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INFLUENCE OF CLIMATIC CONDITIONS ON THE MECHANICAL AND PHYSICAL PROPERTIES OF PARTICLEBOARD PRODUCED AT THE TELAGH FACTORY (WESTERN ALGERIA)

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Abstract:

This study allowed us to have an indication on the particleboard produced at the Telagh factory. The physical and mechanical properties of the panels subjected to this study have the values below the standard conditions. These panels are arranged in 10 lots and exposed in three sites with different climatic conditions during 30, 60 and 90 days.

During the 90-day experimental period, the test pieces placed in stable laboratory conditions (20°C & 65% RH) show a better MOR. Particleboard of the continental station (3) which has an unstable relative humidity (37%; 65%; 54.5%) and temperature (27°C; 22°C; 18°C) between the three months take greater ST and WA. In the moist area of the coastal station (2), the panel loses its IB; he becomes denser and present a high WA.

The mechanical properties decreased in time for all specimens no matter the site. Great changes were observed for physical properties due to high RH and its variation (site 2 and 3) compared to the reference specimens.

Key words: *particleboard; climatic conditions; physical and mechanical properties.*

INTRODUCTION

The use of a synthetic resin allowed the development of fibrous resources such as particleboard held in Bremen, Germany in 1941. A volume of more than 99 million m^3 of particleboard produced in 2013 (FAO 2014) is proves of the importance of this material in many uses like furniture industry, buildings, packaging (Youngquist and Hamilton 2000, Elbadawi *et al.* 2014). This industry use as fibrous raw material: by-products of silvicultural operations and waste from other chains of wood transformation (Jaudon 1970, Copur *et al*. 2007, Thoemen *et al*. 2010). In addition, the use of lignocellulosic resources outside the wood raw material has a great importance (Akyildiz *et al*. 2015).

Starting from 1976, Algeria has installed particleboard factories where the Aleppo pine forests are important, this species cover 850000ha and its treatment requires the valorization of small woods in trituration (Letreuch 1995). There are four factories: Béjaia (17500m^3/year), Khenchla (17500m^3/year), Djelfa (30 000m^3/year) and Telagh (30000m^3/year).

Other than lignocellulosic material, the manufacture of particleboard requires glue, paraffin and hardener (Copur *et al*. 2007, Thoemen *et al*. 2010, Melo 2014). Manufacturing conformity is realized by testing the physical and mechanical properties of the product at the end of the production (Jaudon 1970, Garay 2009, Laemlaksakul 2010, Melo 2014, Felix *et al*. 2015).

In order to better understand the correlation between the climate variability and the use of particleboards, the objective of this work is to analyze its comportment according to the temperature and relative humidity conditions in which it is placed. We chose the Telagh factory located in the west of Algeria as study case.

MATERIALS AND METHODS

General consideration

The raw material of this study consisted of Aleppo pine (40%), Eucalyptus (20%) collected from the forests of the western region of Algeria and others wood wastes and residues based on fir, beech, elm and poplar core (10%). Per m^3 of finished panels, 58kg of thermosetting glue of urea-formaldehyde type and 6.5kg of ammonium chloride, ammonia and hydrophobic products are used.

The Telagh factory produces the three-layer particleboard, its density is 650kg/m^3 and finished panel dimension: 3660x1830x19mm. The pressing conditions were as follows; number of the press floor: 05, maximum operating pressure: 310kg/cm^3, closing speed of press: 200mm/s. compression speed of press: 10.8 to 3.2mm/s. high-pressure speed: 0.7mm/s, opening speed: 150mm/s and power: 120Kwh.

Mechanical and physical properties of manufacturing control are: Modulus of rupture (MOR) (NF EN 310); Internal bond (IB) (NF EN 319); Density (NF EN 323), thickness swelling (TS) and water absorption (WA) (NF EN 317).

Depending on the availability of climatic parameters to be studied, the sites designated to analyze the evolution of the particleboard properties are:

- The factory laboratory with a temperature of 20°C and relative humidity of 65%.
- The locality of Beni Saf, a coastal town located at 200km in the north of the factory; During the test period, relative humidity and temperature recorded are (79%; 81.5%; 78.5%) and (25°C; 23.5°C; 20°C).
- The locality of Ain El Djouher, an inland town located at 30km south of the factory. During the test period, relative humidity and temperature recorded are (37%; 65%; 54.5%) and (27°C; 22°C; 18°C).

NB: In the last two stations, the specimens are placed in a weather shelter model BMO1161.

The test results are compared with the values presented in standards as are shown in Table 1:

Table 1

Control standards for manufactured particleboard panel

Characteristics	UM	Specimens number	Specimens dimensions (mm)	Standard	Values	
MOR	N/mm^2	10	340 x 75 x 19	NF EN 310	> 16	
Density	kg/m^3	10	340 x 75 x 19	NF EN 323	minimal	< 650
					average	650 - 750
					maximal	≥ 75O
IB	N/mm^2	05	50 X 50 x 19	NF EN 319	> 0,55	
TS after 24 & 48h	(%)	05	100x100 x19	NF EN 317	average	≤ 12
					maximal	≤ 15
WA after 24 & 48h	(%)	05	100x100 x19	NF EN 317	≤ 64	

Preparation of test specimen

After finishing operation, five panels were taken at intervals of 24 hours. The cutting of the particleboards into test pieces is determined according to CTB-P (2016). Fig. 1 illustrates this operation.

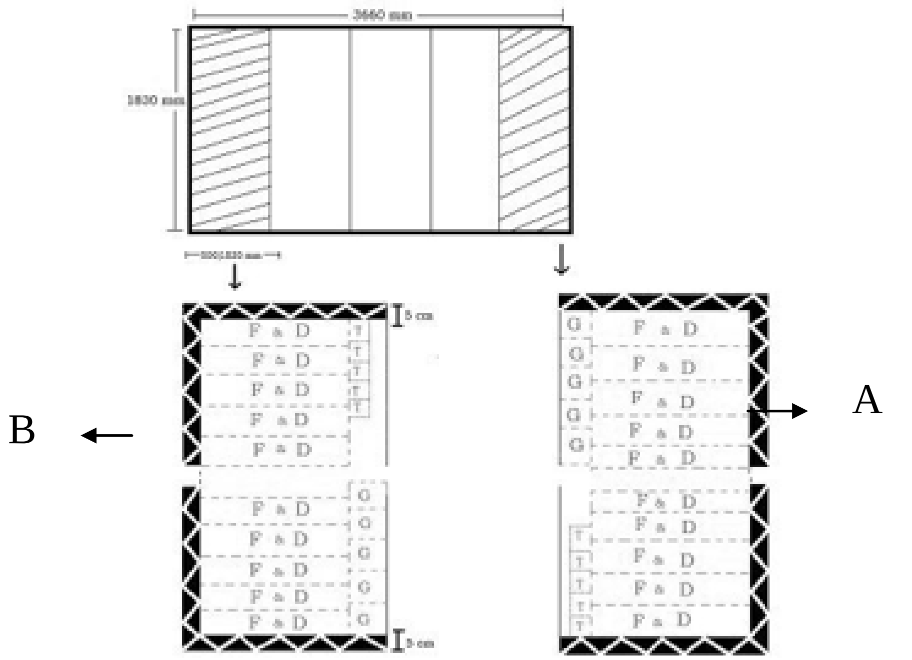

Fig. 1.
Scheme of sampling: A: Factory control samples; B: Samples for experimental protocol; F & D: samples for MOR and density; T: samples for IB; G: samples for TS & WA.

The experimental period takes three months, all test pieces were randomly divided into 10 lots of tests. The first lot consists of reference test pieces "Witnesses" which is tested in the laboratory of the factory, just after the operations of cutting and designation of the lots. Reference lot is composed of 10 samples for the tests of the density and MOR, 5 specimens for the test of the IB and 05 other test specimens for TS and WA tests. The other lots (09) are randomly and equitably distributed on other three observation sites. Placement of the test pieces at the observation sites took place on 10 August, after 30, 60 and 90 days. The order of passage through the sites to take the test specimens is presented in Table 2.

Table 2

Number of specimens and the passage order in the lots

Sites	30 days			60 days			90 days		
	D & F	T	G & A	D & F	T	G & A	D & F	T	G & A
factory laboratory	10	05	05	10	05	05	10	05	05
Beni Saf	10	05	05	10	05	05	10	05	05
A.Djouher	10	05	05	10	05	05	10	05	05

D&F: density and MOR; **T**: IB; **G&A**: TS & WA.

RESULTS AND DISCUSSIONS

The results are presented in Table 3, Table 4 and Table 5. Table 3 shows the results of the mechanical and physical properties of the panel test specimens manufactured at the Telagh factory. Beginning August 10 and in 30 days intervals, the average conditions of the places designated to follow the evolution of the properties are shown in (Table 4). The results of the evolution of the properties of the particleboard produced at the Telagh factory are presented in (Table 5).

Table 3

Mechanical and physical properties of the particleboard panel test specimens "control lot"

Properties	Values				
	average	SD	CV(%)	min	max
MOR (N/mm^2)	12.63	*3.09*	*24.51*	*69.87*	*174.84*
***I B* (N/mm^2)**	0.28	0.02	8.20	2.60	3.2
Density (kg/m^3)	625.57	*38.36*	*6.13*	531.96	*664.84*
TS after 24 h (%)	9.31	3.28	35.21	5.97	14.74
TS after 48 h (%)	11.46	3.47	30.31	8.46	17.36
WA after 24 h (%)	87.35	8.12	9.28	77.69	97.6
WA after 48 h (%)	89.12	7.64	8.57	80.00	99.2

CD: standard deviation**; CV:** coefficient of variation**; min:** minimal; **max:** maximal.

Table 4

Average conditions of the temperature (T) and relative humidity (HR) of the study stations

	30 days		60 days		90 days		Average	
	T° (°C)	HR (%)	T° (°C)	HR (%)	T° (°C)	HR (%)	T° (°C)	HR (%)
Station 1 of laboratory	20	65	20	65	20	65	20	65
Station 2 of Beni Saf	25	79	23.5	81.5	20	78.5	22.83	79.66
Station 3 of A.Djouher	27.5	37	22.5	65.5	18	54.5	22.66	52.33

The data collected from the meteorological stations in which the test specimens were placed show that the station (2) has a stable and higher humidity level (79%; 81.5%; 78.5%) compared with the station (3) which has an unstable relative humidity (37%; 65%; 54.5%) and temperature (27°C; 22°C; 18°C) during the three months of observation. The difference between extreme temperatures is greater in the continental station (3), 9.5°C compared to 5°C for the littoral station (2).

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Table 5

Evolution of the properties of the particleboard produced at the Telagh factory

Station	Time (day)	MOR (N/mm^2)	IB (N/mm^2)	Density (kg/m^3)	TS (%)		WA (%)	
					24h	48h	24h	48h
Witnesses	1	12.63	0.28	625.57	9.31	11.46	87.35	89.12
Station 1 of laboratory	30	10.23	0.32	630.68	9.53	10.35	86.49	91.19
	60	11.42	0.23	644.93	7.29	7.65	81.59	84.10
	90	11.56	0.23	630.39	7.05	7.67	81.01	83.67
Station 2 of Beni Saf	30	8.03	0.29	601.74	6.97	8.32	74.62	79.50
	60	8.99	0.31	625.45	7.13	7.37	84.59	87.32
	90	9.51	0.20	643.71	9.01	9.40	88.40	89,79
Station 3 of A.Djouher	30	10.02	0.31	626.74	8.70	8.80	87.48	99.494
	60	8.29	0.26	617.85	7.25	7.76	77.50	80.57
	90	7.39	0.23	622.75	8.24	9.00	92.86	95.20

Discussion of control lot results

MOR of control lot panel manufactured at the Telagh factory is $12.63N/mm^2$, it is less than the value indicated in standard (Table 1). We consider that the low MOR is caused by one of these parameters of the external layer particles witch influence this propriety: particles moisture > 2.5%, particles larger than normal or a gluing >10.5%. IB is $0.28N/mm^2$, it's also less than the value indicated in standard (Table 1). The sizes, the quality and the gluing of the particles of the inner layer can explain IB: particles moisture >1%, particles larger than normal or a gluing >8.5%. Ashori and Nourbakhsh (2008) estimate that the pressing cycle influence also mechanical properties of the particleboards. (Jaudon 1970, Nemli and Aydın 2007, Thoemen *et al*. 2010) note that the mechanical and physical properties of particleboard are related to lignocellulosic material used. (Nemli and Aydın 2007, Copur *et al*. 2007, Thoemen *et al*. 2010) mention that the IB between the particles and lack of mastery of manufacturing technology cause decreasing of mechanical properties and other characteristics. Thoemen *et al*. (2010) estimate that for a single specie MOR increase with compaction.

The density of the panel manufactured in Telagh is $625.57kg/m^3$, less than the minimum standard of $650kg/m^3$. The particleboard density is linked with the density of the raw material, conformation and the pressing parameters. The density determines the physical and mechanical properties of the particleboard (Dias *et al*. 2005, Thoemen *et al*. 2010). High-density particleboards have lower porosity so that particles and adhesives can interact with each other more easily to form stronger crosslink (Zheng *et al*. 2006).

The results of the physical tests are respectively 9.31% and 11.46% for the TS after 24h and 48h and 87.35% and 89.12% for WA after 24h and 48h. Compared to Table 1, these results are considered acceptable only for TS. The high WA may be related to the low density and the low compaction of the particles of the inner layer or a consequence of a poor gluing and to the non-control of hydrophobic products (Kalaycioglu 1992, Copur *et al*. 2007, Thoemen *et al*. 2010, Guler and Buyuksari 2011).

Evolution of MOR

The Fig. 2 and the Table 5 shows that the best resistance to MOR are the test pieces of the control lot. In stable conditions of temperature and HR of the laboratory, the results are better than the other two stations. The coastal station (2) of Beni Saf with the high level of HR (79.66%, +/- 1.5%), the resistance to MOR becomes low during the first 30 days. Later, the resistance to MOR improves. In the station (3) with low HR (52.33%, +/- 15%) the resistance to MOR tends to decrease with time.

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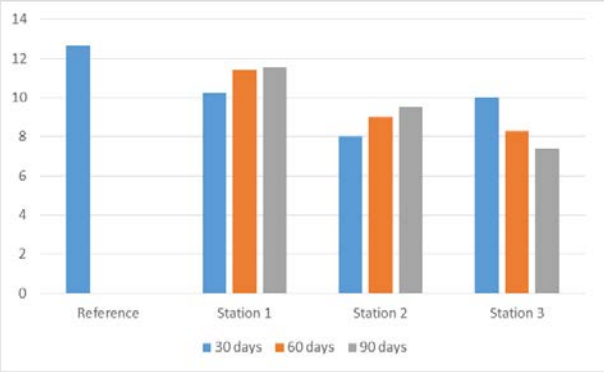

Fig. 2.
Evolution of the MOR of the particleboards according to the stations:
Station 1 of laboratory; Station 2 of Beni Saf; Station 3 of A. Djouher.

The evolution of the MOR is linked to the test results of the test specimens "Witnesses" which are low compared to the test standards of the 19mm thick panels. This situation is a consequence of the manufacturing conditions, which lead to low density panel (raw material and pressing). Medved *et al.* (2010) note that wood particles are not only one responsible for swelling but also the conditions under which they are pressed into board. The low density gives a porous particleboard and the wood particles once in contact with moisture tend to increase the thickness. When the particle moisture is increased, the urea-formaldehyde adhesive loses its adhesive effect. The panels least exposed to the action of constant relative humidity are the most resistant, as is the case with the panels of station 1of laboratory. The fluctuation of relative humidity and even if it is low is detrimental to particleboards, as is the case with the panel of station 3 of A. Djouher. In controlled experimental conditions, (Hann *et al*. 1963) showed that a cyclic exposure of T°C and HR caused much more deterioration than continuous exposure. According to Medved *et al.* (2006) the interaction between moisture and the particleboard leads to the development of swelling stresses that cause the failure of the resin bond and the dislocation of the particles within the panel.

Evolution of IB

The results of IB presented in Fig. 3 and Table 5 are in their majorities qualified as mean (≥2.5Kg/cm^2). About the evolution of this property, the highest resistances in the three stations are obtained during the first 30 days. In the station (2) of Beni Saf with an important HR, the decrease of IB is more visible. The high HR decreases the bond between adhesive and wood particles and lead to deterioration of adhesive and failure due to repetitive shrinkage and swelling due to variable conditions and more particularly in the third month.

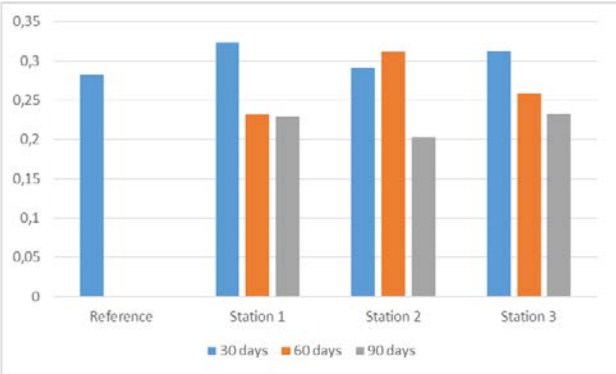

Fig. 3.
Variation of IB on specimens and site exposure:
Station 1 of laboratory; Station 2 of Beni Saf; Station 3 of A. Djouher.

Evolution of the density

The density values presented in Fig. 4 and Table 5 are below the reference of 650kg/m^3. This is due in part to the use of Eucalyptus wood in a proportion higher than normal (50% against 30%). The evolution of density over time, shows a certain stability of the specimens placed under stable conditions of T°C and HR (station 1 of laboratory) and under dry conditions (station 3 of A. Djouher). The panel placed in the station (2) of Beni Saf increase in density with time. The high HR cause an increase of moisture and of thickness due to

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porosity of panels. Due to the low flow rate of the gluing due to the blocking of the nozzles of the gluing machine, the low presence of paraffin on wood particles had influence on the performance of samples in humid conditions.

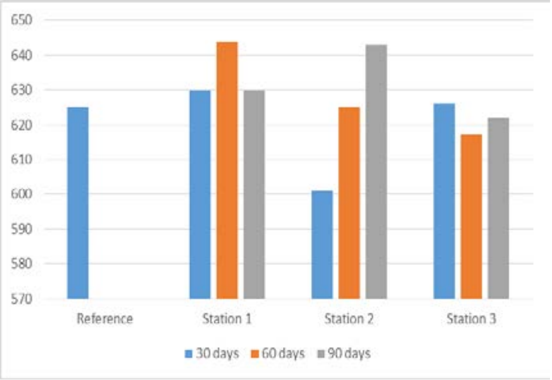

Fig. 4.
Variation of the density on specimens and site exposure:
Station 1 of laboratory; Station 2 of Beni Saf; Station 3 of A. Djouher.

Evolution of TS

The results of TS tests after 24 hours and 48 hours of immersion in water presented in Fig. 5, Fig. 6 and Table 5 are in their majorities lower than the mean value (≤12%). The best results are those of the test panel of the station (2) of Beni Saf and the poorest ones are those of the station (3) of Ain Djouher. Under the effect of moisture, the dry wood particles tend to resume their initial volume and stops at fiber saturation point, the panel placed in dry places show some need to moisture and take greater swelling in thickness.

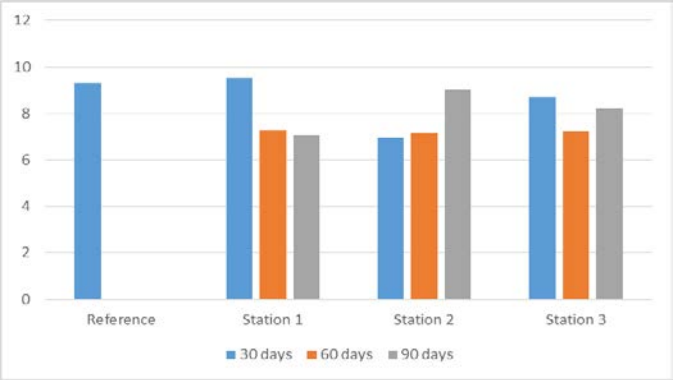

Fig. 5.
Variation of TS after 24 h on specimens and site exposure:
Station 1 of laboratory; Station 2 of Beni Saf; Station 3 of A. Djouher.

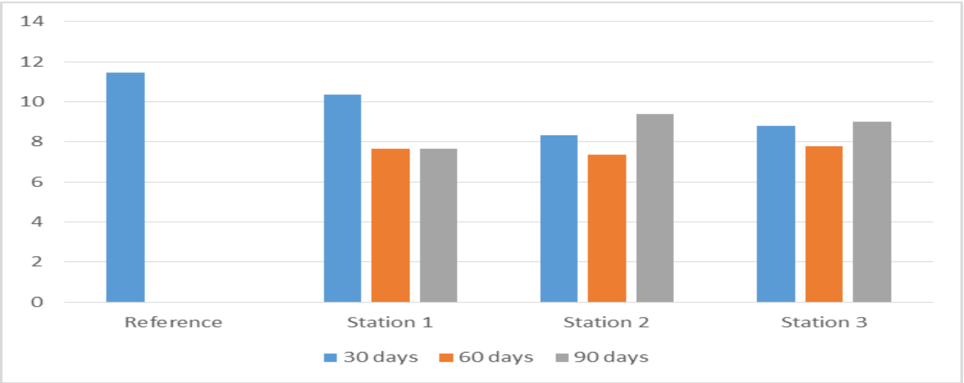

Fig. 6.
Variation of TS after 48h on specimens and site exposure:
Station 1 of laboratory; Station 2 of Beni Saf; Station 3 of A. Djouher.

Evolution of WA

The results of WA tests after 24 hours and 48 hours of immersion in water presented in Fig. 7 and Table 5 are in their majorities above the mean value (≤64%). When we compare the mean values of the samples from the three sites with references, we note that the panel absorbs less than the control panel in station 1 of laboratory (- 4.32%). In this same site, the level of absorption of the last two periods stabilized at 81%. In station 3 of A. Djouher and after 90 days, the panel shows a high affinity to water after 24 hours of immersion and absorbs 05.51% more than the control panel. As long as the absorption is determined by the quality of the inner layer, the results suggest poor quality of this layer. With time, the humidity lowers the adhesiveness of the glue (Hann *et al*. 1963, Zhang *et al.* 2011).

The best results are those of the test panel of the station (2) of Beni Saf and the poorest ones are those of the station (3) of Ain Djouher. For this purpose, the test panel placed also in dry places show some need for moisture and absorb more. As long as the absorption is determined by the quality of the inner layer, the results suggest poor quality of this layer.

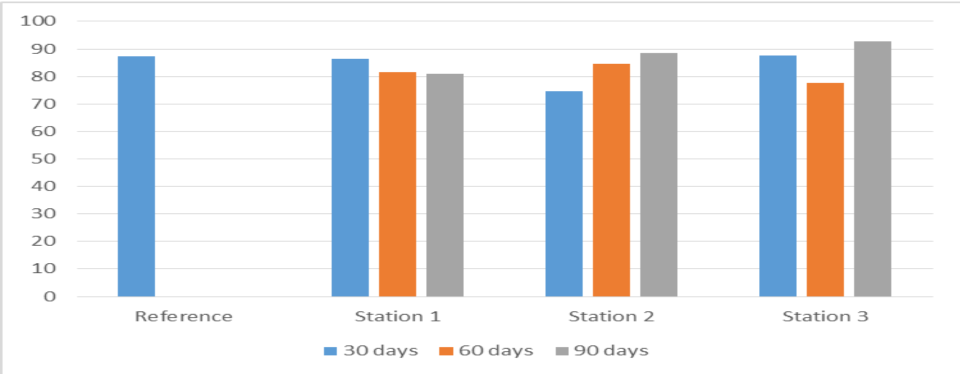

Fig. 7.
Variation of the WA after 24 h on specimens and site exposure:
Station 1 of laboratory; Station 2 of Beni Saf; Station 3 of A. Djouher.

Variance analysis

The Analysis of the variance of the effect of the station on the mechanical and physical properties of particleboards produced at the Telagh factory (Western Algeria) is given in Table 6:

Table 6

Effect of the station on the properties of the particleboards

Proprieties		Average				SD				CV (%)				F-value (5%)		
		Ref	St.1	st.2	St.3	Ref	St.1	st.2	St.3	Ref	St.1	st.2	St.3	F.obs	F.the	diff
MOR (N/mm^2)		12.63	11.03	8.84	8.53	*3.09*	4.12	3.13	2.48	*24.51*	37.33	35.32	31.11	4.856	1.96	S
IB (N/mm^2)		0.28	0.25	0.26	0.27	0.02	0.07	0.07	0.04	8.20	15.33	27.15	13.24	0.052	1.96	NS
Density (Kg/m^3)		625.57	635.33	623.56	622.43	*38.36*	54.45	56.16	43.56	*6.13*	8.61	9.11	6.98	0.55	1.96	NS
TS (%)	24h	9.31	7.94	7.72	8.05	3.28	2.35	2.10	1.68	35.21	29.64	26.86	23.26	0.098	1.96	NS
	48h	11.46	8.55	8.35	8.51	3.47	2.77	2.42	1.65	30.3	30.85	28.04	21.57	0.03	1.96	NS
WA (%)	24h	87.35	83.02	82.49	85.83	8.12	14.12	12.43	17.76	9.28	16.57	14.26	20.08	0.687	1.96	NS
	48h	89.12	86.32	85.53	91.66	7.64	13.98	12.89	16.43	8.57	16.45	12.12	17.54	0.791	1.96	NS

SD: standard deviation; ***CV* (%)**: coefficient of variation; **F. obs:** F. observed**; F. the:** theoretical; **diff**: difference**; Ref:** Reference; **St. 1:** Station 1 of laboratory; **St. 2:** Station 2 of Beni Saf; **St. 3:** Station 3 of A. Djouher; **MOR**: modulus of rupture; **IB**: internal bond; **TS**: thickness swelling; **WA:** water absorption **S**: significant difference; **NS**: non-significant difference.

The results of the variance analysis (ANOVA) of Table 6, present F. obs < F. the for the IB, the density, TS after 24h, the TS after 48h, the WA after 24h and WA after 48h. Hence, we can conclude that for our confidence interval there is no significant difference between proprieties parameters and stations. To this effect, we can say that the particleboard on Telagh factory have a certain homogeneity between all studies parameters. However, the MOR present F. obs > F. the, and we can conclude that there is significant difference between stations for this proprieties.

CONCLUSION

This study allowed on the quality of these panels produced at Telagh factory (western Algeria) and on the other hand to analyze their behavior in different climatic conditions according to its future location.

Compared to constant conditions, we notice that:

- The coastal station (2) of Beni Saf with the high level of HR, the MOR decreases during the first 30 days. Later, MOR increases. In the station (3) with low HR, the resistance to MOR tends to decrease with time.
- The best IB resistances in the three stations are obtained during the first 30 days. A high HR. in the station (2) of Beni Saf decreases visibly IB.
- The evolution of density over time shows a certain stability of the specimens placed under dry conditions (station 3 of A. Djouher).
- The best results of TS are the specimens of the station (2) of Beni Saf and the poorest TS are the panel placed in the station (3) of A. Djouher.
- In station 3 of A. Djouher, the panel shows a high affinity to water and absorbs more especially after 90 days. The test panel placed in dry station (3) of Ain Djouher show some need for moisture and absorb more.

The effect of time and independently of the station or site, gives the following results:

- After 90 days exposure to climatic conditions, MOR lost 5.24N/mm^2 in site 3 of A. Djouher, which is characterized by an important difference in HR (52.33, +/- 15%) and T (24.05, +/- 9.5°C). In site 2, which presents climatic conditions of (79.66%, +/- 1.5%) in HR and (23.77, +/- 5°C) in T and in stable conditions of the site 1, MOR is (+/-) stable near of the reference tests values.
- Compared to the references tests and after exposure to climatic condition, IB decreases in all sites, principally in the site 2 due to its high HR.
- After 90 days exposure to climatic conditions, the high RH of site 2 increases the particleboard density by (18.14kg/m^3) compared to the reference test value.
- The TS analysis reveals and independently of reference tests that in site 2, the panel shows a great affinity to water as time passes, 2.04% more after 90 days compared to the result of TS after 30 days.
- WA analysis shows that after 90 days of exposure to climatic conditions, the highest WA values are obtained in site 3, which is dry and of high thermal amplitude.

The particleboard manufactured at Telagh in western Algeria, do not resist to the fluctuations in temperature and relative humidity. The best results were obtained in the stable conditions (T°C & HR) of utilization. The results of the effect of time on this particleboard demonstrate that in a wet setting, the panel becomes denser. The properties that are linked to the inner layer (IB & WA) are most affected by the aging. MOR that is in relation with the particles of the outer layer reacts differently. In humid environment of site 2, MOR decreases from the first 30 days and then stabilizes. In dry conditions of site 3, MOR decreases with time.

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