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# COMPARATIVE ANALYSIS OF STATIC AND DYNAMIC MOE OF PANNÓNIA POPLAR TIMBER FROM DIFFERENT PLANTATIONS

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## ABSTRACT

The aim of this study has been to investigate the suitability of Pannónia poplar (*Populus* × *euramericana* cv. Pannónia) timber for structural purposes. Static and dynamic modulus of elasticity (MOE) has been determined on samples of 4 different Hungarian plantation origins. The results of the dynamic test showed the same range as the static test, showing a good correlation of the two measurements. As result it can be stated that the domestic Hungarian Pannónia poplar species have in average 11000 N·mm$^{-2}$ modulus of elasticity. This exceeds considerably the threshold limit value (7000 N·mm$^{-2}$) necessary for structural applications according to Eurocode 5. Therefore Pannonia poplar is suitable for structural applications, and are a good alternative of the widely used coniferous species in construction sector.

KEYWORDS: Pannónia poplar, modulus of elasticity (MOE), bending strength.

## INTRODUCTION

The territory of Hungary is populated roughly in 10% by hybrid poplar species. Around half of the hybrid poplar species consists of Pannónia poplar, which is planted on large areas, as result of good cultivation experiences, high resistance against diseases, good radication vein and favorable shape developed. In spite of these good properties, poplar is mostly used for paper and stillage production in Hungary. Hungary needs to import coniferous species for the purpose of wooden structural element production, whilst large stocks of straight, branch free, 30 year old, 50-70 cm diameter poplar trunks are available (Papp and Horváth 2016). The aim of this study is to investigate the suitability of the Pannónia polar for construction purposes, first of all for glulam production. This prime material supply, with its annual 1 million m$^3$ exploitation may contribute to the reduction of the imported stocks (Rábai et al. 2020). In our study we put the accent on the modulus of elasticity measured both with dynamic and static method, in order to define the category of the EN 338 met by the values of the 4 sample groups, representing different territories of origin. In the past years other investigations of poplar hybrids also have been performed. Pásztory et.al. (2017) investigated the development of physico-mechanical properties of young Pannónia poplar during dry thermal treatment. According to these measurements based on three point bending tests, the average modulus of elasticity of small size samples (20 × 20 × 300 mm) didn't reached 8000 N·mm$^{-2}$. International publications also point out the remarkable properties of the poplar species (Beery et al. 1983, Bodig 1979, Pellicane and Bodig 1981, Zhou 1989, Kruger and Wagenfuer 2020). The poplar mechanical properties are very similar to coniferous wood species (Schniewind 1968, Schniewind 1972, Hoffmeyer and Davidson 1989, Martins et al. 2019). Hodusek et al. (2017) investigated MOR of Mexican cedar and Canadian poplar *Populus × canadensis*) with static and dynamic method. Testing 60 pieces of 80 × 80 mm poplar samples, they have found 10000 N·mm$^{-2}$ MOR, what considerably exceeds 7000 N·mm$^{-2}$, required for structural applications. They also stated, that the MOR values in case of poplar, obtained with 4 point bending test respectively with vibration, dynamic method differed from each other only in 1-2%. Castro and Fragnelli (2006) stated as conclusion, that poplar wood is suitable for load bearing purposes, especially for LVL (laminated veneer lumber) beam production. Zhou (1990) had been successful with poplar in OSB production. Basterra et al. (2012) investigated poplar wood material similar to Pannónia poplar. The MOR values measured by him showed an average of 7700 N·mm$^{-2}$, whilst the average bending strength used to be 67 N·mm$^{-2}$, thus the poplar wood tested, was found to be suitable for load bearing purposes. These values could be raised with 50% by combining the boards with fiber reinforcement. Mirzaei et al. (2018) tested glulam beams manufactured from hydrothermally treated poplar lamellas and stated that both the MOE and the bending strength increased due to the treatment. Cheng and Hu (2011) investigated the effect of carbon fiber reinforcement on the static and dynamic MOE of polar samples. Their defect free samples showed 11500 N·mm$^{-2}$ MOE, whilst with the model set up by them the effect of fiber reinforcement could be clearly shown. Castro and Paganini (2003) investigated mechanical properties of poplar and eucalypt wood with the purpose of glulam production. The investigated poplar samples showed an average MOE of 9600 N·mm$^{-2}$, and bending strength of 44 N·mm$^{-2}$, complying thus with the requirements set for structural use of the material. They were successful in combining the eucalypt and poplar lamellas in order to improve with 50% the MOE of the beam solely composed by polar lamellas. Roohnia et al. (2010) searched for a typical parameter by vibration analysis, in order to enable the evaluation of the end cracking of beams. They stated that the measure of cracking is associated with the difference between the $GL_R$ and $GL_T$. In case of defect free beams these two values are mostly the same. The poplar samples tested by them showed a MOE of 10000 N·mm$^{-2}$. Based on these results we can state that poplar may be suitable for structural purposes, or as massive wood, or as glulam, or as LVL, or as other materials like OSB.

In the followings we search for an answer whether the strength values of the Hungarian Pannónia poplar wood material reach the level suitable for structural application, as large stocks of this material are available. Furthermore also needs to be investigated whether is there a relevant influence of the territory of origin on the properties of the wood material growing on different sites.

## MATERIAL AND METHODS

Four groups of samples have been prepared for investigation, each being collected on representative Hungarian sites Győr, Kapuvár, Solt and Újrónafő (Tab. 1). From the trunks collected on four different plantation sites. The 25 mm thick boards have been prepared, kiln dried, planed, cut to size 2200 × 70 × 20 mm (grain × tangential × radial) and conditioned at 20°C and 65% relative humidity (RH). The moisture content of the sample batches has been determined as average of 3 measurements per lamella. The equilibrium moisture content (MC) has been 12% ± 1%. A total of 146 knot free samples have been investigated.

*Tab. 1: The characteristics of the plantation sites and wood samples according to the forest registry.*

| Plantation site | Height above sea level (m) | Character of the site | Age of trees (years) | Average height of trees (m) | Average diameter BH (cm) |
|---|---|---|---|---|---|
| Győr 540B | ≤ 150 m | lowland not flood basin | 25 | 26 | 27 |
| Kapuvár 35A | ≤ 150 m | lowland not flood basin | 28 | 30 | 36 |
| Solt 3A | ≤ 150 m | lowland flood basin | 28 | 20 | 24 |
| Újrónafő 11G | ≤ 150 m | lowland not flood basin | 25 | 27 | 32 |

When deciding on the length of samples, a second phase of investigation has been taken into consideration, where 5 layer glued laminated beams are foreseen to be tested. Choosing this length the ratio of length/cross section meets the requirements of the standard, being 18-20. This value makes possible the effect of the shear strength to be ignored at bending tests and in the same time when measuring the static MOE of the lamellas, this ratio allowed a 400 mm span. The distance between the two upper crossheads has been 120 mm, during the four point bending test. The length of lamellas made possible three measurements to be performed, on three different portions of the sample, on one lamella.  As consequence, the MOE of each lamella is calculated as average of three measurements. Beside the mechanical tests reported here, other complex material science investigations are in progress at the University of Sopron, regarding these hybrids. In the frame of those investigations the density of these samples originating from three different plantations of the KAEG Ltd has been measured and reported: Kapuvár 35A, Győr 540B and Újrónafő 11G showed 409.6 kg·m$^{-3}$, 420.3 kg·m$^{-3}$, and 459.6 kg·m$^{-3}$ (Farkas and Horváth 2018). Based on these values can be stated, that  even the lowest average densities reach the value of 410 kg·m$^{-3}$, typical for class C22, and are far higher  than the value of 350 kg·m$^{-3}$, typical for C14, being the lowest density class allowed for structural uses. MOE of samples originating from different plantations has been determined with two different methods: on one side by sound velocity measurements   performed with the Fakopp-PLG nondestructive timber grading instrument (Divos and Tanaka 1997), and on the other side by static four point bending tests as per EN 408. After the measurements the results of the static and the dynamic tests have been compared in order to check the reliability of the dynamic tester when measuring Pannónia poplar timber also, as those measurements are easy to be performed even on site. For bending strength measurements 18 samples from each plantation have been collected, according to EN 408.

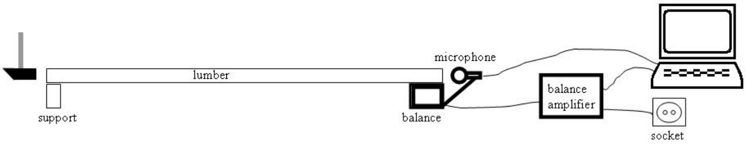

*Fig. 1: Fakopp-PLG measuring instrument.*

Fakopp-PLG is a dynamic MOE measuring instrument which provides data on the bending strength upon calculation. The measuring principle of the instrument is based on the detection with a microphone of the longitudinal sound frequency emitted by a hammer (Fig. 1).

During the measurement, the investigated sample was placed on a balance and its weight was measured. Based on a length measurement, performed with laser distance meter and the size of the cross section, the software calculated the density of the sample using Eq. 1 taking into account the difference in MC at the time of measurement and in the laboratory:

$$\rho = \frac{\mathrm{m}}{l*w*h*\left(1+\frac{u}{100}\right)} \tag{1}$$

where: m – mass (kg), l – length (m), w – width (m), h – thickness, u (%) – difference in MC between at the time of measurement and in the laboratory.

The measuring method defines the dynamic MOE based on equation Eq 2:

$$MOE_{mean} = \frac{\mathrm{m}}{l*w*h} * (2lf)^2 * 0{,}92 * (1+\mathrm{U}/50) \tag{2}$$

where: f – the frequency of the longitudinal wave.

The instrument provides the characteristic value of the sample based on the determined average MOE, and associates the strength class (Divos and Tanaka 2000), taking into account the values of Eurocode 5.

## RESULTS AND DISCUSSION

The average static and dynamic MOE values of the different plantations are shown on Fig. 2. Comparing the results of the static tests to the dynamic ones, we can state that in case of samples from Győr, Kapuvár and Solt the dynamic measurements resulted 1%, 6% and 7% higher values than the static measurements, respectively.

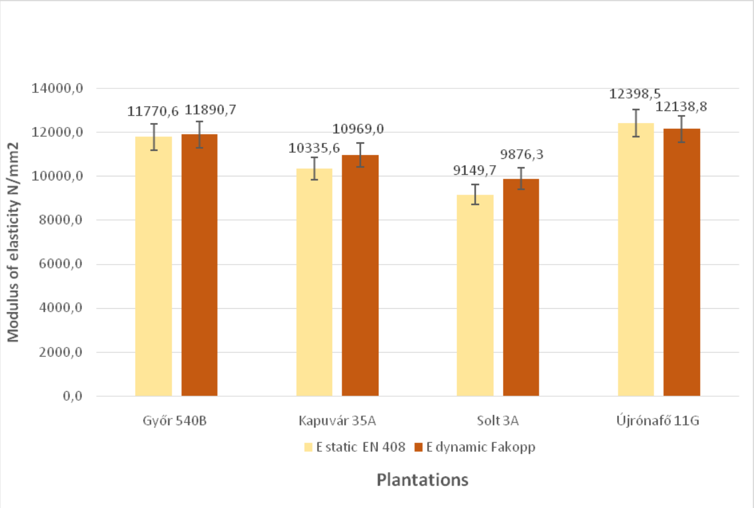

*Fig. 2: Comparison of the static and dynamic MOE.*

In case of samples from Újrónafő, the dynamic tests resulted 2% lower values relative to the static test values. The samples from Győr and Újrónafő originated from younger trunks than the two others, and whilst they showed mostly similar MOE, compared to the samples from the other plantations their modulus of elasticity used to be significantly higher. Comparing the absolute value of the averages measured/calculated with the two different methods, 4% difference has been found, thus the much faster dynamic method is considered  a suitable method for the approximation of the expected modulus of elasticity in practice. The main parameters of the samples are shown in Tab. 2.

*Tab. 2: Static and dynamic MOE of Pannónia poplar samples from four different sites.*

| **Plantation ID** | **Number of samples Stat/Dyn** | **MOE stat EN408 ($N{\cdot}mm^{-2}$)** | **Std ($N/mm^2$)** | **MOE dyn Fakopp ($N{\cdot}mm^{-2}$)** | **Std ($N{\cdot}mm^{-2}$)** | **Difference (%) Dyn/Stat** |
|---|---|---|---|---|---|---|
| Győr 540B | 135/45 | 11770.6 | 1288.7 (11%) | 11890.7 | 977.4 (8%) | 1.01 |
| Kapuvár 35A | 165/55 | 10335.6 | 1267.5 (12%) | 10969.0 | 1166.7 (11%) | 5.77 |
| Solt 3A | 114/38 | 9149.7 | 1248.5 (14%) | 9876.3 | 1353.5 (14%) | 7.36 |
| Újrónafő 11G | 24/8 | 12398.5 | 768.8 (6%) | 12138.8 | 919.7 (8%) | -2.14 |

* Values in brackets are the standard deviation (%).

The difference between the number of samples of the static and dynamic tests is due to the measuring techniques, as during the dynamic measurements the boards have been measured once, whilst during the static test the length of the board allowed three measurements per board. This way the static MOE of each board has been calculated as average of three measurements.

The lowest average MOE has been measured in case of Solt3A samples, whilst the highest in case of Újrónafő 11G samples, and the difference between these two has been 26% in case of static tests, whilst 17% in case of dynamic tests. The samples originating from flood basins (Solt3A) resulted the lowest MOE, showing that the soil conditions are with negative influence not only on the mass increase/diameter of the trunk, but on the mechanical properties also, such as the MOE. As Tab. 2 shows, the standard deviations both in case of static and dynamic tests approximate 10%, which can be considered a conveniently low value, taking into account that remains under 20%, which is typical to wood, as biological material  (Kánnár 2014, Kánnár et. all. 2019, Galuppi and Royer 2014, Yue et al. 2019, Lang et al. 2003). Considering all the tested samples the static MOE has been calculated 10 914 $N{\cdot}mm^{-2}$, whilst the dynamic MOE has been 11 219 $N{\cdot}mm^{-2}$, which means that in average the results of the dynamic tests have been 2.8% higher, and this has been considered a good correlation. The differences between static and dynamic MOE values are shown in the last column of  Tab. 3. Based on these results can be stated that the dynamic tests result in general about 4% higher values than the static test. The only exception are the values measured in case of Újrónafő samples, in this case the static measurements resulted higher values than the dynamic ones, but has to be mentioned, that in this case the number of tested samples has been significantly lower, which may be the reason of the deviation. The relatively small difference between the two measuring technics leads to the conclusion, that the dynamic method is also suitable for the calculation and prediction of the MOE. In order to authenticate the measurements, 18 randomly chosen samples have been selected for bending strength tests, according to EN 408. Result are shown in Tab. 3.

*Tab. 3: Static and dynamic strength of Pannónia poplar samples of different origin.*

| Plantation ID | Number of samples Dyn/Stat | Strength class according EN 338 estimated by Fakopp-PLG | Average static bending strength (N·mm$^2$) |
|---|---|---|---|
| Győr 540B | 45/3 | C30 | 67.22 |
| Kapuvár 35A | 55/3 | C27 | 76.61 |
| Solt 3A | 38/11 | C22 | 68.12 |
| Újrónafő 11G | 8/3 | C30 | 87.54 |

The reason of the relative small number of samples and the random test used to be, that after being tested for bending strength, the boards/lamellas went for further processing: 5 layer glued, laminated beams have been produced and tested.

The third column of Tab. 3 shows the average estimated bending strength class, the value of which is characteristic, meaning that its 5% quantile's value gives the value of the expected bending strength in N·mm$^{-2}$. Thus the strength class gives the expected value of the bending strength with high reliability, from 100 cases only 5 case it can be expected to get lower values. The values recorded by measurement exceed considerably the estimated bending strength values, thus suit with high reliability to the design values calculated from the strength class.

We would like to mention in the same time, that the tested samples have been all defect and knot free, thus probably manifested somewhat higher bending strength than unselected, common boards would show. As conclusion can be stated that the investigated Pannónia poplar populations possess in average 11 000 N·mm$^{-2}$ MOE. The expected strength associated with this elasticity characteristic not only reaches, but exceeds the threshold limit value 7 000 N·mm$^{-2}$ prescribed for structural applications, respectively the 14 N·mm$^{-2}$ bending strength of class C14. Based upon these data can be confirmed that the investigated plantation sites provide Pannónia poplar timber suitable for structural applications, and can replace the widely used coniferous species in construction sector.

## CONCLUSIONS

In frame of this research the main question used to be the suitability of the harvestable, mature, 0.5 mil·m$^3$ Pannónia poplar timber of different Hungarian plantations, for structural applications. Four plantation sites have been involved in the research, a total of 146 samples of 2240 x 70 x 20 mm dimension have been tested both by static and dynamic MOE test. Beside performing static measurements according to EN 408 in the laboratory, the suitability of the Fakopp instrument, which measures dynamic MOE has been also evaluated and compared to the static measurement. However it is more efficient applicable in industrial environment and makes possible even on site measurement and adjudication of the MOE. Comparing the average MOE of the different sites, they showed a maximum of 26% deviation in case of static measurements, whilst only 17% in case of dynamic measurements, which means that the conditions of the different sites have a major influence on the modulus of elasticity of the wood material. The most unfavorable results have been measured in case of flood area samples. The standard deviation of both static and dynamic measurements remained under 10%, which is much lower than the 20%, considered minor for wood as inhomogeneous biological material. The static MOE in average of all tested samples resulted 10 914 N·mm$^{-2}$, whilst the dynamic one 11 219 N·mm$^{-2}$. Considering all samples, the dynamic tests MOE have been 2.8% higher than the one measured by static method, which means that the dynamic one is also suitable for MOE testing. In conclusion can be stated that that the investigated plantation sites provide Pannónia poplar timber with average MOE of 11 000 $N \cdot mm^{-2}$. This exceeds considerably the threshold limit value necessary for structural applications. Therefore poplars of these sites are suitable for structural applications, and are a good alternative of the widely used coniferous species in construction sector.

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