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Abdy Kermani
Professor of Timber Engineering, Napier University, Edinburgh, UK

Performance of structural insulated panels

A. Kermani PhD, MSc, CEng, MIStructE, FIWSc

Structural insulated panels (SIPs) are gradually gaining popularity as an alternative construction material for residential and light commercial buildings in the UK. They show marked advantages in strength, thermal performance and speed of installation when compared with the traditional timber frame method of construction. While many types of composite panel building systems have been developed, panels made from a thick layer of foam (often expanded polystyrene) sandwiched between two layers of oriented strand board (OSB) or plywood are usually referred to as SIPs. They were developed in North America and although they have experienced wide-scale utilisation around the world, the concept is still relatively unknown in the UK. This paper details part of a comprehensive research study on SIPs at Napier University and deals with their performance under combined bending and axial compression and the effects of medium-term loading on panel integrity for use as load-bearing walls and columns. The results have illustrated that SIPs perform as an effective composite material possessing considerable strength and stiffness necessary to sustain required design loads.

1. INTRODUCTION

Timber frame construction is currently on the increase, representing approximately 60% of annual new-build homes in Scotland, and around 12% in England and Wales.[1] This method of construction has been recognised as possessing many inherent environmental and energy efficient qualities. Its ability to comply with all the relevant building regulations has enabled its full approval and acceptance by authorising bodies and house builders in the UK. Furthermore, advances in pre-fabricated construction are also generating increased interest from industry.

The increased number of such construction techniques in the UK housing sector has provided the scope for new and innovative technologies to be established. These types of construction methods are being introduced into the UK with little knowledge of performance issues and industry compliance. This may be the case with structural insulated panels (SIPs).

SIPs are factory-produced, pre-fabricated building panels used as wall, roof and floor components on all types of residential and commercial buildings. They were developed in North America and have experienced wide-scale utilisation around the world. The greatest benefit with the system is that the structural support and the insulation are incorporated into a single system during manufacture. This enables high-quality, more accurate thermal efficiency and a greater level of structural support to be achieved. There are a number of other advantages obtained through implementing the system.[2,3]

The concept is relatively unknown in the UK, but its success in other countries especially in the USA and Canada has stimulated UK manufacturers and builders to initiate its arrival. As with any new product on the market, proof testing is required to ensure compliance with industry standards. Other issues may also have to be addressed concerning building regulations and government/environmental compliance before SIPs are approved as a recognised form of building construction. This may prove challenging in an industry that is inauspicious to change.

A research programme being carried out at Napier University has aimed to address many of the engineering concerns on the SIPs with regard to strength, stiffness and structural performance for use as load-bearing wall panels, columns, roofing and flooring systems and also in relation to connection mechanisms between the elements of the SIPs systems.

2. WHAT ARE SIPS?

SIPs are engineered composite load-carrying panel products consisting of a rigid insulating foam core sandwiched between two structural facings. The materials used to produce these building components can vary greatly in both the structural sheathing and the inner insulation core. After assessment of the systems being produced in the UK and imported from other countries, it is evident that they generally adopt the same construction materials. Materials commonly used for the panels are orientated strand boards (OSB) grade 3, or plywood combined with a variety of plastic foams including expanded polystyrene (EPS), extruded polystyrene, urethane and other similar insulation cores. Examples of SIPs are shown in Fig. 1.

There are two main fabrication techniques: (*a*) an industrial adhesive is applied to a pre-cut foam core and then the core is cold pressed between two pieces of facing (panel boards) until the adhesive is cured; and (*b*) the foam is poured into pre-spaced facings and the foam cures to bond to the facings.

Fig. 1. Examples of SIPs (photographs courtesy of SIPA)

for estimating initial strengths. Full correlated tests on the products behaviour are necessary to ensure that assumptions on material behaviour are correct or adjusted. Currently, a European technical approval guideline (ETAG) for product certification for 'prefabricated wood-based load-bearing stressed skin panels' is being drafted but no formal acceptance of this is as yet released.[6]

This paper aims to evaluate the performance of SIPs under combined bending and axial compression and the effects of medium-term loading on panel integrity for use as load-bearing walls and columns.

Either method produces a single solid building element that provides both structural and insulation qualities. These panels are produced in varying sizes and thicknesses depending on application and thermal/structural requirements.

Before SIP panels can be fully recognised in the UK, they require approval from numerous building regulation and government legislation bodies to ensure their suitability to UK construction. One area of importance is their behaviour in fire. When considering SIPs construction in residential dwellings the internal linings of the structure will require a class 0 (non-combustible) or class 1 (semi-combustible) lining, depending on the size and occupancy of the building relative to the required fire protection. This can be achieved by providing one layer of 12·5 mm gypsum plasterboard to obtain class 1, and two layers to obtain a class 0 fire rating.

The manufacturing process has a major influence on the panel's strength and stiffness, and high-quality bonding throughout is essential. Similarly the method of erection and connection has a large influence on the finished strength of the components. The strength and design flexibility of SIPs may be of benefit in the UK because larger and complex buildings can easily be constructed without increasing the weight of materials required to achieve this. This could result in lower cost, construction time and foundation requirements.

Although SIPs have been used extensively as an alternative structural system to conventional framing for residential and light commercial buildings, to date little independent data are available on their structural performance and behaviour. There are also no current SIPs design standards. The American Plywood Association supplement No. 4[4] is the only standard dealing with wood-based sandwich panels and provides some limited design information on the uniform transverse or the combined loading cases. Current timber codes are not directly applicable for the design of SIP products and require correlation with product tests. A draft European code prEN 14509 CEN/TC 128: 'Self supporting double skin metal faced insulated sandwich panels'[5] is considered partly appropriate for the design of SIPs. As each product is unique to the manufacturer, and is dependent on the composite action of the component parts and manufacturing techniques, behaviour using linear elastic theory is considered to be appropriate only

3. EXPERIMENTAL PROGRAMME

Panel specimens used in this study were of type 'SIPs Eco Panels' manufactured, using method (*a*) above, and supplied by Structural Insulated Panels Scotland Ltd, which utilises OSB grade 3 facings and a core of polystyrene insulation.

Tests were carried out as defined below using a number of universal testing machines at a constant rate of 0·045 kN/s. The applied load and the resulting deformation were monitored and recorded at regular intervals by an automated data-logging system up to failure loads, where possible. In each test an appropriate pre-load was applied and the resulting deformation was taken as the datum for the subsequent readings.

In the first series of tests, panels of 600 mm wide by 600, 1200 and 1800 mm long and also panels of 400 mm wide by 2400 and 3000 mm long, all with OSB facings 11 mm thick and insulating core of 95 mm (overall thickness of 117 mm) were subjected to uniform axial compression. In order to examine the effects of stiffeners/studs (often used as connection media between the panels) on the strength and structural performance of the panels, timber sections of 47 × 95 mm, grade C16, were slotted along the edges of the specimens between the OSB faces and connected by 2·65 mm diameter screws, 35 mm long at approximately 250 mm centres. A minimum of three replicates of each configuration was tested; details are shown in Table 1 and illustrated in Fig. 2.

In the second series of tests, panels of 400 mm wide by 2400 mm long with OSB facings 11 mm thick and insulating core of 95 mm (overall thickness of 117 mm) were subjected to the following combined bending and axial compression

(*a*) panels with constant axial load = 0 kN and with increasing four-point lateral bending to failure
(*b*) panels with constant axial load = 8 kN and with increasing four-point lateral bending to failure
(*c*) panels with constant axial load = 16 kN and with increasing four-point lateral bending to failure

Panel height: mm	Specimen details	Mean ultimate load: kN/m	Mean deflection: mm	Typical failure modes
600	Without any stiffeners	227·3	6·5	End bearing
	With header and footer	230·4	4·2	End bearing
	With header, footer and studs	244·5	4·2	End bearing
1200	Without any stiffeners	189·3	5·5	Buckling
	With header and footer	211·8	4·8	End bearing
	With header, footer and studs	231·7	7·0	End bearing
1800	Without any stiffeners	177·9	8·0	Buckling
	With header and footer	202·3	8·4	End bearing
	With header, footer and studs	204·9	9·5	End bearing
2400	With header and footer	128·6	10·2	Buckling with some end bearing
3000	With header and footer	68·7	13·2	Buckling

Table 1. Compression test details and results

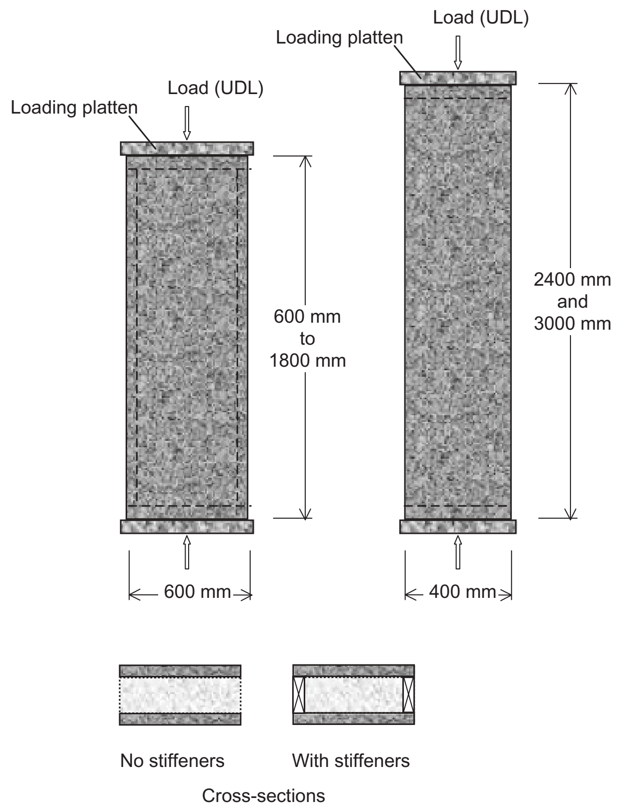

Fig. 2. Specimen(s) and test details

(*d*) panels with constant axial load = 24 kN and with increasing four-point lateral bending to failure.

These specimens were constructed with timber sections of 47 × 95 mm slotted along the edges at extreme ends only (as header and footer) between the OSB faces and connected by 2·65 mm diameter screws, 35 mm long at approximately 100 mm centres. Minimum of three replicates of each configuration was again tested, details are illustrated in Fig. 3.

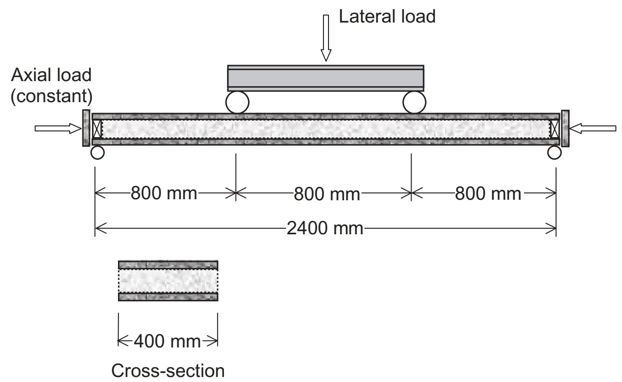

Fig. 3. Combined bending and direct compression test details

4. RESULTS

The results from the first series of tests are summarised in Table 1 and are presented as load per metre run. A comparison between the effects of provision of stiffeners/header and footer and the panel height up to 1800 mm high on the ultimate compression capacity of the SIP panels are shown in Fig. 4. In this figure each data point represents a mean ultimate strength value. Overall, the trendlines illustrate an improvement in strength owing to addition of stiffeners along the edges of the panels and a decrease in strength owing to an increase in the effective panel height.

Typical failure modes are given in Table 1 and are shown in Fig. 5. In order to examine the possible effects of discontinuity

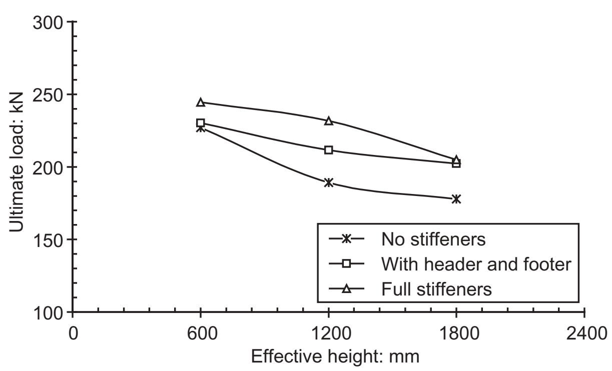

Fig. 4: Effect of panel height and provision of studs/stiffeners/ header and footer

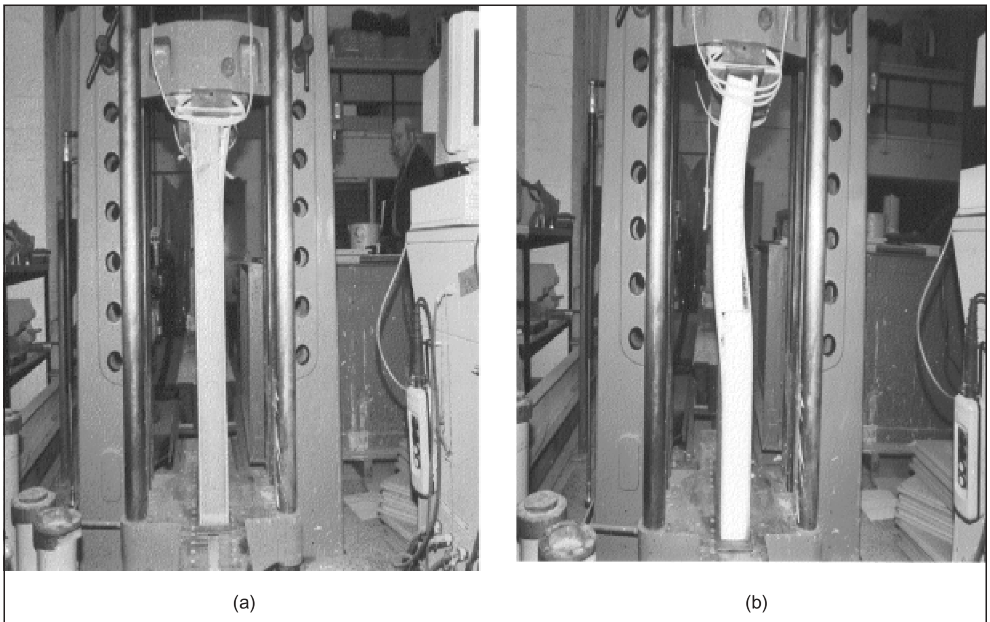

Fig. 5. Failure modes are shown (a) specimen with header, footer and studs; (b) specimen with header and footer

characteristic strength values were taken from BS EN 12369-1: 2001.[9]

The load–deformation behaviour of panels subjected to combined bending and axial compression is shown in Fig. 7 and detailed in Table 2. This figure illustrates the effects of increase in lateral bending moment for panels subjected to sustained uniform axial compression of 0, 8, 16 and 24 kN.

The chart shown in Fig. 8 provides an estimate of the combined bending and axial compression capacity of SIPs 2·4 m high and 117 mm overall thickness using 11 mm thick OSB side boards. In this figure a comparison is also made of the test performance of the panels with their load capacities based on EC5 (prEN 1995-1-1 : 2003E).[7] The calculation of the load capacities to EC5, with the assumption of a full composite action and shear transfer between the elements of SIP panels, particularly under loading combinations where bending is dominant, leads to an overestimation of their strength capacities, as illustrated in Fig. 8. It is therefore important that, in the absence of a detailed analysis (e.g. a non-linear finite element method), correlated/adjusted test results are used for determination of the design properties.

in the core material, a number of panel specimens were tested with an unglued joint between the polystyrene core blocks at the mid-height of the panel. In these panels failure was initiated predominately at that joint where up to 20% reduction in strength was noted; see Fig. 5(b). This highlighted the importance of continuity of the core material in providing an adequate composite action over the full loading range, in particular at high stress levels. In all tests specimen ends were only held in position by the loading plattens.

In Fig. 6 the ultimate load capacity and the characteristic strength values of the tested SIP panels subjected to direct compression are compared with their corresponding load capacities based on EC5 (prEN 1995-1-1: 2003E).[7] The test characteristic strength values were determined in accordance with DD ENV 1995-1-1: 1994.[8] For calculation of the load capacities to EC5, the panels were considered as two 1 m wide parallel OSB boards of 11 mm thick each spaced by a polystyrene core of 95 mm, as illustrated in Fig. 6. The stiffness and strength properties of the polystyrene core were ignored and the OSB boards were considered to act in unison; their

4.1. Tensile and in-plane shear

Since the structural integrity of SIPs depends entirely upon the glue bonds between the skins and the core, a series of supplementary tests were carried out to determine the effects of tensile loading (perpendicular to the plane of the panels) and also skewed/eccentric loading (in-plane shear) on the deformational characteristics and bond strength between the elements of SIPs acting as load-bearing wall units.

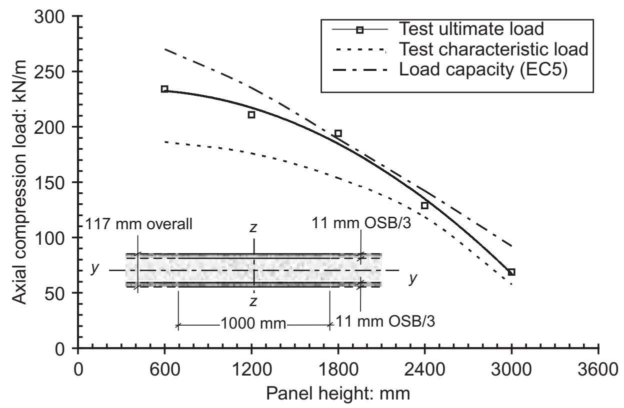

Fig. 6. Chart for estimation of direct compression capacity

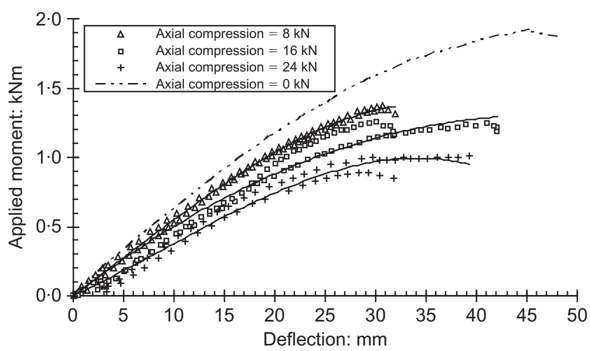

Fig. 7. SIPs panels subjected to combined bending and axial compression

Axial compression load (constant and uniform): kN	Ultimate lateral bending moment: (kNm)/m	Mid-span deflection: mm	Failure mode
0	4·80	45·8	Bending
8	3·50	31·6	Bending
16	3·10	40·5	Bending
24	2·45	32·2	Bending

Table 2. Combined bending and axial compression test results

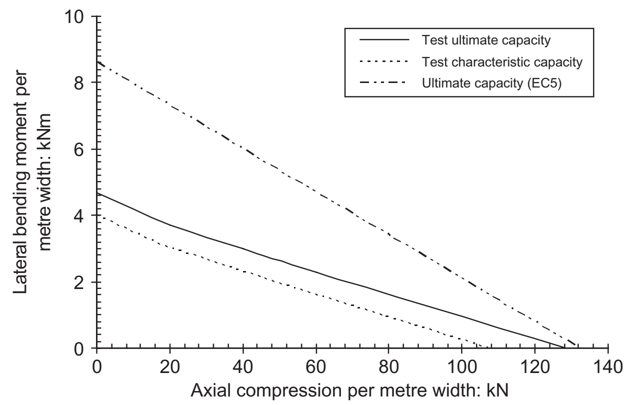

Fig. 8. Comparison of combined bending and axial compression capacity of SIP wall panels of 2·4 m high with 117 mm overall thickness and 11 mm thick OSB facings

Specimens of 200 mm × 200 mm were cut from randomly selected SIP panels and tested, as illustrated in Fig. 9. Timber sections acting as stiffeners were again connected to a predetermined number of specimens by 2·65 mm diameter screws, 35 mm long, at approximately 100 mm centres. Several samples of each type were tested and details and results are summarised in Table 3.

The application of uniformly distributed tensile load led to a yielding effect in the polystyrene infill at loads above 3 kN. No de-bonding (i.e. no damage to the glue lines between polystyrene and the OSB boards) occurred. Typical tensile load–deformation behaviour is shown in Fig. 10. The average moisture content of the OSB panels used was 7·2% with coefficient of variance of 0·2.

In all skewed/shear loading tests failure occurred in the polystyrene owing to excessive deformation at high loads, but the glue lines remained intact. The provision of stiffeners along the edges had a positive effect on increasing the stiffness and the ultimate load capacity of the panels. Typical load–deformation behaviours are shown in Fig. 11.

4.2. Medium-term loading

To determine the effects of medium-term loading on the deformational characteristics (creep effects) of SIPs under axial compression and to examine the possibility of de-bonding/bulging within the sandwich panels tests were carried out as defined below using a universal testing machine. The applied sustained loads and the resulting deformations (with an accuracy of ± 0·1%) were monitored and recorded against duration of loading at regular intervals. A randomly selected SIP panel, from a batch of 20 panels, 400 mm wide by 1000 mm long with OSB sheets of 11 mm thickness, (overall thickness of 117 mm) was subjected to the following loading regimes.

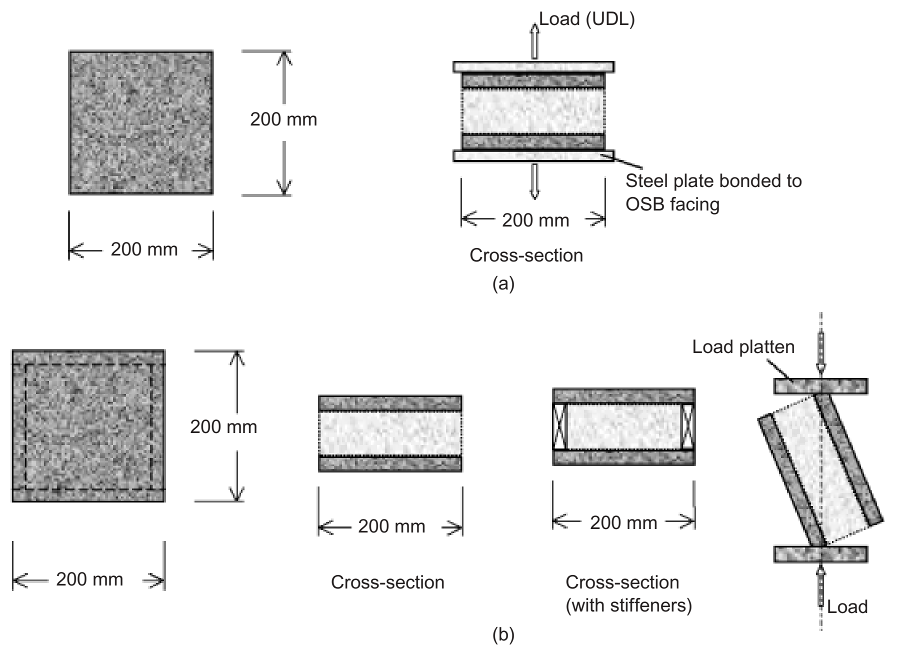

Fig. 9. Tension and shear tests: specimens and details. (a) Tension perpendicular to the plane of the panel; (b) shear/skewed loading

(*a*) Axial compression load of 4 kN applied and sustained for 168 h, released and then allowed to recover for 72 h. This process was repeated four times.
(*b*) Axial compression load of 8 kN applied and sustained for 168 h, released and then allowed to recover for 72 h. This process was repeated two times.
(*c*) Axial compression load of 4 kN applied and sustained for 168 h and then released. This was followed by an application of 8 kN load and sustained for a further 168 h and then released. This process was continued by application of 12 kN, 16 kN and

Loading type	Specimen details	Ultimate load: kN	Deflection: mm	Comment/failure mode
Tension	Without any stiffeners	3·86	20·00	Yielding of polystyrene
Shear	Without any stiffeners	2·57	25·54	Tearing of foam Glue lines remained intact
Shear	With header and footer	3·18	17·91	Tearing of foam with buckling of the OSB panels. Glue lines remained intact
Shear	With header, footer and studs	5·96	5·24	Buckling of the OSB panels. Glue lines remained intact

Table 3. Tension and shear test details and results

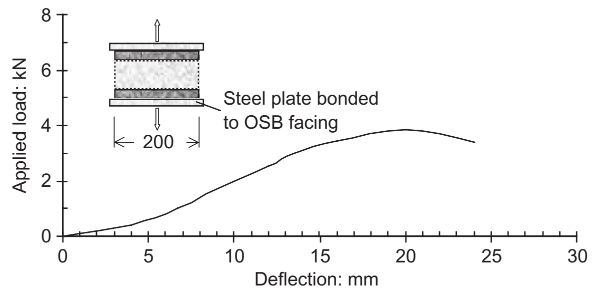

Fig. 10. Tension perpendicular to the plane of the panel

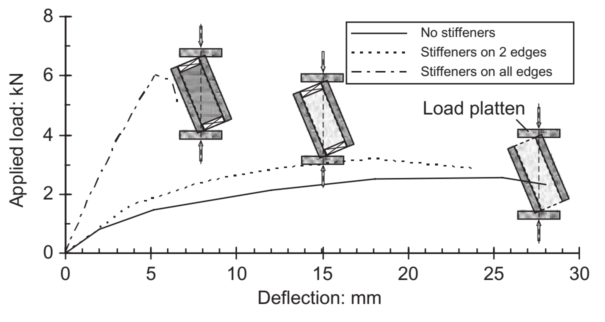

Fig. 11. Load–deformation behaviours of panels under in-plane shear/skewed loading

20 kN, sustaining the loads for a further 168 h each time before releasing.

Figure 12 details the creep effects of the panel under the final loading regime ((c) above). The nominal fluctuations in creep values under different loading levels particularly during the 8 and 20 kN loading shown in this figure are believed to have been caused by fluctuation in temperature and humidity at this particular testing laboratory.

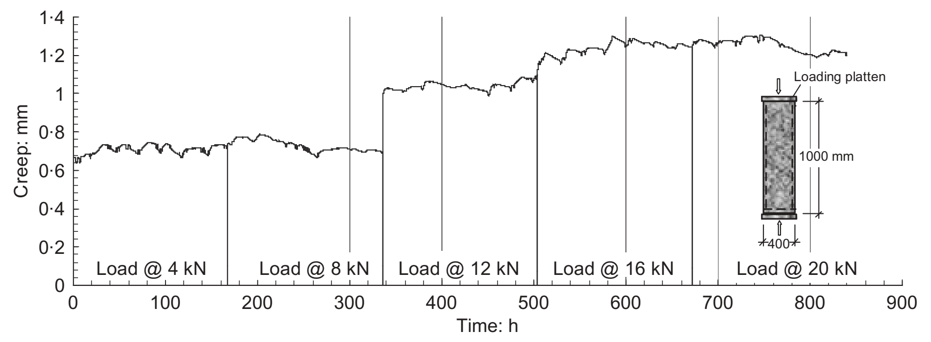

Fig. 12. Creep characteristics of the panel subject to axial compression load of 4, 8, 12, 16 and 20 kN over 840 h

Throughout the testing programme the integrity of the panel was closely monitored and it was found that the creep effects under a series of normal to high loads (much higher than the normal intended loading) are negligible and the panel recovered after load removal. Also there was no de-bonding (i.e. damage to glue lines between polystyrene and OSB boards) or bulging of the boards.

5. CONCLUSIONS

A series of experimental tests was conducted to determine the structural behaviour and performance of 117 mm thick SIPs with 11 mm OSB side boards (facings) under combined bending and direct compression and also under a series of sustained medium-term loadings. The results illustrated that the SIPs behaved as an effective composite material and that the polystyrene membranes, which were glued on to the OSB side boards in a sandwich construction, were effective in transferring shear forces and provided the stiffness and strength necessary to sustain the applied loads that they were subjected to.

The creep effects under a series of normal to high loads were negligible and the panel recovered after load removal. Also there was no de-bonding (i.e. damage to glue lines between polystyrene and OSB boards) or bulging of the boards.

Design calculations using linear elastic theory and assuming a full composite action and shear transfer between the elements of SIPs overestimate their strength properties. Based on the test results, design charts were produced for estimation of compressive strength with respect to wall height and also for combined bending and direct compression for 2·4 m high walls.

6. ACKNOWLEDGEMENT

The SIP panels used in this study were of type SIPs Eco Panels manufactured and supplied by Structural Insulated Panels Scotland Ltd.

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