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Raw material factors affecting the quota of structural wood in sawmill production

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Abstract: Construction wood has to meet high requirements for loads capacity. Thanks to the selection and adequate classification of raw materials it is possible to decide how specific wood products can and should be used. The usage of solid wood for structural elements purposes has been precisely classified and specified in standardized requirements. Twelve classes of structural timber, ranging from C14 to C50, have been identified for softwood. Only part of Polish raw wood meets the standards of strength classes required in the building industry, as its strength corresponds to classes C24 and C30. A conclusion from research on the assortment structure of the raw materials in Poland was formed that it is particularly important to sort wood effectively according to its quality and intended use during processing. The material and strength efficiency is the main indicator of rational use of wood. The research resulted in setting the initial classification limits of selected round wood groups according to its strength. Properties determining the possibilities of obtaining a high quality product from the available raw wood material were taken into account in the research. Crucial factor was to select the proper research technology of determining dependencies between the applied research methodology and the defined wood quality, sorting class and strength class. The lower limit of availability of raw material with appropriate technical characteristics is determined during the selection of the research formula.

Keywords: pine raw material, structural timber, strength classes

INTRODUCTION

Wood needs to meet increasingly high qualitative requirements to be useable as building material. The right classification of the raw material is of utmost importance, as it facilitates planning its applications and specifies the characteristics of wood products. Especially timber must meet strict requirements concerning safety in order to be recognized as proper building material. The assortments which do not meet these requirements can only be used for non-structural purposes – garden structures, packaging materials, fuels, solid wood furniture, etc. European standards number: PN-EN 1995-1-1: 2010 and PN-EN 338: 2003 categorise structural timber into twelve strength quality classes (from C14 to C50). Only part of the Polish raw material meets the standards of strength classes required in the building industry, i.e. C24, C30 and C35. As results from the amendment to the PN-EN 1995-1-1 and PN-D-94021: 2013 standards, other classes have not been fully applied in Poland [Dzbeński et al., 2005].

Results of various sawmills assortment structure studies in Poland, present that its very important to have the effective solution to sort wood according to its quality while it is being processed. The share of individual strength classes resulting from the processing of raw material into timber and sawmill products is a synthetic indicator of round wood [Hruzik, 2003; Hruzik, et al., 2005] rational sawing efficiency.

Basic strength classes of softwood, i.e. C24, C30 and C35, were sorted out in the research, allowing for the factors limiting the possibility of obtaining high-quality products from the available materials. Visual assessment being a standard procedure forced mechanical tests to be introduced and verified, what allowed to precisely determine the dependencies between the origin and quality of wood, its sorting class and strength class. In both cases the question arises how to provide the raw material with appropriate technical characteristics.

Analysis of reference publications and industrial practice based on methods of visual assessment used for sorting domestic wood according to its strength, we now know it is possible to sort 3-6% of sawn timber in the KW class. This result can be defined as a function of the distribution of specific wood structure traits, which affect its mechanical strength [Kozakiewicz and Krzosek 2013].

Correlation between: strength class and sorting class was determined (Tab. 1). The PN-EN 1995-1-1 standard specifies the dependence between: wood species, sorting class and strength class and the PN-EN 338 standard expands specification by dependence between the wood strength class and its sorting class and species defined according to the methodology specified in the PN-D-94021: 2013 standard.

Table 1. The reference from the visual classification PN-D-94021:2013 to strength classes PN-EN 338

Species	Timber thickness [mm]	Structural wood classes						
		C 14	C18	C20	C22	C24	C30	C35
Pine	≥22			KG		KS		KW
Spruce			KG			KS	KW	
Fir		KG	KS		KW			
Larch						KG	KS	KW

Currently there are two relation assigning approaches between the strength class and sorting class, depending on the reference document.

Structural wood used in constructions that has to meet special requirements concerning the strength. Furthermore structural wood together with designed joints must also meet the strict requirements in seismic areas [Deam et al. 2008]. High resistance to damage is an important aspect of wood properties, which is taken into account by constructors and designers [Loss et al., 2018]. In order to select the proper available structural timber in particular areas, researchers model stresses and calculate the forces acting on the constructions skeleton [Ellingwood et al., 2004]. This research helped to develop the knowledge which is necessary to replace commonly used non-renewable construction materials with wood materials while maintaining the designed strength of structures [Li et al., 2019].

AIM, METHOD AND DESCRIPTION OF STUDY

The aim of this study was to determine the quality of structural components made from pine timber. The capacity and qualitative properties of the raw material were compared and referred to its properties and European standards, allowing for the dimensional ranges of timber.

In order to classify constructional elements according to their quality intermediate products were acquired from separate parts of fresh mixed forest model long logs. The intermediate products came from the butt zone (symbol A), the middle zone (symbol B) and the apical zone (symbol C) of model long logs of a 86-year-old tree that gave logs with a 3m. The static bending strength of intermediate products and solid wood samples were tested with strength-testing machines SAM and DM 2214.

Machine tests, used in assessment of the modulus of elasticity, i.e. the relation between the stress applied to an area and the resulting deformation (relative elongation), are the basis for determining the strength of materials. The efficiency of construction materials increases along with the number of their applications. Machine tests reflect the real strength characteristics of wood what means that the modulus, which is calculated during static bending tests or sonic tests, can be the basis for comparative assessment of technical value of wood.

During the research wood was bent at four points to make measurements and calculate the modulus of elasticity. Large-sized elements underwent bending tests on a SAM strength-testing machine. The modulus of elasticity was tested according to the PN-EN 408: 2012 and PN-EN 384:–2016 standard. The size of the deflection arrow was measured with a dial indicator to an accuracy of 0.01 mm. The samples were pre-loaded with a force of 100 N. The bending force was gradually increased by 50 N. The wood moisture was determined after destructive testing on laboratory samples and it was included in the calculation of the strength parameters to a reference humidity of 12%, according to the Bauschinger formula.

SUMMARY OF DATA AND ANALYSIS OF TEST RESULTS

Density is a basic physical property which reflects the mechanical properties of wood in raw material characteristics. Table 2 presents the characteristics of the density of the tested intermediate products. The highest average density of timber (542 kg/m^3) was noted in the structural elements in sample B. The lowest average density of laths (520 kg/m^3) was noted in the structural elements in sample A. It was caused by the content of juvenile wood in the butt zone of model long logs. The density ranges were comparable to the data reported in reference publications [Kokociński, 2004].

Table 2. Mean timber densities in samples A, B and C

Cross section of intermediate products (mm)			
A		**B**	**C**
Lath	ζ [kg/m^3]	ζ [kg/m^3]	ζ [kg/m^3]
1(S)	529	554	526
2(S)	520	490	542
3(R)	511	557	520
Mean	**520**	**529**	**529**

S – tangent zone
R – core zone

Table 3. The mean width of growth rings in the material

Intermediate product cross section (mm)			
	A	**B**	**C**
Lath	[mm]	[mm]	[mm]
1(S)	1.95	1.51	1.85
2(S)	2.09	2.51	1.74
3(R)	1.76	1.57	1.82
Mean	**1.93**	**1.90**	**1.96**

The width of growth rings is another physical property related to the quality and usefulness of pinewood. Data in reference publications [Kollman and Core 1968, Krzysik 1978, Kokociński 2004] confirm that narrow annual growth rings indicate higher quality parameters in softwood. According to the standard of visual assessment of structural timber PN-D-94021:2013, the average width of growth rings is a criterion of raw material quality classes. Table 3 shows the average width of annual growth rings measured in subsequent pieces of timber used for the production of intermediate products.

The greatest midpoint width of growth rings in timber (1.96 mm) was noted in the structural elements of group C of the apical zone. The smallest average width of growth rings in laths (1.51 mm) was noted in the structural elements of group B. The width of the rings in all the samples ranged from 1.51 mm to 2.51 mm. The mean width of the growth rings ranged from 1.90 to 1.96 mm. Following the adopted classification, the raw material was rated as narrow-ringed and meeting the requirements for structural timber.

Humidity being a factor affecting wood strength, its condition was determined within the hygroscopic range, i.e. 0-30%, during the laboratory tests. The average moisture of timber intermediate products in groups A and B was 10%, whereas it was 11% in group C.

STATIC BENDING STRENGTH OF LARGE-SIZED SAMPLES

Static bending strength is one of the most common strength tests, which has direct influence on the design of wooden structures. The static bending strength limits for large-sized samples were set in tests according to the standard assumptions [PN-EN 408]. Table 4 array the results.

The average strength of large-sized timber elements from the test batch ranged from 29 to 40 N/mm^2. The intermediate products from the butt part of the logs were characterised by the lowest average strength ranging from 29 to 39 N/mm^2. At the highest spread of values, this timber could be categorised as the C27 strength class. The lowest strength, i.e. 22 N/mm^2, was noted in the raw material from the butt zone (A) with the radial cross section (R). The highest strength, i.e. 55 N/mm^2, was noted in the wood from the middle (B) and butt zones (A) with the tangential cross section (S)

Table 4. The bending strength of structural elements

R_{g12} [N/mm^2]									
	A			B			C		
Zone	min	mean	max	min	mean	max	min	mean	max
1(S)	25	39	48	23	40	55	26	34	45
2(S)	24	35	55	23	36	50	26	39	46
3(R)	22	29	41	26	34	45	25	36	45

The low values of bending strengths of the structural elements were caused by the cumulative scale of defects and changes in the structure in the juvenile wood zone. The central zone between the pressures was the most common place of horizontal stratification in the solid wood under study.

Static bending strength of laboratory samples

Following the PN-EN 408:2012 standard, laboratory samples of solid wood were collected from the structural elements for comparative purposes. Table 5 shows the average static bending strength of the samples.

Table 5. The bending strength of model samples

R_{g12} [N/mm^2]									
	A			B			C		
Zone	min	mean	max	min	mean	max	min	mean	max
1(S)	53	79	97	49	71	90	59	78	89
2(S)	51	76	90	53	69	85	57	72	82
3(R)	50	71	87	47	63	83	57	67	84

The laboratory samples of raw material from the tested surface were characterised by the lowest mean strength, i.e. 63-79 N/mm^2. The greatest decrease in the strength was observed in the assortments in group B, i.e. 63-71 N/mm^2, in contrast to the higher results noted in samples A and B of the structural elements. The greatest midpoint strength, i.e. 71-79 N/mm^2 was noted in the samples collected from the butt assortments. The highest bending strength value in the butt zone sample amounted to 97 N/mm^2, whereas the lowest was 47 N/mm^2. The results were at least twice as high as in those noted in the tests on large-sized elements. This fact confirmed the significant influence of the scale of the tested elements.

MODULUS OF ELASTICITY

Table 6 lines up the mean values of Young's modulus of elasticity, as the main classifying property structural timber into individual structural groups.

Table 6. The modulus of elasticity of large-sized samples with humidity of 12%

Value	Origin of intermediate product [N/mm^2]		
	A	**B**	**C**
min	7,845	8,651	8,731
mean	9,646	10,931	9,869
max	11,415	12,415	10,982
Class according to standard PN-EN 338	C20	C22	C20

The highest mean value of the modulus of elasticity (10,931 N/mm^2) was noted in the intermediate products from the middle zone (B) of the long logs, whereas the lowest mean modulus of elasticity (9,646 N/mm^2) was marked in the intermediate products from the butt zone. It is noteworthy that the mean value of the modulus of elasticity of the raw material from the apical zone met the requirements of strength class C22, according to the PN-EN 338 standard. The lowest value of the modulus of elasticity was noted in the samples from the butt zone – 7,845 N/mm^2, whereas the highest value of the modulus of elasticity in the assortments from the middle zone – 12,415 N/mm^2. The mean value of the modulus of elasticity of all the intermediate products was 10,148 N/mm^2, with a 5% quantile of 7,845 N/mm^2. Thus, the whole batch of the tested material can be categorised as strength class C20.

CONCLUSIONS

The research led to the following conclusions:

1. The average width of the annual growth rings in domestic softwood subjected to tests and intended for the production of structural elements amounted to about 2 mm. The raw material was narrow-ringed and met the set standard requirements. The density ranged from 520 to 542 kg/m^3, which indicated good strength parameters of the pinewood samples. These values were greater than 490 kg/m^3 – the value given in the reference publications and required by structural timber standards.
2. In comparison with data given in the PN-EN standard for structural timber, the minimum static bending strength of the intermediate products was low and samples were categorised as class C22 (sample A). According to the strength standards for solid structural timber and the mean values measured in the tests, samples A could be categorised as strength class C27, whereas samples B and C could be categorised as strength class C30. The structural elements with a tangential cross-section were classified

according to the mean value as C35 for samples A and B. The mean values of the intermediate products with a radial cross-section in zone A amounted to 29 N/mm^2, which met the standards of class C27.

3. The midpoint value of the modulus of elasticity of samples A and B was too low to categorise them as structural timber strength class C24. The values of Young's modulus of elasticity noted in the intermediate products were lower than those measured in the destructive test. The values met the standards of wood strength classes C20 and C22.
4. The values of the static bending strength of the pinewood laboratory samples measured in the experiments met the standards of the highest strength classes and significantly exceeded the values measured in the large-sized elements. Nevertheless, the values measured in these tests were lower than the strength data presented in the reference publications (about 87 N/mm^2).
5. The low values of the modulus of elasticity and static bending strength were largely affected by the share of the juvenile wood zone and the origin of the material, which varied from the tangential to radial cross section. In practice, this caused a decrease in the strength parameters of the large-sized samples from the central zone.

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Streszczenie: *Czynniki surowcowe wpływające na udział drewna konstrukcyjnego w produkcji tartacznej.* Drewno konstrukcyjne posiada wysokie wymagania związane z przenoszeniem określonych obciążeń. Dobór i odpowiednia klasyfikacja surowca pozwala na określenie kierunków oraz sposobów zastosowania wyrobów drzewnych. Zastosowanie drewna litego na elementy konstrukcyjne zostało precyzyjnie zaklasyfikowane i ujęte w wymaganiach spełniających procedury normowe, wydzielając dla drewna iglastego dwanaście klas tarcicy konstrukcyjnej od C14 do C50. Tylko część rodzimego surowca odpowiada zdefiniowanym klasom wytrzymałości znajdującym zastosowanie w budownictwie charakteryzując się zgodnością wytrzymałości dla klas C24, C30. Badania struktury asortymentowe surowca w Polsce wskazują, iż fundamentalne znaczenie posiada efektywne sortowanie jakościowo-przeznaczeniowe drewna w trakcie jego przerobu. Głównym wskaźnikiem racjonalnego wykorzystania drewna jest wydajność materiałowo-wytrzymałościowa z danego surowca.
Badania pozwoliły ustalić wstępne granice klasyfikacji wytrzymałościowej dla wybranych grup drewna. Uwzględniono właściwości, które określają możliwości pozyskania wysoko jakościowego produktu z dostępnego materiału. Dużą wagę niesie za sobą dobór technologii badań, która określa zależności między metoda badań i jakością drewna, klasą sortowniczą, jak i klasą wytrzymałości. W doborze formuły badawczej określa się graniczny poziom dostępności surowca o odpowiednich cechach technicznych.

Słowa kluczowe: surowiec sosnowy, drewno konstrukcyjne, klasy wytrzymałości

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