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21 February 2013

TO: [redacted] **S.A.**
Wooden pallets & fruit crates
[redacted]

FULL REPORT ***(through project no. 874, Research Committee, TEI of Larissa)***
QUALITY CONTROL OF THREE (3) WET-PROCESS HARDBOARD SAMPLES

1. Introduction

This report includes the data and results found after an extensive laboratory testing on wet-process **hardboard samples**, collected from the wood industry [redacted] based in [redacted], Greece.

At 14th February, 2013, the industry [redacted] SA requested from Prof. George Mantanis *(PhD, Dipl.)* of the *Lab of Wood Technology*, at Tech. Educ. Inst. (TEI) of Larissa, so as to examine the production facilities and production lay-out of its wood crates line production, as well as to collect samples and to investigate the *quality* of the raw materials used. The industry claimed *that several problems have been appearing with the instability of quality properties of the imported wet-process hardboard material, coming from the foreign industry* [redacted]. A visit was paid, and a careful and fully random selection of hardboard samples was made by Prof. George Mantanis at that date (14.02.2013). Namely, three different *hardboard* samples were collected and taken in the Karditsa's lab facilities for a full *quality control* testing. That is:

- **Sample A**: it was claimed by Mr. [redacted], director of [redacted] SA, *that this early hardboard sample, which was delivered by the* [redacted] *industry 4 months*

ago, was supposed to be of excellent quality, of high mechanical properties etc. The industry [redacted] SA claims: *that these hardboard products are those that the company desires to receive/import at a constant basis*.

Sample B: this sample of hardboard is that one that was received that date of 14th February, at [redacted] SA, with the presence of Dr. George Mantanis; this sample will pass a full investigation on all properties according to standard EN 622-2 to verify the claimed properties by the [redacted] producer [redacted]

- **Sample C**: this sample of hardboard was collected by the storage room of company [redacted] SA. According to Mr. [redacted], *this sample was of the worst quality*; it was received at [redacted] last November 2012, and caused many problems in the production, that is, it was characterised by lower mechanical properties and strength, lower rigidity, and several other problems (e.g. deformations) were occurred during the production phase. Nowadays this batch C has been removed out and it is not going to be used any more due to the above.

All three hardboard samples were covered and carefully transferred at Karditsa's laboratory by Dr. George Mantanis. The samples were stored covered in a laboratory room with normal climatic conditions. Note: *no climatisation* was carried out in the Samples A, B and C. The first date the moisture content of the Sample B, which has been received by industry [redacted] SA, the day before, was measured according to the European standard requirement using the oven process, at a temperature of 103°C for 48 hours. The rest of the tests carried out in the hardboard samples were carried out in the dates of 18/02/13, 19/02/13, 20/02/13 and 21/02/13. The samples B and C were also assessed for their formaldehyde content using the standard so-called *Perforator method* (EN 120).

Fig. 1. *Samples marked "A", "B" and "C" at the TEI/Larissa laboratory facilities.*

2. Materials and Methods

The materials used in this test were three (3) different hardboard samples, as collected from the [redacted] SA company, at 14th February 2013. The hardboard materials were labeled as A, B and C, and are of the type: *wet process fibreboards*, namely hardboards from the European industry [redacted] Their average thickness is approx. 2,6-2,7 mm.

The samples, prior to the testing, were cut properly, and the 150mm edge parts of the hardboard panels were removed out. Only center-located samples were used (Figs. 2, 3).

Fig. 2. *Cutting of 50mm x 50mm samples for the swelling & absorption tests.*

Fig. 3. *Specimens cut for the bending strength MOR tests (measuring 95mm x 50mm).*

The methods used in this work are described in detail as follows.

2.1. Moisture content

From hardboard sample B, 2 samples from each panel were collected. Each sample was measuring dimensions 25mm x 25mm, and being taken from the centered parts of each panel (total 4 panels were used). The total samples were eight (8).

Each sample was measured carefully for its weight using a modern three-decimal balance (Fig. 4), prior to the testing. This mass weight is called *initial weight*. The 8 small hardboard samples were placed in an air-circulating oven (Fig. 5), having been warmed-up at the temperature of 103°C (±2°C). This temperature was kept constant for 48 hours; the full drying of the samples leads to the removal of the containing moisture, until the samples eventually reach the so-called *constant weight*.

At that point, the 8 samples were removed, one-by-one, and weighed carefully in the same balance; this weight is called *final dry weight*. For the simple type below, one can estimate the initial *moisture content* (MC) that the hardboard samples had upon their arrival at [redacted].

$$MC = \frac{\text{Initial weight} - \text{Final dry weight}}{\text{Final dry weight}} \times 100 \ (\%) \qquad (1)$$

This test for moisture content was carried out only for the sample B since the samples A and C are **old** and have been left *exposed out* in the industry conditions for a long period of time. **This MC test must be carried out (in-house) of new hardboards right after their arrival**.

Fig. 4. *High accuracy electronic balance with 3-decimals.*

Fig. 5. *Drying oven suitable for wood samples with air-circulating system.*

Note: An assessment of the moisture content was carried out for a hardboard sample (see Fig. 6a) that was taken from [redacted]; this sample was a part of a wooden fruit crate which had been under deformation (Fig. 6a), after its manufacturing.

a

b

Fig. 6a,b. *A hardboard sample (having deformation on a wooden crate) was tested for MC.*

2.2. Density

For each of Samples A-B-C, three (3) different boards were selected and cut; the edge parts were removed out. As shown in Fig. 2, sixty (60) different small specimens, each measuring dimensions approx. 50mm x 50mm, were cut carefully and the three dimensions, namely length, width and thickness were estimated using a modern electronic caliper (Fig. 7) and also the weight (see balance in Fig. 6b; with accuracy 3-decimal units). The density of the samples was after that calculated from type: **Density = weight (kg) / volume (m^3)** **(2)**

2.3. Variability in board thickness

From hardboard Samples B, one random panel -cut in the middle- was selected at the lab. As in Fig. 8, a measurement using the electronic caliper was made at *eight edge points*

Fig. 7. *Electronic caliper Mitutoyo*

Fig. 8. *Measuring the board thickness at the edges*

of the selected board. By this simple test we aim at seeing the variability in a board thickness on all of the sides. **This simple test can be done regularly at the industry, upon receipt of the imported hardboard panels; at least in 10 random panels.**

2.4. Internal Bond (IB)

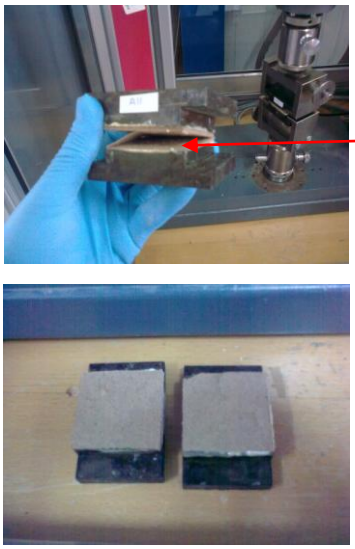
The European standard EN 319 was used in the IB tests. The specimens were measuring dimensions 50mm x 50mm. In total, twenty (20) specimens were very randomly selected from each of the Samples A, Samples B, and Samples C.

Fig. 9. *Prepared cut specimens for IB breaking tests.*

Fig. 10. *Modern, fully automated machine Zwick for panels mechanical testing.*

This IB test is the most important of all; it clearly proves and demonstrates the **glue ability** and **cohesion** of each hardboard panel, that is: *the higher the IB, the better quality wises.*

Specimens cut as in Fig. 9, are glued with a thermoplastic resin and pressed well (Fig. 12). The glued specimens in between 2 metal plates are left to cool down. Afterwards, the specimens will be broken apart, using the *modern Zwick testing equipment* shown in Fig. 10, and disintegrated apart. Actually the successful break-up, is like in that shown in Figs. 11a & 11b, where each glued panel specimen is split in *two distinctive parts*, and not in the surfaces.



a, b

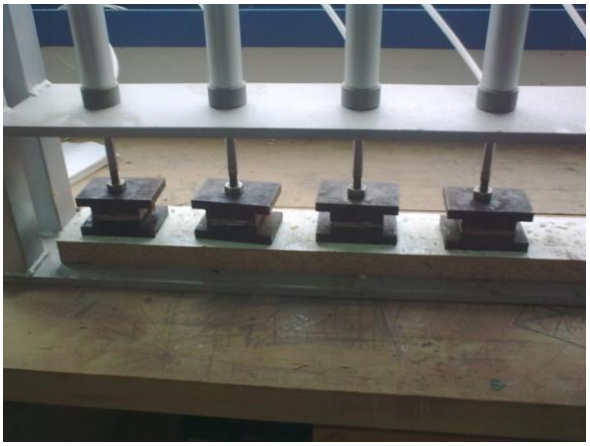
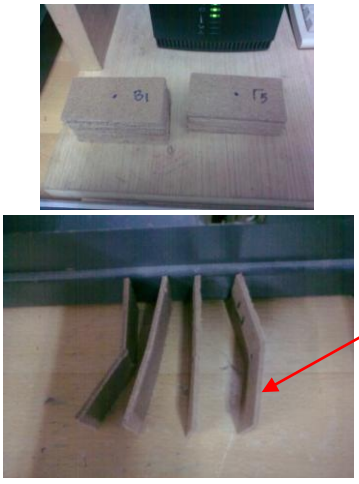


Fig. 11. *(a) Opened specimen after IB test; (b) Disintegrated specimen after bond failure (IB test).*

Fig. 12. *Pressing device for better gluing.*

2.5. Bending strength (MOR)

The European standard EN 310 was used in the MOR tests. The specimens were measuring dimensions 95mm x 50mm. In total, sixteen (16) specimens were selected randomly, from only the Samples B and Samples C.



a,b

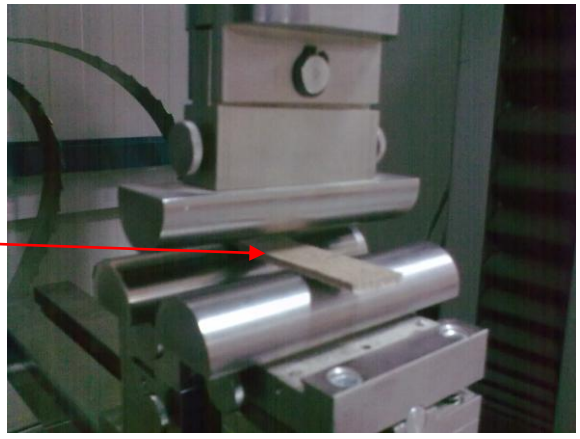


Fig. 13. *(a) Specimens before MOR test; (b) Under deformation, broken specimens after MOR testing.*

Fig. 14. *Zwick device, as in the MOR testing.*

Specimens cut as in Fig. 13a, are forced under a slow vertical pressing in order to measure the maximum force for rupture (Fig. 14). The broken specimens in between the two metallic elements look like deformated, as in Fig. 13b. The speed is very low (that is: 2 mm/min) of the breaking vertical element, and the maximum force (F_{max}) is recorded, while MOR values are estimated using the type: $MOR = (3 F_{max} \times l) / (2 \times b \times h^2)$ **(3)**

2.6. Swelling in water (24h)

The European standard EN 317 was used in the water swelling tests. The specimens were measuring dimensions 50mm x 50mm. In total, sixteen (16) specimens were selected randomly, from the Samples B, and Samples C; also, ten (10) specimens from the Samples A.

a, b

Fig. 15. *(a) Metal basket for swelling tests, (b) Measuring the specimen thickness.*

Fig. 16. *Modern water bath having a controlled temperature meter.*

The specimens were measured in thickness in the beginning *(dry thickness),* let to swell in a bath (Fig. 15a) fully covered with water, being into a metal basket. After 24 hours, the specimens were measured accurately (Fig. 15b) and the *wet thickness* was recorded. The following type was used: **24h swelling (%) = 100 x [(wet th. – dry th.) / dry th.]** **(4)**

2.7. Water absorption (24h)

This test is not included in the European standards; however, it is done regularly according to the standard ASTM D1037, as it was carried out in this work. The specimens were measuring dimensions 50mm x 50mm.

Fig. 17. *Weighing wet specimens*

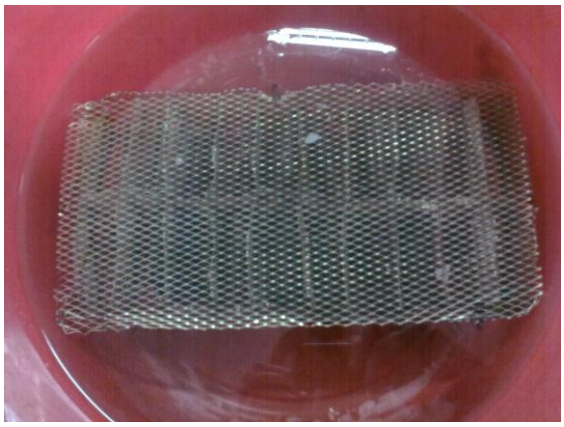


Fig. 18. *Metal basket used for absorption tests.*

In total, sixteen (16) specimens were selected from Samples B and Samples C. An initial *dry weight* was recorded. The specimens then were immersed in a water bath. After 24 hours, the specimens were weighed accurately (Fig. 17) and their *wet weight* was recorded. This type was used: **24h Absorption (%) = 100 x [(wet wgt. – dry wgt.) / dry wgt.] (5)**

2.8. Formaldehyde content (Perforator method)

This test was carried out according to the European standard EN 120. The method estimates the *free formaldehyde content* existing in the hardboard samples.

In Greece, according to the existing law, **only class E1** and lower fibreboard and particleboard products must be imported and used in the market (law: *ΚΥΑ Ζ3-5430/09, ΦΕΚ 746/Β/22-4-2009*).

In this test, small specimens weighing ~110 g, measuring dimensions 25mm x 25mm, were selected randomly, from Samples B and Samples C.

The specimens are extracted with pure toluene in a system called *Perforator* (as in Fig. 19); the free formaldehyde is then extracted off and collected in a water solution. This solution remains over-night in a climatised room and cooled off.

Afterwards, the aqueous solutions are mixed with 2 special chemicals *(ammonium acetate, acetyl acetone)* at specific volumes, and a so-called *Hantzsch reaction* takes place; which gives a yellow-to-green solution depending upon the concentration of formaldehyde captured.

These fibre- board products, namely hardboard Samples B and Samples C are expected to have *minimal formaldehyde contents* since they are produced with the wet-process in which no synthetic resins are added in the gluing process, and only the so-called *"auto-adhesion"* takes place. Then, by using a modern spectrophotometer (Fig. 20a), one can approximate the colour variables and make an assessment of the formaldehyde content per 100g of tested panel.

The two *Perforator tests* were carried at the specialised laboratory (see Figs. 19-20) at the TEI of Larissa, in the dates of 19 and 20 February 2013.

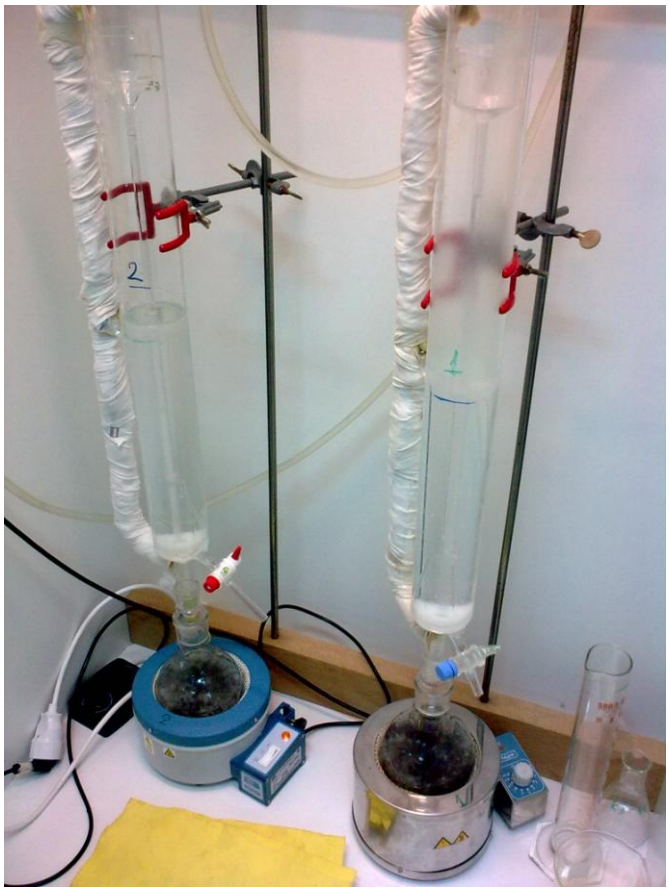


Fig. 19. *A complete double-extracting Perforator equipment at the TEI/Larissa.*

a,b

Fig. 20. *(a) Spectrophotometer used; (b) Chemical toluene & other materials*

3. Results

This chapter incorporates all the testing results found in this study on the hardboard samples investigated, on behalf of industry [redacted] SA.

3.1. Results of moisture content (MC)

From hardboard sample B, eight small samples were measured and the analytical protocol is shown in below Table 1.

Table 1a. *Testing protocol of moisture content of hardboard* ***samples B****.*

Initial weight (g)	*Final dry weight (g)*	
9,754	*9,036*	7,36
9,328	*8,638*	7,40
10,164	*9,425*	7,27
9,328	*8,643*	7,34
9,186	*8,517*	7,28
9,360	*8,679*	7,28

10,354	*9,581*	7,47
9,308	*8,617*	7,42
	Mean	***7,35***
	Standard deviation	*0,07*

The average moisture content of the hardboard **samples B** is **7.35%** which is a value *fully acceptable* for this type of hardboard. It is supposed that these samples arrived at [redacted] SA almost right after production; this explains the low moisture content.

Table 1b. *Protocol of moisture content of deformated hardboard sample (Fig. 6a).*

Initial weight (g)	*Final dry weight (g)*	
3,076	*2,794*	9,17
2,842	*2,580*	9,22
2,969	*2,697*	9,16
3,431	*3,113*	9,27
2,760	*2,508*	9,13
	Mean	***9,19***
	Standard deviation	*0,05*

3.2. Results on Density

The results of the density measurements are shown below in Tables 2a-2b-2c.

Table 2a. *Protocol of density measurements in* ***Samples A****.*

Specimen	Length	Width	Thickness	Mass (g)	Volume (cm3)	**Density** (in kg/m3)
A1	4,961	4,952	0,273	6,579	6,71	*981,0*
A2	4,970	4,954	0,273	6,612	6,72	*983,7*
A3	4,963	4,964	0,273	6,723	6,73	*999,6*
A4	4,976	4,968	0,273	6,628	6,75	*982,1*
A5	4,943	4,962	0,272	6,628	6,67	*993,5*
A6	4,959	4,987	0,271	6,623	6,70	*988,2*
A7	4,949	4,967	0,272	6,547	6,69	*979,2*
A8	4,954	4,978	0,270	6,403	6,66	*961,6*
A9	4,967	4,971	0,272	6,545	6,72	*974,5*
A10	4,968	4,964	0,271	6,587	6,68	*985,6*
A11	4,963	4,981	0,271	6,516	6,70	*972,6*
A12	4,972	4,966	0,274	6,677	6,77	*986,9*
A13	4,975	4,964	0,272	6,721	6,72	*1000,6*
A14	4,963	4,961	0,273	6,591	6,72	*980,6*
A15	4,965	4,966	0,273	6,572	6,73	*976,4*

A16	4,962	4,965	0,273	6,703	6,73	*996,6*
A17	4,968	4,971	0,274	6,590	6,77	*973,9*
A18	4,971	4,950	0,273	6,528	6,72	*971,8*
A19	4,973	4,961	0,275	6,531	6,78	*962,6*
A20	4,965	4,982	0,272	6,559	6,73	*974,9*

MIN	961,6
MAX	1000,6
Mean	**981,3**
AVEDEV	8,5

Table 2b. *Protocol of density measurements in* ***Samples B****.*

Specimen	Length	Width	Thickness	Mass (g)	Volume (cm3)	**Density** (in kg/m3)
B1	4,943	4,964	0,250	6,215	6,13	1013,2
B2	4,937	4,956	0,253	6,233	6,19	1006,9
B3	4,972	4,932	0,262	6,290	6,42	979,0
B4	4,968	4,964	0,259	6,208	6,39	971,9
B5	4,912	4,901	0,283	6,134	6,81	900,4
B6	4,948	4,967	0,261	6,287	6,41	980,1
B7	4,959	4,872	0,270	6,062	6,52	929,3
B8	4,931	4,969	0,262	6,169	6,42	961,0
B9	4,892	4,969	0,270	6,085	6,56	927,1
B10	4,932	4,942	0,263	6,040	6,41	942,2
B11	4,969	4,923	0,257	6,007	6,29	955,5
B12	4,882	4,975	0,262	6,046	6,36	950,1
B13	4,909	4,981	0,265	6,139	6,48	947,4
B14	4,914	4,915	0,276	6,041	6,67	906,2
B15	4,959	4,941	0,255	6,200	6,25	992,3
B16	4,971	4,952	0,260	6,237	6,40	974,5
B17	4,949	4,982	0,267	6,363	6,58	966,6
B18	4,963	4,933	0,286	6,155	7,00	879,0
B19	4,954	4,945	0,284	6,140	6,96	882,5
B20	4,957	4,971	0,266	6,351	6,55	968,9

MIN	879,0
MAX	1013,2
Mean	**948,5**
AVEDEV	30,1

Table 2c. *Protocol of density measurements in* ***Samples C****.*

Specimen	Length	Width	Thickness	Mass (g)	Volume (cm3)	**Density** (in kg/m3)
C1	4,950	4,959	0,246	6,023	6,039	997,4
C2	4,956	4,961	0,245	5,931	6,024	984,6
C3	4,972	4,961	0,243	5,940	5,994	991,0
C4	4,966	4,941	0,242	6,025	5,938	1014,7
C5	4,991	4,964	0,247	5,937	6,120	970,2
C6	4,969	4,972	0,251	6,103	6,201	984,2
C7	4,972	4,963	0,242	6,098	5,972	1021,2
C8	4,974	4,938	0,235	6,049	5,772	1048,0
C9	4,944	4,965	0,252	5,922	5,922	1000,0
C10	4,970	4,946	0,237	6,087	5,826	1044,8
C11	4,955	4,964	0,253	6,053	6,223	972,7
C12	4,944	4,977	0,253	6,047	6,225	971,3
C13	4,945	4,965	0,253	5,895	6,212	949,0
C14	4,931	4,926	0,252	5,808	6,121	948,8
C15	4,964	4,964	0,245	6,152	6,037	1019,0
C16	4,978	4,954	0,246	6,204	6,067	1022,6
C17	4,964	4,928	0,252	5,918	6,165	960,0
C18	4,959	4,963	0,237	6,086	5,833	1043,4
C19	4,959	4,962	0,252	6,006	6,201	968,6
C20	4,968	4,950	0,251	6,035	6,172	977,7

MIN	948,8
MAX	1048,0
Mean	**994,3**
AVEDEV	26,1

Density

- *Samples A showed a mean Density of* ***981,3*** *kg/m^3*
- *Samples B showed a mean Density of* ***948,5*** *kg/m^3*
- *Samples C showed a mean Density of* ***994,1*** *kg/m^3*

The above results from the density measurements are **fully satisfactory**, according to the requirements of standard EN 622-2 (density > 900 kg/m^3).

3.3. Results on Variability in board thickness

As shown in Fig. 8, eight (8) simple thickness measurements were made in a random panel of Samples B only.

The results are shown right in the table below: ***Table 3. Thickness variability***

- *2,64 mm*
- *2,54 mm*
- *2,64 mm*
- *2,76 mm (all these 4 measurements in one side), and*
- *2,77 mm*
- *2,61 mm*
- *2,60 mm*
- *2,57 mm (the last 4 measurements are taken from the opposite side).*

From Table 3, the average thickness of the one (1) panel tested is therefore:

- **mean value**: **2,64 mm**, SD: 0,06

This means that the average thickness is slightly below the desired 2,80 mm, as ordered by [redacted] SA; however the variability of this panel tested is very low, and low is the standard deviation of the results. **The company [redacted] SA is advised to use this simple thickness test (as in Fig. 8) to randomly examine some panels (for instance, 10 samples-panels) every time a new hardboard batch arrives in**.

3.4. Results of Internal Bond (IB)

All three Samples A, B and C were tested for internal bond (IB) properties. **This test is the most important mechanical property shown by a hardboard**; showing its internal strength and cohesion. The IB results are very revealing usually as far as it concerns the quality of the panels brought in. The results are shown in the following Tables 4a, 4b, 4c.

Table 4a. *Internal bond (IB) of hardboard* ***Samples A.***

	Dimensions (mm)		Surface area (mm^2)	Force	**Internal bond**
Sp.	length (b)	width (a)	S=a*b	Fmax (N)	σ=F/ S (N/mm^2)
A1	49,61	49,52	2456,7	2051,2	0,83
A2	49,70	49,54	2462,1	1348,0	0,55
A3	49,63	49,64	2463,6	2226,4	0,90
A4	49,76	49,68	2472,1	1583,7	0,64
A5	49,43	49,62	2452,7	2703,8	1,10
A6	49,59	49,87	2473,1	2363,5	0,96
A7	49,49	49,67	2458,2	1982,1	0,81
A8	49,54	49,78	2466,1	2786,0	1,13
A9	49,67	49,71	2469,1	2734,0	1,11
A10	49,68	49,64	2466,1	2016,5	0,82

A11	49,63	49,81	2472,1	2434,1	0,98
A12	49,72	49,66	2469,1	1531,4	0,62
A13	49,75	49,64	2469,6	2222,2	0,90
A14	49,63	49,61	2462,1	2168,8	0,88
A15	49,65	49,66	2465,6	1430,0	0,58
A16	49,62	49,65	2463,6	1516,9	0,62
A17	49,68	49,71	2469,6	1912,6	0,77
A18	49,71	49,5	2460,6	1200,0	0,49
A19	49,73	49,61	2467,1	2310,6	0,94
A20	49,65	49,82	2473,6	2560,0	1,03

Mean	**0,83**
AVEDEV	0,16

Table 4b. *Internal bond (IB) of hardboard* ***Samples B.***

	Dimensions (mm)		Surface area (mm^2)	Force	**Internal bond**
Sp.	length (b)	width (a)	S=a*b	Fmax (N)	σ=F/ S (N/mm^2)
B1	49,43	49,64	2453,7	3367,2	1,37
B2	49,37	49,56	2446,8	2378,7	0,97
B3	49,72	49,32	2452,2	2558,9	1,04
B4	49,68	49,64	2466,1	2451,7	0,99
B5	49,12	49,01	2407,4	1706,1	0,71
B6	49,48	49,67	2457,7	3031,0	1,23
B7	49,59	48,72	2416,0	1633,4	0,68
B8	49,31	49,69	2450,2	1318,3	0,54
B9	48,92	49,69	2430,8	2196,7	0,90
B10	49,32	49,42	2437,4	1942,1	0,80
B11	49,69	49,23	2446,2	1502,2	0,61
B12	48,82	49,75	2428,8	3878,2	1,60
B13	49,09	49,81	2445,2	3452,0	1,41
B14	49,14	49,15	2415,2	1678,0	0,69
B15	49,59	49,41	2450,2	2216,1	0,90
B16	49,71	49,52	2461,6	2494,0	1,01
B17	49,49	49,82	2465,6	2506,4	1,02
B18	49,63	49,33	2448,2	1935,7	0,79
B19	49,54	49,45	2449,8	1450,7	0,59
B20	49,57	49,71	2464,1	3748,2	1,52

Mean	**0,97**
AVEDEV	0,25

Table 4c. *Internal bond (IB) of hardboard* ***Samples C.***

	Dimensions (mm)		Surface area (mm_2)	Force	**Internal bond**
Sp.	length (b)	width (a)	S=a*b	Fmax (N)	σ=F/ S (N/mm_2)
C1	49,50	49,59	2454,7	1179,3	0,48
C2	49,56	49,61	2458,7	878,4	0,36
C3	49,72	49,61	2466,6	812,6	0,33
C4	49,66	49,41	2453,7	1590,7	0,65
C5	49,91	49,64	2477,5	595,8	0,24
C6	49,69	49,72	2470,6	1389,2	0,56
C7	49,72	49,63	2467,6	1386,9	0,56
C8	49,74	49,38	2456,2	839,0	0,34
C9	49,44	49,65	2454,7	1134,8	0,46
C10	49,70	49,46	2458,2	981,1	0,40
C11	49,55	49,64	2459,7	920,9	0,37
C12	49,44	49,77	2460,6	653,0	0,27
C13	49,45	49,65	2455,2	786,2	0,32
C14	49,31	49,26	2429,0	768,0	0,32
C15	49,64	49,64	2464,1	1207,5	0,49
C16	49,78	49,54	2466,1	1450,0	0,59
C17	49,64	49,28	2446,3	715,4	0,29
C18	49,59	49,63	2461,2	1549,0	0,63
C19	49,59	49,62	2460,7	1568,0	0,64
C20	49,68	49,5	2459,2	1426,2	0,58

Mean	**0,44**
AVEDEV	0,12

Internal bond (IB)

- *Samples A showed a mean IB of* ***0,83*** *N/mm^2*
- *Samples B showed a mean IB of* ***0,97*** *N/mm^2*
- *Samples C showed a mean IB of* ***0,44*** *N/mm^2*

Samples B are quality wises **the best** as far as it concerns IB properties. Samples A are also of high strength bond quality. **Both samples A and B have superior IB strength, far higher than the limit of 0,50 N/mm^2**, which is the *requirement* of standard EN 622-2 for IB. **Samples C are of very low IB quality**, **below** the minimum IB limits of the said EN 622-2 standard.

3.5. Bending strength (MOR) results

From Samples B & C, 16 random samples from panels selected, were cut for the experiments in the *Zwick* device. Each sample was measuring dimensions approx. 95mm (length) x 50mm (width). All samples were taken accidentally from centered parts of panels.

Table 5a. *Bending strength (Modulus of rupture) of hardboard* ***Samples B.***

Specimen	Dimensions *height (mm)*	*width (mm)*	*length (mm)*	*span (mm)*	F_{max} (N)	Bending strength σ=3Fl /2bh2 (N/mm^2)
B1	2,91	49,50	95	45	218,1	35,1
B2	2,86	49,79	95	45	235,6	39,0
B3	2,83	47,80	95	45	237,1	41,8
B4	2,84	49,13	95	45	229,4	39,1
B5	2,94	49,27	95	45	228,6	36,2
B6	2,71	49,17	95	45	216,2	40,4
B7	2,66	48,11	95	45	243,9	48,4
B8	2,66	48,96	95	45	267,3	52,1
B9	2,78	49,65	95	45	271,8	47,8
B10	2,81	49,76	95	45	267,7	46,0
B11	2,66	48,94	95	45	202,5	39,5
B12	2,65	49,05	95	45	261,3	51,2
B13	2,69	49,06	95	45	290,5	55,2
B14	2,95	49,28	95	45	222,2	35,0
B15	3,02	49,63	95	45	202,3	30,2
B16	3,09	49,54	95	45	222,2	31,7

* *speed 2mm/min LE 390*

min	30,2
max	55,2
mean	**41,8**
SD	7,5

Table 5b. *Bending strength (Modulus of rupture) of hardboard* ***Samples C.***

Specimen	Dimensions *height (mm)*	*width (mm)*	*length (mm)*	*span (mm)*	F_{max} (N)	Bending strength σ=3Fl /2bh2 (N/mm^2)
C1	2,66	49,47	95	45	178,4	34,4
C2	2,52	49,61	95	45	168,9	36,2
C3	2,56	49,40	95	45	161,8	33,7
C4	2,52	49,44	95	45	163,1	35,1
C5	2,52	49,37	95	45	168,3	36,2
C6	2,53	49,44	95	45	181,9	38,8
C7	2,73	49,30	95	45	144,8	26,6
C8	2,50	49,19	95	45	130,5	28,7
C9	2,50	49,39	95	45	133,6	29,2
C10	2,54	49,27	95	45	151,6	32,2
C11	2,70	49,06	95	45	136,5	25,8
C12	2,71	49,48	95	45	152,5	28,3
C13	2,65	48,10	95	45	158,6	31,7
C14	2,74	49,26	95	45	142,1	25,9

C15	2,58	49,41	95	45	169,6	34,8
C16	2,53	49,03	95	45	167,9	36,1
			96			

min	25,8
max	38,8
mean	**32,1**
SD	4,2

* *Speed 2mm/min LE 390*

Bending strength (MOR)

- *Samples B showed an average MOR of **41,8** N/mm²*
- *Samples C showed an average MOR of **32,1** N/mm²*

Therefore, **Samples B are** quality wises **much better** than the **Samples C**, as far as it concerns bending strength properties. **Both samples B and C are above the limit of 30 N/mm²**, which is the *requirement* of standard EN622-2 for bending strength.

3.6. Results of Swelling in water (24h)

Hardboard specimens from Samples B and Samples C, after a 24-hour swelling in water, have given the following results presented in below Tables 6a & 6b.

Table 6a. *24-hour water swelling results of hardboard **Samples B**.*

Initial thickness (mm)	*Final thickness (mm)*	*24h Thickness Swell (%)*
2,66	*3,27*	22,93
2,63	*3,27*	24,33
2,64	*3,28*	24,24
2,64	*3,28*	24,24
2,64	*3,26*	23,48
2,69	*3,36*	24,91
2,59	*3,21*	23,94
2,59	*3,21*	23,94
2,58	*3,24*	25,58
2,60	*3,27*	25,77
2,59	*3,28*	26,64
2,60	*3,22*	23,85
2,61	*3,24*	24,14
2,58	*3,22*	24,81
2,63	*3,25*	23,57
2,62	*3,23*	23,28
	Mean	***24,3***
	SD:	*1,0*

Table 6b. *24-hour water swelling results of hardboard **Samples C.***

Initial thickness (mm)	*Final thickness (mm)*	*24h Thickness Swell (%)*
2,57	*3,50*	36,19
2,59	*3,47*	33,98

2,63	*3,52*	33,84
2,51	*3,43*	36,65
2,53	*3,43*	35,57
2,56	*3,40*	32,81
2,49	*3,40*	36,55
2,52	*3,43*	36,11
2,63	*3,54*	34,60
2,57	*3,53*	37,35
2,55	*3,48*	36,47
2,48	*3,34*	34,68
2,64	*3,54*	34,09
2,79	*3,87*	38,71
2,71	*3,67*	35,42
2,71	*3,68*	35,79
	Mean	***35,5***
	SD:	*1,5*

24-hour swelling in water

- *Samples B showed 24h swelling: **24.3**%*
- *Samples C showed 24h swelling: **35.5**%*

Therefore, **Samples B are** quality wises **much better** than the **Samples C**, as far as it concerns the water swelling properties. **Both samples B and C are below the limit of 37%**, which is the *strict requirement* of standard EN622-2 for the 24h water swelling.

The **old** Samples A were also measured (Table 6c), for 24h swelling and gave a mean value of **31,4**% which is very acceptable value actually.

Table 6c. *24-hour water swelling results of hardboard* ***Samples A.***

Initial thickness (mm)	*Final thickness (mm)*	*24h Thickness Swell (%)*
2,75	*3,57*	29,82
2,72	*3,59*	31,99
2,74	*3,66*	33,58
2,73	*3,56*	30,40
2,73	*3,56*	30,40
2,79	*3,67*	31,54
2,78	*3,67*	32,01
2,79	*3,67*	31,54
2,80	*3,68*	31,43
2,74	*3,60*	31,39
	Mean	***31,4***
	SD:	*1,05*

3.7. Results of Water absorption (24h)

Hardboard specimens from Samples B and Samples C, after a 24-hour water absorption test, have given the following results presented in below Tables 7a and 7b.

Table 7a. *Water absorption results of hardboard* ***Samples B****.*

Initial (dry) mass (g)	*Final (wet) mass (g)*	*24h Water absorption (%)*
6,213	*9,291*	49,54
6,177	*9,278*	50,20
6,192	*9,334*	50,74
6,112	*9,173*	50,08
6,291	*9,342*	48,50
6,139	*9,374*	52,70
6,127	*9,225*	50,56
6,207	*9,295*	49,75
6,049	*9,130*	50,93
6,131	*9,241*	50,73
6,198	*9,173*	48,00
6,217	*9,217*	48,25
6,101	*9,053*	48,39
6,050	*9,079*	50,07
6,177	*9,242*	49,62
6,161	*9,114*	47,93
	Mean	***49,7***
	SD:	*1,3*

Table 7b. *Water absorption results of hardboard* ***Samples C.***

Initial (dry) mass (g)	*Final (wet) mass (g)*	*24h Water absorption (%)*
5,955	*8,780*	47,44
5,905	*8,759*	48,33
5,990	*8,939*	49,23
5,890	*8,902*	51,14
6,063	*8,930*	47,29
5,970	*8,726*	46,16
5,855	*8,772*	49,82
5,930	*8,876*	49,68
5,944	*8,825*	48,47
5,932	*8,983*	51,43
5,928	*8,827*	48,90
5,994	*8,786*	46,58
5,949	*8,951*	50,46
6,070	*9,540*	57,17
5,931	*9,050*	52,59
5,819	*8,948*	53,77
	Mean	***49,9***
	SD:	*2,9*

24-hour Water absorption

- *Hardboard Samples B exhibited water absorption (24h):* ***49.7****%*
- *Hardboard Samples C exhibited water absorption (24h):* ***49.9****%*

Samples B are *statistically* **the same** with the **Samples C** in respect to the water absorption property. **Both samples B and C are higher than 40%**, which means that both **do not comply** with the *qualities* offered by the producer to [redacted] SA.

3.8. Results of Formaldehyde content using the Perforator method

For the hardboard Samples B & Samples C, the following (see Tables 8a and 8b) results from *Perforator method* were obtained. **Both boards belong to E0 class**.

Table 8a. *Perforator test results of hardboard* ***Sample B****.*

	Perforator method (EN 120)	
	Hardboard **Sample "B"**	mean
Date of test	19.02.2013	
Total mass of specimens (g)	115,8997	
Mean MC (%)	7,55%	
Concentration of blank sample	1,625	
Concentration of test sample (mg/l)	1,697	
Perforator value at MC (mg/100g)	0,134	0,134
Corrected Perforator value (6,5%)	**0,114**	**0,114**

Moisture content of specimens

	1	*2*	*3*	*4*	*5*		
Initial mass (g)	*1,3927*	*1,4638*	*1,4551*	*1,4844*	*1,4752*		*Mean MC*
Final dry mass (g)	*1,2945*	*1,3606*	*1,3529*	*1,3805*	*1,3723*		
Moisture content (%)	*7,59%*	*7,58%*	*7,55%*	*7,53%*	*7,50%*		*7,55%*

Table 8b. *Perforator test results of hardboard* ***Sample C****.*

	Perforator method (EN 120)	
	Hardboard **Sample "C"**	mean
Date of test	19.02.2013	
Total mass of specimens (g)	116,6014	
Mean MC (%)	6,75%	
Concentration of blank sample	1,625	

Concentration of test sample (mg/l)	1,661	
Perforator value at MC (mg/100g)	0,066	0,066
Corrected Perforator value (6,5%)	**0,063**	**0,063**

Moisture content of specimens

	1	*2*	*3*	*4*	*5*		
Initial mass (g)	*1,4008*	*1,3844*	*1,4265*	*1,3933*	*1,3724*		*Mean MC*
Final dry mass (g)	*1,3103*	*1,2971*	*1,3384*	*1,3051*	*1,2851*		
Moisture content (%)	*6,91%*	*6,73%*	*6,58%*	*6,76%*	*6,79%*		*6,75%*

4. Conclusions

The results of this full report are summarised altogether in the below Table 9.

Table 9. *Comparative results of the hardboard samples as measured in this work.*

Property measured (unit)	***Samples A***	***Samples B***	***Samples C***
Moisture content, MC (%)	---	**7,35**	---
Density (kg/m^3)	**981,3**	**948,5**	**994,1**
Internal bond, IB (N/mm^2), EN 310	**0,83**	**0,97**	**0,44**
Bending strength, MOR (N/mm^2), EN 310	---	**41,8**	**32,1**
24h Thickness Swelling (%), EN 317	**31,4**	**24,3**	**35,5**
24h Water Absorption (%) *	---	**49,7**	**49,9**
Formaldehyde content (mg/100g), EN 120	---	**0,133 (E0 class)**	**0,063 (E0 class)**

* *Important note:* ***No requirement*** *exists for this property in the EN 622-2.*

The *technical tests* carried out in this study, have led to the following final conclusions:

- Samples A are of **very good** quality; with excellent mechanical IB strength.
- Samples B are also of **very good quality**; with excellent IB properties; only the water absorption is 49,7%, which is not in accordance with the [redacted] factory *guarantee* of <40%.
- **Samples C have poor properties** *(e.g. not acceptable IB; high swelling; high water absorption; quite low MOR).* The IB strength is very low; *that explains the* ***low bonding strength*** *and the frequent breaking off of the panel edges.*

- Typically, Samples C **should** be avoided from production due to the inferior quality properties shown in here.
- Samples B and Samples C belong to **Class E0**, according to EN-120 standard regarding formaldehyde content; separate documents will be sent to [redacted] SA, in Greek language, to use them in the inside Greek market *(when necessary).*

Final suggestions for the industry [redacted] S.A.

✓ [redacted] **SA must arrange a closed area of storage room**; well closed from high relative humidity of air, in order to safely store there the wet-process hardboard panels which are **very sensitive** products. Extremely sensitive to high humidities.

✓ This covered wearhouse should be an inside area. **That outdoor area used today is fully inappropriate for storing the hardboard panels**. [redacted] SA should arrange for a wearhouse with average temperature of 15-16°C and relative humidity lower than 60%. The company should invest on this important topic.

✓ **A continuous quality control of the raw materials used is suggested therefore**. This control testing can be done once or twice each month, in randomly selected hardboard samples (note: 2 basic properties are needed to be checked only, and not a full series of quality control).

✓ **Specific property guidelines should be given** to the [redacted] hardboard supplier [redacted]; this list should include the *minimum acceptable properties* for the hardboard products of ~2.8 mm. The *Lab of Wood Technology* can supply this necessary *technical feedback* to [redacted] SA.

✓ **An English review of the quality tests performed at TEI/Larissa may be sent to the [redacted] hardboard producer** so as they know that their products are being checked regularly in Greece, by an authorised *Wood Technology* lab.

✓ Finally, **the company [redacted] SA can easily establish an *internal quality control system*** in order to check the properties of hardboard received; preferably, most suitable is to check e.g. moisture content; 24h swell in water; 24h water absorption, simple tests to be performed *in-house*. However, the most important property of

hardboard remains the very special IB (internal bond) test according to standard EN 319, and

- ✓ We suggest to [redacted] SA: **to invest in small quality control equipment**; that is: a) an electronic caliper (for thickness measurements), b) an accurate balance; three-decimal points; c) a laboratory dryer for measuring the moisture content of the raw materials; thus, simple tests can be performed in-house for [redacted] SA.

Karditsa, 21-02-2013

We verify this herein

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