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Comparison of results between visual and machine strength grading of Polish-grown pine timber (Pinus sylvestris L.) from the Baltic Forestry Region

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Abstract: *Comparison of results between visual and machine strength grading of Polish-grown pine timber (Pinus sylvestris L.) from the Baltic Forestry Region.* The paper presents the analysis of results of strength grading of Scots pine wood (*Pinus sylvestris* L.) with two different methods: visual and machine strength grading, conducted on raw material from the Baltic Forestry Region. Visual strength grading was carried out in accordance with PN-D-94021:2013, while machine strength grading was performed with the use of the MTG device by a Dutch company, Brookhuis Electronics BV. The machine assisted method of timber strength grading proved to be more efficient, resulting in a higher amount of timber in the C30 class (28.7%) than in the best (KW) class after visual strength grading (3.3%). On the basis of the conducted tests, it has been confirmed that machine strength grading results in very few (6.0%) rejected timber pieces. At the same time, there have been cases of timber pieces that hadn't been classified in any of the classes or rejected during machine strength grading. Such pieces were treated as rejected.

Keywords: strength grade, structural timber, mechanical properties, pine sawn timber

INTRODUCTION

Wood, as a natural, ecological and renewable material, is being widely used in construction applications. While in traditional civil engineering it used to be just an auxiliary material applied mostly in roof trusses and in interior finishing, now it's becoming a structural material as well. Contemporary wooden buildings make use of several construction techniques: classical timber frame houses of the "Canadian" type, assembled from the scratch on the construction site; as well as buildings made of prefabricated elements. A classical timber frame house consists in assembling timber walls directly at the construction site, on top of the previously prepared foundation, and then filling them with insulating materials. Prefabricated elements are manufactured in advance in production plants as modules of walls, ceilings, roof trusses or entire spatial modules (Beśka 2018). Ready elements are transported and assembled at the construction site. According to the level of complexity, we may speak of flat prefabs, resulting in ready walls and ceilings; as opposed to spatial prefabs, that may provide spatial modules that are completely finished and equipped, allowing for a very fast assembly after their delivery to the construction site, even in case of multi-storey buildings.

Flat prefabs can include timber frame walls, as well as walls made of solid wood in the form of panel elements making use of adhesives. At the moment, prefabs are being used in Poland to erect up to 4-storey buildings (Beśka 2018). Local authorities more and more often decide to build schools and kindergartens out of prefabricated wood. The best example can be found in the city of Gdańsk, where 6 such buildings were constructed between 2015÷2018 (Krzosek et al. 2018). The prefabricated elements technique is based on structural solid wood with glued finger joints or in the form of glued laminates (glulam). CLTs - Cross Laminated Timber boards - are gaining more and more popularity (Kotwica, Krzosek 2018). With the use of those modern materials, multi-storey buildings have been erected in the recent years all around the world, counting even 14, like in Norway (Abrahamsen, Malo 2014) or 18 storeys, such as a student's house in Canada (Fast 2016, Haden 2017) or Mjøstårnet in Norway (Abrahamsen 2017). Currently, the highest wooden building in the world is the 24-storey HoHo Tower in Vienna (Woschitz 2015, Palfy, Woschitz 2016).

In accordance with the current legal framework and taking into account safety considerations, the wood used in construction has to meet specific resistance parameters, which is verified through strength grading. Glulam and CLT materials are produced exclusively out of wood that has undergone the process of strength grading. There are two methods of strength grading: visual and machine-assisted. In Poland, visual strength grading is carried out in accordance with PN-D-94021:2013, while the devices used in machine strength grading have to fulfil the requirements specified in PN-EN 14081-4: 2009 Wooden structures – Strength graded structural timber with rectangular cross section – Part 4: Machine grading – Grading machine settings for a machine-controlled system.

Strength grading based on visual inspection consists in examining every piece of timber carefully and classifying it within appropriate strength class on the basis of the visible defects of wood structure, shape and processing. The following structural wood defects are taken into account: knots, twisted fibres, cracks, resin pockets, inbarks, wounds, rot and insect tunnels. The defects of shape and processing taken into account during visual strength grading are the following: wanes, bows, cups, springs, warping and other defects due to wrong processing, such as mechanical damage, non-parallel surfaces or exceeded dimensions tolerance. As a result of strength grading based on visual inspection, the timber is classified into different grades. Each EU member state has its own, national standard for visual strength grading of timber. Due to the differences in tradition, the standards differ as to their grading criteria (eg. the criterion of knot evaluation) and as to the number of strength classes. In Poland, strength grading based on visual inspection is carried out on the basis of the Polish standard PN-D-94021:2013, Tarcica iglasta konstrukcyjna sortowana metodami wytrzymałościowymi [Strenght graded coniferous structural timber]. Visual strength grading sorts timber into the best, KW class; medium, KS class; or a worse, KG class. Timber that does not fulfil the KG class requirements is not fit for use in construction and is called "rejected".

The visual method of strength grading is a slow and time-consuming process. The m^3 per hour capacity of this kind of grading is very low. Moreover, it always involves the risk of the human factor to some extent, which makes it subjective: the result of grading depends on the person who is doing it. If two graders sort the same batch of timber, the results will not be identical. A timber grader - aware of his responsibility and the possible consequences of a potential error - in ambiguous situations (the grey area) subconsciously tends to underestimate the class of the timber. This is why, in the middle of the previous century, the first machines for the strength grading of timber were created. Such machines have to meet several basic requirements, the most important being:

- strength grading of full size structural timber elements,
- non-destructive strength grading.

Due to that second requirement, strength grading machines measure specific wood properties that can be verified in a non-destructive way and that are linked to wood’s bending strength. The higher the correlation between the property tested by the machine and the bending strength, the more reliable will be the results of strength grading performed by that machine.

The use of strength grading machines provides objective results and, moreover, contemporary automatic devices are able to do the grading much faster than people. Automatic, computer-controlled, highly efficient machines (up to 200 m/min feeding speed in some cases) can be integrated in production lines of, for example, glued laminated timber (German: BSH – Brettschichtholz, English: glulam), glued finger joint structural timber

(German: KVH – Konstruktionsvollholz) or CLT boards (English: Cross Laminated Timber). In such automatic lines, grading machines are connected to transverse sawing machines (the next step in the production line) that cut out the fragments of planks containing unacceptable defects on the basis of the measurements provided by the grading machines.

The history of machine strength grading has almost 60 years now. The first industrial scale application of such devices was introduced in 1963 in the United States. In Europe, many different kinds of devices were developed and introduced at industrial scale, and have been described by various researchers, such as: Glos 1982, Denzler et al. 2005, Krzosek 2005 and 2009, Krzosek and Bacher 2011.

The most important advantage of strength grading machines for structural timber is the fact that the timber is classified directly into C classes in line with EN 338:2016 (in Poland PN-EN 338:2016 Structural timber. Strength classes). This standard introduced the following classes for coniferous structural wood: C14, C16, C18, C20, C22, C24, C27, C30, C35, C40, C45 and C50; and the following classes for deciduous wood: D30, D35, D40, D50, D60, D70. Poplar is treated as a coniferous species in this standard, so poplar is classified in C classes. At the same time, the standard defines the characteristic values for every class. Resistance (strength) properties, elasticity properties and wood density were taken into account. The standard specifies a series of physico-mechanical parameters for each class. If a plank is classified in a given C class, we assume that it meets the minimum values of strength, elasticity and density properties. If a designer of, for instance, a roof truss, knows the strength grade of timber, let's say: C24, then this class guarantees that the plank's properties are in line with the EN 338:2016 standard for this grade, that is: bending strength 24 MPa; and he can assume this strength for his calculations.

In practice, machine grading aimed at classifying a plank as belonging to a given C grade requires a measurement of its modulus of elasticity and density. The remaining characteristic values can be calculated on the basis of the known mathematical relations and the known correlations between those properties. It follows that the modulus of elasticity and density are the key parameters for the machine strength grading of timber. These properties, of course, can be tested by a strength grading machine in a non-destructive way, on full-size timber elements. The calibration of such a machine and its approval for use is carried out in accordance with strict procedures specified by the standards and consists in testing a given amount of timber on the machine that is being verified and then checking the results with the use of a destructive machine in the lab. The values of rigidity and resistance measured with non-destructive methods are later verified and confirmed by tests that destroy that timber. After achieving a satisfying conformity of results, the machine is considered calibrated and ready for use (under many additional conditions; refer to: EN 14081-4:2009, in Poland: PN-EN 14081-4:2009 Timber structures. Strength graded structural timber with rectangular cross section. Part 4: Machine grading. Grading machine settings for machine control systems).

Polish lumber mills use mostly the visual strength grading method. Only in 2016, the first Polish lumber mill (Tartak Janina i Wacław Witkowscy) installed a machine strength grading device (Bekas 2016, Krzosek et al. 2015). In 2018, Tartak Abramczyk lumber mill bought devices for machine strength grading. A machine strength grading device is also used by the biggest manufacturer of roof trusses in the Mitek system - Tartak Burkietowicz - and the ODNOVA company - a wooden house manufacturer.

As it can be concluded on the basis of the research conducted up to date, visual strength grading results in a high percentage of rejected pieces, and only a small share of timber classified in the highest grade. Machine strength grading allows to classify more timber in higher resistance classes, and the number of rejected pieces is much lower (Diebold 2009, Karlsson 2009). According to research conducted at WTD SGGW in Warsaw, visual strength grading results in rejecting 52.9% of a timber batch, while only 4.4% is qualified as the highest, KW class. When the same batch of timber was graded with an MTG device, only 17.5% of the batch was rejected (Krzosek 2009). Currently, the Institute of Wood Sciences and Furniture at the University of Life Sciences in Warsaw (SGGW) is carrying out the BIOSTRATEG 3 research project, which consists in testing pine timber from different forestry regions in Poland. In a study of timber from the Silesian Forestry Region (Krzosek et al. 2019) visual strength grading resulted in 19.5% of timber being classified as KW, while 39.5% was rejected. When the same batch was graded with a device, 60% was classified as C30 or better, and only 1.4% of the batch was rejected.

INVESTIGATED MATERIAL

The study was conducted on a batch of pine timber from the Baltic Forestry Region. The raw material was about 120 years old and originated from logs of trees that grew in a fresh, mixed forest under the Regional National Forest Directorate of Piła (Nadleśnictwo Kalisz Pomorski, Leśnictwo Cybowo (department 526k). Before its delivery for research to the Institute of Wood Sciences and Furniture at the Warsaw University of Life Sciences (SGGW), the timber was dried in an industrial chamber drier until its moisture content amounted to ca. 12%, and planed. The nominal dimensions of timber after drying and planing were: 40 x 138 x 3,000 mm. There were 150 pieces of timber in the batch under research. The timber was prepared in a lumber mill in Kalisz Pomorski.

AIM AND SCOPE OF RESEARCH

The aim of research consisted in verifying the conformity of visual and machine-assisted strength grading methods used to grade the same batch of pine timber. The scope of research included the strength grading of the timber batch with both methods.

RESEARCH METHODOLOGY

The visual strength grading was carried out on the basis of PN-D-94021:2013, Strength graded coniferous structural timber. As a result of the test, timber was classified as KW, KS, KG or rejected.

The machine strength grading was performed with the use of the MTG device by the Dutch company, Brookhuis Electronics BV. The device operates on the basis of measuring the frequency of timber's own vibrations caused by dynamically hitting the end of the tested piece of timber. The device had already been used in previous research conducted in the Wood Sciences Department (Krzosek, Grześkiewicz 2008, Krzosek 2009, Krzosek et al. 2019).

TEST RESULTS AND THEIR ANALYSIS

Table 1 presents the results of visual strength grading, and Table 2 contains the results of machine strength grading of the same batch of timber.

Table 1. Results of visual strength grading in accordance with PN-D-94021:2013

Grade according to PN-D-94021:2013							
KW		KS		KG		Reject	
[no. pcs]	[%]	[no. pcs]	[%]	[no. pcs]	[%]	[no. pcs]	[%]
5	3.3	12	8.0	57	38.0	76	50.7

As a result of visual strength grading of the timber batch (150 pieces), 5 pieces (3.3% of the entire batch) were classified as KW, 12 pieces (8.0%) as KS, 57 pieces (38.0%) as KG and 76 pieces (50.7%) were rejected. In reference to another study conducted in the previous years (Krzosek 2009). Table 1 shows that the properties of tested timber from the Baltic Region were comparable with the properties of timber from previously tested Regions. The share of

KW was similar to the average from previous studies (4.4%) and almost three times lower than timber from the same Region tested in previous studies (10.6%). The percentual share of the KS timber class in the research being described (8.0%) was slightly higher than the average share determined in previous tests (7.2%). The percentual share of timber in KG class was 38.0% and it was higher than the mean share of KG class timber obtained in previous research (35.5%). The number of rejected pieces amounted to 50.7% of the entire batch from the Baltic Forestry Region, so it was at a similar level to the average amount of rejected pieces, as determined by previous research (52.9%). On the basis of the obtained results it can be concluded that the pine timber under research, originating from the Baltic Forestry Region, had similar quality as the average quality of pine timber from five different Forestry Regions tested in previous years (Krzosek 2009). Comparing to timber from the Silesian Forestry Region (Krzosek et al. 2019) the quality of timber from the Baltic Forestry Region was significantly worse. The most common cause of downgrading or rejecting were knots and slope of grain.

Table 2. Results of machine strength grading with the MTG device.

Strength grade in line with EN 338:2016											
C40		C35		C30		C24		C18		Reject	
[pcs]	[%]	[pcs]	[%]	[pcs]	[%]	[pcs]	[%]	[pcs]	[%]	[pcs]	[%]
2	1.3	10	6.7	31	20.7	76	50.7	22	14.7	9	6.0

As a result of machine strength grading with the MTG device, 1.3% of timber was classified as grade C40, 6.7% as C35, 20.7% as C30, 50.7% as C24, 14.7% as C18, and 6% was rejected. The pieces whose machine strength grading was impossible were also classified as rejected. In case of 4 timber pieces, the device displayed the ERROR message, the modulus of elasticity and C grade could not be determined. Such situations occurring during timber tests with MTG had already been reported in previous studies (Krzosek et al. 2008). This happens when knots are located on timber ends, when boards are not cut evenly, or the fibres are extremely twisted. The authors suspect that in such situations the wave excited by hitting the board's end - due to the above-mentioned defects - does not reach the other end, so it cannot be reflected by it and come back to the vibration detector, which is why the device displays the ERROR message on its screen. What draws attention, is the small number of timber pieces in classes that are unattainable in visual grading (C40 and C35) comparing to the Silesian Forestry Region (Krzosek et al. 2019), 8% and 32.4%, respectively, of such timber from the Silesian Forestry Region. On the basis of strength grading results, it has been concluded that pine timber from the Baltic Forestry Region is of average quality comparing to the timber that was tested in previous years, originating from five different Forestry Regions in Poland. The quality of the tested timber from the Baltic Forestry Region was significantly lower than the quality of timber from the Silesian Forestry Region in Poland.

CONCLUSIONS

1. As a result of visual strength grading of pine timber from the Baltic Forestry Region, only 3.3% of the batch was classified as grade KW, and 50.7% was rejected.
2. As a result of machine strength grading of pine timber from the Baltic Forestry Region, 28.7% of the batch was classified as grade C30 or higher, and only 6% of the batch under research was rejected.
3. This confirms that machine strength grading results in very few rejected timber pieces.
4. Sometimes, there are timber pieces that are not classified in any of the classes or rejected during machine strength grading. Such timber should be treated as rejected, on the basis of its appearance.

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Streszczenie: *Porównanie wyników wizualnego i maszynowego sortowania wytrzymałościowego polskiej tarcicy sosnowej (Pinus sylvestris L.) pochodzącej z Bałtyckiej Krainy Przyrodniczo Leśnej.* W artykule zawarto analizę wyników sortowania wytrzymałościowego drewna sosny zwyczajnej (*Pinus sylvestris* L.) metodami – wizualną oraz maszynową, przeprowadzonego dla surowca pozyskanego z Bałtyckiej 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 efekcie sortowania wytrzymałościowego tarcicy metodą maszynową uzyskano wyraźnie większą wydajność tarcicy w klasie C30 i więcej (28,7%) niż tarcicy w klasie KW przy sortowaniu metodą wizualną (3,3%). W wyniku przeprowadzonych badań potwierdzono prawidłowość, że przy sortowaniu maszynowym otrzymuje się bardzo mało (6,0%) sztuk tarcicy zakwalifikowanej jako odrzut. Jednocześnie w trakcie badań zdarzyły się sztuki tarcicy, które przy sortowaniu maszynowym nie zostały zaliczone do żadnej klasy ani do odrzutów. Taką tarcicę potraktowano jako odrzut.

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