TAMPERE POLYTECHNIC
Forestry

Final thesis

Mikko Rantanen

CIRCUMFERENTIAL VARIATION IN WOOD DENSITY IN RADIATA PINE

Supervisor	Eeva Sundström
Commissioned by	Forest Research New Zealand
Tampere 2005	

Rantanen, Mikko 2005 Circumferential variation in wood density in radiata pine. Final thesis. Tampere Polytechnic, faculty of forestry. 27 Pages + 12 Appendices

Commissioned by Forest Research, New Zealand
Supervisor Dr. Jonathan Harrington

Keywords Radiata pine, pinus radiata, density, resin, G2Ring

ABSTRACT

The aim of this study was to examine how big the circumferential variation in wood density in radiata pine is in terms of range, standard deviation and coefficient of variation. Measurements were done to six trees; two sample disks were taken from each tree. One disk was taken from the butt (0 meters) and the other from 5 meters. All the disks were further cut to 16 sectors and to 5 growth ring groups. To obtain basic density, volume and oven dry weight were to be measured.

$$\text{Basic density (kg/m}^3\text{)} = \text{oven dry weight / volume}$$

Average density among the examined disks was between 369,5 kg/m³ and 474,2 kg/m³ whereas the range was 33,2 kg/m³ - 81,8 kg/m³.

Some disks had severe resin bleed and to get defect free results resin extraction needed to be done. Three disks were chosen to represent the whole sample material. Samples were refluxed in methanol in a Soxhlet extractor for 72 hours. The highest amount of resin in heartwood was approximately 20% whereas in sapwood the amount of resin was from one to three percent.

To predict compression wood from the disks, newly invented software G2Ring was used. G2Ring detects compression wood from digital images. However, lighting of the photos was not optimum and software failed with all but one photo.

Any clear pattern for circumferential density variation was not found. Variation can be quite noticeable especially with low density trees.

Rantanen, Mikko 2005. Kehänsuuntainen tiheysvaihtelu radiata männyllä. Tutkintotyö. Tampereen ammattikorkeakoulu, metsätalouden koulutusohjelma. 27 sivua + 12 liitesivua

Työn teettäjä Forest Research, Uusi-Seelanti
Työn valvoja Tohtori Jonathan Harrington

Asiasanat Radiata mänty, pinus radiata, tiheys, pihka, G2Ring

TIIVISTELMÄ

Tutkimuksen tarkoituksena oli selvittää kehän suuntainen tiheysvaihtelu radiata männyn puuaineksessa. Mittaukset tehtiin kuudelle puulle kahdelta eri korkeudelta, tyveltä ja viiden metrin korkeudelta. Tiheyden laskemiseksi tarvittiin näytteen tilavuus ja kuivapaino.

$$\text{Tiheys (kg/m}^3\text{)} = \text{kuivapaino} / \text{tilavuus}$$

Tutkittujen näytekiekkojen kehänsuuntainen tiheyden vaihtelu oli 33,2 kg/m³ - 81,8 kg/m³ kuiva tiheyden keskiarvojen ollessa 369,5 kg/m³ - 474,2 kg/m³.

Suuri pihkan määrä aiheutti ongelmia muutaman kokonaisen näytekiekon kanssa, joten pihkan erottaminen oli ainoa vaihtoehto tarkkojen tiheysmittausten saavuttamiseksi. Pihkan erottaminen tehtiin 72 tuntia kestävällä metanolin tislausmenetelmällä kolmelle pihkamäärän suhteen eriasteiselle kiekolle. Suurimmillaan pihkan määrä oli sydänpuussa jopa 20 %, pintapuussa pihkaa oli yhdestä kolmeen prosenttia.

Tiheyteen vaikuttavan reaktiopuun (lylypuu) havaitsemiseen käytettiin digitaalista kuvantulkintaa. Käytetty vielä kehitysvaiheessa oleva ohjelmisto ”G2Ring” epäonnistui 11 kiekon kohdalla 12 kiekosta. Epäonnistuminen johtui kuvien valaistusolosuhteista.

Mitään selkeää johdonmukaisuutta kehänsuuntaisesta tiheysvaihtelusta ei löytynyt. Vaihtelu saattaa olla huomattavan suurta varsinkin puilla, joilla on alhainen tiheys.

PREFACE

This project was originally assigned to John Lee in Forest Research who kindly forwarded this project to my responsibility. Without all the help and know-how from several directions in Forest Research, the project would have been impossible to accomplish.

Thanks to everyone in the Wood and Fibre Quality unit, especially:

John Lee for giving me this project and helping with the measurements.
Pat Hodgkiss for the help in workshop and resin extraction
Russell Mckinley for ideas in sorting the results
David Pont for helping with G2Ring and visualizing the results
Jonathan Harrington for help and ideas in many stages

All the students in Forest Research who made my whole trip to New Zealand a unique experience.

TABLE OF CONTENTS

1 INTRODUCTION

Undoubtedly Radiata pine plantation forests in the southern hemisphere are really fast growing. Even growth of 20m³/hectare/year is possible. This means that the cutting cycle can be as short as 28 years when trees can be almost 50 meters tall and have breast height (1,4 meters) diameter of more than 50 cm. Fast growth comes with some disadvantages, too. Compression wood, also known as reaction wood, is one of the major problems. Tree reacts to stress caused by e.g. wind by forming thicker walled cells to keep the stem properly straight. What makes compression wood an unwanted phenomenon is the fact that its properties are different than in normal wood. Compression wood is denser; it shrinks more and therefore in some cases distorts sawed boards (Kininmonth 1991). Other problematic features are curvy stems and resin bleeding in standing stems.

Despite these problems radiata pine makes first class timber and pulp. Timber is used as both construction and cladding material. Pulp is used for various paper products: newsprint, tissues, corrugated board among others.

Wood density, as well as other wood properties, is known to be a variable both radially and circumferentially in radiata pine. Radial variation is a well known subject from previous studies (Kininmonth 1991) whereas the circumferential variation has not been particularly studied before.

Radial variation in density is a consequence from the age of the cambium at the time each annual growth ring is formed. The older the cambial age gets the denser the forming wood material. (Cown, 1980)

The density of the wood is of interest to the pulp mills. Higher density means bigger pulp yield. In sawmills, stiffness is more the important variable but then again wood density is correlative to stiffness (Huang 2003). The use of core wood needs more planning. Because of its low quality, low stiffness and tendency to crook, it can not be used in load bearing constructions. The ability to estimate radial and circumferential variation in wood properties would give advantage in planning the use of wood more precisely. However, the circumferential variation in wood density is not so big that it would have crucial affect on the operations in either of these production processes.

Of all wood properties, density is one of the most important variables. Normally density correlates well with other wood properties e.g. stiffness, shrinkage and moisture content just to name few. This makes density measurements ideal target for this study because circumferential variation in density gives a hint on how other wood properties change circumferentially, too. Density measurements are also the easiest to complete.

In many studies where wood samples are needed (e.g. increment cores) there is only one or sometimes two samples taken from one tree. This can cause some problems if a tree has a great wood density variation circumferentially. The effect of circumferential density variation to this kind of sample collecting has been studied before (Kininmonth 1991) and will not be examined in this study.

The aim of this study was to measure the circumferential variation in density in order to get some numeric data for forthcoming studies. If the results are somewhat reasonable, circumferential variation will be studied from other wood properties as well. The spiral grain angle and dive angle would be the most interesting at this point, because that is where the density variation derives from.

2 SAMPLE MATERIAL

Sample material (wood disks) was collected from the log yard of a nearby pulp mill. Logs are most probably transported from the Kaingaroa forest. More specific information about log's origin is not available. Genetic information (clone) was not considered important at this point thus samples were not collected from a specific genetic trial stand. The samples were chosen with a Hitman tool which measures the sound velocity in the log. Six logs were chosen, two with high sound velocity, two low ones and two from the middle. Sound velocity is known to correlate well to stiffness which is somewhat correlative to density. (Huang et al. 2003) The idea was to get a range of disks with different density to see if trees with various overall densities had different variation circumferentially. The easiest and fastest way to make this kind of grading was with a Hitman tool. Six logs were chosen and two approximately five centimetre thick disks were cut from each log, one from the butt and other from 5 meter height. The disks were labelled from 1 to 6, “B” meaning butt disk (0 meters/cutting point) and “T” top disk (5 meters). All in all 12 disks were examined in this study.

Table 1 Sound velocity of the logs

Tree	Sound velocity (km/s)
1	3,72
2	3,70
3	3,46
4	3,07
5	3,47
6	3,04

Trees 1 and 2 had the highest sound velocity (Table 1) thus they were expected to be the densest ones too.

3 WORKING METHODS

When measuring the wood density moisture content is always an influencing factor. The best and the easiest way to eliminate this variable is to use oven dry weight when calculating the density. Then moisture content is practically zero. Oven dry density is also the most common way to present density results and therefore results from many other studies are comparable.

The first procedure for the disks was to measure their diameter and to mark the cutting lines before cutting the disks. The preparation of the sample disks started with cutting the disks into smaller samples. Each of the 12 disks was cut into 16 sectors and into 5 growth layer groups (Figure 1). The last roughly 10 growth layers were quite small in many disks and the sample size would have been very small. Thus last ring group has normally more than five layers to keep the sample size reasonable. Samples were cut with a band saw. Some of the wood material was lost to sawing dust of course, but not noticeably much. From here on the new sample blocks are called “wedges” because of their shape. Each new sample wedge was labelled so that it was possible to rebuild the whole disks again from the wedges. All the disks were not uniformly circle because of felling damage or off-centred pith which gave no other choice than to establish some uneven ring groups (not all the 16 sectors).

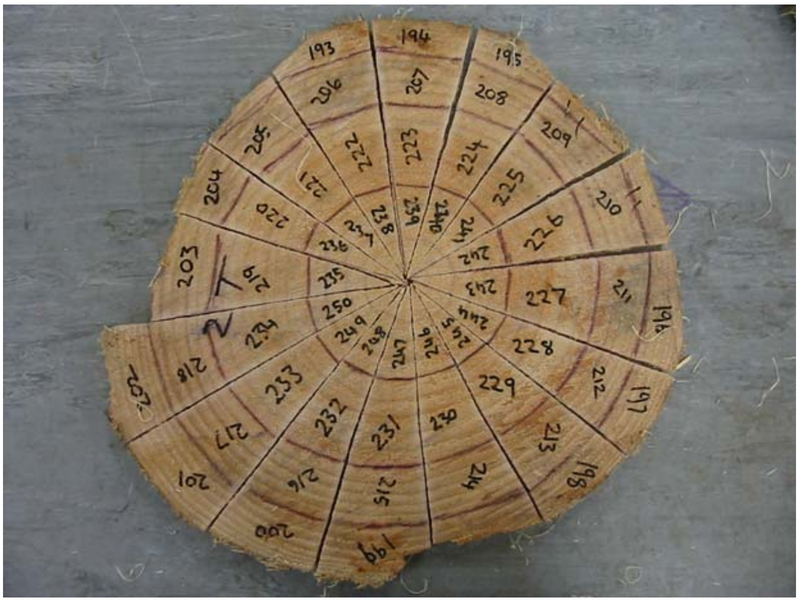


Figure 1 Disk 2T cut pattern

The next stage was to measure the volume from each wedge. Before measurements wedges were soaked in a tightly closed and water filled bucket from where air was vacuumed away. This means that absolutely all the air from the wedges was sucked away and replaced by water. In other words, wedges had maximum moisture content. This ensured that wedges would not suck any water and distort results when volume was obtained by water immersion. Each wedge was immersed and the scale automatically recorded the weight of water forced aside which is same as the volume of the wedge. Results were recorded directly to an excel sheet.

Oven drying was next procedure. All the disks were rebuilt on oven trays so that all the wedges from the same disk would get the most similar drying conditions. Wedges were dried in 103ºC for 48 hours. Temperature above 100ºC would guarantee that all the water would vaporize but it is still not that high temperature that it would start other chemical reactions causing other substances to vaporize. After drying all the wedges were weighted and results recorded to an excel sheet again.

Now all the information to calculate the density for each wedge was gathered. Density was determined for each wedge according to formula:

$$\text{Wood density } (kg/m^3) = \text{oven dry weight} / \text{green volume}$$

3.1 Resin extraction

Already when the wedges were taken out from the oven some severe resin bleed was found. Density results showed that some disks had unexpectedly high densities which were clearly because of high amount of resin. Because resin extraction with this kind of wedge shaped samples has not been done before, it was considered worth doing although it was not in the work plan. Wedges were cut so that the whole surface area of the disk was examined.

Extracting all the samples would have been too big and expensive a task. Three disks from the original 12 disks were chosen to represent the whole sample material. One disk with severe resin bleed, one with minor resin bleed, and one that did not have any noticeable bleed. Wedge samples, as they were then, were too big to be efficiently extracted, so they needed to be cut to even smaller pieces again. Small sample size, smallest samples weighed less than 5 grams, meant very accurate work, samples even needed to be sanded so that absolutely no material would get lost undeliberately during the resin extraction. Hairy samples would probably distort results because samples were oven dried and weighed before and after the extraction and during the drying hairy wood tends to loose some of the material into the oven.

Extracted oven dry weight was compared to the oven dry weight before extraction and the percentage of extracted material was obtained.

Samples were refluxed in methanol in a Soxhlet extractor for 72 hours (Figure 2). In this process methanol circulates through the system many times. Methanol is heated up and steamed when the newly distilled methanol gets into a container where the samples are. The methanol level rises to certain level before refluxing back to the heating container. Same circulation starts again. After 72 hours methanol had clearly changed its colour to dark yellow.

Figure 2 Soxhlet extractor

3.2 G2Ring

Before cutting disks a digital photo was taken from each disk. The reason was that it would be possible to test new software G2Ring which detects compression wood from digital image. Severe compression wood tends to be denser, too, and with this software it was expected to be possible to comprehend some of the unexpected densities.

The basic idea in this software is simple. First the colour digital image is turned into black and white image. Software gives a greyscale value from 0 to 9 to every pixel in the picture. Value 0 means white whereas 9 is black. Severe compression wood (Figure 5) is clearly darker than surrounding late wood so it will be given higher greyscale value, as well. Compression wood is always located in late wood, therefore all the ring edges needed to be manually digitized with G2Ring, too (Figure 3). After digitizing all the growth ring edges, G2Ring calculates all the grey scale values and determines which areas, more correctly late wood stripes, had exceptional values compared with average values among the disk. Indicator colour visualizes the results (Figure 4).

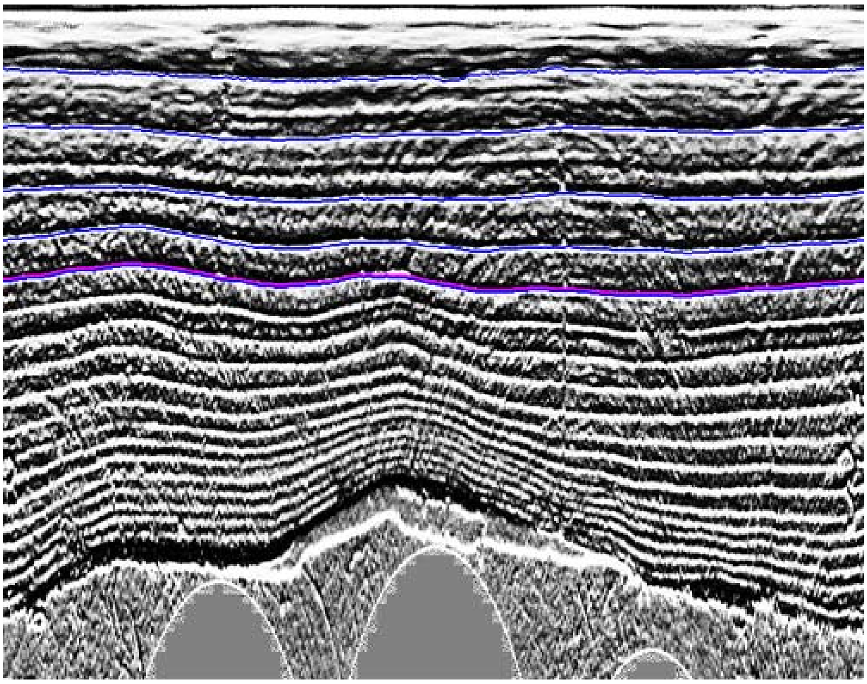


Figure 3 Growth layer digitizing with G2Ring

Figure 4 G2Ring indicator colour

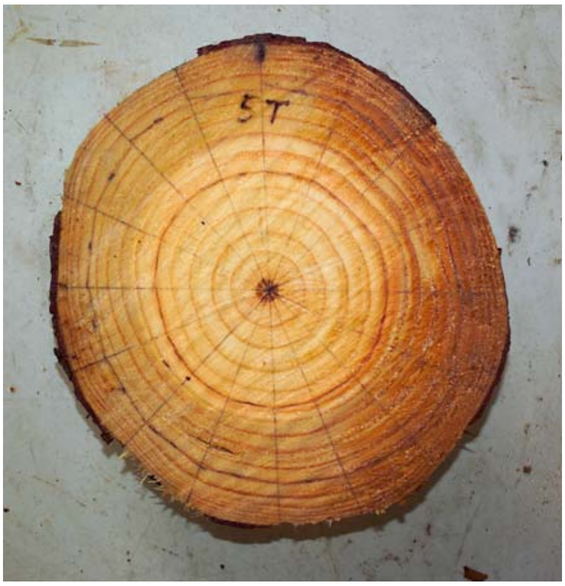


Figure 5 Original image on disk 5T, lots of compression wood

4 RESULTS

Visualized density results for each disk are shown in appendices 1-12. Here are the results concerning standard deviation, range of densities and coefficients of variation. Also resin extraction results are shown here.

Table 2 Density results with interval for the mean and range

Disk	Average density (kg/m3)	Confidence interval for the mean (kg/m3)	Range (kg/m3)
1B	443,1	± 9,2	33,2
1T	419,9	± 12,8	39,6
2B	474,2	± 11,0	38,5
2T	430,1	± 12,4	39,8
3B	385,5	± 9,5	29,6
3T	375,6	± 15,6	49,3
4B	369,5	± 14,6	44,4
4T	370,4	± 18,1	56,6
5B	456,0	± 21,7	68,8
5T	396,1	± 23,8	69,0
6B	420,3	± 23,6	81,8
6T	413,8	± 21,0	50,6

The range and confidence interval were biggest with trees five and six. They had the worst variation. Still, they were not the low density trees but had many defects that affected the results.

Table 3 Standard deviation and coefficient of variation

Disk	Standard deviation		Coefficient of variation	
1B	9,4	10,4	2,1	2,3
1T	11,3		2,6	
2B	11,3	12,0	2,4	2,7
2T	12,7		2,9	
3B	8,4	11,1	2,2	2,9
3T	13,8		3,7	
4B	13,0	14,5	3,6	4,0
4T	16,0		4,4	
5B	19,2	20,1	4,2	4,6
5T	21,0		5,0	
6B	20,9	18,0	5,0	4,4
6T	15,1		3,7	

As expected, the cambial age seems to affect to density. All the younger “top” disks had more variation in density than the comparable “butt” disks.

4.1 Density variation of each disk, Tables 4-16, (all disks with unextracted densities)

Appendices 1-12 have visualized results from each disk. Visual results support results shown here and should be read alongside with each other.

Table 4 Summarized results, disk 1B

1B			
Average density		Standard deviation	Coefficients of variation
	kg/m3		%
Rings 1-5	387	8,1	2,10
Rings 5-10	432	8,1	1,88
Rings 10-15	475	9,5	2,00
Rings 15-20	514	11,9	2,31
Disk	443	9,4	2,08

Disk 1B had the smallest variation of all the disks. High density disk, small variation.

Table 5 Summarized results, disk 1T

1T			
Average density		Standard deviation	Coefficients of variation
	kg/m3		%
Rings 1-5	353	9,1	2,56
Rings 5-10	400	7,7	1,92
Rings 10-15	507	17,1	3,37
Disk	420	11,3	2,62

For a top disk, 1T is variation was small. All in all, tree 1 had the smallest variation.

Table 6 Summarized results, disk 2B

2B			
Average density		Standard deviation	Coefficients of variation
	kg/m3		%
Rings 1-5	455	12,9	2,83
Rings 5-10	478	8,7	1,81
Rings 10-15	456	12,2	2,68
Rings 15-20	507	11,3	2,22
Disk	474	11,3	2,39

2B had the highest density, but had also severe compression wood. Unevenly divided compression wood caused a bit higher variation than the other high density tree, tree no. 1.

Table 7 Summarized results, disk 2T

2T			
Average density		Standard deviation	Coefficients of variation
	kg/m3		%
Rings 1-5	370	14,4	3,91
Rings 5-10	398	9,4	2,36
Rings 10-15	467	17,1	3,66
Rings 15-20	529	9,8	1,86
Disk	430	12,7	2,95

Disk 2T had also some compression wood.

Table 8 Summarized results, disk 3B

3B			
Average density		Standard deviation	Coefficients of variation
	kg/m3		%
Rings 1-5	341	5,6	1,63
Rings 5-10	373	9,4	2,51
Rings 10-15	442	10,3	2,32
Disk	385	8,4	2,15

Disk 3B had surprisingly small variation; its cambial age was only 19 years and still it had the second smallest variation. Growing conditions must have been optimal.

Table 9 Summarized results, disk 3T

3T			
Average density		Standard deviation	Coefficients of variation
	kg/m3		%
Rings 1-5	336	17,1	5,09
Rings 5-10	371	10,7	2,88
Rings 10-15	420	13,7	3,26
Disk	376	13,8	3,74

Disk 3T had several defects, resin pockets in first ring group, which affected density results and caused more variation.

Table 10 Summarized results, disk 4B

4B			
Average density		Standard deviation	Coefficients of variation
	kg/m3		%
Rings 1-5	331	15,6	4,71
Rings 5-10	367	12,0	3,26
Rings 10-15	411	11,2	2,72
Disk	369	12,9	3,56

Disk 4B had one obvious patch of compression wood. As a low density tree variation is quite big.

Table 11 Summarized results, disk 4T

4T			
Average density		Standard deviation	Coefficients of variation
	kg/m3		%
Rings 1-5	332	17,3	5,21
Rings 5-10	350	14,4	4,12
Rings 10-15	434	16,3	3,75
Disk	370	16,0	4,36

The cambial age of disk 4T was only 20 years and therefore variation was rather big.

Table 12 Summarized results, disk 5B

5B			
Average density		Standard deviation	Coefficients of variation
	kg/m3		%
Rings 1-5	468	32,4	6,92
Rings 5-10	437	14,7	3,35
Rings 10-15	463	10,5	2,26
Disk	456	19,2	4,18

Disk 5B had lots of small knots which affected results clearly. Variation in first ring group is really big

Table 13 Summarized results, disk 5T

5T			
Average density		Standard deviation	Coefficients of variation
	kg/m3		%
Rings 1-5	326	6,5	2,00
Rings 5-10	391	22,1	5,66
Rings 10-15	471	34,4	7,30
Disk	396	21,0	4,99

Disk 5T had severe compression wood in half of the disk. Variation is therefore big.

Table 14 Summarized results, disk 6B

6B			
Average density		Standard deviation	Coefficients of variation
	kg/m3		%
Rings 1-5	415	44,0	10,62
Rings 5-10	411	10,2	2,48
Rings 10-15	435	8,5	1,95
Disk	420	20,9	5,01

One single sample in the first ring group caused disk 6B to have huge variation. Without that it would have been reasonably stable disk.

Table 15 Summarized results, disk 6T

6T			
Average density		Standard deviation	Coefficients of variation
	kg/m3		%
Rings 1-5	396	21,5	5,42
Rings 5-10	431	8,8	2,03
Disk	414	15,1	3,73

Cambial age on disk 6T was only 13 years. Again, slightly bigger variation because of that.

4.2 Resin extraction results

Table 16 Resin extraction results

Visual selection							
Severe resin bleed after oven drying			No resin bleed			Minor resin bleed	
Resin extraction results (relative amount of extracted material)							
2B			5T			6B	
Group	%		Group	%		Group	%
15–20	0,81						
10–15	1,06		10–15	1,75		10–15	1,29
5-10	7,40		5-10	2,81		5-10	1,82
1-5	15,96		1-5	2,16		1-5	3,60

Visual selection (discussed in paragraph 3.1) seemed to work pretty well. Disk 2B had severe resin bleed and results say the same (Table 16). Disk 6B did not have so much resin as the bleed indicated. Ring groups 5-10 and 10-15 had even less resin than comparable groups from disk 5T which did not have any noticeable resin bleed after oven drying. Disk 2B had so severe resin bleed already that it sounds pretty impossible to find wood with twice as much resin.

“Methanol extractives vary from about 2% in sapwood up to as much as 30% in the inner heartwood rings of radiata pine, but are normally up to 5% to 10%.” (Kininmonth 1991)

4.3 Comparison with Douglas fir

Cown has made similar study earlier with Douglas fir (1971). Coefficient of variation was examined from 5 trees (Table 17).

Table 17 Circumferential density variation in Douglas fir (Cown 1971)

Breast height				60 ft (18 meters)		
Tree	Ring no.	v%	average	Ring no.	v%	average
1	1-10	1,67	1,87	1-10	4,24	4,22
	11-30	1,79		11-20	3,72	
	31-50	2,15		21-32	4,71	
2	1-10	5,95	4,44	1-10	3,92	4,19
	11-30	3,2		11-20	4,42	
	31-50	4,18		21-30	4,23	
3	1-10	1,07	2,85	1-10	5,8	4,68
	11-20	1,82		11-20	5,2	
	21-40	4,33		21-32	3,05	
	41-50	4,17				
4	1-10	2,85	3,82	1-5	5,92	4,59
	11-30	5,1		6-10	3,26	
	31-50	3,5				
5	1-10	2,54	2,40			
	11-30	1,93				
	31-50	2,74				

Results are very comparable to radiata pine. The higher the measurement point, the greater the variation. Coefficient of variation is around 2% at its smallest. Only difference is that the top range is slightly higher on radiata pine even if those high variation disks do have more resin pockets or other defects. Cown (1971) mentioned that radiata pine would often have smaller variation than Douglas fir. Highest coefficient of variation Cown found from radiata pine was only 3,75. This study gave different results. Highest coefficient of variation was even 10,62 although that is because of that one weird sample. Still, even one of the high density, low variation disks, disk 2T, had coefficient of variation of 3,91 in first ring group.

4.4 Effects of resin extraction to density

As noticed in resin extraction results (figures 6 and 7), the biggest amount of resin is in the heartwood, mostly in the first ring group. Especially disk 2B´s density results changed dramatically after resin extraction.

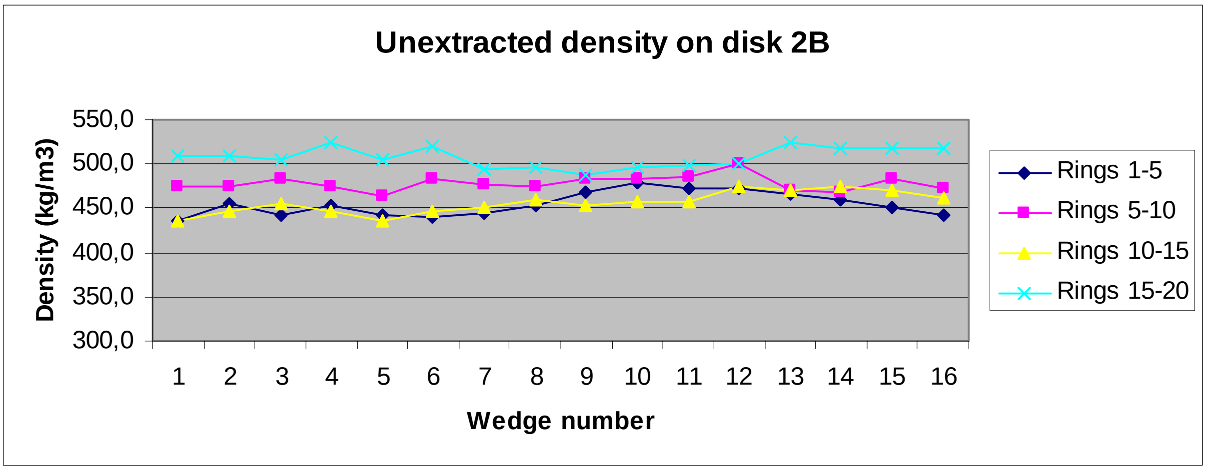


Figure 6 Unextracted density on disk 2B

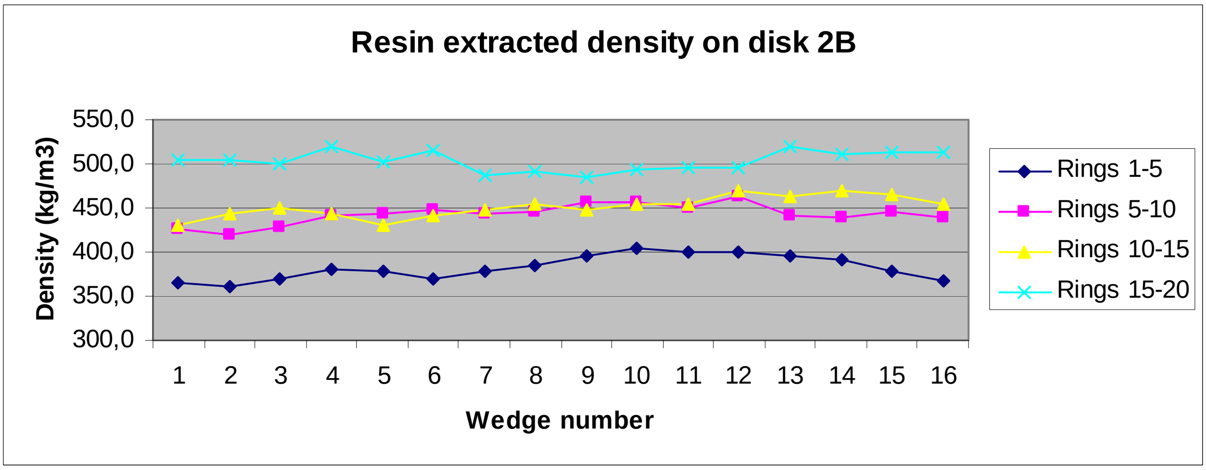


Figure 7 Extracted density on disk 2B

As seen on the figures 6 and 7, Rings 1-5 had very high density before resin extraction. First density was at the same level with rings 10-15 but after extraction it went down about 16%. Surprisingly variation grew bigger after extraction. (Tables 18 and 19) This means that resin is not always the explainable factor for high density peaks. Tracheid angle study would probably explain this unexpected result instead.

Table 18 Variation on disk 2B before extraction

2B			
Average density		Standard deviation	Coefficients of variation
	kg/m3		%
Rings 1-5	455	12,9	2,83
Rings 5-10	478	8,7	1,81
Rings 10-15	456	12,2	2,68
Rings 15-20	507	11,3	2,22
Disk	474	11,3	2,39

Table 19 Variation on disk 2B after extraction

2B Extracted			
Average density		Standard deviation	Coefficients of variation
	kg/m3		%
Rings 1-5	382	11,9	3,12
Rings 5-10	443	11,2	2,54
Rings 10-15	451	12,0	2,66
Rings 15-20	503	11,4	2,27
Disk	445	11,7	2,65

4.5 Success with G2Ring

With one disk and photo G2Ring worked as was expected. Disk 5T had so clear compression wood that software found it easily (Figures 4 and 5). G2Ring also gathers data from image into numeric data. In figure 8 grey scale values and densities are combined into same table and clear pattern is found. Clearly darker patches are also denser.

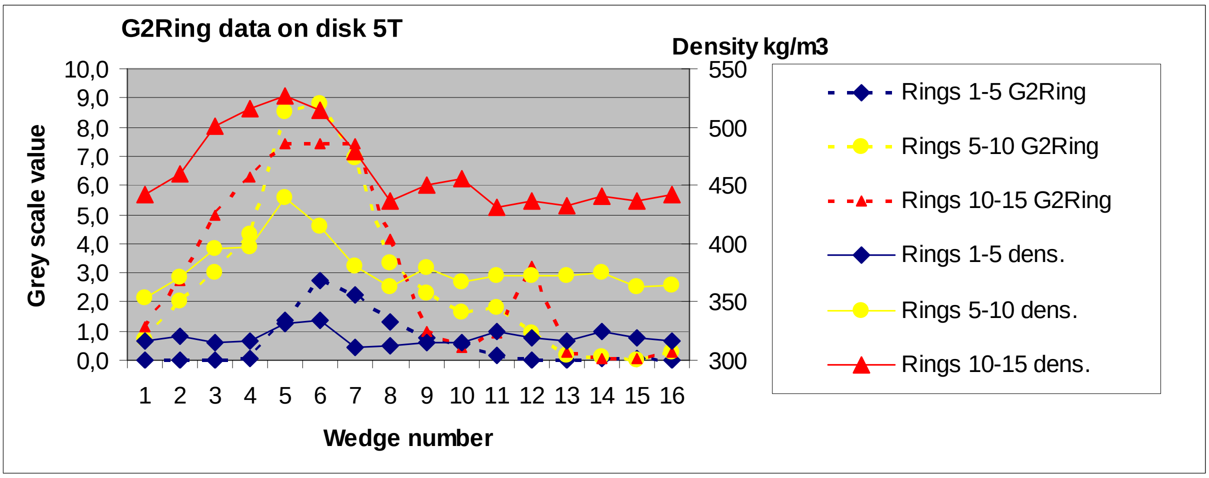


Figure 8 G2Ring data on disk 5T

5 DISCUSSION

Density results were largely as expected: Trees 1 and 2 (disks 1B, 1T, 2B, 2T) had the highest density which means that Hitman tool results indicated density results well on high density disks. Medium and low density trees had more variation when comparing Hitman results to density results.

Comparing the disk from the same tree, there was no clear pattern in circumferential variation between the disks. High density peaks did not repeat in the same spots at all and the variation could be very different. Only the high density trees had pretty consistent variation. Among the ring groups there was no clear repetition either. Variation did not always get smaller the closer to bark the measurement point was even if that would be very logical as the cambial age gets older. Only tree four had this kind of diminishing variation from pith outwards. Variation between the trees was also big. Only clear conclusion is that high density trees have smaller variation.

Circumferential variation grows bigger the higher the measurement point is. Big amount of compression wood does not necessary mean big variation in density if it is fairly even distributed as seen on disk 2B (appendix 3).

Some single sample wedges had really abnormal densities, like one from disk 6B. All the wedges that had unexpected results were re-examined even though the results did not change that much. No measurement mistakes were found. Some high density peaks remain unexplained. In the particular case possibly the explanation is that the whole disk was cut off just beneath the branch whirl and that specific wedge was very close to a branch and because of that had different tracheid angle.

Disk 5B was really problematic sample. While cutting the samples, several small branches were found inside of the disk. That is clearly shown in visualized density results. (See appendix 9). All those small branches affected to density results. Defect free density would be much lower at this disk.

Many other defects, like resin pockets and needle flecks (Figure 9), affected results in many cases. The disks 3T, 4B, 4T, 5B, 5T, 6B had all some defects that affected results. High density peaks derived mostly from resin pockets. Standard deviation for the defect free disks is roughly around 12 kg/m³ where as the other disks had standard deviation of more than 15 kg/m³. Same trend is found in density range results, too.

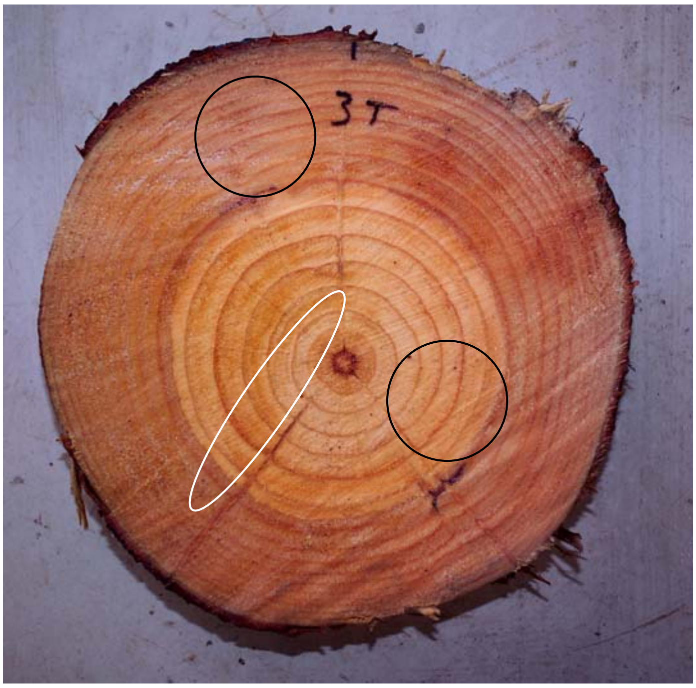


Figure 9 Disk 3T with resin pockets (black) and needle flecks (white)

This study is easily repeatable and should be redone with bigger sample material to get more defect free measurements. Growing conditions should be taken into account too by selecting trees from certain site.

6 POSSIBLE ERRORS

While measuring density it is easy to do some minor faults. Handling such a big number of samples (almost 600) is always difficult. There were already some problems with labelling the wedge samples which led to time consuming puzzle like rebuilding of all the disks. However, all the wedge samples were found and located to their correct places.

Volume measurement offered one possible issue for errors. When immersing wedges to water the scale needed to be tared after every wedge because some water dropped off from the container every time. The difference is not big, approx. 1g per time but the error would grow bigger on smaller wedges whose volume that one gram would affect relatively more.

Drying ovens were automatized to keep the temperature in 103°C and 48 hours of time would guarantee to dry the wedges properly. The only problematic issue was to weighing the wedges right after taking them out of the oven. Completely dry wood starts to suck moisture from the air and put up weight immediately after taking them into room temperature. This problem was solved by taking only small number of samples out from the oven at a time.

Resin extraction needed special chemistry skills, and so this part was conducted under the supervision of a more experienced scientist. Methanol is an extractor that most certainly extracts resin. On the other hand it is so strong that it might possible extract small amount of other material as well (Maria Pesco). But the procedure for every sample is the same, so that should not affect results.

Half of the extraction samples were extracted in four small Soxhlet extractors and the rest in a big one. There was a slight difference in the results between the small ones and the big one although the extraction time was the same with both. The amount of extracted material was obviously a bit bigger in small extractors. The only explanation that in the bigger extractor the methanol did not circulate so many times, because the sample container was bigger and it took more time to fill it with distilled methanol before refluxing back to heating container. In other words, the procedure was not as intense as in a smaller Soxhlet extractor. Another thing worth consideration is that the samples at the bottom of the container were in contact with methanol much longer time than the samples on the top. Top samples were examined separately but anything totally abnormal was not found from the results.

All in all, only six trees is a very small taking and accurate results would need more samples.

6.1 Problems with G2Ring

Compression wood detection with G2Ring did not work very well. Only with one disk results were somewhat expectable. Obviously the lighting conditions were not good enough when the photos were taken. From each of the remaining 11 disks G2Ring found some false compression wood from exactly the same place. Every disk had one darker patch at six o'clock direction. (Figure 10) That might be some kind of shadow. However, useful feedback to software developers was gathered.

Figure 10 Failed results from G2Ring

7 REFERENCES

Carter, P & Lausberg, M. 2001. Application of Hitman® Acoustic Technology, The Carter Holt Harvey Experience. Published in" 4th Wood Quality Workshop, Tools & Technologies to Improve Log & Wood Products Segregation". Rotorua, New Zealand 2001. Session 2, Forest Assesment Techniques & Technologies.

Cown, D.J. 1971. Circumferential variation in wood density in douglas fir. Laboratory report no. FP/WQ 5 (unpublished)

Heikkilä, T 1998. Tilastollinen tutkimus. Edita Oy, Helsinki, 327 pages

Huang, C.-L., Lindström, H., Nakada R., Ralston J.
"Cell wall structure and wood properties determined by acoustics - a selective review" Holz als Roh- und Werkstoff 61 (2003) 321 - 335 Springer Werlag 2003

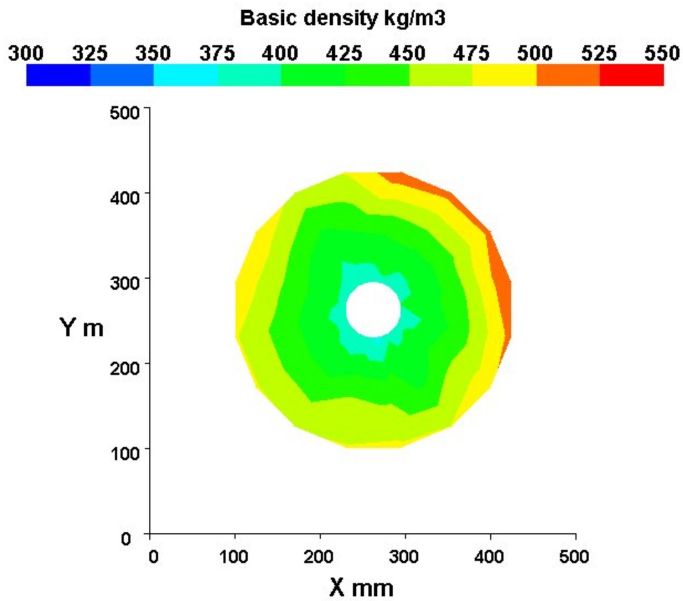
Kininmonth, J.A & Whitehouse L.J. 1991. Properties and uses of New Zealand radiata pine, volume one – wood properties

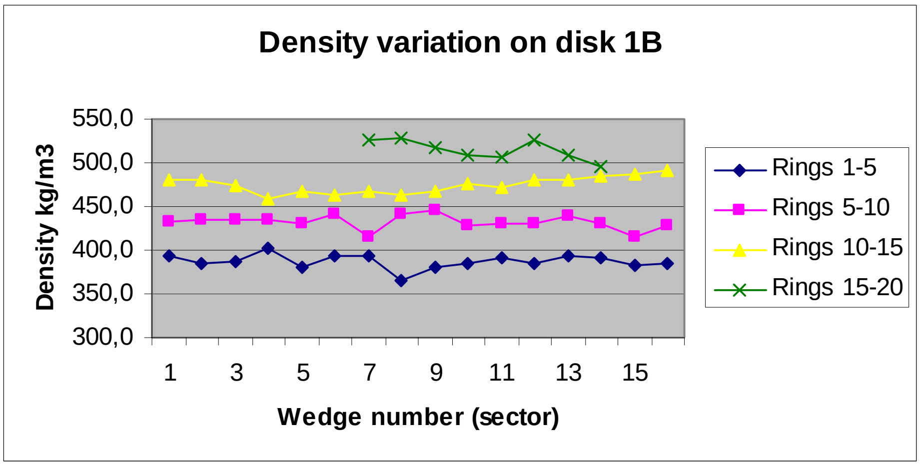
Klitscher, Ken etc. 1995. Wood quality workshop 95, FRI bulletin no. 201

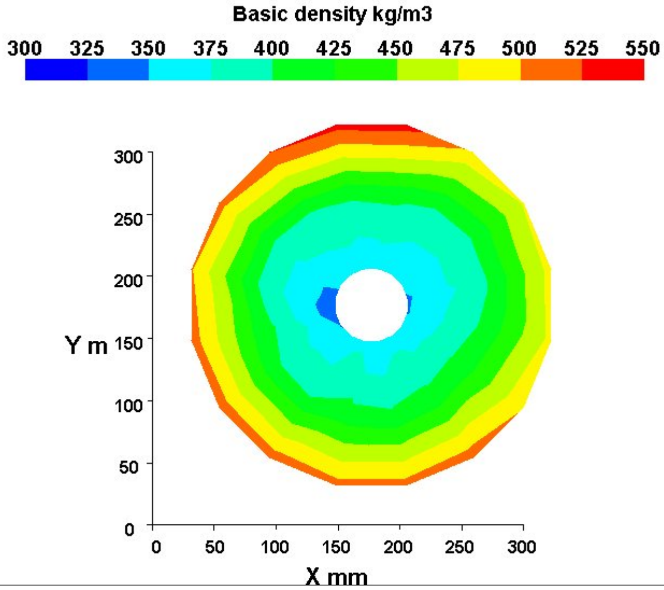
Pesco, Maria Interview 29.7.2004 Rotorua

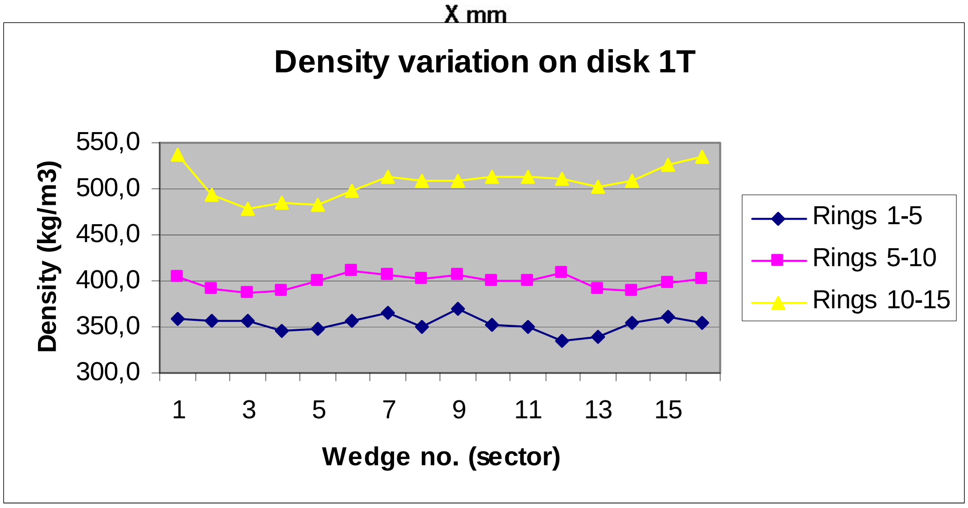
APPENDICES 1-12

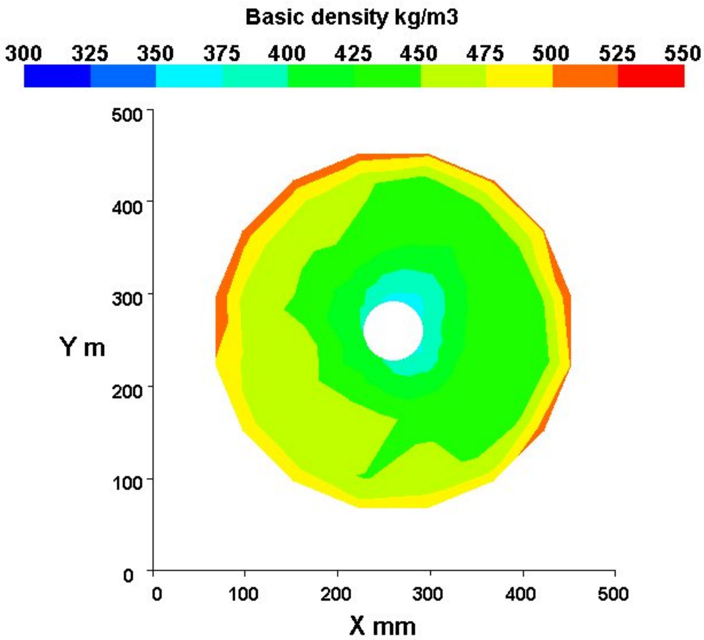

1B

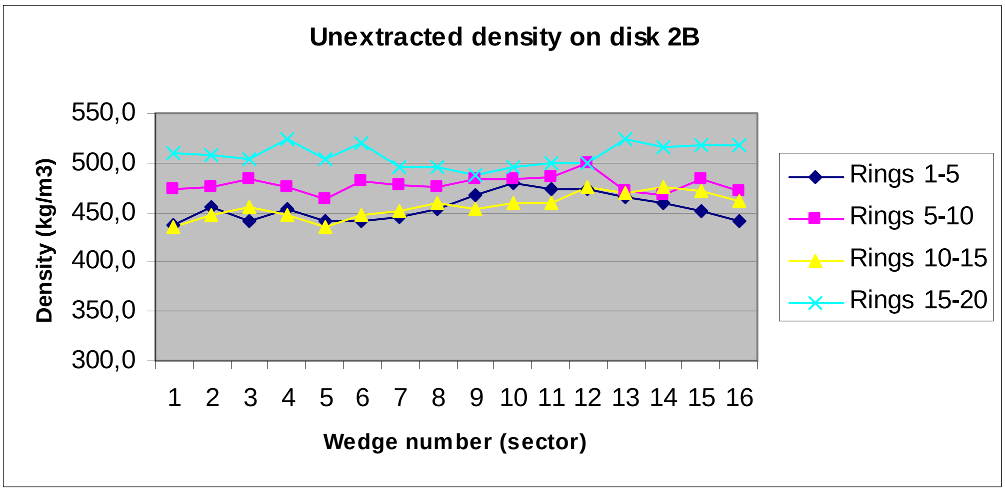

Basic density kg/m3
300 325 350 375 400 425 450 475 500 525 550
Y m
X mm
0
100
200
300
400
500

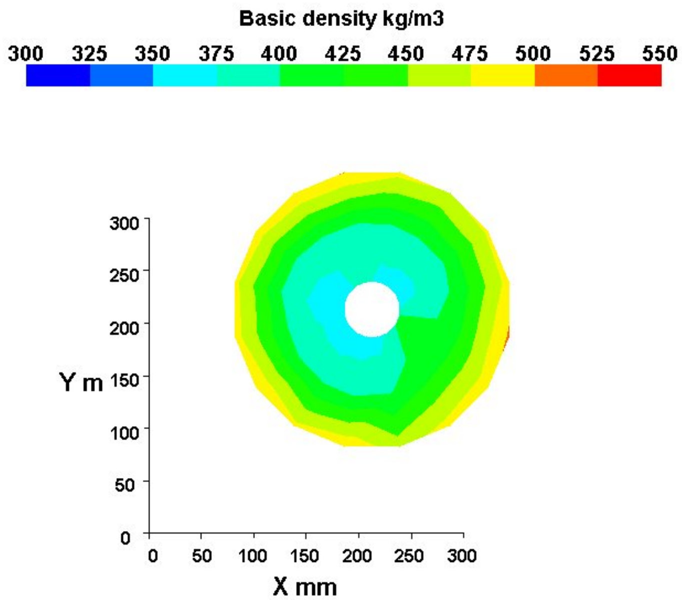

Density variation on disk 1B
Density kg/m3
550,0
500,0
450,0
400,0
350,0
300,0
1 3 5 7 9 11 13 15
Wedge number (sector)
Rings 1-5
Rings 5-10
Rings 10-15
Rings 15-20

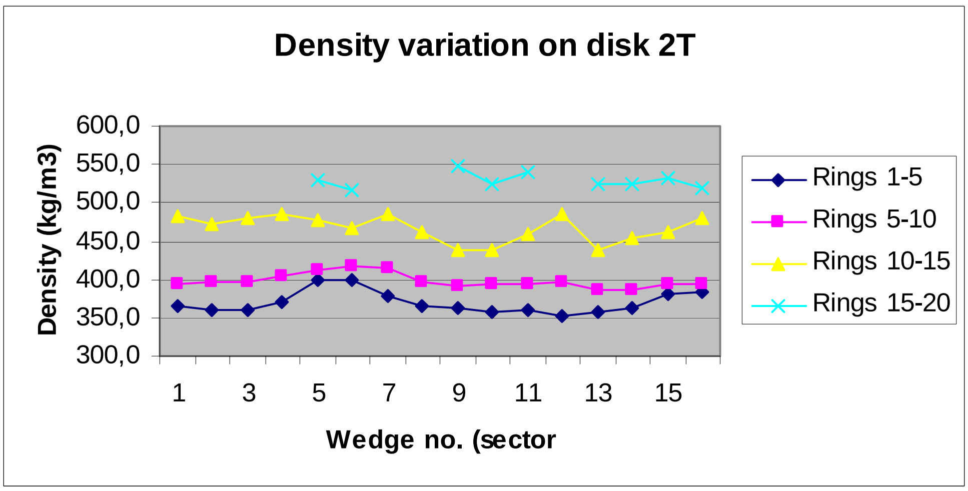

Basic density kg/m3
300
325
350
375
400
425
450
475
500
525
550
Y m
X mm
0
50
100
150
200
250
300


Density variation on disk 1T
Density (kg/m3)
550,0
500,0
450,0
400,0
350,0
300,0
1
3
5
7
9
11
13
15
Wedge no. (sector)
Rings 1-5
Rings 5-10
Rings 10-15

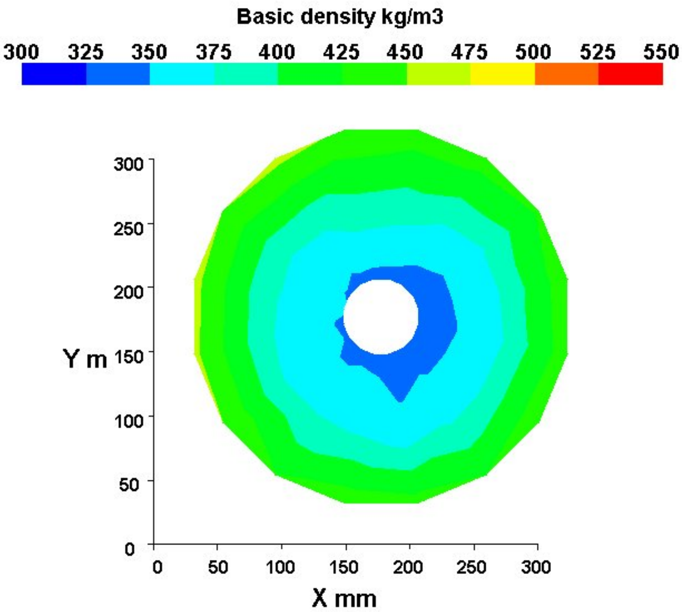

Basic density kg/m3
300 325 350 375 400 425 450 475 500 525 550
Y m
0
100
200
300
400
500
X mm
0
100
200
300
400
500

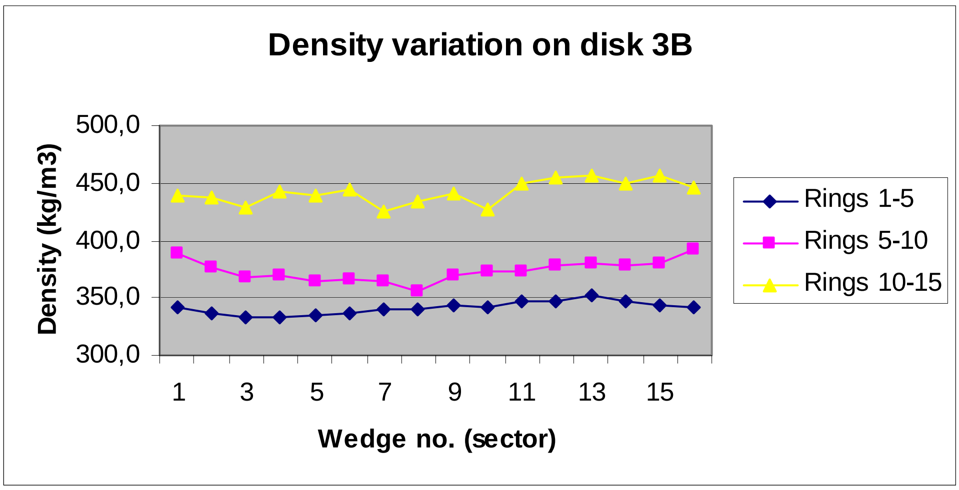

Unextracted density on disk 2B
Density (kg/m3)
550,0
500,0
450,0
400,0
350,0
300,0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Wedge number (sector)
Rings 1-5
Rings 5-10
Rings 10-15
Rings 15-20

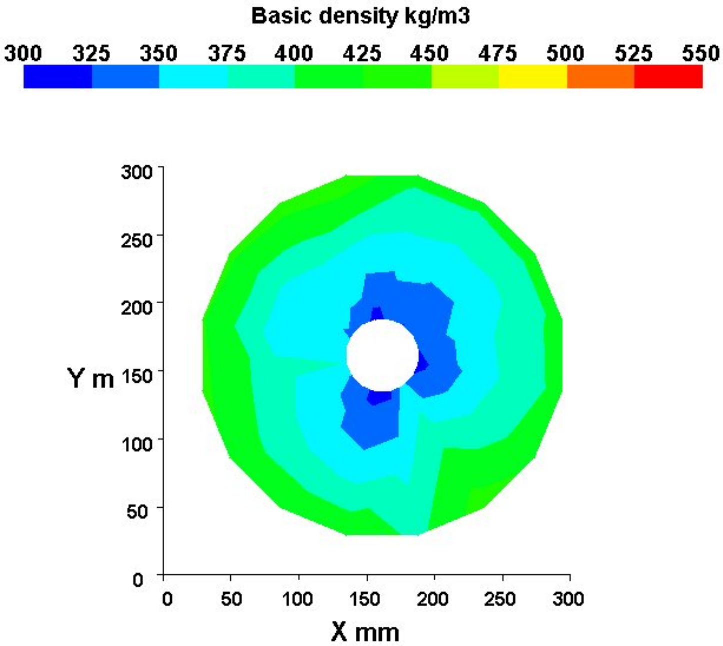

Basic density kg/m3
300 325 350 375 400 425 450 475 500 525 550
Y m
300
250
200
150
100
50
0
0 50 100 150 200 250 300
X mm

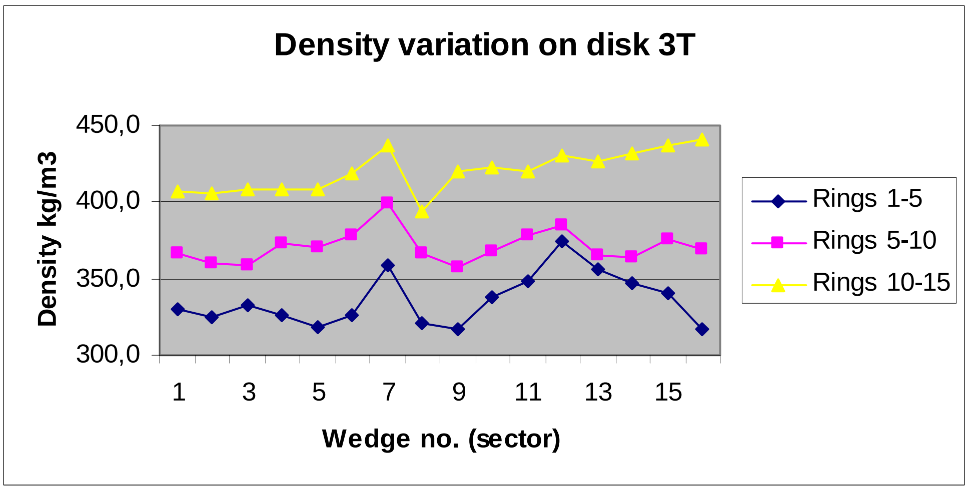

Density variation on disk 2T
Density (kg/m3)
600,0
550,0
500,0
450,0
400,0
350,0
300,0
1 3 5 7 9 11 13 15
Wedge no. (sector
Rings 1-5
Rings 5-10
Rings 10-15
Rings 15-20


3 B

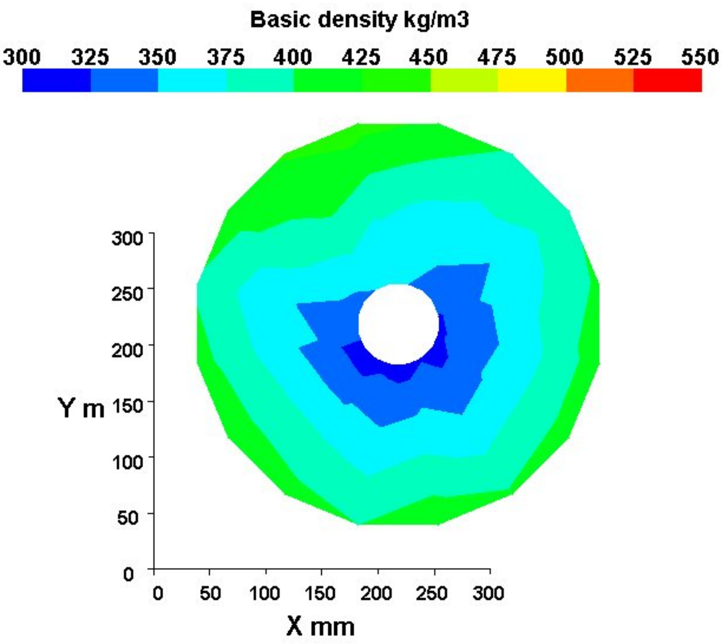

Basic density kg/m3
300 325 350 375 400 425 450 475 500 525 550
Y m
300
250
200
150
100
50
0
0 50 100 150 200 250 300
X mm

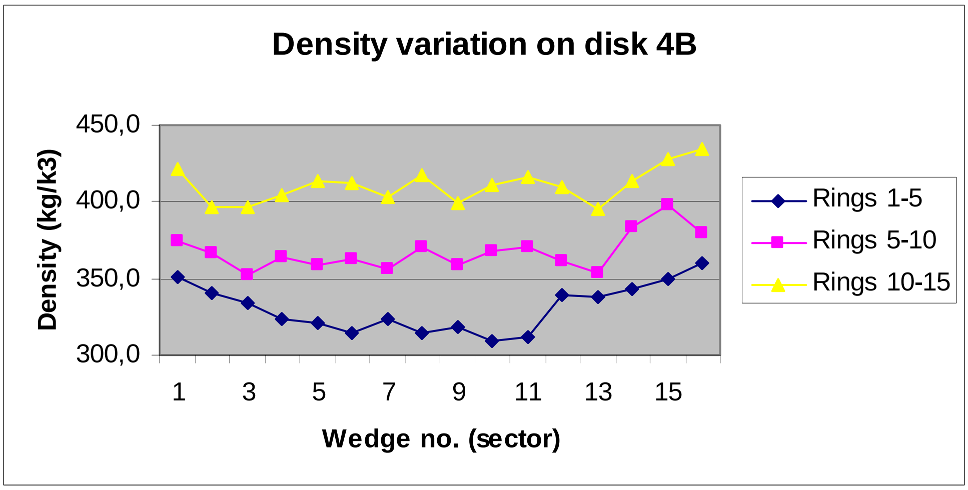

Density variation on disk 3B
Density (kg/m3)
500,0
450,0
400,0
350,0
300,0
1 3 5 7 9 11 13 15
Wedge no. (sector)
Rings 1-5
Rings 5-10
Rings 10-15


Basic density kg/m3
300 325 350 375 400 425 450 475 500 525 550
Y m
X mm
0 50 100 150 200 250 300

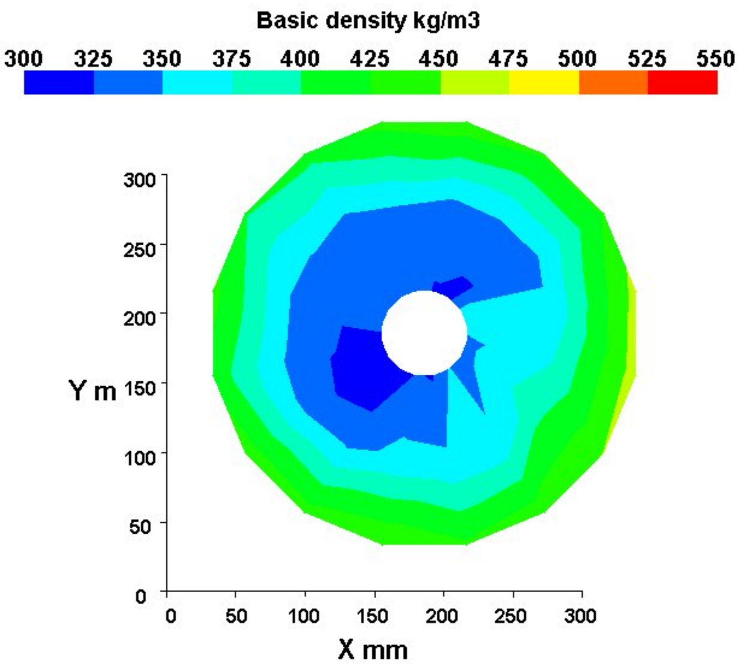

Density variation on disk 3T
Density kg/m3
450,0
400,0
350,0
300,0
1 3 5 7 9 11 13 15
Wedge no. (sector)
Rings 1-5
Rings 5-10
Rings 10-15

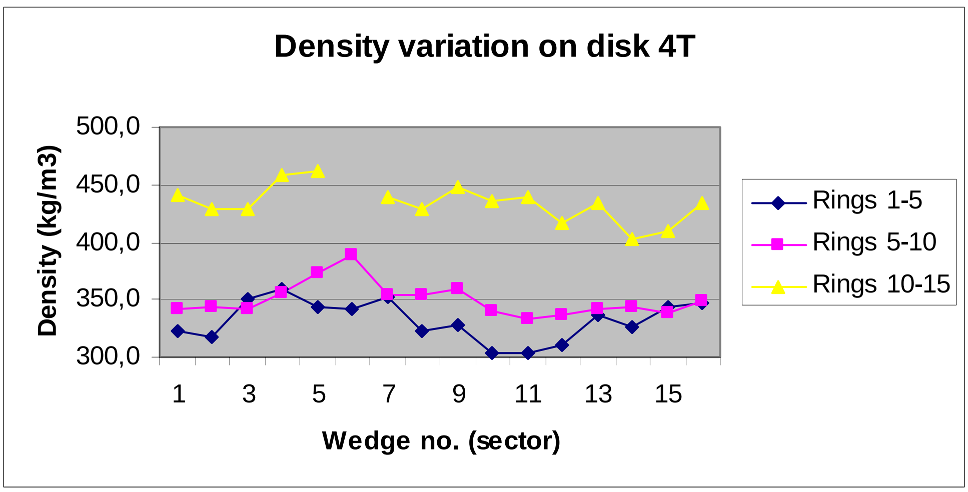

4 B
0.5

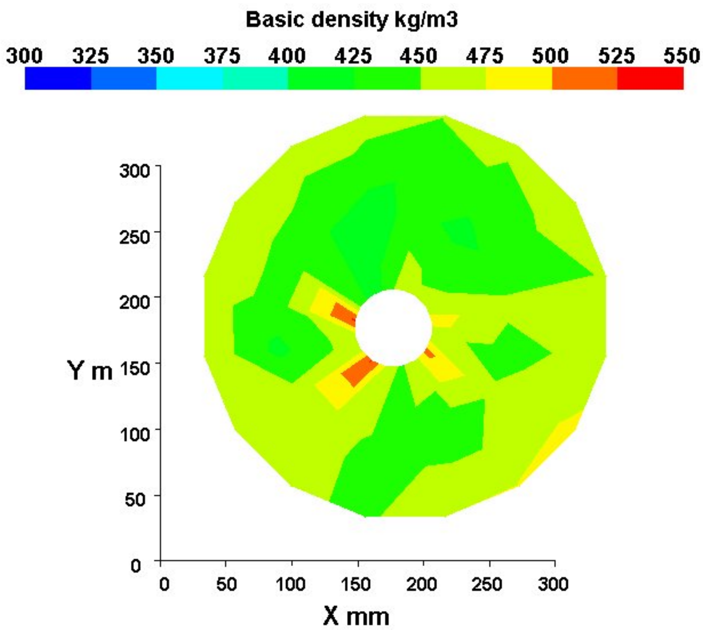

Basic density kg/m3
300
325
350
375
400
425
450
475
500
525
550
Y m
300
250
200
150
100
50
0
0
50
100
150
200
250
300
X mm

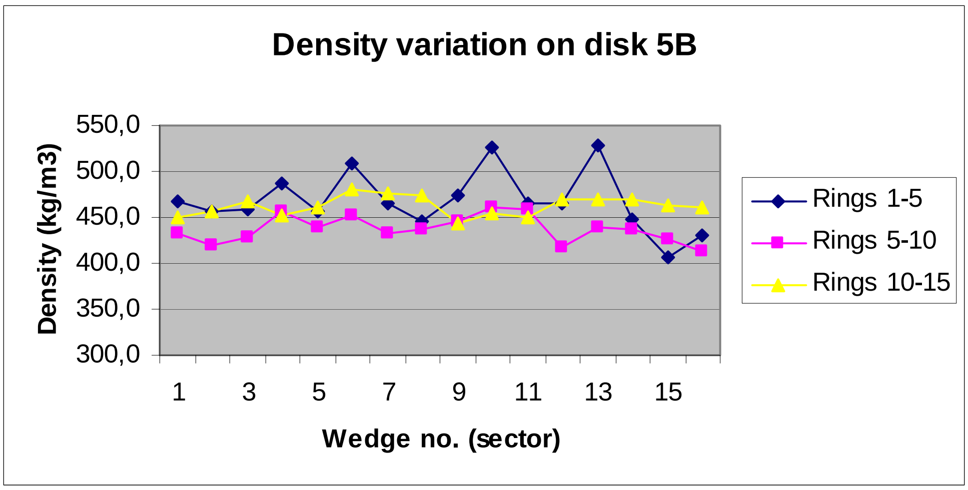

Density variation on disk 4B
Density (kg/k3)
450,0
400,0
350,0
300,0
1
3
5
7
9
11
13
15
Wedge no. (sector)
Rings 1-5
Rings 5-10
Rings 10-15


1
4T

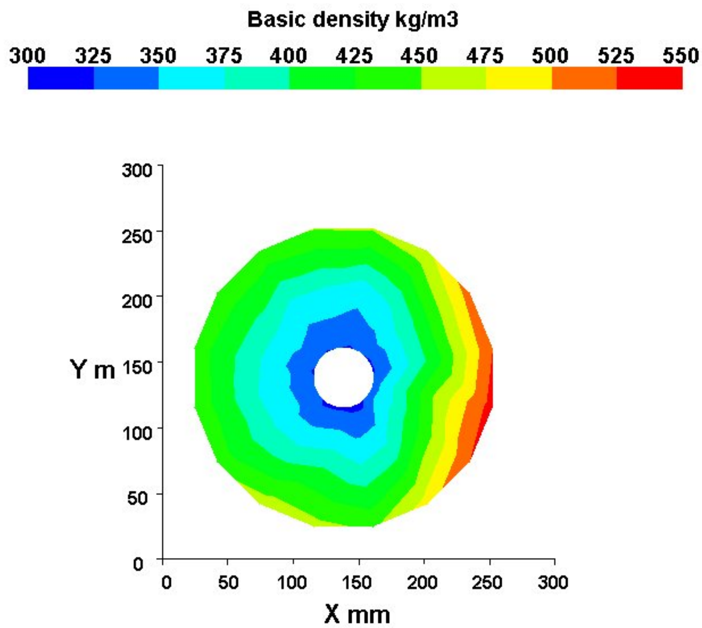

Basic density kg/m3
300 325 350 375 400 425 450 475 500 525 550
Y m
300
250
200
150
100
50
0
0 50 100 150 200 250 300
X mm

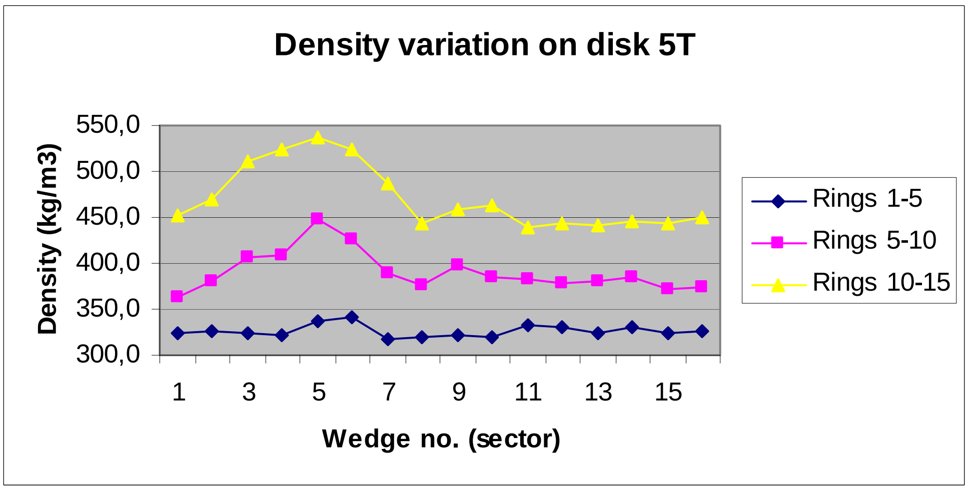

Density variation on disk 4T
Density (kg/m3)
500,0
450,0
400,0
350,0
300,0
1 3 5 7 9 11 13 15
Wedge no. (sector)
Rings 1-5
Rings 5-10
Rings 10-15


Basic density kg/m3
300 325 350 375 400 425 450 475 500 525 550
Y m
300
250
200
150
100
50
0
0 50 100 150 200 250 300
X mm

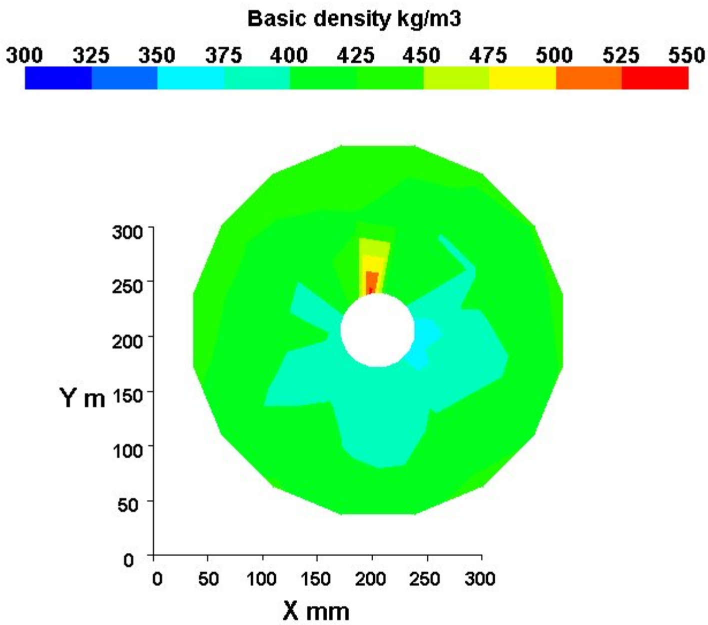

Density variation on disk 5B
Density (kg/m3)
550,0
500,0
450,0
400,0
350,0
300,0
1 3 5 7 9 11 13 15
Wedge no. (sector)
Rings 1-5
Rings 5-10
Rings 10-15

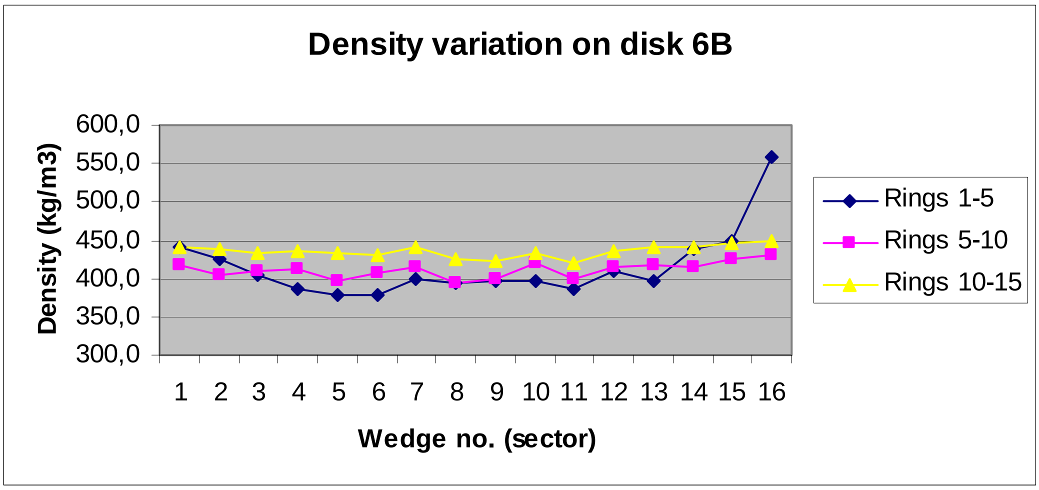

5T

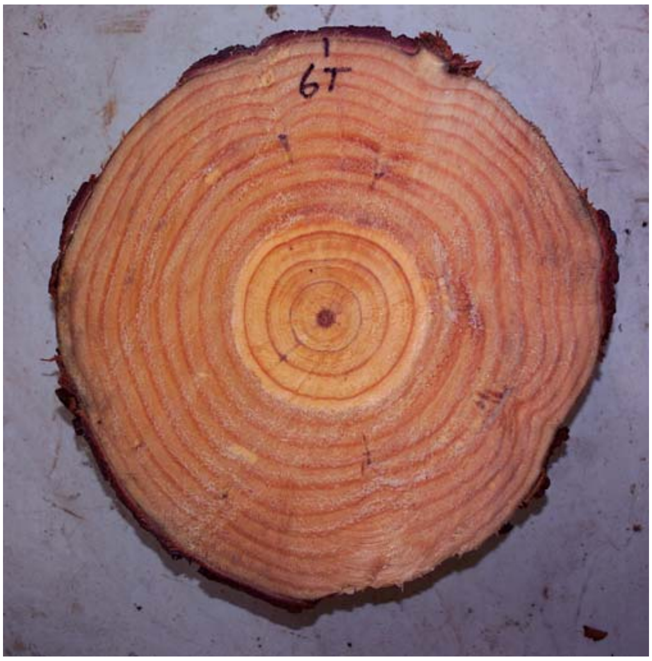

Basic density kg/m3
300 325 350 375 400 425 450 475 500 525 550
300
250
200
Y m 150
100
50
0
0 50 100 150 200 250 300
X mm


Density variation on disk 5T
Density (kg/m3)
550,0
500,0
450,0
400,0
350,0
300,0
1 3 5 7 9 11 13 15
Wedge no. (sector)
Rings 1-5
Rings 5-10
Rings 10-15

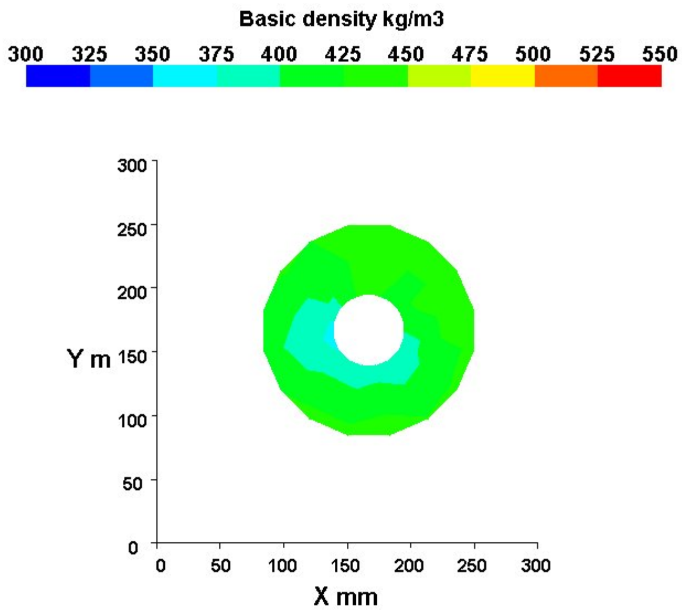

6B


Basic density kg/m3
300 325 350 375 400 425 450 475 500 525 550
Y m
300
250
200
150
100
50
0
0 50 100 150 200 250 300
X mm

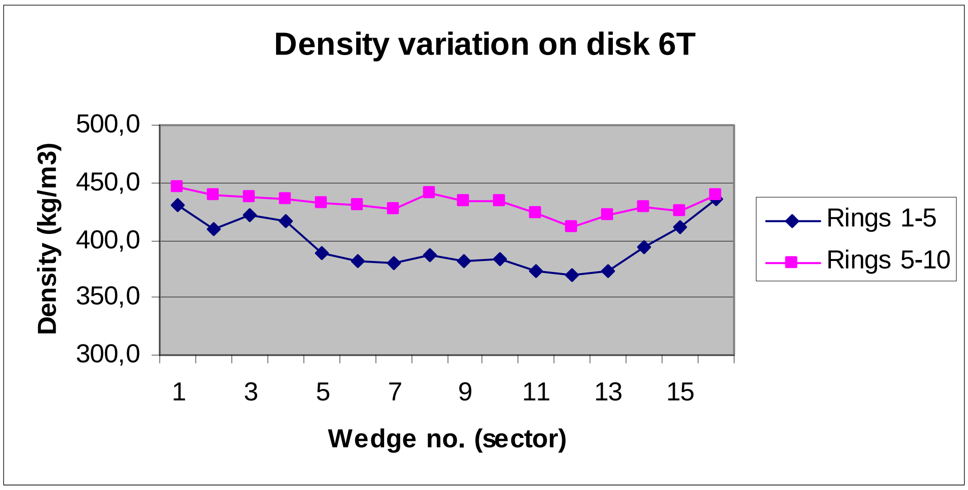

Density variation on disk 6B
Density (kg/m3)
600,0
550,0
500,0
450,0
400,0
350,0
300,0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Wedge no. (sector)
Rings 1-5
Rings 5-10
Rings 10-15



1
6T



Basic density kg/m3
300
325
350
375
400
425
450
475
500
525
550
Y m
X mm
0
50
100
150
200
250
300



Density variation on disk 6T
Density (kg/m3)
500,0
450,0
400,0
350,0
300,0
1
3
5
7
9
11
13
15
Wedge no. (sector)
Rings 1-5
Rings 5-10