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MULTI-LAYER STRAND-BASED WOOD MATERIALS IN CONSTRUCTION: MECHANICAL PROPERTIES AND TEST METHODS

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ABSTRACT: Unplanned and planned deforestation as well as forest management regimes and forest degradation influence the current and more importantly the future supply of wood. Given the high demand for wood products, it is crucial to optimize the utilization of low-quality, non-sawable wood and wood sidestreams, which are currently predominantly combusted. Strand-based engineered wood products provide a viable solution but are typically used in single-layer configurations. There is limited research on their multi-layer performance, particularly for use as structural material in multi-story buildings, highlighting the need for further investigation. The present study examines the mechanical properties of multi-layer strand-based wood materials, specifically six-layer Oriented Strand Board (OSB) and three-layer Unidirectional Strand Board (USB). Comprehensive experiments evaluate the bending, shear, and compression properties, as well as the elastic constants and strength properties, of both materials, clearly showing the suitability of these materials to be used in construction. These findings serve as a basis for modeling and design and fill a critical gap in literature by providing detailed data on multi-layer strand-based wood materials. Additionally, insights into the most suitable test methods for these materials are given, guiding future applications and developments in the construction industry.

KEYWORDS: Wood construction, Strand based engineered, Wood products, Oriented strand board, Bending test, Shear test

1 – INTRODUCTION

Timber construction has gained significant attention, driven by factors such as population growth, rising demand for sustainable materials, its ability to store carbon, and its promising mechanical properties [1]. However, limitations of solid wood, such as low bending strength, poor biological durability and the declining availability of timber resources, have highlighted the need to explore alternative materials [2]. Engineered Wood Products (EWPs), made of strands or veneers and bonded with adhesives, were developed, demonstrating compelling properties compared to solid woods of the same wood species [3]. The strand-based EWPs, originated in the early 1970s as waferboards, and are seen as the forerunners of modern strand boards. The initial waferboards evolved into Oriented Strand Boards (OSB), now commonly used in flooring and walls. They show higher resource efficiency when compared to veneer-based counterparts such as Plywood and lumber-based products, e.g. Glued Laminated Timber (GLT) [4]. First only produced in single layer configurations, the strand-based EWPs further evolved to multi-layer products, such as the Swiss Krono Magnumboard® (MB), making them suitable for use in mass timber applications [5].

Within the search for higher resource efficiency within the timber construction sector, researchers of the BOKU University began their investigations of a product from the strand-based EWPs family with a homogenous vertical density profile, namely "Unidirectional Strand Board (USB)", introduced firstly by Barbuta et al. [6]. The product features a three-layered configuration with the strands of each layer aligned in only one direction. The middle layer is placed perpendicular to the outer

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layers to enhance load-bearing behaviour and therefore creating a suitable material for multi-story construction from round wood raw materials, which would otherwise be combusted.

To efficiently utilize these products in multi-story applications, understanding their mechanical properties is crucial for proper dimensioning [7]. As studied by the authors [8], the absence of standardized test methods for these products creates uncertainty about the most appropriate testing procedures for evaluating their mechanical performance. Therefore, the present study aims to achieve two primary objectives: first, the evaluation of the mechanical properties of multi-layer products, specifically three-layer USB and six-layer OSB, to inform modelling and design of multi-story construction; and second, the identification and introduction of suitable test methods for these materials, addressing the absence of a global standard.

2 – SPECIMEN PRODUCTION

To produce six-layer OSB panels, OSB/4 boards, with a nominal density of 650 kg/m³ and dimensions of 5000 x 1250 x 22 mm, were sourced from Egger, an Austrian producer, and sanded to 20 mm thickness by Hasslacher. The panels were then glued together using melamine-urea-formaldehyde (MUF) to form the six-layer layup with a total thickness of 120 mm (see Fig. 1.A). For the production of USB panels at Dieffenbacher, Eppingen, pine strands supplied by Swiss Krono, Heiligengrabe, were used. These strands were sprayed with 5% polymeric diphenylmethane diisocyanate (pMDI) adhesive, manufactured by Huntsman, using a rotating blender. After forming the mat and orienting all strands unidirectionally lengthwise, the mat was pressed with a hydraulic press at 200°C using a press factor of 14 sec/mm of thickness, resulting in a total pressing time of 350 seconds. The single-layer panels had a nominal density of 650 kg/m³ and final dimensions of 2600 x 1200 x 27 mm after sanding. Using these base panels, the three-layer specimens (thickness of 81 mm with the face layers aligned parallel to strand orientation and the core layer placed perpendicular) were produced at the BOKU University's laboratory in Tulln. The layers were bonded using a polyurethane resin (PUR) adhesive applied with 200 g/m² and pressed at 0.6 MPa for 12 hours to achieve strong interlaminar bonding (see Fig. 1.B).

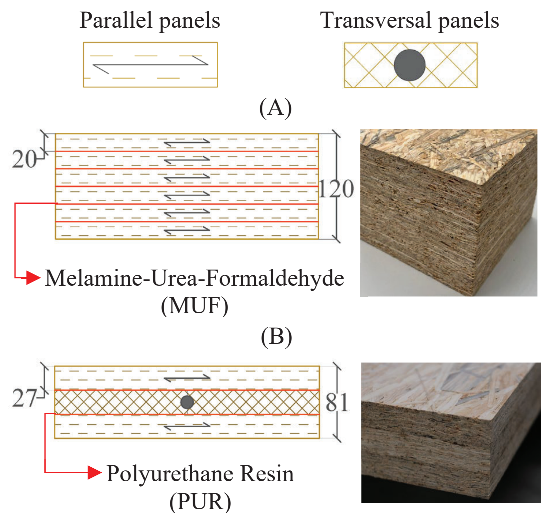

Figure 1. Layup schematization of two under-studied multi-layer materials: (A) six-layered Oriented Strand Board (OSB); (B) three-layered Unidirectional Strand Board (USB)

3 – EXPERIMENTAL SETUP

3.1 SPECIMEN PREPARATION AND TEST STANDARDS

To determine the mechanical properties of each product, a series of mechanical tests was conducted, including four-point bending tests with longer span (bending test) as well as shorter span (shear test), and compression tests on cubic specimens in both major and minor axis of the specimens. The dimensions of each specimen with respect to the mechanical tests are presented in Table 1. Each specimen was cut according to ÖNORM EN 326 [9], ensuring that specimens for different test methods were taken from various locations to minimize bias. To achieve a constant mass, as recommended by ÖNORM EN 323 [10], the specimens were stored in a climate chamber for two weeks under controlled conditions of 20 ± 2°C and 65 ± 5% relative humidity prior to testing. Furthermore, in accordance with ÖNORM EN 325 [11], the density of each specimen was determined.

Given the absence of a specific testing standard for strand-based EWPs, various alternative European standards were referenced for the different tests, allowing a comparison of the results. Bending and compression tests were conducted following European Standards ÖNORM EN 408 [12] and ÖNORM EN 16351 "Timber structures - Cross Laminated Timber (CLT)"[13],

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respectively, for both materials. These standards specify specimen dimensions based on the total panel thickness. For bending tests, the specimen length is set at 18 times the panel thickness (18h), with the span divided into three equal sections of 6h. For the compression tests, cubic specimens were used, with both the length and width equal to the panel thickness. The specimen configurations for both test series are illustrated in Fig. 2A and 2B, with detailed dimensions provided in Table 1. The shear tests on USB specimens were conducted in accordance with the European Assessment Document (EAD-1400015-00-0304) [14], which prescribes a specimen length equal to 10 times its thickness (10h). In this setup, the distance between the load application and the supports is defined as twice the specimen's thickness (2h), whereas the span between the load application points corresponds to six times the thickness (6h) (Fig. 2C). In contrast, the OSB shear tests followed the guidelines of ÖNORM EN 16351 [13] (a standard, mainly used for CLT), with the specimen length 12 times the thickness (12h) and the distance between the loading points three times the thickness (3h) (Fig. 2D).

3.2 DISPLACEMENT MEASUREMENT DEVICES

For both bending and shear tests, Linear Variable Differential Transformers (LVDT) were employed to measure deformations with high precision. Within the bending test setup six 200 mm LVDTs (SM407.200.2) were installed, three at the front and three at the back of the specimen within the bending zone. For the shear test setup four 10 mm LVDTs (SM222.10.1.S) were positioned at the corners to capture shear deformation in areas prone to shear failure.

For the compression tests a Digital Image Correlation (DIC) system was used as a non-contact optical measurement technique to measure horizontal and vertical strain, and displacements in order to subsequently calculate the Poisson's ratios and Modulus of Elasticity (MOE). The DIC consists of two high-resolution digital cameras, each with a 25-megapixel sensor, capturing images at predefined intervals (in this case one second), and therefore documenting the deformation of the specimen. The acquired images were subsequently analysed using VIC-3D software [15].

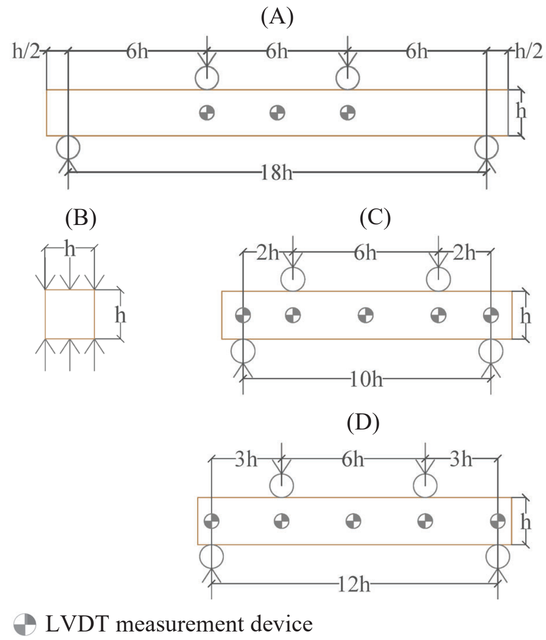

Figure 2. Mechanical test setups: A. bending test (OSB & USB); B. compression test (OSB & USB); C. shear test (USB) and D. shear test (OSB)

3.3 TESTING PROCEDURE

While the bending and shear tests on the USB specimens were performed using a Zwick-Roell 250 kN testing

Table 1. Overview of mechanical properties conducted on Oriented Strand Board (OSB) and Unidirectional Strand Board (USB)

Material	Type of test	Panel direction	Dimensions [mm]	Number of specimens	Standard	Measurement tool
OSB	Bending	Major	2280 x 295 x 120	4	ÖNORM EN 408 [12]	LVDT
	Shear	Major	1560 x 600 x 120	4	ÖNORM EN 16351 [13]	LVDT
	Compression	Major	120 x 120 x 120	8	ÖNORM EN 16351[13]	DIC
		Minor	120 x 120 x 120	8	ÖNORM EN 16351 [13]	DIC
USB	Bending	Major	1540 x 300 x 81	8	ÖNORM EN 408 [12]	LVDT
	Shear	Major	890 x 300 x 81	8	EAD-1400015-00-0304 [14]	LVDT
	Compression	Major	81x 81 x 81	8	ÖNORM EN 16351 [13]	DIC
		Minor	81x 81 x 81	8	ÖNORM EN 16351 [13]	DIC

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machine, with loading rates of 0.8 mm/min and 1 mm/min, respectively, the OSB specimens were tested with a Walter+bai ag 650 kN testing machine. Compression tests for both materials were conducted on a Walter+bai ag 5 MN machine, applying a loading rate of 1 mm/min along the major axis and 0.6 mm/min along the minor axis. All elastic constants and strength properties were determined based on the formulas specified in the relevant standards, as summarized in Table 1.

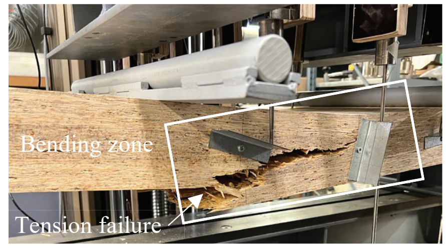
4 – RESULTS AND DISCUSSION

4.1 BENDING FAILURE MODES AND PROPERTIES

For both materials, the typical failure mode for all specimens was tensile failure in the area of the highest bending moment, where cracks initiated and propagated once the tensile stress exceeded the material's strength. Within the USB specimens, this failure initiated in the middle layer (the weaker layer due to the transverse orientation of the panel) and propagated to the outer layers vertically or diagonally, as shown in Fig. 3A. The OSB specimens exhibited similar tensile failure patterns, yet the cracks predominantly propagating vertically. This behaviour can be attributed to the parallel orientation of all panels, as illustrated in Fig. 3B. The consistent occurrence of these failure modes across multiple tests confirms the reliability and effectiveness of the test setups and standards for multi-layer strand-based EWPs.

The force-displacement curve (Fig. 4A) shows that USB exhibited a steep slope, indicating high stiffness and load-bearing capacity, with an average maximum force of approximately 55 kN. In addition, the calculated MOE and Modulus of Rupture (MOR) values (Fig. 4B) averaged around 16000 MPa and 33 MPa, respectively. The standard deviation, represented by the vertical lines in Fig. 4B, indicates high dispersion in the data for USB in both MOE and MOR. Determining the exact cause of this variability is challenging, as multiple influencing factors may contribute, including lay-up configuration, inherent material structure, and production process. OSB failed at approximately 33 kN. The MOE for OSB was measured with approximately 6,500 MPa, and the MOR reached 18 MPa. The standard deviation for OSB, as presented in Fig. 4B, suggests low data dispersion.

(A)



(B)

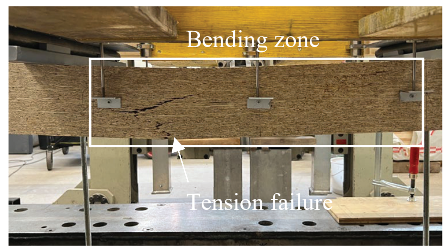


Figure 3. Common failure modes under the bending test; (A) tension failure of USB in bending zone and (B) tension failure of OSB in bending zone

Despite the fact that OSB and USB had similar average densities of 635 kg/m³ and 642 kg/m³, respectively, and moisture contents of 10.2% and 9.5%, other material-related parameters could contribute to these variations in results, despite using the same testing procedure.

4.2 SHEAR FAILURE MODES AND PROPERTIES

The shear test setup recommended by EN 16351 [13] (refer to Fig. 2D) led to six-layer OSB failing in the bending zone due to tension failure rather than in the designated shear area, as shown in Fig. 5A. This indicates the unsuitability of this test method for strand-based materials, despite its effectiveness for CLT. Several factors contribute to this discrepancy, including the inherently higher shear strength of OSB compared to its bending strength, leading to initial failure in bending and therefore non-significant results. Additionally, the absence of perpendicular layers, which typically induce rolling shear failure in CLT, further reduces the likelihood of shear failure in OSB. Moreover, the larger load-to-support distance (3h) in this test setup resulted in increased bending stresses, making tensile failure more dominant. In contrast, the shear test on USB, conducted based on the EAD 140015-00-0304 [14], with shorter

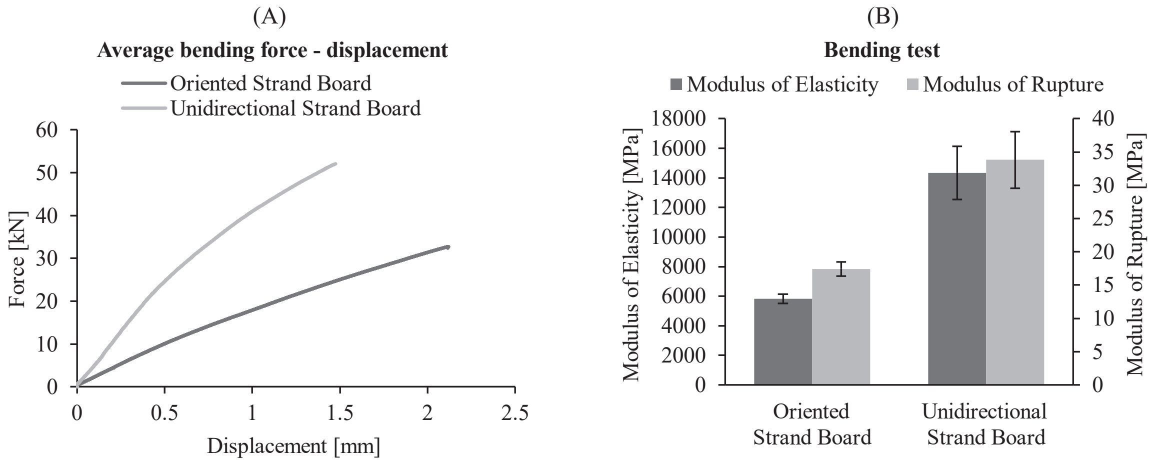


Figure 4. (A) average bending force-displacement diagram for Oriented Strand Board (OSB) and Unidirectional Strand Board (USB) and (B) bending Modulus of Elasticity (MOE) and Modulus of Rupture (MOR)

load-to-support distance (2h), proved to be more appropriate. As shown by the failure modes in Fig. 5B, a majority of the USB specimens exhibited horizontal shear failure across all three layers within the designated shear zone. Notably, despite the crosswise orientation of USB layers, no rolling shear failure was observed, an outcome that contrasts with CLT, where rolling shear is a commonly reported failure mode.

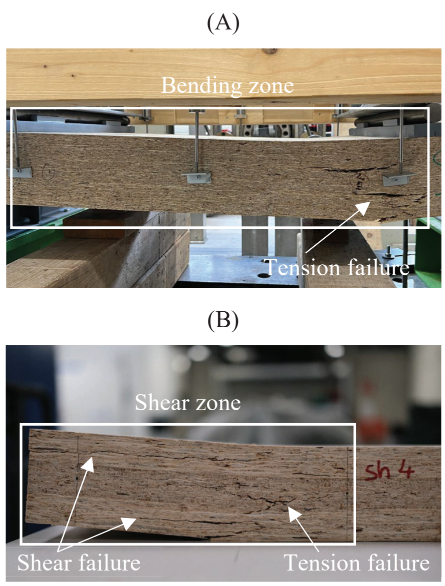


Figure 5. Common failure modes under the shear test; (A) tension failure of OSB in bending zone and (B) horizontal shear and tension failure of USB in shear zone

The shear force-displacement curve (Fig. 6A) for the USB specimen, exhibits a steep and linear response throughout loading, similar to that of the bending test. The average maximum force reached approximately 115 kN, while the localized displacement in the shear zone was around 1 mm. The calculated shear modulus and shear strength (Fig. 6B) provide further insight into USB's shear behaviour. The shear modulus averaged around 450 MPa and the shear strength was almost 3.2 MPa. The standard deviation, represented by the vertical lines in Fig. 6B, reflects higher variability in shear modulus than shear strength.

4.3 COMPRESSION FAILURE MODES AND PROPERTIES

The failure modes in USB and OSB specimens under compression were analysed using DIC, capturing strain distribution and crack development at 50% and 100% of the maximum force. For the USB specimens loaded at 50% of the failure force, the DIC images (Fig. 7A) reveal the formation of microcracks, which appear as localized strain concentrations (red spots), marking the onset of material degradation. As the load increased to 100% (Fig. 7B), these microcracks propagated further, forming distinct cracks along the strand direction. The final failure mode was characterized by longitudinal splitting, a common failure mode under compression in longitudinal direction to the strands (Fig. 7C). For the OSB specimens, a similar failure mode was assessed with one key differences. At 50% of the maximum force, the

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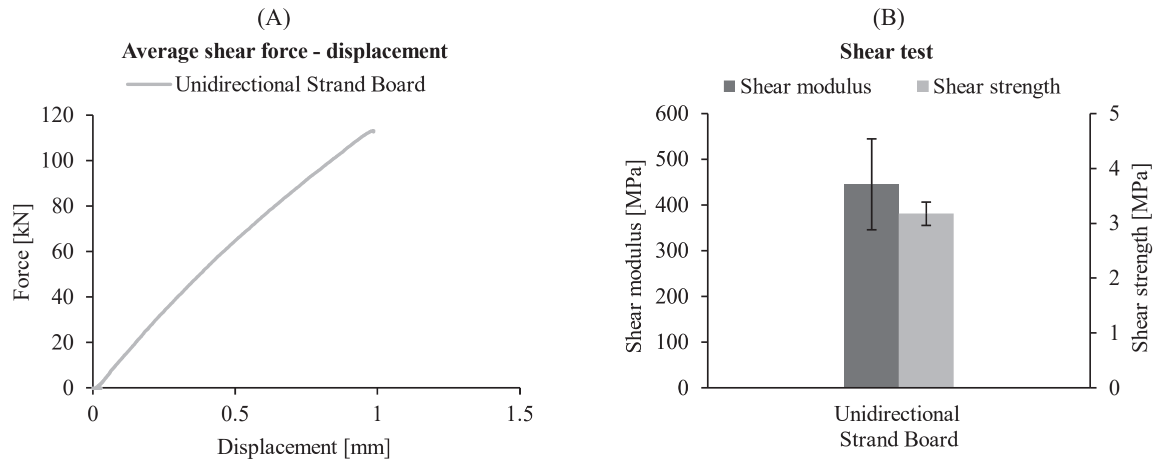

Figure 6. (A) average shear force-displacement diagram for Unidirectional Strand Board (USB) and (B) shear modulus and strength

DIC images (Fig. 7D) show the formation of localized cracks in high-strain regions, indicating the onset of material damage. However, due to the OSB's layered structure and absence of crosswise orientation, crack propagation was more irregular. By 100% loading (Fig. 7E), the failure mode was predominantly crushing, where the material compacted and deformed under increasing compressive stress rather than forming distinct splitting cracks. This differs from USB, where failure followed a relatively straight path along the strands. The final failure mode, captured in Fig. 7F, confirms that OSB failed

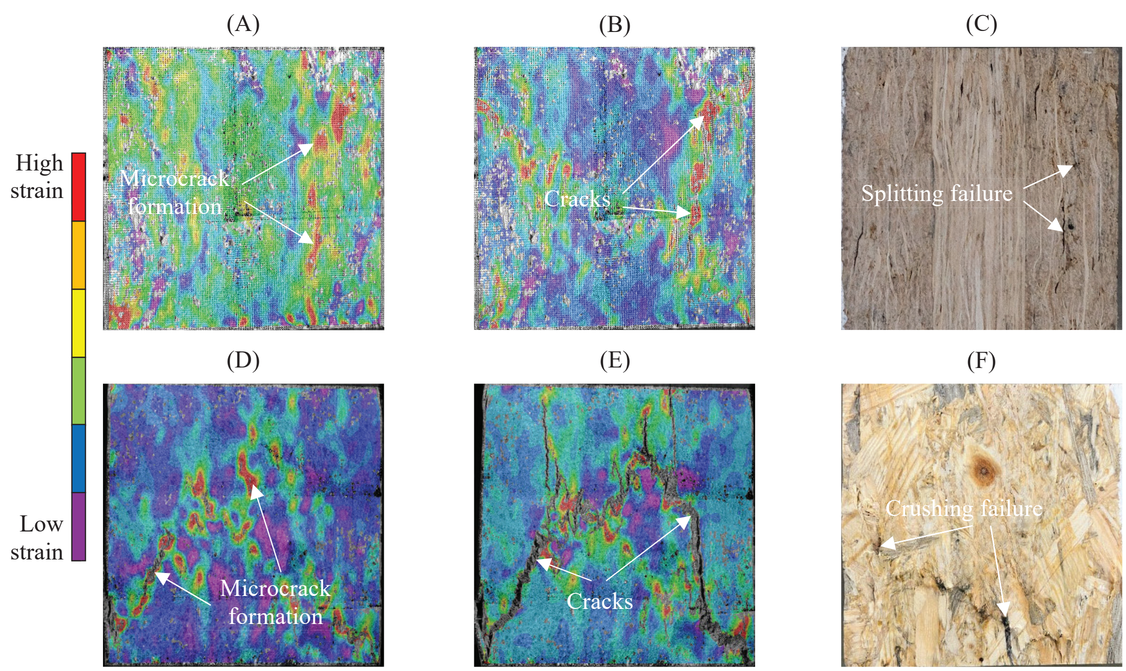

Figure 7. Common failure modes under the compression test; (A) horizontal strain and scale at 50 percent of maximum force in USB (front view); (B) horizontal strain and scale at 100 percent of maximum force in USB (front view); (C) splitting failure in USB (side view); (D) horizontal strain and scale at 50 percent of maximum force in OSB (front view); (E) horizontal strain and scale at 100 percent of maximum force in OSB (front view) and (F) crushing failure in OSB (side view)

through progressive crushing rather than splitting from the side view.

The compression force-displacement curves (Fig. 8A) illustrate the behaviour of OSB and USB under compressive loading along both the major and minor axes. Unlike shear and bending tests, the compression response exhibits a distinct non-linear behaviour, where the initial elastic region transitions into a nonlinear phase before failure. In the major axis, OSB exhibited an average ultimate force of approximately 300 kN, while along the minor axis, it reached around 190 kN, representing a 36% decrease.

The MOE for OSB was measured at approximately 5,900 MPa in the major axis and 3,800 MPa in the minor axis (35% decrease). The ultimate compressive strength (UCS) was recorded at 18 MPa along the major axis and 13 MPa along the minor axis (27%). The standard deviation, represented by the vertical lines, indicates greater variability in MOE than in UCS (see Fig. 8B).

USB exhibited an average peak force at approximately 200 kN in the major axis, while along the minor axis, it reached around 100 kN, representing a 50% decrease. The MOE for USB averaged around 8,000 MPa for the major axis and 5,500 MPa for the minor axis, showing a 31.25% reduction. The UCS for USB was measured at approximately 25 MPa for the major axis and 20 MPa for the minor axis, indicating a 20% decrease. The standard deviation indicates greater variability in MOE than in UCS, likely due to the sensitivity of MOE to material inconsistencies. USB also exhibited a higher standard deviation.

The results highlight the significance of orthotropic behavior in strand-based materials, emphasizing the need to consider this characteristic in future applications.

4 – CONCLUSION

This study investigated the mechanical properties and evaluated different test methods prescribed by various European standards for compression, bending, and shear in six-layer Oriented Strand Board (OSB) and three-layer Unidirectional Strand Board (USB). The results highlight that both USB and OSB in a multi-layer layup exhibit satisfactory mechanical properties, particularly in terms of elastic moduli and strength in bending, shear, and compression. Based on the observed failure modes, the application of the four-point bending test according to ÖNORM EN 408 [12] and the compression test based on EN 16351 [13] is recommended for evaluating multi-layer strand-based products, as these methods effectively captured the expected failure mechanisms. The four-point bending test setup with a shorter span, as suggested by EN 16351 [13] (with a load-to-support distance of three times the thickness), was found to be unsuitable for multi-layer OSB, as it primarily led to bending failure rather than shear failure. Instead, the same method with a shorter load-to-support distance of two times the thickness on USB, as proposed by European Assessment

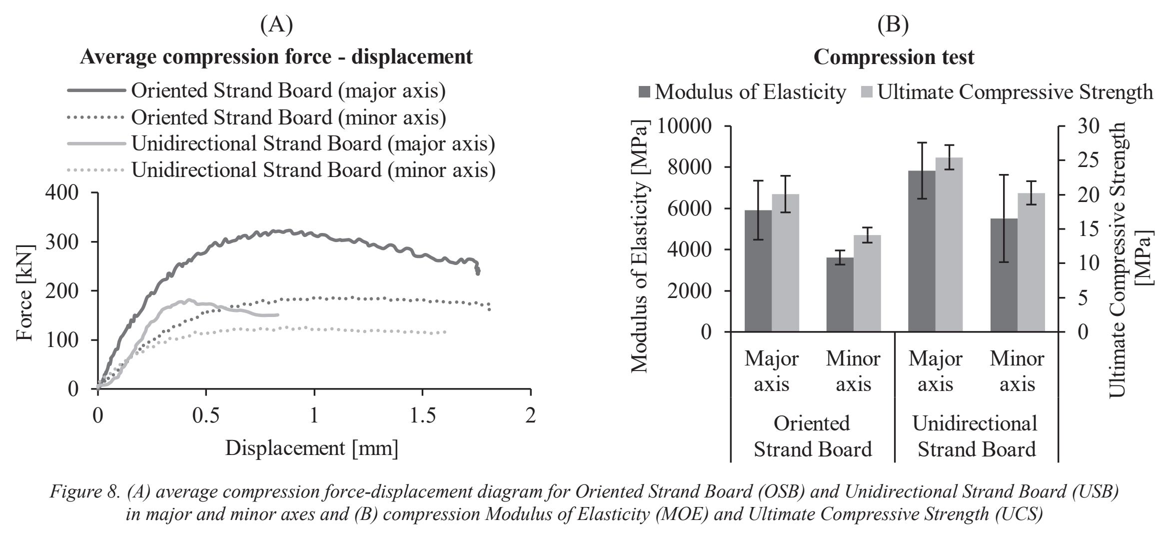

Figure 8. (A) average compression force-displacement diagram for Oriented Strand Board (OSB) and Unidirectional Strand Board (USB) in major and minor axes and (B) compression Modulus of Elasticity (MOE) and Ultimate Compressive Strength (UCS)

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Document (EAD-1400015-00-0304) [14], is recommended for obtaining reliable shear failure results. Future research should focus on the development of suitable dimensioning methods and optimizing USB manufacturing process and exploring its potential in various construction applications.

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