LECH RUDZIŃSKI[1]
AGNIESZKA WDOWIAK[2]
Kielce University of Technology
[1]e-mail: lech@tu.kielce.pl
[2]e-mail: awdowiak@tu.kielce.pl

STRENGTH AND STRUCTURAL PROPERTIES OF STRUCTURAL TIMBER

Abstract
Taking into account the growing significance of structural timber in the building industry, the paper aims at defining the selected mechanical and physical properties of the Polish pine structural sawn timber from four nature and forest lands: Land A – Mazovian-Podlasian Nature and Forest Land (Forest District Garwolin), Land B – Little Poland Nature and Forest Land (Forest District Przedbórz), Land C – Silesian Nature and Forest Land (Forest District Kedzierzyn Koźle), Land D – Carpathian Nature and Forest Land (Forest District Piwniczna)[4]. The paper presents the definition of timber, its macroscopic and microscopic structure as well as factors affecting the mechanical properties of timber such as moisture or structural defects. The conducted tests involved sorting sawn timber in terms of strength using visual method according to the PN-D-94021 standard as well as characterizing the average moisture of the fresh and artificially dried sortment [6-8].

Keywords: timber, macroscopic and microscopic structure, physical and mechanical properties, moisture, Poland's nature and forest lands, fresh and dried sawn timber, artificial drying, sorting in terms of strength

1. Introduction

Timber is an organic material whose properties depend on wood species and, thus, are immensely varied. Timber is anisotropic (it has different qualities in different directions) and non-uniform (it has defects). Macroscopic features include elements larger than 0.1 mm such as annual growth rings, latewood and early wood zones, heartwood, wide medullary rays, large vessels, resin leaks and knots. On the basis of macroscopic features, it is possible to distinguish the type of structure, identify the specific wood species, and determine its properties. These features are most commonly observed on three basic wood sections: tangential, radial and transverse. Timber microscopic structure includes such structural details that can be studied by examining the material under an optical microscope. Most of the cells are parallel to the longitudinal axis of the trunk, and some have a shape of well-elongated spindles [1]. The factors that most significantly affect timber mechanical properties include the following: wood anatomical direction, moisture content, the distribution of structural defects (knots, twisted fibres, cracks, resin pockets, bark pockets and rind galls, insect galleries) [2]. Timber moisture is the most significant parameter of this material. Moisture content affects timber's weight, dimensions, volume, strength, resistance to fungi and insects. As a hygroscopic material, wood is capable of exchanging water vapour with the surrounding air. Surface sorption mechanism is dominant in the process. Wood moisture content changes until the pressure of the water vapour inside the material and that of the water vapour in the surrounding air reach equilibrium. Changes in the moisture content within the hygroscopic range are accompanied by the changes in the dimensions and volume of the timber. That is a two-way process resulting in timber shrinking or swelling. Timber shrinkage involves the reduction in size and volume due to the water vapour release. Swelling increases wood linear dimensions and volume as a result of water (vapour) absorption, which leads to a higher moisture content. Changes in timber dimensions, together with the material anisotropy and non-uniformity produce a number of adverse effects, including shape deformation of wooden elements (warping) and disruption of the material structure (cracking) [3].

2. Strength and structural properties of structural sawn timber

2.1. Origin of research material

The paper aims at defining the chosen mechanical and physical properties of the Polish pine structural sawn timber from four selected nature and forest lands, characterized in Table 1.

Table 1. Origin of research material

Code	Habitat
Land A	Mazovian-Podlasian Nature and Forest Land **Forest District Garwolin**
Land B	Little Poland Nature and Forest Land **Forest District Przedbórz**
Land C	Silesian Nature and Forest Land **Forest District Kędzierzyn Koźle**
Land D	Carpathian Nature and Forest Land **Forest District Piwniczna**

Five batches of sawn timber with differently sized cross-sections and with 40 pieces each were selected from each land, with the exception of the cross section of 40 x 82 mm. The length of the sawn timber was app. 4.0 m [4]. 240 pieces of the sawn timber were examined in total [5]. The dimensions of the sawn timber from different lands are presented in Table 2.

Table 2. Dimensions of the cross sections of the sawn timber from different Poland's nature and forest lands

Dimension [mm]	Nature and forest land				In total
	A	B	C	D	
	Number of pieces				
37 × 48 × 4050	10	10	10	10	40
40 × 82 × 3650	20	25	25	10	80
50 × 100 × 4000	10	10	10	10	40
50 × 125 × 4000	10	10	10	10	40
50 × 200 × 4000	10	10	10	10	40
Total	60	65	65	50	**240**

2.2. Measuring the moisture content of the fresh and artificially dried sawn timber

The examinations were conducted in industrial conditions in the Tartak OLCZYK company in Świdno. Prior to the examinations, the sawn timber was marked, measured and stacked in packets with regard to the dimension and the origin. The moisture was measured using a moisture meter regularly checked and calibrated in accordance with the manufacturer's (the GANN company) instructions (Fig. 1).

Fig. 1. Measuring the moisture content of the fresh sortment using the HT 65 GANN moisture meter [6-7]

Table 3. Moisture content in the fresh sawn timber from different Poland's nature and forest lands

Land code	Dimensions [mm]	Number of samples n [pcs]	Average moisture content before drying m_{av1} [%]	Standard deviation s [%]	Mean error s_r [%]	The coefficient of variation v [%]	Accuracy rate (for 1-α = 0.95) p [%]
A	37 × 48 × 4050	10	33.66%	1.48%	0.47%	4.40%	0.92%
B	37 × 48 × 4050	10	34.10%	2.21%	0.70%	6.48%	1.37%
C	37 × 48 × 4050	10	34.69%	1.23%	0.39%	3.54%	0.76%
D	37 × 48 × 4050	10	**35.40**%	1.94%	0.61%	5.48%	1.20%
A	40 × 82 × 3650	20	35.90%	1.20%	0.27%	3.34%	0.53%
B	40 × 82 × 3650	25	39.79%	1.88%	0.38%	4.71%	0.74%
C	40 × 82 × 3650	25	36.60%	1.74%	0.35%	4.76%	0.68%
D	40 × 82 × 3650	10	**40.94**%	2.19%	0.69%	5.34%	1.36%
A	50 × 100 × 4000	10	34.00%	2.19%	0.69%	6.44%	1.35%
B	50 × 100 × 4000	10	38.30%	1.32%	0.42%	3.45%	0.82%
C	50 × 100 × 4000	10	**39.40**%	1.98%	0.63%	5.01%	1.23%
D	50 × 100 × 4000	10	38.40%	1.99%	0.63%	5.18%	1.23%
A	50 × 125 × 4000	10	39.20%	1.44%	0.46%	3.68%	0.89%
B	50 × 125 × 4000	10	41.30%	1.96%	0.62%	4.74%	1.21%
C	50 × 125 × 4000	10	39.20%	1.37%	0.43%	3.50%	0.85%
D	50 × 125 × 4000	10	**42.50%**	1.71%	0.54%	4.03%	1.06%
A	50 × 200 × 4000	10	40.40%	1.46%	0.46%	3.60%	0.90%
B	50 × 200 × 4000	10	42.20%	1.86%	0.59%	4.41%	1.15%
C	50 × 200 × 4000	10	40.20%	1.28%	0.40%	3.18%	0.79%
D	50 × 200 × 4000	10	**43.60%**	1.34%	0.43%	3.09%	0.83%

During the sawn timber moisture content measurements the following recommendations were observed. The moisture content was measured in the middle of the plank width, no farther than 0.5 m from the head, with the spots of measurement being selected at random provided they were not soiled or defective. There were three measuring spots on each side of the sawn timber, in each spot the moisture was measured at least three times. The distance between the measuring spots was 10-15 mm.

The arithmetic mean of three measurements with most similar values was adopted as the measurement result [6].

Small differences of results were caused by the fact that all the sawn timber assortments were prepared for the examination at the same time (Table 3). The analysis shows that the sawn timber from the Mountain Pine Belt has the maximum average moisture content, the exception being the sawn timber planks measuring 50 x 100 x 4000 mm from Land C – forest district Kędzierzyn Koźle, with the maximum average moisture content of 39.4%. The sawn timber from Land A – Mazovian Podlasian Nature and Forest Land had the lowest recorded value (Fig. 2).

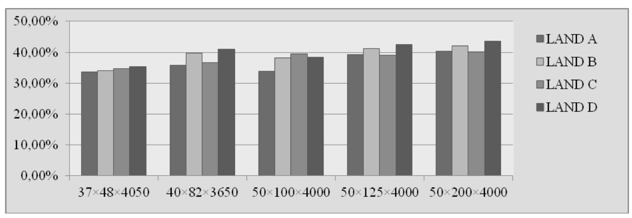

Fig. 2. Moisture content of the fresh sortment from different nature and forest lands

Then the timber was arranged into packets with regard to cross sections and transported by forklift truck to 5 drying chambers. There were different initial and final temperatures determined for each sortment. The target moisture content of 10% was adopted. When the adopted parameters were achieved, the moisture content in each piece of the sawn timber was analyzed again (Fig. 3).

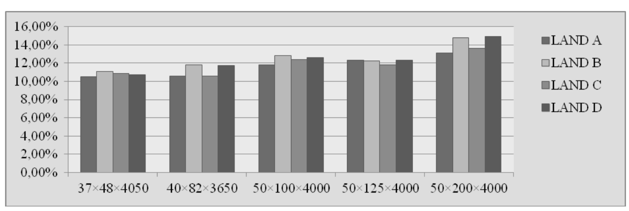

Fig. 3. Moisture of the dried sortment from particular Poland's nature and forest lands

Table 4. Artificial drying of sawn timber from different Poland's nature and forest lands

Land code	Dimensions [mm]	Number of samples n [pcs]	Ts [°C]	Tf [°C]	t [h]	Average moisture after drying m_{av2} [%]	Standard deviation s [%]	Mean error s_r [%]	The coefficient of variation v [%]	Accuracy rate (for 1-α = 0.95) p [%]
A	37 × 48 × 4050	10	60	65	192.5	10.51%	0.46%	0.14%	4.36%	0.28%
B	37 × 48 × 4050	10	60	65	192.5	**11.1**%	0.82%	0.26%	7.38%	0.51%
C	37 × 48 × 4050	10	60	65	192.5	10.85%	0.61%	0.19%	5.59%	0.38%
D	37 × 48 × 4050	10	60	65	192.5	10.7%	0.45%	0.14%	4.19%	0.28%
A	40 × 82 × 3650	20	55	60	220.08	10.6%	0.54%	0.12%	5.12%	0.24%
B	40 × 82 × 3650	25	55	60	220.08	**11.78**%	0.78%	0.16%	6.62%	0.31%
C	40 × 82 × 3650	25	55	60	220.08	10.6%	1.13%	0.23%	10.65%	0.44%
D	40 × 82 × 3650	10	55	60	220.08	11.77%	0.67%	0.21%	5.69%	0.42%
A	50 × 100 × 4000	10	55	65	278.08	11.8%	0.27%	0.08%	2.26%	0.17%
B	50 × 100 × 4000	10	55	65	278.08	**12.8**%	0.42%	0.13%	3.26%	0.26%
C	50 × 100 × 4000	10	55	65	278.08	12.4%	0.32%	0.10%	2.59%	0.20%
D	50 × 100 × 4000	10	55	65	278.08	12.6%	0.60%	0.19%	4.74%	0.37%
A	50 × 125 × 4000	10	55	65	298.25	**12.4**%	0.58%	0.18%	4.71%	0.36%
B	50 × 125 × 4000	10	55	65	298.25	12.2%	0.80%	0.25%	6.53%	0.50%
C	50 × 125 × 4000	10	55	65	298.25	11.8%	0.88%	0.28%	7.43%	0.54%
D	50 × 125 × 4000	10	55	65	298.25	12.3%	1.09%	0.34%	8.85%	0.68%
A	50 × 200 × 4000	10	55	65	316.75	13.2%	0.48%	0.15%	3.64%	0.30%
B	50 × 200 × 4000	10	55	65	316.75	14.8%	0.53%	0.17%	3.58%	0.33%
C	50 × 200 × 4000	10	55	65	316.75	13.6%	0.60%	0.19%	4.38%	0.37%
D	50 × 200 × 4000	10	55	65	316.75	**15.0**%	0.51%	0.16%	3.41%	0.32%

Artificial drying allows the dry timber to be obtained in a short time and eliminates infecting the timber with fungi, growing easily in the humidity of 22-24%. However, artificial drying requires costly specialist equipment and is more expensive than natural drying. A very important rule should be observed, the rule says that in the initial period of drying the air in the dryer is not very hot and it has a high humidity content, then – as the timber dries – the air temperature can be raised and humidity can be decreased.

The first period of drying is characterized by high desorption stress in timber. If, during this period, the timber drying process is too rapid (drying is too fast), a sudden increase in stress occurs in the timber structure and the timber breaking point is exceeded. It causes the appearance of the surface and head cracks in the pieces of the sawn timber. In the further stage of the rapid timber drying inner cracks are formed. They are seemingly imperceptible. The moisture content analysis of the dried sawn timber shows that as far as small cross sections are concerned, the sawn timber from Land B – Little Poland Nature and Forest Land has the maximum average moisture content, whereas Land A has the lowest one. The exception is the cross section measuring 50 x 125 x 4000 mm, in the case of which Land A sawn timber has the maximum moisture content, and Land C sawn timber – the minimum one. The sawn timber with the cross section of 50 x 200 x 4000 mm has the maximum moisture content in the samples from Land D and the minimum one in the specimens from Land A (Fig. 3). The coefficient of variation is significant, since the analyzed sortment was not divided into sapwood and heartwood (Table 4).

2.3. Methodology of sorting of the sawn timber in terms of strength using the visual method in accordance with the PN-D-94021 standard [8]

After the moisture content examination the visual sorting took place [9]. Each piece was thoroughly analyzed. All the features were measured, including knottiness, twisted fibres, surface and head cracks, lengthwise curvature of sides and planes, crosswise curvature, warpedness, wanes, bark pockets, fibre waviness. Most attention was paid to knots, which usually determined the quality grade of the sawn timber. Along the length of each piece of the sawn timber the knots therein were projected on the auxiliary checked paper sheets with the dimensions of the cross section of the sorted sawn timber. The obtained drawings provided the base for determining the knottiness coefficient. In determining the knottiness coefficients the attention was paid to the location of knots in all the cross section an in the marginal zones [4].

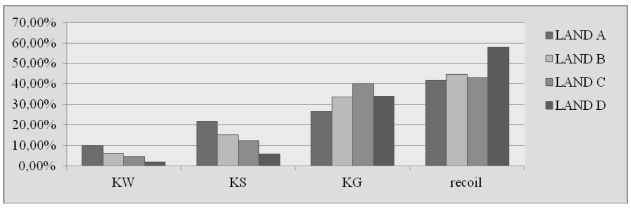

Fig. 4. Percentages of the sorting classes obtained as a result of the visual sorting of the sawn timber from particular Poland's nature and forest lands

The strength-related sorting revealed that Mazovian-Podlasian Nature and Forest Land yielded the highest number of pieces in the KW (high quality) class (six pieces) and in the KS (medium quality) class (13 pieces) in comparison with other lands. The sawn timber from Carpathian Nature and Forest Land was distinctly the worst of all the analyzed batches. Only one piece was classified as being the KW class and only three pieces as the KS class. This batch of the sawn timber yielded the largest number of rejects – as many as 29 pieces, which amounts to 58% of the whole sawn timber from this land (Fig. 4).

3. Conclusions

1. In general, the sawn timber from Carpathian Nature and Forest Land revealed the highest value of average moisture content. The sawn timber batch measuring 50 × 100 × 4000 mm from Silesian Nature and Forest Land is an exception here.
2. When subjected to artificial drying, the sortment with smaller cross sections from Little Poland Nature and Forest Land revealed the highest average moisture content.
3. Sorting the sawn timber from Mazovian-Podlasian Nature and Forest Land yielded the highest number of pieces of the KW class (six pieces) and of the KS class (13 pieces) in comparison with the results of sorting the sawn timber from other lands.
4. The sawn timber from Carpathian Nature and Forest Land was distinctly the worst of all the analyzed batches. Only one piece was classified as being the KW class and only three pieces as the KS class [4].
5. The obtained results permit the conclusion that the introduction of Polish classes: KW, KS and KG (lower quality) into the PN-EN 1912 standard should be connected with the introduction of the division into the sawn timber from Northern Poland and from Southern Poland [4, 10].

References

[1] Kozakiewicz P.: *Physics of timber in theory and problem. Selected issues* [in Polish]. Wydawnictwo SGGW, Warszawa 2003.

[2] Rudziński L.: *Repairs and strengthening of timber structures* [in Polish]. Wydawnictwo Politechniki Świętokrzyskiej, Kielce 2000.

[3] Wdowiak A.: *Assessment of technical condition of wooden structures,* Proceedings of TRANSCOM 2015, pp. 326.

[4] Krzosek S.: *Strength-related sorting of Polish pine structural sawn timber* [in Polish], Rozprawy Naukowe i Monografie, Wydawnictwo SGGW, Warszawa 2009.

[5] PN-EN 336:2013-12 Structural timber. Dimensions, permitted deviations [in English].

[6] PN-EN 13183-2:2004 Moisture content of a piece of sawn timber – Part 2: Estimation by electrical resistance method [in Polish].

[7] PN-EN 13183-3:2007 Moisture content of a piece of sawn timber – Part 3: Estimation by capacitance method [in Polish].

[8] PN-D-94021:2013-10 – Softwood structural sawn timber sorted using strength methods [in Polish].

[9] PN-EN 14081-1:2016-03 Timber structures – Strength-sorted structural timber with a rectangular cross section – Part 1: General Requirements [in English].

[10] PN-EN 1912:2012 Structural timber – Strength classes – Visual division into classes and sorts [in English].

Lech Rudziński
Agnieszka Wdowiak

Właściwości strukturalno-wytrzymałościowe drewna konstrukcyjnego

1. Wprowadzenie

Drewno to materiał pochodzenia organicznego, wykazujący w zależności od gatunku ogromną zmienność swoich właściwości. Jest anizotropowy (różne właściwości w różnych kierunkach) i niejednorodny (posiada wady). Do cech makroskopowych zalicza się wielkości ponad 0,1 mm, takie jak przyrosty roczne, strefy drewna późnego i wczesnego, twardziel, szerokie promienie rdzeniowe, duże naczynia, wycieki żywiczne, sęki. Do budowy mikroskopowej zaliczane są szczegóły jego struktury, które można zobaczyć przy użyciu mikroskopu optycznego [1, 3].

2. Właściwości strukturalno-wytrzymałościowe tarcicy konstrukcyjnej

2.1. Pochodzenie materiału badawczego

Za cel pracy przyjęto określenie wybranych właściwości mechanicznych i fizycznych polskiej sosnowej tarcicy konstrukcyjnej, pochodzącej z czterech wybranych krain przyrodniczo-leśnych Polski, scharakteryzowanej w tabeli 1. Z każdej krainy wybrano po pięć partii tarcicy o różnych wymiarach przekroju poprzecznego i liczebności 40 sztuk każda, z wyjątkiem przekroju poprzecznego 40 x 82. Długość tarcicy wynosiła około 4,0 m [4]. Ogółem badaniom poddano 240 sztuk tarcicy [5]. Charakterystykę wymiarową tarcicy pochodzącej z poszczególnych krain przedstawiono w tabeli 2.

2.2. Pomiar wilgotności tarcicy świeżej i wysuszonej sztucznie

Badanie zostało przeprowadzone w warunkach przemysłowych, w firmie Tartak OLCZYK w Świdnie. Przed rozpoczęciem badań tarcica została oznakowana, zmierzona oraz poukładana w pakiety, ze względu na wymiar i pochodzenie. Przeprowadzono pomiar wilgotności, posługując się wilgotnościomierzem regularnie sprawdzanym i kalibrowanym, zgodnie z instrukcją producenta przyrządu [6]. Następnie ponownie poukładano przekrojami tarcicę w pakiety i za pomocą wózka widłowego, przetransportowano ją do pięciu komór suszarnianych. Dla każdego sortymentu ustalono różną temperaturę początkową i końcową. Za punkt docelowy przyjęto uzyskanie wilgotności 10%.

2.3. Metodyka wytrzymałościowego sortowania tarcicy metodą wizualną zgodnie z PN-D-94021 [8]

Po przeprowadzonej analizie wilgotności przystąpiono do sortowania wizualnego [9]. Każdą sztukę dokładnie obejrzano. Dokonywano pomiaru wszystkich występujących w niej cech, jak: sękatość, skręt włókien, pęknięcia na płaszczyźnie i pęknięcia czołowe, krzywizny podłużne boków, krzywizny podłużne płaszczyzn, krzywizny poprzeczne, wichrowatość, obliny, zakorki, pęcherze żywiczne, falistość włókien [4].

3. Wnioski

Tarcica świeża, pochodząca z Karpackiej Krainy Przyrodniczo-Leśnej, odznaczała się najwyższą wilgotnością średnią. Wyjątkiem jest partia tarcicy o wymiarach 50 × 100 × 4000, ze Śląskiej Krainy Przyrodniczo-Leśnej. W wyniku suszenia sztucznego najwyższa średnia wilgotność, charakteryzowała sortyment o mniejszych przekrojach poprzecznych, pochodzący z Małopolskiej Krainy Przyrodniczo-Leśnej. W wyniku sortowania tarcicy z Mazowiecko-Podlaskiej Krainy Przyrodniczo-Leśnej, uzyskano największą liczbę sztuk w klasie KW (6 sztuk) i w klasie KS (13 sztuk), w porównaniu z wynikami sortowania tarcicy pochodzącej z pozostałych krain.