Ph.D. Theses

Anatomical and physical characteristics influencing the modern utilisation of hybrid poplars for industrial and energy purposes

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Introduction and objective

Poplars due to their light, homogenous woody material suitable for versatile utilisation have a continuously increasing role in domestic and international wood management. This high rate due to their fast growth, short rotation, easily marketable wood material and continuously expanding utilisation for energy purposes is expected to gradually increase in the next few years. This is also promoted by the afforestation of agricultural land, which cannot be cost-effectively cultivated.

The previously planted 'Marilandica', 'Serotina' and Robusta poplars featured similar wood technological characteristics, therefore a uniform "poplar" (*Populus x. euramericana*) concept was adopted in the Hungarian woodworking technology. Later on the Italian poplar clones of 'I-214' were also introduced in masses in logging, with a 20 to 25% less density and solidity compared to previous varieties, which caused significant issues both in the wood- and cellulose industry. This happened because growers and wood workers failed to separate different poplar varieties. Nowadays in Hungary the following poplar clones play a significant role: 'Pannonia', 'I-214', 'Koltay', 'Kopecky'.

For the production of woody crops for energy purposes especially fast growing species (poplar, salix, robinia) are used. This is due to several reasons, for example high dry matter mass and good gemmating ability. Growers have accumulated several decades of experience in the management of poplar plantations, which is also a big plus for poplars, and this experience can be easily adapted to the establishment and management of woody crop plantations for energy purposes with a shorter rotation. Numerous special literature materials mainly focus on the yields of woody crops, which are influenced by several factors. One of the main factors is the habitat type, but also species, cultivars and factors closely related to various cultivation technologies. However in the rational utilisation of poplars for energy purposes the identification of the optimum logging age is crucial, by doing so the clarification of the influencing role of the age.

The general opinion about diffuse-porous hardwood - also including poplars - is that the wider the annual ring, the lower the density and strength. In order to clarify this generalisation, I have

carried out tests with respect to poplars, based on which the correctness of the statement can be proved or contradicted.

In practice mainly materials with various wood defects are used, which may significantly distort certain physical and mechanical properties. One of the most common and important defects is knottiness, which results in a different structure compared to the normal tissue setup of the woody material, and therefore the material acts differently under load. An additional complication is that many varieties feature genetically different anatomical setups. As a result they are expected to react differently to various stress impacts. The utilisation of poplars for different structural purposes is influenced by various wood defects, knottiness being the most important one. I thought that it is worth doing an investigation in this area, because poplars are unfairly ignored with respect to utilisation for structural purposes, therefore I strived for providing an accurate picture of the role of knottiness by carrying out anatomic and wood physical tests.

Based on the characteristics of woody materials in the case of older trees within the heartwood we differentiate a so called juvenile wood, a wood layer around the pith. Trunks logged at a younger age have a greater juvenile wood proportion compared to older trees. This part of the wood in the case of most varieties is unsuitable for several industrial utilisation purposes and in terms of economic aspects it is unfavourable due to the divergent physical, mechanical and chemical characteristics. For this reason I decided to clarify the influencing role of the “juvenile wood” located around the pith with special respect to poplar varieties.

Material and methods

Looking at the dispersion – with respect to quantity- of various poplar varieties and making conclusions about the varieties to be planted in the future based on the available reproductive materials, I have included in my study those poplar clones, which will provide the processing industry in the future with the largest amount of woody materials. Based on the above I have focused on poplar clones of 'I-214', 'Pannonia', 'Koltay' and 'Kopecky'.

The applied research methods can be classified under three test groups, and within these the following characteristics have been defined:

- Anatomic and physical tests

  I have measured *annual ring width*, *density* and *fibre length* values by annual rings using the samples taken from the breast height diameter discs of the 4 selected clones. I have carried out the measurement of the *ratio of wall thickness to lumen diameter* using the poplar clone of 'I-214', as usually, this clone is used as a control variety. I have elaborated new method elements in order to improve the measurement of density by annual rings and fibre length.

- Test referring to utilisation for energy purposes

  I have used poplar clones of 'Pannonia' and 'I-214' of various ages (and cultivation purpose) for the tests. In terms of wood, as a fuel, four elements of wood characteristics are considered as determinative with respect to utilisation for energy purposes: therefore I have studied *density*, *heating value*, moisture content, *ash content and element content*. Furthermore *wood/bark ratio* and *dry substance content* have also been established.

- Tests referring to strength

  For the tests I have also selected Scotch pine besides the poplar clones of 'Pannonia' and 'I-214'. For the non-standard strength tests the size of test specimen was 1200x140x21 mm, which complies with the top element of the pallets. During the measurements the below characteristics were defined:
  transverse strength (MOR4p), transverse strength modulus (MOEstat3p, MOEstat4p), tensile modulus (G)

Thesis-based summary of the new scientific results

1. *I have proved that in the case of poplars the „juvenile wood" period may be deferred up to rotation age (age of 20 to 22 years); however these materials do not feature the typical physical characteristics of other wood varieties (for example lower density). The young juvenile woody material in the case of poplars has identical value to the mature wood.*
   My anatomic and density related measurements by annual rings proved that even though in the juvenile wood fibres around the pith are slightly shorter and thinner than in the more grown woods, but the wood's porosity is lower (the proportion of double periblast and lumen is greater). These anatomic characteristics in the initial stage resulted in slightly greater (5-10%) density.

2. *I have established that in the juvenile poplar wood the fibre length varies between 0.5 and 1.2 mm. There is no significant difference between the fibre lengths of the inspected poplar varieties. The average value was around 1 mm, similarly to the majority of hardwoods, therefore as a culturing goal the selection of long fibre varieties cannot be indicated.*
   Poplars despite of their short fibres have low density and due to their easy fibrillation ability they can also be used in the following areas: as a combination wood variety in the manufacturing of quality (writing-printing) paper increasing the opacity of papers, and on its own for manufacturing wrapping papers. Poplars, compared to softwood are less suitable for the production of quality paper, but they comply with the requirements of semi-cellulose, cardboard and chipboard manufacturing.

3. *My tests proved that there is no correlation between the annual ring width of poplars and the density of the woody material. Density is mainly a variety-related character.*
   My microscopic shots and density measurements also confirmed that both the narrower and wider annual rings have a thin fibre width featuring identical physical characteristics. Therefore during the utilisation of poplars the indication of annual ring

width borders is not justified (for example pallet manufacturing). Density is mainly a variety characteristic. The air-dry density of the poplar clone of 'I 214' - which plays a significant role in the logging industry of Hungary - is 350 kg/m^3, whilst the air-dry density of the poplar clone of 'Pannonia' is about 400 kg/m^3. During the processing and manufacturing process namely not the width of the annual rings shall be prescribed, but the various varieties need to be handled separately. For structural purposes in my opinion varieties with higher density shall be used (such as 'Pannonia', 'Koltay', 'Kopecky').

4. *With respect to characteristics having an impact on utilisation for energy purposes (heating value, ash content, ash composition) in the case of poplar cultivations the logging age does not play a significant role.*
   Namely thin, mini rotation materials have similar value as the older heartwood. However there are significant differences between poplars with respect to heating value applied to tree value (for example the heating value of the clone variety of 'Pannonia' was 20% higher than that of the clone variety of 'I-214'). The values of basic density can be well used for the definition of the dry mass material production of cultivations. During the utilisation for energy purposes the bark layer is not removed, therefore it is important to be aware of the major characteristics of this layer: the heating value applied to weight is only slightly below that of the wood, but the ash content of the bark is extremely high (4-5%). Nearly 50% of the poplar's ash is made up of CaO, the insignificant Cl content is very favourable, but the 9 to 14% presence of sulphur dioxide also needs attention.

5. *I have proved that the strength of poplars is less influenced by knottiness as in the case of softwood, by carrying out strength tests on product-sized samples. This research result may open up a completely new scope in the utilisation of poplars.*
   Test results showed that in the poplar wood, knots acted less like an alien body compared to the behaviour of knots in softwoods; therefore they do not have such significant impact on bending

strength and modulus of elasticity compared to the impact detected in the case of softwoods. The static bending strength of faultless Scotch pine is about 80 MPa. Despite of this value, the strengths of test specimen with knots showed a reduced result by 60% with a static bending strength value of only 31.2 MPa. In the case of the poplar clone variety of 'Pannonia' the reduction was 43% (from 67.4 to 38.4 MPa); whilst in the case of the poplar variety of 'I-214' the reduction was 35% (from 58 to 37.8 MPa).

6. *My anatomic tests proved that in the case of poplars the attachment of knots to the normal wood show a gradual transition, in the contrary to softwoods where this transitional zone is missing.* The microscopic observations also proved the fact that the normal poplar wood and the "knotty body" is less separated compared to softwoods. This characteristic of poplars may be favourable in the utilisation of poplars for structural purposes.

Practical utilisation of the research results

One of strategic and improvement related questions of the Hungarian wood management is the versatile and modern utilisation of the increasing amount of poplar woody material produced by the fast growing and newly planted cultivations. The new scientific results presented in the frame of this study partly directly and partly indirectly support these activities.

- The woody material tests of poplar cultivations with various ages and with utilisation for energy purposes proved that age does not play a vital role neither in terms of heating value nor ash content in the case of poplars with a thin fibre width. As a result the biomass produced from younger plantations ("mini rotation plantations") has an identical value than the woody materials from older plantations.

- In the case of poplars genetic factors (the variety itself) play a significant role in the utilisation for energy purposes. With respect to heating value applied to wood volume shows a 20 to 30% difference between poplar varieties. Namely it is advisable to take over the poplar raw materials for energy purposes (chips, waste with larger chunks, cylindrical wood) at all times in bone dry tons.

- My researches proved that knots have a smaller impact on the strengths of the woody material in the case of poplars than in the case of softwood. Therefore poplar beams, rafters, pallet elements having identical knottiness values as softwood materials shall not be pushed in the background in terms of knottiness having an impact on strength. In relation to this topic it is also thought-provoking that how justified is the prescription referring to EUR pallets stipulating that the 3 connecting elements should only be made of softwood. According to my measurements referring to the strength of poplars and softwood planks with the allowed wood defects (knottiness), the strength of poplars is much better.

- My research results, which proved that the size of the annual ring width does not influence the density and strength of woody materials within the same poplar variety, have a significant impact. Therefore in the case of poplar products (e.g. pallets) the indication of authorised maximum annual ring width is completely unjustified.

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