Environment. Technology. Resources. Rezekne, Latvia
Proceedings of the 15th International Scientific and Practical Conference. Volume I, 251-256

Opportunities of improving harvesting technologies for wider use of Scots pine (Pinus sylvestris L.) in construction elements

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Abstract. **Although *Pinus sylvestris* has a wide distribution throughout Europe, there are lack of scientifically approved information related to the sapwood timber strength parameters impregnated with natural resins comparing to the strenth parameters of non-resinous wood and industrially impregnated roundwood assortments using as the elements of wooden constructions such as wood poles for power lines. The main goal of the study is to work out the *Pinus sylvestris* stems which were previously treated using resin tapping technologies and harvested in final felling sites, timber strength parameters depending on timber quality characterized data based on the testing methods: moisture content - according to *ISO13061-1:2014*; density - according to *ISO13061-2:2014*; compression strength paralel to the grain- according to *ISO 13061-17:2017*; modulus of elasticity- according to *ISO 13061- 4:2014*; three point bending strength - according to *ISO 13061- 3:2014.* The results of the study might help for practical applications so that this wood specie can be processed more efficiently for the value - added products whose timber quality indicators would allow it to be used in wooden structures without additional chemical and thermal treatment, to establish more accurate quality requirements for roundwood assortments and to provide useful information for optimizing Scots pine harvesting management programs**.

Keywords: Pinus sylvestris, resin taping, timber strength parameters.

I. INTRODUCTION

Wood is one of the popular building materials at all times. In the era of steel and concrete, wood structure has a special charm. However, wood products are vulnerable to microbial damage during storage and cause a serious waste of resources, affecting their service life. It is reported that 40% of the planned wood used in the world every year is vulnerable to decay and damage by insects, with a loss of billions of US dollars. Therefore, the preservative, anti-mildew and anti-insect treatment for wood plays a key role in prolonging the service life of wood products and protecting forests. Common wood preservatives are divided into fumigant type, tar type, oil-soluble type and water-soluble type. At present, water-soluble preservatives are one of the most widely used preservatives with various types in the world, accounting for 75% of the total amount of preservatives used. Commonly used water-soluble preservatives include chromium-copper-arsenic (CCA), ammoniacal copper quats (ACQ-B, ACQ-D), copper citrate (CC) and copper azole (CopperTriazole, RNCuAz). Although CCA preservatives have a good preservative effect, they contain heavy metals such as chromium and arsenic, which affect human health and ecological environment. (Fig. 1)

At present, the research on wood preservatives in the world still mainly focuses on the application of chemical wood preservatives. However, with the increasing awareness of environmental protection worldwide, natural wood preservatives with non-toxicity, harmlessness, good durability, no impact on bonding properties, wide range of raw materials and low price will be paid increasing attention.

Print ISSN 1691-5402
Online ISSN 2256-070X
https://doi.org/10.17770/etr2024vol1.7943

Fig. 1. *Pinus sylvestris* roundwood preservation with CCA when heartwood cannot be pressure impregnated

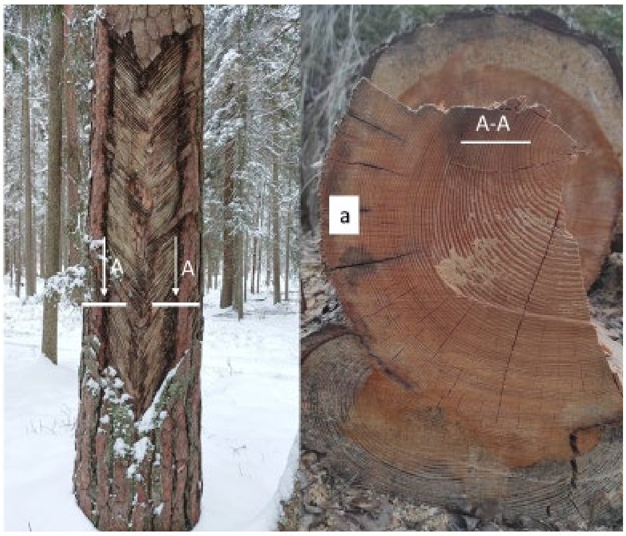

Fig. 2. Overmature stand of *P. sylvestris*. Resin-tapped in 1970 Felled by wind in 2020 year-51 years after it was resin tapped. For 2 years it was left on the ground. Resin tapped side protected the tree from rot and pioneer fungi (Fig.2a)

Therefore, it is advisible to return to knowledge related to resin tapped firewood preparing before harvesting in Latvia [16]; [25] (Fig.3) investigations made in this area by foreign researchers [5], [6], [7], [8], [9] [26], [28] and Scandinavian wood preservations traditions based on high degree of social responsibility not only in relation to materials and resources but also in regards to community-created spaces. Scandinavian tradition is based on systematically injuring growing *Pinus sylvestris* trees. In this process the sapwood is being impregnated with natural resins with a high consentration of Pinosylvin which is the most rot resistant contant that can be produced.

If the high quality roundwood with high concentration of resin are used in engineering constructions, that constructions will last for many hundred years. The barking must be done in the springtime. After barking the growing tree woodcells are impregnated with resins and other rot resistant substances. The sapwood formed as the formstable and hydrofobic material with avery high resistance against rot. The barked trees have been standing for 5 years after the barking started before eventually felled.

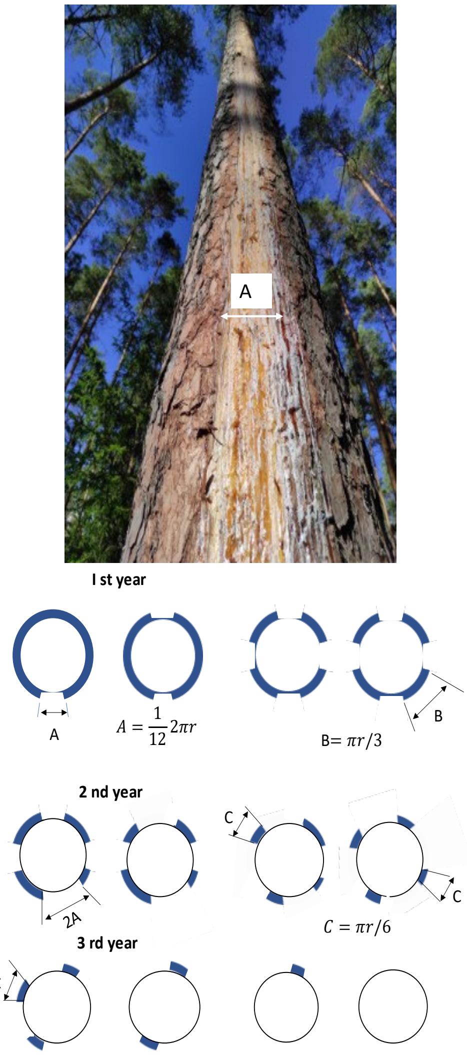

Fig. 3. Resin tapped firewood preparing scheme, when in just 3 years before tree harvesting sapwood is completly resin penetrated.

As an approvement of the durability of resin taped trees wood is the fact that overmature trees of *Pinus sylvestris* bearing large wounds made by resin tapping decades ago are still present in woodlands of south-eastern Baltic Sea region (Fig.2). Investigations [29] reveal that, even on the long term, resin tapping has little influence on health condition and vitality of *P. sylvestris*, even at the very old age.

The wood of resin taping area is highly resinous, making machining difficult. However, the increased resin content in the wood as a result of tapping causes a major change in the physical properties of the wood, such as an increase in density, as well as changes in the chemical properties [27]; [24] including improving the tree’s natural protection from xylophagous agents [4]; [18]; [17]; [26]. The accessory substances of the cell wall can modify the mechanical behavior of wood in two ways: by acting as an inert mass in relation to the cell wall matrix structure, or by affecting hygroscopicity and therefore swelling [9]. Some studies have associated wood extractives and their influence with fracture parameters. In addition, resin incrustation in the cell lumen may act as a transmitter of efforts from one tracheid to another, helping the wood achieve a higher mechanical response, as occurs with synthetic polymers artificially included inside the cell lumen [17].

According to the investigation [24] the obtained results showed that the higher density of resinous wood compared with non-resinous wood is a result of the tree's defense processes. The repeated wounding of the tree during the 25 years of tapping causes the permanent activation of its defense mechanisms. While wounding generates both axial and radial traumatic resin canals, it also increases resin production through the metabolic route from the ray parenchyma cells to the axial tracheid lumen through the cross-field pits. The combination of these two processes results in the artificial resinification of the wood, increasing the wood density [3].

Tapping cause changes in the chemical composition of the cell wall, and this affected the physical and mechanical properties of the wood.

All the mechanical properties are strongly correlated with wood density [19], [23], [8], [9] showed that extractives strengthen the wood structure and therefore the mechanical properties, whereas investigations [1] had the opposite opinion. According to investigations [2] an increase in extractives had no effect on the mechanical properties, but according to other authors, these properties decreased [1].

The results for resistance to compressive strength parallel to the grain in the resinous wood compared with the non-resinous wood concurred with those obtained by investigations [9] for hardwoods, indicating that density is associated with increased accessory substances of the cell wall and that these substances positively affect the compressive properties of wood. However, these results differ from investigations [2] that confirmed the lack of correlation between extractives and compressive strength parallel to the grain, In a later study researcher [2] found no relationship between extractives and compressive strength parallel to the grain in *Tectona grandis L.f.* Although *Pinus sylvestris* has a wide distribution throughout Europe, there are lack of scientifically approved information related to the sapwood timber strength parameters impregnated with natural resins comparing to the strenth parameters of non-resinous wood and industrially impregnated roundwood assortments using as the elements of wooden constructions such as wood poles for power lines.

Taking into account the knowledge of Swedish technologies in the use of *Pinus sylvestris* resinous logs in engineering constructions and the investigations carried out in Latvia State Forest Research Institute "Silava" [29] related to evaluation of standing tree quality after the resin tapping, State Stock Company "Latvijas Valsts Meži" (Latvia's State Forests) started the project on the use of resinous wood in engineering constructions without providing the chemical treatment of timber during the period of operation of engineering structures, as the resin tapped sapwood will be naturally preserved.

In Latvia there have been no research on strenth of resin tapped wood, so it is important to ensure the determination of wood strength parameters for the designing the building structures.

The main goal of the study is to work out the Pinus sylvestris stems strength parameters of resinous and non - resinous sapwood zone in the third year after the start of the resin tapping project.

The tests were carried out in Latvia University of Life Sciences and Technologies at the Forest and Wood Product Research and Development Institute Testing Laboratory "MEKA".

The goal of this study was to supplement and synthesize the existing experience and knowledge about *Pinus sylvestris* timber physico- mechanical properties and to work out the recomendations to improve the commercial value of resin tapped roundwood assortments.

The following objectives were set to achieve the study goal:

1. To investigate properties of *Pinus sylvestris* resinous and non-resinous timber using laboratory testing methods:

1.1. Moisture content according to ISO-13061-1:2014

1.2. Density according to ISO-13061-2-2014

1.3. Compression strength paralel to the grain according to ISO 13061-17-2017

1.4. Three-point bending strength and modulus of elasticity according to ISO 13061-3(4)-2014

2. To compare the strength parameters of resinous sapwood to non-resinous sapwoods and to offer the requirements of building construction elementsd using resinous *Pinus Sylvestris* roundwood.

II. Materials and Methods

To accomplish detailed examination, on harvesting site 505-301-13 (Table 1) one pine was felled on 3rd year after resin tapping in year 2023. 550 trees were selected to resin tapping in all harvesting sites.

TABLE 1 CHARACTERISTICS OF INVESTIGATED FOREST SITE TYPES AND RESIN TAPPED PINUS SYLVESTRIS TREES

Parameter	Harvesting sites		
Block area-Forest block-Forest compartment	505-469-31	505-301-13	505-320-17
Area (ha)	3.39	1.57	3.87
County	Bārbele		
Parish	Vecumnieki		
Forest type	Hylocomniosa	Myrtillosa	Hylocomniosa
Age class	Overmature stand		
Age decade	11	11	13
Species composition	8 Pinus sylvestris103 2 P.Abies 83	10 Pinus sylvestris108	9 Pinus sylvestris123 1 P.Abies98
Specie	01-*Pinus sylvestris*		
Age (years)	103	108	123
Height (m)	30	28	31
Diameter (cm)	34	30	34
Basal area (m^2)	9	32	33
Stock (m^3/ha)	373	418	468
Specie	03-P.Abies		
Age (years)	83		98
Height (m)	27		28
Diameter (cm)	29		28
Basal area (m^2)	9		5
Stock (m^3/ha)	109		62

Pine was 135 years old (Fig. 4). The first resin tapping injury was made in year 2020 second injury was made in 2021 according to the sheme (Fig. 5).

Fig. 4. Overmature stand (Biological age-135 years) of Pinus sylvestris (DBH=43.6 cm). Resin-tapped in 2021.

The tree was felled in 2022 to prepare samples for investigation properties of *Pinus sylvestris* resinous and non-resinous timber using laboratory testing methods.

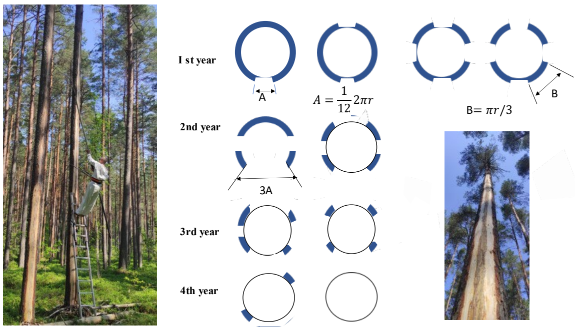

Fig. 5. Overmature stands of *Pinus sylvestris.* Resin-tapped in 2023 (2nd year). One side of the tree after second year of barking (Fig.5a). Here it is barked on both sides with 7-8cm wide stripes that are approximately 7 meters high. The barked trees will be standing for 5 years after the barking started before eventually felled.

Samples for investigation were taken from the trunk sapwood resinous zone and non -resinous zone according to the scheme (Fig.6).

The trunk sapwood was tangentially sawn in to edged boards 30 mm thick, which were air-dried to 16% moisture content (Fig.7) to prepare samples with a cross-section of 22×22mm for investigation of compression strength paralel to the grain- according to *ISO 13061-17:2017* (Fig. 7); modulus of elasticity- according to *ISO 13061- 4:2014* (Fig. 7); three point bending strength - according to *ISO 13061- 3:2014*. (Fig. 7). Testing samples were prepared according to the requirements of the standards [10], [11], [12], [13], [13], [14], [15], [16], [20].

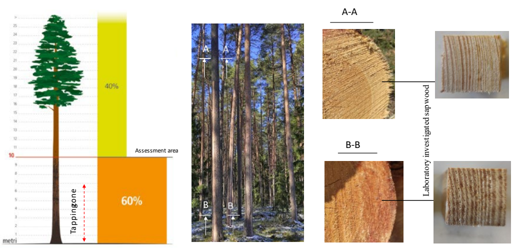

Fig. 6. The scheme of prepared samples from the trunk sapwood resinous zone and non -resinous zone.

Fig. 7. Samples from the trunk sapwood resinous zone (Fig.7a) and non -resinous zone (Fig.7b).

Samples were dried at room temperature until the moisture content equilibrium of the indoor air which was detected by the successive weightings until reaching the constant mass.

After samples were logitudinally sawn, planed and calibrated to actual size 20 mm x 20 mm and cut in 320 mm long pieces for bending test [4] and in 30 mm long pieces for compression test [15]. Test pieces were conditioned at the standard environment of 20±2 °C and 65±5 % relative humidity [13], [14].

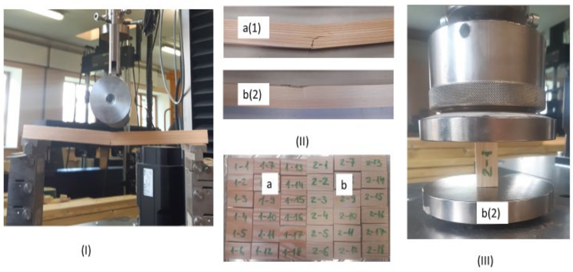

Fig. 8. The laboratory investigation process, where: **(I)**- 3. point bending strength and modulus of elasticity ISO 13061-3(4)-2014; (**II**)-testing samples; **(III)**- compression strenght paralel to the grain ISO 13061-17-2017; **a (1)**- specimens from resin tapping sapwood zone devastated in the stretch zone; **b (1)**- specimens from non-resinous sapwood zone devastated in the stretch zone; **b (2)-** compression of the reference sapwood specimens paralel to the grain.

For each test 50 pcs. of laboratory samples were prepared. All test pieces were identified with a number. Test specimens were measured with an electronic caliper to 0.01 mm and weighed to 0.01 g. Test specimens were conditioned. Before testing moisture content according to standard [11] and density of test specimens according to standard [12] was determined. Test specimens were dried and weighed until the weight of dried timber didn't change in 2 hours more than 0.1%. The scheme of the test arrangement is given (Fig. 8). The results of laboratory analyses are given (Table 2).

III. RESULTS AND DISCUSSIONS

The investigation results are given (Table 2).

TABLE 2 THE RESULTS OF THE LABORATORY INVESTIGATION PROCESS

Testing samples	Mean values (STDEV)				
	Moisture content, %	Density, Kg/m3	3. point bending		Compression strength
			Strength, N/mm²	Modulus of elasticity, N/mm²	Strength, N/mm²
Specimens from resin tapping sapwood zone	16,4	671 (21.4)	89.2 (4.2)	8750 (370)	46.47 (1.58)
Specimens from reference zone	13,7	530 (12.9)	83.5 (6.42)	11200 (388)	47.04 (5.11)
Deviation of the mean value compared to specimens from reference sapwood, %					
Specimens from resin tapping sapwood zone	-	26,70%	6.8*	-22.0*	-0.8*

*- significant impact ($p<0.05$)

p.s, according to the standard [2] the density of timber is calculated if the moisture content of the timber is 12%. All strength properties were recalculated because the moisture content of the specimens in testing was about 15%. If the moisture content of timber increases 1% all strength properties of the timber decrease, for example the modulus of elasticity decreases about 1% and the compression strength parallel to grain decreases about 3% [9]. Decreasing value of moisture increases the values of stiffness and strength in the same range.

IV. CONCLUSIONS

The results of the study indicated the following:

1. Resin tapping of *Pinus sylvestris* has a significant effect on the wood density and mechanical properties in bending, while the compression strength paralel to the grain parameters are not significantly affected.

2. The average density of *Pinus sylvestris* sapwood in resinous zone is 671 kg/m^3 and the average density of sapwood in *non -resinous zone* average density is 530kg/m^3. Sapwood resinous zone density parameter is 27% higher compared to sapwood in non -resinous zone. STDEV parameters characterized mechanical properties (density, kg/m^3) for sapwood resinous zone is 21.4 kg/m^3, for non -resinous zone is 12.9kg/m^3.

3. The average modulus of elasticity for *Pinus sylvestris* sapwood resinous zone is 8750N/mm^2. The average modulus of elasticity for *Pinus sylvestris* sapwood sapwood non – resinous zone is11217 N/mm^2 . The parameter of average modulus of elasticity for sapwood non -resinous zone is 22% higher compared to resinous zone. STDEV parameters characterized mechanical properties (modulus of elasticity EM, N/mm^2) for sapwood resinous zone is 370N/mm^2, for non -resinous zone is 388N/mm^2.

4. Three-point bending strength in the radial direction of *Pinus sylvestris* sapwood resinous zone is 89.2 N/mm^2. In the radial direction of *Pinus sylvestris* sapwood *non - resinous zone* is 83.5 N/mm^2. The parameter of bending strength for sapwood resinous zone is 7% higher compared to non-resinous zone. STDEV parameters characterized mechanical properties (three point bending strength, N/mm^2) for sapwood resinous zone is 4.2N/mm^2, for non -resinous zone is 5.4N/mm^2. Compression strength paralel to the grain for *Pinus sylvestris* sapwood resinous zone is 46.7 N/mm^2. Compression strength paralel to the grain for *Pinus sylvestris* sapwood non -resinous zone is 47.0 N/mm^2. STDEV parameters characterized mechanical properties (compression strength paralel to the grain, N/mm^2) for sapwood resinous zone is 1.58N/mm^2, for non -resinous zone is 1.79/mm^2.

5. According to the investigation [24] there are restrictions to use resin tapped *Pinus sylvestris* roundwood in wooden engineering constructions such as wood poles for power lines because of low strength parameters of modulus of elasticity (EM). The strength parameters of wood poles for power lines determined by standard BS 1990; ANSI/ASTM D 1036 -58 are the sequential:

- Three point bending strength (σ_l)and modulus of elasticity (EM).By standard σ_l =53.8 N/mm^2 ; EM=10480 N/mm^2
- Three-point bending strength (σ_l) and modulus of elasticity (EM) of resin tapped *Pinus sylvestris* roundwood. By investigations σ_l =89.2 N/mm^2 ; EM=8750 N/mm^2

6. There is advisible to use the resinous logs into the roof structures and in the first rows of the log houses (Fig. 9).

Fig. 9. The structural elements of the log house

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