 1-3

Fig. 6 Typical crack patterns of LFCP 4-6

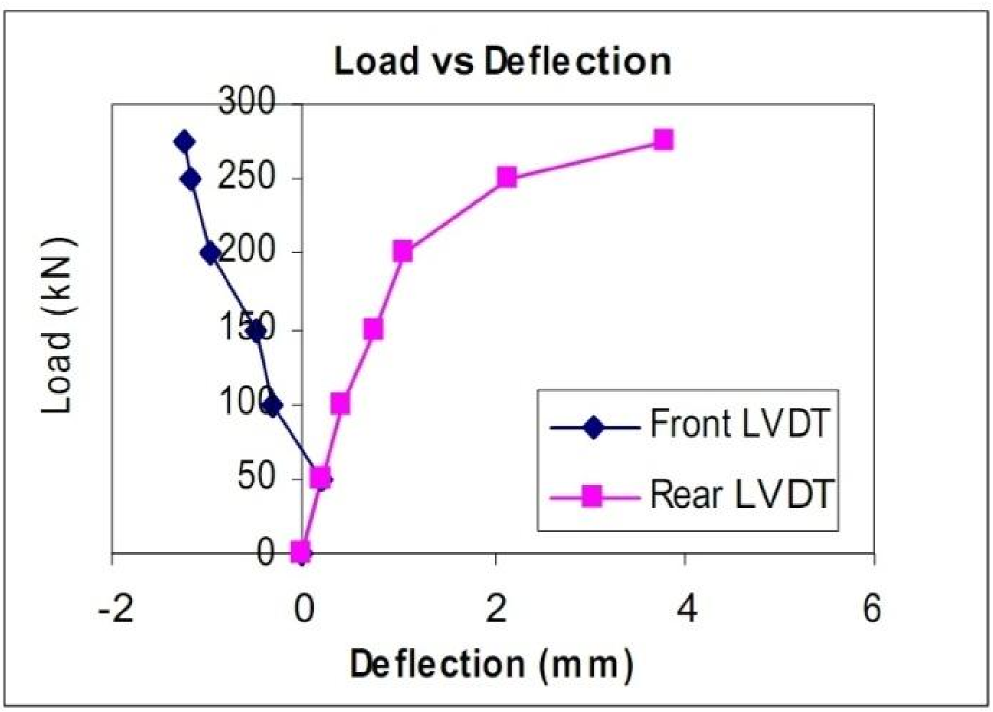

Fig. 7a.

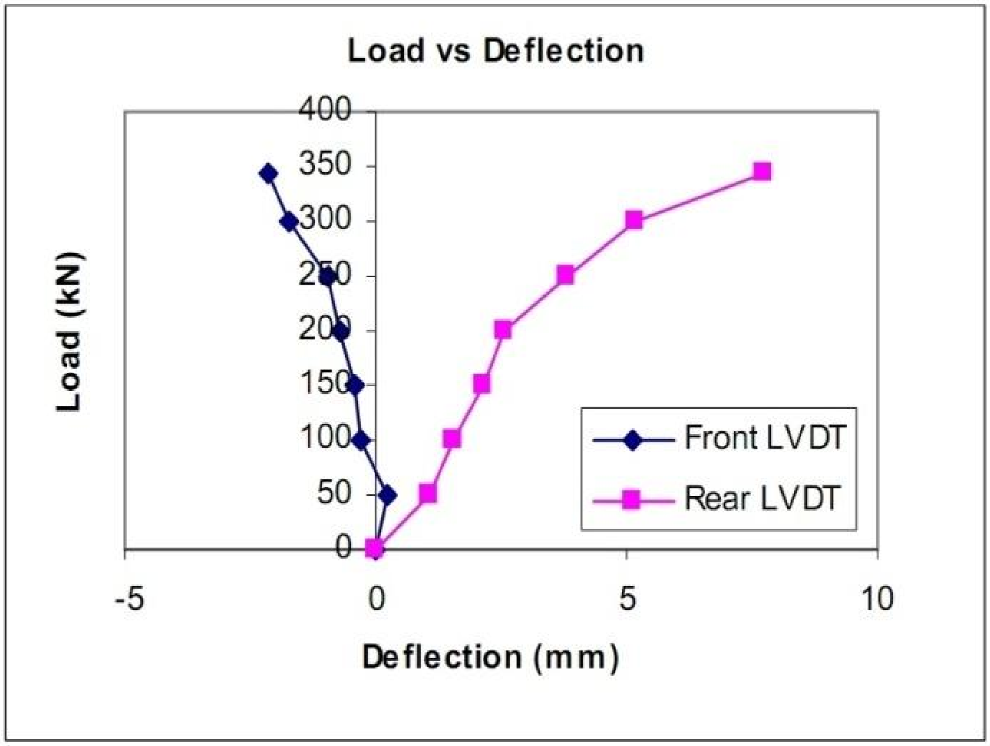
Load vs Deflection
Load (kN)
Deflection (mm)
Front LVDT
Rear LVDT
400
350
300
250
200
150
100
50
0
-5
0
5
10

Fig. 7b.

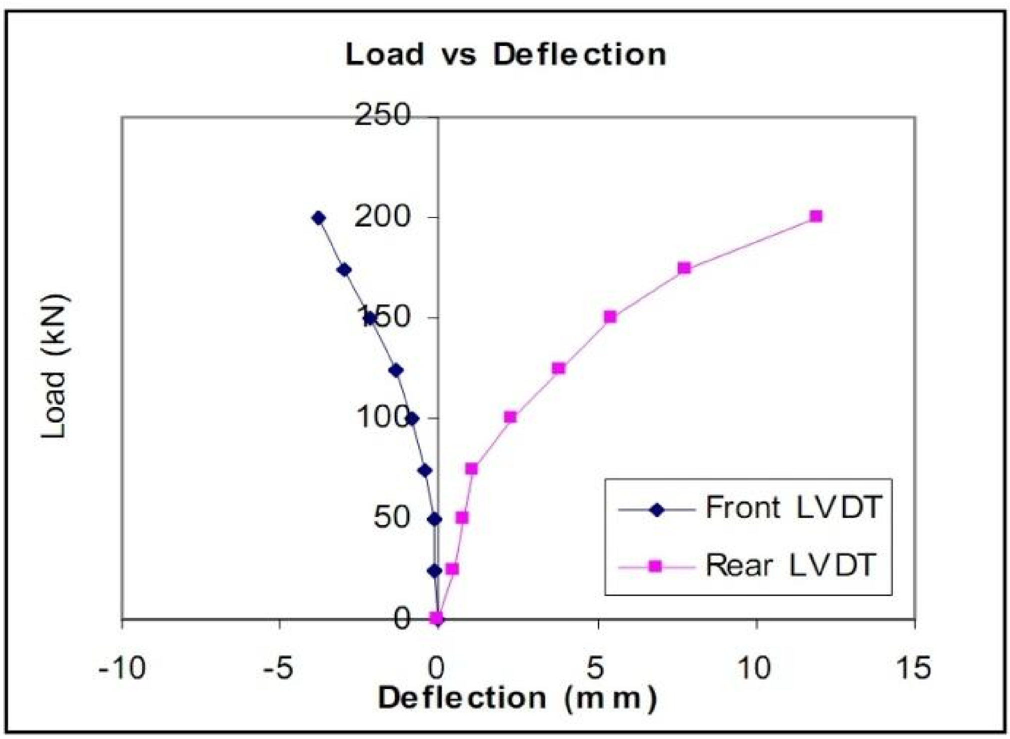
Load vs Deflection
Load (kN)
Deflection (mm)
Front LVDT
Rear LVDT
250
200
150
100
50
0
-10
-5
0
5
10
15

Fig. 7c.

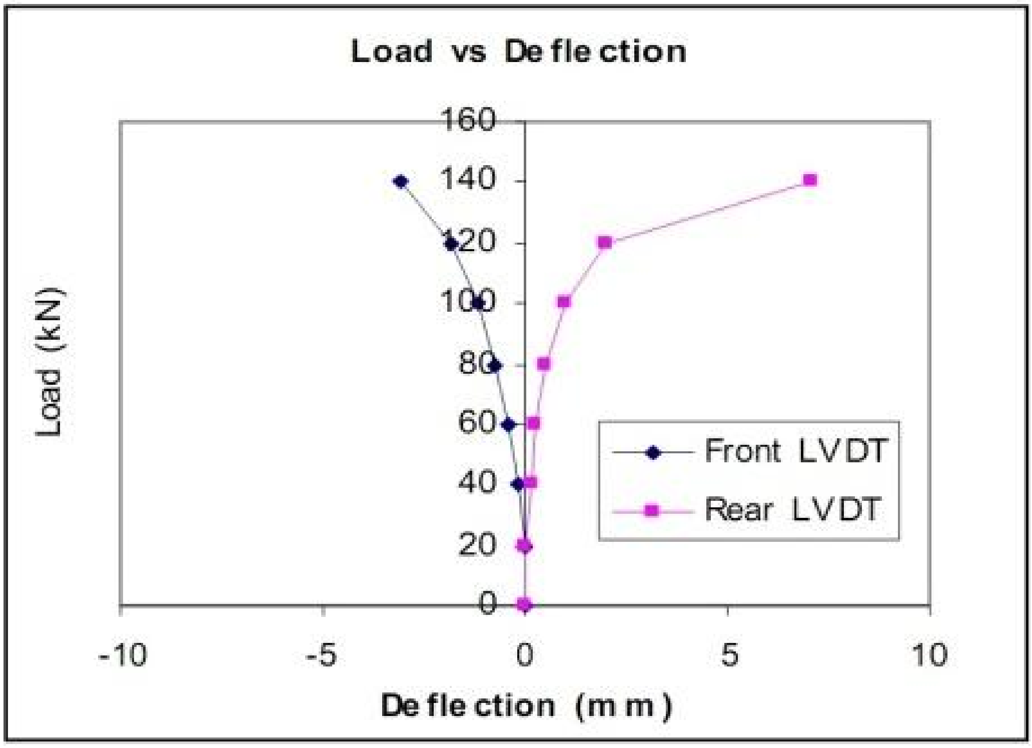
Load vs Deflection
Load (kN)
160
140
120
100
80
60
40
20
0
-10
-5
0
5
10
Deflection (mm)
Front LVDT
Rear LVDT

Fig. 7d.

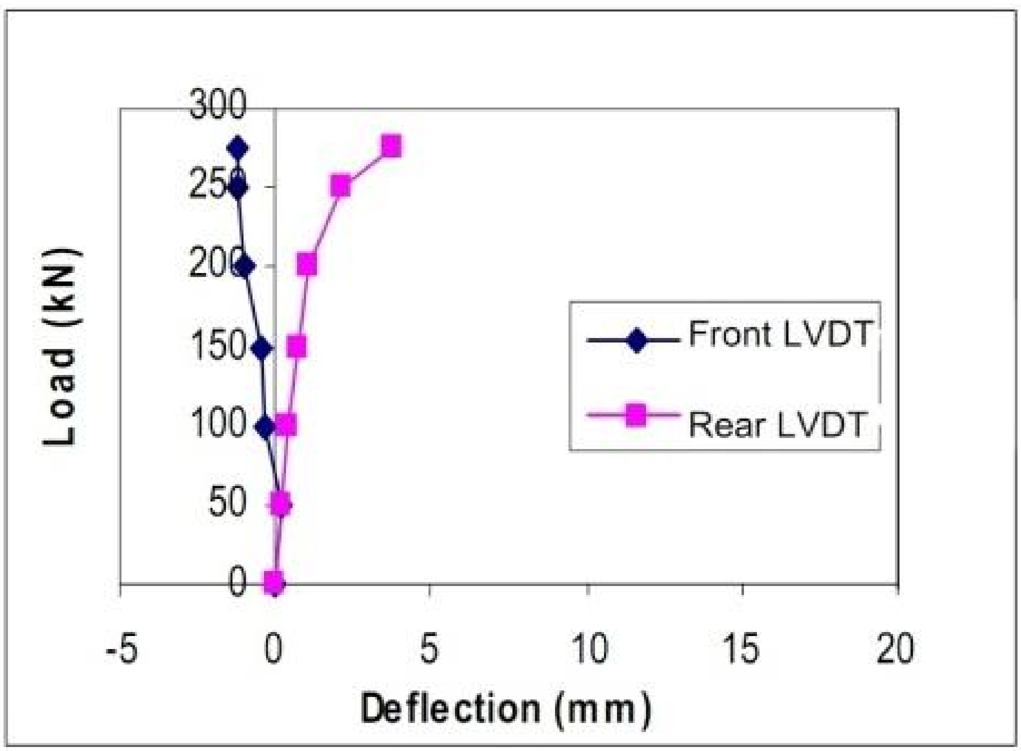
Load (kN)
300
250
200
150
100
50
0
-5
0
5
10
15
20
Deflection (mm)
Front LVDT
Rear LVDT

Fig. 7e.

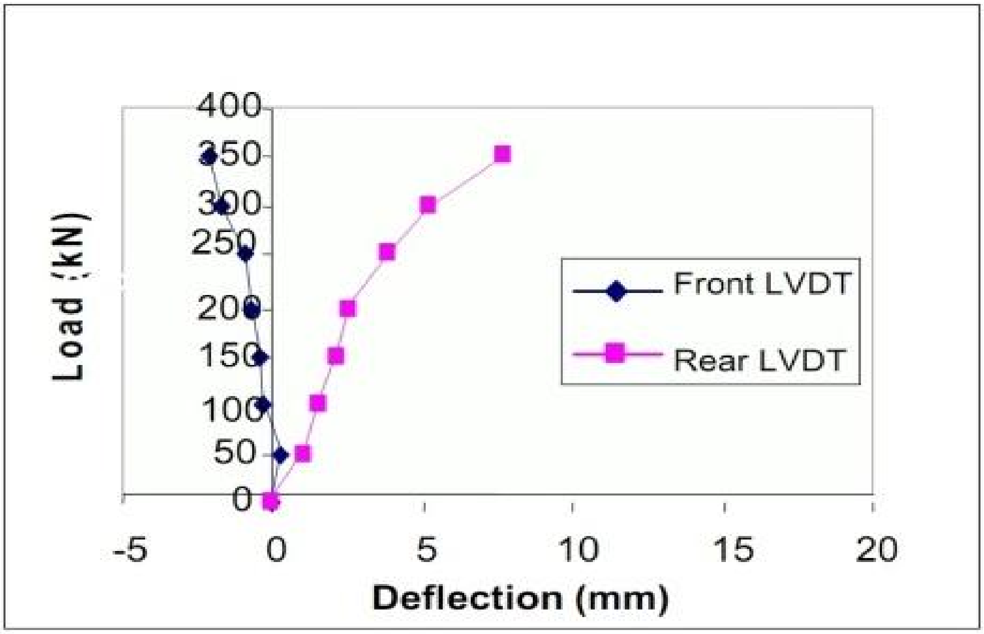

Fig. 7f.

Fig. 7a-6f. displays the analysis of the load deflection of the six panels

6. CONCLUSION

This study shows that there was no even distribution of the applied load in the total area of panels LFCP1-3 and this may be due to the absence of concrete capping. Facings of the panel in LFCP1 to LFCP3 deflected in different directions and near the upper part of the panel unlike the facings of panel LFCP4, LFCP 5 and panel LFCP6 that deflected in the same direction. In the loading process, it was observed that the noticeable first cracks occur at the loading capacity failure of about 34% for panels LFCP1, LFCP2 and LFCP3, while it was 36% for LFCP4, LFCP5 and LFCP6. Meanwhile the panels were observed to be in composite composition despite failure, an indication that the shear connector strain, remain well below the average yield stress strain. The strength gain by the foamed concrete was observed to be as a result of the pozzolanic nature of the fly ash content and also make it sustainable going by the decrease in the content of binder that has been adjudged as a source of greenhouse gas emitter.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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