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USING POPLAR STUD ELEMENTS IN LIGHT FRAME WALL STRUCTURE INSTEAD OF CONIFEROUS

Zoltan Pastori[1], Imre Czupy[2], G.A. Gorbacheva[3]

[1] Innovation Center at the University of Sopron, 4. Bajcsy Zs. Sopron, Hungary 9400
[2] Institute of Forest and Environmental Techniques at the University of Sopron, 4. Bajcsy Zs. Sopron, Hungary 9400
[3] BMSTU (Mytishchi branch), 1 st. Institutskaya, 141005, Mytischi, Moscow reg., Russia

pasztory.zoltan@uni-sopron.hu

The overall objective of the investigation is to change coniferous wood element to poplar in the wall construction of light frame wood residential buildings therefore important properties were compared. Although not all coniferous element of wood wall is worth to be changed, but there are elements such as studs what are not bearing big forces and have lower exposure. It was investigated some of the most important influencing factors determining the utilization of poplar elements in light frame wall constructions. The element chosen to be changed in the wall construction was examined in the following aspects: mechanical properties; thermo-dynamical properties; screw holding strength. Nowadays one of the most important questions is the thermal resistance of the structure. Originally the studs are heat bridges among the thermal insulation materials being between studs. The poplar studs have a lower thermal conductivity than that of the coniferous consequently the thermal bridge effect is lower compared to the coniferous. The other main part of the study is to investigate the properties of the whole construction. According to our investigations the poplar seems to be an appropriate row material of light frame constructions with the condition the bulk density is higher than 400 kg/m^3.
Keywords: Light frame wood structure, poplar PopulusEuramericana, thermal conductivity, screw holding strength

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Introduction

In the northern hemisphere the most widespread raw material used in light frame wood construction is coniferous mostly scots pine and spruce. There are wood species which is used mostly for industrial purposes like poplars and the secondary utilization for higher value added products is desirable. Many countries have great population of different hardwood species e.g. the fast growing poplar. In descending order Canada, the Russian Federation, the United States, China and Germany have the biggest reported natural poplar stands out of the International Poplar Commission (IPC) member countries. China, India, France, Turkey and Italy have the biggest reported planted poplar areas, also in ascending order of IPC members [3, 15]. Some of these countries have high quality poplar plantations that can produce materials with dimensions appropriate for building frame elements.

The possibility of using poplar in exterior structures was already examined [4]. According other researchers' opinions the most promising utilization of poplar among others is structural panel industries [1, 2, 9]. Fraanje [7] examined the possibilities of using poplar wood as purlin.

There have already been numerous experiments to use Hungarian broad leaved wood species raw materials but these attempts have been suppressed by the existing coniferous-based construction techniques.

In the 1970's the Forestry Research Institute in Hungary (FPI) already looked into the possible applications of broad leaved wood materials in glue laminated frame structures [6, 14]. The two applicable species mentioned in their work are poplar and black locust. From a strength point of view, black locust is the most desirable; however, hybrid poplars are more favorable in terms of figure and dimensional properties. The raw material of the first building of this sort, using layered-cemented three-point arc framed was hybrid poplar. In addition, even presently, there are family houses at the Hungarian Great Plane with poplar-based roof structure, what reason is the availability of poplar raw material at the region.

Apart from these, numerous European and North American examples exist for using different wood species than coniferous. There have been a number of experimental attempts on using broad leaved wooden materials for structural purposes. Hernandez et al. [8] reported the construction of a vehicular bridge with a glue laminated structure of tulip tree. Another example is presented by the collaboration of the Swiss architecture company, Bernath and Widmer with other experts (Hermann Blumer, Michael Koller, Bergauer Holzbau GmbH, Heiri Bührer), who constructed a three-story youth hostel of oak logs in Schaffhausen province near Büttenhardt. In summation, experts are constantly examining the possible usage of stratum raw materials, which could open new horizons in wood construction, beyond the conventional coniferous-based methods.

To create safe poplar structures, thorough examination of basic stress factors, like tensile compressive and bending strength followed by the different analysis of the full-sized specimen including the thermo-technical attributes. In the case of full structures where the overall performance depends on the interaction of the adjacent materials and their features, these thermo-technical and strength tests and durability comprise the basis of the examination.

This article focuses on introducing only on some of the important examined attributes, such as strength and thermodynamic differences between poplar and spruce. The authors are aware that deeper analysis of more features is necessary for the applicability but the article does not touch upon these due to space limitations.

MATERIAL AND METHODS

In Hungary, poplar cover 1,5 million ha, accounting for the 9,6 %-a of the full forest area. Every year 1,3...1,5 million m3 poplar raw materials are processed which comprises 23...25 % of all wood cutting. To ensure good quality, poplar plantations have to be branch cut up to 6 meter height what can be called pruning [11].

The coniferous wood species ratio is very low in Hungarian forest contrast to the Siberian forests, and also to the west — and north European forests. Because of this fact high amount of the construction wood is imported in building market. However, Hungary has valuable broadleaved wood species such as poplar (Populus Euramericana cv. Pannonia).

From the 1980's more and more hybrid poplar species have been genetically improved, cutting back the share of then-popular I 214 Italian poplar. Examining the plantation data of the poplar species in the 90's, the Populus Euramericana proves to have had the biggest share (almost 50 %) on the market [13].

Fundamental differences can be observed among certain poplar clones in density, strength, and figure and also in durability. In the table 1 below the attributes of the most common poplar clones and the control variables are highlighted.

Among the mechanical properties density and strength have crucial importance. Bending strength plays a crucial role among strength features. Populus Euramericana (Pannónia) was selected due to its excellence in these two defining parameters along with its figural properties, durability and quantity. Its Hungarian ratio is remarkably high; it is the most important poplar species of the plantation-type poplar growing [13].

Due to the lower mechanical properties of poplar the dimensions of the cross section could expectedly be changed as the distance of studs from each other.

Mechanically the wall should not be significantly weaker than the original construction build with coniferous studs and top and bottom elements.

MECHANICAL PROPERTIES

The utilization of the different wood species depends on their physical and mechanical properties. In general, the strength of poplar wood falls below that of coniferous, but for certain species the differences is not substantial. Examinations by the Witmann and Pluzsik [14] provided strong correlation between the mechanical properties of poplar and their volume mass. According to their findings, the poplar species whose absolute dry volume mass reaches or exceeds 400 kg/m^3 can effectively replace coniferous in strength-stressed structures and in structural units. Taking into account the literature and our test results, these apply to the Populus Euramericana. The comparison investigation results also reveal that the density of wood highly depends on the soil of planting location and the volume of precipitation.

We conducted our tests on 50 Populus Euramericana specimens prepared in accordance with the standards based on the following strength groups:

– tensile strength
– compressive strength
– shear strength
– bending strength
– impact strength

SCREW HOLDING STRENGTH

There is only few literature with exact information about the nail and screw holding strength of the Populus Euramericana but there is indication that their nail holding strength is 5...10 % lower than that of pines [5]. Due to the number of species, the screw holding strength of the hybrid poplar should be measured experimentally, in parallel with pine test units. The last valid standard (MSZ EN 1382) gives an exact description of the examination that can be conducted with arbitrary nail and screw properties so that specific values can be assigned to the joints the most likely to be used.

Thermal conductivity

Our research also examined the conventional thermal conductivity of Populus Euramericana compared that of the spruce, the most widely used wood species in light frame wood construction. Minimizing the thermal bridges is essential when designing the wall structure. There is a huge difference between the thermal conductivity of the wall frame and the insulation materials.

The frame in the wall structure are located every 62,5 cm. This wall structure relates back to the 125 cm table division. The usual 40...50 (45) mm thick studs create a substantial thermal bridge in the wall. 16,5 % of the full wall surface comprises wood compared to insulation material [12]. The bigger the

Table 1

Mechanical properties of polar species (Tóth, 2006; Molnár, 1999) [10, 13]

Механические свойства полярных видов (Tóth, 2006; Molnár, 1999) [10, 13]

Name	Density [kg/m³]	Mechanical properties [MPa]				Elastic modulus [MPa]	Hardness [MPa, Brinell]	
		shear	compressive	bending	tensile		butt	side
I-214	330	6,4	22,5	52	44,3	5330	21,9	8,3
Villafranca	350	6,9	32	64	46,2	5600	19,3	9,9
Triplo	360	–	26,6	57	64,1	–	22,8	7,7
BL-Costanzo	375	7,5	36,9	75,1	59,6	6160	25,4	11,3
Koltay	390	–	–	56	–	–	–	–
Kopecky	390	7,4	33	70,7	56,1	5620	20,6	12,5
Parvifol	400	–	32,9	66,3	75	7830	24,8	9.8
Agathe-F	405	6,9	29,6	58	44,5	5200	20,7	11,7
I-273	410	8,1	32,8	72,2	–	5690	28	13,9
Pannónia	410	8,3	32,6	67,4	56,2	6510	20,6	10,8
Robusta	419	8,1	30,2	66,9	74,4	7500	22,8	7,7
Unal	420	–	–	–	–	–	–	–
White poplar	450	7,8	38,3	67,5	82,3	8250	27	–
Black poplar	450	6	35	65	77	8800	30,5	–
Trembling poplar	450	6.8	32,5	56	75	7800	23	–
Spruce	470	6,7	50	78	90	11000	32	–
Scotch pine	520	10	56	80	104	12000	40	19

difference in thermal conductivity the bigger the thermal bridge effect in the structure. The thermal conductivity of the insulation material is 0,04 W/mK compared to 0,12 W/mK of the spruce studs according to the literature. In accordance, on one sixth of the surface the coniferous material determines the thermal conductivity while the rest of the surface is dominated by the properties of the insulation material in terms of thermal behavior.

If the spruce material is replaced by poplar, the thermal bridge effect changes by the difference between the spruce and poplar thermal conductivity.

In the frame of another project, we also aimed for constructing a test building that makes identifying every step of the necessary technological processes possible. Manufacturing the building blocks requires industrial usage of the new material, and assembling and joining the structures also differs from the spruce technology. Testing and measuring the real stress results become possible on the full-size structure, especially regarding the thermal behavior of the building. Determining the value of low energy need is also possible.

RESULTS

MECHANICAL PROPERTIES

The test results have a strong correlation with density. In numerous cases, the density of Populus Euramericana reaches or even exceeds 400 kg/m³. Using this material for studs in structural applications is also possible, thus it can replace spruce in certain structural units. Our test results are summarized in table 2. In structural materials bending strength is the most important property. According to our tests, the Populus Euramericana should be further examined as raw material for light frame wall construction as its key strength properties approach those of the spruce. It is important to examine which spruce parts can be replaced in the wall structure system, as well as how the dimension of these parts would change.

The strength test results of Populus Euramericana show favorable values; in addition it is available in high quantities. It is reasonably priced and it is a raw material relatively easy to work with. Due to its low natural resistance, the Populus Euramericana needs proper protection as well.

Screw holding strength

Our screw holding strength analysis was conducted in accordance with the latest corresponding standards. Table 3 shows the test results of the Populus

Table 2

Comparison of mechanical properties

Сравнение механических свойств

Name	Poplar	Spruce
	σh — $u_{12\,\%}$ (N/mm²)	σh — $u_{12\,\%}$ (N/mm²)
Tensile strength	52,49	90
Compressive strength	38,51	50
Shear strength	5,24	6,7
Bending strength	57,04	78
Impact strength	3,65	4,6

Table 3

Result of screw holding strength tests of Populus Euramericana
Прочность на сжатие винта Populus Euramericana

Name	Butt [N/mm]	Serial 1 [N/mm]	Serial 2 [N/mm]	Serial 3 [N/mm]	Serial 4 [N/mm]
Minimum	20,00	47,50	47,50	40,00	50,00
Maximum	62,50	92,50	90,00	95,00	102,50
Average	45,70	63,80	63,60	65,40	66,26
Scatter	8,84	12,31	11,92	11,52	9,86
Variance	78,07	151,59	142,13	132,74	97,25

Euramericana test pieces — measurements included 1 from butt direction, 2–2 screw tests from radial and tangential direction.

THERMAL CONDUCTIVITY

During the tests we prepared 20 test specimens per wood species whose corresponding thermal conductivity are shown in table 4. The specimens had been air conditioned in a climate chamber on normal climate (20 °C and 65 % relative humidity). To be able to compare them, the specimens were stored and measured the same way with the same methods.

The data clearly indicates that the thermal conductivity values of the poplar are more favorable. Comparing our test results with the literature we arrive to an even more desirable conclusion: according to our measurements the difference between the two wood species in terms of thermal coefficient is nearly 6 %. During the design process when using spruce the usual values vary between 0,13...0,15 W/mK, in contrast our measurement showed only 0,110 W/mK.

The need for technological change compared to spruce techniques is going to be an important topic to examine during the research, as well as finding out whether the extra technology input is proportional to the benefits derived from using poplar instead of spruce.

CONCLUSION

MECHANICAL PROPERTIES

All of the mechanical properties of poplar showing weaker results than coniferous can be compensate

Table 4

Thermal conductivity of poplar and spruce specimens
Теплопроводность образцов тополя и ели

Specimen id.	Thermal conductivity [W/mK]	Density [g/cm^3]	Specimen id.	Thermal conductivity [W/mK]	Density [g/cm^3]
Poplar 1	0,099	0,319	Spruce 1	0,087	0,397
Poplar 2	0,105	0,335	Spruce 2	0,091	0,409
Poplar 3	0,106	0,343	Spruce 3	0,090	0,417
Poplar 4	0,105	0,357	Spruce 4	0,092	0,401
Poplar 5	0,101	0,346	Spruce 5	0,095	0,428
Poplar 6	0,100	0,340	Spruce 6	0,092	0,405
Poplar 7	0,112	0,414	Spruce 7	0,091	0,406
Poplar 8	0,098	0,410	Spruce 8	0,110	0,491
Poplar 9	0,117	0,406	Spruce 9	0,128	0,515
Poplar 10	0,113	0,420	Spruce 10	0,126	0,516
Poplar 11	0,099	0,405	Spruce 11	n.a.	0,517
Poplar 12	0,108	0,406	Spruce 12	0,124	0,503
Poplar 13	0,106	0,407	Spruce 13	0,124	0,519
Poplar 14	0,105	0,409	Spruce 14	0,128	0,529
Poplar 15	n.a.	0,410	Spruce 15	0,125	0,532
Poplar 16	0,096	0,421	Spruce 16	0,122	0,519
Poplar 17	0,099	0,422	Spruce 17	0,117	0,514
Poplar 18	0,098	0,412	Spruce 18	0,119	0,511
Poplar 19	0,097	0,419	Spruce 19	0,117	0,505
Poplar 20	0,103	0,416	Spruce 20	0,114	0,497
Average	0,104	0,391	Average	0,110	0,477

with higher dimensions or higher processing technologies. The poplar material used for construction materiel have to have higher density than 400 kg/m^3.

SCREW HOLDING STRENGTH

According to the preliminary test results, the screw holding strength of the poplar raw material approximates that of the spruce. Special attention should be taken to the number, size and location of the joints in the important corner units. The point of view this aspect the Populus Euramericana could be substitute the spruce.

Thermal conductivity

Examination of the thermal coefficients revealed that the Populus Euramericana shows better properties leading to decreased thermal bridge effect in wall structures constructed of poplar rib frame. In the wall construction the poplar causes lower heat bridge effect thus the heat loss of the whole structure is lower. In case of a successful project the poplar could be the rival of the widely used coniferous row material of wood residential buildings/

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Author's information

Pastori Zoltan — Ph. D, Director of Innovation Center, University of Sopron, Sopron, Hungary, pasztory.zoltan@uni-sopron.hu

Czupy Imre — Ph. D, Director of Institute of Forest and Environmental Techniques at the University of Sopron, Sopron, Hungary, czupy.imre@uni-sopron.hu

Gorbacheva Galina Aleksandrovna — Cand. Sci. (Tech.), Associate Professor of Department of Wood Science and Technology, BMSTU (Mytishchi branch), gorbacheva@mgul.ac.ru

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ПРИМЕНЕНИЕ ДРЕВЕСИНЫ ТОПОЛЯ ДЛЯ ИЗГОТОВЛЕНИЯ СТОЕК В КАРКАСНЫХ КОНСТРУКЦИЯХ ВМЕСТО ДРЕВЕСИНЫ ХВОЙНЫХ ПОРОД

З. Пастори[1], И. Цзупи[2], Г.А. Горбачева[3]

[1] Шопронский университет, Инновационный центр, Hungary, 9400 Sopron, Bajcsy-Zsilinszky utca 4.
[2] Шопронский университет, Институт леса и природопользования, Hungary, 9400 Sopron, Bajcsy-Zsilinszky utca 4.
[3] МГТУ им. Н.Э. Баумана (Мытищинский филиал), 141005, Московская область, г. Мытищи, ул. 1-я Институтская, д. 1

pasztory.zoltan@uni-sopron.hu

Цель работы заключалась в исследовании возможности замены элементов каркасных конструкций жилых домов из древесины хвойных пород на элементы из древесины тополя, а также в сравнении их основных свойств. Далеко не все элементы из древесины хвойных пород можно заменить, однако имеются стойки каркаса, которые скрыты внутри общей конструкции и не подвергаются большим нагрузкам. Проведены исследования некоторых наиболее важных факторов, определяющих использование тополя в легких каркасных конструкциях стеновых панелей. Элемент, выбранный для замены в конструкции стены, был рассмотрен в следующих аспектах: механические свойства, термодинамические свойства, прочность крепления шурупами. В настоящее время одие из важнейших вопросов — тепловое сопротивление конструкции. Стойки каркаса являются тепловыми мостами между теплоизоляционными материалами внутри каркаса. Стойки каркаса из древесины тополя имеют более низкую теплопроводность по сравнению с древесиной хвойных пород, следовательно, эффект теплового моста проявляется в меньшей мере. В результате исследования всей конструкции. установлено, что тополь является подходящим материалом для каркасных конструкций при плотности выше 400 кг/м^3.

Ключевые слова: каркасные конструкции из древесины, тополь Populus Euramericana, теплопроводность, прочность крепления шурупами

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Сведения об авторах

Пастори Золтан — директор Инновационного центра, Шопронский университет, pasztory.zoltan@uni-sopron.hu

Цзупи Имре — директор Института леса и природопользования, Шопронский университет, г. Шопрон, Венгрия, czupy.imre@uni-sopron.hu

Горбачева Галина Александровна — канд. техн. наук, доцент кафедры древесиноведения и технологии деревообработки, МГТУ им. Н.Э. Баумана (Мытищинский филиал), gorbacheva@mgul.ac.ru

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