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Comparison results of visual and machine strength grading of Scots pine sawn timber from the Silesian Forestry Region in Poland

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Abstract: *Comparison results of visual and machine strength grading of Scots pine sawn timber from the Silesian Forestry Region in Poland.* The paper presents an analysis of the strength grading results performed by two methods – visual (appearance) and machine, carried out for sawn timber obtained from the Silesian Forestry Region in Poland. Visual strength grading was performed in accordance with PN-D-94021:2013, while the machine strength grading with the use of MTG device from Brookhuis Electronics BV. As a result of the tests, it was confirmed that the machine grading results in a very small share of sawn timber classified as rejects. At the same time, during machine strength grading there were some sawn timber pieces that were not classified for any class or a reject. Based on its visual appearance, such timber elements should be graded as rejects.

Keywords: strength grade, Scots pine sawn timber, Polish structural timber, visual grading, mechanical grading

INTRODUCTION

The importance of timber used in construction increases year by year. From the material fulfilling auxiliary functions in traditional construction and used mainly on roof trusses and for interior finishing, wood has become a construction material. In modern timber structures several main techniques can be distinguished: classic frame buildings, assembled from scratch at the building site or made in prefabrication technology. Prefabrication involves the production of complete building components in a factory, and then assemble on the construction site. In terms of prefabrication, panel prefabrication can be distinguished, which results in finished walls as well as volume prefabrication, in which the outcome is ready-made modules, which, after being transported to the construction site, allow for the immediate assembly of a whole, even a multi-storey building. In Poland prefabrication technology is already used to build timber structures with 4 floors (Beśka 2018).

Cross-linked structural slabs (CLT) are getting more and more popular. Buildings with 14 storeys were built in the world using these modern materials, e.g. in Norway (Abrahamsen and Malo 2014), then 18 storeys in Canada (Fast 2016) or in Norway (Abrahamsen 2017).

One of the necessary conditions for safe building with timber is the use of wood with adequate strength parameters. Sawn timber used in construction for structural purposes must be subjected to strength grading. There are two methods for strength grading of structural sawn timber: visual and machine.

Strength grading by visual methods consists of a thorough examination of each piece of sawn timber and its qualification into specific grade classes on the basis of noticed wood structure defects, and shape and processing defects. In visual grading, the following wood features and defects are taken into account: knots, grain deviation, cracks and fissures, resin pockets, bark pockets, rot and insect tunnels, shape deviations, etc. Shape and processing defects are wanes, longitudinal (sides and planes) curvatures, transversal curvatures, twists and other cutting defects, such as mechanical damage or exceeding dimensional tolerances. As a result of visual grading, timber is sorted into specific sorting classes. Each of the EU countries has its own national regulations regarding strength grading of sawn timber by the visual method. Following this, there are distinct sorting classes in different countries and there are different methods of assessing timber features, e.g. knottiness. These standards are historically conditioned, they differ in terms of grading criteria and the number of grade classes. Strength grading by visual method in Poland is carried out on the basis of PN/D-94021:2013. Conifer constructional timber graded with strength methods. As a result of grading sawn timber is qualified into KW – high quality, KS – medium and KG – low. Sawn timber that does not meet the requirements of KG grade class is not suitable for structural applications and call a reject.

Strength grading by the visual method is a slow and time-consuming process. The efficiency of such grading in m^3 per hour is low. Moreover, it is always burdened, to a greater or lesser extent, with a subjective "human factor" – the result of such grading depends on who grades the timber. If two graders sort the same batch of timber, the grade results may not be identical. Graders are aware of the responsibility and consequences of making an error; in ambiguous situations (so-called border pieces), they tend to lower the grade class of timber subconsciously. Therefore, the first machines for strength grading of sawn timber were designed already in the middle of the last century. Such machines should meet several basic requirements, the most important are:

- a possibility to grade full-size structural timber,
- ensuring of non-destructive grading.

Due to the second requirement, machines for the strength grading of timber are based on the measurement of certain characteristics of wood, which can be determined in a non-destructive manner and which are known to correlate with the bending strength. The higher the correlation between the wood characteristic tested by the machine and its bending strength, the more reliable sorting results of this machine.

Because of the use of grading machines, the obtained results are objective; moreover, modern automated machines sort with efficiency much higher than human. Automatic, computer-controlled, very efficient machines (e.g. feed speed of up to 200 m/min) can be integrated into automatic technological lines for the production of, for example, laminated timber (German: BSH – Brettschichtholz, English glulam), solid timber construction glued to length (German: KVH – Konstruktionsvollholz) or CLT (Cross Laminated Timber). In such automatic lines grading machines are joined with the following circular saws, which cut out fragments of boards with unacceptable wood defects.

Mechanical strength sorting has already been in use for over 50 years. For the first time, on an industrial scale, devices dedicated to strength grading were used in 1963 in the United States. In Europe, many different designs have been developed and applied on an industrial scale over the past years, some of them have already been the subject of publications by various authors (Denzler et al. 2005, Glos 1982, Krzosek 1995, Krzosek 2009, Krzosek and Bacher 2011).

The most important advantage of strength grading by machine method is classifying of sawn timber directly to grades C, according to EN 338:2016 (in Poland PN-EN 338:2016 Timber structures – Strength classes). This standard introduced the following classes for coniferous timber: C14, C16, C18, C20, C22, C24, C27, C30, C35, C40, C45 and C50, and for hardwood: D30, D35, D40, D50, D60 and D70. Poplar wood is treated as coniferous, thus, it is placed into the C classes. This standard also defines the characteristic values of strength properties, elastic properties and density of wood for each C and D class. Characteristic values of strength properties for several selected strength C classes (lowest: C14, highest C50 and C18, C24 and C30) are presented in table 1. If the board is qualified as a given C class, it is assumed that it meets the minimum values of strength and stiffness properties as well as density. If the designer of a wooden roof truss knows, for example, the strength class of timber (e.g. C24), then he has a guarantee that the board has such properties as given in EN 338:2016, i.e. bending strength 24 MPa.

Table 1. Characteristic values of strength properties for selected strength classes of sawn timber (in acc. with EN 338:2016)

		Strength class (selected)				
		C14	C18	C24	C30	C50
Strength properties [MPa]						
Bending	f_{mk}	14	18	24	30	50
Tension parallel	$f_{t,0,k}$	8	11	14	18	30
Tension perpendicular	$f_{t,90,k}$	0.4	0.5	0.5	0.6	0.6
Compression parallel	$f_{c,0,k}$	16	18	21	23	29
Compression perpendicular	$f_{c,90,k}$	2.0	2.2	2.5	2.7	3.2
Shear	$f_{v,k}$	1.7	2.0	2.5	3.0	3.8
Stiffness properties [MPa]						
Mean modulus of elasticity parallel	$E_{0,\ mean}$	7000	9000	11000	12000	16000
5 percentile modulus of elasticity parallel	$E_{0.05}$	4700	6000	7400	8000	10700
Mean modulus of elasticity perpendicular	$E_{90,\ mean}$	230	300	370	400	530
Mean shear modulus	G_{mean}	440	560	690	750	1000
Density [kg/m^3]						
Characteristic	ρ_k	290	320	350	380	460
Mean	P_{mean}	350	380	420	460	550

It can be noticed that the number at the C letter in a given strength class corresponds to the bending strength of sawn timber. In practice, in order to qualify the sawn timber for a given C class using sorting machines, its modulus of elasticity and density should be determined. Other characteristic values can be calculated on the basis of mathematical relations and correlations between these parameters. Therefore, modulus of elasticity and density are the key parameters when sorting sawn timber using the machine method. Additionally, they can be determined non-destructively on a full-size sawn timber when using a grading machine. Scaling such a machine, i.e. its release for use, is carried out according to strictly defined procedures and involves examining a certain amount of sawn timber first on a tested machine and then checking the results on the strength testing machine. The results obtained from non-destructive testing are verified by results obtained in traditional, destructive manner of timber testing. After obtaining satisfactory consistency of results, it is assumed that the grading machine is calibrated and can be approved for use (under many additional conditions – see EN 14081-4:2009, in Poland PN-EN 14081-4:2009 Wooden structures – Strength graded structural timber with rectangular cross section – Part 4: Machine grading – Grading machine settings for machine controlled system).

In Polish sawmills, the method of visual grading is used almost exclusively. It wasn't until 2015 when a device for the machine strength grading of sawn timber was installed in the first Polish sawmill – in Tartak Janina i Wacław Witkowscy (Bekas 2016, Krzosek et. all 2015). Another sawmill – Tartak Abramczyk – purchased a machine for the sawn timber strength grading in 2018.

According to the research carried out so far, a large share of rejects is obtained during sorting sawn timber when using the visual method, and only a small amount of timber of high strength grade is obtained. With the applying of strength grading by machine method, much more sawn timber of high strength grades is obtained and far less rejects (Diebold 2009, Karlsson 2009). According to research conducted at Faculty of Wood Technology (WULS-SGGW), as a result of visual strength grading up to 52.9% of sawn timber in the tested batch was classified as reject, and only 4.4% to the highest strength grade KW. When sorting the same batch of sawn timber using the MTG device, only 17.5% of the tested batch was classified as a reject (Krzosek 2009). Further studies on pine sawn timber from selected natural forest regions of Poland are currently ongoing at the Faculty of Wood Technology, within the Biostrateg 3 research project,.

RESEARCH MATERIAL

The research material consisted of sawn Scots pine (Pinus *sylvestris* L.) timber from the Silesian Forestry Region in Poland. The sawn timber was cut of raw materials with age classes IV and V, obtained from the young, mixed forest within the Regional National Forest Directorate of Katowice (Olesno Forest Disctrict, Sternalice Forest Subdistrict, forest compartament 14d, geographic coordinates: 50.898629, 18.423915). The timber was dried in industrial conditions in a chamber drier, up to the humidity of ca. 12%, and planed. The nominal dimensions of timber after drying and planing were: 40 x 138 x 3500mm. There were 210 pieces of timber in the batch under research. The timber was prepared at a sawmill in Kalisz Pomorski.

RESEARCH AIM AND SCOPE

The aim of research was to verify what the differences are between results of visual (appearance) and machine strength grading. The scope of research included strength grading of sawn timber with both methods.

METHODS

Strength grading by visual method was carried out in accordance with PN-D-94021:2013 Structural sawn timber sorted by strength methods. As a result of the grading, the sawn timber was assigned to sorting classes KW, KS, KG or classified as reject. The results of strength grading are presented in table 2. Strength grading by the machine method was carried out with the use of MTG (Mobile Timber Grader) device from Brookhuis Electronics BV. The dynamic modulus of elasticity is measured by the vibration method which measures the natural frequency of vibration after a short impact. The MTG device has already been used in previous studies conducted at the Faculty of Wood Technology (Krzosek and Grześkiewicz 2008; Krzosek 2009). The results of strength grading with the use of the MTG device are presented in table 3.

RESULTS AND ANALYSIS

The results of strength grading results by visual and machine method are presented in table 2 and 3.

As a result of sawn timber grading (210 pieces) by the visual method, 41 pieces were assigned to the KW strength grade (19.5% of the whole batch), 24 pieces to KS grade (11.4% of the whole batch), 62 pieces to KG grade (29.5% of the whole batch), whereas 83 pieces (39.5%) were classified as rejects. With reference to the research conducted in previous years, timber originating from the Silesian Forestry Region was characterized by the highest mechanical properties in comparison to the other regions (table 2). Particularly noteworthy is the large share of sawn timber of KW strength class, many times higher than the average share from the previous studies and twice as high as for the best forest region analysed in the previous studies (10.6% for sawn timber from the Baltic Forestry Region). The percentage share of sawn timber in KS strength grade class in the described studies (11.4%) was also higher than the average from previous studies (7.2%). The percentage share of sawn timber in KG strength grade class (29.5%) was lower than the analogous average share obtained in previous studies (35.5%). Rejects in the analysed batch of timber from the Silesian Forestry Region were about 39.5%, its amount was significantly smaller than the average number of rejects found in the earlier studies (52.9%).

Table 2. Results of sawn timber strength grading by visual method in accordance with PN-D-94021:2013

Visual strength grade acc. to PN-D-94021:2013							
KW		KS		KG		Reject	
[no of pieces]	[%]	[no of pieces]	[%]	[no of pieces]	[%]	[no of pieces]	[%]
41	19.5	24	11.4	62	29.5	83	39.5

On the basis of the obtained results of visual strength grading, it can be noticed that pine sawn timber from the Silesian Forestry Region has the highest quality in comparison with the five others forest lands analysed in the previous studies at the Faculty of Wood Technology of Warsaw University of Life Sciences – SGGW (Krzosek 2009).

Table 3. Results of strength grading of sawn timber by machine method with the use of MTG device

Strength grade acc. to EN 338											
C40		C35		C30		C24		C18		Reject	
[no of pieces]	[%]	[no of pieces]	[%]	[no of pieces]	[%]	[no of pieces]	[%]	[no of pieces]	[%]	[no of pieces]	[%]
21	10.0	47	22.4	58	27.6	63	30.0	15	7.1	3	1.4

As a result of sawn timber grading by the machine method (MTG), 10% of the batch was in C40 strength class, 22.4% in C35 class, 27.6% in C30 class, 30% in C24 class, 7.1% in C18 class and only 1.4% rejects were noticed. It is worth noting that a large number of sawn timber – 32.4% in total – was assigned to classes that are unachievable at visual strength grading (i.e. C40 and C35). On the basis of the obtained results of machine strength grading, it can be noticed that pine sawn timber from the Silesian Forestry Region has the highest quality in comparison with the five other forest lands analysed in the previous studies at the Faculty of Wood Technology of Warsaw University of Life Sciences – SGGW (Krzosek 2009).

A shortcoming of the MTG device is the inability to grade sawn timber with knots occurring on its face side, in cases where an extremely large twist of fibres is present and when planks faces are not precisely cut. In such situations, according to authors' assumptions, a wave caused by an impact to the board forehead does not reach the other side because of the mentioned defects, neither is it reflected from it nor returns to the vibration detector. In such cases, the MTG device displays the message: ERROR. During the tests described, 3 of a total number of 210 sawn timber boards were not classified into strength grades (1.4% of the batch). Practice indicates that such boards should be described as rejects.

CONCLUSIONS

1. Scots pine sawn timber from the Silesian Forestry Region was characterized by the highest quality, determined both during visual and machine strength grading (KW strength grade 19.5%; C40 and C35 in total 32.4%).
2. The assumption that the machine strength grading results in low share of sawn timber considered as rejects has been confirmed.
3. There are sawn timber elements which were not assigned to any class or marked as rejects during the machine strength grading. Such timber should be classified as rejects based on its visual appearance.

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Streszczenie: *Porównanie wyników wizualnego i maszynowego sortowania wytrzymałościowego tarcicy sosnowej ze Śląskiej Krainy Przyrodniczo Leśnej.* Praca dotyczy analizy wyników sortowania wytrzymałościowego drewna sosny zwyczajnej dwoma metodami – wizualną oraz maszynową, przeprowadzonego dla surowca pozyskanego ze Śląskiej Krainy Przyrodniczo Leśnej. Sortowanie wytrzymałościowe metodą wizualną przeprowadzono zgodnie z PN-D-94021:2013, natomiast sortowanie metodą maszynową przy użyciu urządzenia MTG holenderskiej firmy Brookhuis Electronics BV. W wyniku przeprowadzonych badań potwierdzono prawidłowość, że przy sortowaniu maszynowym otrzymuje się bardzo małą liczbę sztuk tarcicy zaliczoną do odrzutów. Jednocześnie w trakcie badań zdarzyły się sztuki tarcicy, które przy sortowaniu maszynowym nie zostały zaliczone do żadnej klasy ani do odrzutów. Taką tarcicę na podstawie jej wyglądu należy zakwalifikować, jako odrzut.

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