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EXPERIMENTAL AND NUMERICAL STUDY OF SELF-SUPPORTING DOUBLE SKIN METAL FACED MINERAL WOOL PANELS

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Abstract

The present study presents the results of experimental and numerical investigation on the behavior of self-supporting, double skin metal faced insulating sandwich panels under compression, tension and shear. More specifically, appropriate number of specimens is subjected to compression, tension and shear loads at the "Laboratory for Strength of Materials and Structures" (LSMS) Department of Civil Engineering of Aristotle University of Thessaloniki (AUTh) in compliance with the terms of BS EN 14509:2013 standard. In addition, numerical models simulating the compression and tension tests are developed and the mechanical properties of the materials composing the insulating panels are calibrated. As a result, stress – strain laws for both compression and tension behaviours of the product are determined. Moreover, numerical model simulating the shear test is built by implementing the previously formed material laws with analytical stress-strain relations for compression and tension. Finally, the response of the numerical model under shear test is compared to the experimental one and consequently the accuracy of determined material laws is assessed.

Keywords: Composite, Self-supporting double skin metal faced MW panels, Experimental tests, Numerical simulation, Material law, Validation

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1 INTRODUCTION

Sandwich panels are modern pre-fabricated construction components used as cladding elements for different types of buildings. Sandwich panels consist of an insulating core material covered by two faces which are typically made of thin metal sheets. The materials can be configured in many possible combinations. For instance, for the cover layers thin metal faces, timber-based plates or glass fiber reinforced plastics can be used. The insulating core layer in most cases is made of structured foams like polyurethane (PUR), polystyrene (PS) or of mineral wool (MW). Sandwich panels are used as light-weight roofs and wall claddings in industrial and commercial buildings. Usually, the structures are loaded by permanent loads, like self-weight, snow and wind loads. However, additional loads like temperature differences between external and internal metal faces or creep of the core must be taken into account for statical calculations of sandwich panels structures. The high load bearing capacity of sandwich panels is the result of a rigid connection between the core material and the cover layers. The bending moment is distributed to the two faces (e.g., for panels with flat faces in the form of axial forces) and the shear loads are borne by the core layer. In standard applications, the panels are mounted and fixed on a load-bearing substructure of beams or purlins. Sandwich panels can reduce the problem of lateral torsional buckling of this substructure of beams or purlins by providing stabilization either by shear stiffness or by torsional restraint. [1,2].

For the structural behavior of sandwich panels, it is necessary to consider all of the potential failure modes: tensile failure of the faces (due to tensile stress), local buckling (wrinkling) of the faces (due to compressive stress), and shear failure of the core or the adhesion between the core and face. In sandwich panels with thin strongly profiled faces, two additional failure modes are introduced: shear strength of the webs in a profiled face and the support reaction capacity of a profiled face [3,4].

The European standard BS EN 14509:2013 [5], or European Recommendations published by the European Convention for Constructional Steelwork (ECCS) and the International Building Council (CIB) do not provide detailed design methods for sandwiches with strongly profiled faces. Determination of the load bearing capacity required for the design of sandwich panels is to a large degree based on test results [6].

Pokharel and Mahendran [7,8] implemented Finite Element Analysis Method (FEM) in order to investigate the structural behavior of flat and lightly profiled sandwich panels. The investigation of structural behavior and failure analysis of composite structures through the use of finite element analyses have also been presented in [9] and [10].

The objective of this paper is to investigate experimentally and numerically lightly profiled insulating panels but most importantly develop a methodology for calibrating and determining materials' law that would enable an accurate simulation and estimation of the structural behavior of theses composite panels.

2 EXAMINED SPECIMENS AND EXPERIMENTAL PROCEDURE

All the experimental tests are executed at the "Laboratory of Strength of Materials and Structures" of Aristotle University of Thessaloniki (AUTh) in compliance with EN 14509:2013 standard. The insulating panel under examination is in fact a sandwich section that consists of two metal faces of thickness 0.45mm, called "lamellas" and a core material between them which is Mineral Wool (MW). This panel is denominated as SP. The profile of the studied section is depicted in Figure 1. Three (3) panel thickness values, d_C, are considered in the present research: 50mm, 80mm and 100mm.

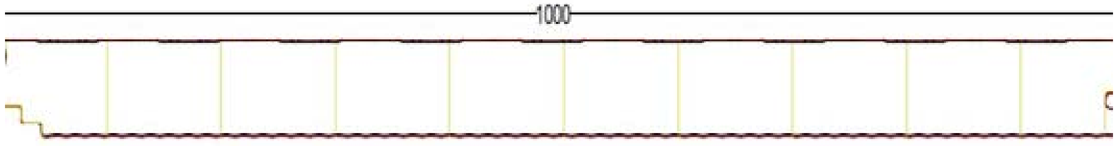


Figure 1: Profile of the examined self-supporting, double skin metal faced insulating SP

The compressive strength (f_{Cc}) and elasticity modulus (E_{Cc}) of the examined panel is measured by testing six (6) specimens of each thickness in compliance with the procedure described in paragraph A.2 of EN 14509: 2013 standard. The specimens, as recommended in EN 826 standard (compressive behavior of thermal insulation products) should have a square cross-section of dimensions between 50 and 300mm. In the present study prisms of 100x100mm are used. Also, six (6) specimens of the same dimensions are tested for evaluating the tensile behaviour of the panels and measuring their tensile strength (f_{Ct}) and elasticity modulus (E_{Ct}) in accordance with the paragraph A.1 of EN 14509: 2013. Finally, the terms of paragraph A.3 of the aforementioned paragraph are implemented for testing three (3) SP specimens of length of 1000mm and width of 100mm under “shear test with two-point loads” and estimating the ultimate shear strength (f_{Cv}) and shear modulus (G_C). The properties of the specimens and details of the procedures are listed below in Table 1.

Examined Characteristics	**Test Method/Procedure**	**Specimens' dimensions**			**min number of tested specimens**
		thickness d_C (mm)	length (mm)	width (mm)	
Compressive strength and modulus	EN 14509:2013 A.2	50, 80, 100	100	100	6
Tensile strength and modulus	EN 14509:2013 A.1	50, 80, 100	100	100	6
Shear strength and modulus	EN 14509:2013 A.3	50, 80, 100	1000	100	3

Table 1: Properties of tested specimens and experimental procedures

3 EXPERIMENTAL RESULTS

In this section the results of the experimental tests are presented. Figures 2, 4 and 6 illustrate the damage pattern of compression, tension and shear, respectively. In Figure 3 the compression stress – strain curve is depicted and the average values of strength and elasticity modulus are presented. The same applies to Figure 5, which refers to tensile behavior, while Figure 7 illustrates the maximum applied load – deflection curve of the examined specimens and shear strength and modulus average rates are displayed.

Observing Figure 3, one can see that the thickness of insulating panels has little effect on their performance under compression test as the characteristic values of compressive strength and elasticity modulus have little difference for the three examined width rates. Also, it is not clear if this little impact is negative or positive since the compressive strength of SP 80mm thick is smaller than that of 50mm, but greater than that of 100mm.

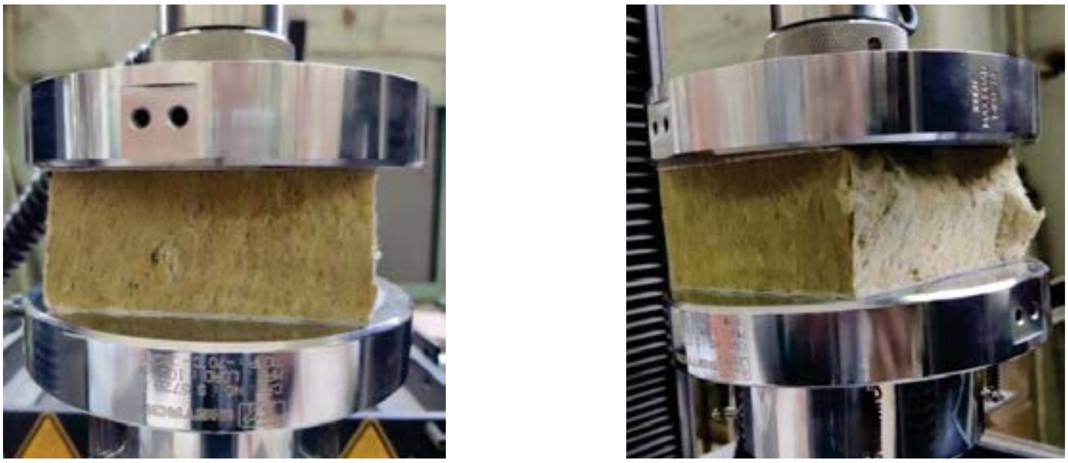
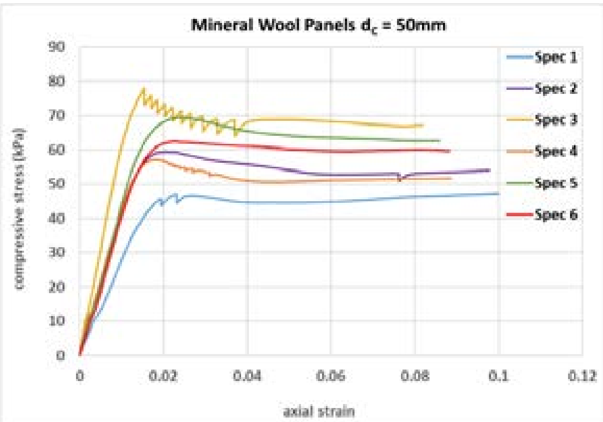
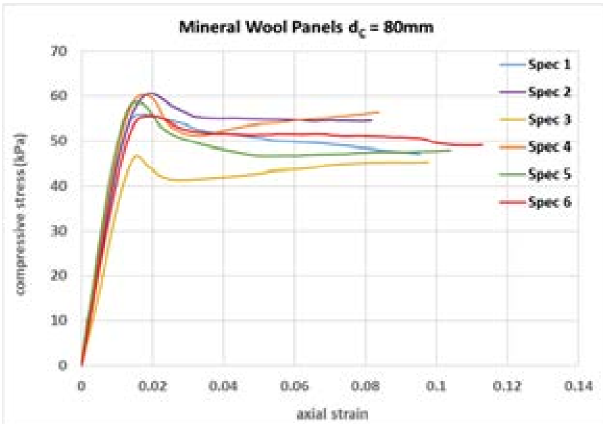
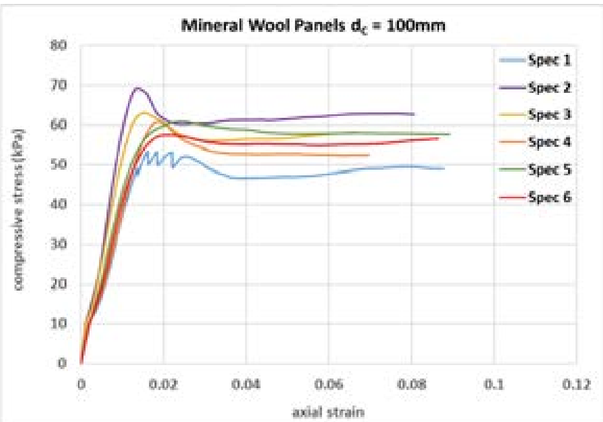


Figure 2: Indicative photographs of SP specimen before (left) and after (right) compression test







Thickness d_C (mm)	Compressive Strength f_{Cc} (kPa)	Compressive Elasticity Modulus E_{Cc} (MPa)
50	62.29 (±9.61)	4.24 (±0.91)
80	56.35 (±4.68)	4.50 (±0.58)
100	60.81 (±4.86)	4.53 (±0.84)
average:	**59.82**	**4.42**

Figure 3: Compressive strength-strain diagrams of six (6) specimens of thickness d_C=50mm (top-left), d_C=80mm (top-right), d_C=100mm (bottom-left) and table of average compressive strength and elasticity modulus values (bottom-right)

The experimental results revealed that the performance of SP under tension test (Figure 5) is deteriorate to that under compression (Figure 3) as the average tensile strength amounts approximately to 10kPa while the average compressive strength is about 60kPa, i.e., 6 times greater. Another interesting finding is that the tensile elasticity modulus of the examined insulating panels is roughly 1/8 of the compressive modulus, fact that is depicted in the corresponding curves' slope angle.

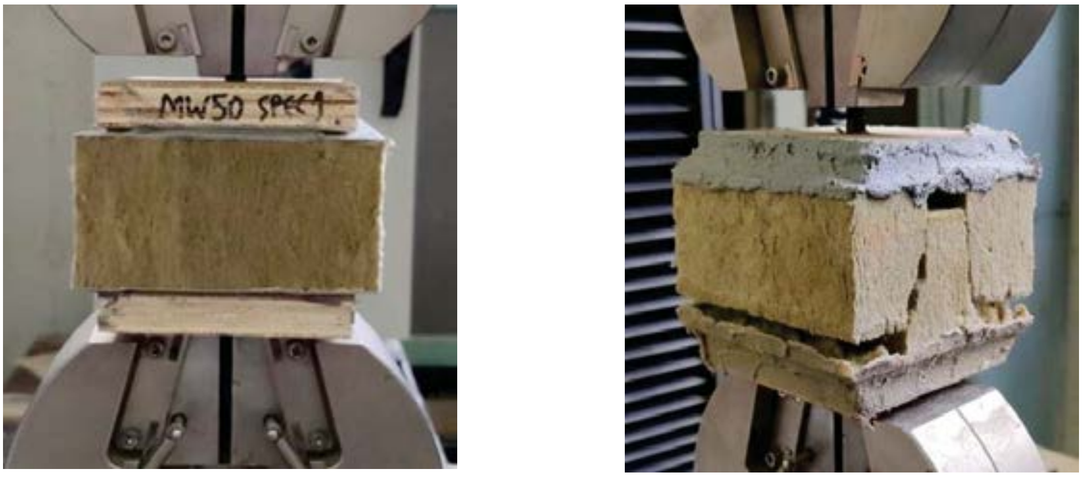
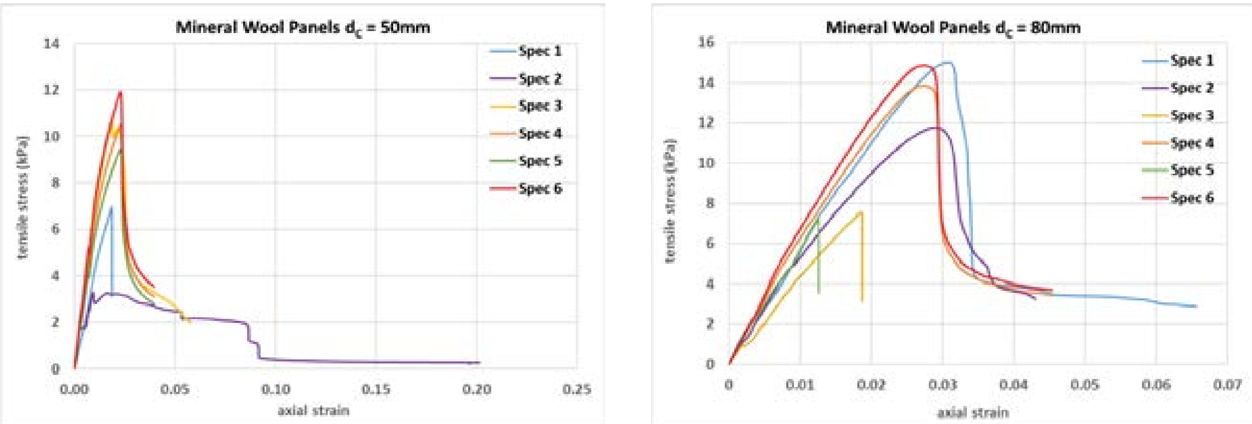
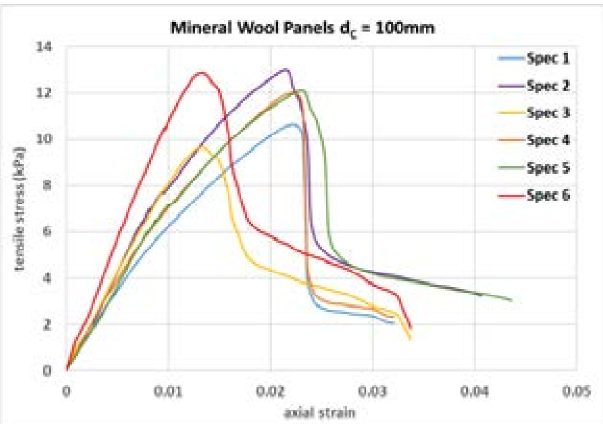


Figure 4: Indicative photographs of SP specimen before (left) and after (right) tension test





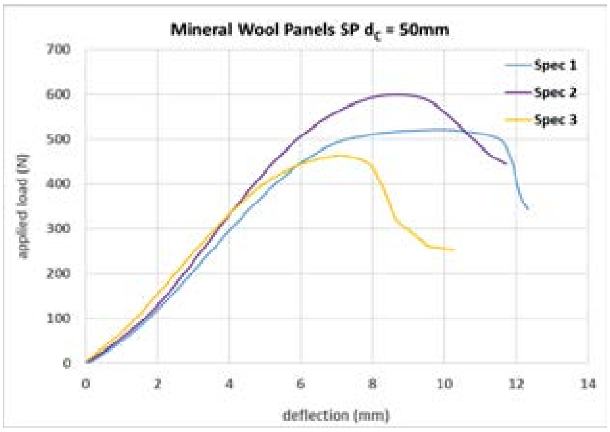
Thickness d_C (mm)	Tensile Strength f_{Ct} (kPa)	Tensile Elasticity Modulus E_{Ct} (MPa)
50	7.85 (±3.02)	0.49 (±0.12)
80	11.10 (±3.18)	0.52 (±0.06)
100	11.10 (±1.40)	0.70 (±0.09)
average:	**10.02**	**0.57**

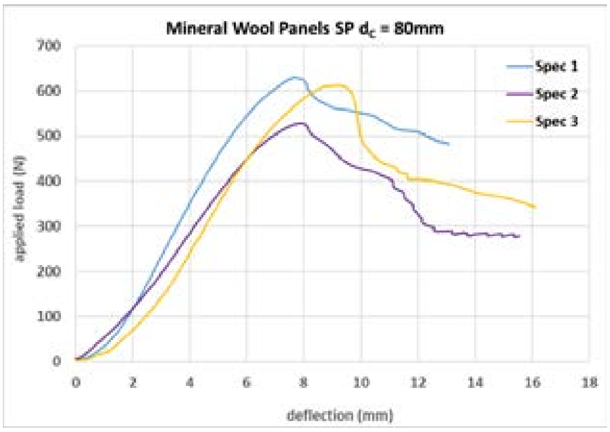
Figure 5: Tensile strength-strain diagrams of six (6) specimens of thickness d_C=50mm (top-left), d_C=80mm (top-right), d_C=100mm (bottom-left) and table of average tensile strength and elasticity modulus values (bottom-right)

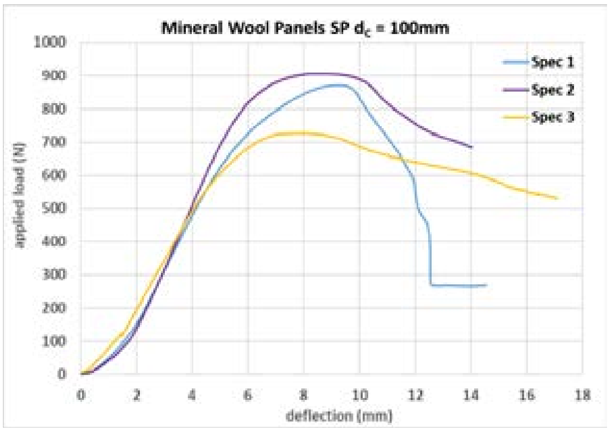
The performance of SP under shear test is very sound as shown in Figure 7. The shear strength average value amounts to 3255kPa, 54 times greater that the compressive strength and

325 than the tensile strength. This happens because of the high contribution of lamellas (steel panels) to the tensile behavior of SP product (lamella material's properties listed in section 4).

Figure 6: Indicative photographs of SP specimen before (left) and after (right) shear test







SP				
Thickness d_C (mm)	Shear Strength f_{cv} (kPa)		Shear Elasticity Modulus G_C (MPa)	
50	2643	(±278)	2.03	(±0.24)
80	2947	(±223)	1.46	(±0.16)
100	4175	(±388)	1.64	(±0.09)
	average:	3255	average:	1.71

Figure 7: Applied load-deflection diagrams of three (3) specimens of thickness d_C=50mm (top-left), d_C=80mm (top-right), d_C=100mm (bottom-left) and table of average shear strength and elasticity modulus values (bottom-right)

4 NUMERICAL MODELING

Three-dimensional finite element numerical models have been developed adopting a macro modeling approach with homogenized non-linear material laws. It should be underlined that the steel face (lamella) of the insulating panel has been at first tested separately at the "Laboratory of Strength of Materials and Structures" of Aristotle University of Thessaloniki and the material's mechanical properties have been calibrated in a Finite Element Analysis (FEA) software. The results of this calibration are presented in Figure 9 and the material's properties are listed in Table 2. After that, the compression and tension tests have been simulated and both the compressive and tensile characteristics of the core material (MW) have been calibrated in order to achieve the actual behaviour of the panels, observed at the laboratory. For indicative reasons and in order to avoid a lengthy paper, only the calibration of panels of width d_C=50mm under compression is demonstrated below. The same procedure is followed for each thickness value for both compression and tension tests. Finally, a material law that satisfies all cases is determined and its parameters are presented in Table 3 and these parameters become the input for FEM simulation of shear tests.

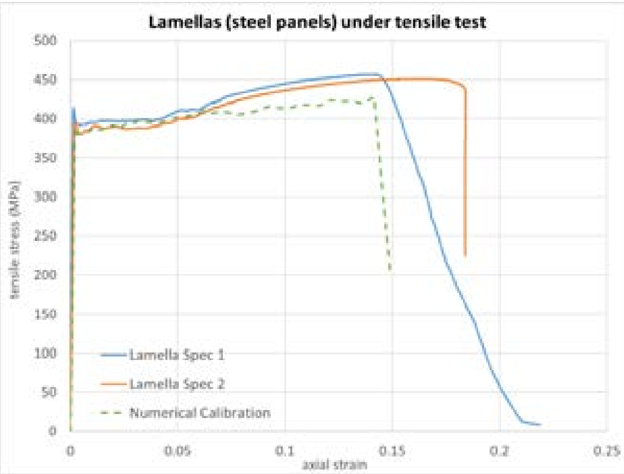


Figure 9: Calibration of tensile behavior of lamellas (steel panels of thickness of 0.45mm)

tension

stress (MPa)	plastic strain
380	0
500	0.1581
50	0.1881

Table 2: The calibrated material law for lamellas of SP

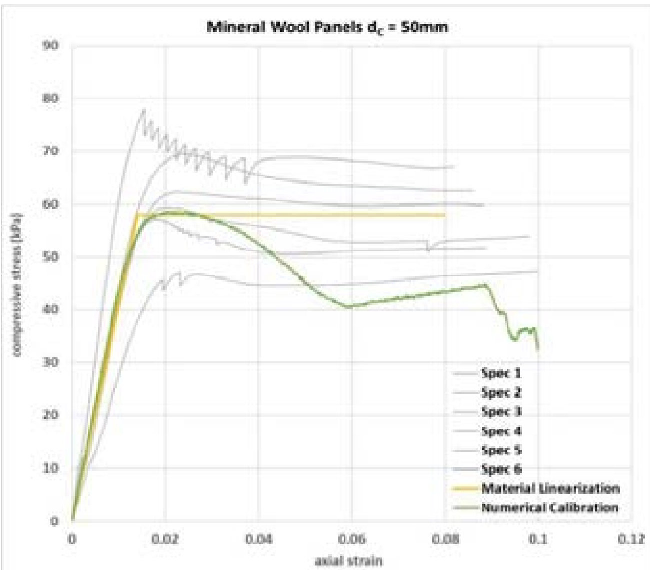


Figure 10: Calibration of compression behavior of the insulating panels of thickness d_C=50mm

compression		tension	
stress (MPa)	plastic strain	stress (MPa)	plastic strain
0.035	0	0.0075	0
0.0175	0.05176	0.0020	0.03324

Table 3: The calibrated material law for Secret Fix Panels (SP)

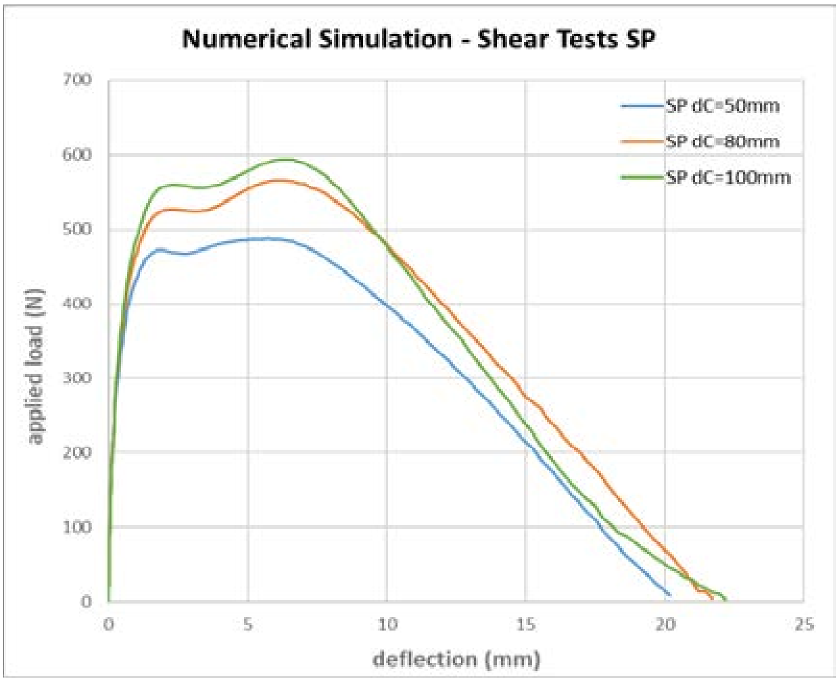


Figure 11: Applied load-deflection curves for numerical FEM simulation of SP

Comparing Figures 7 and 11, one can observe a very good correlation as the results of numerical simulation approach adequately the experimental ones. More specifically, the maximum load values achieved in FEA simulation for SP of thickness of 50mm and 80mm are very close to the real ones (Figure 7), while the maximum load of 100mm thick SP is a little lower than the experimental (600N against 750N – Figure 7). Moreover, the load-deflection curves achieved in numerical simulation have greater slops angle, which possibly can be attributed to elasticity modulus scarce assess. This could be investigated further. Finally, the damage pattern under shear test in FEA software is illustrated below (Figure 12), which is very realistic, comparing to the one observed in laboratory (Figure 6)

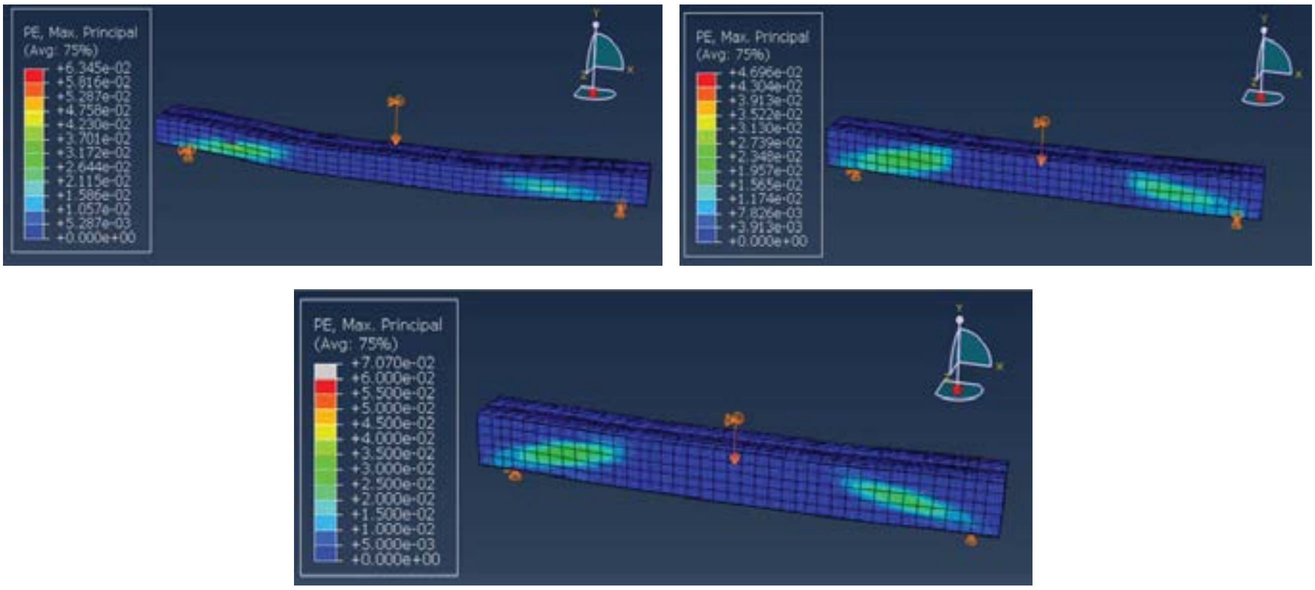


Figure 12: Illustrated damage pattern in FEM simulation models for SP of width d_C=50mm (top-left), d_C=80mm (top-right) and d_C=100mm (bottom)

5 CONCLUSIONS

The performance of insulating MW Panels SP behavior under compression, tension and shear loadings is discussed here, mainly focusing on the FEM simulation capacity to accurately approach the experimental results. The main conclusions are enlisted below:

- The compressive strength of SP is about 6 times greater than the tensile strength. The shear strength of SP is about 54 times greater than the compressive strength and 325 than the tensile, which is mainly attributed to the high contribution of lamellas (steel panels) to shear behavior.
- The thickness of SP has little impact on its performance under compression and tension tests.
- The developed 3-D FEM models, after experimental tests and numerical validation of the materials, can satisfactorily capture the observed shear behavior of the insulating panels, especially in terms of the maximum load bearing capacity, but also in the damage pattern.

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