Wood Material Features and Technical Defects that Affect the Yield in a Finger Joint Production Process

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ABSTRACT

A cost efficient process is the goal for every production process. In wood manufacturing, each step in the process may affect the material utilization and the cost efficiency. Wood as a material has got high diversity in its inherent features and the different manufacturing steps must be able to handle this. In most end products the proportion of the raw material cost is high. Thus, material utilization and cost efficient processes are of great importance.

The overall aim of the project was to study the potential and problems in manufacturing production processes in terms of material utilization efficiency. A production process of finger jointed bed sides for IKEA was chosen as a study case and its chain of production units are; a sawmill for plank production, a finger joint company producing components and finally a furniture company that produce the end product. The aim of this article is to describe the impact of different raw material and what wood and technical defects that affect the total yield of a manufactured product.

In total 177 logs of three different log types were tested; butt logs, intermediate logs and fresh knot logs. The quality of the wood material was detected and measured by aid of 3D-scanning and X-ray (logs), FinScan (planks), and WoodEye (planks/components) and manual inspection of the final products. With a full traceability data collection the quality of the test material was followed through all steps in the manufacturing chain.

The result show differences between log types in down-grade causes, reject volume and the final yield of accepted products. Also, the test material showed high levels of reject with non-biological background which suggest the need of technical improvements in the finger joint and the furniture manufacturing process. The intermediate log group showed overall the best result.

1. INTRODUCTION

A cost efficient process is the goal for every production process. In most end products the proportion of the raw material cost is high [1]. In wood manufacturing, each processing step affects the material utilization and the cost efficiency. Wood as a material has got high diversity in its inherent wood features and the different manufacturing steps must be able to handle this. Thus, material utilization and cost efficient processes are of great importance.

A lot of research has been made on how to measure, grade and process the wood material focusing on the first part of the wood processing chain [2,3,4,5]. Different technologies to reach improved results in the value chain have been described [6,7,8,9]. Also the last part of the chain has to some

extent been described and evaluated by consumer preference studies [10,11,12]. However, few studies have been presented aiming at describing whole wood product chains together with collecting empirical data about the process and raw material [13,14]. Such data can be used for describing the complexity of raw material allocation through a process but also to improve or build simulation models for future use and studies.

The overall aim of this project was to study the potential and problems in manufacturing production processes in terms of material utilization efficiency. The production of finger jointed bed sides for IKEA was chosen as study case. The motive for choosing this example product is that it is a large volume product and that the finger jointed bed sides had high requirements on final quality. The chain of production units are; a sawmill for plank production, a company producing components and finally a furniture company that produce the end product. The research approach was to follow the raw material, its yield and quality issues, through the whole production process with full traceability of the material.

The aim of this article is to describe the impact of different raw material (here log types) and what wood and technical related defects that affect the total yield of the manufactured products. In relation to the whole project the result presented here focus on the later part of the production chain; the finger joint production line and the furniture manufacture process.

2. MATERIAL AND METHODS

This study was designed to follow the quality of the wood material through the long chain of operations, from the log yard to the final finger jointed bed side product. Three different log types were used; butt logs, intermediate logs and fresh knot logs (often top logs). The different log types were seen as representing different input raw material qualities into the wood processing chain. The quality of the logs was detected and measured by aid of 3D-scanning and X-ray and at the sawmill the planks were scanned green with a FinScan Board master. At the finger joint company the quality of the planks were scanned and managed by a WoodEye CrossCut system for the production of bed side components. Finally at the furniture company a manual quality inspection of the final products was made. All measured data was documented. The flow of operations is shown in Table 1.

Table 1. Flow of operations and some details for the wood material studied in the project

Place	Action	Details	Dimension
Log yard	Selection of logs Scanning	Three log Q.-types 3D and X-ray	Ø 134-147mm
Sawmill company	Sawing	2x-log	33x120mm
	Scanning Drying	FinScan Board Master 14 % MC	31x115mm
Finger joint company	Planing Scanning Optimization	Symmetric WoodEye Greyscale WE Crosscut	30x114mm
	Finger jointing	To component length	30x114x2018mm
Furniture company	Planing Quality inspection	Symmetric Manually	25x110x2018mm
	Cutting	Both ends	25x110x2005mm

In the study all process parameters were decided to be similar to what was daily used at the time for the test. The focus of the study was to show how the input raw material affects the yield and quality of the final product.

2.1 Test sawing of three groups of log qualities

In total 180 logs were selected from the appropriate sawing class; top diameters 137-174mm. By manual inspection at the log yard three equally sized groups of butt, intermediate and fresh knot logs was selected. These three types of log qualities represent the normal range of variety in input material quality at the present sawmill. During the 3D- and X-ray scanning this first manual log type classification was verified and some logs were moved from one log type group to another. Each group of logs was sawn with a 2X-log pattern to two 33x120mm centre planks. The side boards were not incorporated in this study. After the sawing, uncertainty occurred about the identity of the planks from three logs. These planks were decided not to be processed further. Thus, the test set of logs sum to total 177 logs and the results from sawing can be seen in Fig. 1.

Log type	Butt	Intermediate	Fresh knot
Quantity	56	55	66

31x115mm 2X-log
Quantity	112	110	132
Vol.yield(%)	33	34	31

Fig. 1. Three groups of logs with different log qualities were selected from top diameters between 137-174mm. The figure shows the amount of planks in each group together with the yield expressed as the dried centre plank volume in percentage of the log volume.

Immediately after sawing the planks were ID-marked, then scanned (green) by aid of a FinScan Board Master and kiln dried to 14% MC. Since it was in wintertime (cold and dry) the final bed side product reached a final MC of 8-10% without any further drying. Normally, at the sawmill all planks are cut in both ends to eliminate drying cracks from log ends. Also, visible (big) defects such as cracks, rot, discolored wood and breakage is cut away at the sawmill. In this study no such operation was made because of the risk of losing traceability of the input raw material.

The data collected from the log scanners and the FinScan Board scanner is not used or analyzed in this article. This report focus on the later part of the product line starting with the finger joint component production.

2.2. Finger jointing for component production

The finger joint production line can be described by following operations, in sequence:

(1)Planing, (2)scanning, (3)optimization, (4)cross cutting, (5)trim cut of short lengths, (6)finger joint cutting, (7)gluing, (8)pressing, (9)cut of final component lengths, (10)packaging and final delivery.

The order of incoming planks was documented and all short length parts (after the cross-cutting operation) were marked with an ID number to make it possible to trace back the accepted raw material to its origin. In the study the three groups of planks (log type) were processed separately.

Each plank was planed 0.5 mm on all sides (op1) to secure a steady feeding at the scanning operation (op2). For this scanning and cross-cut optimization a WoodEye CrossCut system (www.ivab.se) was used. This system had grey scale cameras that scanned all four sides and a laser-profile detector. It scan and test the scanned planks against the current customer defined products quality grades and makes a cut optimization (op3) to obtain maximal yield from the input material. For this particular bed side product only one quality was produced. Its quality requirement setup was the same on all sides of the planks. The quality grade and settings used was the same as the daily production of the bed sides for the furniture producer. Thus, the furniture company quality requirements had earlier been translated into product-specific settings for the WoodEye CrossCut system. The settings were formulated as maximum sizes allowed for each wood defect. These settings are showed in Table 3 - Result. More details about op3: the max and min length was 650mm and 170 mm respectively. A clear end-cut (1mm) of each incoming plank was used. A security distance for cross-cutting close to knots was set to 10 mm. According to the company the precision of the length measurement was ± 5 mm at the crosscutting operation (op4).

A trim cut of 1 mm at both ends of each short length (op5) was automatically made in front of the finger joint cutting to ensure a good result. The finger joint cut (op6) had a depth of 10-11mm. The gluing (op7) was made in this case in batches of seven short cut items which were simultaneously pressed together. The raw bed side components were finally cross cut to ordered length, packed and delivered. The dimension of the delivered components was 30x114x2018 mm and with finger joints visible on the flat sides. Every final component was given an ID mark at its cross section.

2.3. Manufacture of bed sides and quality inspection

Each log type group of components was planed on all sides to the final cross section dimension of 25x110 mm. All components were then taken out from the production line for quality inspection. This manual inspection was made more strict, exact and extreme than usual to point out differences between the input material (here log quality types). A single small defect that in the daily production could be used at non visual parts of the bed was here seen as a reject cause and noted as such. The reason for this was to avoid grey areas, judgment uncertainty and reach as high objectivity as possible.

2.4. Analysis

With focus on the differences between log type quality groups, the yield and reject causes were analyzed and compared. Within the finger joint production the amount of waste material was summarized to show the impact of different raw material. The same was made for the summation of the reject causes of the final bed side product.

3. RESULTS AND DISCUSSION

In this study the input raw material impact on yield and quality issues was inspected for the example product; finger jointed bed sides. The material was studied by means of following the material through the three production lines: Sawmilling, Finger Joint Component (FJC) production and finally the Furniture Component production. Compared with the normal production of this bed side product, the production speed was lowered within the finger joint factory. All production parameters was the same as normally used except one significant difference; at the sawmill, visible cracks, rot and discolored wood is in normal production cut away to improve the performance at the finger joint production line. This was not done in this study to enable traceability of the raw material and also to test the ability of the Wood Eye Cross cut system to cope with this new situation.

3.1 The sawmill step

The three input material groups did already at the sawmill affect the yield which may have impact on how to choose raw material for this product. In Figure 1 (in Material & Methods) the centre plank volume in relation to the log volume is shown. The result was for butt logs 33%, intermediate logs 34% and fresh knot logs 31%. These differences can be explained by the outer shape characteristics. Commonly, fresh knot logs are often associated with high top-taper, butt logs with high butt-taper (and also often crooked) and intermediate logs with low taper and high straightness. Thus, seen from a sawmill point of view intermediate logs should be preferred for this bed side product if the cost per volume is the same for the different kinds of logs.

3.2 The production of finger jointed components

The results from the production of finger jointed components with dimension 30x114x2018mm are shown in Table 2. The yield is expressed as the total length of finger jointed components divided by total input plank length. Again the intermediate log group gave highest yield (86%) followed by the butt log group (81%) and the fresh knot group had the lowest yield (79%).

Table 2. Yield and waste for the Finger Jointed Component (FJC) production.

<i>C. dim.: 30x114x2018mm</i> Resulting parameter	Input material/Log type group			Units
	Butt	Intermediate	Fresh knot	
Input total plank length	502	489	538	metres
Total length FJC	408	422	426	metres
Yield FJC	81	86	79	% of length
Total waste	19	14	21	% of length
Wood Eye Cut waste	15	10	17	% of length
Short pcs mean length	541	545	529	mm
Produced components	202	209	211	pieces
Delivered components [#]	196	204	202	pieces

[#] Due to slow production speed and special requirements within the research project a few produced components were not fully glued. These were lifted out and not delivered to the furniture company.

The causes for these differences can be further studied in Table 3 were the number of defects that were cut away is displayed. Table 3 also displays the settings (the maximum limits for each defect type) that were used for daily production of this bed side product. Inspecting the effect of knots we can see that the Fresh knot log type group had highest waste caused by knots. Surprisingly this

group had the same level of waste caused by black knots as the butt log group. In the table the defect *Fibre knots* are sound knots that are real bright and measured by the laser detector. *Pitch pockets* are frequent causes of waste in all three log type groups even if the intermediate logs had less than the others. The defect *Bark* was not frequent but *Cracks* occurred more often. Our test material was expected to have rather high amount of cracks due to that no crack elimination at the sawmill was done. Fresh knot logs seemed to have the lowest frequency of *Cracks*. The biggest difference between the groups was the detection of *Wane* and *Dimension* errors. The intermediate logs had only a third of detected *Wane* compared to the other two groups. This can be explained by differences in the outer shape of the log types and also how well the sawing class (log dimension) fits the sawing pattern. The defect type *Dimension* is a measure that checks the nominal width and thickness. An error at the plank edge may also fall into this category. *Dimension* is the most frequent cause of waste with the settings used. Fresh knot log and butt log group had higher degree of dimension errors than intermediate group. This again may be explained by differences in outer shape and that the *Dimension* measure also find areas with wane and other edge related problems like breakage.

Table 3. Number of defects cut away as waste in the Wood Eye Cross cut optimization step

(pieces)	Wood material/Log type group			Sum	Settings for max limits of width/length/dept (mm)
Defect type	Butt	Intermediate	Fresh knot		
Sound knot	2	6	11	19	45 / 45
Fibre knot	3	22	48	73	50 / 50
Black knot	41	20	40	101	35 / 35
Pitch pocket	103	76	103	282	1,5 / 15
Bark	6	2	6	14	30 / 30
Cracks	48	36	29	113	0,3 / 100
Wane	159	53	148	360	14 / 14 / 14
Dimension	160	106	224	490	2 / 5
Profile	2	0	0	2	0 / 30 / 0
Sum:	524	321	609		

When analyzing the material efficiency for the FJC line independent from the other production steps it seems that the intermediate log group results in less waste but also the highest average length of the short lengths glued (seen in Table 2).

3.2 The production of the furniture (bed sides)

In this project the most interesting part was the last part, the furniture production step. The goal was to apply an extra strict and precise quality control to map what defects that showed up as vital for the furniture production. This bed side product is particularly sensitive to the shape of the edges. It has got very high requirements on the edges to avoid that the users will hurt themselves (scratches or laceration damages) when using it. Every component that had one or more defect was put aside as reject and the causes was documented.

The proportion of final bed side products that had one or more defects at the manual inspection is shown in Table 4. Normally the total reject proportion lies in between 8-12% according to the furniture company. The very high amount of waste shown in the study can partly be explained by the extra strict quality control but also by details revealed in Figures 2 and 3. Focusing on the differences between the three log type groups and the wood related defects in Table 4 we see that

butt logs results in around 11-12% increase of waste compared with the other log types. Even at the furniture company the intermediate log type group resulted in highest yield.

Table 4. Proportion of produced component length that had one or more defects.

	Butt	Intermediate	Fresh knot
Wood material defects	35	24	23
Technical related defects	14	8	12
Total waste	49	32	35

The different reject causes that was found in the test material is shown in Table 5. The very high levels of waste caused by wood related features can further be analyzed in Fig 2. The most obvious result is that butt logs are associated with detached black knots after planing. Another finding is that the fresh knot group is associated with too big cracks in the centre of the knots but also drying cracks outside the knot (at component edge). The intermediate log type group did not have any typical defects.

Table 5. Reject causes at the quality inspection with corresponding abbreviations

Abbreviation	Wood material defects	Criteria	Assessment
K-size	Knot size too big	size	Measure
K-crack1	Crack in knot-centre	size	Hand
K-crack2	Crack outside knot (black, sound)	size	Hand
K-loss	Detached knot (black, sound)	size	Hand
K-bark	Barkringed knot	N.A.	Size
Top-rupture	Top rupture (forest)	size	Eye
Discolor	Rot/discoloration	N.A.	Eye
Scar	Bole scar or bark pocket	N.A.	Size
Resin-Pocket	Resin pocket	N.A.	Size
Abbreviation	Technical defects		
FingerJoint	Finger joint with defect	N.A.	Eye/hand
Wane	Wane	N.A.	Eye
Wood-loss	Wood material loss (at edge)	N.A.	Eye/hand
PlanerMiss-edge	Planer miss at the edge side	N.A.	Eye/hand
PlanerMiss-flat	Planer miss at the flat side	N.A.	Eye/hand
Cracks	Cracks in clear wood area	N.A.	Eye
Twist	Twisted component	size	Eye
Bow	Bowed component	size	Eye
Roller-mark	Feed-roller marks (sawmill)	N.A.	Eye/hand
Mech-dam.	Mechanical damage (sawmill)	N.A.	Eye/hand

Note: Criteria N.A. stands for not accepted and criteria size for size limited.

Knots that reach the edge of the bed side component cause problems and high risk for reject (from left side in Fig 2, defect no 2-6). This qualitative information may be used for changing the criteria and settings for the Wood Eye cross-cut system aiming at more strict requirements close to the edge zone. Another possible improvement may be to put more strict limits for bark. With current settings very little bark defect areas was cut away (see Table 3). With such a change some of the

Fig. 2. The proportional impact of the wood material related defects found. Metrics: the number of defects divided by the number of rejected components in corresponding log type group.

barkringed knots (*K-bark*) and bole scars (*Scar*) may have been cut away at the previous WE Cross cut operation.

When analyzing Fig 3 the very high amount of waste caused by technical related defects in Table 4 can be explained. Due to that no quality increasing cross-cut operation was done at the sawmill, the planks went to the finger joint production line with higher proportion of cracks, breakage in plank ends, wane and even rot than normal. The figure shows how sensitive the Wood Eye Cross Cut system together with the settings of the finger joint gluing line is for changes in input material. The very high proportion of incorrect finger joints is partly described by too small clear end-cut of each incoming plank (1 mm was used). This resulted in finger joints that did not bottomed. Also the problem with cracks can be explained similarly. A lot of log end cracks followed the input material and caused non-normal levels of waste. Also, with current settings (*Dimension* and *Profile* in Table 3) a large amount of edge related problems initiated already at the sawmill was noted as defect causes. Even roller marks from the harvester and breakage from the debarking machine were visible at the edges of the bed sides. This problem may also indicate that the cross section dimension of the input planks should be increased. The planing operation at the furniture company was badly centered

Fig. 3. The proportional impact of the technical related defects found. Metrics: the number of defects divided by the number of rejected components in corresponding log type group.

for the butt logs (*PlanerMiss-edge*) and show high sensitivity for positioning and supports such a conclusion. Thus, the results shown in Fig 3 emphasize that the current settings for the Wood Eye system need to be changed if similar input raw material will be processed.

A high proportion of the finger joints were defect because of knots too close to the joint. Therefore a special inspection was made of all finger joints for all bed side components that were classified as defect (all causes). All knots closer than 25 mm to nearest finger tip was described by following parameters: Knot size, type, shape, side of the plank, the distance to finger joint and finally if the knot gave rise to a defect finger joint. The result is shown in Table 6.

Table 6. Share of knots causing defect finger joints in different categories. (Finger joint, F-J)

	Number of knots [#]	Causing F-J defect	Share of defect F-J (%)
Sapwood side	234	67	29
Pith side	124	14	11
Sound knots	274	71	26
Black knots	115	10	9
Round knots	223	37	17
Oval knots	113	23	20
Splay knots	40	10	25

[#] The sum of knots for the three parts differ due to difficulties in classification of the knots.

Analyzing the table we see that knots on the *Sapwood side* more often cause problem when being close to the finger joint compared to *Pith side* knots. The knots on the sapwood side were in average larger than the pith side knots. Also, *Sound knots* cause more problem than *Black knots*, which can be explained by having larger average size and that the wood around a sound knot has got more fibre irregularities than a black knot. Concerning the shape of knots, *Oval* and *splay knots* close to the finger joint cause more frequent problem than *Round knots*. The data showed also that with increased knot size the risk for defect finger joint increase. Also, a strong dependency between the knot distance to finger joint and the risk for defect joint was found, see Fig 4.

Fig. 4. Share of defect finger joints dependent on knot distance to finger joint (round knots)

According to the finger joint company they normally apply a security zone of 10 mm between defect and finger joint. This setting may be needed to increase due to that the length measurement precision is ± 5 mm at cross cutting operation. The empirical data showed however too many knots right in the centre or close to the finger joints.

4. CONCLUSIONS

To choose the right input material and also to process it in a way that minimizes the final rejected volume at the end of the processing chain was important due to the reject cost is high for such a long product (2005mm). The advantage of having all data for a whole product chain is that it can be used for optimizing the complete chain. A very high proportion of defects were found within the final bed side product. The extra strict quality control together with the full traceable material data showed results which point out weaknesses in the process chain and areas that can be improved. Some interesting findings follow:

- In the current log dimension the intermediate log group gave highest yield and less problems at all three process units. Butt logs gave lowest yield and caused highest amount of reject mostly due to black knots that detached after the final planing.
- Knots (all types and sizes) do cause problems but only when they reach the edges of the component and when being too close to the finger joint. Also knots cause more problems on the sapwood side of the plank. Both these results point out that some kind of zone-related settings for the Wood Eye optimization step would decrease the reject volume of finished bed side products.
- Very little bark defects were cut away at the finger joint factory but many reject causes related to bark was found in the end product. Higher sensitivity for bark may reduce the amount of wane, barkringed knots, bole scars and to some extent top breakage which often has got bark inclusion.
- A surprisingly high degree of technical related defect causes was found in the study material. These problems originated from the sawmill step and the chosen research strategy not to do any pre cutting of obvious defects such as cracks, rot, discolored wood and breakage at component-ends. The results show how sensitive an existing wood processing chain can be for changes in input material. Also, it shows that the used (current) settings of the Wood Eye cross cut system did not cope with the new situation. Changes in the settings may to some extent solve some of the problems. The test also pointed out the need of having the right dimension and high precision in each process to avoid reject of the final product.

The study resulted in a revision of the settings of the WoodEye CrossCut system and many parameters were changed in line with the findings presented here. This study is unique in that sense that it contains process and material data for a whole wood product chain. The complexity of material allocation through a wood product process has been described and some results are of general interest and other product or process specific. Questions always appear about what the consequences will be if some parameters are changed. The collected data will be a good base for building and validation of simulation models that can be used for answering such questions.

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