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STRESS-STRAIN BEHAVIOR OF PLASTERBOARDS SUBJECTED IN TENSION AND COMPRESSION

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Abstract

Plasterboard components are widely used in current buildings worldwide. Plasterboards are employed for partitions, wall lining and ceilings. Plasterboards are used for both structural and nonstructural walls. Mechanical properties, e.g. modulus of elasticity or tensile/compressive strength, of plasterboards may assume a key role in the whole seismic performance of a building. Numerical models of building components which include plasterboard elements, such as internal partitions, require the definition of the mechanical properties of plasterboards. Despite their extensive use, the lack of a comprehensive test campaign on plasterboards in the current literature is denoted. An extensive test campaign, consisting of 302 tests, is therefore performed aiming at evaluating compression and tension behavior of plasterboards. A set of five plasterboard typologies is selected, considering different board thicknesses and both standard and high-density boards. Both tensile and compression tests are performed according to EN 789. The tests are performed in two different load directions, i.e. parallel or transversal to the direction of production. Tensile strength of boards is systematically smaller than compressive strength, whereas elastic modulus values in compression and in tension are similar. Regression laws that can be employed to model both compression and tension behavior of plasterboards are defined for future implementations of the actual stress-strain relationships in different applications, e.g. FEM analysis of shear stud wall panels. A bilinear stress-strain envelope is adopted for tensile behavior, whereas a model typically used for concrete is selected for compression behavior. An orthotropic behavior is exhibited in case the boards are loaded in tension. The significant influence of board thickness on their mechanical properties is also highlighted. The most appropriate probability distribution function is estimated for several mechanical parameters and the corresponding data dispersion is evaluated. The uncertainty associated to each of the four selected parameters is therefore evaluated considering the corresponding lognormal distribution functions. The dispersion of the data around the median value is significantly influenced by the considered mechanical parameter. In particular, elastic modulus in tension is characterized by a large uncertainty, i.e. β values up to 0.68. Both tensile and compressive strengths show small variability around the mean. Finally, the uncertainty is influenced neither by the direction of loading nor by the thickness of the boards. The performed activities can be used as reference for future numerical studies involving plasterboards.

Keywords: plasterboard, tension test, compression test, nonstructural components, numerical modeling

1 Introduction

Plasterboard components are widely used in current buildings worldwide for partitions, wall lining and ceilings. Plasterboards are composed of a plaster core encased in paper liners to form flat rectangular boards [1]. The properties of these materials, can be modified to meet specific requirements, such as fire resistance, humidity resistance, impact resistance, etc.

Plasterboards are used for both structural [2; 3; 4; 5] and nonstructural [6; 7; 8; 9; 10] walls and may significantly influence the performance of the walls. A dynamic test on a six-story timber framed building during its construction [11] demonstrated that the addition of internal plasterboards resulted in increased natural frequencies of the building, due to their contribution to the lateral stiffness. An experimental study [12] showed that the strength of the studs in compression significantly increased when they were lined with plasterboards. A numerical study on the contribution of plasterboards to the structural performance of multi-story light wood frame buildings [13] also evidenced that they lead to stiffer structures and smaller drifts. Petrone et al. [14] demonstrated the significant contribution of the plasterboards in the out-of-plane seismic behavior of plasterboard partitions through quasi-static tests.

The mechanical properties, e.g. modulus of elasticity or tensile/compressive strength, of the plasterboards may assume a key role in the whole performance of a building. Numerical models [12; 13] of building components which include plasterboard elements require the definition of the mechanical properties of plasterboards. Very limited studies are available in literature concerning the mechanical properties of plasterboard partitions, despite their increasing importance in different areas of civil engineering. Compressive tests aiming at assessing the mechanical properties of an innovative gypsum board for thermal insulation purposes were included in [15]. However, the lack of a comprehensive test campaign on plasterboards in the current literature is denoted.

This paper summarizes an extensive test campaign, consisting of 302 tests, aiming at evaluating compression and tension behavior of plasterboards, presented in [16]. The resulting tensile and compressive strengths, as well as the elastic moduli in tension and compression are assessed for each plasterboard typology. Two different regression laws are defined matching compression and tension behavior, respectively, of plasterboards. The influence of some parameters, such as the thickness of boards and the direction of loading, on the mechanical properties is assessed. Finally, the most appropriate distribution function for several mechanical parameters is estimated and the corresponding data dispersion is evaluated. The estimated parameters can be used as reference material for future numerical studies involving plasterboards.

2 Experimental study

Tension and compression tests were performed according to EN 789 [17] on different boards:

- 12.5 mm thick and 18 mm thick standard plasterboards, named 12SB and 18SB in the following.
- 12.5 mm thick, 15 mm thick and 18 mm thick high density plasterboards, named 12HDB, 15HDB and 18HDB in the following, respectively. These high density core gypsum boards are stronger, harder and heavier than standard plasterboards, providing better fire, impact and acoustic resistance.

Paper liners are characterized by the same properties for the different boards. Their specific mass is in the range 180÷200 g/m^2. A total number of 302 tests were performed (Table 1) for the above mentioned plasterboards and for two different load directions, i.e. parallel or perpendicular to the direction of production.

Table 1 - Number of tests for each board typology

	Longitudinal		Transversal	
	Compressive	**Tensile**	**Compressive**	**Tensile**
12SB	14	15	16	16
18SB	16	16	15	15
12HDB	14	15	12	14
15HDB	15	15	15	15
18HDB	15	17	16	16

The EN 789 standard tensile test consists in applying a tensile stress in the longitudinal direction of the specimen until failure occurs. The objective is to determine the board elastic modulus, strength and ultimate strain. The specimens are obtained by properly shaping a single plasterboard (Fig. 1), obtaining a 3 cm wide central portion. The tests were performed in displacement-control: a monotonically increasing displacement is applied with a 0.5 mm/min velocity. Two displacement transducers (LVDT sensors) were placed on two opposite faces of the specimen; they measure the deformation of a 200 mm long portion of the specimen (). Metallic fixing supports were glued on each side of the board, in order to position the instrumentation on the specimen (Fig. 1). The applied load was recorded by means of a load cell.

Compression tests were also performed according to the EN 789 standard. This test consists in applying a compression stress in the longitudinal direction of the specimen until failure occurs. The objective is the assessment of compression elastic modulus, strength and ultimate strain. The specimens consist of four boards perfectly glued together (Fig. 1), in order to avoid that buckling of the boards dominates the failure. The tests were performed in displacement-control: a monotonically increasing displacement was applied with a 1.0 mm/min velocity. Two displacement transducers (LVDT sensors) were placed on two opposite sides of the specimen, measuring the deformation of a 100 mm portion of the specimen. The applied load was recorded by means of a load cell.

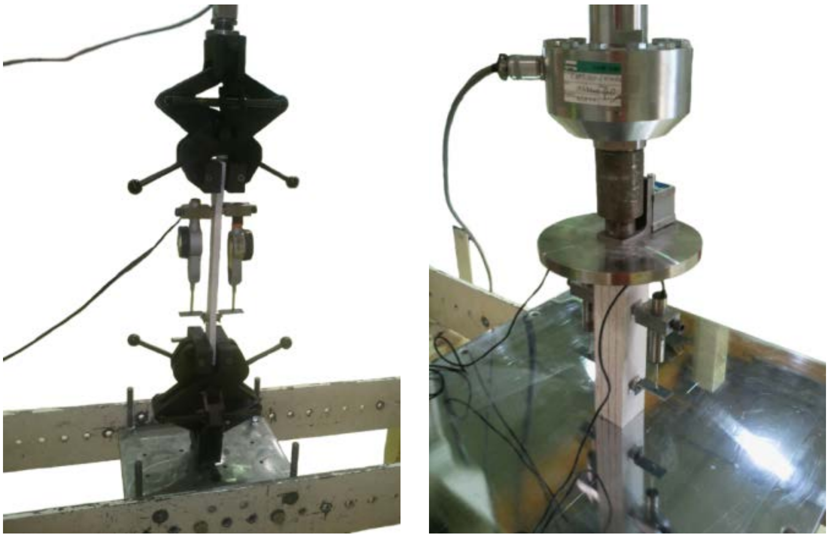
(a) (b)

Fig. 1 - Specimen for (a) tension tests and (b) compression tests (adapted from [16])

3 Results and discussion

Both compression and tension tests were performed until the failure of the specimen was recorded. In the tensile tests, the specimens typically exhibited a sub horizontal crack both in gypsum and in paper, (Fig. 2a). In compression tests, boards typically exhibited a sub-vertical crack in their central portion along with inclined cracks close to their boundaries (Fig. 2b). Moreover, in very few cases adjacent boards detached, due to the failure of the glue layer. These tests are removed from the database, since the collapse of the specimen is not recorded and the recorded deformation is associated to the glue layer failure.


(a) (b)

Fig. 2 - Typical failure mode in (a) tension and (b) compression tests (adapted from [16])

For each compressive and tensile test, a force displacement diagram can be obtained. The force was recorded by a load cell, whereas the displacement is evaluated as the mean displacement recorded by the two displacement transducers. Stress-strain diagrams are are plotted in Fig. 3 and Fig. 4 up to the failure of the specimens. The ultimate strain is evaluated as the strain corresponding to a 20% stress drop with respect to the maximum recorded stress. The board typology is included in the graph, where “L” e “T” suffixes denote whether the test was performed in the longitudinal direction, i.e. direction of production of the boards, or in the transversal direction, respectively.

The comparison of the stress-strain relationships in compression and in tension evidences ductile behavior in tension of the specimen with a more brittle behavior in compression; the ultimate tensile strain is much larger than the ultimate compressive strain. Moreover, the tensile strength is systematically smaller than the compressive strength. Furthermore, in case the specimens are loaded in tension, a more brittle behavior is exhibited in the transversal direction compared to the longitudinal direction; a smaller strength is also recorded in the transversal direction. Compression behavior is not much influenced by the testing direction, since the paper contribution is negligible in case the specimen is loaded in compression. Finally, the comparison among boards with different thicknesses, i.e. 12SB vs 18SB and 12HDB vs 15HDB vs 18HDB, highlights that the larger the thickness, the larger the compressive strength.

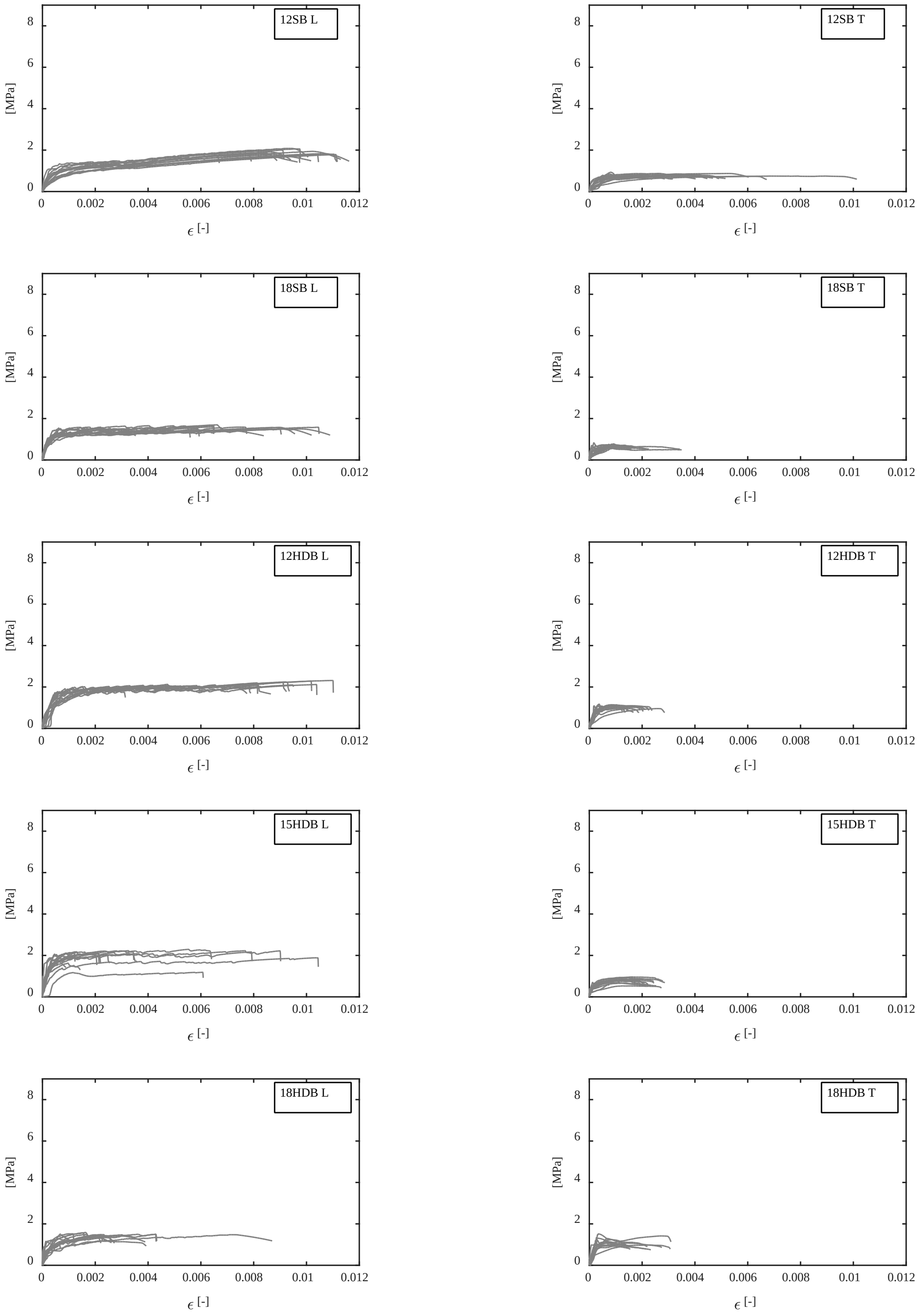

Fig. 3 - Stress-strain diagrams resulting from tension tests on the plasterboards (adapted from [16])

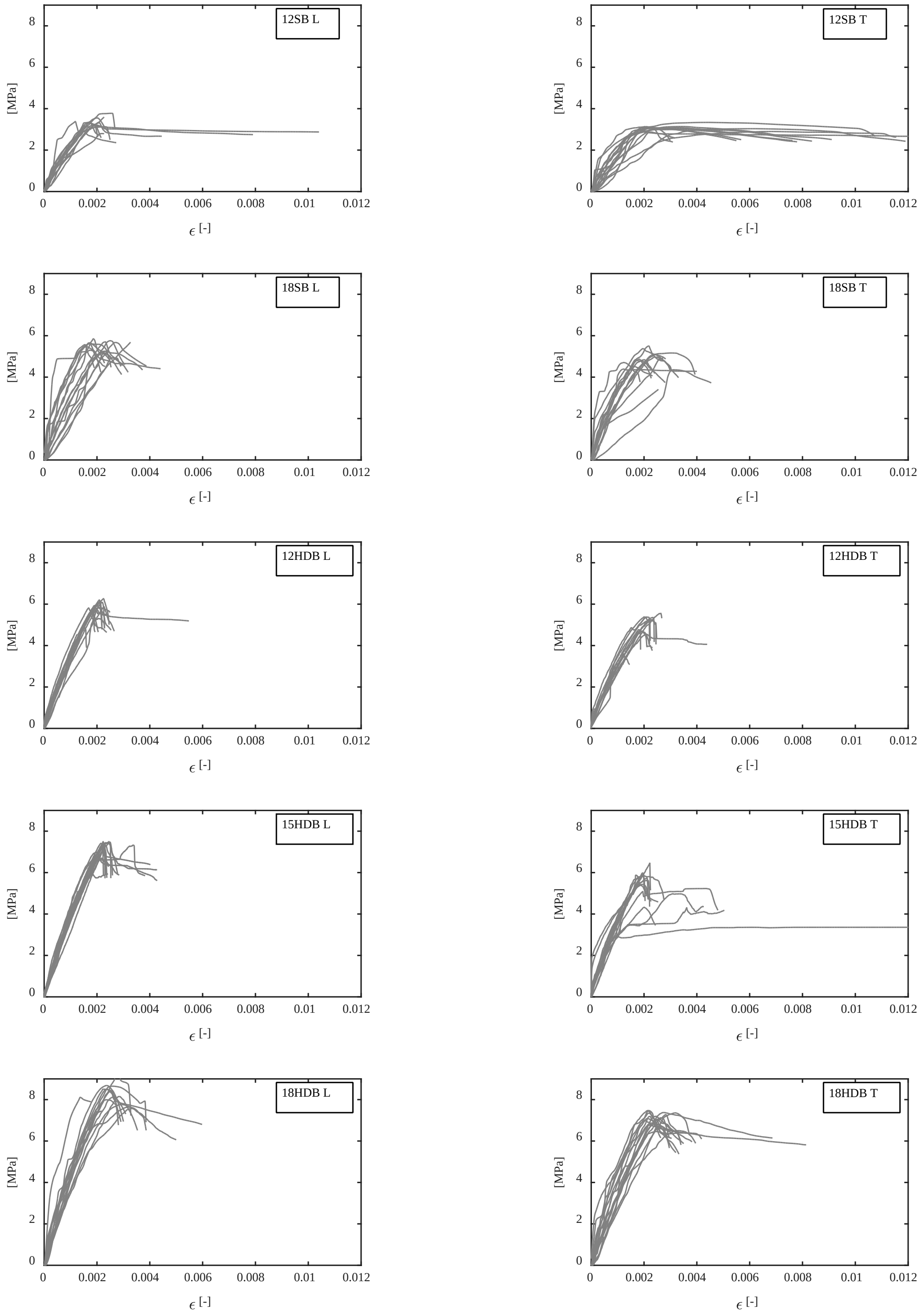

Fig. 4 - Stress-strain diagrams resulting from compression tests on the plasterboards (adapted from [16])

The study then focuses on the definition of a regression laws that can be employed to model both compression and tension behavior of plasterboards. This task would be useful for future implementations of the actual stress-strain relationship in different applications, e.g. FEM analysis of shear stud wall panels. A fitting curve is assessed for each board typology in each direction, by adopting different methodologies for tension and compression tests.

Tensile tests show a stress-strain diagram which assumes a typical bilinear shape. This suggests that the stress-strain relationship can be enveloped by a bilinear curve. Four different parameters univocally define a bilinear curve. In this case, the initial elastic modulus E_t, the "yielding" and ultimate stresses f_y and f_u , and the ultimate deformation ϵ_u, are selected as the parameters. Further details on the procedure can be found in [16]. The procedure is applied to each of the ten test groups. The resulting bilinear stress-strain curves along with the resulting parameters are included in Fig. 6.

The comparison between tension tests performed in longitudinal direction and transversal direction highlights a systematic smaller strength in transversal direction. This feature underlines the orthotropic behavior exhibited by the tested plasterboards. Moreover, a much smaller ultimate strain is exhibited in the transversal direction compared to the longitudinal direction. Finally, the elastic modulus is less influenced by the testing direction. The comparison between boards characterized by different thicknesses, i.e. 12SB vs 18SB and 12HDB vs 15HDB vs 18HDB, underlines that the tensile strength is not clearly influenced by the thickness of the boards. Stiffness is instead generally influenced by the thickness: the larger the thickness, the larger the elastic modulus. Finally, the ultimate strain is also influenced by the thickness of the boards: the larger the thickness, the smaller the ultimate strain.

Compressive tests require a different approach, due to their typical stress-strain shape (Fig. 4). The compressive behavior could be enveloped by a model defined by Mander et al. [18] for the concrete compression constitutive law. The constitutive law proposed by Mander et al. is defined upon four different parameters: the maximum strength f_c, the corresponding strain ε_c, the initial elastic modulus E_c and the ultimate strain ε_u. The parameters f_c, ϵ_c and ϵ_u are evaluated as the mean values measured in each test group. The initial elastic modulus E_c is estimated in order to achieve the best fitting with the experimental curves. A set of different elastic moduli is considered and the corresponding stress-strain envelopes are compared to the recorded relationships. A least squares approach is therefore adopted to select the elastic modulus. The procedure is applied for each board loaded in each direction in compression. The resulting fitting curves are overlapped to the experimental data in Fig. 7 along with the resulting parameters of the envelope curve.

Compressive strength of the tested boards is in the range $3.02 \div 8.14 MPa$, whereas the elastic modulus is in the range $2130 \div 4161 MPa$. The strain at which the maximum strength of the specimen is recorded, i.e. ϵ_c, is in the vicinity of 0.25% for all the specimens, whereas the ultimate deformation is typically smaller than 0.40%, except for 12SB boards tested in their transversal direction. The comparison between compression tests performed in longitudinal and transversal direction generally highlights negligible discrepancies in terms of strength, stiffness and ultimate strain. The orthotropic behavior is therefore limited to tension tests.

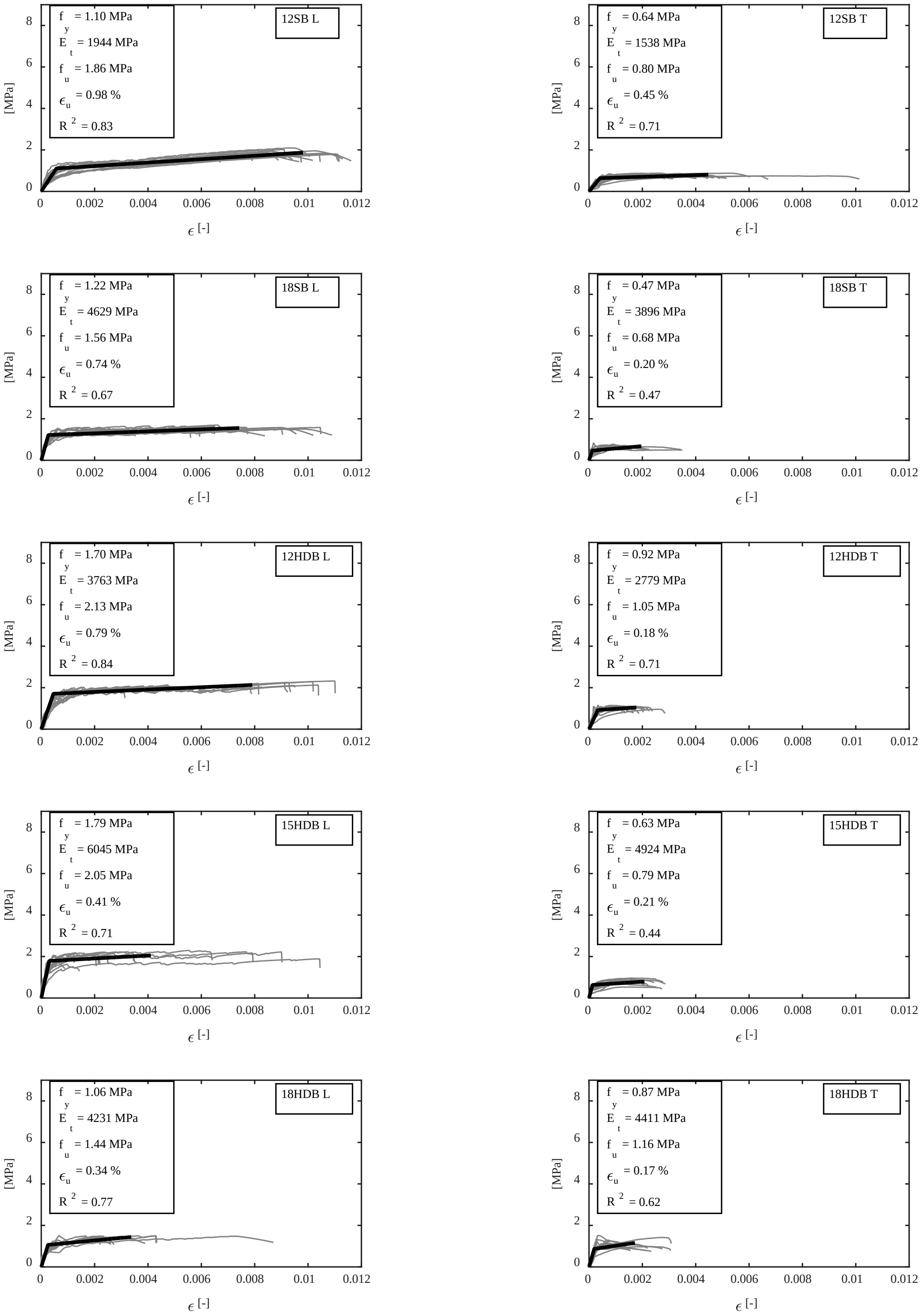

Fig. 5 - Tensile tests fitting for all the plasterboards in both longitudinal and transversal direction (adapted from [16])

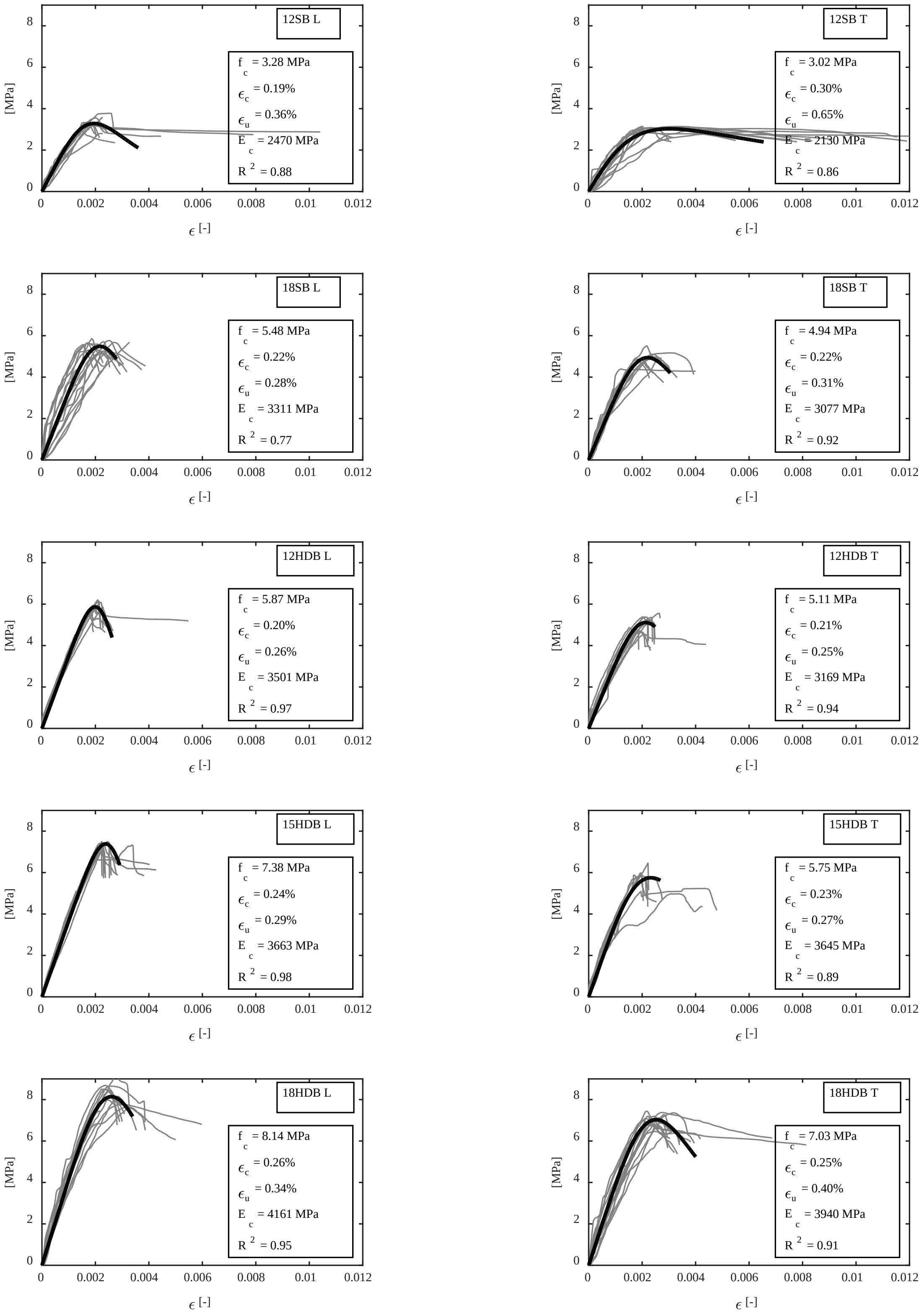

Fig. 6 - Compressive tests fitting for all the plasterboards in both longitudinal and transversal direction (adapted from [16])

4 Conclusions

Plasterboard components are widely used in current buildings worldwide. Plasterboards are typically employed for partitions, wall lining and ceilings. Despite their extensive use, the lack of a comprehensive test campaign on plasterboards in the current literature is denoted. An extensive test campaign, consisting of 302 tests, is therefore performed aiming at evaluating compression and tension behavior of plasterboards. A set of five plasterboard typologies is selected, considering different board thicknesses and both standard and high-density boards. Both tensile and compression tests are performed according to EN 789. The tests are performed in two different load directions, i.e. parallel or transversal to the direction of production.

The comparison of the stress-strain relationships in compression and in tension shows that:

- a ductile behavior is exhibited in tension along with a more brittle behavior in compression; the ultimate tensile strain is much larger than the ultimate compressive strain. Moreover, tensile strength is systematically smaller than compressive strength.
- smaller tensile strength is recorded in the transversal direction compared to the longitudinal direction, clearly underlining the orthotropic behavior exhibited by plasterboards; compression behavior is not much influenced by testing direction, since the paper contribution is negligible in case the specimen is loaded in compression;
- the comparison among boards with different thicknesses highlights that the larger the thickness, the larger the compressive strength;

Regression laws that can be employed to model both compression and tension behavior of plasterboards are defined for future implementations of the actual stress-strain relationships in different applications, e.g. FEM analysis of shear stud wall panels. A bilinear stress-strain envelope is adopted for tensile behavior, whereas a model typically used for concrete is selected for compression behavior.

Some additional comments can be drawn from the fitted stress-strain relationships.

- The strain at which the maximum compression strength of the specimen is recorded occurs at about 0.25%, whereas the ultimate deformation is typically smaller than 0.40%.
- Smaller tensile ultimate strain is exhibited in the transversal direction compared to the longitudinal direction. The tensile elastic modulus is less influenced by the testing direction, exhibiting similar values in the two orthogonal directions.
- Tensile strength is not clearly influenced by the board thickness, whereas compression strength and both tensile and compressive stiffness are influenced by board thickness.

Acknowledgements

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