Glulam beams made of Hungarian raw materials*

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ABSTRACT

A research team was established at the Faculty of Wood Sciences in September 2011, in order to foster the production of glued-laminated beams based on Hungarian raw materials. The goal is to support the production of straight, and, later, curved beams through creating, testing and evaluating model beams and prototypes. Historic examples found in the literatures should first be reviewed. Because of the general lack of construction wood, many studies were conducted in the 1960's and 70's for replacing conifers with poplar raw materials, e.g. in the Wood Research Institute in Budapest. The physical and mechanical properties of various hybrid poplars were investigated. The 'Robusta' hybrid, and occasionally the 'Marilandica' and 'Serotina' varieties, were found to be applicable for construction purposes to carry medium loads, with some technical conditions (wood protection). Other tests showed that a basic criterion for using poplars is that their density should exceed 400 kg/m^3, because density and strength values correlate closely. This is the criterion for wood to satisfy the standards concerning construction materials (like EN 338 and EN 1194). The apex of contemporary research was designing and constructing an 800 m^2 hall built of poplar raw material, with a novel, three-hinged truss structure. Built in

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Velence, Hungary in 1974, the hall is still in use today, and has a surprisingly sturdy wood structure. This proves that poplar has great potential as a structural wood, and justifies further investigation of the available hybrid poplars (e.g. plantation 'Pannonia' poplar.)

INTRODUCTION

Glued constructional wood was first introduced by master carpenter and entrepreneur Otto Hertzer who was granted a patent in 1906 for his invention of a constructional element made up of several lamellae glued together. He applied pressure to create a permanent bond between the lamellae. Hetzer's technology was further improved in the second half of the 20th century, and today laminated beams of homogeneous quality, as long as 50 m, with heights in excess of 3 m may be created. A further advantage is that beams may be curved in one or two directions, or even twisted around their own axes. Products are manufactured precisely in a plant, and thus construction times of buildings (houses, halls and bridges) made of glued elements are considerably shorter than those of traditional construction techniques, which offers a competitive edge. In terms of environment protection, there is hardly another building material that can meet the ever more stringent requirements, which will make wood even more attractive in the future.

HUNGARIAN WOOD SPECIES SUITABLE FOR GLULAM BEAM MANUFACTURE

None of the wood species are completely excluded from constructional use, but economic factors and structural design requirements limit the range of practically applicable species (Wittmann 2000). Of the many wood properties, mechanical and physical characteristics are especially relevant.

When producing wood beams, reliable glueline strength calls for consistent wood quality. In this respect, coniferous species with their homogeneous structure are most suitable, and therefore are most commonly used. Growth characteristics, physical and mechanical properties and workability are also vital, these also put softwoods in a preferred position. On the other hand, aesthetic requirements, high strength and durability may necessitate the use of high density hardwoods, even considering the higher costs.

In Hungary, the following species are typically used:

- softwoods: spruce, silver fir, Douglas fir, Scots pine, and, for special purposes, larch.
- hardwoods: oak, occasionally black locust, as well as beach, poplar and alder with appropriate wood preservation.

Arguments for hardwoods include high strength, in case of oak and black locust, and good dimensional characteristics and favourable price, for poplar. The construction industry, as well as door and window manufacturers almost exclusively use softwood, mostly in the form of sawn lumber (Zoller and Molnar, 1974). In terms of softwood, Hungary is entirely dependent on import. There were several research projects aimed at technical development that takes the species mix of Hungarian forests into consideration. These projects proved that poplars can usually be used instead of softwoods as raw materials for glued-laminated beams (Erdelyi et al, 1976). Compared to other hardwood species, poplar grows fast, and the age of harvest is low (15-30 years). In forest management it is considered economically important because of the high yield of industrial wood.

A member of the salicaceae family, the poplar genus includes many species. Earlier, poplars used to be divided into two groups in Hungary, including domestic poplars (silver, grey, black poplar, and quaking aspen) and noble poplars that included hybrid species. This classification is not valid any more, because, in addition to the Marilandica, Serotina and Robusta varieties, more than 10 other hybrids are being cultivated today (Molnar 2004). Different poplar species and hybrids may have widely variable density, so mechanical properties vary as well. Three different groups can be distinguished based on density (Table 1.)

Table 1: Classification of poplar species and hybrids

Group	Density	Hybrid
Very low density	< 360 kg/m^3	I-214, Villafranca, etc.
Low density	360 – 400 kg/m^3	Kopecky, Sudar, etc.
Moderately low density	> 400 kg/m^3	Robusta, Marilandica, Pannonia, etc.

The macroscopic identification of domestic and noble poplars are effectively impossible based on a small section. Still, their characteristics are very different, and this may cause many problems during utilisation. This fact often discourages wood industry professionals from using poplar. One way to overcome this problem is by attaching a certificate of origin to each shipment. Also, due to the uniform density of late and earlywood, no serrulate notching of the cutting edge occurs, as is the case when cutting softwood. Poplars are not resistant to fungal and insect attack, but pressure treatment is effective both with oil- and water-based preservatives. Preservative uptake is 180 kg/m^3 when using oil-based preservatives, and approx. 5 kg/m3 is required when using a aqueous solution (Hadnagy 1968).

Erdelyi and Wittmann were the first to study the physical and mechanical characteristics of poplar comprehensively, in 1969. They collected samples from various locations in the country, including Baja, Szolnok, Nyirseg and Sarvar, to study their properties. They carried out the strength measurement of the robusta, marilandica and serotina varieties, as well as the I-214 hybrid, at 15% moisture content. Their data show that the physical and mechanical properties of the same hybrids can be different when grown at different locations. This proves that, in addition to genetics, site characteristics influence physical and mechanical properties significantly (Erdelyi and Wittmann 1969).

Their study also proved that, even though, traditionally, poplar was traditionally deemed unsuitable for uses that call for high strength, the properties of the robusta poplar are outstanding, and approach the strength values of some softwood species. However, differences between the strength properties of the four varieties are so significant that they limit their practical application. I-214, especially, yielded such low values that this hybrid may not be used in load-bearing applications. With medium loads, when fulfilling some technical criteria (wood protection), particularly the robusta variety, but also the marilandica and serotina hybrids may be suitable (Erdelyi and Wittmann 1969).

Table 2: Mechanical characteristics

Characteristic	Unit	Marilandica*	Marilandica**	Pannonia**	Pannonia***
Density	kg/m^3	396	425	406	411.3
Compression strength	N/mm^2	28.8	22.6	32.6	38.8
Bending strength	N/mm^2	54.4	60.8	67.4	63.5
Shear strength along the grain	N/mm^2	7.7	7.6	8.3	
Brinell hardness	N/mm^2	27.1	30.9	20.6	
Bending MOE	N/mm^2	7651.8	7800	6510	7695.8

Erdelyi and Wittmann 1969, **Molnar 2004, * Horvath 2008, u_{ave}=12,26%*

Based on the results of Erdelyi and Wittmann, as well as those of Molnar and Horvath, there is sometimes a significant difference between the results of the same hybrids grown at different sites. Non-destructive testing techniques would be useful for the strength grading these hardwoods.

The robusta, marilandica and serotina varieties are the primary species used to be considered for structural use, not only because they fulfilled the strength and density criteria, but because of their availability in the necessary quantities and in adequate length and cross sectional dimensions. Today, however, Pannonia poplar may be the best choice. Since growing this material has been permitted since 1980, almost 40% of all poplar propagation material was made up of this species in 1991, and 30-32 year-old-stands may exist today.

GLUED-LAMINATED BEAM PRODUCTION TECHNOLOGY

The production technology of glued laminated beams consist of the following processes:

- raw material preparation
- cross-cutting
- end jointing
- planing the lamellae
- adhesive application
- pressing
- finishing

During raw material preparation, low quality materials that are unsuitable for lamella manufacture are rejected, and do not get dried. The remaining lumber is classified according to width. Drying lumber with nearly uniform width together ensures that the raw material is available for a given beam width.

Cross cutting is based on the quality and shape of the raw material in order to provide full-size, defect-free blanks. This seriously impacts both the cost of production and final product quality. After cross-cutting, rip sawing may be included (usually with a double blade edging saw). The lumber is sawn 10-15 mm wider than its final size to allow for subsequent planing losses. After cutting, the moisture content should be verified.

10 to 20 mm long finger joints are used for end jointing according to the relevant standards. An automated combined finger jointing machine moulds the end of the blanks, applied the adhesive and performs the longitudinal pressing of the meshing finger jointed ends. Choosing the right type of adhesive is very important. Resorcinol adhesives used to be used for this, but nowadays some of the more modern adhesives like polyurethane based construction grade adhesives and emulsion polymers are most widespread. The applied pressure should also be chosen carefully. Based on earlier studies, the applied load depends on the wood species and the dimensions of the finger joints. Table 3 shows the recommended minimum values.

Table 3: Recommended minimum pressing forces (Kajli et al., 1975)

Finger length (mm)	Pressing force N/mm^2 *	
	poplar	black locust
7.5	12–19	16–25
10	8–12	11–16
20	5–7	6.5–9
50	2.5–3	3.5– 4.5

**Based on the cross-sectional area of the jointed lumber*

The planing of the lamellae occurs after the finger joint strength reaches the required level. Lamellae are planed in a single step, with a multi-head moulder.

Adhesive may be applied to both side using rollers, or to one side only, using a curtain coater. The recommended mode of application depends on the type of adhesive used. The adhesive should be used within its gel time. E.g., in case of resorcinol glues, at a 20 °C temperature, pot life was approx. 3–4 hours.

After the adhesive application, the bundle containing the appropriate nr. of lamellae according to the beam dimensions, are placed in presses that can provide the necessary pressure. This varies between 0.5–1.5 N/mm^2, depending on the species. There are many pressing setups, from simple horizontal screw presses to vertical hydraulic presses with automated feeding. In addition to the appropriate level of pressure, uniform pressure distribution is ensured through the use of shims and pressure distributing bars. At the beginning of the pressing cycle, lateral presses are used to adjust the lateral faces of the lamellae. Clamping starts in the middle of the beam, and proceeds outward towards the two ends. During pressing, some of the adhesive gets pressed out of the gluelines, and the wood suffers a permanent viscoelastic deformation. This leads to a drop in the applied pressure over time, so, in case of mechanical clamping, the presses need tightening after 15 minutes. Temperatures and pressing times vary according to the type of adhesive used, and some adhesives require several weeks to reach their final strength (Kajli et al. 1975).

A MULTIFUNCTIONAL HALL BUILT OF POPLAR WOOD

The load-bearing structure of the first poplar glulam beam-supported building was manufactured at the Wood Research Institute in Budapest, commissioned by the National Technical Development Committee in 1975. This was also the first building with a three-hinged truss structure in the country (Wittmann and Pluzsik 1975).

The structure was built mostly of glued-laminated (robusta) poplar raw material. The base girder is an exception; it was manufactured of black locust, another Hungarian species. The laminate structure is very important when using hardwood species. This should consist of at least 4 laminates in order to prevent subsequent warpage. A great advantage of lamination, especially when using hardwood, is the elimination of wood defects. This improves strength and fire resistance, as well.

The curved „shoulders” of the three-hinged arches are appended to support the sheathing.

Principal dimensions:
- span: 18 m
- distance between arches: 6 m
- shoulder height: 4 m
- top hinge height: 7.5 m
- floor space: 800 m^2

The interior height of the building is 3.9–7.4 m in-between, and about 0.2–1.5 m lower underneath the arches. The structural elements of the framework are jointed with steel connectors. Poplar has low resistance against degradation, and was treated with a preservative (Pharmol HSL 1019) and a transparent finish (Pharmol PVK 1085). The outside sheathing consists of wood-frame panels made of glued-laminated poplar.

The primary joists are made of glued-laminated arches with shoulder appendages, 120 mm in width and variable in height (0.64 m at the base, 1.54 m at the middle of the curve, and .36 m at the top hinge.) The distance between the lower hinge and the shoulder is 4 m, the height of the top hinge is 7.5 m. The vertical column on the outside of the joist allows the connection of sheathing. The purlins are 100 mm in width and 320 mm in height, and are 6 m long to match the distance between the joists. The two ends of the purlins have a 20 cm high rabbet, so that only 12 cm of the material sits on top of the joist, and 20 cm rests on the side. Thus, they also provide lateral support for the joists. On the two ends of the building, purlins protrude over the façade to support the rim. (Wittmann and Pluzsik, 1973).

According to the technical description, the hall (Fig. 1) was designed as a multi-functional building. The large, unbroken, enclosed internal space is uninterrupted by any internal support element, and thus it is suitable for the purposes of storage, industrial hall or even as a sports hall. Throughout the years it was used for all three of these purposes (most recently as a winter tennis court), and it performed well in all capacities. The fact that, even after 40 years, there is no evidence of damage to the joists, the building still stands and is structurally sound, bears witness to the to the quality of construction. During a 2012 visit, the building was found in excellent conditions, no deterioration was evident when compared to its original state.

Figure 1: Glued-laminated structure made of poplar

SUMMARY AND CONCLUSIONS

A thorough review of the Hungarian literature revealed that some poplar hybrids are suitable for structural use. The necessary production technology is well known and established. The use of the Pannonia variety, not included in earlier studies, as a construction material necessitates further studies. In case of positive results, Pannonia poplar can be included in the list of hardwoods applicable for structural purposes. A more detailed examination of the hall designed and built using poplar glued-laminated joists in the ‘70s by the Wood Research Institute in Budapest, and preserved in a good condition, may provide further important learnings as well.

REFERENCES

ERDÉLYI, GY., KAJLI, L., PLUZSIK, A., SZARKA, A., WITTMANN, GY, (1976) Rétegelt ragasztott faszerkezetek alkalmazásának jelentősége és a gyártási lehetőségei. [The importance of use and possibilities of production of glued-laminated wood structures.] WRI research report, Budapest

ERDÉLYI, GY., WITTMANN, GY. (1969) A hazai termesztésű nemesnyárak faanyagának fizikai- mechanikai tulajdonságai. [Physical and mechanical properties of hybrid poplars grown in Hungary] WRI research report, Budapest

HADNAGY, J., PLUZSIK, A. (1968) Hazai fafajok építőipari alkalmazásának vizsgálata. [A study of the structural application of Hungarian species.] WRI research report, Budapest

HORVÁTH, N. (2008) A termikus kezelés hatása a faanyag tulajdonságaira, különös tekintettel a gombaállóságra. [The effect of thermal treatment on wood properties, especially fungal resistance.] , PhD. Dissertation, University of West Hungary, Sopron.

KALJI, L.,WITTMANN, GY., PLUZSIK, A., BÁRÁNY, A. (1975) Hazai fafajok alkalmasságának vizsgálata egyenes rétegelt- ragasztott tartók gyártásánál, valamint e tartók felhasználása vázszerkezetek kialakításánál. [*The applicability of Hungarian wood species for producing straight glued-laminated beams, and using such beams for structural framing.*] WRI research report, Budapest

KAJLI, L., SZARKA, A., BÁRÁNY, A. (1976) Hazai fafajok alkalmasságának vizsgálata egyenes rétegelt- ragasztott tartók gyártásánál és felhasználásánál. [*The applicability of Hungarian wood species for producing and using straight glued-laminated beams.*] WRI research report, Budapest

MOLNÁR, S. (2004), Faanyagismeret [Wood Science], Szaktudás Publishing House, Budapest, ISBN: 9639553174

PLUZSIK, A, KAJLI, L., PATOCZKY, I. (1980), Fenyőhelyettesítés vizsgálata. [Substituents of softwood.] WRI research report, Budapest

WITTMANN, GY., PLUZSIK, A. (1975) A faanyagú rétegelt-ragasztott tartószerkezetek hazai alkalmazásának új eredményei. [Newest results of using glued-laminated wood structures in Hungary.] Faipari Kutatások, WRI published research reports, Budapest, pp. 61- 69.

WITTMANN, GY. (2000), Mérnöki faszerkezetek I. [Engineered wood structures, Vol I.] Szaktudás Publishing House, Budapest, ISBN 9633563147

WITTMANN GY., PLUZSIK, A. (1973), Faanyagú váz és térelhatároló szerkezetek felhasználásával készülő, többcélú csarnokjellegű épület kialakítása [Designing a multifunctional hall with wooden frames and sheathing.] WRI research report, Budapest

ZOLLER, V., MOLNÁR, F. (1974) A fenyőhelyettesítés helyzete és konkrét lehetőségei a felhasználási célok megjelölésével [Substituting other species for softwood – state of the art, opportunities and utilisation] Faipari Kutatások, WRI published research reports, Budapest, p. 54.