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Folia Forestalia Polonica, Series A – Forestry, 2018, Vol. 60 (4), 241–247

ORIGINAL ARTICLE

DOI: 10.2478/ffp-2018-0025

Influence of machining technologies and quality of logs on material losses of typical supply of Scots pine wood (*Pinus sylvestris* L.) destined for layered floorboards

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Abstract

Pine wood is commonly used in the production of floorings and is mainly used for solid wood planks and as a base in multi-layer flooring material. From an economic and ecological point of view, flaws such as flattening or heartwood ratio are very important when buying material for production. 40 logs of Scots pine (*Pinus sylvestris* L.) have been selected from wood deposit, from typical wood delivery. The ratios of sapwood and heartwood have been quantified, as well as eccentricity and flattening, in order to determine the suitability of the selected material for processing into floorings. There are two existing methods of log processing: sawing and peripheral cutting. Sawing is the most common one and widely used, although peripheral cutting could be more effective, especially for production of base in multi-layer floorings. The total loss volume for the two methods of manipulation and processing have been calculated. First one is sawing in accordance to schematics used in the sawmill of one of the largest producers of multi-layer floorings in Europe. Second one is peripheral cutting with three diameters of peeler roll. Total loss volume for sawing was 55.8 ± 10.5% and for peripheral cutting with peeler roll with biggest chosen diameter of 100 mm was 45.6 ± 9.5%. Therefore, in presented case, peripheral cutting is more efficient than sawing.

Key words

eccentricity, flattening, taper coefficient, heartwood fraction, multi-layer floorings, *Scots pine* L., loss on sawing, loss on peripheral cutting

Introduction

Scots pine (*Pinus sylvestris* L.) is the most common tree in the Polish forests. The participation of both pine and larch in the Polish forests is assessed on 75.5%. It is mostly III and IV age class (41–80 years old, accordingly 21.5% and 19.7%) and V class (above 81 years old, 25.9%). Pine covers 58.2% of the forest area. Growing stock of standing wood is assessed on 1550 mln m^3 (58.2%) (GUS 2017).

Scots pine wood (the trade name according to EN 13556:2003) is also a popular species used for the production of wooden floorings (Kozakiewicz te al. 2012). Pine wood, due to its lower density comparing to hardwoods (Galewski and Korzeniowski 1958; Wagenfür 2007), is destined for usage in multi-layer floorings.

Received 23 November 2017 / Accepted 15 November 2018

Multi-layer wooden flooring planks are composites made of two main parts. First, top part, is a layer of high quality solid heartwood (e.g., European oak wood). Second part, the base, is made from at least one layer of cheaper wood, usually the cheapest available softwood (e.g., Scots pine wood), most common one, that meets producer's standards. The base is usually made from two layers of slats oriented perpendicular to each other. The layer placed directly under the top layer is perpendicular to it (EN 13489:2002). The solutions with only one layer of slats in their base are being used, as well as the base made from plywood. General direction of changes in the manufacturing of multi-layer floorings is towards the reduction of layers in the base of multi-layer wooden floorings. The efficiency of production of this kind of floorings is determined by used technology of wood processing – the production of each layer in chip technology (sawing) or chip-less technology (cutting). Selection of one of these methods generates demand for wood supply of specific characteristics. Availability of the chosen kind of wood is determined by demand from other kinds of industry (Kozakiewicz et al. 2011; Mantau 2012). Despite this, the production of floorings in Europe is systematically increasing (FEP 2016).

Among the available literature, there are articles either about sawing timber (e.g., Steele 1984 or Bennet 2014) or cutting timber (Porankiewicz et al. 2007), not both methods at the same time.

The goal of this research has been to analyse the selected dimensional characteristics of Scots pine, of typical wood supply, such as sap and heart wood ratio, eccentricity and flattening. Based on those parameters, the valuation of suitability for processing into floorings has been made.

Material and methods

40 logs of Scots pine (*Pinus sylvestris* L.) have been selected from wood deposit of one of the biggest Polish floorings producers. All the logs came from the deliveries to the deposit made on the date of measuring. Maximal and minimal log diameters chosen for selection have been assessed on the basis of logs diameters most commonly used in and best suited for producer's sawmill. Therefore, the maximal diameter (D_{max}) of chosen logs was 353 mm; the minimal dimeter (D_{min}) was 206 mm and the average diameter (D_{av}) was 279 mm. Measurement of each log have been performed at its top end. Four half-axes were measured on each log, perpendicular to each other. First half-axe was the longest one; others were measured in a clock-wise order. Additionally, the radius of sap and heartwood combined and the radius of heartwood only have been measured in all four directions (Fig.1).

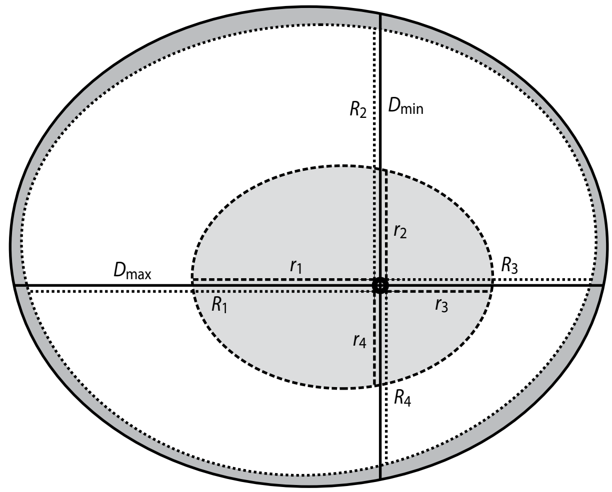

Figure 1. Method of measuring of log top end: D_{max} – the bigger centric diameter with bark, D_{min} – perpendicular (smaller) centric diameter with bark, R_n – outer radius of sapwood in *n*-direction, r_n – radius of heartwood in *n*-direction

On the basis of measurement, the following parameters have been calculated: heartwood fraction, flattening, eccentricity of log core and taper coefficient. Heartwood volume fraction is a ratio of heartwood area to the whole cross-section area without bark.

Flattening described as a subtraction between maximal and minimal diameter of cross-section (Method I – F), and as a ratio of that subtraction to maximal diameter (Method II – f) – according to PN-D-01011:1979 (EN 844-5:1997 and EN 844-8:1997):

$$F = D_{>} - D_{<} \tag{1}$$

$$f = \frac{D_{>} - D_{<}}{D_{>}} \cdot 100\% \tag{2}$$

where:
F – flattening in millimetres,
f – dimensionless relative flattening ratio,

$D_{>} = R_1 + R_3$ – the biggest centric diameter in millimetres (without bark),
$D_{<} = R_2 + R_4$ – perpendicular (smaller) centric diameter in millimetres (without bark).

Flattening is an essential parameter of peripheral cutting with significant influence on loss. In the case of sawing flattening, which does not force the change in cutting scheme, basically does not have to be considered.

Absolute eccentricity of log core is the displacement of core compared to the theoretical centre of the largest circle described on the log without bark. The relative eccentricity refers to the radius and given as percentage. Both parameters have been calculated according to the following formulas:

$$E = \frac{R_1 - R_3}{2} \tag{3}$$

$$e = \frac{R_1 - R_3}{R_1 + R_3} \cdot 100\% \tag{4}$$

where:
E – absolute eccentricity in millimetres,
e – relative eccentricity ratio,
R_1 – the bigger radius of wooden log (without bark),
R_3 – the smallest radius (see Fig. 1).

Eccentricity is one of the measures of material quality, which influences, for example, texture of veneers when cut peripherally. Considering the significance of this feature, it will be given as material characteristic without direct influence on the material loss calculations.

The taper coefficient is defined as follows:

$$t = \frac{D_b - D_t}{H} \tag{5}$$

where:
t – taper coefficient in centimetre per meter,
D_b – butt end diameter of log,
D_t – top end log diameter,
H – length of log.

The length of the actual logs was 3 metres and the taper coefficient were assumed to be 1.3 cm per 1 m.

According to the measurements and manipulation procedures and cutting/sawing schematics, the efficiency of wood processing have been calculated. Efficiency of peripheral cutting and sawing is a ratio of wood that is gained during manipulation and can be used for production. The ratio of wood that cannot be used (kerf and edgings) is the total loss volume.

Sawing procedure showed in schematics (Fig. 2A) is the current method of wood manipulation. This

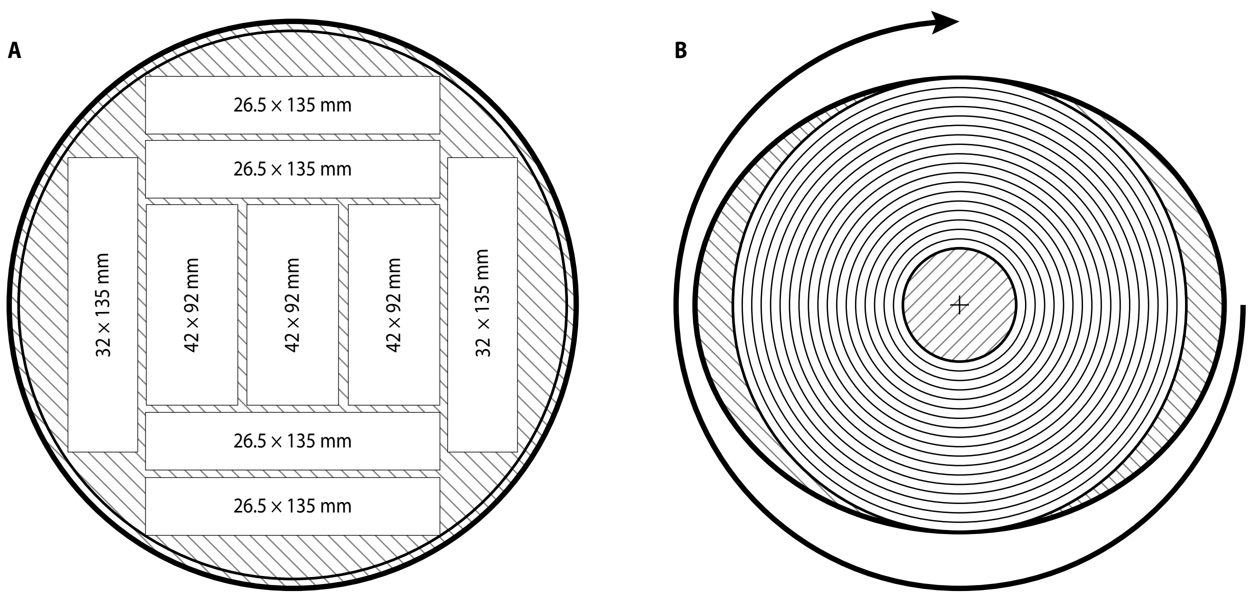

Figure 2. Schematics of log sawing – A and peripheral cutting – B

schematics is destined for logs of average diameter of 24 cm in the top end. The peripheral cutting schematics shown in Figure 2b is the new method of wood processing.

Sawing efficiency is the ratio of boards' volume gained in processing, according to Schematic 2a, compared to the log volume. The outcome is the total loss of wood (edgings and kerf). Peripheral cutting efficiency is the volume of veneer gained in processing, according to Schematic 2b. The outcome is the total loss of wood (edgings and peeler roll).

Therefore, relative loss is always calculated according to the formula:

$$loss = \frac{V_l - V_p}{V_l} \cdot 100\% \tag{6}$$

where:
loss – loss of material (percentage),
V_l – log volume (without bark),
V_p – product volume (boards or veneer).

Treating log as a truncated cone, its volume can be given as the diameter of its top end, the length and taper coefficient:

$$V_l = \frac{\pi}{4}\left[D_t^2 + t\,H\,D_t + \frac{1}{3}(t\,H)^2\right]H \tag{7}$$

For calculations, the log have been treated as flattened roller with elliptic bases, its volume is calculated according to the formula (see the signs as (1) and (2)):

$$V_l = \frac{\pi}{4} D_> D_< H \tag{8}$$

The cutting efficiency was measured for the three diameters of peeler roll (counted as loss) 60, 80 and 100 mm. Thickness of veneer was 3 mm (lesser thickness of veneers than cut lamellas is due to the qualitative requirements of production process – tested thicker veneers of 6–7 mm were of worse quality). Longitude of veneer was calculated according to the formula:

$$L = \frac{\pi(D+d)(D-d-2h)}{4h} = \\ = \frac{\pi(D^2-d^2)}{4h} - \frac{1}{2}\pi(D+d) \tag{9}$$

where:
L – length of veneer,
D – diameter of peeler log (equal $D_<$ of thinner end D_t),
d – diameter of peeler roll,
h – veneer thickness.

According to the formula (9), the additional loss of veneer strip longitude can be observed. This loss is even to half of the sum of internal and external girth $\pi(D + d)/2$, and it stems from the assumption that with a steady blade feed, the thickness of veneer in the first turn of peeler log will change from 0 mm to h, and in the last turn from h to 0 mm. Therefore, the volume of total loss will be higher in this model.

The total loss volume in sawing is the ratio of sum of volume of material lost as kerf and edgings (with taper coefficient) in the whole log volume. The total loss volume in peripheral cutting is the ratio of sum of volume of material lost in edgings (with taper coefficient) and peeler roll in the whole log volume. Assessed diameter of peeler log was the smallest diameter of log.

Therefore, the total loss of sawing is composed of:

$$loss_S = loss_E + loss_K = \\ = loss_T + loss_{E1} + loss_{K0} + loss_{K1} \tag{10}$$

where:
$loss_S$ – total loss in sawing,
$loss_E$ – total loss on endings,
$loss_K$ – total loss on kerf.
$loss_T = loss_{E0}$ – loss on log tapering (part of total loss on endings),
$loss_{E1}$ – additional loss on endings (independent of log tapering),
$loss_{K0}$ – loss on timber kerf (with a thickness 3.2 mm),
$loss_{K1}$ – loss on lamellas kerf (thickness of lamella assumed – 6 mm, kerf 1.2 mm).

Similarly, the total loss of peripheral cutting is composed of:

$$loss_C = loss_T + loss_F + loss_R \tag{11}$$

where:
$loss_C$ – total loss in peripheral cutting,

$loss_T$ – loss on tapering,
$loss_F$ – loss on flattening,
$loss_R$ – loss on peeler roll (and ends veneer).

According to (6), (7), (10) and (11), the formula for loss volume stemming from the taper coefficient can be derived:

$$loss_T = \left[\frac{t\,H}{D_t} - \frac{2}{3}\left(\frac{t\,H}{D_t}\right)^2 + \ldots \right] \cdot 100\% \qquad (12)$$

For formula shortening, the Taylor series has been used for taper coefficient t.

Loss on flattening can be derived into simple formula according to (2), (6), (8) and (11):

$$loss_F = f \cdot 100\% \qquad (13)$$

while consideration of formula (9) in accordance to (6) and (11) leads to the formula:

$$loss_R = \left(\frac{d}{D}\right)^2 \cdot 100\% + \left(1 + \frac{d}{D}\right)\frac{2h}{D} \cdot 100\% = \\ = loss_{R0} + loss_{R1} \qquad (14)$$

Where the loss stemming from wedged beginning and ending of veneer ribbon is included (as mentioned earlier).

Results and discussion

Summary of the results have been shown in Table 1.

Table 1. Characteristics of logs (H = 3 m) of its top end

The trade name of wood according to EN 13556	Scots pine
Number of logs (pcs)	40
Investigated property of logs: average value ± sample standard deviation	
Bigger diameter $D_>$ [mm]	254 ± 29
Smaller diameter $D_<$ [mm]	236 ± 27
Heartwood volume fraction $(r/R)^2$ [%]	22.1 ± 5.6
Eccentricity E [mm], e [%]	16.8 ± 7.6, 13.1 ± 5.5
Flattening F [mm], f [%]	18.4 ± 10.7, 7.3 ± 4.0
Taper coefficient t [cm/m]	1.35 ± 0.77
Average log volume [m^3]	0.18 ± 0.04

Note that the total loss on endings is $loss_E = loss_T + loss_{E1}$ = (27.1 ± 9.5)%, and total loss on kerf in lamellas sawing is $loss_K = loss_{K0} + loss_{K1}$ = (28.7 ± 9.5)%. Sawing lamellas is the next step of technological process after timber sawing. During this process, the materials of the same thickness is made as in peripheral cutting process (6 mm).

Table 3. Average veneer length gained in peripheral cutting technology according to peeler roll diameter

	Per. cutting		
	60	80	100
Average veneer length ± sample standard deviation L [m]	6.6 ± 1.7	6.2 ± 1.7	5.7 ± 1.7

Table 2. Average material loss in different processing methods (Values 60, 80, 100 in per. cutting are the diameters of peeler rolls in mm.)

Technology of processing	Kind of loss (average value ± sample standard deviation) [%]							
	taper $loss_T$	endings $loss_{E1}$	flattening $loss_F$	kerf		roll		total
				$loss_{K0}$	$loss_{K1}$	$loss_{R0}$	$loss_{R1}$	loss
Sawing timber	14.7 ± 7.5	12.4 ± 5.8	x	14.2 ± 2.0	x	x	x	41.3 ± 9.7
Sawing lamellas		12.4 ± 5.8	x	14.2 ± 2.0	14.5±4.0	x	x	55.8 ± 10.5
Per. cut. 60		x	7.3 ± 4.0	x	x	6.0 ± 1.4	6.1 ± 1.4	34.1 ± 8.7
Per. cut. 80		x		x	x	10.7 ± 2.4	6.5 ± 1.7	39.2 ± 9.0
Per. cut. 100		x		x	x	16.7 ± 3.8	6.9 ± 1.9	45.6 ± 9.5

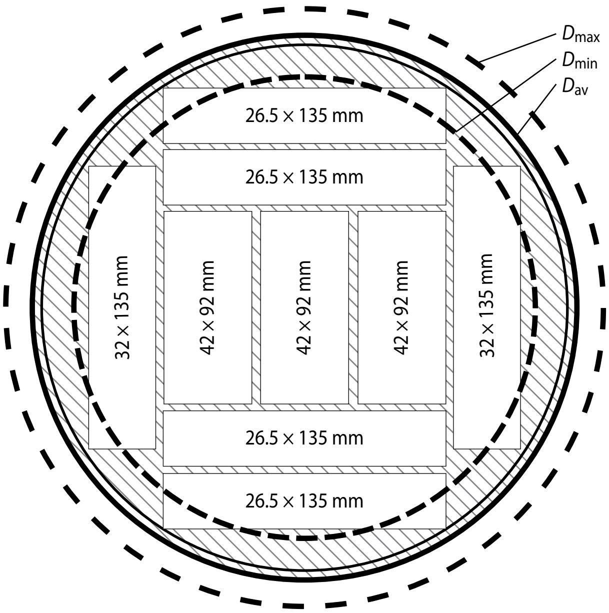

Figure 3. Schematics of log sawing. The maximal and minimal diameter of its top end of logs have been shown.

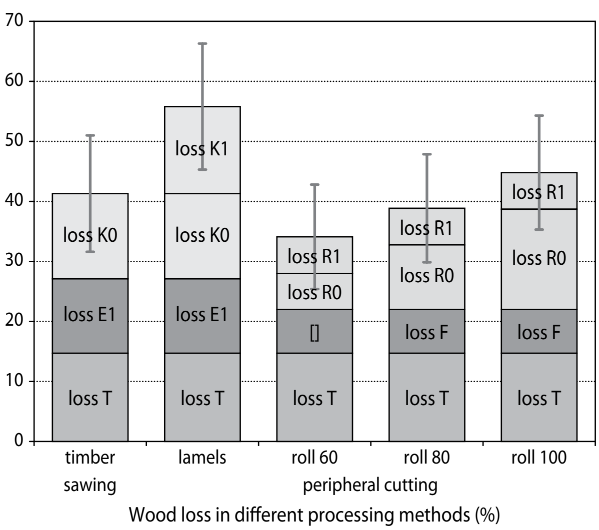

Figure 4. Bar diagram showing the material loss calculations in Table 2

When the log diameter is smaller than the diameter for which sawing schematics have been developed (24 cm), the peripheral boards includes wanes (undersized), up to the point when log taper evens diameters. These parts of peripheral boards should be considered as a loss. On the other hand, when log diameter is bigger than assumed diameter of 24 cm, all edgings are considered as a loss, even when other elements could be cut out of it (Fig. 3). In those cases, the procedure of sawing should be developed individually for each log; therefore, the loss volume would be different. In this research, the average loss volume for the chosen population of logs have been calculated; therefore, individual cases have not been considered.

As shown in Table 2 and in Figure 4, the standard deviation occurs stemming from the natural variability of material. For comparison of loss value, the deviation of mean values (standard error) is more meaningful, and it is $\sqrt{40} \approx 6.32$ times smaller. Therefore, mean total loss at sawing may be shown as follows:

$$loss_S = \left(55.8 \pm \frac{10.5}{\sqrt{40}}\right)\% = \left(55.8 \pm 1.7\right)\% \qquad (15)$$

Whereas on average, the biggest loss at peripheral cutting is:

$$loss_C = \left(45.6 \pm \frac{9.5}{\sqrt{40}}\right)\% = \left(45.6 \pm 1.5\right)\% \qquad (16)$$

Therefore, mean loss at sawing is significantly bigger ($\alpha = 0.05$), then loss at chipless peripheral cutting.

$$\left|55.8 - 45.6\right| = 10.2 > 2.3 \approx \sqrt{1.7^2 + 1.5^2} \qquad (17)$$

As it is shown, surplus factor $10.2/2.3 \approx 4.4$ exceeds the critical values 1.65 and 1.96 for one- and two-sided Student's t- test (in practice, normal distribution for considered test size).

Conclusions

On the basis of the concluded research, the following conclusions could be drawn:

1. Total average loss volume for sawing with kerf of lamellas (55.8%) is bigger than for peripheral cutting with peeler rolls of diameter of 60, 80 and 100 mm (45.6%). Peeling with peeler rolls 60 and 80 mm have a significantly smaller loss than sawing, but for peeler roll, 100 difference is not greater than the standard deviation.
2. With used schematics for cutting and sawing for production of base materials for layered floorboards, peripheral cutting is a more material-efficient manipulation procedure than sawing.

3. Total kerf loss (28.7%) represents more than half of the whole loss in sawing.
4. Considering the influence on loss of flattening and tapering, the second leads to largest losses during manipulation.
5. The peeler rolls can also be processed further, for example, for lamellas sawing and decreasing total loss volume for peripheral cutting.

Acknowledgements

The presented research was performed as part of project: "Timber usage effectiveness elevation in industrial production processes" (Consortium leader: Barlinek Inwestycje sp. z o.o.). Project founded by The National Centre for Research and Development (NCBiR) under Strategic research and development programme "Environment, agriculture and forestry" – BIOSTRATEG, project NR BIOSTRATEG 501-04-062700-N00189-01.

References

Bennett, N. 2014. Sawing methods for improving lumber yield recovery of out-of-shape hardwood saw logs. *General Technical Report*, NRS-130.

EN 13489:2002 Wood flooring. Multi-layer parquet elements.

EN 13556:2003 Round and sawn timber – nomenclature of timbers used in Europe.

EN 844-5:1997 Round and sawn timber – Terminology – Part 5: Terms relating to dimensions of round timber.

EN 844-8:1997 Round and sawn timber – Terminology – Part 8: Terms relating to features of round timber.

FEP 2016: The parquet industry. European Federation of the Parquet Industry.

Galewski, W., Korzeniowski, A. 1958. Atlas najważniejszych gatunków drewna. Państwowe Wydawnictwo Rolnicze i Leśne, Warszawa.

GUS. 2017. Leśnictwo – Forestry 2017. CSO, Agriculture Department.

Kozakiewicz, P., Borysiuk, P., Krzosek, S. 2011. Struktura zapotrzebowania na surowiec drzewny głównych odbiorców w Polsce. Konferencja naukowo-techniczna SITLiD „Rozwój zasobów drzewnych i strategia ich wykorzystania", 8 listopada 2011, Gołuchów.

Kozakiewicz, P., Pióro, P., Noskowiak, A. 2012. Atlas drewna podłogowego. Wydawnictwo Profi-Press Sp. z o.o., Warszawa.

Mantau, U. 2012. Wood flows in Europe. Commissioned by: CEPI Confederation of Europe Paper Industries and CEI-Bois European Confederation of Woodworking Industries.

PN-D-01011:1979. Drewno okrągłe. Wady.

Porankiewicz, B., Bermudez, J.C., Tanaka, Ch. 2007. Cutting forces by peripheral cutting of low density wood species. *BioResources*, 2 (4), 627–681.

Steele, P.H. 1984. Factors determining lumber recovery in sawmilling. *General Technical Report*, FPL-39.

Wagenführ, R. 2007. Holzatlas.6., neu bearbeitete und erweitere Auflage. Mit zahlreichen Abbildungen. Fachbuchverlag Leipzig im Carl Hanser Verlag.