

Article

Quality and Bending Properties of Scots Pine (*Pinus Sylvestris* L.) Sawn Timber

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Abstract: The paper presents the partial research results of a mechanical properties study conducted on Scots pine from the Silesian Forestry Area in Poland. The scope of research included the visual strength grading of the timber according to the PN-D-94021:2013 standard, mechanical testing (according to EN 408:2012) and an attempt to assign visuals to the C strength classes. The EN 1912:2012 standard assigns the visual sorting classes of individual wood species (according to national sorting standards) to the C strength classes introduced by the EN 338:2018 standard. At the moment, this standard does not assign Polish visual sorting classes (KW, KS, and KG) to C strength classes. The obtained MOE (modulus of elasticity) and MOR (static bending strength) values were corrected according to the EN 384:2018 standard, and their characteristic values were later calculated. On this basis, we proposed a classification of the grading classes determined on the basis of PN-D-94021 into C classes described in EN 338:2018, which is necessary in the process of the transposition of Polish strength grades (KW, KS, KG, and Reject) and the qualification of them in line with EN 1912:2012. The calculated characteristic values of density, MOR and E_0 (the modulus of elasticity parallel to the grain) allowed us to assign Polish visual grades KW, KS, and KG to C35, C30, and C20, respectively. The pine timber under research had high physical and mechanical parameters, which translated into high C classes to which the KW, KS, and KG timber categories were assigned.

Keywords: scots pine timber; visual grading; strength grading

1. Introduction

Wood, as a natural material, has an anisotropic structure. For this reason, and due to possible wood defects, wood can have very diverse mechanical and physical properties, even within the same species. Therefore, only timber with guaranteed resistance—that is, strength graded timber—can be used in civil engineering for construction applications, according to the legal requirements binding in Poland and in other member states of the European Union. There are two methods of strength grading: by visual inspection and with the use of a grading machine. There are two types of grading machines. One of them works on the basis of the determination of the dynamic modulus of elasticity (using resonance frequency or ultrasounds), and the second one on the basis of the static modulus of elasticity within bending. In this situation, timber is machine-graded by passing it between rollers and measuring either the load required to give a fixed deflection or the deflection within fixed load.

The first standards and publications concerning visual strength grading appeared in the 1950s in the USA [1,2], Canada [3], Finland [4], and Great Britain [5,6].

Strength grading based on visual inspection consists of examining every piece of timber and classifying it within the appropriate strength class on the basis of visible defects of wood structure,

shape, and processing. The following structural wood defects are taken into account: knots, twisted fibers, cracks, resin pockets, bark pockets, wounds, rot, insect tunnels, and the presence of sclerenchyma. The defects of shape and processing taken into account during visual strength grading are the following: waness, bows, cups, springs, warping, and other defects due to wrong processing, such as ends whose surfaces are not parallel. As a result of strength grading based on visual inspection, timber is classified into different grades. Each strength grade has its resistance parameters. Each EU member state has its own national standard for the visual strength grading of timber. Therefore, different countries have different numbers of strength grades (for instance, in Poland, Germany, Austria, and Slovakia, there are three grades; in Great Britain, there are two grades; and in France, there are four grades), and there are also different methods of assessing the features of timber that are important in the classification process, such as the area of knots in relation to the cross section area or the diameter of knots in relation to the cross section dimensions. The only common requirement that has to be fulfilled by the national standards of visual strength grading is that they have to comply with EN 14081-1. In Poland, visual strength grading is carried out on the basis of PN-D-94021, in Germany: DIN 4074-1, in Great Britain: BS 4978, in Austria: ÖN DIN 4074, Slovakia: STN 49 1531, Italy: UNI 11035-2, France: NF B 52-001-1, etc. The strength grades or classes functioning as a result of applying those standards are the following: in Poland, KW is a high quality grade, KS is a medium quality grade, and KG is a grade of less quality; in Germany, S13, S10, and S7 are the corresponding grades; in Great Britain, SS and GS are the lower and upper grades; in Austria, S13, S10, and S7 are the corresponding grades; in Slovakia, S0, SI, and SII are the corresponding grades; Italy has the classes S1, S2, and S3 for pine timber; and France has TI, TII, TIII, and TIV (for elements with the cross section of 16,000 mm² or less). In view of such huge diversity of strength classes used in visual strength grading in Europe, it became necessary to unify and harmonize them. This unification consisted of specifying which national classes correspond to which European strength “C” classes introduced by the EN 338 standard. This standard was introduced in 1995 and has been amended many times since then (the current version is the EN 338:2016). The EN 1912 standard specifies how the national strength grades of different countries correspond to the C strength grade binding for the entire European Union. In the first edition of this standard, from 1998, it could generally be found that “Timber of a grade, species, and source may be assigned to a strength class and listed in this standard provided there is long experience of use and/or test data in accordance with EN 384.” Considering that the standard permitted classification is based not only on tests but also on long experience, there are not many publications available that would describe the results of examinations performed in line with EN 384 [7–12]. On the other hand, many publications around the world have been devoted to the mechanical properties of timber from a specific place of origin, including various forest lands and habitats [13,14], as well as to the comparison between the results of visual strength grading and the results of the—more and more popular—machine strength grading method carried out using devices of different manufacturers making use of various different principles of operation [15–22]. At the same time, several studies have compared the properties of the same timber classified according to different standards [23,24]. The most recent amendment was introduced to EN 1912 in 2013. To give an example, the current assignment of strength grades and visual classes is the following: for German and Austrian Scots pine timber (*Pinus sylvestris* L.): S13 = C30, S10 = C24, and S7 = C18; for British pine (*Pinus nigra* Arn., *Pinus sylvestris* L.): class SS = C22 and GS = C14; for Italian timber, Corsican pine (*Pinus nigra* Arn.): class S1 = C24, S2 = C24, and S3 = C14; and for Slovakian Norway spruce (*Picea abies* L.): S0 = C30, SI = C24, and SII = C18. The standard still does not include any guidelines for Polish strength grades for any wood species. For several years now, studies have been being carried out in Poland in order to include the Polish grading classes KW, KS, and KG in the EN 1912 standard [25–29]. The aim of the study described in this paper was to assign the Polish strength grades to the C strength grades, which will facilitate the introduction of Polish strength grades used in visual strength grading to the EN 1912 standard. The studies that are being carried out at this moment are limited to Scots pine timber because this wood species is the most frequently used in construction applications in Poland.

2. Experimental Setup

2.1. Material

The research material consisted of 210 pieces of Scots pine timber from the Silesian Forestry Region in Poland. The timber was acquired from raw wood aged about 120 years. The timber originated from logs of trees that grew in a fresh mixed forest under the Regional National Forest Directorate of Katowice (Olesno Forest District, Sternalice Forest Division, unit 14 d, geographical coordinates: 50°53'55.1" N and 18°25'26.1" E). The sawn timber was obtained from logs 3.5 m-long. Logs were cut on a sawline consisting of a canter, 4 vertical bandsaws, and an edger for side boards. The line was operated in a “merry go round” system. In the first pass, 150 mm-wide central lumber and side boards were obtained. In the second pass, planks were cut into mine boards with a depth of 50 mm and side boards. Only the main boards were used for the tests. Construction elements (according to PN-94021:2013 with the cross section at least 2000 mm²) with nominal cross-section dimensions after drying and planning—40 × 138 × 3500 mm—were used in the tests. This cross-section is often used for the production of roof trusses in popular MiTek system (gang nail connections).

2.2. Methods

During the study, the batch of Scots pine timber from the Silesian Forestry Region was sorted into KW, KS, KG, and “Reject” classes according to the visual strength grading method described in PN-D-94021:2013. In the process of strength grading based on visual inspection according to PN-D-94021:2013, defects of wood structure, shape, and processing are taken into account. The following structural wood defects are analyzed: knots, twisted fibers, cracks, rot, insect tunnels, compression wood, blue stain, and graininess. The defects of shape and processing taken into account during visual strength grading are the following: wane, bows, cups, springs, warping, and other defects due to wrong processing.

Knots are assessed by their total knot area ratio (TKAR—the ratio of the sum of the total projected cross-sectional areas of all knots intersected by any cross-section to the total cross-sectional area of the piece) and their margin knot area ratio (MKAR—the ratio of the sum of the projected cross-sectional areas of all knots or portions of knots in a margin intersected at any cross-section to the cross-sectional area of margin). In each piece of timber with width h , there are two marginal zones (with width $h/4$) on both sides of the timber. Table 1 shows the values of the knot area ratio and the average width of annual rings according to PN-D-94021:2013.

Table 1. Knot area ratio and average width of annual rings for individual visual strength grades according PN-D-94021:2013.

Classification Criterion.	Visual Strength Grade				
	KW	KS		KG	
		Variant 1	Variant 2	Variant 1	Variant 2
MKAR	$\leq \frac{1}{4}$	$\leq \frac{1}{4}$	$\leq \frac{1}{2}$	$\leq \frac{1}{2}$	$> \frac{1}{2}$
TKAR	$\leq \frac{1}{4}$	$\leq \frac{1}{3}$	$\leq \frac{1}{4}$	$\leq \frac{1}{2}$	$\leq \frac{1}{3}$
Average width of annual rings [mm]	≤ 4	≤ 6		≤ 10	

MKAR = margin knot area ratio; TKAR = total knot area ratio.

Wane is a typical defect occurring at the face of sawn timber—in the tested batch of sawn timber, there were no pieces of the sawn timber, in which there could have been wane in the central part that was subject to visual grading.

Another important structural feature that determined the sorting class of timber was the twist of the fibers. The PN/D-94021:2013 standard allows for the maximum slope of grain in the KW class up to 7% (1:14), up to 10% (1:10) in the KS class, and up to 16% (1:6) in the KG class. Completely

unacceptable, regardless of the class, are rot and insect galleries. Blue stain, on the other hand, is admissible without restrictions. The admissibility of the remaining structural features taken into account for sorting is subject to the rule that in the highest class (KW), the admissibility of these defects is the lowest compared to the other classes, and it is the highest in the lowest class (KG).

The grading was carried out for the middle parts of the timber pieces located between the load points of the strength testing machine during bending tests, and the wood quality at the ends of timber pieces was not taken into account. This was due to the fact that the quality at the ends of timber pieces, located outside of the strength testing machine measurement area, does not influence the measured values of the modulus of elasticity and bending strength determined by the machine.

The next step consisted of a four-point static bending strength test according to EN 408:2010 + A1:2012, with the use of a TIRA Test 2300 universal strength testing machine (TIRA GmbH, Schalkau, Germany). In four-point bending tests, the test piece normally has a minimum length of 19 times the depth of the cross section. In the conducted research span, the depth ratio was 18:1. Additionally, to prevent buckling, lateral restraints were used. The span-to-depth ratio is an important parameter because it can affect structural behavior [30]. The weakest section of each piece was determined by visual inspection. When possible the weakest section was located within the load points of the strength testing machine. Bending strength and the modulus of elasticity were determined. Finally, according to the guidelines of EN 384:2018, moisture content adjustment was carried out for density and the modulus of elasticity parallel to the grain (E_0), and size adjustment was carried out for bending strength. Later, a free-from-failure-defects sample was taken from the rupture area to test its density and moisture with the gravimetric method (drier and scale).

The next stage consisted of calculating the characteristic values: the density, MOR, and E_0 of the timber under research. On the basis of the characteristic values, we proposed a manner of assigning the KW, KS, and KG grades to the C strength classes according to EN 338:2018, which is indispensable in order to introduce Polish strength grades to the EN 1912:2012 standard.

2.3. Statistical Analysis

The statistical analysis of test results was carried out in the Statistica v.13.3 software (StatSoft, Inc., Tulsa, USA). The statistical analysis involved an ANOVA to determine whether there were differences within specific grades (KW, KS, KG, or Reject) concerning the values of physico-mechanical parameters (wood density, modulus of elasticity parallel to the grain, and bending strength). Bearing this in mind, we tested whether the distribution of the variable (physico-mechanical parameter) under analysis was normal. For all the analyzed cases, in each strength grade, the normal distribution of results was verified with the Kolmogorov–Smirnov test, with the minimum level of significance $p = 0.05$. Subsequently, the homogeneous variance of the tested parameter was verified with Levene's test. If the test confirmed the fulfilment of the zero hypothesis, we carried out a post-hoc test with the Tukey method. If the Levene's test revealed a lack of variance homogeneity for a given parameter, we used a corrective coefficient and an adequate method of post-hoc test: the Dunnett's test.

3. Results and Discussion

As a result of visual strength grading, while considering the middle part (within the test span of the strength testing machine), the batch of 210 timber pieces was divided into strength grades in the following manner: 83 pieces were classified as KW (39.5% of the whole batch), 31 pieces were classified as KS (14.8% of the whole batch), 60 pieces were classified as KG grade (28.6% of the whole batch), and 36 pieces (17.1%) were classified as Reject (Table 1). Features that had more influence in the downgrading process were knots (share of over 92%), followed by twisted fibers (share around 5%) and then rot (share around 3%).

In reference to the research conducted in previous years concerning timber from five different forestry regions [20], timber originating from the Silesian Forestry Region was characterized by a very high share of timber pieces classified as KW (24.6% higher than the average value of timber from all

five regions classified as KW on the basis of the visual strength grading of the middle part of the timber piece, located within the span of loading points of the machine head during the bending strength test of each timber piece).

The timber under research (Table 2) had high average density (541 kg/m^3), modulus of elasticity parallel to the grain ($12,680 \text{ MPa}$), and static bending strength (47 MPa) values compared to the values obtained previously in the study of timber from five different Polish forestry regions [20]. A higher average density value was related to the higher density values of timber, compared to the density values of timber from the aforementioned five different Polish forestry regions, qualified to each grading class (KW, KS, KG, and Reject), respectively: by 30, 48, 38, and 58 kg/m^3 . Similarly, the values of the modulus of elasticity parallel to the grain determined for Silesian timber for the KW, KS, KG, and Reject classes corresponded to, respectively, 118%, 119%, 124%, and 136% of the average values of the modulus of elasticity parallel to the grain obtained for timber from the five Polish forestry regions. Regarding the static bending strength (MOR), the values determined for timber from the Silesian Forestry Region for each class (KW, KS, KG, and Reject) respectively corresponded to 123%, 105%, 114%, and 130% of the average MOR determined for timber from five different Polish forestry regions [20].

Table 2. Corrected (in line with EN 384) average values of: density (ρ), modulus of elasticity parallel to the grain (E_0), static bending strength (MOR), and width of the annual rings of the timber under research.

Physico-Mechanical Properties of Timber Under Research.		All	Visual Strength Grade			
			Number of Pieces			
			KW	KS	KG	Reject
		210 Pieces	83 Pieces	31 Pieces	60 Pieces	36 Pieces
ρ [kg/m^3]	Mean	541	576	559	506	506
	SD	71	75	66	51	46
	COV	13	13	12	10	9
E_0 [MPa]	Mean	12,680	14,810	13,250	11,250	10,120
	SD	3430	2890	2340	2340	3000
	COV	27	20	18	21	30
MOR [MPa]	Mean	47	63	44	37	31
	SD	19	17	7	9	14
	COV	40	27	16	24	45
Width of annual rings [mm]	Min	0.60	0.66	0.60	0.83	1.07
	Mean	1.84	1.43	1.74	2.07	2.49
	Max	3.90	2.87	3.37	4.10	3.80

Silesian timber has very good physico-mechanical parameters, which has also been confirmed by studies conducted on Polish-grown Scots pine timber by other researchers. For example, a study of 219 Polish pine timber [12] resulted in an average density value that was by 4% lower than density obtained within reported study, analogously modulus of elasticity parallel to the grain, and static bending strength that was 12% lower than the values determined within reported study for Silesian timber. At the same time, the coefficients of variation of the physico-mechanical properties (density, modulus of elasticity parallel to the grain, and static bending strength) were similar in both studies. Analogous relations were confirmed after comparing the physico-mechanical parameters determined for Silesian timber with the results obtained within the framework of the Gradewood project carried out by the VTT Technical Research Centre of Finland. The average density of Scots pine timber from the Silesian Forestry Region in Poland was approximately 4% higher than the average density of

Polish-grown timber tested within the framework of the Gradewood project and 12% higher than Swedish pine timber [21]. Regarding the modulus of elasticity parallel to the grain, Polish-grown Scots pine timber from the Silesian Forestry Region had a similar average value of the modulus of elasticity parallel to the grain as Polish timber in general, and it had a value 9% higher than Swedish timber. Regarding static bending strength, the average value obtained in the research was 11% higher than the average static bending strength value for Polish-grown timber in general and 2% lower than the value for Swedish pine timber [21].

The statistical analysis (one-way analysis of variance) revealed that there were no statistically significant differences between the average density values of wood classified in the KW and KS grades. In this respect, the strength grade did not determine the density. A similar situation concerning wood density was also observed between the two lower grades of KG and Reject. What is more, the analysis of variance revealed that the KW and KS strength grades were directly correlated with the values of the modulus of elasticity parallel to the grain and static bending strength (MOR). On the other hand, KG and Reject grades did not present statistically significant differences in the values of MOR and E_0 .

Figure 1 presents the correlations between the modulus of elasticity parallel to the grain and wood density (the values were corrected according to the guidelines from EN 384). The coefficient of determination for the entire timber batch (210 pieces) amounted to 0.31. This value was significantly lower than the coefficient of determination between the modulus of elasticity and density determined in a previous study of 764 pieces of Scots pine timber from various Polish forestry regions, which amounted to 0.43 [20]. In a case of Finnish pine timber, the coefficient of determination between the modulus of elasticity parallel to the grain and wood density amounted to 0.54 [21]. In turn, studies of Scots pine timber pieces with different cross-section dimensions have shown that the coefficient of determination between the modulus of elasticity parallel to the grain and static bending strength can fall in the range between 0.49 and 0.66 [17]. Taking the division of timber into strength grades (KW, KS, KG, and Reject) into account, the highest value of coefficient of determination (0.66) was obtained for timber from the KS grade. The coefficient was lower for both KW and KG grades (0.54), while the Reject grade had a coefficient of determination of 0.60. These values were clearly higher than the values obtained in a previous study of Polish-grown timber from five different forestry regions. The coefficients of determination obtained in that study were 0.59 for KW, 0.50 for KS, 0.52 for KG, and 0.48 for Reject [20].

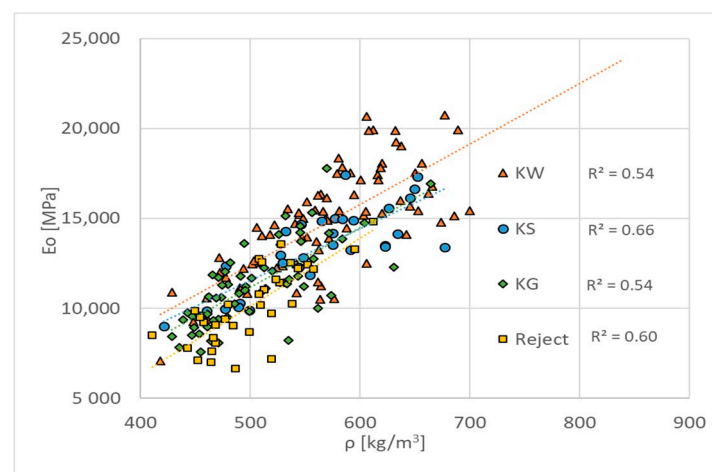


Figure 1. Correlations between the modulus of elasticity parallel to the grain and density, taking strength grades into account.

The coefficient of determination between the static bending strength and wood density corrected for the moisture content of 12% (Figure 2) for the entire batch of timber (210 pieces) amounted to 0.27. This value was significantly lower than the coefficient of determination between the bending

strength and density corrected for a 12% moisture content determined in a previous study of 764 pieces of Scots pine timber from various Polish forestry regions, which amounted to 0.42 [20]. In a case of Finnish pine timber, the coefficient of determination between the static bending strength and wood density amounted to 0.21 [21]. In turn, studies of Scots pine timber pieces with different cross-section dimensions have shown that the coefficient of determination between the modulus of elasticity parallel to the grain and density can fall in the range between 0.43 and 0.56 [17].

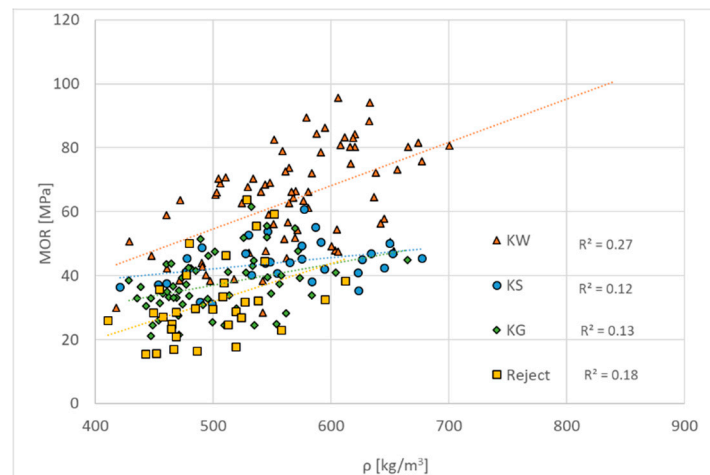


Figure 2. Correlations between the static bending strength and wood density, taking strength grades into account.

Taking the division of timber into strength grades (KW, KS, KG, and Reject) into account, the highest value of coefficient of determination (0.27) was obtained for timber from the KW grade. For the KS and KG grades, the coefficients of determination amounted to 0.12 and 0.13, respectively. In the case of timber classified as “Reject,” the coefficient of determination amounted to 0.18. These values were clearly lower than the values obtained in a previous study of Polish-grown timber from five different forestry regions. The coefficients of determination obtained in that study were: 0.55 for KW, 0.37 for KS, and 0.25 for KG and Reject [20]. Those lower values of the coefficient of determination obtained in the cited research could have been due to lower numbers of timber pieces in the entire batch and pieces sorted into strength grades.

The coefficient of determination between the modulus of elasticity parallel to the grain and static bending strength (values corrected in line with EN 384) (Figure 3) for the entire batch of timber (210 pieces) amounted to 0.38. This value was lower than the coefficient of determination between the modulus of elasticity and the static bending strength determined in a previous study of 764 pieces of Scots pine timber from various Polish forestry regions, which amounted to 0.67 [20]. In the case of Finnish pine timber, the coefficient of determination between the static bending strength and modulus of elasticity parallel to the grain amounted to 0.53 [21]. In turn, studies of Scots pine timber pieces with different cross-section dimensions have shown that the coefficient of determination between the modulus of elasticity parallel to the grain and static bending strength can fall in the range between 0.72 and 0.79 [17]. Taking the division of timber into strength grades into account, the highest value of coefficient of determination (0.68) was obtained for timber of the “Reject” grade. The coefficient of determination amounted to 0.40 for the KW grade, 0.31 for the KS grade, and 0.38 for the KG grade. The obtained values of the coefficient of determination were lower than the values obtained during tests of Scots pine timber from five different forestry regions classified into different grades (KW—0.56; KS—0.50; KG—0.52; and Reject—0.48). According to [26], the coefficient of determination between the corrected values of the modulus of elasticity and static bending strength for timber from Tuchola (Kujawsko-Pomorskie voivodeship, Poland) amounted to: KW—0.87; KS—0.44; and KG—0.41.

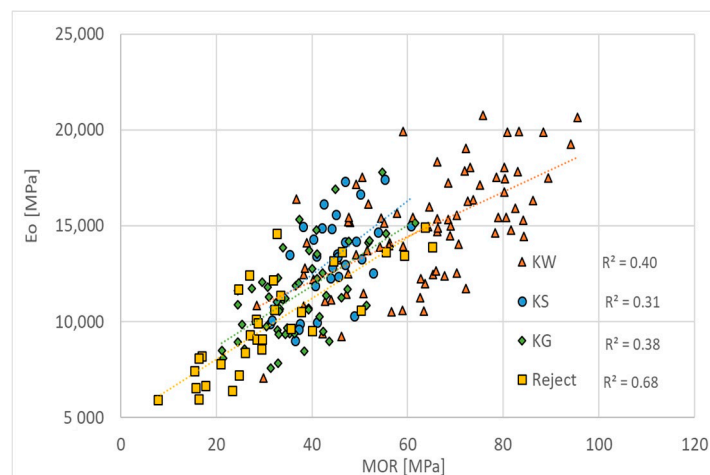


Figure 3. Correlations between the modulus of elasticity parallel to the grain and static bending strength, taking strength grades into account.

Figure 4 presents the cumulative strength distributions for each strength grade of timber. Considering that the cumulative strength distribution makes it difficult to analyze the results in the lower and upper part of the curve, Figures 5 and 6 present the values of the cumulative probability of the occurrence of each property (static bending strength and the modulus of elasticity parallel to the grain) in a logarithmic scale. An analysis of the curves presented in Figures 5 and 6 allows one to notice a typical shift of strength distributions (MOR and E_0) of timber classified into different grades (KW, KS, KG, and Reject). Higher values of the parameters (MOR and E_0) were achieved by timber classified in higher strength grades as a result of the visual strength grading process. Figures 5 and 6 show a clear, typical, and high variance of the parameter within a given strength grade. This variance can be reduced by a more careful selection of research material, as well as by sub-dividing strength grades into smaller sub-grades [31,32]. Another possibility consists of improving the sorting methods, especially by preparing models that would provide higher correlations between the physico-mechanical properties of timber and timber strength grades.

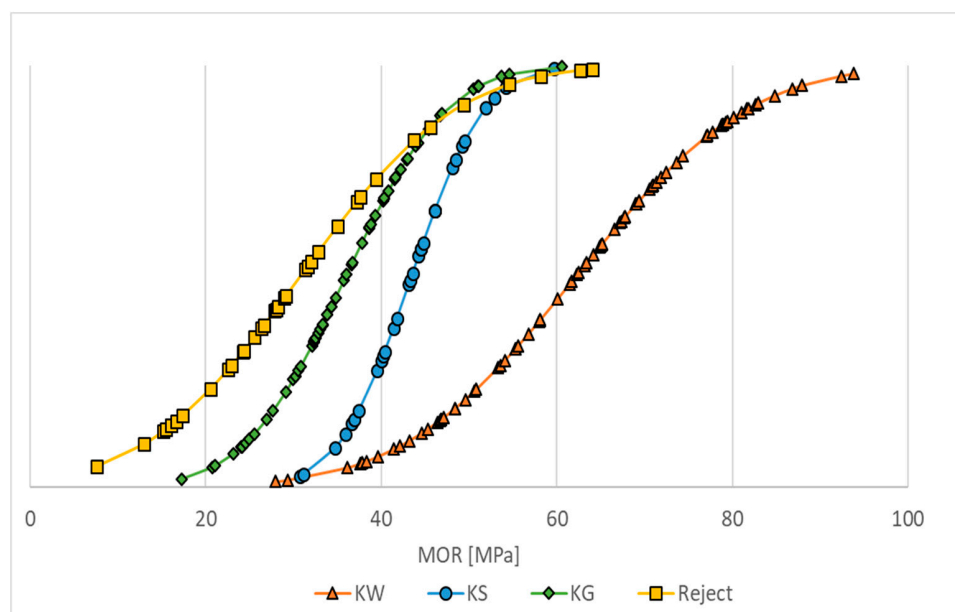


Figure 4. Cumulative distribution of static bending strength for Scots pine timber, taking strength grades into account.

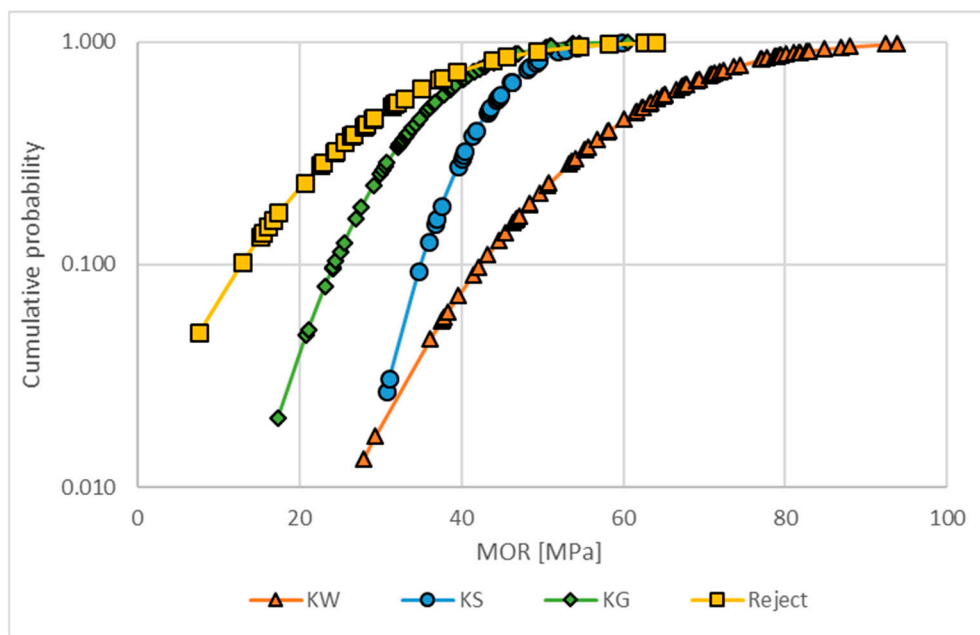


Figure 5. Distribution of static bending strength of different strength grades for Scots pine timber in a logarithmic scale.

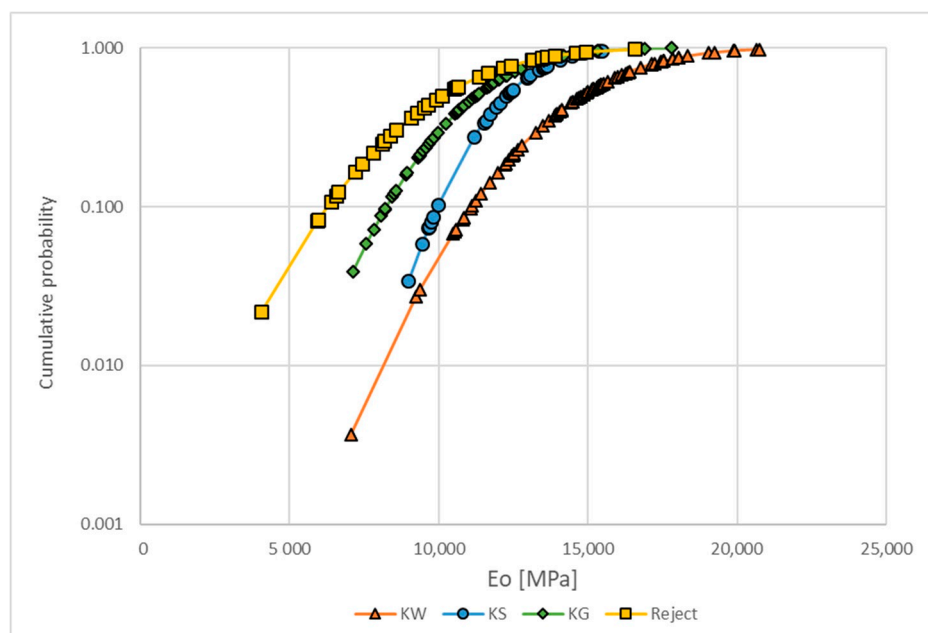


Figure 6. Distribution of modulus of elasticity parallel to the grain for different strength grades of Scots pine timber in a logarithmic scale.

Polish-grown Scots pine timber from the Silesian Forestry Region proved to have a quality comparable to Finnish spruce timber. In a study performed by Ranta-Maunus et al. [33], only five timber pieces (out of the 600 pieces tested) had a static bending strength lower than 20 MPa. An analysis of Figure 5 shows that a total of nine timber pieces had bending strength lower than 20 MPa: one of them classified as KG and eight classified as Reject. At the same time, we can notice that the highest range of distribution of static bending strength was achieved by the timber classified as KW (from 28 to 94 MPa) in comparison to the timber from other strength grades. On the basis of the cumulative distribution of the modulus of elasticity parallel to the grain (Figure 6), we can notice that two timber pieces (one in KW and one in Reject) had significantly different values of the modulus of elasticity

parallel to the grain than other timber pieces from the given grade. Additionally in this case, the KW grade had the highest range of distribution for the modulus of elasticity parallel to the grain (from 7100 to 20,750 MPa). In the case of single pieces of classified sawn timber, for example, in the KW class, very low E_0 and MOR values were obtained. This was due to crack initiation in the zone outside the area to be sorted by the visual method.

On the basis of the characteristic values of density, MOR, and MOE for each strength grade, the grades were assigned to C strength classes while considering the minimum requirements specified by the EN 338 standard. According to Table 3, Scots pine timber from the Silesian Forestry Region graded as KW corresponds to the C35 class, KS corresponds to C30, KG corresponds to C20, and Reject is also classified as Reject. On the basis of other studies conducted on Scots pine [10], the grades were transposed as: KW—C35 class; KS—C24 class; and KG—C20 class. On the basis of the obtained MOR and MOE values, the study of Polish-grown Scots pine timber from five different Polish Forestry Regions [20] (for the entire batch of timber under research, determined) that the KW grade corresponded to C30, KS corresponded to C24, and KG corresponded to C18, while transposition made on the basis of density assigned KW to C45, KS to C40, and KG to C30. Considering the obvious differences in the transposition of visual strength grading classes to the C strength classes, depending on timber origin and its physical and mechanical parameters, it would be convenient to perform resistance tests for a larger set of timber from different forestry regions. The final result of such research would consist of a transposition proposal between the Polish grades (KW, KS, and KG) and the universal system of C strength classes (in line with EN 1912).

Table 3. Characteristic values of physico-mechanical parameters for different quality classes of timber.

Characteristic Value	Visual Strength Grade According to PN-D-94021									
	All	C	KW	C	KS	C	KG	C	Reject	C
ρ_k [kg/m ³]	383	C30	400	C40	402	C40	368	C27	362	C27
$E_{0,mean}$ [MPa]	11,810	C24	13,720	C35	12,270	C30	10,130	C22	8960	C16
$f_{m,k}$ [MPa]	17	C16	35	C35	32	C30	22	C20	12	<C14
Strength class	C16		C35		C30		C20		Reject	

4. Conclusions

1. The calculated characteristic values of density, the modulus of elasticity, and bending strength allowed us to assign the visual grades KW, KS, and KG to C35, C30, and C20, respectively.
2. The Scots pine timber under research had high physico-mechanical parameters that translated into high C classes to which the KW, KS, and KG timber grades were assigned.
3. Despite the classification of timber into strength grades (KW, KS, KG, and Reject), there was still a high variance of the tested properties (wood density, MOR, and E_0). This proves that the visual strength grading method is not perfect.

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