THE USE OF BLACK POPLAR PLYWOOD AS A STRUCTURAL COMPONENT OF PREFABRICATED BUILDINGS

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Abstract

Nowadays, construction in Spain has been closely related to the use of brick as material for vertical enclosures. However, other construction methods, widely used in other markets, are the use of plywood panels. Especially in the U.S. market and in northern Europe, the expansion of this product in the prefabricated buildings has increased considerably in recent decades. Current Spanish Technical Building Code (CTE) and certain specifications set by the European legislation establish the prerequisites for these boards to can be considered as structural elements in Spain. In this paper the use of poplar plywood boards as structural element for prefabricated buildings is studied. Using Spanish standard UNE-ENV 14272 is possible to calculate majority of mechanical properties of plywood panels without carrying out the experimental tests required by standard UNE-EN 789. Results show the strengths of poplar plywood for construction.

***Keywords**: Spanish Technical Building Code; plywood; Spanish standards; experimental tests*

Resumen

Actualmente, la construcción en España ha estado íntimamente relacionada con la utilización del ladrillo como material destinado a los cerramientos verticales. Sin embargo, otros métodos constructivos, muy extendidos en otros mercados, son la utilización de tableros de contrachapado de madera. Especialmente en el mercado norteamericano y en el norte de Europa, la expansión de este producto en las edificaciones prefabricadas ha sufrido un incremento considerable en las últimas décadas. El vigente código técnico de la edificación (CTE) y ciertas especificaciones fijadas por la normativa europea establecen los requisitos fundamentales para que dichos tableros puedan ser considerados elementos estructurales en España. En este artículo, se estudia la utilización de tableros de contrachapado de madera de chopo como elemento estructural de construcciones prefabricadas. Mediante la utilización de la norma española UNE-ENV 14272 pueden obtenerse la mayoría de las propiedades mecánicas de los tableros contrachapados sin la necesidad de realizar todos los ensayos experimentales que requiere la norma UNE-EN 789. Los resultados muestran los puntos fuertes del contrachapado de chopo para la construcción.

***Palabras clave:** Código Técnico de la Edificación; tablero de contrachapado de madera; normativa española; ensayos experimentales*

1. Introduction

Spain and France are two important countries in manufacture of black-poplar wood (Cooper 2002). The most well known product derived from black-poplar wood harvested from both countries is the plywood panel. However, up to now, plywood panels have mostly been used as decorative purposes as boards for construction processes. Thus the use of plywood panel as load-bearing wall for small constructions is a promising market for companies in the European Union (EU) (Navarrete-Castillo 2008). This is due mainly to their excellent mechanical properties, lightness and the added value in terms of providing the building with additional thermal and acoustic isolation. Plywood allows to get a good relationship between modulus of elasticity and weight. Other significant advantage is that this kind of plywood product is a prefabricated element. This generates new opportunities in the building of small houses such as storehouses, country houses, hostels or summer apartments in campsites where it is not necessary skilled labour. Additionally a decrease in labour costs can be easily achieved and in the same way, building times can be drastically reduced through a standardised design of the building.

Plywood companies need to characterize their panels in order to sell them for construction. Spanish standard UNE-EN 789 describes all tests necessary to characterize plywood panels but this method requires spending too much time and resources. The Spanish standard UNE-ENV 14272 is the alternative to the previous method. UNE-ENV 14272 allows us to calculate the majority of the mechanical properties of plywood panels without carrying out many experimental tests. Only one series of experiments is necessary for each species of wood. For this reason we study the possibility of using standard UNE-ENV 14272 instead of classical standard UNE-EN 789 to save time and costs in the characterization process of plywood panels. The accuracy of this alternative is also analyzed to evaluate its reliability.

Figure 1: Black-poplar forest, more especially poplar clone I-214 located in La Rioja (Spain).

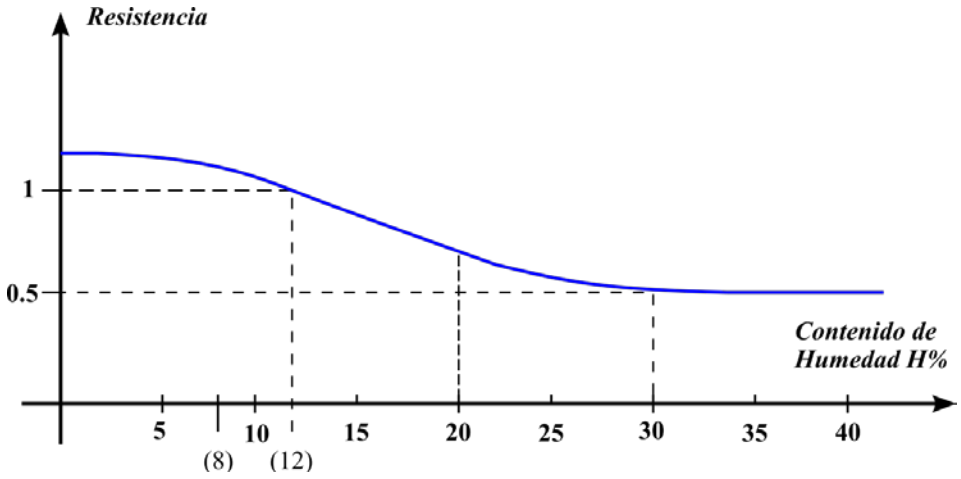
The other strong point is that companies can promote good ecological awareness. It is well known that the use of wood materials instead of ceramic or concrete can contribute to reduce the environmental impact of construction sector. This aspect takes on a specially important role in rural environments and those which have special ecological riches. Several

organizations have determined carbon footprints of many building products. The principal influences on carbon footprints include economic, population and energy of the economy. Wood based products have the lowest values, thus they can reduce environmental impact more than others (Salazar and Meil 2009).

But black-poplar wood is a limited material source and plantations of black-poplar have low resilience to several external aspects like fires, plagues and dry seasons. Nowadays they must be exploited using a detailed ecological sustainability plan. This plan involves maintaining the health of trees, cleaning the soil and replanting the felled areas. The cost of all these operations makes the product more expensive that other alternatives, for this reason plywood companies are looking forward to participating in finding concrete and practical steps for any improvement.

Plywood panels are formed by several plies of equal or different materials. Sometimes wood used for a single panel is not the same species. Then plies are with each other using synthetic resins such us urea-formaldehyde adhesive, phenolic adhesive or melamine adhesive. The orientation of the fibbers in the plywood panel uses to change in order to obtain mechanical properties desired. The modus operandi depends on the type of mounting machine utilized to make the panel but at present, the main use is to alternate plies by 90 degrees.

Figure 2: Influence of humidity in mechanical resistance of wood



Source: Arriaga (2003).

Poplar plywood panels are normally treated to obtain additional properties like high resistance against humidity or flames retard. Most of treatments are focused on finding more suitable properties for using plywood for construction. Figure 2 shows that strength is definitely influenced by humidity. For this reason tests pieces used in the experiments were storage in controlled atmosphere. In this context, if content of humidity rises, both strength and modulus of elasticity decrease. Spanish Technical Building Code (CTE) (2009) considers humidity as a critical parameter and depending on its level, a structural element must be classified in one type of service or another. In this article, plywood panels completely made of black-poplar clone I-214 wood without any treatment were studied.

2. Related Works

In the last two decades, plywood products have been very much studied by the specialists in wood. N. Baldassino et al. (Baldassino, Zanon et al. 1996) presented a new methodology to determinate the behaviour of poplar plywood under planar shear. This method is a

reasonable alternative to classical tests suggested by the European Standards. The method was applied successfully to several medium-sized test pieces of poplar wood. Subsequently N. Baldassino et al.(Baldassino, Zanon et al. 1998) reported a several tests conducted using EN-789 to determine the mechanical properties of poplar plywood. They carried out the tests mentioned following the EN-789 standard for medium-sized test wood pieces of clone I-214. They concluded that poplar plywood of clone I-214 has a great structural potential.

Other studies carried out by (Kljak and Brezović 2007) measured the influence of the veneer thicknesses ratio in plywood plies on bending properties of sandwich panels. A three dimensional analysis was developed and validated using a set of experimental results from a three-point bending test. The results showed that the variation of thickness changes the stress distribution of each layer of the sandwich panel. In 2008 (Arriaga-Martitegui, Peraza-Sánchez et al. 2008) analysed mechanical properties of radiate pine plywood using both EN-789 and EN-1058 standards. They tested 8 different pieces with thicknesses from 9 to 30 mm of this wood, reporting strength and modulus of elasticity for bending, compression and tension. Finally, J. Kljak et al. (2009) studied the influence of plywood grain direction on bending properties of sandwich panel. Sandwich panel of thickness 29 mm was utilized and its fibber directions were raised by 15 degrees between 0 to 90 degrees. The conclusion are that grain direction has a great influence on bending properties of sandwich panels due to the great difference between parallel and perpendicular modulus elasticity.

3. Methodology and materials for determining mechanical properties

3.1. Testing methods based on Spanish standards

Table 1: Distribution and thickness of the layers in both types of plate

12 mm			18 mm		
Ply	Thickness (mm)	Orientation	Ply	Thickness (mm)	Orientation
1	1	0	1	1	0
2	2.8	90	2	2.6	90
3	1.3	0	3	2.3	0
4	2.8	90	4	2.6	90
5	1.3	0	5	2.3	0
6	2.8	90	6	2.6	90
7	1	0	7	2.3	0
			8	2.6	90
			9	1	0

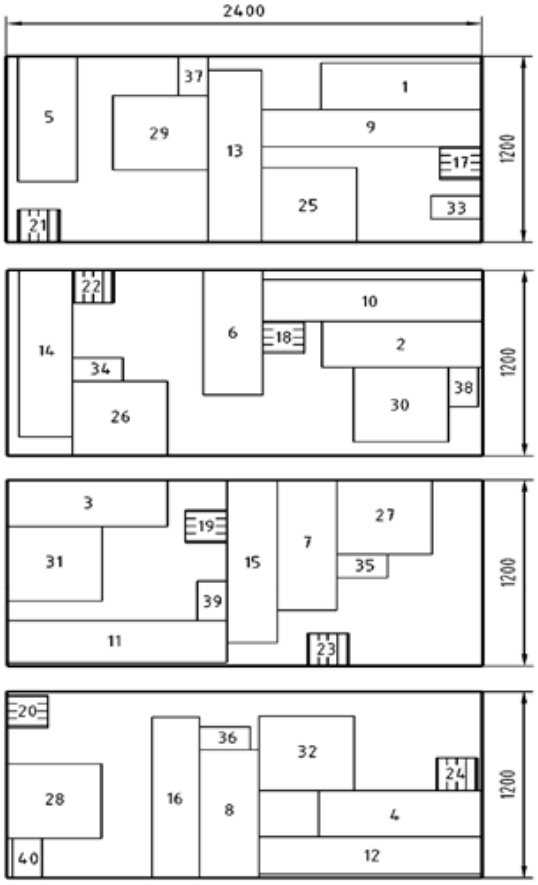
In the first phase of this research, mechanical properties of plywood panels were obtained by carrying out five different tests according to Spanish standard UNE-EN 789 (2006). The international plywood company Garnica Plywood, S.A. provided us initial reports about testing. The reports were accomplished by the certificated Spanish association AITIM (Asociación de Investigación Técnica de las Industrias de la Madera, AITIM) that was given the charge of achieve testing process by UNE-EN 789.

One series of experiments were performed for black-poplar species to determine mechanical characteristics of plywood. The initial specimens were plates of 2400 x 1200 mm, which layer distribution is detailed in Table 1. In this study, 7 and 9 plies panels with thicknesses of 12

and 18 mm respectively were chosen and each plate only included plies of wood from the same species. Finally, the adhesive used was the same in all panels.

In order to achieve 40 testing pieces, plates were firstly cut as in figure 3 where it can be seen that pieces for the same test are always sampled from different areas of the four plates. Figure 3 shows the position and orientation of each piece. Testing pieces were storage in a controlled atmosphere of (65±5)% of relative humidity and (20±2)ºC of temperature.

Figure 3: Sampling scheme included in Spanish standard UNE-EN 789



Source: UNE-EN 789

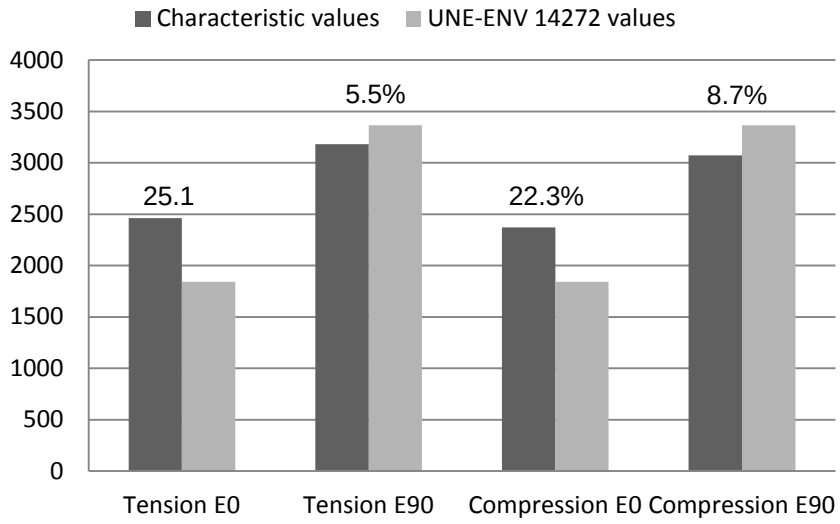
Test	Number of the tests pieces
Bending	
Longitudinal	1 to 4
Transversal	5 to 8
Tension	
Longitudinal	9 to 12
Transversal	13 to 16
Compression	
Longitudinal	17 to 20
Transversal	21 to 24
Shear	
Longitudinal	25 to 28
Transversal	29 to 32
Roller shear	
Longitudinal	33 to 36
Transversal	37 to 40

3.2. Determining mechanical properties of black-poplar plywood

Based on Spanish standard UNE-EN 789, the method for determining the properties of the plies is formed by 6 steps. UNE-EN 789 involves bending, compression, tension and shear testing processes for wood products. The standard includes the specific explanations of steps and necessary conditions. Consequently, modulus of elasticity and strength for each type of plywood were achieved from compression and tension test results. The following step is to use Spanish standard UNE-EN 1058 (2010) to calculate characteristic values corresponding to the fifth percentile of results. The characteristic values are the necessary ones to characterize the panels of this study and for the numerical simulating of their behaviour.

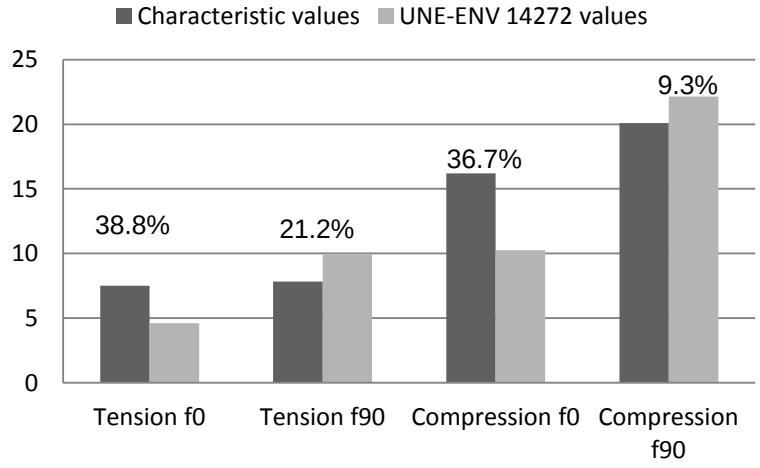
Figure 4 shows a comparative between four modulus of elasticity obtained using UNE-EN 1058 and those obtained with Spanish standard UNE-ENV 14272 (2003). Both values should be theoretically similar, but Fig. 4 demonstrates that there are big differences between them.

Figure 4: Modulus of elasticity of black-poplar plywood of 12 millimetres



In one hand, there is a difference of 22.3% between modulus of elasticity in compression parallel to the grain determined using UNE-EN 1058 and UNE-ENV 14272. It also happens the same with tension parallel to the grain (25.1%). But otherwise modulus of elasticity in parallel and perpendicular to the grain has high accuracy using both standards. In other hand, figure 5 shows the same comparative for strength instead of modulus of elasticity. Tension and compression parallel to the grain are not very reliable because they have the highest differences (38.8% and 36.7% respectively) using UNE-EN 1058 and UNE-ENV 14272.

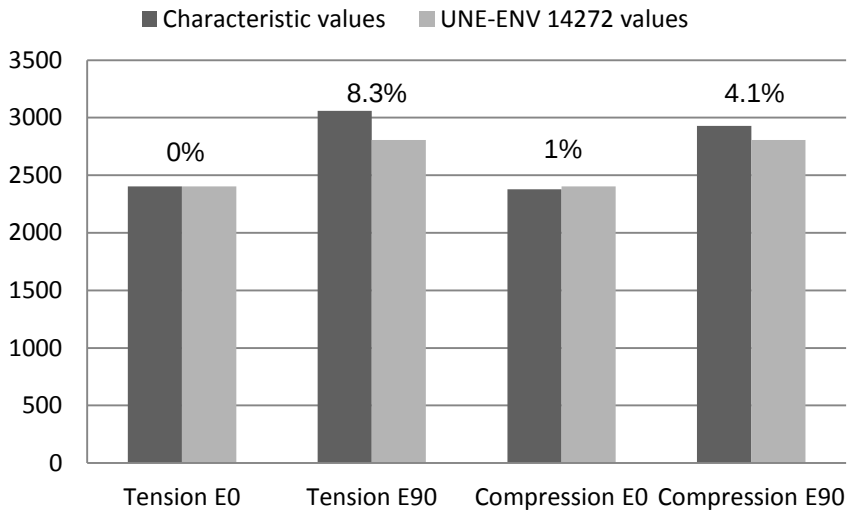
Figure 5: Strength values of black-poplar plywood of 12 millimetres



These obtained differences demonstrate that the use of the standard UNE-ENV 14272 to obtain the mechanical properties of black-poplar plywood panels is not appropriate. Consequently, further use of these values to structural applications is non convenient without a deeper analysis. This is due to they can lead on a structural problem, especially in those cases in which UNE-ENV 14272 is providing higher values than experimental data.

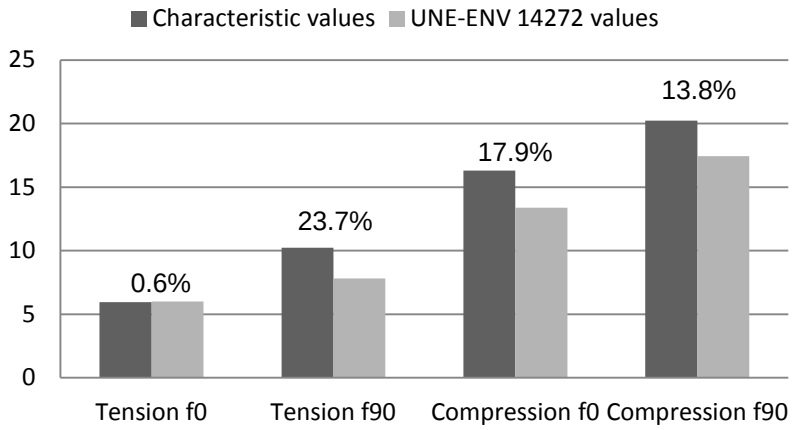
The same comparatives were performed for a 18 mm plywood panel.

Figure 6: Modulus of elasticity of black-poplar plywood of 18 millimetres



In contrast to previous results related to 12 mm panel, the results of the modulus of elasticity for the panel of width 18 mm are more accurate in both parallel and perpendicular cases. On the other hand for perpendicular modulus of elasticity differences are quiet bigger but there are not very high.

Figure 7: Strength values of black-poplar plywood of 18 millimetres



For resistances high differences happen again, as it can be shown in figure 7. These variations cannot be permissible.

One important aspect to take into account is that the normative gives exactly the same value for tension and compression modulus of elasticity. Comparing with test results it is shown that there are few variations. In the case of resistances results the normative reflects this variation, but the accuracy is not good at all.

3.3. Resulting characterization by comparing with previous studies

In order to have a second comparative to validate de accuracy of the normative UNE-ENV 14272. Values obtained with this normative are compared with results of a previous study, (Baldassino, Zanon et al. 1998). In this case the panels have same thicknesses that previous, but the distribution of the layers is quite different.

Table 2: Distribution of the layers

12 mm			18 mm		
Ply	Thickness (mm)	Orientation	Ply	Thickness (mm)	Orientation
1	1.3	0	1	2.1	0
2	2.1	90	2	2.1	90
3	2.1	0	3	2.1	0
4	2.1	90	4	2.1	90
5	2.1	0	5	2.1	0
6	2.1	90	6	2.1	90
7	1.3	0	7	2.1	0
			8	2.1	90
			9	2.1	0

Firstly characteristic test results obtained using UNE-EN 789 and UNE-ENV 1058 standards are shown in tables 3 and 4.

Table 3: Characteristic Tension Results

Panel	E_0 (N/mm^2)	F_0 (N/mm^2)	E_{90} (N/mm^2)	F_{90} (N/mm^2)
12 mm	3195	11.4	3995	11
18 mm	2903	10.2	2771	7.8

Table 4: Characteristic Compression Results

Panel	E_0 (N/mm^2)	F_0 (N/mm^2)	E_{90} (N/mm^2)	F_{90} (N/mm^2)
12 mm	2570	14.7	2723	16.3
18 mm	3275	16.2	2856	14.4

Source:(Baldassino, Zanon et al. 1998).

Then like on 3.2. section, UNE-ENV 14272 is used to obtain the values shown in tables 5 and 6, and compared to the previous ones.

Table 5: UNE-ENV 14272 Tension Results

Panel	E_0 (N/mm^2)	F_0 (N/mm^2)	E_{90} (N/mm^2)	F_{90} (N/mm^2)
12 mm	3062.595	9.344	2837.405	10.8
18 mm	3277.778	10	2622.222	10.286

Table 6: UNE-ENV 14272 Compression Results

Panel	E_0 (N/mm^2)	F_0 (N/mm^2)	E_{90} (N/mm^2)	F_{90} (N/mm^2)
12 mm	3062.595	14.534	2837.405	16.8
18 mm	3277.778	15.556	2622.222	16

In this case results are quiet better. But there are some values, like the perpendicular modulus of elasticity in the panel with 12 mm thickness with a very low accuracy. Differences between tension and compression modulus of elasticity in these tests is higher than previous one. So it is demonstrated that UNE-ENV 14272 should reflect this difference instead or giving the same value for both tension and compression.

This two comparatives prove that this normative is not high accurate. It is necessary to study this field to improve this normative or obtain a new one which provide better results.

5. Conclusions

On the basis of points treated and explained in the article, we conclude that plywood panels present great advantages as a material for construction. This is even more relevant in case of small prefabricated constructions. All mechanical properties determined are agreed with expected values.

Firstly we obtained the properties of each black-poplar plywood panel in this study. Results of modulus of elasticity and strength calculated using UNE-ENV 14272 for all panels, showed high variability comparing with values obtained using standard UNE-EN 789. We are agree with Arriaga-Martitegui, Peraza-Sánchez et al (2008) that UNE-ENV 14272 is an efficient method to save time calculating mechanical properties of plywood panels. On the other hand the accuracy of the obtained values is not high all so the values sometimes can only be used as an indicative. In summary, it is necessary to improve the method included in this standard to obtain a better accuracy or develop a new method.

Futures works will continue analysing this standard using other species of wood. Okume wood is one particularly appropriate species because this wood uses to be included as the external surfaces of black-poplar plywood panels.

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