EXPERIMENTAL ANALYSIS OF ACTUAL BEHAVIOUR OF FIBER CEMENT BOARDS

Milan PILGR[1], *Marcela KARMAZINOVA*[1], *Jindrich MELCHER*[1]

[1]Institute of Metal and Timber Structures (UKDK), Faculty of Civil Engineering (FAST), Brno University of Technology (VUT v Brne), Veveri 331/95, Brno, The Czech Republic

pilgr.m@fce.vutbr.cz, karmazinova.m@fce.vutbr.cz

DOI: 10.35181/tces-2023-0016

Abstract. *The paper is focused on analysis of limit states and actual behaviour of the great size fibre cement boards that are produced without autoclaving. In this paper the basic information on the testing of the fibre cement boards is summarized, but its main goal is the utilization of acquired specification and data for the elaboration of backgrounds for direct determining of the defined load carrying capacity of boards for basic cases of loading, span and support conditions. The elaborated solutions and results follow the contemporary approach of the structural design method and reliability verification based on the concept of limit state design using the partial safety factors.*

Keywords

Fiber cement boards, actual behaviour, tests, load carrying capacity.

1. Introduction

Problems of limit states and actual behaviour of the great size fibre non-autoclaved cement boards Cemvin are solved i. a. in the workplace of the Institute of Metal and Timber Structures (KDK) of Faculty of Civil Engineering (FAST) of Brno University of Technology (VUT) recently. The Czech Wood Plants Prague (CDZ) JSC., the Cernousy plant, are a manufacturer of the Cemvin boards. Properties, technology and applications of the Cemvin boards were analyzed and perfected by the Research Institute of Building Materials (VUSTAH) JSC., placed in the city of Brno, and by the Institute KDK FAST VUT. Michal Frank, MEng, was the responsible worker and coordinator.

This issue is being addressed by many researchers around the world, see e.g. [1], [2], [3], [4].

Submitted paper provides the basic information on the testing of the fibre cement boards and on the utilization of acquired specification and data for the elaboration of backgrounds for direct determining of the defined load carrying capacity of boards for basic cases of loading, span and support conditions. The work took place in two stages: the 1st stage between 2007 and 2011 in cooperation with the above entities, whereupon the achieved results were published in a summary in the handbook [5]; the 2nd stage took place based then on the request and assignment of the company Topwet Ltd. in 2018, whereupon the achieved results were published in a summary in the handbook [6], which complements and expands the previous handbook.

The test results of the static load tests were the source of data for the determination of the characteristic quantities of the fiber cement boards. The stress and strain state of the test specimens and the resulting strength and deformation quantities were analysed using structural mechanics methods. Subsequently, the values of the characteristic quantities of the fiber cement boards were statistically evaluated according to the annex D to the EN 1990 [7].

2. The 1st Stage – Technology & Tests & Tables & Graphs

The 1st stage of works realized between 2007 and 2011 represented the research complexly focused both on the questions of properties and technology of starting structural material and on the problems of specimens testing and data processing. The research was carried out in the framework of two projects of Ministry of Industry and Trade (MPO) especially: 1) project No. FI-IM5/161

„New conception of prefabricated building elements of fibre-cement sheets by CDZ Praha, a.s. for wood constructions and low-power houses“, 2) project No. FI-IM4/068 „Research of the new fibre cement nonautoclaved great size products of the high quality in Czech Wood Plants Prague, j.s.c., plant Cernousy“.

2.1. Tests of the Fibre Cement Boards

The determination of characteristic quantities for the fibre cement boards proportion with respect to the applied load in their structures application was a partial initial goal of the test program. An overview of the set of test specimens with a breadth of 100 mm is given in Tab. 1, and specimens were loaded parallel to the production direction. The same number of specimens was loaded in the case of load perpendicular to the direction of boards production. A total of 164 material specimens were tested in a dry (total of 82 parallel to the production direction and total of 82 perpendicular to the production direction). The tests were carried out in accordance with the EN 12467 Fibre-cement flat sheets – Product specification and test methods [8].

The defined dry state was achieved by the normative conditioning procedure, i.e. the specimens were left between 7 and 14 days in ambient laboratory conditions.

Tab. 1: Number of specimens loaded parallel to the production direction in a dry (82 in total)

Specimen span L [mm]	Thickness t [mm]			
	5	10	15	20
200	3	3	3	–
400	3	23	23	3
600	3	3	3	3
800	–	3	3	3

An illustrative shot of fiber cement board material samples is shown in Fig. 1. A shot of the realization of load tests of standard test specimens is shown in Fig. 2.

Fig. 1: Example of set of test specimens

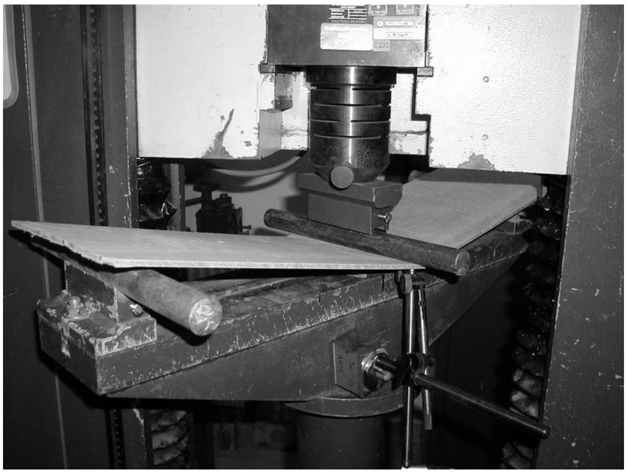

Fig. 2: Realization of load tests of standard test specimens

A set of material samples was tested for basic orientation information about the influence of moisture on the strength quantities of fiber cement boards in a wet, and the prescriptive wetting procedure according to EN 12467 [8] was followed. An overview and the sizes of the set of test specimens in a wet is given in Tab. 2, and specimens were loaded parallel to the production direction. The same number of specimens was loaded in the case of load perpendicular to the direction of boards production. A total of 54 material specimens were tested in a wet (total of 27 parallel to the production direction and total of 27 perpendicular to the production direction). The number of test specimens was limited by the production capacity of the research contractor, i.e. the company CDZ Prague.

The defined wet state was achieved by the normative conditioning procedure, i.e. the specimens were immersed in water for 24 hours; the specimens were tested immediately upon removal from the water.

Tab. 2: Number of specimens loaded parallel to the production direction in a wet (27 in total)

Specimen span L [mm]	Thickness t [mm]			
	5	10	15	20
200	–	–	–	–
400	12	5	5	5
600	–	–	–	–
800	–	–	–	–

The test specimens for the load tests were made from the supplied boards of thickness 5, 10, 15 and 20 mm, of uniform width 100 mm and with lengths of 400, 600, 800 and 1000 mm. The specimens were cut perpendicular to the direction of boards production, respectively parallel to the direction of boards production. The static model of the test specimen is a simply supported beam with a span of L = 200, 400, 600 and 800 mm and with an overhang of 100 mm behind the supports. The loading was caused by a point load at the mid-span of the test specimen.

2.2. Evaluation of Strength Quantities

The test results of the static load tests and their analysis were the source of data for the determination of the characteristic quantities of the fiber cement boards, and the procedure of design of load-carrying structures according to unified European codes based on the reliability concept of limit states was followed for the results analysis. The values of the load force F and of the deflection at mid-span w were measured and recorded at each load test – we provide an example of the typical stress-strain relationship of one of the tested specimens for illustration in Fig. 3.

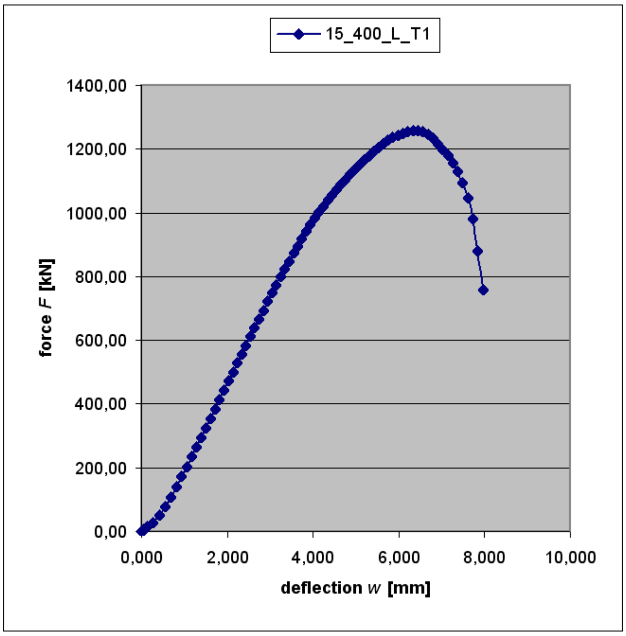

Fig. 3: Example of the stress-strain relationship – the test specimen loaded parallel to the production direction with the thickness of t = 15 mm and with the span of L = 400 mm

The EN 1990 Eurocode: Basis of Structural Design [7] is the basic basis for the processing of measured data. The second moment of cross-sectional area I and the section modulus W were determined for each test specimen, the geometrical properties of cross-section were determined based on actual measured values of thickness and breadth – the board thickness was measured in 6 places, the cross-sectional breadth was measured in 3 places, the mean values of the dimensions was determined from the detected data set. The characteristic quantities were determined for each test specimen: a) ultimate tensile strength in bending – based on the actual value of the section modulus W and on the limit value of the load force F, b) tensile and compressive modulus of elasticity – based on the actual value of the second moment of area I and on the linear part of the F–w relationship. The values of the characteristic quantities of the fiber cement boards were evaluated according to the annex D to the EN 1990 [7].

The strength and deformation quantities were analysed by elementary methods of structural mechanics. First, the internal forces (bending moment M) in the cross-sections of the plate were solved based on the static equilibrium conditions. Subsequently, the stress components (normal stress σ) were calculated from the internal forces assuming the Navier hypothesis. In doing so, the geometrical properties of cross-section (the second moment of area I, the section modulus W) determined according to the actual dimensions of the tested boards were used. The above procedure was used both for the direction parallel to the production direction and for the direction perpendicular to the production direction.

The tensile strength in bending is defined: a) by the characteristic value X_k according to paragraph D.7.2 of the above code, b) by the design value X_d according to paragraph D.7.3, c) by the partial safety material factor $\gamma_M = X_k / X_d$. The result values of the basic characteristic quantities determined on the basis of the tests are shown in Table 3.

Tab. 3: The characteristic quantities of the fiber cement boards

The characteristic quantity		In a dry		In a wet	
		perpendicular to the production direction	parallel to the production direction	perpendicular to the production direction	parallel to the production direction
The tensile strength in bending [MPa]	mean value	20,47	31,00	15,75	21,84
	characteristic value	16,63	24,84	11,29	16,10
	design value	13,35	19,58	7,36	11,06
The partial safety material factor γ_M		1,25	1,27	1,53	1,46
Young's modulus by bending – mean value [MPa]		11 159	12 140	9 254	9 436

The characteristic value X_k corresponds to the 5% fractile of the actual statistical distribution of the relevant characteristic quantity. The design value X_d corresponds to the relevant design reliability index $\beta = 3{,}8$. The partial safety material factor γ_M is the ratio of the characteristic value X_k and the design value X_d.

The statistical evaluation of the mean, characteristic and design values of the strength and deformation quantities was performed assuming the Normal distribution. That is, the mean m_X and the standard deviation s of the n sample results were first estimated. Subsequently, the characteristic fractile factor k_n and the design fractile factor k_d were calculated for the known coefficient of variation $V_x = 0{,}15$ and the corresponding number n of numerical test results. Finally, the characteristic value X_k and the design value X_d were calculated; the ratio of the characteristic value and the design value gives the partial safety material factor γ_M.

2.3. Tables and Graphs of the Defined Load Carrying Capacity

The load carrying capacities of the fiber cement boards were determined from the design values of the tensile strength in bending by the loading both perpendicular and parallel to the production direction in a dry. In addition to the load carrying capacities determined only on the basis of the strength quantities, the ultimate loads including deflection limitation with size of L / 100, L / 200, respectively L / 300 were processed as well, where L is the board span. The deflections were determined from the mean value of the tensile modulus of elasticity by bending by the loading both perpendicular and parallel to the production direction in a dry. The board thicknesses of 3, 4, 5, 6, 8, 10, 12, 15, 18, 20 and 24 mm were considered; the board spans were graduated in the interval from 100 to 1200 mm by 50 mm.

The static models and the decisive cross-sections for a proportion were chosen as follows: a) simply supported beam + uniformly distributed load → bending moment at mid-span, deflection at mid-span; b) two-span continuous beam + uniformly distributed load in both spans → bending moment above inside support, deflection of span; c) three-span continuous beam + uniformly distributed load in all spans → bending moment above inside support, deflection of end span; d) four-span continuous beam + uniformly distributed load in all spans → bending moment above inside support of end span, deflection of end span; e) infinity-span continuous beam + uniformly distributed load in all spans → bending moment above inside support, deflection of inside span; f) simply supported beam + point load at mid-span → bending moment at mid-span, deflection at mid-span.

We present an example of the simply supported beam loaded with uniformly distributed load and loaded parallel to the direction of boards production for illustration in Fig. 4.

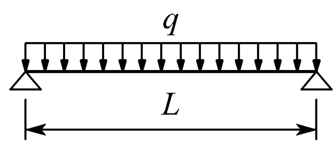

Fig 4a: The static model of the simply supported beam

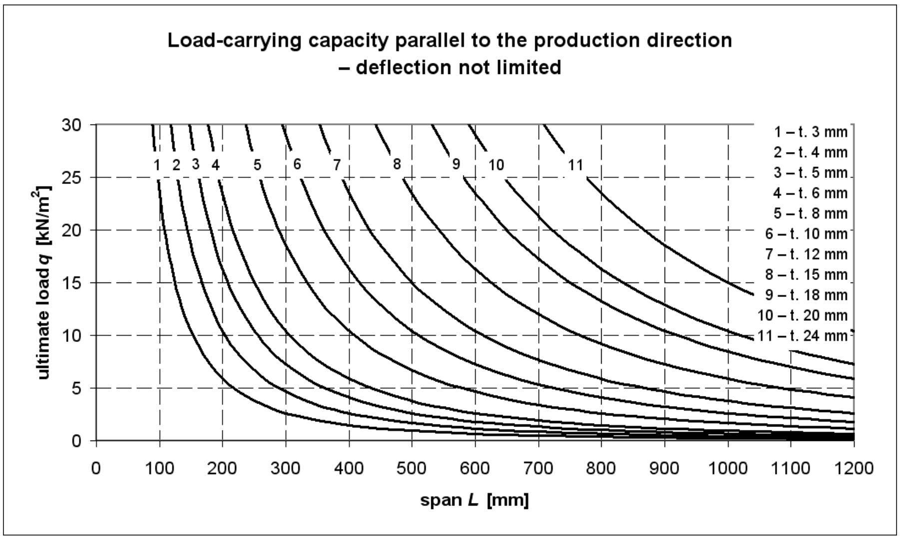

Fig 4b: The ultimate load of board by loading parallel to the production direction – deflection not limited; simply supported beam – uniformly distributed load

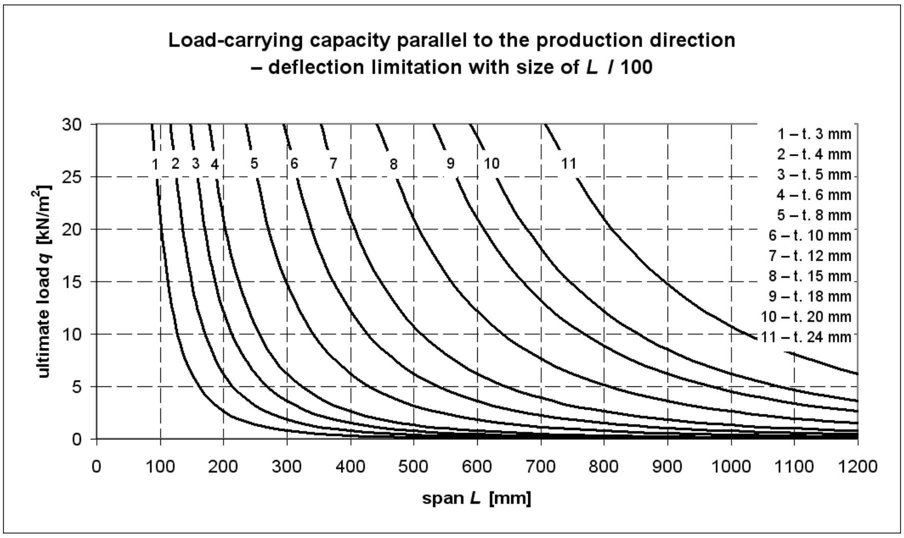

Fig 4c: The ultimate load of board by loading parallel to the production direction – deflection limitation with size of *L* / 100; simply supported beam – uniformly distributed load

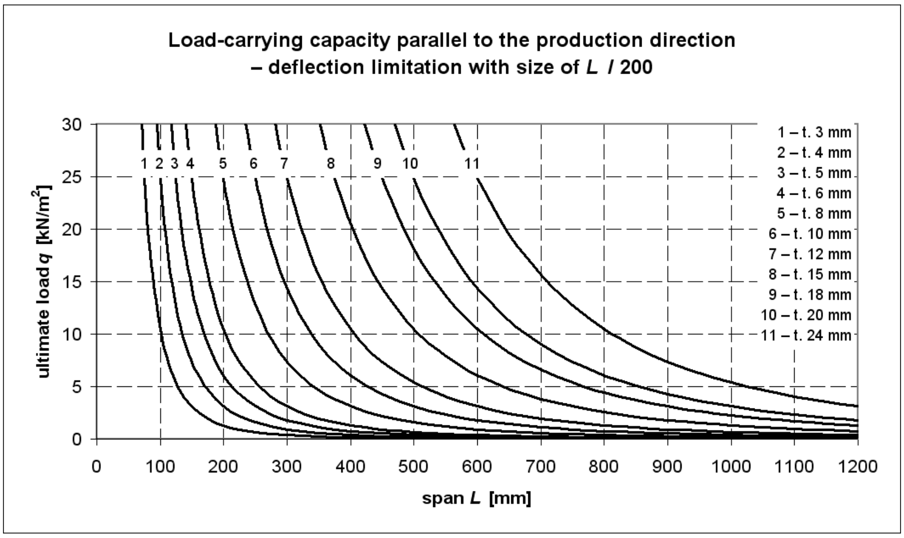

Fig 4d: The ultimate load of board by loading parallel to the production direction – deflection limitation with size of *L* / 200; simply supported beam – uniformly distributed load

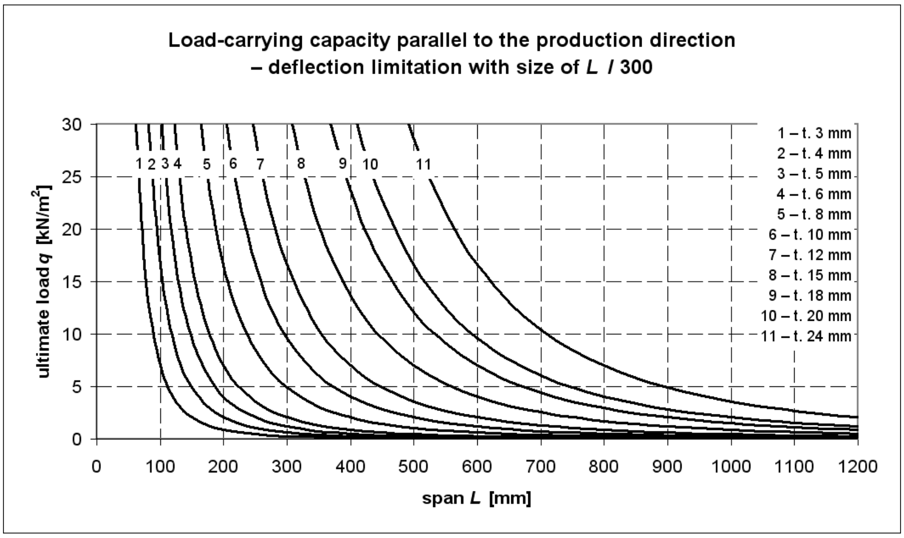

Fig 4e: The ultimate load of board by loading parallel to the production direction – deflection limitation with size of *L* / 300; simply supported beam – uniformly distributed load

3. The 2nd Stage – Additional bases for thicknesses of 20, 25 and 30 mm

The 2nd stage of works realized in 2018 was focused on problems of the evaluation and processing of data acquired from load tests. It was a contract research commissioned by the company Topwet Ltd. The goal of the research was to complement and expand the solutions and results elaborated so far for boards thicknesses of 20, 25 and 30 mm in a wet.

3.1. Tests of the Fibre Cement Boards

The load tests themselves were not the subject of this stage of works. The load tests, as well as the measurement and recording of salient quantities, were previously carried out by the research contractor.

3.2. Evaluation of Strength Quantities

The test results of the static load tests and their analysis were again the source of data for the determination of the characteristic quantities of the fiber cement boards, and the procedure of design of load-carrying structures according to unified European codes based on the reliability concept of limit states was followed for the results analysis. The characteristic quantities were determined again for each test specimen: a) ultimate tensile strength in bending – based on the actual value of the section modulus W and on the limit value of the load force F, b) tensile and compressive modulus of elasticity – based on the actual value of the second moment of area I and on the linear part of the F–w relationship. The values of the characteristic quantities of the fiber cement boards were evaluated again according to the annex D to the EN 1990 [7].

The result values of the basic characteristic quantities determined on the basis of the tests are shown in Table 4.

Tab. 4: The characteristic quantities of the fiber cement boards

		Thickness t = 20 mm		Thickness t = 25 mm		Thickness t = 30 mm	
		ll to the production direction	⊥ to the production direction	ll to the production direction	⊥ to the production direction	ll to the production direction	⊥ to the production direction
The tensile strength in bending [MPa]	mean value	17,57	14,78	21,10	15,55	19,09	14,73
	characteristic value	13,04	10,96	15,66	11,54	14,17	10,93
	design value	9,06	7,62	10,88	8,02	9,84	7,59
The partial safety material factor γ_M		1,44	1,44	1,44	1,44	1,44	1,44
Young's modulus by bending – mean value [MPa]		8528	8323	7316	7574	6896	5667

3.3. Tables and Graphs of the Defined Load Carrying Capacity

The load carrying capacities of the fiber cement boards were determined from the design values of the tensile strength in bending by the loading both perpendicular and parallel to the production direction in a wet. In addition to the load carrying capacities determined only on the basis of the strength quantities, the ultimate loads including deflection limitation with size of L / 100, L / 200, respectively L / 300 were processed as well, where L is the board span. The deflections were determined from the mean value of the tensile modulus of elasticity by bending by the loading both perpendicular and parallel to the production direction in a wet. The board thicknesses of 20, 25 and 30 mm were considered; the board spans were graduated in the interval from 100 to 1500 mm by 50 mm.

4. Conclusion

The basic information on the testing of the fibre cement boards is summarized in the submitted paper; the paper also deals with the utilization of acquired specification and data for the elaboration of backgrounds for direct determining of the defined load carrying capacity of boards for basic cases of loading, span and support conditions. The elaborated solutions and results follow the contemporary approach of the structural design method and reliability verification based on the concept of limit state design using the partial safety material factors. Another information on the testing and the load-carrying capacity of fiber cement boards was published, for example, in [9].

The results can be used for the design and dimension verification of the fibre cement boards affected by loading actions in load-carrying building and technology structures (permanent formwork of bridge structures, load-carrying structure of timber floors and dry floors, structures of building envelopes, formwork of prefabs in precast concrete plants etc.).

The elaborated research will continue in the coming period so that both the characteristic quantities of the new type of plates will be studied and the load-carrying capacities tables for plates supported around the perimeter and stressed in both directions will be processed.

Acknowledgements

This research has been supported by the project of specific university research No. FAST-S-23-8317, supported by the Ministry of Education, Youth and Sports of the Czech Republic.

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