Folia Forestalia Polonica, series A, 2010, Vol. 52 (1), 13–19

ORIGINAL ARTICLE

Size and localisation of knots in timber from mountain spruce stands in the Dolomites

Anna Barszcz[1] ✉, *Anna Sandak*[2] , *Jakub Sandak*[2]

[1] Department of Forest and Wood Utilization, Agricultural University, Al. 29 Listopada 46, 31–425 Cracow, Poland, phone: +48 12 6625085, fax: +48 12 4124418, e-mail: rlbarszc@cyf-kr.edu.pl

[2] IVALSA/CNR Trees and Timber Institute, 38010 San Michele all Adige, via Biasi 75, Italy

Abstract

The aim of the study was evaluation of knots in wood of 150-year-old Norway spruce [*Picea abies* (L.) Karst.] in stands situated at the altitude of 1450–1740 m above sea level in the Dolomites in Italian section of the Alps. In selected stands, spruce trees were cut down and their length, stem thickness, height to the crown base and stem diameters at every 1 m along the length of merchantable bole were measured. The diameter of knots was measured and they were classified according to their healthiness and the degree of their tightness with the surrounding wood. The relative knot diameters were calculated and the relative height of their location on stem was determined.

In total on sample trees there were analysed 1070 knots, of which sound knots (close to 75%) and tight (more than 60%) prevailed. Sound and tight knots had largest diameters, relative diameters and relative heights of location on merchantable boles. The smallest diameters and relative diameters were indicated by rotten and not tight knots that were located at the lowest merchantable bole parts.

Key words

Picea abies, spruce timber, knot healthiness, degree of knot tightness, location on merchantable bole

Introduction

The Norway spruce [*Picea abies* (L.) Karst.] is one of important tree species which create forests in Poland and Europe, and its timber presents a range of qualities acknowledged in the construction sector and chemical industry. Timber defects can considerably decrease spruce timber, and these are in particular knots. Negative effects of knots depend on their number, size, healthiness and a degree of their tightness with stem wood. These features are included in the classification system of roundwood.

Researchers have recently undertaken studies on models of spruce timber knottiness both outside and inside merchantable boles as well relations between tree or roundwood features and quality of sawn timber (Gjerdrum and Høibø 2008; Kantola *et al.* 2007; Moberg 2006). Attention-grabbing research which has been carried out in the areas of spruce range in Europe concerns relations between knot location on merchantable boles and their size including knot healthiness and the degree of their tightness with the surrounding wood (Barszcz 1995, 1999; Barszcz and Gjerdrum 2008).

Received 31 March 2010 / Accepted 15 June 2010

The aim of this study was the analysis of selected characteristics of knots in wood of mature Norway spruces growing in upper montane in the Dolomites. There were evaluated knot dimensions, healthiness and the degree of knot tightness with the surrounding wood as well as relations between knot dimensions and their location on spruce merchantable boles.

The research was granted by COST Action E53 and carried out during a short-term scientific visit in Italy (IVALSA).

Materials and methods

The study was carried out in northern Italy, in the province Trento in the Dolomites. After consultations with IVALSA (Trees and Timber Institute) specialists in San Michele all Adige and local foresters, three experimental stands were selected. The stands were of natural provenience at the age of about 150 years. The stands were treated as sample areas which represented nature-forest conditions for growing of local spruce in upper montane. Below there is presented characteristics of experimental areas:

Sample area 1. Forest situated at 1450 m above sea level; site fertility 5 (in a 9-degree scale where 1 = most fertile sites), tree cover 0.7; volume 285 m^3/ha; western slope.

Sample area 2. Forest situated at 1740 m above sea level; site fertility 5; tree cover 0.7; volume 479 m^3/ha; north-western slope.

Sample area 3. Forest situated at 1450 m above sea level; site fertility 6; tree cover 0.7; volume 357 m^3/ha; north-western slope.

The methods used at selection of sample trees were the same as previously described for studies conducted in Poland and Norway (Barszcz 1995, Barszcz and Gjerdrum 2008). In each of selected stands there were chosen 3 sample Norway spruces with DBH more than 40 cm. After delimbing, each tree was measured for: total tree length, length of merchantable bole of the diameter not smaller than 7 cm over bark (PN–93/D–02002... 1993) timber diameters at each 1 m of the merchantable bole length and the height of the crown base. Subsequently, at the stem half point, the diameters of knots (≥ 1 cm) were measured as well as their distances from the base stem (PN-EN 1310... 2000). Knots were classified according to their healthiness (sound, unsound and rotten) and according to the degree of their tightness with the surrounding wood (tight, partially intergrown and not tight knots) (PN–79/D–01011... 1980). The volume of merchantable boles as well as the relative height of the crown bases was assessed. Characteristics of sample trees are presented in Table 1.

For each knot recorded at the point of its occurrence the timber diameter was determined by means of

Tab. 1. Characteristics of studied trees

No. of sample area	No. of tree	Total length (m)	Length of merchantable log (m)	$D_{1.3}$* (cm)	Vgr* (m^3)	Wk* (m)	Wwk*
1	1	25.0	23.0	40	1.22	10.5	0.456
	2	30.9	28.4	43	1.39	12.6	0.444
	3	33.5	30.8	51	2.48	14.0	0.454
2	1	36.0	33.6	67	4.39	6.9	0.205
	2	23.3	21.0	40	1.20	5.4	0.257
	3	31.4	28.6	51	2.45	6.6	0.231
3	1	33.5	30.7	52	3.67	10.7	0.348
	2	26.0	23.8	43	1.80	8.7	0.365
	3	35.5	32.0	60	3.82	11.0	0.344
Average		30.6	28.0	49.5	2.49	9.6	0.340

* $D_{1.3}$ – DBH; Vgr – roundwood volume; Wk – height of crown base; Wwk – relative height of crown base

interpolation. Next, the knot relative diameter was calculated in relation to the timber diameter. The locality of knots was determined by the relation of the distance of knot from the lower stem end to the length of merchantable bole. Next step concerned description of the statistical characteristics of the features of particular knot categories. Because of lack of the accordance of the features with the normal distribution (Shapiro-Wilk test, W from 0.781 to 0.971, $p < 0.05$) as well as lack of homogenous variants (Levene test, F from 10.888 to 67.443, $p < 0.05$), further statistical analyses were carried out with the non-parametric Kruskal-Walis test and the multiple comparison test (α=0.05). The significance of differences between the knots from different healthiness categories as well as the degree of knot tightness with the surrounding wood were statistically tested by comparisons of knot diameters, their relative diameter and the height of their location on sample tree stems. Then the effect of the relative height of location on the diameter and the relative diameter was determined. Based on correlation coefficient R and the coefficient of determination R^2 ($\alpha = 0.05$) the best matching dependency models were determined.

Results

The results of analyses of knot groups in combined categories of healthiness and degrees of tightness with the surrounding wood (Fig. 1) indicated that in the whole tested material there prevailed sound-tight knots (almost 60%). Considerably less frequent were rotten-not tight and sound-not tight knots (more than a dozen %). The rest of observed knots constituted less than 10% and the shares of knots: tight-unsound and rotten as well as rotten-partially intergrown was never higher than 1%.

In total 1070 of knots were measured (Tab. 2). It was observed that the largest diameters, relative diameters and the relative height of location on merchantable boles were characteristic for sound knots and tight knots which in this study were found most often time. The lowest values of evaluated parameters were observed for rotten knots and not tight knots. The knots from intermediate categories i.e. unsound and partially intergrown were found least frequently. Except for intergrown, in all knot categories the absolute diameters were characteristic of lesser variability than the relative diameters. Immense variability (more than 50%) was indicated by the relative height of location of rotten as well as not tight knots. The Kruskal-Wallis test showed that knot categories were significantly different in terms of the analysed parameters (H from 167.741 to 569.344, $p = 0.000$). The multiple comparison test (Tab. 3) showed that in most cases the knot categories (3 categories of healthiness and 3 categories of the degree of their tightness) were significantly different in terms of their size and location on merchantable bole. Not significant differences were observed only between the diameters of tight and intergrown knots as well as the relative heights of location of unsound and rotten knots. Based on the results obtained on knot categories further analyses were carried out.

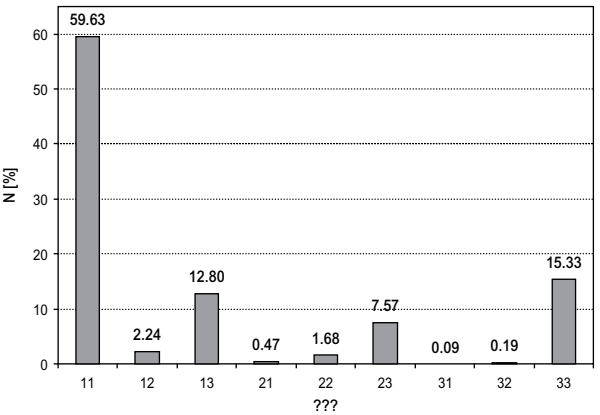

Fig. 1 Share of knots (%) in categories: 11 – sound and tight; 12 – sound and partially intergrown; 13 – sound and not tight; 21 – unsound and tight; 22 – unsound and partially intergrown; 23 –unsound and not tight; 31 – rotten and tight; 32 – rotten and partially intergrown; 33 – rotten and not tight

At the next stage of this study the relations between the relative height of location and the diameters and relative diameters of knots were tested. In Table 4 there are presented only significant relations, with correlation coefficients close to the value of 0.50 or higher. Observed dependencies can be best described by the linear model $y = ax + b$. The exponential as well as power law models were excluded as weaker matching. It was shown that the relative height of knot location influences significantly the relative diameters of knots of all observed categories except for the group of partially intergrown knots. Most evident was the relation between the relative height of knot location

Tab. 2. Statistical characteristics of studied knots

Knot category	Feature, unit	$\bar{x}$	x_{min}	x_{max}	δ	V_{zm} (%)	Number of knots	Share (%)
Sound	sS (cm)*	2.25	1.0	4.8	0.79	34.99	799	74.67
	SSW**	0.089	0.01	0.286	0.034	38.23		
	WS/L7***	0.66	0.06	1.00	0.23	34.55		
Unsound	SS (cm)	1.65	1.0	3.8	6.09	36.80	104	9.72
	SSW	0.049	0.018	0.136	0.022	44.21		
	WS/L7	0.46	0.05	0.90	0.21	46.50		
Rotten	SS (cm)	1.24	1.0	2.3	0.31	24.79	167	15.61
	SSW	0.036	0.016	0.100	0.01	41.54		
	WS/L7	0.39	0.07	0.93	0.21	52.79		
Tight	SS (cm)	2.28	1.0	4.8	0.82	35.83	644	60.19
	SSW	0.097	0.010	0.286	0.031	32.52		
	WS/L7	0.72	0.06	1.00	0.19	26.27		
Partially intergrown	SS (cm)	2.13	1.0	4.3	0.77	36.23	44	4.11
	SSW	0.070	0.030	0.179	0.028	39.71		
	WS/L7	0.54	0.19	0.90	0.20	37.92		
Not tight	SS (cm)	1.61	1.0	4.0	0.62	38.45	382	35.70
	SSW	0.044	0.016	0.118	0.019	43.62		
	WS/L7	0.40	0.05	0.93	0.20	50.52		
Total	SS (cm)	2.03	1.0	4.8	0.81	39.92	1070	100.00
	SSW	0.077	0.010	0.286	0.037	48.53		
	WS/L7	0.60	0.05	1.00	0.25	41.28		

* SS – knot diameters
** SSW – relative knot diameters
*** WS/L7 – relative height of location
δ – standard deviation
V_{zm} – coefficient of variation

and the relative diameters of all investigated population of knots.

Discussion

Studied Norway spruces were characteristic of DBH considerably higher than the average when compared with the trees observed during similar research carried out in Poland within the area of the Beskidy Mountains (DBH 37.9 cm) and south–eastern Norway (DBH 42.7 cm) (Barszcz 1995, Barszcz and Gjerdrum 2008). Tested spruces' total length and the length of merchantable bole was greater than in the case of spruces from Norway (26.8 m and 24.5 m, respectively), but similar to the lengths observed in spruces in Poland (29.2 m and 26.5 m). The spruce trees growing in the Dolomites were characteristic of the low height of the crown base. Similar absolute and relative heights of the crown base were noted for spruces in Norway (8.8 m and 0.35 m, respectively). Observed in Norway small heights of the crown base and conse-

Tab. 3. P – values for multiple comparisons with the Kruskal–Wallis one-way analysis of variance

Knot category	Sound	Unsound	Rotten	Knot category	Tight	Partially intergrown	Not tight
		SS*				SS*	
Sound		+	+	Tight		–	+
Unsound	0.0000		+	Partially intergrown	0.8035		+
Rotten	0.0000	0.0000		Not tight	0.0000	0.0001	
		SSW**				SSW**	
Sound		+	+	Tight		+	+
Unsound	0.0000		+	Partially intergrown	0.0000		+
Rotten	0.0000	0.0012		Not tight	0.0000	0.0000	
		WS/L7***				WS/L7***	
Sound		+	+	Tight		+	+
Unsound	0.0000		–	Partially intergrown	0.0000		+
Rotten	0.0000	0.1725		Not tight	0.0000	0.0033	

* SS – knot diameters
** SSW – relative knot diameters
*** WS/L7 – relative height of location
\+ significant
– not significant

Tab. 4. Relations between the relative height of location along merchantable log (WS/L7) and knot diameters (SS) as well as knot relative diameters (SSW)

Independent variable	Dependent variable	R	R^2 [%]	p	b	a
WS/L7	Tight knots SS	–0.5369	28.82	0.0000	3.9410	–2.3147
	Partially intergrown knots SS	–0.4639	21.52	0.0015	3.0733	–1.7563
WS/L7	Sound knots SSW	0.6195	38.38	0.0000	0.0028	0.0093
	Unsound knots SSW	0.5074	25.75	0.0000	0.0026	0.0052
	Rotten knots SSW	0.6871	47.21	0.0000	0.0016	0.0049
	Tight knots SSW	0.4972	24.72	0.0000	0.0037	0.0083
	Not tight knots SSW	0.4799	23.03	0.0000	0.0026	0.0046
	Total of knots SSW	0.6922	47.91	0.0000	0.0014	0.0105

quently larger taper are mainly connected with spruce geographical position (high latitude) (Modrzyński 1998), and in the present study – with the high altitude above sea level

The results of analyses on Italian spruce knots, grouped according to their healthiness and the degree of their tightness showed similar patterns in the case of knots sound and tight when compared with the re-

sults on spruces from Norway (Barszcz and Gjerdrum 2008). Spruces from the Beskidy Mountains (Poland) (Barszcz 1995) were characteristic of lesser shares of these knot categories. In the case of spruce from Poland the share of sound knots was only 65.5% and that of tight knots was 54.3%. These results are connected first of all with the small length of crown in Beskidy spruces, and knots of the above categories occur mainly in tree crowns.

Based on the results of analysis of the size of knots it was concluded that the knots in spruces in Italy indicated bigger mean diameter values when compared with the data from Poland and Norway. Only in the case of the present study the unsound and rotten knots had smaller absolute diameters. The average relative knot diameter of the total number of analysed knots was same in the material from Italy and Norway, and at the same time considerably smaller than that of spruces from Poland. Even though considerable sample variability was observed, the average relative height of location of knots (total) was almost identical for spruces from Italy and Poland. Spruces from Norway showed slightly smaller values of this feature.

The comparison of the results of this study with those obtained in Poland and Norway indicates the significance of relations between the relative height of knot location and the relative knot diameter. In the material from the three cited countries statistically significant relations were found for the relative height of location of knots and the diameter of tight knots, and what is more, in the spruces from Poland as well Norway this relation was also indicated with the diameter of sound knots. The significant relation was proven for the relative diameter of knots and the height of their location for all knot categories investigated in spruces from Poland and for 3 categories (sound, rotten not tight) in spruces from Norway.

The results of Gjerdrum and Høibø (2008) on the models of knottiness of sawn timber obtained also from 150-year-old spruces from the Italian section of Alps showed a great share of sound knots (56%) which at the same time indicated the biggest diameters. The share of rotten knots was about 37% and their diameters were about 1/3 of the value obtained for sound knots. In this study it was shown that the share of sound knots was by 20% higher than reported from Norway and Poland. At the same time, there was observed 50% lesser share of rotten knots with the diameter of about ½ of the diameter of sound knots.

Conclusions

- In spruce timber from mature alpine stands in the Dolomites there prevailed sound knots and tight knots with the biggest diameters, relative diameters and relative heights of location along merchantable boles. The big share of not tight knots with the very small mean relative diameter was also noted on lower parts of merchantable boles.
- Statistical tests confirmed determined division of knots into the groups according to the criteria of their healthiness and tightness. All knot categories significantly differed with regard to the absolute diameter, the relative diameter and the relative height of location, except for two cases: the height of location compared between unsound and rotten knots and the diameter between tight and partially intergrown knots.
- The significant effect of the relative height of location of knots from different categories along merchantable boles on the size of knots was shown. This relation was confirmed more often for the relative diameter (5 times) when compared with calculations based on the absolute diameter of knots as the dependent variable.
- The Norway spruce is susceptible to effects of external conditions and creates many geographical forms and races. Similarities between relative values of knot parameters were shown – this can indicate the regularity which is independent of provenance of the material collected for research.

References

Barszcz A. 1995. Ocena jakości surowca drzewnego i zmienności wad drewna w rębnych drzewostanach świerkowych na terenie Beskidów. Zesz. Nauk. AR Kraków, 199 pp.

Barszcz A. 1999. The variability of features and sizes of knots and their relation to location on stems in spruce timber from thinned stands. Sci. Pap. Agric. Univ. Poznań, Forestry 2, 3–12.

Barszcz A., Gjerdrum P. 2008. The zonality of occurrence of knots and relations between their location and size in large-dimensioned spruce stems in south-eastern Norway. EJPAU. 11 (3), 305.

Gjerdrum P., Høibø O. 2008. Modelling knot size and distribution in sawn boards from large sized trees of Norway spruce. [In:] Modelling connection between forest resources and wood quality. IUFRO WP 5.01.04, Koli, Finland, 08–14.06.2008, 37.

Kantola A., Mäkinen H., Mäkelä A. 2007. Stem form and branchiness of *Norway spruce* as a sawn timber – predicted by a process based model. For. Ecol Manag., 241, 209–222.

Moberg L. 2006. Predicting knot properties of *Picea abies* and *Pinus sylvestris* from generic tree descriptors. Scand. J. For. Res., 21, 49–62.

Modrzyński J. 1998. Ekologia. [In:] Ekologia świerka pospolitego (eds: A. Boratyński, W. Bugała). Wyd. Nauk. Poznań, 303–426.

PN–79/D–01011.1980. Drewno okrągłe. Wady. Wyd. Normalizacyjne, Warsaw, Poland.

PN–93/D–02002.1993. Surowiec drzewny. Podział, terminologia i symbole. Wyd. Normalizacyjne, Warsaw, Poland.

PN-EN 1310. 2000. Drewno okrągłe i tarcica. Metody pomiaru cech. PKN, Warsaw, Poland.