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RESEARCH PAPER

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by

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Behaviour of structural fibre composite sandwich panels under point load and uniformly distributed load

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Abstract

An innovative fibre composite sandwich panel made of glass fibre reinforced polymer skins and a modified phenolic core material was developed for building and other structural applications. The behaviour of this new generation sandwich panel was studied to with reference to the main fibre orientation in floor applications, so that the effect due to erroneous installation could be evaluated. The two- and four-edge supported sandwich panels with different fibre orientations and fixity systems between panel and joist were tested under point load and uniformly distributed load (UDL) to determine their strength and failure mechanisms. The results of this experimental investigation show that the panels behave similarly under both loading conditions. Moreover, the fixity does not have a major effect on its failure mode and deflection.

Keywords: Fibre composites; Sandwich panels; Point load; Slabs; Fibre orientation; Fixity.

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1. Introduction

Sandwich panels are a type of composites that consist of two outer skin laminates and a core located in between the skins. Fibres are placed in the skin laminate to provide tensile and some compressive strength of the panel. The core is made of a lightweight material that provides good shear strength. Composite materials have been utilised in a variety of engineering fields such as marine, aeronautical and automotive industries [1-3]. Composites have only just recently been utilised in civil engineering practices [4]. The use of sandwich panels as a civil construction material has often been overlooked in favour of traditional materials such as concrete and steel as these are relatively cheap and readily available. The advantages of sandwich panels over traditional building materials though are starting to become apparent [5-7].

Sandwich panels are lightweight, strong and their water and termite resistant properties making them a very viable alternative for civil construction [8, 9]. A major area where sandwich panels are beneficial is flooring systems. Due to their lightweight and strength properties, the use of sandwich panels proves a much better alternative to traditional wood or concrete flooring [5]. The reduced dead weight of the floor results in reduced overall load and hence the need for smaller supporting members.

An innovative fibre composite structural sandwich panel has recently been developed for various civil applications [9]. This new generation sandwich panel has the potential for applications in floors, bridge decks, walls and roofs for its multifunctional structural/insulation properties. Specifically, the behaviour of sandwich panels in flooring systems comprising of two-edge and four-edge supported slabs have not yet been fully investigated. A change in the fibre orientation during construction than the original intention could change the sandwich behaviour. This could well happen in many sites, where it could be difficult to identify the main fibre orientation in a panel cut to size. On the other hand, although the uniformly distributed loads are not so critical for sandwich panels, the point loads are, because they create stress concentration and can damage the panel. Therefore, a detailed understanding of the behaviour and failure mechanisms of the fibre composite sandwich panels under different loading conditions is necessary to provide some useful insight into its behaviour.

This paper presents the experimental results on two- and four-edge supported sandwich panels with varying fibre orientation and panel fixity with the joists under point load and uniformly distributed load (UDL). The behaviour of two- and of four-edge supported slabs under different loading conditions was investigated to provide more knowledge into the behaviour of sandwich panels as flooring systems.

2. The new structural sandwich panel

The fibre composite sandwich panel under study is made up of glass fibre composite skins co-cured onto the modified phenolic core material using a toughened phenol formaldehyde resin [9, 10]. The fibre composite skin is made up of 2 plies of stitched bi-axial (0/90) E-CR glass fabrics manufactured by Fiberex and has a total thickness of around 1.8 mm. The 0° fibres and the 90° fibres of the skin contain 400 gsm and 300 gsm respectively. The core has a density of 850 kg/m^3. The improved compressive strength and rigidity of this new composite sandwich structure together with its higher density core make this material suitable for structural applications. The combined density of the overall sandwich panel is around 990 kg/m^3, similar to that of hardwood timber The mechanical properties of the skin and the core of this sandwich structure are given elsewhere [10]. The average strengths of the skin in flexure, tension, compression and shear are 317, 247, 202 and 23 MPa respectively for 0° fibre orientation and 135, 208, 124 and 22 MPa respectively for 90° fibre orientation. The average skin modulus in flexure, tension, compression and shear are 14285, 15380, 16102 and 2466 MPa respectively for 0° fibre orientation and 3664, 12631, 9949 and 2174 MPa respectively for 90° fibre orientation. The core consists of average strengths in flexure, tension, compression and shear of 14, 6, 21 and 4 MPa respectively and modulus of 1154, 980, 2571 and 747 MPa respectively.

3. Experimental program (for point loading)

3.1 Test specimens

The prototype slabs were designed and constructed to replicate a two-edge and a four-edge supported slab systems in a typical floor structure adopted from the Particleboard Structural Flooring Design Manual published by the Australian Wood Panels Association Incorporated [11]. The design was based on a deck type system with a 15 mm thick sandwich panel of 950 mm x 950 mm and with timber joists underneath. The 45 mm x 145 mm hardwood timber joists support the panel such that the centre-to-centre spacing of the joists was 450 mm and 900 mm for the two and four-edge supported slab respectively. Figure 1 shows the design layout of the slab specimens. A list of variables for specimen preparation is given in Table 1. Sikaflex®-221 was used as glue for fixity between slab and joist. For screw fixity, the screws with 10G x 40 mm specification were placed with a spacing of 285-300 mm to each other depending on the length of the joist. In case of fixity with screw and glue, the glue was placed first and then the slab was screwed before curing of the glue. The screw were counter-sunk into the top of the slab.

3.2 Test set-up and procedure

The static loading test on the two and four-edge supported sandwich slabs was conducted based on an idea from the Particleboard Structural Flooring Design Manual [11] by applying a point load onto an area of 100 mm x 100 mm at the centre of each of the spans. The set-up and instrumentation are shown in Figure 2. The load was applied to the specimen using a hydraulic jack and measured through a load cell. Strain gauges were placed on all the specimens at specific areas and orientations. Three strain gauges were placed as shown Figure 1. Two of them directly under the loading point (at bottom surface of the panel) perpendicular to each other to record the strain in the 0° and 90° fibre orientations to understand the strain levels in the varying fibre orientations. Another strain gauge was placed in the centre of the unloaded span on top of the panel. This was placed to measure any strain in the unloaded span due to the load applied in the other span. The applied load, mid-span deflection and strains were recorded and obtained using a data logger. A single point load was applied on the two-edge and four-edge supported slab specimens with varying main fibre orientations of 0° and 90° and fixity system. These tests were conducted to demonstrate the effect of the varying fibre orientations and fixities on the slab system behaviour under point loading.

4. Test results (for point loading)

The results from the four-edge supported slab systems are discussed in this section with particular attention to the load-deflection characteristics, strain variations and failure mode.

4.1 Load-deflection relationship

Figure 3 depicts the load versus deflection relationship of the two-edge and four-edge supported slabs systems with varying fixities and fibre orientations. There was linear increase in the deflection until an initial drop in the load was observed due to core cracking. The specimens were then loaded until ultimate failure. The specimens continue to carry the load until the debonding between the skin and the core from the core shearing occurred as shown in Figure 4. All the panels failed in the same manner, with core cracking being the initial failure of the specimens. The core cracking occurred due to a shear failure. In general, the 0° fibre orientation performed better with an increased stiffness and a higher ultimate failure load. This result suggests that the skins have some contribution to the shear strength of the core. All specimens of two-edge supported slabs failed around the same value but due to the fixity of the bracket to measure the deflection separating at initial failure on two of the specimens, only two specimens ultimate failure are shown in Figure 3(a).

Table 2 summarises the test results on the two-edge and four-edge supported slabs with different fixities and fibre orientations under point load. As per the Particleboard Structural Flooring Design Manual, a 2.1 kN load was considered as the service load. The deflection was recorded during the test of each specimen. The deflections at the point of loading at 2.1 kN were found to be ranging from 1.81 to 2.38 mm depending on the test variables. The allowable deflection based on the manual is 1.5 mm, corresponding to a deflection of span/300. Hence, the observerd deflections are slightly higher than what is allowed in the manual. The deflection of the four-edge supported slabs with 90° fibre orientation is greater at the 2.1 kN load which is consistent with the two-edge supported slab system. In general, 2.1 kN loading did not cause much deflection in comparison to the core cracking load of the specimen. The deflection measured at the unloaded span shows a similar pattern with the upward deflection being greater for the 0° fibre orientation due to higher cracking load. The table shows that the fixity of the specimen does not have a major effect on the overall performance of the slab system.

As can be seen in Figure 5, the glue had initially caused a slight decrease in deflection but once the glue separated, the screws were essentially the only fixity acting on the specimen. Table 2 shows that the 90° fibre orientation slabs deflected more on the loaded span as well as the unloaded span. This was due to the reduced stiffness of the panel compared to the 0° fibre orientation slabs.

4.2 Load-strain relationship

Figure 6 depicts the load strain relationship in two-edge supported slabs for 0° and 90° fibre orientations with strain gauges placed in varying direction placed at the bottom of the loaded span as shown in Figure 1. The graphs show that the strain is distributed between the main fibre orientation, either 0° or 90°, and its transverse direction. Two sets of strain data were achieved by positioning strain gauges into parallel to the main fibre orientation and its transverse orientation for each case. Initially, the screw and glue fixity exhibited a slightly higher load for the strain achieved than the screw only but the curves started to converge as the glue peeled off and it ultimately became a screw only fixity at around the cracking loads of 20 kN. Therefore, it can be interpreted that for both 0° and 90° main fibre orientations of the panel, the fibre running from span to span for a two-edge supported slab system undergoes a higher strain for a smaller loading. It was also observed that the higher strain was experienced by the 90° fibre orientation from a lower loading in comparison to the 0° main fibre orientation. This was due to the reduced stiffness of the 90° fibre orientation panel.

Figure 7 shows the load strain relationship for the four-edge supported slab system with varying direction of strain gauges as shown in Figure 1. The graph shows a similar relationship to the two-edge supported slab system. The strain is being distributed between the fibre directions but the main fibre direction is taking a higher strain under a smaller load. This is consistent with both the 0° and 90° main fibre orientations. This is due to the main fibre running along the smallest span length of 450 mm. The shorter the span length of the slab, the higher is the strain taken by the fibre in that direction. This was due to the less area of the panel for the strain to be distributed. The 0° fibre orientation also took a higher loading for the strain achieved in comparison to the 90° fibre orientation, which is consistent with the two-edge supported slab results.

4.3 Strain-deflection relationship

Figure 8 depicts the strain-deflection relationship of the two-edge supported slab systems with different fixities used. The graph shows a fairly consistent linear relationship except for 90° screw only specimen. The graph indicates that the strains were consistent throughout the panel no matter the fibre orientation or fixity used.

In comparing the strain-deflection relationship to Figure 9 for the four-point flexural testing of the sandwich beam specimens, it shows that the two-edge supported panel undergoes a higher deflection compared to the sandwich beam for the same amount of strain obtained. This can be explained by the longer span length of the slab in comparison to the flexural tests done on the sandwich beam. In the flexural testing of the beam, the strain is localised to only a short span. In the slab testing, the strain is spread over the panel and hence a larger deflection occurs before high strain values at the centre of the slab are obtained.

The 90° fibre orientation in the four-edge supported slab also had increased strain under smaller loading in comparison to the 0° fibre orientation as shown in Figure 10. Comparing this to Figure 9 for the flexural test results, it shows a consistent relationship with a greater deflection occurring for the same amount of strain incurred.

4.4 Ultimate load carrying capacity

The ultimate load of the two and four-edge supported slab systems under point load can be observed in the diagram for load-deflection relationship shown in Figure 3. The figure shows its range as 33 to 50 kN. The result shows that this type of sandwich composite has a reasonably good ultimate load carrying capacity for its flooring application, where the service load is considered to be 2.1 kN as per the Particleboard Structural Flooring Design Manual [11]. In addition, it should also be noted that the screw and glue fixity would have a significant impact under service loading conditions rather than at ultimate. The glue may be used to reduce the panel deflections in service while the screws could be used to provide adequate capacity for ultimate loading conditions.

4.5 Failure mode

The experimental investigation showed that the sandwich panels exhibited almost a common failure mechanism for all the slab specimens regardless of their skin fibre orientations, fixity between panels and joists and their edge support (two and four-edge support). Figure 3 shows the typical failure phenomena which occurred during the test. In general, a core shear cracking was first observed near the loading point of the specimen at the applied load of around 18 to 23 kN. However, the nearest (outer) edge of the sandwich from the loading point started to separate from the joist before the first crack occurred in the sandwich core, due to wrinkling of the panel at the vicinity of the loading point. The debonding between the sandwich core and the skins was also easily noticed at the edge of the wrinkled part as shown in Figure 11. The separation of the sandwich from the joist became extensive with the continuation of applying the load (Figure 5). Some simultaneous cracking and skin delamination were observed before the final failure of the specimen. The core cracking was not found to be necessarily diagonal from the corners for all the specimens although some diagonal cracking were also observed.

5. Experimental program (for uniformly distributed loading)

5.1 Test specimens

The uniformly distributed load (UDL) tests were undertaken using different restraints for the two and four-edge supported slab systems. The two-edge supported slab was restricted on two opposite sides to simulate a two-edge supported slab system. The four-edge supported slab was restricted on all four sides to replicate a four-edge supported slab system.

The tests were carried out on 900mm x 900mm square panels. For the two-edge supported slab system, the specimens were tested at 0° and at 90° main fibre orientations. The orientation of the main fibre for the four-edge supported slab does not matter as the panel was square. The joists used were 45 mm x 145 mm hardwood timber, similar to the ones used in the point-load testing. A list of variables for specimen preparation is given in Table 1.

5.2 Test set-up and procedure

The tests were conducted using a high pressure airbag. The airbag was 0.95 m square. When the air pressure increases, a uniformly distributed load is placed on the sandwich panel. The air bag was continually pressurised until failure occurred.

The slabs were placed on a base plate that was connected to four load cells as shown in Figure 12. A large steel metal plate was then fixed to the upper cross arm of the apparatus to prevent the upward movement of the airbag. The airbag was then placed in between the steel plate and the slab where the increase in the height of the airbag was restricted as shown in the figure. The airbag was inflated through pressurised air along yellow tubing going into the airbag. Once the airbag was inflated, it caused a uniformly distributed load (UDL) onto the slab specimen. The four load cells located under the base plate then measure the loading on the slab.

A draw-wire displacement transducer (string pot) was placed under the centre of the specimen to get the deflection of the panel under loading. The string port was attached by wire to a bracket located at the centre of the panel. Strain gauges were placed under the centre of the panel in perpendicular directions in similar manner as the point load testing. UDL testing was undertaken on the two-edge and four-edge supported slab specimens with varying main fibre orientations of 0° and 90°. As with the point load test, the fixities were varied to determine their behaviour under a different loading condition. As the slabs tested were 900mm x 900mm and supported on all four sides, the fibre orientation for four-edge supported slabs is always the same.

6. Test results (for uniformly distributed loading)

This test results for uniformly distributed loading is discussed under this section, with similar emphasis on load-deflection relationship, strain variation and ultimate failure.

6.1 Load-deflection relationship

Figure 13 demonstrates the distributed load versus deflection relationship of the varying fibre orientations and fixities in a two-edge supported slab system. The results are consistent with those of point loading with the initial stiffness for the 0° fibre orientation being greater than the 90° fibre orientation. The initial stiffness of the combined screw and glue fixity was also greater until the glue peeled off and the panel behaved as a screw only fixity. The panels however did not fail but deflected greatly before the joists supporting the panel failed as shown in Figure 14.

The four-edge supported slab specimens behaved similarly to the two-edge supported slabs, however the joists did not fail. The initial stiffness for the 0° fibre orientation was greater than the 90° fibre orientation as shown in Figure 15 as similar to two-edge supported slab system. It should be noted that the deviation in the four-edge supported screw and glue line in the figure is not a failure but letting the load off the slab.

Table 3 shows the deflection of the two-edge and four-edge supported slabs with varying fibre orientations and fixities at different uniformly distributed loads. The slabs with screw and glue fixity deflected less in comparison to the screw only. On the other hand, the 90° fibre orientation deflected more than the 0° fibre orientation except for screw only under 5 kPa and 10 kPa loading. This is because the readings were taken at low loading, the differences were very small and once a higher loading of 20 kPa was reached the 90° fibre orientation slab deflected more.

6.2 Load-strain relationship

Figure 16 shows the load (UDL)-strain relationship of the two-edge supported slabs for the two varying directions of strain gauges that were placed under the centre of the panel. The graphs show the comparison between the screw only and combined screw and glue fixity for both 0° and 90° fibre orientations (Figures 16(a) and 16(b)). As shown in each graph, the two relationships are very close showing the fixity not having any major effect on the behaviour of the slab. The strain gauge parallel to the main fibre orientation experienced a higher strain from a lower UDL until the strain gauge failed. This shows that the main strain of the panel was taken by the main directional fibres running from span to span for a two-edge supported slab. This was expected as the UDL increased across the panel, the main strain incurred was from span to span. The fibre running transverse to the main fibre orientation experienced a much smaller strain under higher loading. On the other hand, for the two-edge supported 0° screw and glue specimen, as the strain keeps increasing the load plateaus. This was due to the joists starting to buckle inwards and the panel still deflecting greatly without failing. The connection between the joist and bearer failed resulting in the inward buckling of the joists (Figure 14(a)). The joist itself also failed in some cases with the timber cracking around the screw fixings (Figure 14(b)).

Figure 17 shows the relationship between load and strain for four-edge supported slab specimens under UDL. The strain gauges were placed along the 0° and 90° fibre orientations under the centre of the panel. The strain was distributed evenly between the fibre orientations. The majority of the strain of the panel was taken by the fibre that ran from span to span of the slab system. In the four-edge supported slab system this was in both directions, hence the strain was distributed evenly between the fibre orientations. As it can also be seen in the graph, the specimens with screw and glue took a higher initial loading for the amount of strain occurred due to the glue providing initial strength before peeling off. This was evident in the load strain relationship but had no significant effect on the overall performance of the panel. It should be mentioned that the strain gauge of the 0° screw and glue specimen broke at 72 kPa load and hence no more data could be obtained from it. Also, in the case of “Screw only (90°)”, no useful readings were taken from the strain gauge because of a fault found in it.

6.3 Strain-deflection relationship

Figure 18 represents the deflection versus strain relationship of two-edge supported panels under UDL. The deflection was recorded at the centre of the slab and the strain taken along the main fibre direction (span to span). Comparing the relationship to Figure 9 for the flexural tests, it can be seen that the slab experienced a considerably larger deflection for the same strain levels incurred. This was due to the joists failing as explained earlier as well as the uniformly distributed load. Due to the load being spread across the entire panel instead of being concentrated over the middle of the panel, the strain was distributed over the entire panel. Therefore, the strain at the centre of the panel was lower until large deflection occurred in the panel.

The panels did not fail again for four-edge supported slabs but deflected greatly at high loading when the base plate also started to deflect. This is evident in Figure 19 with the deflection strain relationship for the four-edge supported specimens. This relationship should be linear if the base plate did not deflect with the specimen. The initial relationship was linear until the base plate started to deflect and then the relationship became non-linear.

6.4 Ultimate load carrying capacity

Almost all the cases for UDL, the two and four-edge supported slab systems were not loaded until their ultimate failure. The loading on the two-edge supported slabs were required to stop before their ultimate deflection when the mid-span were about to touch the bottom or joists were about to fail (Figure 14). For the four-edge supported slabs, the loading was stopped when the based plate started to deflect, as mentioned before. However, based on the observation from the diagrams for load-deflection relationship shown in Figures 13 and 15, the ultimate load carrying capacity of the slabs under UDL is higher than 80 MPa. The result of this high UDL carrying capacity indicates that this loading type is less critical than point loading.

6.5 Failure mode

Figure 14 shows bucking and cracking as the typical failure modes of the joist for two-edge supported slabs under UDL. However as mentioned before, the panels did not fail but deflected greatly. The strain of the two-edge supported specimens was taken by the fibre that ran from span to span. Therefore, in the 0° fibre orientation, the 0° fibre orientation took the majority of the strain. The same case happened for the 90° fibre orientation where the 90° fibre orientation took the majority of the strain. The strain of the panel was distributed almost evenly between the fibres for the four-edge supported slab system due to the same span lengths in each direction, although a slight variation was noticed probably due to variation in fibre content in two directions. These results were consistent with the results from the two-edge supported slabs. The joists on the two-edge supported slab system failed before the panel could with the joists buckling inwards and the timber cracking at the fixity of the panel. The four-edge supported slab systems did not fail either, but deflected greatly. At high loading, the base plate began to deflect with the slab specimen and failure could not occur. It should be noted that the highest possible deflections observed during testing were usually at above 60 kN load (or around 80 kPa UDL) when no failure was noticed in the panel for UDL (Figures 13 and 15). However, under point load the core failed in shear at only around 20 kN load. So, UDL is less critical than the point load for sandwich panel failure, which is also found by other researchers [12, 13].

7. Conclusions

The behaviour of the innovative structural fibre composite sandwich panels was investigated experimentally by developing prototype two-edge and four-edge supported slab systems. Various test variables were considered to determine the effects of varying the sandwich skin fibre orientation, the fixity between slab and joist and the slab edge support on the slab properties under point load and uniformly distributed load (UDL). Experimental investigation suggests that fibre composite sandwich panels as slab systems behave similarly under point load and uniformly distributed load no matter the fixity, fibre orientation or slab edge support. Also, the point load case was found to be critical compared to UDL.

It was found from point load testing that the fixity of the slab systems had no major effect on the deflection of the slab or on its overall performance, although the screw and glue fixity initially performed better than the screw only fixity. This was due to the increased initial stiffness provided by the screw and glue fixity, however once a higher loading was placed on the slab the glue peeled away and the panel acted as a screw only fixity. The 0° fibre orientation provided a smaller initial deflection due to the higher stiffness of the fibre orientation which was consistent for all types of fixities and slab systems. The initial failure of the panels, no matter what the slab system, fibre orientation or fixity is, was due to shear cracking of the core. The strain in the panels was carried in both fibres directions, but the main fibre direction carried a higher strain than the perpendicular fibre. For both fibre orientations, the fibre that ran along shorter span length took the higher strain under smaller loading in both the two-edge and four-edge supported slab systems.

It was found from UDL testing that the behaviour of the fibre composite sandwich panel under UDL is similar to the panels under point load. The fixity of the slabs did not have a major effect on the behaviour of the panels, only the initial deflection being reduced as in the point load tests. The 90° fibre orientation deflected more than the 0° fibre orientation due to the higher stiffness of the 0° fibre orientation panel. None of the panels however, no matter the fixity, fibre orientation or slab system failed. None of the two-edge and four-edge supported panels failed under UDL but great deflections were observed in both. For the four-edge supported slab system, the span length was equal in both directions hence the strain was distributed evenly between both fibre directions.

Overall, the results were consistent and the information recorded was highly valuable in determining the behaviour of fibre composite sandwich panels for slab system applications. However, there is need to investigate the behaviour of such composite sandwich panels analytically and conduct a parametric study to have a better understanding of its behaviour in flooring systems.

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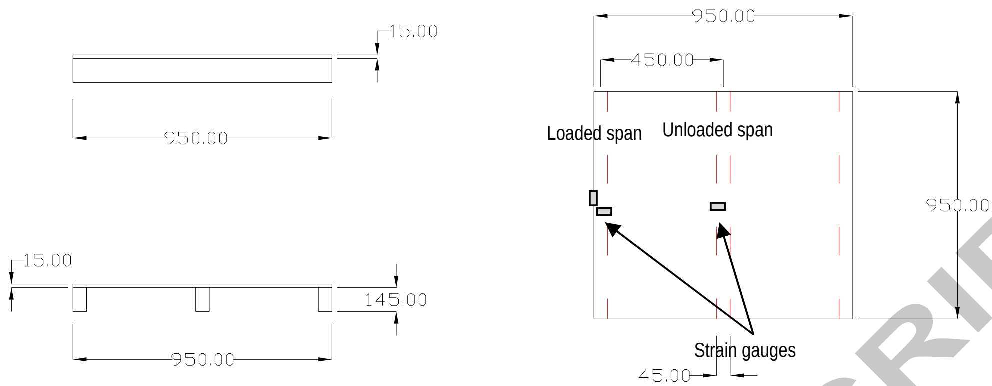
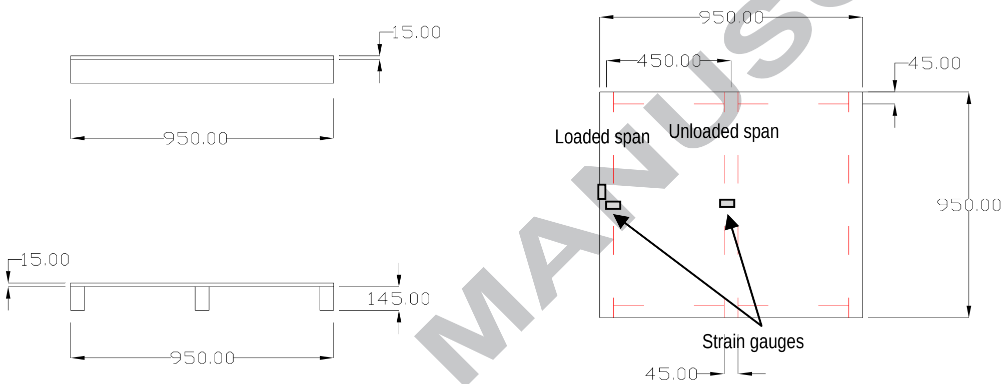
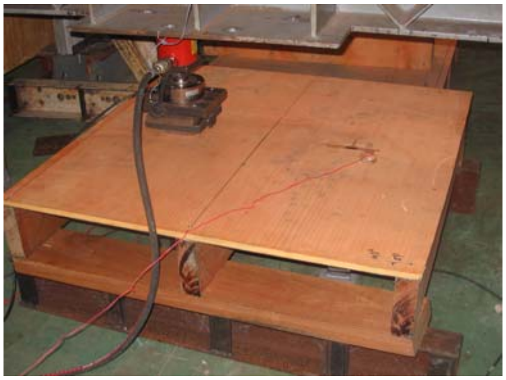


(a) Two edges supported slab



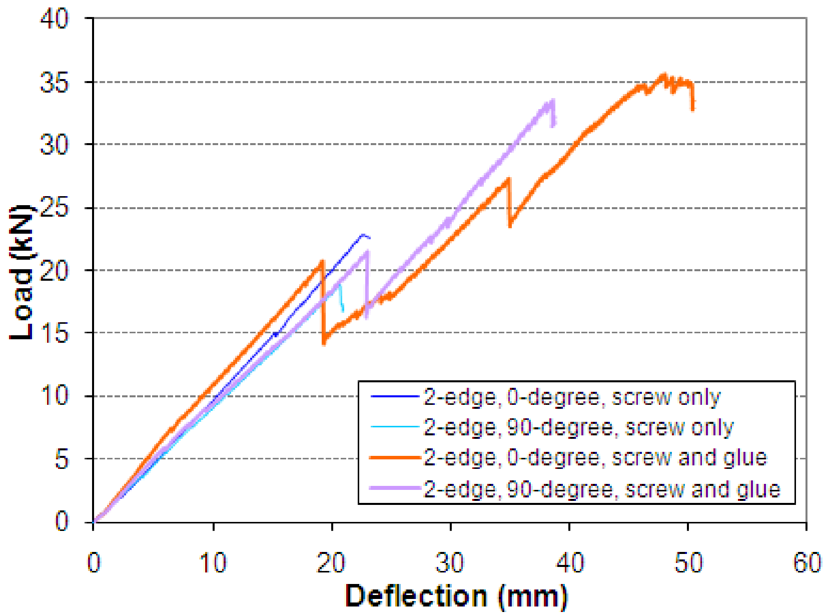
(b) Four edges supported slab

Fig. 1. Slab design and strain gauge placement for point load test (dimensions are in mm)

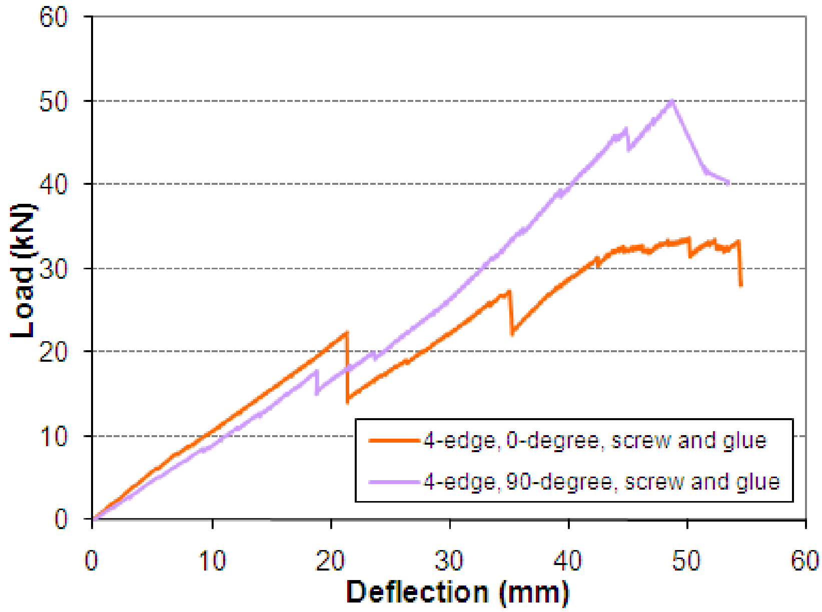


(a) Two edges supported slab testing (b) Four edges supported slab testing

Fig. 2. Instrumentation and set-up for sandwich slab testing under point load



(a) Two edges supported slabs



(b) Four edges supported slabs

Fig. 3. Load-deflection relationship of sandwich slabs under point load

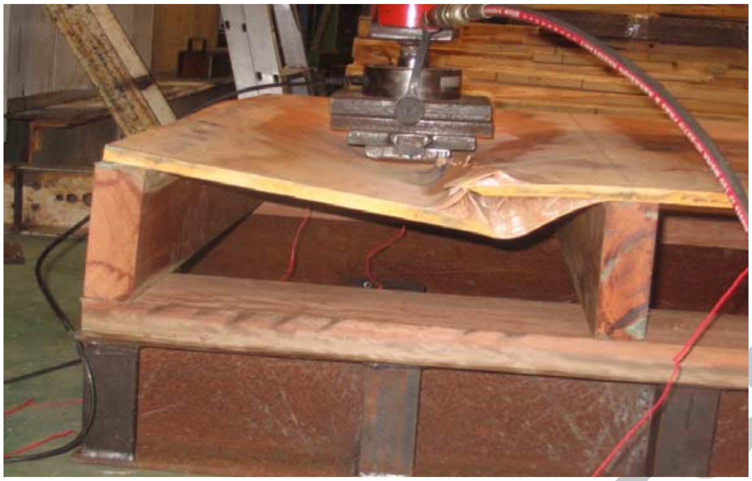
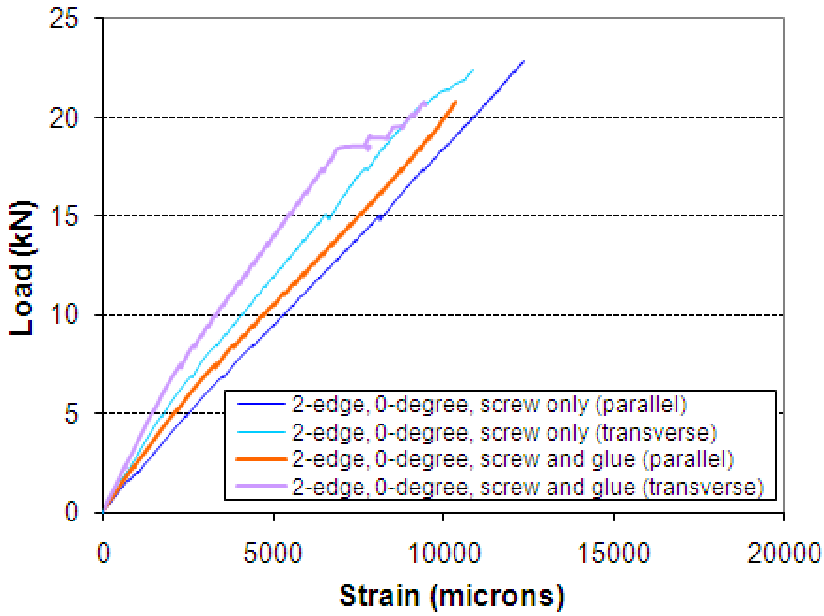
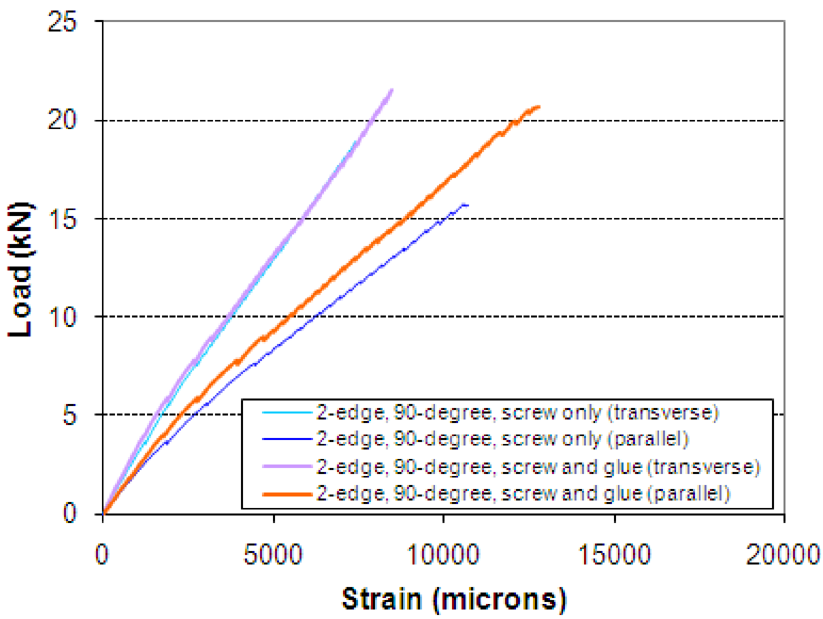


Fig. 4. Ultimate failure of two edges supported slab from delamination between skin and core


Fig. 5. Glue separation from joist and panel under point load



(a) 0° fibre orientation



(b) 90° fibre orientation

Fig. 6. Load versus strain with varying direction of strain gauges for two edges supported slabs under point load

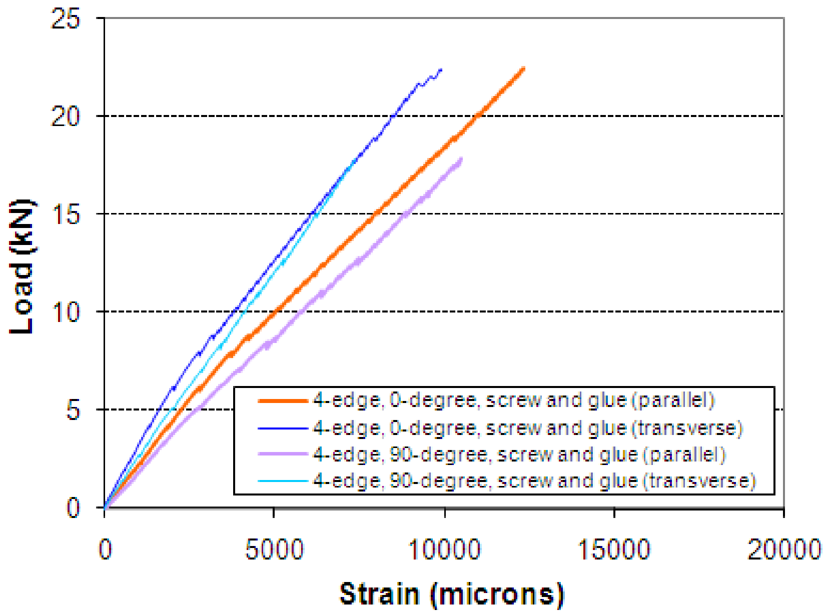


Fig. 7. Load versus strain with varying direction of strain gauges for four edges supported slabs under point load

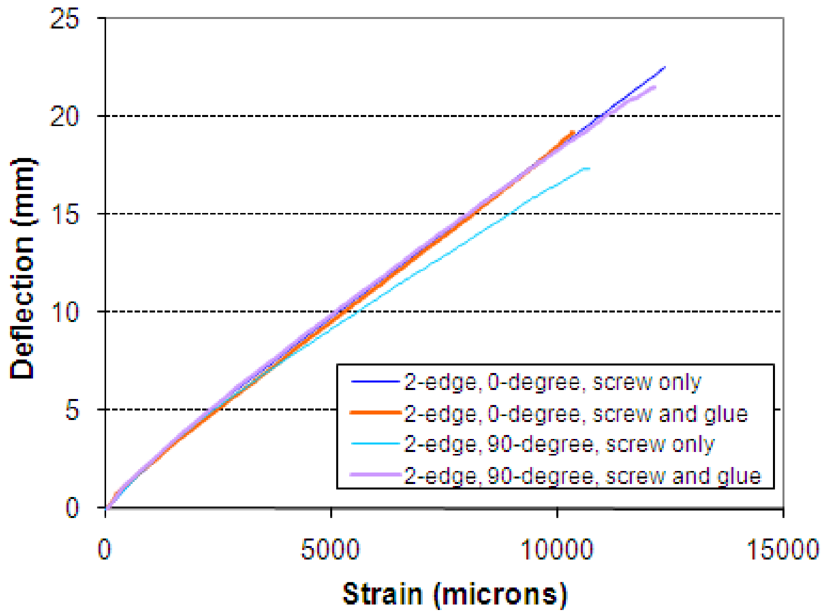
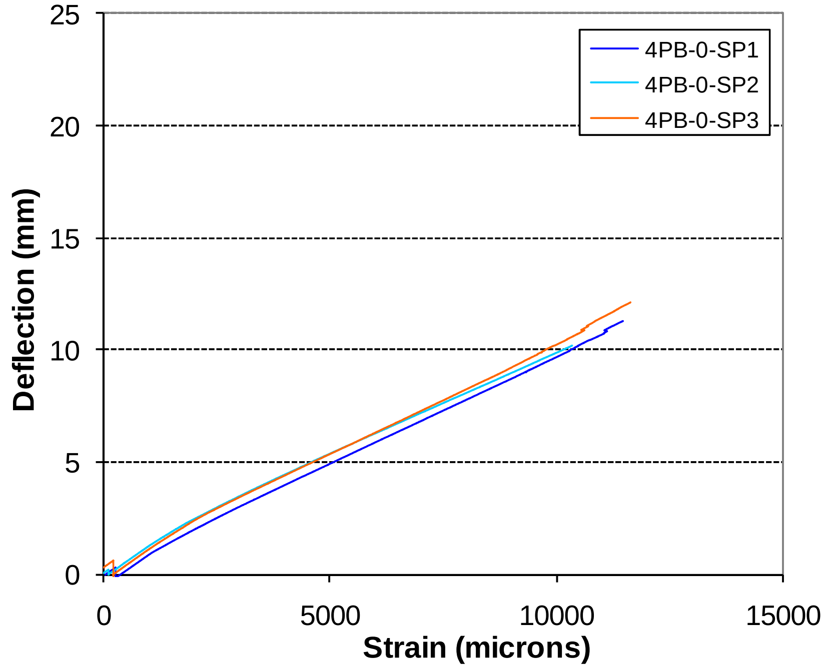
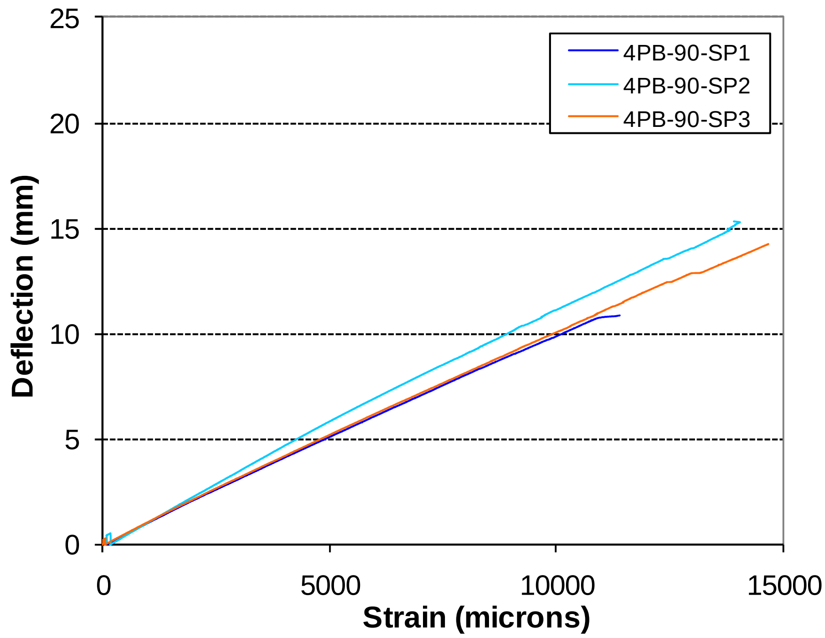


Fig. 8. Deflection versus strain on loaded span of two edges supported slabs under point load



(a) 0° fibre orientation



(b) 90° fibre orientation

Fig. 9. Deflection versus strain diagram of the sandwich beams achieved from four-point flexural tests

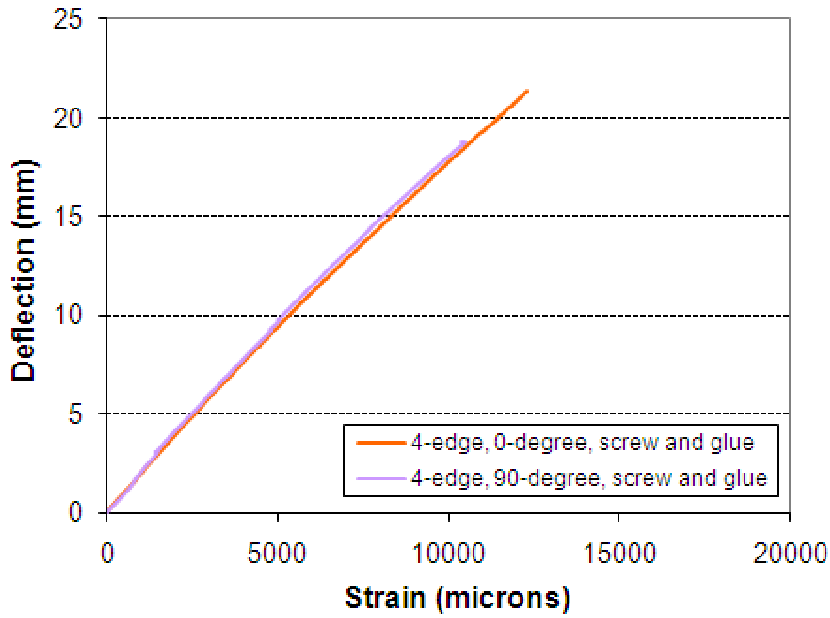


Fig. 10. Deflection versus strain on loaded span of four edges supported slabs under point load

Fig. 11. Debonding failure between sandwich core and skins

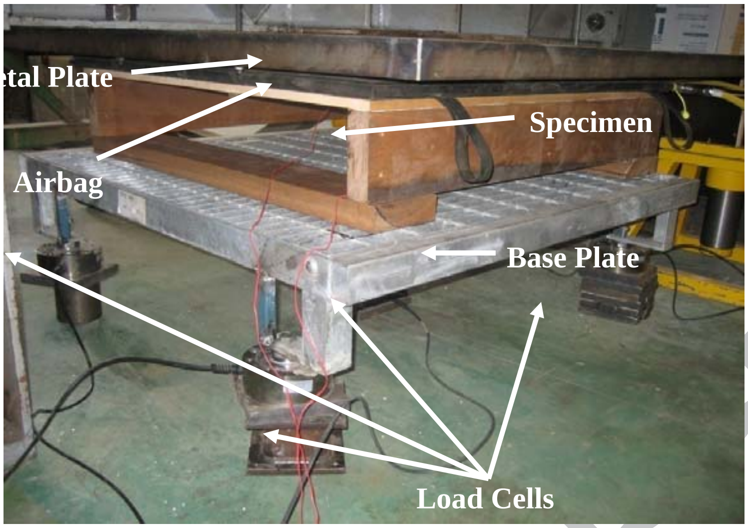


Fig. 12. Uniformly distributed load (UDL) testing set-up

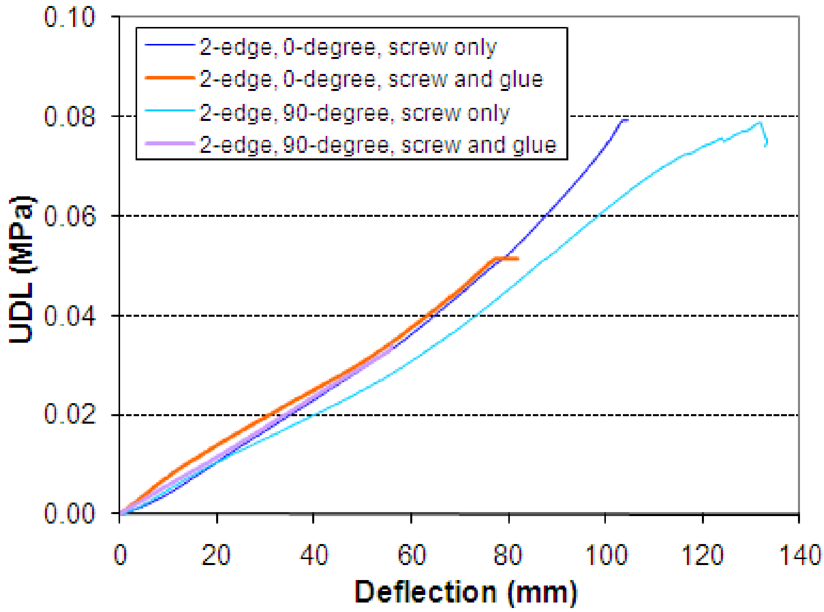


Fig. 13. Uniformly distributed load (UDL) versus deflection diagram for two edges supported slabs

(a) Joist buckling

(b) Joist cracking

Fig. 14. Joist failure of two edges supported slab under UDL

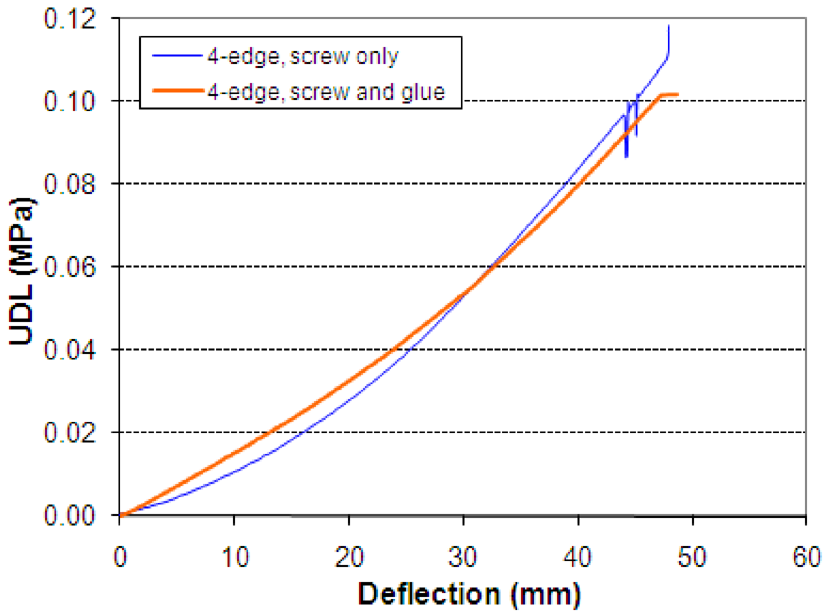
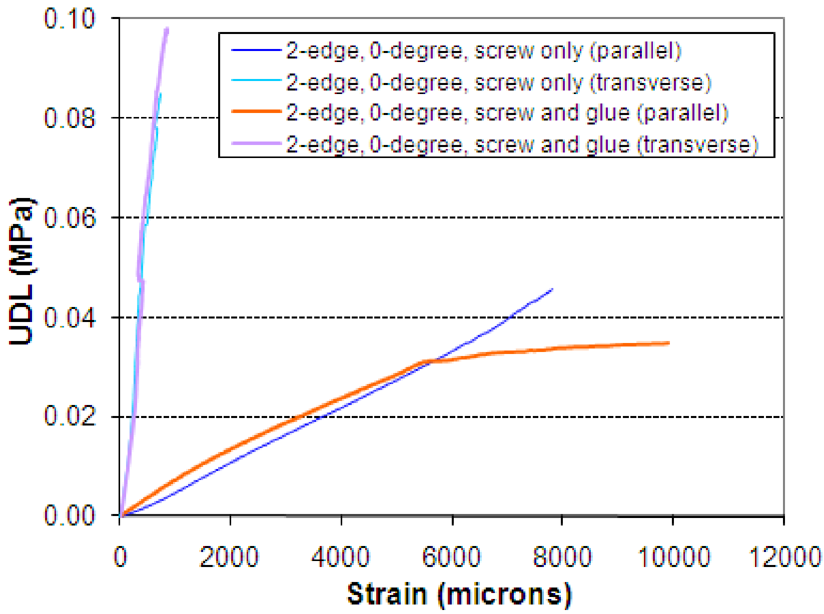
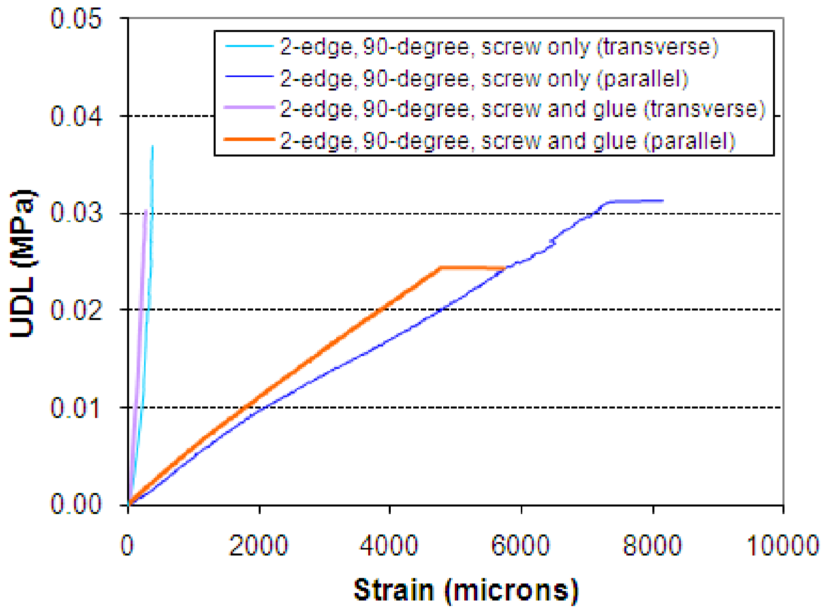


Fig. 15. UDL versus deflection diagram of four edges supported slabs



(a) 0° fibre orientation



(b) 90° fibre orientation

Fig. 16. Load (UDL) versus strain diagram in varying direction of two edges supported slabs

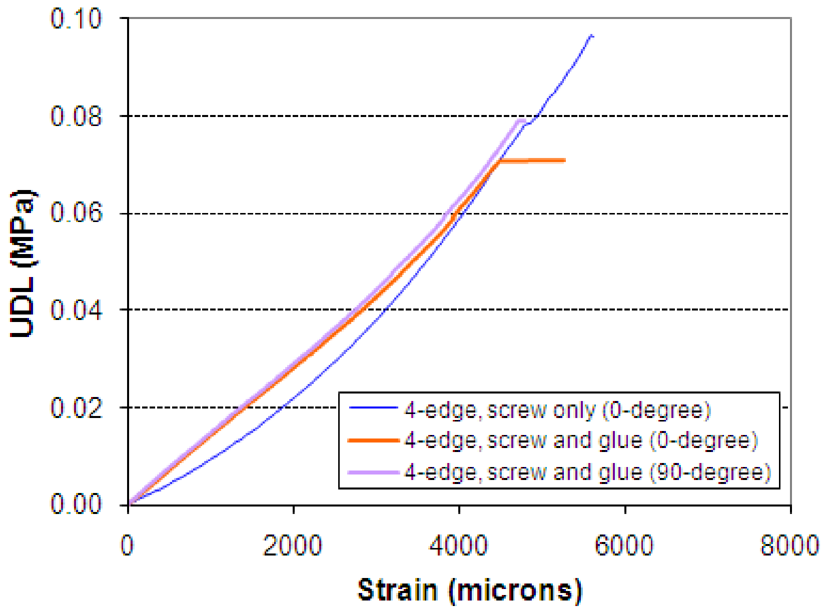


Fig. 17. Load (UDL) versus strain diagram in varying direction of four edges supported slabs

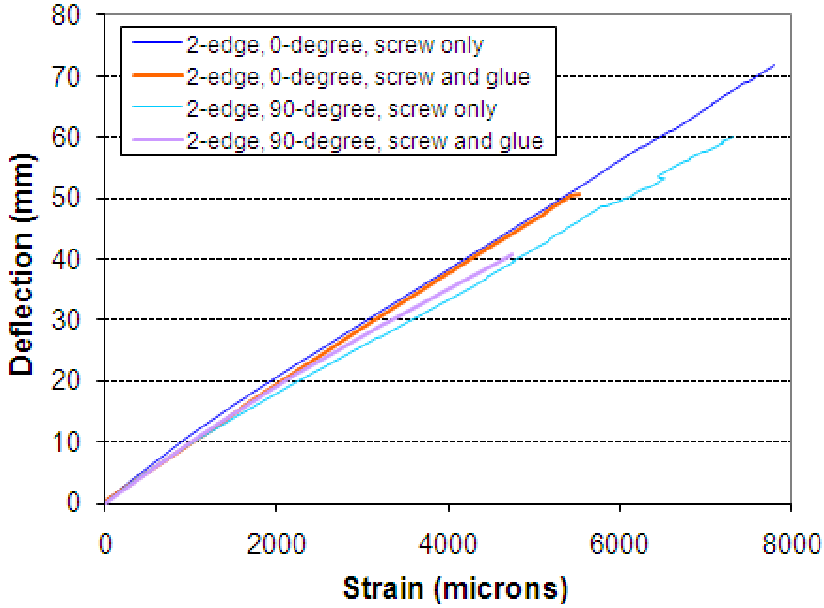


Fig. 18. Deflection versus strain diagram of two edges supported slabs under UDL

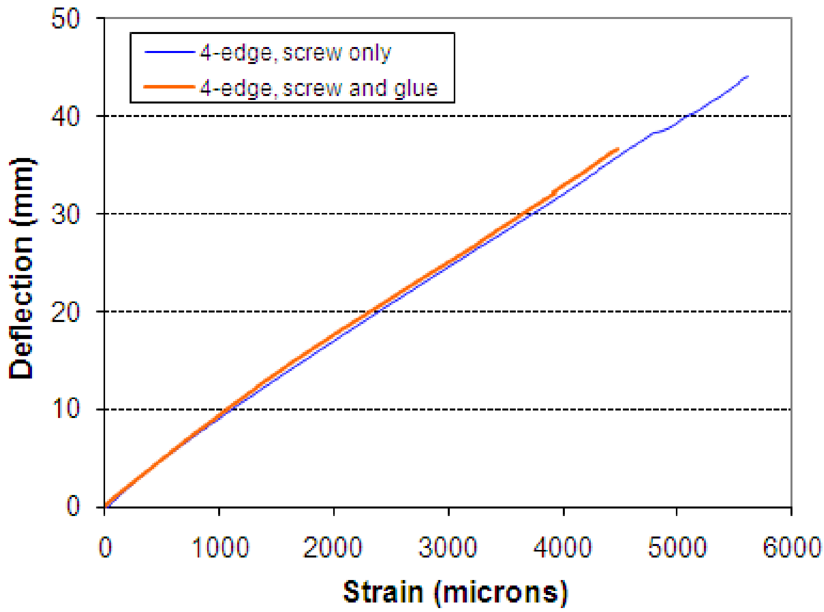


Fig. 19. Deflection versus strain diagram of four edges supported slabs under UDL

Table 1. List of variables for preparing slab specimens for point load and uniformly distributed load (UDL) testing

Test	Support condition	Main fibre orientation at 0°	Main fibre orientation at 90°
Point load	Two edges	Screw only	Screw only
	Two edges	Screw and glue	Screw and glue
	Four edges	Screw and glue	Screw and glue
UDL	Two edges	Screw only	Screw only
	Two edges	Screw and glue	Screw and glue
	Four edges	Screw only	
	Four edges	Screw and glue	

Table 2. Test results on load and deflection for all the specimens under point load

Support condition	Slab fixity	Main fibre orien-tation	Deflection at loaded span at 2.1 kN (mm)	Deflection at unloaded span at 2.1 kN (mm)	Core cracking load (kN)	Deflection at loaded span at core cracking load (mm)	Deflection at unloaded span at core cracking load (mm)
Two	Screw	0°	2.38	- 0.06	22.88	22.57	- 2.86
edges	only	90°	2.31	- 0.13	18.72	20.70	- 1.92
Two	Screw	0°	1.96	- 0.05	20.61	19.19	- 1.67
edges	and glue	90°	2.19	- 0.40	21.05	22.56	- 2.05
Four	Screw	0°	1.81	- 0.04	22.44	21.36	- 1.30
edges	and glue	90°	2.34	- 0.26	17.84	18.78	- 1.19

Table 3. Deflections at different loads at mid-span of the slabs for different fixities under UDL

Support condition	**Slab fixity**	**Main fibre orient -tation**	**Deflection at mid-span at 0.005 MPa (mm)**	**Deflection at mid-span at 0.01 MPa (mm)**	**Deflection at mid-span at 0.02 MPa (mm)**
Two edges	Screw only	0°	11.31	19.19	35.04
		90°	9.87	18.89	39.77
Two edges	Screw and glue	0°	6.67	13.74	31.02
		90°	8.41	17.23	33.98
Four edges	Screw only	-	5.64	9.82	16.13
	Screw and glue	-	3.52	6.64	12.95