Sigma J Eng & Nat Sci 11 (2), 2020, 159-166

Publications Prepared for the Sigma Journal of Engineering and Natural Sciences
Publications Prepared for the ORENKO 2020 - International Forest Products Congress Special Issue was published by reviewing extended papers

Research Article

INCREASING THE OUTDOOR DURABILITY OF UREA FORMALDEHIDE PARTICLE BOARD WITH NEW GENERATION WATER-BORNE ACRYLIC COATINGS

Özlem ÖZGENÇ*[1], Gökay NEMLI[2]

[1]*Karadeniz Technical University, Dept. of Forest Industry Eng., TRABZON;* ORCID:0000-0001-9428-5681
[2]*Karadeniz Technical University, Dept. of Forest Industry Eng., TRABZON;* ORCID:0000-0002-8172-1875

Received: 01.12.2020 Accepted: 06.12.2020

ABSTRACT

In general, urea formaldehyde glue has a low moisture resistance ratio and therefore, particle boards produced with urea formaldehyde are suitable for use in closed areas. However, melamine formaldehyde glue moisture resistance is relatively higher than urea formaldehyde glue moisture resistance. Particle board products produced with melamine formaldehyde can be used in semi-open outdoor conditions and indoor structures, except for common usage areas, where there may be hot-cold water leaks, moisture deposits or steam, such as bathrooms, showers, sinks, cellars or sinks (kitchen sinks).

In this study, it is aimed to increase the resistance of urea formaldehyde particle board to semi-open outdoor conditions (temperature and humidity) by applying water-borne acrylic coatings. The outdoor durability of urea formaldehyde particle boards (test panels) prepared with in two different water-borne acrylic coating formulations was compared with urea formaldehyde and melamine formaldehyde particle boards (control panels). For the test and control samples, artificial weathering test was applied for 12 days (288 h). After the weathering test, some mechanical (flexural strength, modulus of elasticity, tensile strength) and physical (surface roughness, water absorption, moisture and density) of the test and control samples were determined.

After the outdoor test, the change in the mechanical and physical properties of the test samples were found close to the control on melamine formaldehyde particle boards. However, it was determined that the semi-open outdoor durability of the test samples was quite higher than urea formaldehyde particle boards without coating applied. The results of this study showed that in semi-open outdoor conditions, urea formaldehyde particle boards can be preferred instead of melamine formaldehyde particle boards.
Keywords: Acrylic coating, mechanical properties, outdoor durability, particle board, physical properties.

1. INTRODUCTION

Particle board is a very popular engineered wood-based panel produced from wood particles and a synthetic resin. It is designed for a wide range of substrate applications including furniture, kitchen worktops, interior signs, sliding doors, home constructions, flooring, shelving and cabinets, office drivers, counters, wall and ceiling, tables, and other industrial products [1]. The demand for particle board composite recently increased throughout the world. This increase can

* Corresponding Author: e-mail: oozgenc@ktu.edu.tr, tel: (462) 377 40 92

be attributed to the economic advantage of low-cost wood, other lignocelluloses fibrous materials [2].

Urea formaldehyde (UF) resin is significantly used in the manufacture of particle board because of its low price, short press time and high reactivity. However, the main disadvantage of UF resin lack of resistance to water. For his reason, many researchers have focused on developing new chemicals for solving this problem such as melamine addition to UF, paraffin and polyethylene glycol usage, coating of particle board surfaces with decorative papers [3], [4].

In recent years, the use of particle board as a structural building material has been increasing. For this reason, the durability of the particle board in semi-open outdoor conditions becomes important. The best way to evaluate the durability of the particle board in semi-open outdoor conditions is to determine the changes in its physical and mechanical properties during practical use [5]. For this purpose, "short-term accelerated aging tests" regarding the durability of materials to semi-open outdoor conditions are applied and the performance of the materials must be estimated from this information [6]. Disadvantages such as increased surface roughness, increased thickness and loss of mechanical resistance were determined in particle boards exposed to semi-open outdoor conditions. Particle boards are widely used as a substrate for thin coatings such as resin-impregnated papers, vinyl films, etc. for aesthetic and strength purposes. The surface roughness of the particle board plays an important role in the coating properties, because any surface irregularities can be displayed through thin coatings, which reduces the final quality of the board. Raw material properties and production parameters affect the surface roughness of particle board panels [7]. Also, wettability is defined as the state of a surface that determines how quickly a liquid will wet the surface or whether it will be sprayed on the surface. Wettability is crucial for good adhesion between particle board and coating. Liquid surface coatings or adhesives have to wet, flow, and penetrate the cellular structure of wood in order to maintain close contact between the composite surface molecules and the coating. Dimensional changes of wood-based panels in humid conditions are the main disadvantage of using board as a building material [8]. Moisture absorption causes a decrease in the strength of the particle board and destruction between the wood and adhesive bonds. There is a lot of extensive research to improve the dimensional stability of particle boards. One of these are liquid surface coatings that are widely used to improve the dimensional stability and water repellency of boards due to their low cost and ease of use [9], [10], [11].

Melamine formaldehyde glue moisture resistance is relatively higher than urea formaldehyde glue moisture resistance. Particle board panels produced with melamine formaldehyde can be used in semi-open outdoor conditions and indoor structures, except for common usage areas, where there may be hot-cold water leaks, moisture deposits or steam [12], [13] [14]. The objective of this study is to increase the resistance of urea formaldehyde particle board to semi-open outdoor conditions (temperature and humidity) by applying water-borne acrylic coatings.

2. STUDIES

2.1. Manufacturing of the Particle Board Panels

2.2. Coating Systems

The commercial water-based impregnation product, having active ingredients of 1.20% propiconazol, and 0.30% iodopropynyl butylcarbamat, was used as a primer for the protection of the samples against biological deterioration, including soft rot and blue stain. The primer was applied to the samples at a spread of 120 g/m² using a brush. Tinuvin 5333 DW as UV absorbers were used in this study. Commercially produced finishing, having acrylic resins, three copolymer dispersion was used as a topcoat for the specimens. A small amount of defoamer and 2,2,4-trimethyl-1,3-pentandiolemonoisobutyrate, a coalescending agent was added in the topcoat formulation to reduce the effect of other additives on the photostabilization performance. The characteristic features of wood coating materials in the study are given in Table 1. These formulation products were supplied from BASF Company for the wood coatings (Table 2). Three layers of topcoats were also applied to each sample at a spread rate of 100 g/m² by brush. Later, the specimens were sanded with a 240 grit size of sandpaper and kept at room temperature for two days before applying the second layer of topcoat.

Table 1. Acrylic resin types for wood coating systems.

Pruducts	Description	Physical form	Active content (%)
Acronal Eco 6270	Pure acrylic	liquid	50
Joncryl 8226	Acrylic emulsions	liquid	42
Tinuvin 5333 DW	UV Absorber	liquid	40

Table 2. The formulations of wood coating systems.

Formulation products	X	AX	Y	AY
Acronal Eco 6270	73.7	50	-	23.7
Joncryl 8226	-	23.7	73.7	50
Tinuvin 5333 DW	6.0	6.0	6.0	6.0
Film-forming agents	0.67	0.67	0.67	0.67
Defoamers	1.0	1.0	1.0	1.0
Dispersing agent	0.6	0.6	0.6	0.6
Rheology modifier	1.3	1.3	1.3	1.3
Distiled water	16.73	16.73	16.73	16.73

The viscosity of the four different coatings applied in this study was determined by using DIN cup/4mm/20 ^{0}C.

Table 3. The physical characteristics of the four different coatings

Coating Systems	Solid Content (%)	PH	Viscosity
X	39	8.2	80
AX	30	8.3	65
Y	44	8.5	120
AY	35	8.4	75

2.3. Artificial Weathering Test

Artificial weathering was performed in a QUV/spray accelerated weathering tester (Q-Panel Lab Products, Cleveland, OH, USA) equipped with 313 nm fluorescent UV (UVB) lamps; the temperature in the chamber was approximately 60 ^{0}C (ASTM G 154-12a).The weathering experiment was carried out in cycles of UV-light irradiation for 4h followed by condensation temperature of 50 ^{0}C for 4h in an accelerated weathering test cycle chamber over 12 days (288 h). Eight replicate samples for each coating system were prepared for each artificial weathering test condition.

2.4. Surface roughness test

A Mitutoya SurfTest SJ-301 instrument was employed for surface roughness measurements. The R_a and R_b roughness parameters were measured to evaluate the surface roughness of the surfaces of unweathered and weathered coated particle board and uncoated particle board samples according to DIN 4768. R_a is the arithmetic mean of the absolute values of the profile departures within the reference length, and R_z is the arithmetic mean of the 4-point height of irregularities [16]. The cut-off length was 2.5 mm, the sampling length was 12.5 mm, and the detector tip radius was 10 µm in the surface roughness measurements.

2.5. Physical and mechanical tests

Panels were kept in a conditioned room with a relative humidity of 65% and a temperature of 20 °C until they reached equilibrium moisture content. They were then cut into test samples based on EN standards and determined the densities of the test samples [17], [18]. Modulus of elasticity (MOE) and modulus of rupture (MOR) from static bending, internal bond strength (IB) and thickness swelling (TS) after 24 h immersion of the samples were determined. Ten samples were cut from test panels to measure physical and mechanical properties [19], [20], [21]. Mechanical tests were performed on a Universal Introns testing machine.

3. RESULTS

3.1. Change in mechanical and physical properties

The single most important factor contributing to the weather conditions of particle boards is the change in moisture content. It appears that UV radiation and chemical changes do not have a significant effect on the effect of weather conditions. Continuous changes in moisture content create shrinkage and swelling stresses in the glue line between adjacent particles in the particle board content, as well as in the particles themselves. It is the absorption and desorption of liquid water that causes excessive thick swelling of the sheet, surface roughness and deterioration. Thickness swelling occurs due to the normal swelling of wood particles and their swelling due to release of the compressible set [6]. The single most important factor contributing to the weather conditions of particle boards is the change in moisture content. It appears that UV radiation and chemical changes do not have a significant effect on the effect of weather conditions. Continuous changes in moisture content create shrinkage and swelling stresses in the glue line between adjacent particles in the particle board content, as well as in the particles themselves. It is the absorption and desorption of liquid water that causes excessive thick swelling of the sheet, surface roughness and deterioration. Thickness swelling occurs due to the normal swelling of wood particles and their swelling due to release of the compressible set [6]. Some of the mechanical and physical properties of the test and control panels before and after the artificial weathering test are given in Table 4. This table generally shows that coating application increases the outdoor durability of UF control panels.

From the observations given in Table 4, it is seen that after the weathering test, UF control panels swell by 13.35-29.1% of their original thickness while standing and this process is irreversible. This increase in volume is clearly reflected in the strength properties of the plates. The tear modulus decreased by 40-45% due to the weathering test. While the density was 5.00 g / cm3 in the UF control panels before the weathering exposure, the higher internal bond strength and rupture modulus values of the panels whose density decreased to 4.14 g / cm3 after weathering exposure also decreased. The positive effect of panel density on mechanical properties was mentioned in a similar study. However, the increase in board's density resulted in poor thickness swelling properties similar to the results of a previous study. Acrylic coating application has significantly improved the rupture modulus and thickness swelling values in weathering conditions. This is due to the reduction of moisture absorption of the sheet surface in weathering conditions with coating application. Thus, the amount of decrease in the internal bond strength values of test plates applied with coating when exposed to weathering conditions is much lower than the UF control panel and is close to MF control panel [10].

Table 4. Mechanical and physical properties of experimental panels.

	BEFORE WEATHERING						
	Density (g/cm^3)	MC (%)	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)	Thickness swelling (%) 2 h	Thickness swelling (%) 24 h
AX	4.90±0.8	6.65±0.7	13.8±1.7	1916±457	0.66±0.1	1.38±0.1	10.42±2.9
X	4.99±0.8	6.69±0.7	14.6±1.8	2316±434	0.72 ± 0.1	3.11±0.9	13.38±3.1
AY	5.06±0.9	6.54±0.5	13.9±1.7	1865±260	0.70 ± 0.1	3.62±0.8	13.01±3.1
Y	4.93±0.7	6.98±0.8	13.1±1.1	2109±478	0.64± 0.1	1.29±0.1	10.41±1.9
ÜF	5.00±0.9	7.18±1.1	13.8±1.2	2361±441	0.59 ± 0.1	11.5±3.9	20.58±4.1
MF	5.05±0.8	7.09±1.1	20.8±2.5	3393±593	1.77 ± 0.1	2.09±1.2	8.63±2.2
	AFTER WEATHERING						
	Density (g/cm^3)	MC (%)	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)	Thickness swelling (%) 2 h	Thickness swelling (%) 24 h
AX	4.29±0.6	6.45±1.3	11.8±1.1	1499±170	0.59±0.02	5.85±1.52	18.51±3.94
X	4.41±0.8	6.32±1.2	12.9±1.1	1844±324	0.64±0.08	14.69±3.21	21.65±5.73
AY	4.32±0.9	6.54±0.8	13.3±1.2	1764±256	0.59±0.04	6.61±2.14	16.75±3.94
Y	4.43±0.8	5.86±0.9	12.3±2.8	1731±221	0.59±0.06	9.12±2.59	18.66±4.56
ÜF	4.14±0.8	6.94±0.9	7.80±1.9	1256±150	0.24±0.02	13.35±2.85	29.1±8.38
MF	4.47±0.8	7.11±1.2	16.8±2.3	2296±495	1.43±0.09	2.96±0.83	9.13±3.58

Based on EN 312 standards, 11.5, 13, and 1600 N/mm2 are the minimum requirements for modulus of rupture, and modulus of elasticity of particle board panels for general uses and furniture manufacturing, respectively [19]. Comparing to MF control panels, X, AY and Y test panels met the minimum modulus of rupture requirement of the EN standards for general uses after artificial weathering test. In addition, AX test panel satisfied the modulus of rupture requirement for furniture manufacturing application. The results showed that X, AY and Y test panels were found to comply with modulus of elasticity for interior fitments (including furniture). On the other hand, with the exception of UF control panel, the other panels were found to comply with internal bond strength values for general uses, which is 0.24 N/mm2 as stated in EN 312 standard [19]. According to the test results, AX, AY, X and Y panels had the required level of internal bond strength for interior fitments that is 0.35 N/mm2 according to the EN312 [19]. Figs. 1 and 2 show the changes in mechanical strengths of experimental panels after weathering. Based on EN 312 standard [19], particle board should have a maximum thickness swelling value of 8% (for 2 h immersion). Average thickness swelling of the specimens ranged from 5.85 to 14.69 % for 2 h immersion. X test and UF control panels did not satisfy the thickness-swelling requirement for general uses. This is due to the X and Y coating systems separate from the UF chipboard surface during the 2 hour immersion. However, the thickness swelling value of AX, and AY wafers (5.85% and 6.61 for 2 hours immersion) was very close to the required thickness swelling level of the panels for general use. Fig.2 illustrates the artificial weathering test effects on the thickness swelling values (for 2 and 24 hours immersion) of the test and control particle boards.

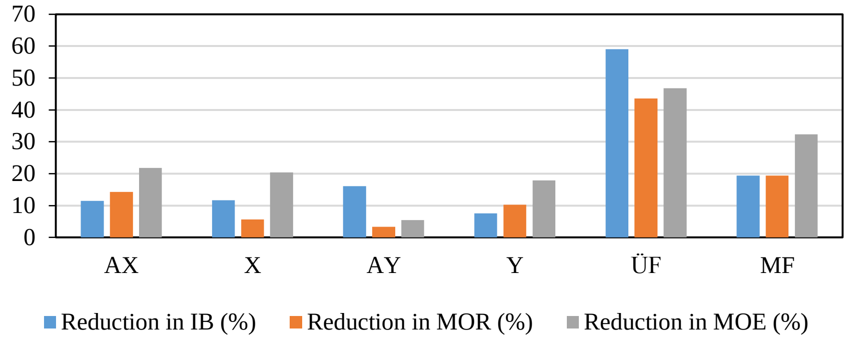

Figure 1. Changes in mechanical strengths of experimental panels after weathering

After the artificial weathering test, the best result in thickness swelling results for 2 and 24 hours was determined in the MF control panel, and the coating applied AY variations as the test panels. After the weathering test, it was understood that the 2 and 24 hour thickness swelling results were at the highest UF control panel, and the coating application provided important protection in the thickness swelling results.

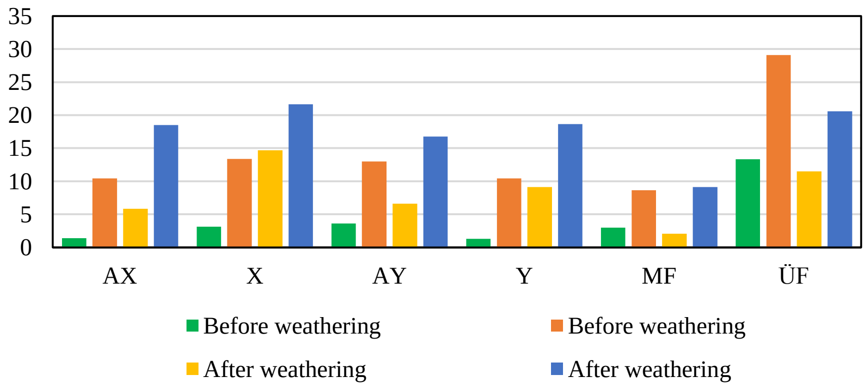

Figure 2. Changes in thickness swelling of experimental panels after weathering

3.2. Change in surface roughness parameters

Table 5 shows the surface roughness index values and Ra and Rz roughness parameters before and after the artificial weathering test of the control and test panels. After the weathering test, the lowest change index of the Ra roughness parameter was in the Y variation, and the index values of AX variation and MF control panels were also determined to be close index values. The index values of the AY and X variations were also found to be close. After the weathering test, the change index in the Rz roughness parameter is at the lowest AY variation, and the change index in the Y and AX variations is also close values. After weathering testing, the highest Rz change index values were found in UF and MF control panels.

Table 5. Changes in surface roughness parameters of experimental panels after weathering

Coating Code	Before weathering		After weatherıng		Change rate	
	Ra	**Rz**	**Ra**	**Rz**	**RI_a**	**RI_z**
AX	1.46±0.2	15.4±1.7	1.73±0.2	18.4±2.1	0.19±0.1	0.18±0.1
AY	0.65±0.1	4.82±0.8	0.71±0.2	6.1±1.0	0.29±0.1	0.09±0.1
X	0.52±0.1	5.27±0.4	0.72±0.1	6.39±1.3	0.22±0.2	0.38±0.2
Y	1.73±0.3	16.7±2.5	1.96±0.3	19.4±2.0	0.17±0.1	0.13±0.1
MF	3.27±0.4	34.0±2.7	4.62±0.8	40.52±4.5	0.19±0.1	0.41±0.2
UF	3.68±0.8	34.8±5.3	6.07±0.9	45.04±4.3	0.31±0.2	0.64±0.2

In fact, a coating film can delay and prevent excessive moisture ingress into the panel at best, but cannot stop it. Before coating, the gaps between the particles are closed and the effectiveness of the paints increases if the surface is smoothed. A normal acrylic coating has a limited external life of about two years in particle boards. Therefore, a regular maintenance coat is required to extend the service life of such structures. While smooth surfaces are preferred in the end-use applications of chipboard panels, the thickness of the panels should also be at acceptable levels. Surface roughness and bursting of wood particles have also been serious problems due to weather conditions of particle boards. It allows rainwater to stay on the surface of the board for a long time, thus increasing the risk of more water entering the board. These defects can only be eliminated by using microchips on the surface and making the surface of the card waterproof. Although particle boards have large dimensions, their applications in buildings require many joints [6], [8].

In this study, the durability of UF panels in semi-open outdoor conditions was improved with 4 different waterborne acrylic coating systems. After exposure to the artificial weathering test, the percentage of decrease in the physical and mechanical properties of UF control panels applied the waterborne acrylic coatings is close with MF control panels. The coating systems applied in the study positively affected the durability of the UF control panel in semi-open weathering conditions. In addition, the fact that waterborne acrylic coatings are renewable preservatives can make a significant contribution to the particle board industry. In semi-open outdoor conditions, the durability time of UF control panel is increased with the application of waterborne acrylic coating system, and it has reached a durability close to MF control panel. It is suggested that this study be evaluated in the industry by performing a cost analysis of the application of waterborne acrylic coating on the surface of UF particle board and MF particle board production.

Acknowledgments

Authors are grateful to BOYSAN company, the sales representative of BASF chemicals in Turkey, for the supplying the coating formulation products and Starwood Forest Product Company, Bursa, Turkey for the producing the particle boards. A part of this study was presented at the 2nd International Forest Products Congress (ORENKO) on September 23-26, 2020 in Trabzon, Turkey.

REFERENCES

[1] Baharoğlu M., Nemli G., Sarı B., Ayrilmis N., Bardak S. and Zekoviç, E. (2014). Effect of paraffin application technique on the physical and mechanical properties of particle board, *Sci Eng Compos Mater* 21(2), 191–195.

[2] Nemli G., Demirel S., Gümüşkaya E., Aslan M. and Acar C., (2009). Feasibility of incorporating waste grass clippings (*Lolium perenne* L.) in particle board composites, *Waste Management* 29, 1129–1131

[3] Nemli G., Ors Y., Kalaycıoglu H., (2005). The choosing of suitable decorative surface coating material types for interior end use applications of particle board, *Construction and Building Materials*, 19, 307–312.

[4] Girods P., Anthony Dufour A., Rogaume Y., Rogaume C. and Zoulalian A., (2008). Pyrolysis of wood waste containing urea-formaldehyde and melamine-formaldehyde resins, *J. Anal. Appl. Pyrolysis* 81, 113–120.

[5] Geimer R.L., Heebink B.G., Hefty F.V., (1973). Weathering Characteristics of Particle board, *USDA Forest Service, Research Paper*, FPL 212.

[6] Kajita H., Mukudai J., Yano H., (1991). Durability evaluation of particle boards by accelerated aging tests, *Wood Sci. Technol*., 25, 239-249.

[7] Nemli G., Akbulut T., and Zekoviç E., (2007). Effects of Some Sanding Factors on the Surface Roughness of Particle board, *Silva Fennica*, 41(2), 373-378.

[8] Sahin H.T., Arslan M.B, (2011). Weathering performance of particle boards manufactured from blends of forest residues with red pine (*Pinus brutia*) wood, *Maderas. Ciencia y tecnología* 13(3), 337-346.

[9] Barnes H.M. and Lyon D.E., (1978). Effect of weathering on the dimensional properties of particle board decking, *Wood and Fiber Science* 10(3), 175-185.

[10] Kalaycıoglu K. and Nemli G., (2006), Producing composite particle board from kenaf (*Hibiscus cannabinus* L.) stalks, *Industrial Crops and Products* 24, 177–180.

[11] Nemli G. and Aydın A., (2007). Evaluation of the physical and mechanical properties of particle board made from the needle litter of *Pinus pinaster* Ait., *Industrial Crops and Products* 26, 252–258.

[12] Park B.D., Lee S.M., Roh J.K., (2009). Effects of formaldehyde/urea mole ratio and melamine content on the hydrolytic stability of cured urea-melamine-formaldehyde resin, *Eur. J. Wood Prod.* 67, 121–123.

[13] Young No B. and G. Kim, M.G., (2007). Evaluation of Melamine-Modified Urea-Formaldehyde Resins as Particle board Binders, *Journal of Applied Polymer Science*, 106, 4148–4156.

[14] Sun Q.N, Hse C.Y., Shupe T.F., (2011). Characterization and performance of melamine enhanced urea formaldehyde resin for bonding southern pine particle board, *Journal of Applied Polymer Science*, 119, 3538–3543.

[15] ASTM G154-12a, (2015). Practice for Operating Fluorescent Ultraviolet (UV) Lamp Apparatus for Exposure of Nonmetallic Materials, ASTM International, West Conshohocken, PA.

[16] DIN 4768 (1990) Determination of values surface roughness parameters Ra, Rb, Rmax using electrical contact (stylus) institute.

[17] EN 323 standard, (1999). Wood Based Panels, Determination of the Density, European Committee for Standardization, Brussels, Belgium.

[18] EN 312 standard, (2003). Particle boards-Specifications. European Committee for Standardization, Brussels, Belgium

[19] EN 310 standard, (1993). Wood Based Panels, Determination of Modulus of Elasticity in Bending and Bending Strength. European Committee for Standardization, Brussels, Belgium.

[20] EN 317 standard, (1993). Particle boards and Fiberboards, Determination of Swelling in Thickness after Immersion. European Committee for Standardization, Brussels, Belgium.

[21] EN 319 standard, (1993). Particle boards and Fiberboards, Determination of Tensile Strength Perpendicular to Plane of the Board. European Committee for Standardization, Brussels, Belgium.