Wax Distribution Quantification Using Digital Image Analysis Techniques

by

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(Abstract)

A wax distribution quantification procedure using digital image analysis and fluorescence microscopy techniques was developed. The procedure was evaluated by investigating the effect that variable application rates have on wax distribution. The effect of emulsion type and application on IB strength, thickness swell, water absorption, and linear expansion of flakeboard panels were also investigated.

Tests revealed that increasing the wax emulsion flow rate and application pressure had a significant affect on wax coverage. A lower amount of flake surface area was covered when the flow rate and air pressure was increased. It was also found that the presence of resin on the flakes affected wax coverage. Resin presence generally increased the wax coverage variability. The application flow rate and pressure also seemed to affect the interaction present between the resin and wax spots.

The fractional coverage area of spot size classes was also significantly affected by the emulsion's application parameters. Increasing the flow rate and air pressure was shown to create more variable wax spot distributions. The presence of resin spots on the flakes was also shown to significantly affect the

spot size distribution. Changes in the emulsion flow rate and application air pressure also appeared to have a significant affect on wax spot distribution.

The type of wax emulsion used, as well as increased application flow rate and pressure, was shown to significantly affect both 2 hour and 24 hour water absorption (by weight). It was found that using a soap based emulsion improved the water absorption characteristics, and that increasing the emulsion's application flow rate and air pressure adversely affected the water absorption.

Differences in IB strength and 24 hour thickness swell were also seen between the panels made using increased flow rate and pressure and the panels produced with standard parameters. However, due to possible influence of press malfunctions on the boards performance, conclusions about the effect of increased parameters can not be clearly drawn. No significant difference in linear expansion was seen for any of the samples tested.

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1.0 Introduction

The use of wood composites, such as particleboard and flakeboard, has grown at a steady pace for the last 50 years. Wood composite panels are used in large quantities by many industries, including the construction and furniture manufacturing industries. Due to their widespread use and continued growth, it has become increasingly important to ensure that the wood composites produced today are of the highest possible quality. For this reason manufacturers are emphasizing the importance of optimizing all of the process parameters involved in board production. Although optimizing press operations and resin distribution has always been a concern, optimizing the use and performance of wax sizing has often been overlooked. For this reason, it is the purpose of this project to develop a method that can be used as a quality control measure for evaluating wax sizing performance.

2.0 Project Objectives

1) To develop a post-blending wax distribution quantification procedure using microscopy and digital image analysis techniques.
2) To evaluate the technique developed by determining the effect that different wax emulsion types, and application parameters (ie; increase in additive application flow rate and air pressure), have on wax distributions.
3) Determine the effect that wax distribution has on the thickness swell, water absorption, linear expansion, and internal bond properties of conventionally manufactured flakeboard properties.

3.0 Literature Review

3.1 Wax Sizing in Wood Based Composites

3.1.1 Chemistry and Properties of Wax

The base wax most commonly used in wood based composite manufacture is paraffin wax$_{15}$. This type of wax is a naturally occurring hydrocarbon consisting of large numbers of methylene groups$_{22}$. The paraffins commonly used in wood based composites are typically low grade and tend to contain both straight chain, or n-paraffins, and branched chain, or iso-paraffins. The amount of n- or iso-paraffins present in the wax depends upon both the origin of the paraffin, as well as the extent that the wax was refined$_{22}$.

It has been shown by Roffael et al. that the sizing properties of paraffin wax can be affected by its chemistry. For example, the effectiveness of the sizing was shown to increase as the average chain length of the n-paraffin portion of the wax increases$_{22}$. They observed that the best sizing performance, defined in terms of 24-hr. thickness swell and water absorption characteristics, were obtained when the average chain length was between 28 and 36 methylene groups long for the waxes studied$_{22}$. Roffael et al. also concluded that the sizing characteristics of paraffin generally tended to be better when the percentage of iso-paraffins (branched chain paraffins) present in the wax was kept to a minimum.

3.1.2 Purpose of Wax Sizing

Studies have shown that the performance of wax sizing has a definite impact on the properties of wood composite panels. Proper sizing positively affects the water repellency and dimensional stability of wood composites, while improper sizing can reduce board strength and internal bond, as well as cause problems in subsequent gluing and finishing operations [1,6,19,15]. These facts bring the importance of efficient and proper wax sizing to the forefront of wood composite manufacture.

The efficiency and performance of wax sizing is dependent upon several factors. Among these are: the properties of the wax used, the form the wax is in (ie; molten vs. dispersion), the process temperature and pressure, and blending techniques [22,19,15]. However, wax sizing performance is thought to be most strongly affected by the wax distribution on the raw particles, and within the finished board itself [6,19,15]. Therefore, the necessity of having a simple and effective method for quantifying wax distribution is apparent. The presence of such a method would help wood composite manufacturers not only determine what an appropriate wax distribution pattern is, but it would also help improve process quality control prior to pressing. This would in turn create another method that could be used to prevent the production of costly substandard boards.

Past researchers have developed various techniques that can be used to qualitatively observe wax distribution in wood composites. Pecina (1966) mixed paraffin wax with anthracene, a fluorescent dye, prior to emulsification and then blended the wax emulsion with wood particles[21]. This enabled him to study the distribution and coverage of the stained wax, which became visible under ultraviolet light (300 - 400nm)[19,21]. In another study, Berrong (1968), also mixed a fluorescent stain in neat wax emulsion prior to blending. After blending, he qualitatively observed the apparent wax distribution using an ultraviolet light source[3].

Although both of the aforementioned methods were successful in observing the wax spot distribution, using these methods in a production environment would not be feasible. For example, both methods involve dying the wax prior to application. In an industrial environment this would not be possible due to the shear magnitude of the amount of wax used in a given shift. Also, when mixing the dye with a wax emulsion prior to blending, it is impossible to insure that the dye actually stays with the wax throughout the furnish preparation process. For effective and accurate wax quantification this is a necessity. Therefore, the need for a "post-blending" evaluation technique is obvious.

3.2 Image Analysis

Image analysis or digital image processing is commonly used to measure or characterize a material by analyzing a captured image[23,24]. This type of analysis method uses the different characteristic gray levels of an object to study and analyze the material, as well as to separate the features of interest from the rest of the object[23,24]. Image analysis is commonly used in areas where the accuracy and reproducibility of quantified visual data is important[23,24]. For instance, it is commonly used in studying the characteristics of different materials, both organic and inorganic[23,24]. Image analysis is also used as a quality control technique in several industries. For example, the electronics industry uses image analysis as a QC technique in printed circuit board manufacture[23,24].

3.2.1 Applications of Image Analysis in Wood Science

Image analysis techniques have been employed to some extent in the wood science field. For example, Ilic et al. used image processing to quantify the various anatomical features of wood. Their study describes methods that can be used to measure such features as cell wall area, lumen area and diameter, as well as fiber length, just to name a few[7]. Other applications for image analysis in wood science was summarized by McMillan (1982). Applications mentioned include using image analysis to characterize the dimensional stability and failure mechanisms in wood, as well as in quality control situations where image analysis can be used to detect faulty parts[16]. McMillan (1982) also mentions using image analysis as a method to quantify surface roughness and tool wear in machining, and to measure treatment effectiveness in preservation applications.

Image analysis has recently seen some use in the area of wood composites. For instance, image processing techniques have been used to describe the surface roughness of plywood veneers, as well as the percent of wood failure in plywood shear specimens[4,17,18]. Geimer et al. (1988) used image analysis to classify types of wood flake furnish. They accomplished this by using a coordinate system to describe the shape and dimensions of various types of wood flakes[5]. Resin distribution and penetration has also been studied using image analysis techniques. Kuo et al. used fluorescence microscopy and digital image processing techniques to characterize the distribution of phenol formaldehyde resin on filter paper. Johnson et al. (1991) also used a combination of fluorescence microscopy and digital image analysis techniques to quantify the resin penetration attained with different types of liquid phenol formaldehyde resins. His report indicates that the resin penetration attained is affected by the molecular weight distribution of the pre-polymer, with penetration decreasing as molecular weight distribution increases[10]. Johnson previously looked at penetration differences attained when using a polymeric methyl-diisocyanate resin as opposed to an aqueous phenol formaldehyde[9].

4.0 Preliminary Study

A preliminary study was conducted to evaluate a quantification method being developed. The evaluation was accomplished by investigating the effect that various application air pressures (nozzle air pressures) have on wax distribution and wax spot size on blended wood flakes. The following is a brief summary of the experimental procedure, as well as the results of the study.

4.1 Experimental Procedure

4.1.1 Flake Manufacture:

Yellow Poplar flakes with average thickness of 0.030 inches, were prepared using a CAE Machinery disc flaker equipped with a 3 foot diameter cutting disc. The flakes ranged from 0.5 to 1 inch in width , and from 2.5 to 3.5 inch in length. After manufacture, the flakes were oven dried to 5% moisture content, and then stored in plastic bags at ambient conditions until the study commenced.

4.1.2 Wax Application :

To simulate industry conditions, the wax emulsion was applied to the flakes at a level of 1% wax solids, based on the oven dry wood weight. The wax emulsion used was obtained from the Dominion Chemical Company (Petersburg, Virginia).

The air pressures used for atomization ranged from 20 psi to 60 psi. This range of pressures is commonly used in industry to apply both resins and waxes, and should yield wax distributions comparable to those found in industry$_{15}$. Refer to **Table 1** for the batches and their respective application pressures.

Table 1 : Batch Classification used in the preliminary study.

Batch Group	Application Pressure
DC20	20 psi
DC40	40 psi
DC60	60 psi

4.1.3 Blending Procedure and Flake Selection:

The wax emulsion was applied using a 4 foot diameter rotating blender. For additive application the blender was equipped with a Cole Parmer "Master Flex" pump (model 7553-00) that is connected to a Binks Model 603V external mix pressure fed spray gun fitted with a 64vt - 64pa nozzle. This particular nozzle setup has an orifice size of 0.064 inches (64vt) and is capable of moving 12.1 cfm of air at 30 psi. Refer to **Appendix B1** for a diagram of the blender used.

Once the wax emulsion was applied, the flake batches were post blended for 5 minutes before being removed from the blender. Post-blending refers to continued flake agitation by the blender, after the additives are applied. This was done to further randomly mix the flakes and achieve better distribution throughout the furnish. After blending, fifteen flakes from each batch were hand selected for quantification. In retrospect, due to the amount of human input, this sampling method did not produce a true random sample and may have led to a systematic error.

4.1.4 Quantification Procedure:

4.1.4.1 Equipment Used:

The wax distribution was quantified using fluorescence microscopy and digital image analysis techniques. The imaging system used includes : a Carl Zeiss Axioskop (equipped for both general and fluorescence microscopy), a DAGE MTI CCD-72 series video camera, a WIN 386 Model AT personal computer fitted with an Image 1 A/T (v. 4.1) digital image analysis program, and a SONY Trinitron High Resolution Monitor. The imaging software used is capable of distinguishing 256 different gray levels (0 - 255) and has a measuring area capability of 512 x 480 pixels (245,760 pixels). Refer to **Table 2** for the system resolutions at different objective magnification levels. A diagram depicting the image analysis system used can be found in **Appendix B2**.

Table 2 : System resolution at various magnifications. The resolution is defined as the area measured per pixel (ie; region area divided by the total number of pixels in the measuring region)

Objective Magnification	Area Measured per Pixel (square micrometers)
2.5 x	29.53
4.0 x	13.18
10.0 x	2.15
20.0 x	0.538
40.0 x	0.134

4.1.4.2 Staining Procedure :

To increase the contrast between the wax and the wood, the flakes to be examined were immersed in a 0.5% aqueous stain solution (based on the solids weight) for three hours. The stain used was a 50/50 solution of Acridine Orange and Rhodamine 6G, both of which are fluorescent stains. Staining the flakes also allowed better image characterization.

The above stain solution was chosen because this combination yielded the best contrast between the flakes and the applied wax during preliminary studies. Other methods investigated included "single stain" applications, solvent extraction of the wax, and flake surface enhancement (using diluted paint) followed by abrasive removal of the paint off of the wax. Refer to **Appendix A, Table A1** for the different stains and stain concentrations investigated.

4.1.4.3 Wax Spot Confirmation

To confirm that the dark spots observed on the flakes were wax spots, a surface analysis technique was performed on both stained and unstained flakes. The analysis technique used is known as ESCA (electron spectroscopy for chemical analysis). This technique bombards a specific region of a surface with monoenergetic x-rays, and then uses the emitted photo-electron intensity to identify surface substances present. As expected, the ESCA scans of the wax spots and the wood samples were different, and indicated that the suspected wax spots contained chemical constituents indicative of wax (ie; very high carbon content). Refer to **Figures 1** and **2** for the ESCA scans that were obtained for both a wood sample and wax spot.

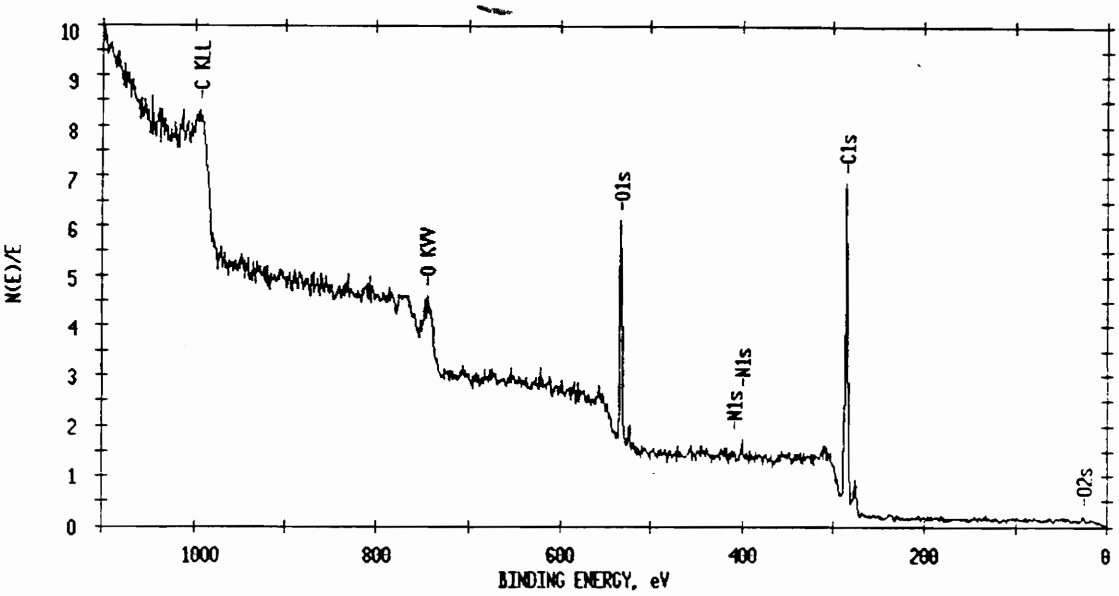


Figure 1 : ESCA scan of wood sample. (Scale factor = 1.206 kc/s, Offset = 0.048 kc/s, Pass energy = 44.750 eV Mg 400 W)

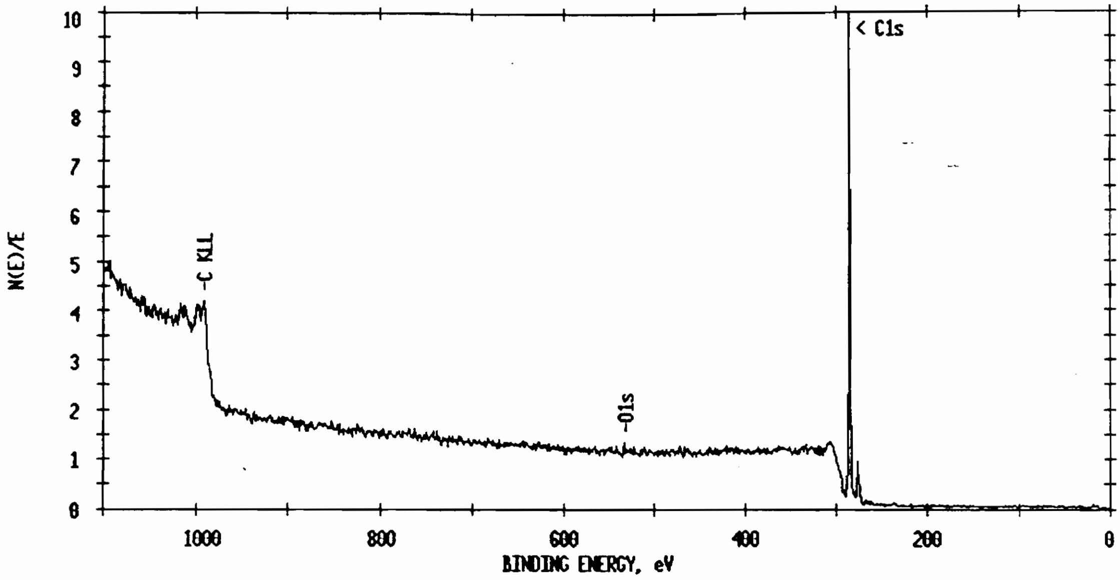


Figure 2: ESCA scan of wax spot. (Scale factor = 4.178 kc/s, Offset = 0.092 kc/s, Pass energy = 44.750 eV Mg 400 W)

4.1.4.4 Quantification Techniques :

4.1.4.4.1 Average dust size measurements and filtering:

Due to the fact that dust particles on flakes appear to have similar features as small wax spots, their presence had to be dealt with to insure they would not be quantified. This was accomplished by obtaining the average dust particle size and then configuring an internal filter within the Image 1 A/T software that would omit particles that are the same size, and smaller.

The average dust particle size was determined by taking ten measurements on fifteen flakes. These measurements indicated that the average dust particle size was 262 μm^2 (2.62×10^{-4} mm^2). In retrospect, this may not have been the best filtering method to use, due to the fact that some of the smallest wax spots may have been inadvertently filtered out with the dust particles.

4.1.4.4.2 Distribution Quantification :

The wax distributions were measured using a 2.5x objective, which corresponds to 88x on the image monitor. This magnification was used because it presented the largest field of view for measurement. However, due to the imaging systems resolution at this magnification it is possible that not all of the wax present on the flakes was quantified. Refer to **Table 3** for the monitor magnifications and field of views specific to the different objective magnifications.

Table 3 : Monitor field of views. The monitor magnification levels were obtained by developing a video transfer function for the video system. F.O.V. refers to the "Field of View" of the monitor at the different magnifications.

Objective Magnification	Monitor Magnification	Monitor F.O.V. (sq. mm)
2.5 x	88 x	7.259
4.0 x	135 x	3.239
10 x	340 x	0.529
20 x	670 x	0.132
40 x	1320 x	0.033

The features to be measured were chosen on the basis of their characteristic brightness level, or shade of gray. This selection process was done manually, and is commonly referred to as "thresholding". After the image's features of interest are chosen (thresholded), the program analyzes the image and produces various statistical descriptors. Some common descriptors are average spot area, percent flake area (occupied by spots), average perimeter and diameter, among others.

4.1.5 Statistical Evaluation :

Two sample t-tests and ANOVA's were performed to identify any significant differences that may exist between the different groups. The data was assumed to be normally distributed. The statistical tests were performed using Minitab (version 8.2) manufactured by Minitab Inc., located in State College, Pa.

4.2 Preliminary Report Results

4.2.1 Affect of Application Pressure:

It was observed that a larger flake area was covered when 20 psi was the application pressure than when 40 or 60 psi were used. Two-sample t-tests conducted between the different data sets showed a significant difference, at the 95% confidence level, between the coverage areas observed for batch DC20 and the coverage areas observed for batches DC40 and DC60. These observations infer that higher wax coverage of the flakes' surfaces can be obtained at lower atomization pressures. However, due to the noticeably large difference in coverage between the pressures, it can be inferred that some over-spray may have occurred at the higher air pressures (40 and 60 psi). This would have resulted in some of the wax being applied to the sides of the blender instead of the furnish, therefore decreasing the measured wax coverage. Refer to **Figure 3** for the relationships seen between the observed percent flake area that was covered by wax.

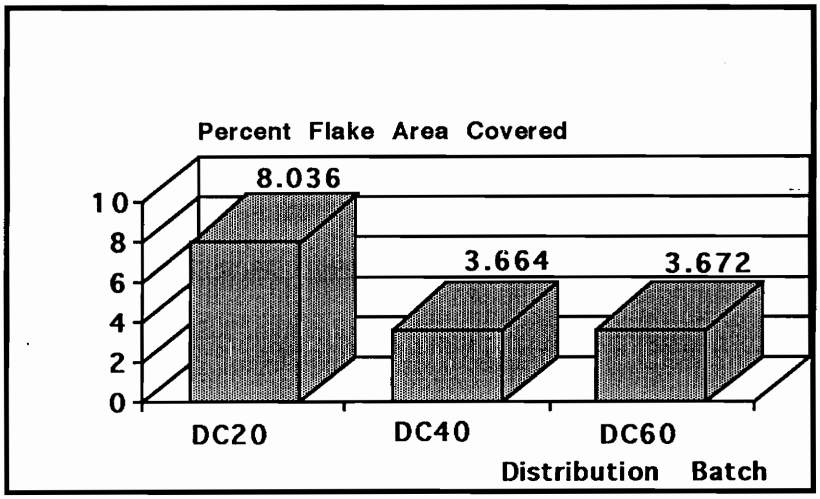


Figure 3 : Percent of flake area covered versus distribution batch. (DC20 = 20psi, DC40 = 40psi, DC60 = 60psi)

No significant difference in coverage was observed between batches DC40 and DC60. This observation may imply that once a certain application pressure is reached, the pressure is no longer an influencing factor in creating the observed distribution. Refer to **Table 4** for a summary of the wax coverage data obtained at the different application pressures.

Table 4 : Summary of average percent flake area covered. The difference between the maximum and minimum percent flake area covered, is due to some of the chosen flakes having very little, if any, wax on them

Batch	Appl. Press. (psi)	Avg % Area Covered	Standard Deviation	Max. % Area Covered	Min. % Area Covered
DC20	20	8.036	4.479	29.867	0.62
DC40	40	3.664	2.407	14.078	0.513
DC60	60	3.672	2.501	13.928	0.498

A difference in the average size of the wax spots between the groups was also noticed. On average, the wax spots observed in DC20 where significantly larger, at the 95% confidence level, than those observed in DC40 and DC60. However, no significant difference in spot size was observed between DC40 and DC60. The wax spot size trend between the three pressures, can be seen in **Figure 4**.

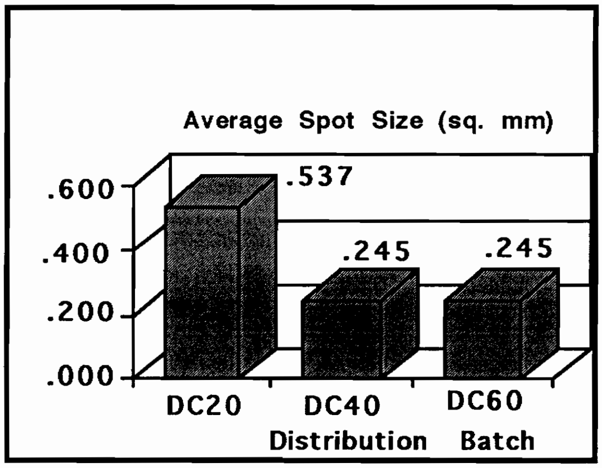


Figure 4 : Average wax spot size versus application pressure. (DC20 = 20psi , DC40 = 40psi, DC60 = 60psi)

The spot size observations are explained by considering the amount of atomization that occurs at the different pressures. At lower pressures, the atomization would not be as severe as at higher pressures, due to the decreased amount of air used to break up the emulsion as it leaves the nozzle. This would lead to the observed difference in the spot sizes seen in DC20, compared to those observed in DC40 and DC60. Refer to **Table 5** for a summary of the spot size data obtained at the different application pressures.

Table 5 : Summary of average wax spot size.

Batch	Appl. Press. (psi)	Avg. Size (sq. mm)	Standard Deviation	Max. Size (sq. mm)	Min. Size (sq. mm)
DC20	20	0.537	0.2996	2	0.041
DC40	40	0.245	0.161	0.941	0.034
DC60	60	0.245	0.167	0.931	0.033

4.2.2 Performance of Quantification Technique :

Overall, the quantification technique used seem to work quite well. Adequate thresholding and measuring of the flakes' image was achieved, and the trends observed seemed to be appropriate. However, some technical problems were encountered and need to be addressed before the current method can be used with confidence.

One problem that must be addressed is the accidental measurement of dust particles with the wax. Although a size filter was configured to filter out the dust, due to their variable size some dust particles may have been measured with the wax. If this occurred, the measured percent flake area covered would not be accurate. Also, since some wax spots may have been the same size as the dust particles, there is a possibility that they may have been filtered out with the dust. Not only would this affect the measured distributions, but the average wax spot size calculated would also be adversely affected.

Another problem noticed involved the flakes themselves. It was observed that while the majority of flakes had a significant amount of wax on them, some flakes had very little, if any. During the manufacture of composite panels this would not be a problem since a random mix of flakes in the formed flake mats is achieved and the distribution of the wax throughout the flake mat is probably the critical factor in sizing performance. However, when considering flake sampling for distribution measurements, between flake variability in distribution could be a serious problem. For example, if a sample pulled from the blender is not representative of the entire batch of flakes, then the measured distribution obtained from the sample may not be accurate. Therefore, it may be necessary to use a larger sample size to account for wax distribution variability.

Finally, due to the system's resolution at 2.5x (88x on monitor) there is a possibility that the smallest wax spots may not have been detected and quantified. This may have lead to a systematic error in the data collection, and will need to be addressed. A solution may be to increase the measurement magnification to 4.0x (135x on monitor). Although the field of view at this magnification is smaller than at 2.5x, increasing the magnification should lead to better results.

4.3.0 Preliminary Study Conclusions

The application air pressures used appear to have an impact on the observed percent flake area covered and average wax spot size. It was observed that both the percent flake area covered and mean spot size was higher at lower application pressures, than at higher application pressures. This is explained by considering the atomization level of the wax emulsion at the different air pressures.

The preliminary data collected indicated that the statistical distribution was not normal. For this reason, a different type of statistical operator may need to be used in determining an appropriate flake sample size and to describe the data in future studies.

5.0 Project Experimental Procedure

5.1 Furnish

To exemplify industry conditions, the flakes used in conducting the project were OSB size flakes obtained from Weyerhaueser's Structurewood OSB mill located in Elkin, NC. The species mix used was 60% softwood, 30% soft hardwood and 10% hard hardwood. The flakes were screened on site using an oscillating screening bed that has the ability to remove flakes with an average width of one quarter inch and less.

5.2 Wax Emulsions and Resin Used

The affect that different wax emulsion types have on distribution, as well as the specified board properties, was investigated using two different types of wax emulsions. One emulsion used a sodium-lignosulfonate based emulsifier and was obtained from the Dominion Chemical Company in Petersburg, VA. The other emulsion used a two-part soap based emulsifier, and was obtained from the Borden Chemical Company. Both emulsions were representative samples of those commonly used in industry.

The resin used was an OSB type aqueous phenol formaldehyde resin that was approximately 53 % solids. The resin was obtained from the Neste Resin Company, and was a representative sample of an industry used resin.

5.3 Sample Batch Preparation

After screening, the flakes were randomly separated into three main groups, one group for each board type. These groups were then subdivided into separate portions for board manufacture. The portion size depended upon the desired oven dry density of the board to be manufactured and on the moisture content on the flakes at the time of manufacture.

5.4 Wax and Resin Application

Wax and resin were applied to the flakes using the same laboratory blender set up used in the aforementioned preliminary study. Refer to **Appendix B1** for a diagram of the blender set up used.

The percentage by weight of wax and resin applied to each batch was representative of the application levels commonly found in industry. The amount of liquid resin and wax applied was based on the oven dry weight of the flakes. The application levels used were 1% and 3.5% solids for the wax emulsions and the resin, respectively.

For two of the three batches, 30 psi was used as the wax application pressure. This pressure was chosen because it was previously determined, by experimentation, to be the optimal application pressure for the current nozzle and blender set up. This pressure should also create a spot size distribution similar to that found in industry since it is within the range commonly used in commercial applications (20 - 60 psi)$_{15}$. To optimize the blender's performance, the nozzle was mounted in the center of the blender, at approximately -60° to the horizontal axis. Mounting the nozzle in this fashion ensured that the maximum number of flakes had approximately equal portions of the respective additives applied to them.

The flow rate of the resin and wax to the spray head was controlled through the use of a Cole-Parmer "Master - Flex" electric fluid pump. Two different flow rates were used. The first, 1.8 ml/s for distilled water, is the optimal flow rate for the blender set up. This rate was used to apply the additives to the flakes used to examine the effect that wax emulsion types have on distribution properties. The second flow rate, 5.6 ml/s for distilled water, was used to examine the effect that application flow rate and increased pressure may have on wax distribution. A pressure of 40 psi as opposed to 30 psi was used to apply the wax emulsion on these flakes.

The wax and resin were applied separately, with the wax emulsion being applied first. Once the additives were applied, the flakes were post-blended for 5 minutes before being removed from the blender. Post-blending refers to continued flake agitation by the blender, after the additive application. This process was done to optimize the distribution of resin and wax throughout the furnish. In theory, the longer the flakes are allowed to tumble and agitate against each other, the higher the probability that each flake will have approximately the same amount of additive applied. It was experimentally determined that for the blender used, 5 minutes was the optimal time.

5.5 Board Production

To examine the effect that wax emulsion type and application may have on board properties, 1/2 inch by 24 inch by 24 inch flakeboard panels, with a target oven dry density of 40 lbs/ft^3 were produced. The panels were manufactured using a conventional press schedule on a 24" by 24" laboratory press. The schedule used was determined from preliminary experiments, and trial and error.

5.6 Wax Distribution Quantification

5.6.1 Flake Sampling

The flakes used in the distribution measurements were removed toward the end of the post-blending period, while the blender was still operating. Flakes with only wax present and flakes with both wax and resin present were gathered out of the blender using a 8" by 8" fine mesh fishing net. Using a net to catch the tumbling flakes, ensured a random and representative flake sample. The flakes were then placed in an oven at 104°C for approximately 24 hours to "set" the resin. This was done to prevent the uncured resin from flowing on the flakes.

To obtain statistical significance (at the 95% level) in the wax distribution analysis, 8 boards per board type were produced. Recall that the board types refer to the boards produced using the two different wax emulsions, and the boards produced with the increased application flow rate and air pressure. This corresponds to three different board types, therefore a total of 24 boards were manufactured. Since the statistical model developed required 15 flakes per board, a sample size of 120 flakes per board type was used.

The flake sample size was calculated from data collected during a pilot study conducted to determine the amount of blending variability present at 30 psi. This study involved blending three batches of flakes at 30 psi, randomly selecting fifteen flakes for wax spot measurement (the flakes were measured two times, five on each side), and then statistically evaluating and examining the data. Since the skewness of the data was known, due to observations made during the preliminary study, a F-distribution function was chosen to calculate the sample sizes[20]. This type of distribution is non-symmetrical, bounded on one side, and can only assume positive values, all of which characterize the observations made during the pressure study[20].

5.6.2 Sample Preparation

Due to the inherent chemical differences between the two types of wax emulsions used, different sample preparation procedures were needed for each wax emulsion type.

5.6.2.1 Lignosulfonate Based Emulsion :

Although the staining procedure used during the preliminary study worked well, another procedure had to be developed to study the wax distribution in this study. This was due to the fact that the aforementioned procedure failed to develop adequate contrast and recognition between the resin and wax spots that were present on the flakes. Since the objective of this study was to develop a quantification procedure that could be used in industry, the presence of resin on the flakes had to be accounted for. Even though staining the flakes using a 0.5% solution of Acridine Orange and Rhodamine 6G was able to make the wax visible and measurable, the resin present on the flakes posed a thresholding problem because it appeared in the same gray level range as the wax. This made distinguishing the wax spots from the resin spots very difficult. Therefore a new procedure was sought.

Several different methods were examined to distinguish the resin from the wax. One method involved using an image analysis function known as "background subtraction". This operation involved subtracting the gray levels present in one image from the gray levels present in another image. Since PF resin spots are visible on the flakes prior to staining, and the wax used is not, it is possible to acquire and save an image that contains only resin spots. This image could then be "subtracted" from an image taken at the same location on the flake after staining. Since after staining, the wax and the resin appear as the same color, subtracting the before-staining image from the after-staining image should yield an image that only has dark wax spots remaining against a light background. Although in theory this method should have worked, it did not.

The main problems with the above method was the inability to go back to the exact location on the flake to get the after-staining image. Due to the preciseness of the image analysis system being used, it was imperative that the flake be indexed back to the exact same location on the flake after staining as it was before staining when the "background" image was obtained. Even though a measurement template and indexing system were developed, it was found not to be precise enough.

Another problem, that made the background subtraction method variable, is attributed to the staining variability of wood. Since different cuts or orientations of wood stain differently, it was difficult to get the same degree of "subtraction" with every image. This means that although the subtraction method may work well with one flake, it may give different results with another. For these reasons, another method to distinguish the wax from the resin was sought.

For image processing reasons, the ideal situation would be one in which either the resin visually disappeared from the image, or was made to have a visually distinguishable difference from the wax spots. Therefore, staining the flakes prior to measurement appeared to be the most viable method. From the previously mentioned study it was known that the stains being used not only stained the wood, but the wax as well. Acridine Orange is capable of forming hydrogen bonds with the phenol groups in lignin and is therefore also chemically active with the lignosulfonate emulsifier used in the wax emulsion[14]. Due to this type of chemical activity, Acridine Orange may have also been able to bond with the phenol formaldehyde spots present on the flakes. This would have resulted in the resin spots having the same characteristic gray level as wax spots, therefore resulting in the thresholding problems previously mentioned. For this reason, a stain that stained the wax, but did not affect the resin, was sought.

In the preliminary study the flakes were not exposed to any high temperatures, therefore the continued presence of the lignosulfonate emulsifier with the wax was assured. However, since the flakes being used for this distribution study were exposed to high temperatures to set the resin, the continued presence of the emulsifier with the wax was not known and needed to be confirmed. Before and after drying images were taken of several large wax spots to confirm the continued emulsifier and wax association.

Exposure to high temperature had little affect on the wax spots as can be seen in **Figures 5** and **6**, and the continued presence of the emulsifier was thus confirmed. As a secondary confirmation, a small sample of the lignosulfonate emulsion in a watch glass was placed in a dry oven at the same temperature and the length of time as the flakes to determine if the emulsifier stayed with the wax. At the end of the "testing" time the sample was removed and the residue was observed to be a brown homogeneous substance that resembled the liquid emulsion in both color and odor, again confirming the continued co-existence of the wax and the emulsifier after drying.

Figure 5 : Wax spots prior to drying at 219°F.
(mag = 135x; calibration bar is in μm)

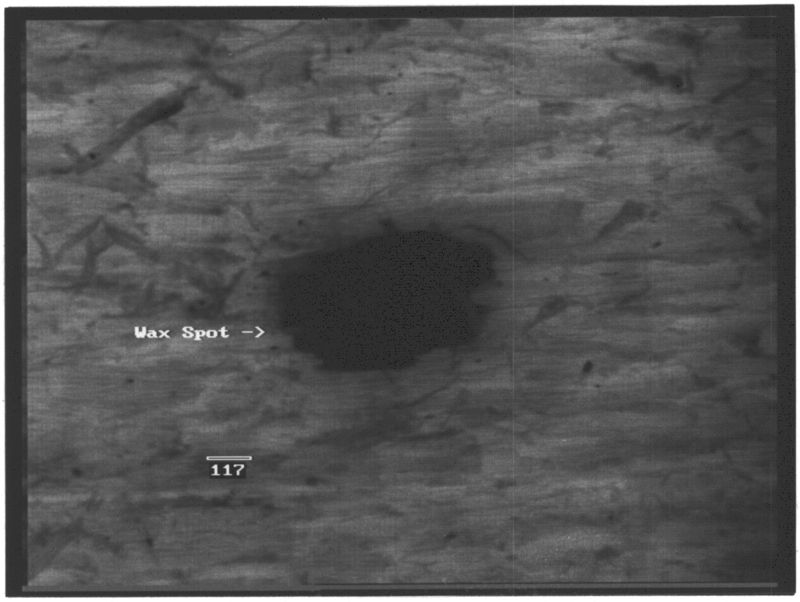


Figure 6 : Wax spots after drying at 219°F for 24 hours. (mag = 135x; calibration bar is in μm)

Since the previously mentioned image processing methods did not produce adequate results in distinguishing wax and resin spots, staining experimentation began again with the most commonly used wood stains. Safranin O and Fast Green FCF were the first two stains tried. Several different concentrations of the stains were experimented with, as well as some counter-staining methods. Refer to **Appendix A, Table A1** for a listing of the concentrations investigated.

After some experimentation, Safranin O was the stain chosen to be used. Like Acridine Orange, Safranin O is used as a lignin stain and had the same affect on the wax spots as Acridine Orange (ie; the wax spots were dark in color against a light wood background). However, unlike Acridine Orange, it was observed that after staining the resin spots on the flakes seemed to "disappear". This observation was confirmed by taking "before and after" images of flakes that had both resin and wax applied. Refer to **Figures 7** and **8** to study these observations.

Figure 7 : Resin spots prior to staining with 0.5% Safranin O. (mag = 135x; calibration bar is in μm)

Figure 8 : Resin spots after staining with 0.5% Safranin O. (mag = 135x; calibration bar is in μm)

After noticing that staining with Safranin O appeared to produce images where the wax and the resin were distinguishable, further experimentation was done to determine the best staining procedure. These experiments revealed that staining the flakes with a 0.5% aqueous solution of Safranin O for 5 minutes produced the best results. To remove any residual stain that remained after soaking, two successive distilled water rinses followed by a final rinse with 95% Ethyl Alcohol (190 proof) were performed. After staining, the flakes were allowed to air dry, and were stored in plastic bags at ambient conditions until testing began.

Although Safranin O is more commonly used in general microscopy, and not fluorescence microscopy, it appeared to work well under a fluorescent light source. Good contrast between the wax and wood was attained using a filter set consisting of a 546nm excitation filter, 580nm dichroic mirror, and a 590nm low pass barrier filter. Refer to **Appendix C** for a description of the microscope used, and **Table C1** for the filter sets that were experimented with.

5.6.2.2 Soap-Based Emulsion

Unlike the lignosulfonate based emulsion, the emulsifier used in the soap based emulsion does not stay with the applied wax after exposure to high heat. For this reason, the same technique used for observing the wax in the above case could not be used to see the soap-based wax spots. Therefore, further experimentation was performed to identify another method that could be used.

Preliminary studies with the soap-based emulsion began by placing 0.5μl droplets at known locations on wood flakes and then observing the wax spots under the aforementioned fluorescence microscope. This investigation revealed that the soap based wax spots were not as visible prior to staining as were the lignosulfonate based wax spots. However, these spots seemed to possess a somewhat fluorescent characteristic, which the lignosulfonate based wax spots lacked. This observation resulted in a need to better characterize the fluorescence properties of the soap-based emulsion.

Since the wax spots appeared to have some fluorescent properties, it was theorized that the fluorescence of the wax was perhaps being overwhelmed or "drowned" by the fluorescence of the lignin component of wood. To see if this was the case small droplets (0.5μl) of the soap based emulsion were placed onto 100% cellulose (cellulose does not fluoresce) filter papers, allowed to dry, and then observed using the fluorescence microscope. Under the different filter sets (Refer to Appendix C, Table C1 for the filter sets used during the study), the wax spots appeared as light spots against a dark cellulose background. This observation seemed to indicate that it may be possible to see the wax spots on wood flakes by somehow altering, or totally blocking, lignin's fluorescence.

In an attempt to change the fluorescence of wood, the same stains used with the lignosulfonate based wax emulsion were used to stain a selected number of flakes that had 0.5μl drops of the soap based emulsion applied. In all the cases, staining did not appear to improve the appearance of the wax spots. As a matter of fact, Toluidine Blue O (a fluorescence inhibitor used in several resin penetration studies to block wood's fluorescence) did not seem to work either. In its case, the flakes appeared extremely dark and no wax spots were seen at all. Due to these poor results, and the knowledge that both wood and the soap based wax spots appeared to fluoresce, the fluorescence properties of each were investigated.

Since fluorescence is a chemical phenomenon, different chemical structures and groups normally possess different, if any, fluorescent properties[13]. Using this idea, an attempt was made to separate the wax and the wood based solely on their respective properties. This involved trying to first characterize the fluorescence properties of both the wax and wood, and then distinguish between the two using any difference that may exist.

The aforementioned properties were investigated using both ultraviolet and fluorescence spectroscopy techniques. Diluted samples of soap-based emulsion, lignosulfonate emulsion, pure paraffin wax (dissolved in hexane), and aqueous phenol formaldehyde resin were studied. Experiments with the lignosulfonate based emulsion and PF resin samples were conducted to see if either possessed any distinguishable properties that could be of use. The paraffin sample was studied for the reason that in the soap-based emulsion case, the emulsifier does not remain with the wax after exposure to high heat. Therefore, the paraffin wax present in the emulsion would be the spot remaining on the flake.

The first fluorescence experimentation conducted was ultraviolet spectroscopy. These experiments were conducted using a Perkin Elmer Lambda 6 UV/Vis Spectrophotometer, with the main goal being to learn if any absorbance activity was present. All of the materials experimented with showed some activity in both the UV (less than 365nm) range and the visible (365-800nm) range. The soap based emulsion was active throughout most of the range, with the greatest activity exhibited in the 200 to 400nm range (a slight absorption peak was seen at 199nm). The paraffin solution was also active in the 200 to 400nm range, with two distinct absorption peaks occurring at 220nm and 275nm. The lignosulfonate based emulsion exhibited a defined peak at 263nm and the phenol formaldehyde solution showed activity throughout the range, with a well defined peak occurring at 564nm. Since all of the materials tested showed absorbance activity, further study of the fluorescence properties of the materials were conducted using fluorescence spectroscopy.

The fluorescence spectroscopy work was performed using a Perkin Elmer Luminescence Spectrometer LS50, networked with a NEC 386sx microcomputer. These spectroscopy experiments were conducted using samples from the same materials used in the UV spectroscopy work. In addition to these materials, a suspension of wood powder (milled using a Wiley mill with a 60 mesh screen) was also tested. This sample was tested in an effort to obtain a range, or spectrum, over which a mixture of wood species fluoresces. Although it is well known that wood fluoresces, literature giving the wavelengths over which it is active could not be located.

For all of the materials tested, a wide scan from 200 to 800nm (both excitation and emission) was performed. No fluorescence was seen with the lignosulfonate based emulsion and, surprisingly, no activity was seen with the aqueous phenol formaldehyde either. The absence of PF fluorescence was unexpected, since the cured PF on the flakes appeared to fluoresce when viewed under the microscope using a filter set consisting of a 546nm excitation filter and a 590nm barrier filter. Refer to **Figure 9** to observe the fluorescence of cured phenol formaldehyde resin spots, and **Figures 10** and **11** for the emission and excitation spectra of the respective materials.

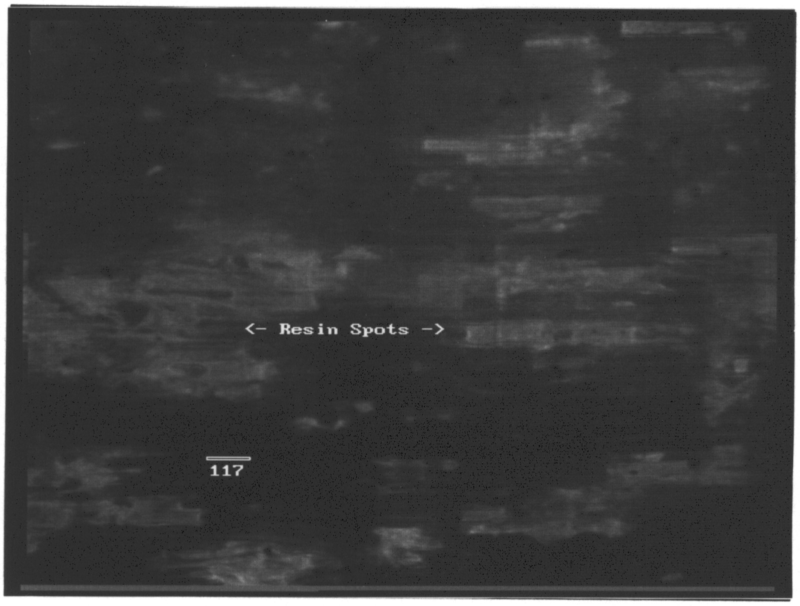


Figure 9 : The observed fluorescence of phenol formaldehyde resin spots under a filter set composed of a H546 excitation filter, FT580 dichroic mirror, and LP590 barrier filter, provided by Carl Zeiss Inc. (magnification = 135x; bar is in μm)

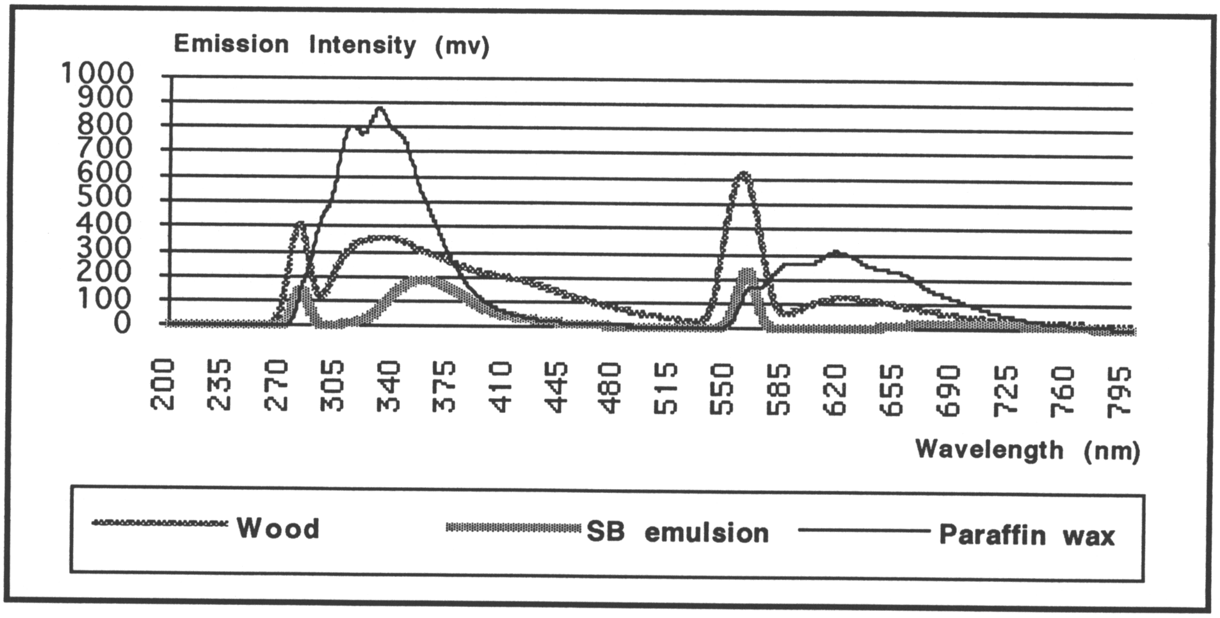


Figure 10 : Emission spectra of the tested materials. The intensity of the wood and soap based emulsion peaks at 280 and 560 most likely resulted from solvent activity, and should therefore be disregarded. The solvent used was distilled water, and produced peaks in these areas

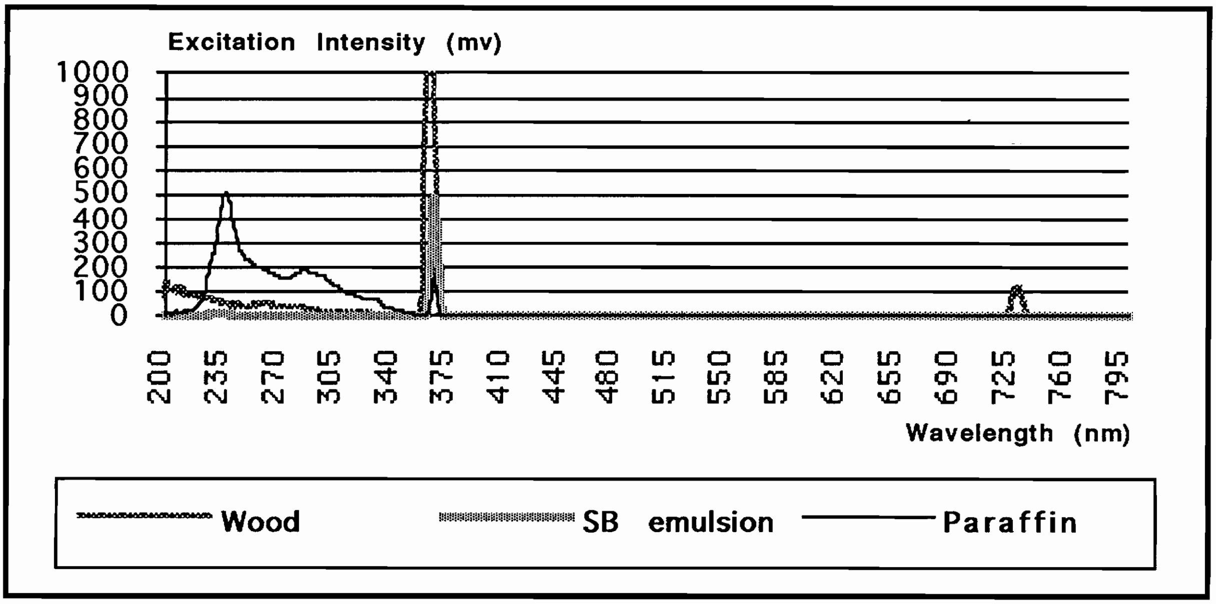


Figure 11: Excitation spectra of the tested materials. The intensity of the wood and soap based emulsion peak at 370nm was most likely affected by solvent activity. The solvent used was distilled water

Fluorescent activity was seen for both the paraffin and soap based emulsion samples, as well as the wood powder sample (as expected). They were all active throughout the range scanned, 200nm to 800nm, and their respective emission scans appeared to have similar forms. The wood powder and soap based emulsion samples were remarkably similar in some areas, as can be seen in Figure 10. The fact that the wood and soap based samples produced similar emission spectra, especially in the 290 to 370nm range, indicates that the samples tested may contain similar chemical constituents. Although the most profound peaks are found around 280 and 560nm, the intensity of these peaks were affected by the solvent used and should therefore be disregarded.

Even though the intensity of the emission spectrums produced by the wood, paraffin and soap based emulsion samples were not exactly alike, they all seemed to be active around the same wavelengths. For instance, the wood and soap based emulsion samples both showed substantial emission activity in the 290 to 390nm range, with the pure paraffin sample also showing a peak in this range. These observations lead to the conclusion that with the equipment available, it would not be possible to separate the wax from the wood based solely on the fluorescence properties of the respective substances. Since the samples have similar emission spectra, there is not enough spectral difference between the samples to distinguish them with the current microscope setup available. However, there may be enough to distinguish them using a different, more specific, microscope setup.

Since the UV and fluorescence spectroscopy studies did not yield any conclusive results regarding a method that could be used to distinguish the soap based emulsion spots from the wood, due to time restrictions this wax type was dropped from the study.

5.6.3 Distribution Quantification Procedure:

5.6.3.1 Equipment Used:

The wax distribution was quantified using the same equipment and set up used in the preliminary study, with two exceptions. First, instead of using an objective magnification of 2.5x (88x on monitor), a magnification of 4.0x (135x on monitor) was used. This magnification gave the system a substantially higher measuring resolution, therefore increased the accuracy and precision of the procedure. This magnification also made feature discrimination easier .

Due to differences that exist between the Safranin O and Acridine Orange/Rhodamine 6G stain solutions a different filter set was also used to conduct the study. The filter set used with the Safranin O stained flakes consisted of a H546 excitation filter, FT580 dichroic mirror, and a LP590 barrier filter, all supplied by Carl Zeiss, Inc. This filter set generally produced better contrast between the wax spots and the wood. Refer to **Appendix B2** for a diagram depicting the image analysis system used.

5.6.3.2 Quantification Measurement:

Each flake was measured ten times, five on each side. To prevent any operator bias when choosing the measurement locations, the flakes were placed into a "template" which had five holes machined into each side. The template holes were machined with a diameter slightly larger than the log axis diameter of the image monitor when used with a 4x objective and served to identify the measurement locations. Using a template to identify the measurement areas not only lessened the amount of human decision introduced into the measurements, but it also allowed the individual flakes to be measured in approximately the same general location. This would allow spot size comparisons to be drawn between locations if desired. Refer to **Figure 12** for a schematic of the template used.

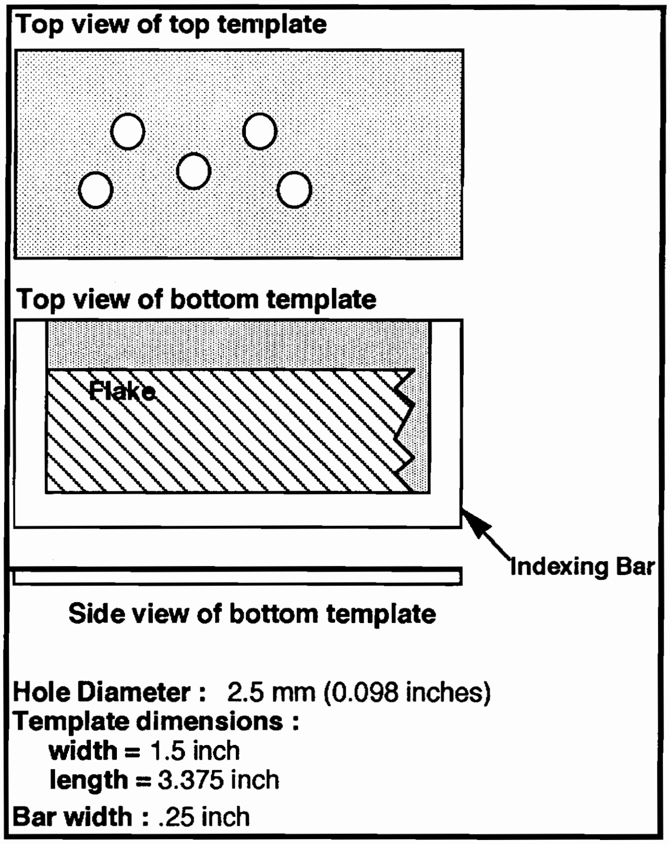


Figure 12 : Schematic of quantification template.

After the measurement location is positioned correctly and the image is acquired and processed as needed, the image is thresholded to identify the features of interest. The program then characterizes the selected features, summarizes the information, and lists several statistical descriptors of the images. Some common descriptors are gray level, perimeter measurements, and longest chord length. For the present project, the main descriptors used were spot size (spot area, μm^2), percent area (area occupied by the wax spots as a percentage of the total measurement area), and the total wax spot count. In addition to these summary descriptors, the spot sizes of the individual spots themselves were also retained. These measurements were used to characterize the spot size distributions observed.

To statistically examine the percent of flake surface area that was covered by wax a general linear model was used$_{20}$. This model was developed in conjunction with the Virginia Tech Statistical Consulting Center, and was used to lessen the affect of coverage variability that may have occurred between the different boards, the individual flakes, as well as the measurement locations on the flakes. The model distinguishes the data by panel type, board, flake, and measurement location, and uses "nesting" to decrease the amount of variability between samples that were obtained from the same panel type and panel. The model itself looks for differences in the data that may exist due to panel type, panel, the presence or absence of resin, and any differences between the flakes that may be present.

5.6.3.3 Image Processing:

The Image 1 A/T imaging system allows the operator to manually select the objects of interest. This selection process, known as thresholding, discriminates the features of interest from the background on the basis of brightness, or gray level. Since the accuracy of the thresholded region tends to rely on the judgment of the operator, it is important to use a thresholding technique that can minimize any "human" error that may take place. This can be done by performing different image enhancement techniques on the selected images which have the ability to improve the contrast between the features of interest and the image's background. The processing techniques used in this study concentrated primarily on improving the sharpness of the image and the contrast between the wax spots and the wood background.

Two different imaging functions were used to improve the contrast and sharpness of the image. The first, known as summation, is the function that is used to acquire the image for measurement. Summation serves to reduce the amount of video signal noise present in an image by performing an arithmetic average of the incoming video signal[8]. The number of image frames averaged determines the amount of noise removed from the image, therefore the higher the number of images averaged the better the image attained. However, summation is also a time function, meaning that the time required to process the image is directly related to the number of image frames that is averaged. The images used in this project were obtained using an average of 128 frames. Summation of more than 128 frames did not significantly improve the image resolution.

Another image processing function used is known as automatic image enhancement. This function increases the contrast of an image by modifying the contrast settings used. This is done by first creating a brightness histogram using the brightness values of the individual pixels. Then, the minimum and maximum brightness values are identified and reset to become black and white, respectively[8]. Doing this creates an image that contains a higher degree of contrast between the different features present. For example, in the images being studied the wax spots appear dark against a light wood background. Performing automatic enhancement on the image increases the contrast between the wax spots and the wood by turning the wax spots black (or nearly black depending on the darkness of the spot), and the wood background white (or nearly white depending on the degree of staining of the wood). This improves the image by making the boundary distinction between the wax spots and the wood more visible, and the subsequent image thresholding more accurate.

A third processing function used did not increase the sharpness or contrast of the image, but rather it removed or deactivated specific areas from the image for measurement. This function is known as a "paint" function, and it was used to manually select the places within the image that are undesirable for measurement$_8$. For example, due to the nature of wood itself it does not accept the stain homogeneously, the wood may stain darker in some places than in others. This can especially be seen in images where a large grouping of rays or a heavy band of summer wood may exist, or in flakes where the grain orientation may be changing. In these images the anatomical differences between the different wood tissue types result in heavy staining in specific areas, which create dark areas that would threshold with the wax spots. "Painting" these areas deactivates the pixels they occupy and produces an image that is easier to threshold.

5.7 Board Property Determination

To evaluate the effect that wax type and application has on flakeboard properties several different physical and mechanical tests were conducted. Thickness swell, water absorption, and internal bond tests were all conducted in accordance to ASTM D-1037$_2$. In addition, a linear expansion test was also conducted. The testing method used in this case was not ASTM but rather a different method where the affect of edge swell does not influence the results of the test. Refer to **Appendix D** for the procedure used to conduct this test and

Figure D1 for an illustration depicting the specimen's size and measurement locations.

To ensure that the respective test specimens showed uniform and consistent behavior, each specimen type was obtained from specific locations in each board. In addition, each specimen was identified using a numbering scheme that was later used to remove any effect that specimen placement may have had on the results. Refer to **Appendix E**, **Figure E1** for a drawing detailing the board cut-up used.

To obtain statistical significance at the 95% confidence level for the wet board properties tested, 1 sample from each board produced was required. This resulted in a total of 24 samples (8 from each panel) being used to conduct each test. The thickness swell and water absorption tests were conducted using the same samples, however, the linear expansion tests were conducted using a separate set of samples.

Seventeen specimens from each board were used to conduct the internal bond tests. This provided a total of 136 samples for each application type, corresponding to a total of 408 test specimens. Although only 336 specimens were needed (14 per board) to obtain a 95% confidence level, it was decided to run all the available samples.

A general linear model was used to detect the affect, if any, that the emulsion type and application, may have on board properties on board properties[20]. This model, as well as the model used to examine the wet properties, was developed in conjunction with the Virginia Tech Statistical Consulting Center, and was designed to lessen the effect of any sample to sample variability that may be present. The model distinguishes the data points based on panel type, panel produced, and sample placement. Density of the samples was used as a covariate.

6.0 Results and Discussion

For ease of recognition and understanding, the following symbols will be used to represent the different panel types that were produced and studied.

Symbol	Panel Type
LB	Lignosulfonate based emulsion used
SB	Soap based emulsion used
LB2	Higher flow rate and pressure used

6.1 Mechanical and Physical Properties Testing

6.1.1 Internal Bond (IB)

The statistical tests revealed a significant difference in IB strength between the three different panel groups produced. Paired GLM tests showed that although no significant difference existed between LB and SB (p-value = 0.648), there was a difference between LB and LB2, as well as SB and LB2 (p-values of 0.004 and 0.021, respectively). Refer to **Table 6** for the mean IB of the different groups, as well as the standard deviations and coefficient of variations associated with each.

Table 6 : Internal bond data summary. The average %MC at testing was 10%.

Panel Type	Mean IB (psi)	St. Dev.	C.O.V.
LB	43.47	17.93	0.412
SB	49.14	25.85	0.526
LB2	24.76	14.02	0.566

Although the statistical evaluation of the IB data indicates that increasing the wax emulsion application parameters (ie; application flow rate and atomization pressure) adversely affects the internal bond strength of the panels produced, this may not be the sole cause. The noticeably low mean IB values (especially in the case of LB2) indicate that some other factor may have contributed to the differences seen.

One such factor could have been the performance of the press. During panel manufacture the press's hydraulic system experienced pressure fluctuations, which were not noticed until the later stages of board production. These fluctuations may have resulted in the inability of the press to adequately hold position, which would cause the press to randomly oscillate around the desired final target position. If this occurred, the quality of bonding in the boards would have been adversely affected, resulting in low IB values. This theory is supported by considering some observations that were made during board testing and subsequent data analysis. One such observation involves the densities of the boards and respective IB samples.

The IB strength of a board is known to be directly influenced by the density of the board. The higher the board density, the higher the IB strength should be if all other factors are equal. This statement can also be applied to the variability of the IB values for any given board (ie; density variability should result in IB variability). Refer to **Table 7,** for a brief description of the mean density of the IB samples that were tested, as well as a comparison of the variability in density and IB strength of the test specimens.

Table 7 : Comparison of sample density variation and IB strength variation.

Panel Type	Mean Density (lbs/ft^2)	St. Dev.	Density C.O.V.	IB strength C.O.V.
LB	41.6	3.177	0.076	0.412
SB	42.3	3.507	0.083	0.526
LB2	41.1	3.341	0.081	0.566

As can be seen from **Table 7**, the IB COV values are approximately 6 times larger than the density COV values, indicating that the variability in IB strengths within the board type groups is much greater than the density variability. Also, the mean density of all the panel types are nearly equal, yet panel type LB2 had only half the IB strength when compared to the other groups. The uniformity and low variation of the respective sample densities indicate that density was not the sole controlling factor in the IB strength of the test panels. Therefore, some other factor, possibly poor bonding, may have influenced the performance of the boards more heavily.

Another observation that suggests a factor, other than changes in wax application, may have influenced IB strength relates to the physical appearance of the individual LB2 IB samples. During testing, the investigator noticed that quite a few of the LB2 samples appeared to have poorly consolidated cores. This observation could indicate two things. First, during lay up, some "void" spaces, or spaces with too few flakes, may have been formed. Although, this could occur it is unlikely that it occurred often, due to the fact that since all the boards were laid up in the same manner, all of them should have had samples with noticeable poor consolidation. This was not the case. Secondly, poor core consolidation may indicate that the press did not reach the final target position, or may have been fluctuating too much around the final position. Either case would most likely result in the poor consolidation of the core and the lack of good adhesive bonds being formed. This would have in turn caused low IB strength, high variability in the LB2 samples, and a difference in IB strength between the panel types.

6.1.2 Thickness Swell (TS) and Water Absorption (WA) :

6.1.2.1 Thickness Swell :

The thickness swell results indicate that no significant difference, at the 95% confidence level, exists between the LB, SB, and LB2 groups after soaking for 2-hours. However, paired GLM tests indicate that a difference exists between LB and LB2 after a 24-hour soak (p-value = .057). No difference exists between LB and SB, or SB and LB2 for the 24-hour soak. Although technically the p-value for the LB and LB2 paired test is not in the rejection, it lies close enough to the border that it should be given consideration. Refer to **Tables 8** and **9** for a description of the thickness swell data of the respective groups.

Table 8 : 2-hour thickness swell results. The average sample %MC was 10%.

Panel Type	Mean 2h %TS	St. Dev.	C.O.V.
LB	1.3081	.3807	.291
SB	1.2096	.3558	.294
LB2	1.611	.2021	.174

Table 9 : 24-hour thickness swell results. The average sample %MC was 10%.

Panel Type	**Mean 24 h %TS**	**St. Dev.**	**C.O.V.**
LB	7.054	.447	.063
SB	6.603	1.829	.277
LB2	8.495	1.618	.189

The statistical analyses indicates that changing the wax emulsion application (ie; the nozzle flow rate and the application air pressure) adversely affects the observed 24-hour thickness swell. However, the differences seen may not have been caused solely by the change in application. As with the IB tests, the high variability of the LB2 data compared to the LB data, may indicate that some other factor had a role in the thickness swell performance of the panels. Since the press's hydraulic pressure fluctuations was mentioned as a possible factor in the reported IB strength differences, it is likely that the same pressure fluctuations had a role in the thickness swell performance of LB2.

Even though, thickness swell is influenced by the performance of the wax being used, the quality of the adhesive bonds also contributes to the overall thickness swell properties. If poor bonding in the respective board groups occurred, it is likely that the thickness swell properties of the boards may have been adversely affected. If some poor bonding occurred, the adhesive bonds produced may not have been strong enough to resist the swelling stress, which would have resulted in high thickness swell variability in the respective board groups.

6.1.2.2 Water Absorption :

The water absorption test results indicate that a statistically significant difference exists between the respective groups in both the 2 hour and the 24 hour measurements. Paired GLM tests between LB and SB, LB and LB2, and SB and LB2, with respective p-values of 0.000, 0.000, 0.002 for the 2 hour examination and 0.001, 0.001 and 0.013 for the 24 hour examination, indicate that both the type of emulsion used, as well as the emulsion application affects the amount of water absorbed by the flakeboard samples. Refer to **Tables 10** and **11** for a description of the data.

Table 10 : 2 hour water absorption results. Absorption is based on a percent of weight gain. The average %MC at testing was 10%.

Panel Type	Avg. 2h %Abs	St. Dev.	C.O.V.
LB	4.85	0.443	0.091
SB	4.29	0.525	0.122
LB2	5.41	0.526	0.097

Table 11 : 24 hour water absorption results. Absorption is based on a percent of weight gain. The average %MC at testing was 10%.

Panel Type	Avg. 24h %Abs	St. Dev.	C.O.V.
LB	18.60	1.83	0.098
SB	15.84	2.04	0.129
LB2	21.09	2.95	0.139

Since water absorption is related to the density of the boards tested, before any concrete conclusions about the affect that emulsion type and application on water absorption are made, the densities of the respective groups should be analyzed. Refer to **Table 12** for a description of the densities of the samples.

Table 12 : Mean thickness swell and water absorption sample densities.

Panel Type	Mean Density (lbs / ft^3)	St. Dev.	C.O.V.
LB	42.68	1.372	0.032
SB	44.47	2.021	0.045
LB2	42.11	1.447	0.034

As can be seen from **Table 12,** the densities of the samples within the respective groups are not highly variable, and the mean densities are comparable. Therefore it is unlikely that any density variations played a role in the reported water absorption differences. Due to this fact, as well as the low p-values, the type of emulsion used as well as the emulsion application affects the water absorption of the samples studied. Therefore, the soap based emulsion performs better than the lignosulfonate emulsion, and the standard application parameters (air pressure of 30 psi and flow rate of 1.8 ml/s) performs better than the increased parameters.

6.1.3 Linear Expansion Results

The linear expansion tests indicate that neither the wax type used nor the way that it was applied (increased flow rate and pressure) had any significant effect on the measured linear expansion. The p-values for the 24 hour measures ranged from 0.5 to infinity (when the F-test denominator is equal to 0) for the dimensional changes in the L1 and L2 directions. Refer to **Tables 13** and **14** for a description of the data, and **Appendix D**, **Figure D1** for an Illustration of the linear expansion sample and measurement scheme.

Table 13 : Mean linear expansion and standard deviation values for the 24 hour soak times. The changes in dimension are in inches. The average %MC at testing was 10%.

Panel Type	Mean 24 hour change in L1	St. Dev.	Mean 24 hour change in L2	St Dev.
LB	0.00243	0.000644	0.00173	0.00057
SB	0.00223	0.001357	0.00102	0.00085
LB2	0.00205	0.00113	0.00292	0.00123

Table 14 : C.O.V. values for L1 and L2. The average %MC at testing was 10%.

Panel Type	C.O.V. for L1	C.O.V. for L2
LB	0.265	0.329
SB	0.608	0.833
LB2	0.551	0.421

Although the statistical tests indicate no significant difference between the different panel types, the high C.O.V. values do seem to indicate that something occurred to affect the measurements. This variability was most likely caused by movement in the measuring device during testing. Due to the sensitivity of the device, any movement would have increased the measurement variation, therefore increasing the C.O.V. values.

6.2 Distribution Quantification Results

For ease of recognition and understanding, the following notation will be used to represent the various flake groups examined. Recall that the lignosulfonate based wax emulsion was the only wax type whose spot size distribution was studied.

Symbol	Flake Group / Panel Type
WLB	Original application parameters; wax only present on flakes
WLB2	Increased air and flow rate; wax only present on flakes
RLB	Original application parameters; resin and wax present on flakes
RLB2	Increased air and flow rate; resin and wax present on flakes

6.2.1 Percent Flake Area Covered

As with the mechanical properties, general linear models were used to analyze the percent flake area covered data. The general output from this test describes the performance of the model itself, and reveals any statistically significant difference exists between the different variables. These variables include coverage variations between individual flakes, and between the different panel groups from which the flakes were obtained. In addition to the general test, specific tests were conducted to examine the significance of particular variables that distinguished the respective groups. These variables include a change in the application parameters and the presence of both wax and resin on the flakes (recall that flakes with only wax present and flakes with both wax and resin present were quantified). The latter test was conducted to determine if the presence of resin on the flakes significantly affected the measured percent area covered. Refer to **Table 15** for a general description of the percent area covered data.

Table 15 : Description of the flake area covered data for the respective groups.

Group	Avg %area cov.	St. Dev.	C.O.V.
WLB	3.108	3.746	1.012
WLB2	2.412	3.232	1.339
RLB	4.189	5.219	1.246
RLB2	2.387	3.516	1.473

As Table 15 illustrates, the percent of flake area covered is highly variable and therefore several differences, both within and between the respective groups may exist. For example, the statistical tests conducted revealed that a significant difference exists in the percent flake area covered between the measured flakes within the respective flake groups (p-value = 0.0001). The difference seen between the flakes most likely resulted from uneven wax coverage on the flakes, indicating that the distribution on the flakes was not uniform. Therefore, sampling the distribution ten times per flake played an important role in determining the measured wax distributions.

The statistical tests also indicate that for the blender setup used, increasing the flow rate and the air pressure reduced the percent flake area that was covered. The tests revealed that a statistically significant difference (p-value = 0.0001) existed between WLB and WLB2, with the average percent area covered being 3.108% for WLB and 2.412% for WLB2. Therefore, increasing the application pressure and flow rate adversely affects the percent flake area covered, for the blender set up used.

The presence of resin on the flakes also appears to have affected the measured wax coverage. A significant difference (p-value = 0.0427) was found between the respective wax only and resin and wax flakes that were quantified. A difference in coverage between these two flake groups was expected, due to the fact that 3 times more resin than wax was applied to the flakes. Therefore, it is probable that some wax spots may have been covered by resin and would therefore not be accounted for in the measurements. However, the results did not support this expectation. The percent area covered for WLB and RLB were 3.108 and 4.189, respectively. This observation would appear to indicate that some resin may have become included with the wax during measurement, for these groups.

Although the statistical results do not indicate that the presence of resin on the flakes adversely affected the wax coverage, some conclusions about the role of resin spots can be drawn. It would appear that the presence of resin may increase the variability of the measured percent flake area covered by wax. As can be seen in Table 15, both the standard deviations and the related C.O.V.'s are greater for the measurements taken on flakes with both resin and wax present than those taken on flakes with only wax present. This is most likely due to the resin either partially or entirely covering, some wax spots which would affect the measured percent area covered. This case was commonly observed by the investigator while measuring the wax coverage.

The statistical tests also revealed that a relationship existed between the presence of resin on the flakes and the flake batch from which the flakes were obtained (p-value = 0.0343). This indicates that resin spots had a different impact, or influence, on the measured percent wax coverage for one flake group than the other (RLB vs. RLB2). From this information, one could conclude that the emulsion application parameters used (flow rate and application air pressure) influences the degree to which the resin spots interact with the wax spots ("interact or interaction" refers to frequency and severity that the wax and resin spots contact each other). It would appear that using a higher application flow rate and pressure decreases the amount of resin and wax spot interaction (due to the fact that WLB2 and RLB2 had less dissimilar wax coverage than did WLB and RLB).

Although no resin distribution, or coverage, data was obtained, it may be useful to conduct a study to determine the interaction that takes place between the wax and resin spots using different application parameters. This type of data would be useful in determining if an ideal situation exists where the resin and wax has minimal interaction, which would be the best possible scenario for determining the performance of a given wax spot distribution. Such a study would also be useful in determining if the resin distribution for a given application is as variable, if not more variable, than the wax distribution.

6.2.2 Spot Size Distribution :

The wax spot size distributions were examined using non-parametric statistical procedures. The procedure conducted is known as a Kolmogrov-Smirnov test and was designed to detect any differences that exist in the wax spot distributions.

As expected the wax spot sizes had very skewed distributions, with the number of small spot sizes present being much greater than the number of large spot sizes. Graphs were constructed to illustrate the fraction of total wax coverage by predetermined wax spot size classes. The class size chosen was 23,000 μm^2. Since the flake groups (ie; WLB, WLB2, RLB, RLB2) may not have same number of spots present per class, companion graphs were also constructed to illustrate the number of spots in each size class. Refer to **Figures 13** through **20** to observe the trends present between the different groups.

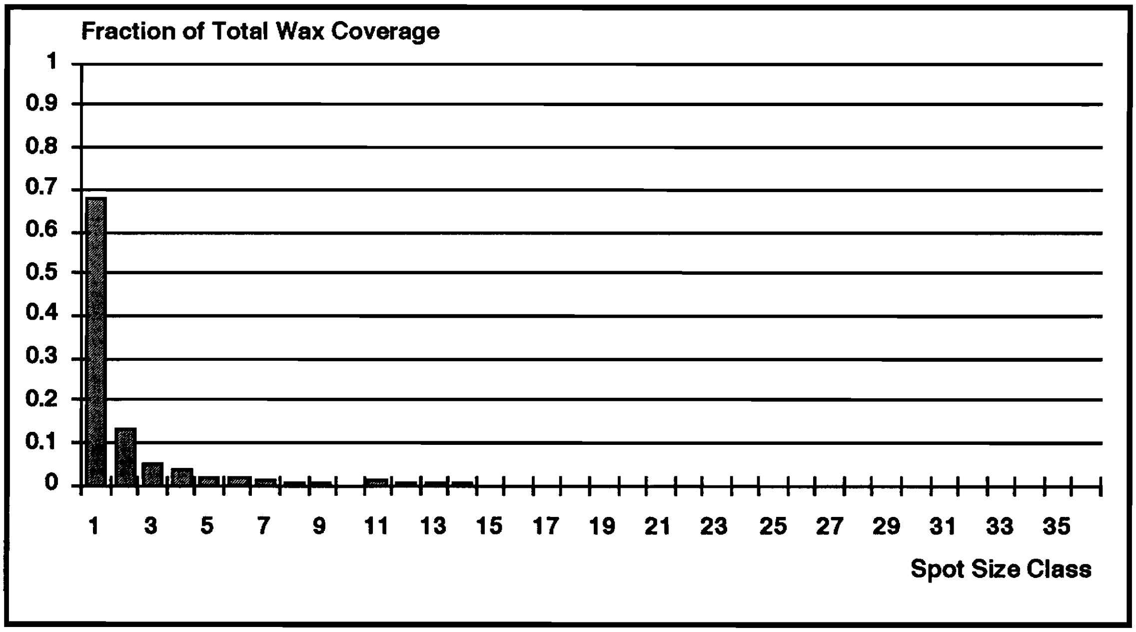


Figure 13: Fraction of total wax coverage vs. spot size class for WLB.

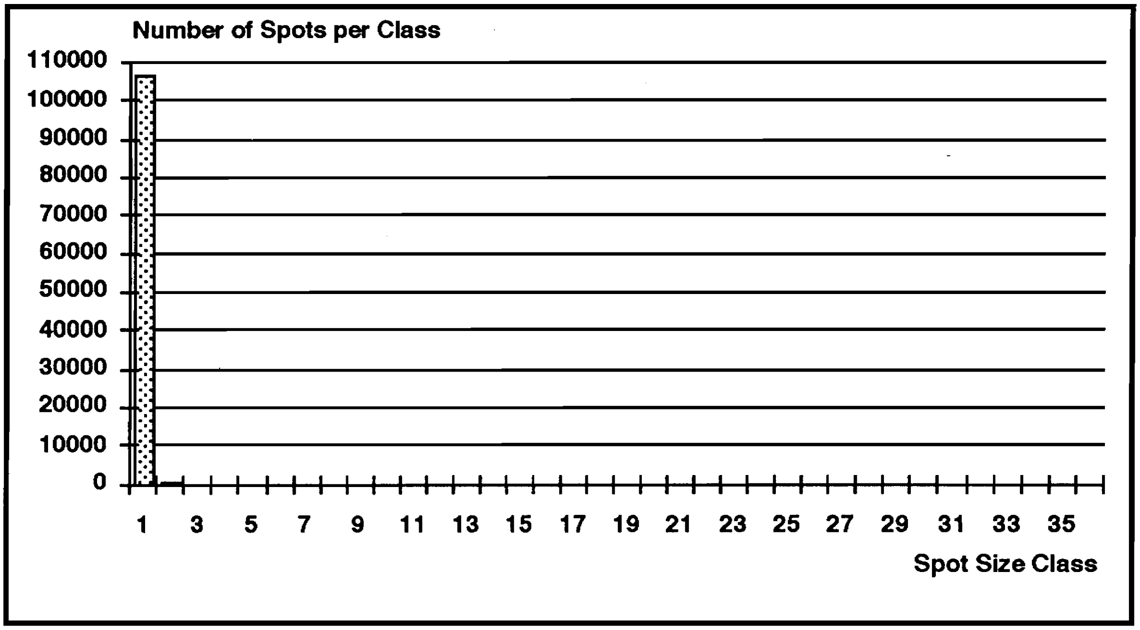


Figure 14 : Count per class for WLB.

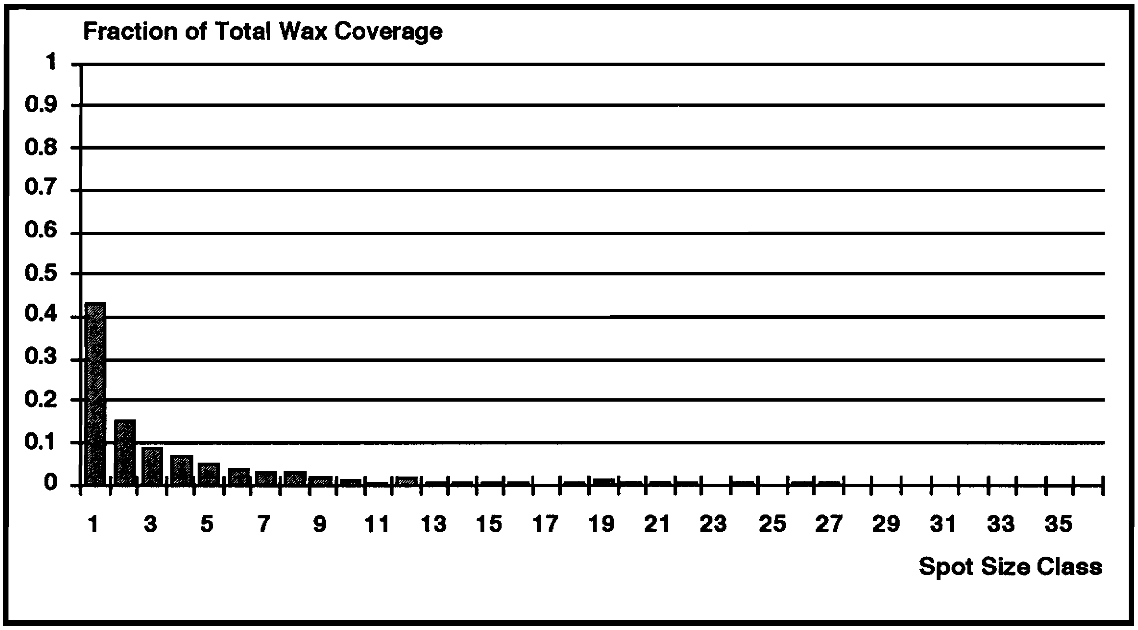


Figure 15 : Fraction of total area covered vs. spot size class for RLB.

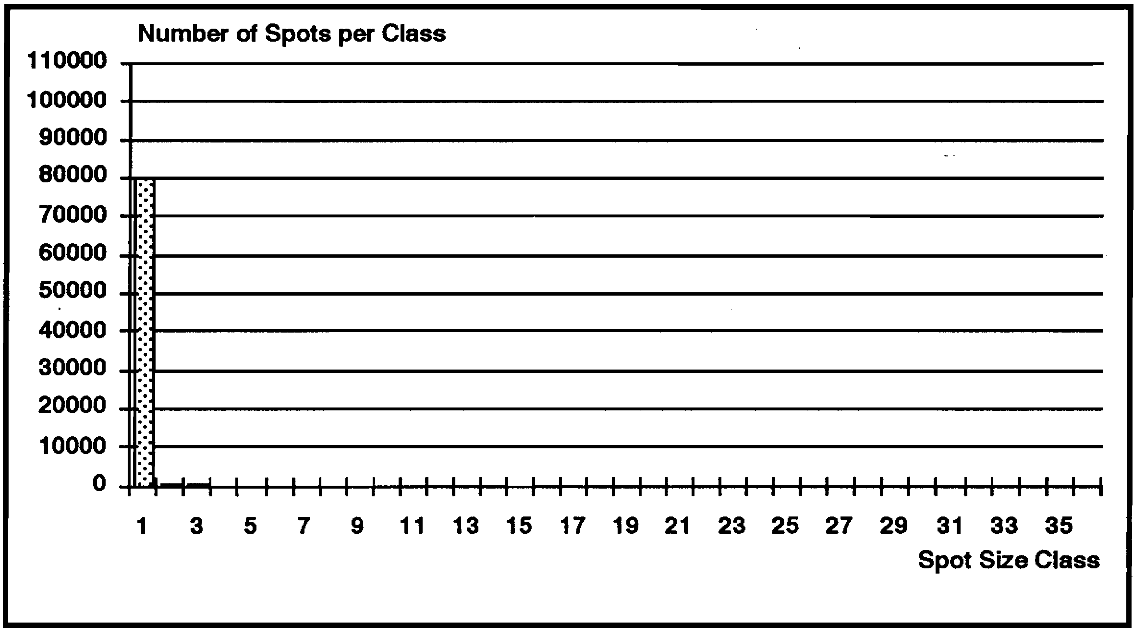


Figure 16 : Count per class for RLB.

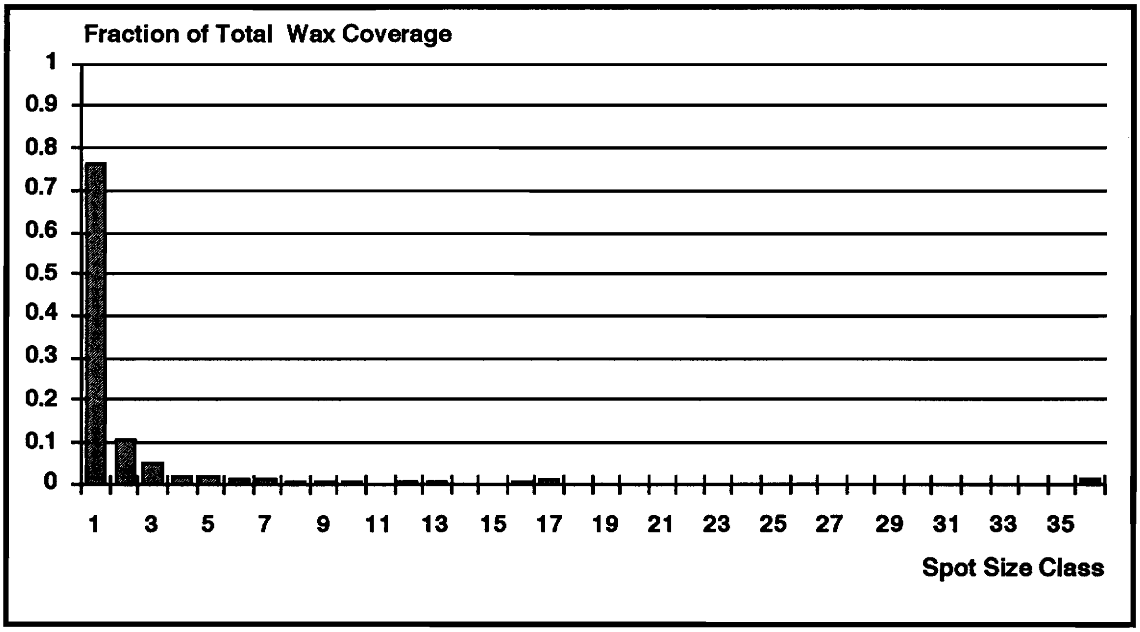


Figure 17 : Fraction of total area covered vs. spot size class for WLB2.

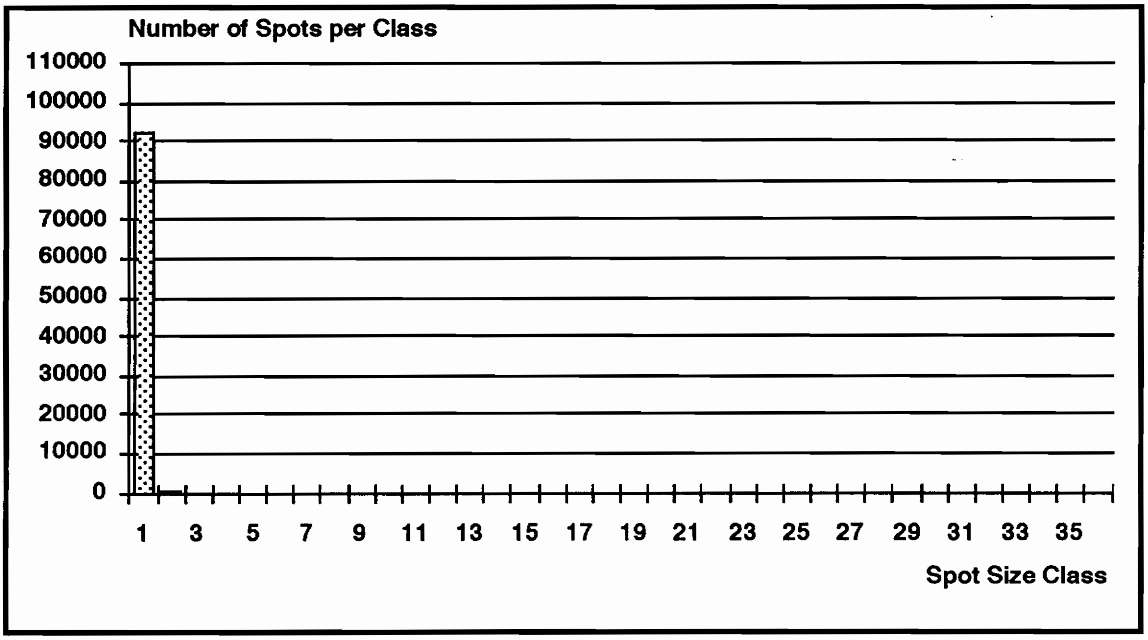


Figure 18 : Count per class for WLB2

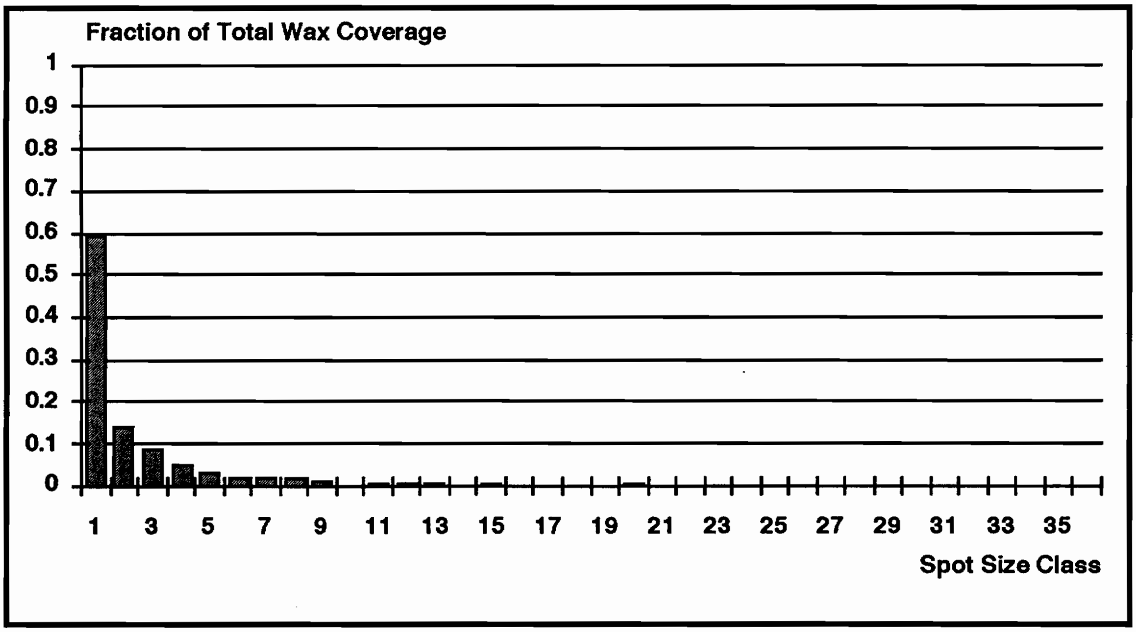


Figure 19 : Fraction of total area covered vs. spot size class for RLB2.

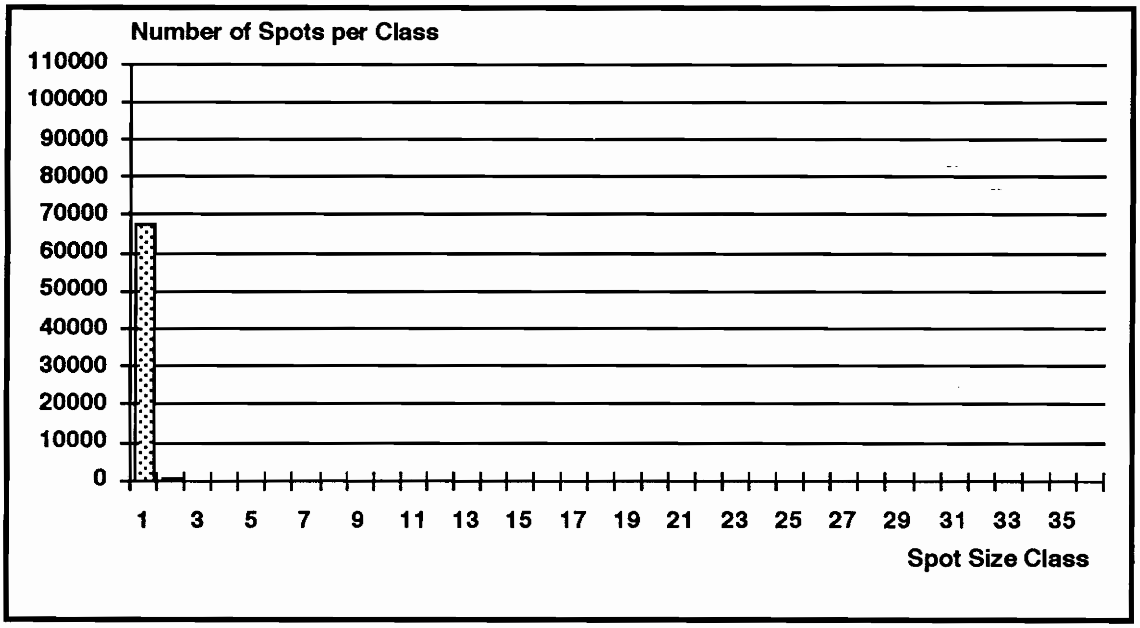


Figure 20 : Count per class for RLB2.

The graphs depict some differences in fractional wax coverage that exist between the different groups. For example, differences in fractional wax coverage in size groups 2 through 17 are seen between WLB and WLB2, with WLB appearing to have more fractional coverage accounted for in these groups. Differences are also seen between WLB and RLB & WLB2 and RLB2, with RLB and RLB2 containing more fractional coverage in groups 2 through 12, and also appearing to have a broader distribution than their respective counterparts. RLB also appeared to have a larger fractional wax area covered by the larger spot size classes (classes 16 through 27) than did WLB, WLB2 and RLB. These observations indicate that not only does changing the wax application result in a different spot size distribution, but so does the presence of resin. In this case, the presence of resin may result in increased distribution variability (the distributions are broader for RLB and RLB2 than for WLB and WLB2).

Although differences in the wax spot distributions do appear to exist between the respective groups, all of the groups have one thing in common. This being that the same size class (class 1; 13.175 to 23,000 μm^2) appears to comprise both the maximum number of spots per class and the largest fractional area covered for all the flake groups. Therefore, it can be inferred that size class 1 contains not only the most frequent spot sizes, but also the spot sizes that contribute the most to wax coverage. For this reason, companion graphs to the ones above were constructed to look at the spot sizes present in class 1. This was done by creating 23 size classes using a class size of 1000μm^2. Refer to **Figures 21** through **28** for these graphs, and to **Appendix F** for the spot size classes used in both sets of graphs.

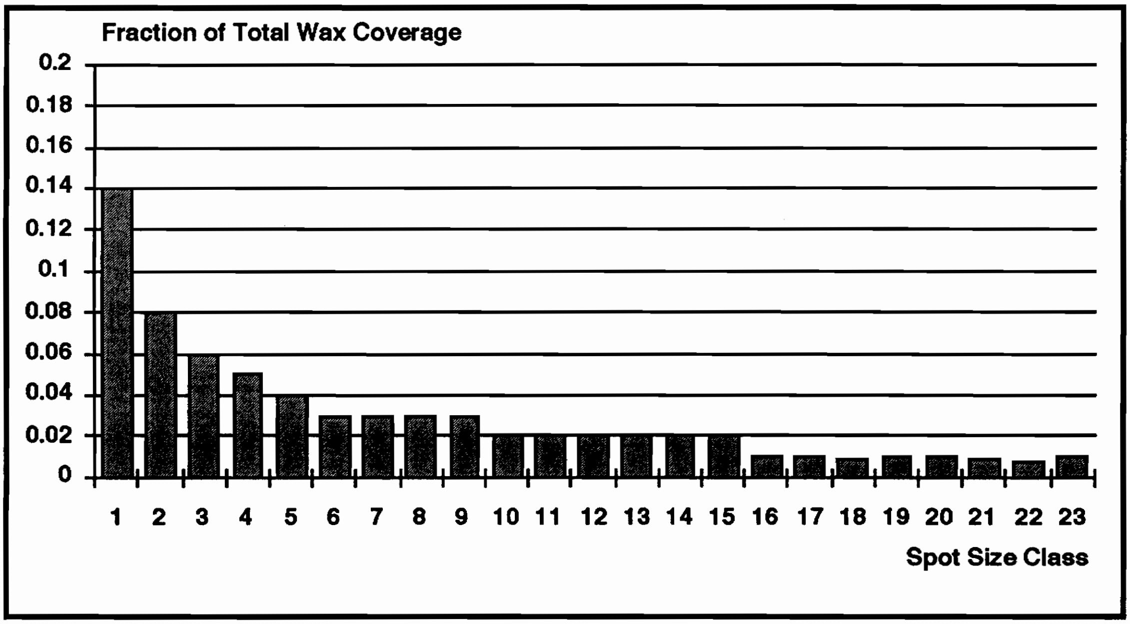


Figure 21 : Fractional wax coverage vs spot size class for WLB. (for Group 1; 0 to 23,000 μm^2)

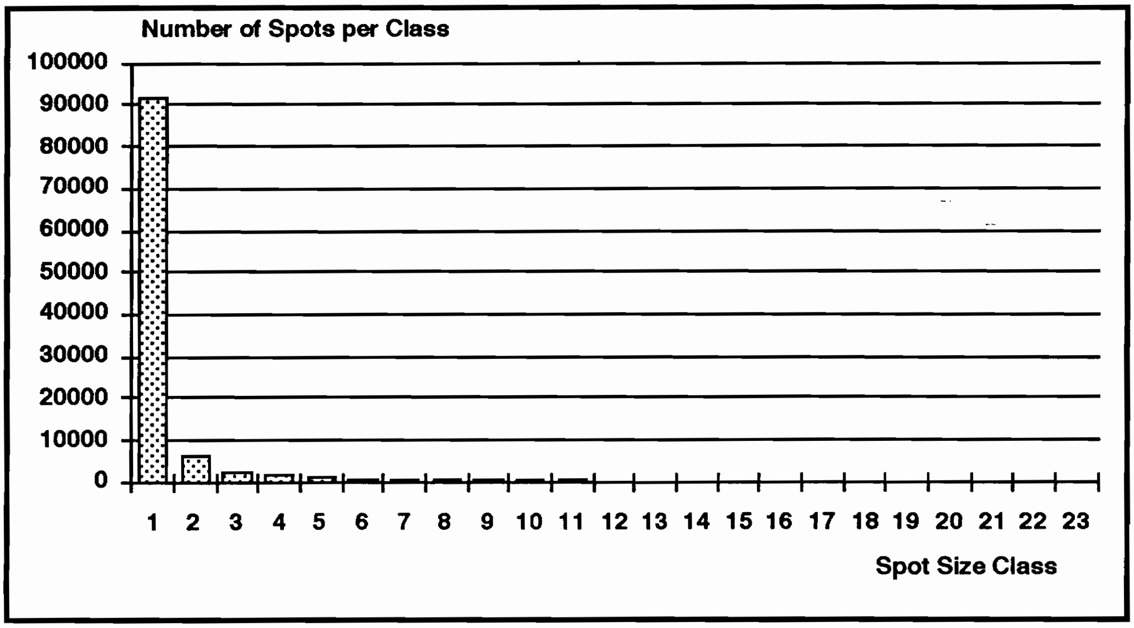


Figure 22 : Number of spots per size class for WLB.
(for Group 1; 0 to 23,000 μm^2)

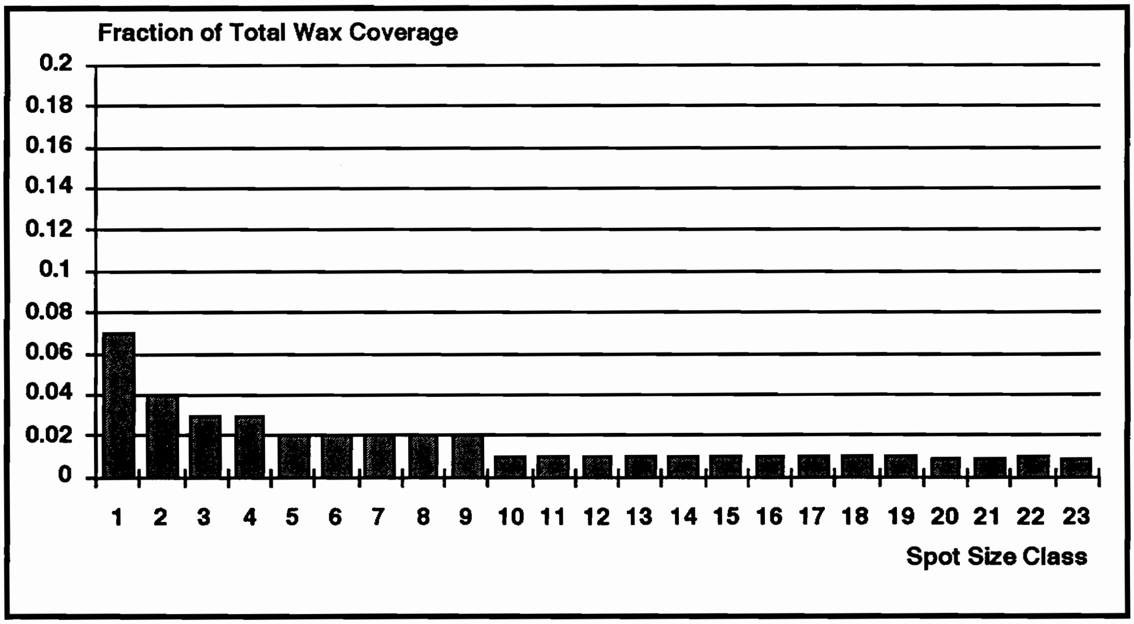


Figure 23 : Fractional wax coverage vs spot size class for RLB.
(for Group 1; 0 to 23,000 μm^2)

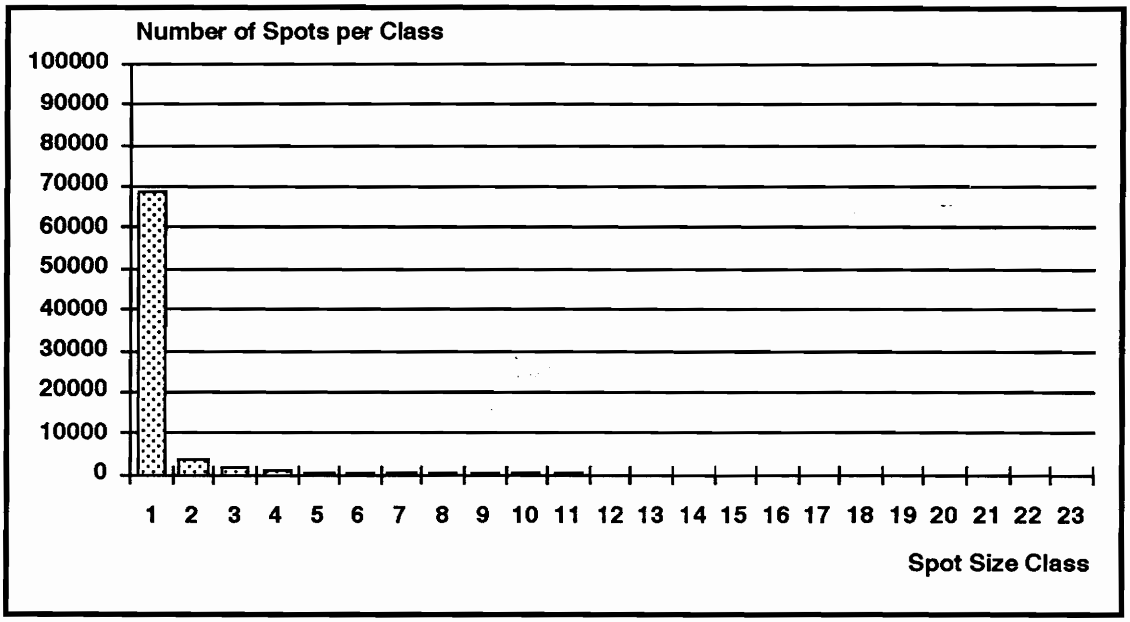


Figure 24 : Number of spots per size class for RLB
(for Group 1; 0 to 23,000 μm²)

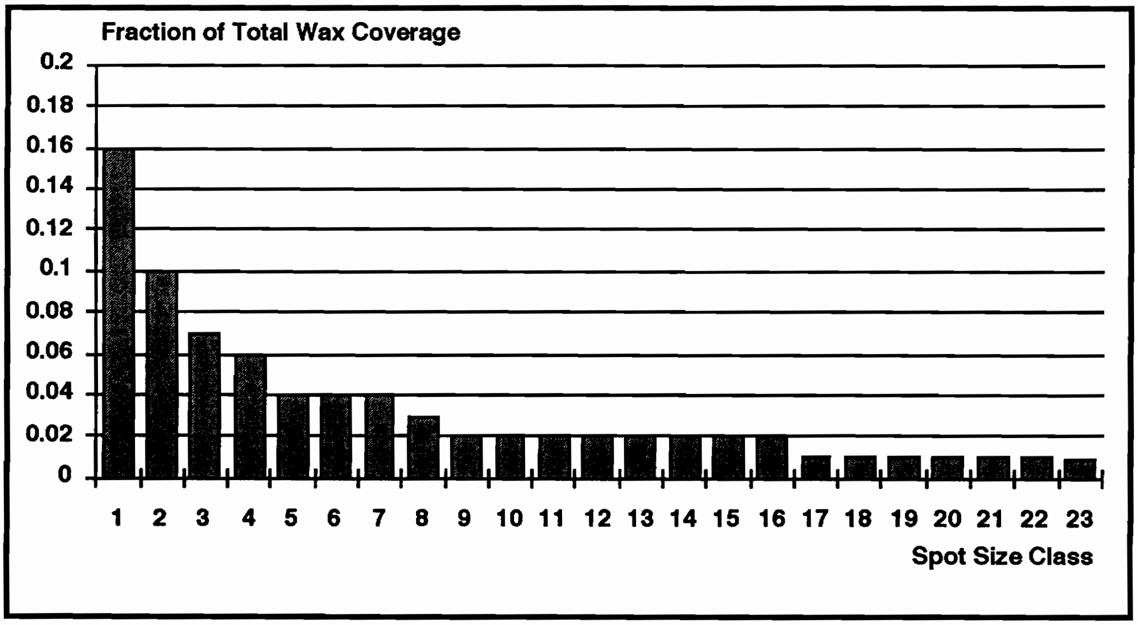


Figure 25 : Fractional wax coverage vs spot size class for WLB2.
(for Group 1; 0 to 23,000 μm²)

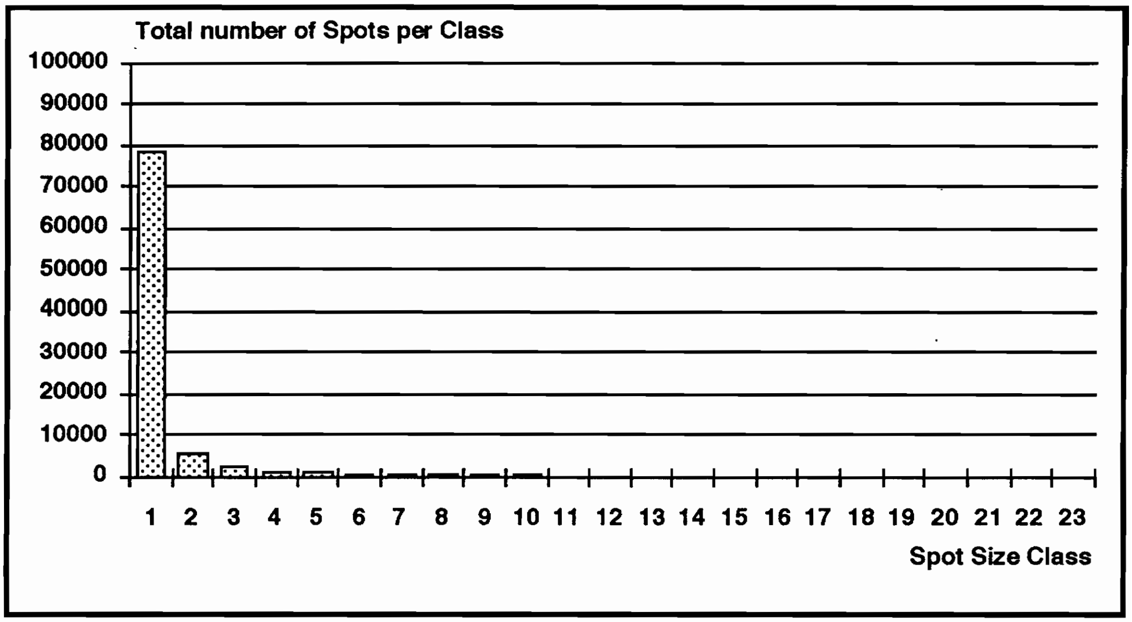


Figure 26 : Number of spots per size class for WLB2.
(for Group 1; 0 to 23,000 μm²)

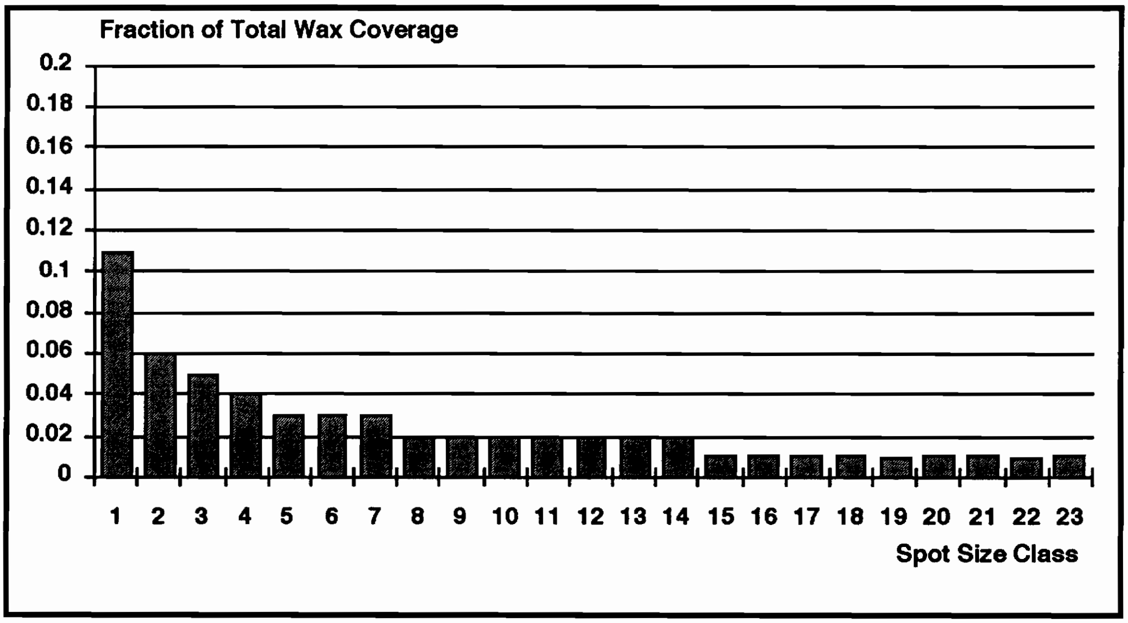


Figure 27 : Fractional wax coverage vs spot size class for RLB2.
(for Group 1; 0 to 23,000 μm²)

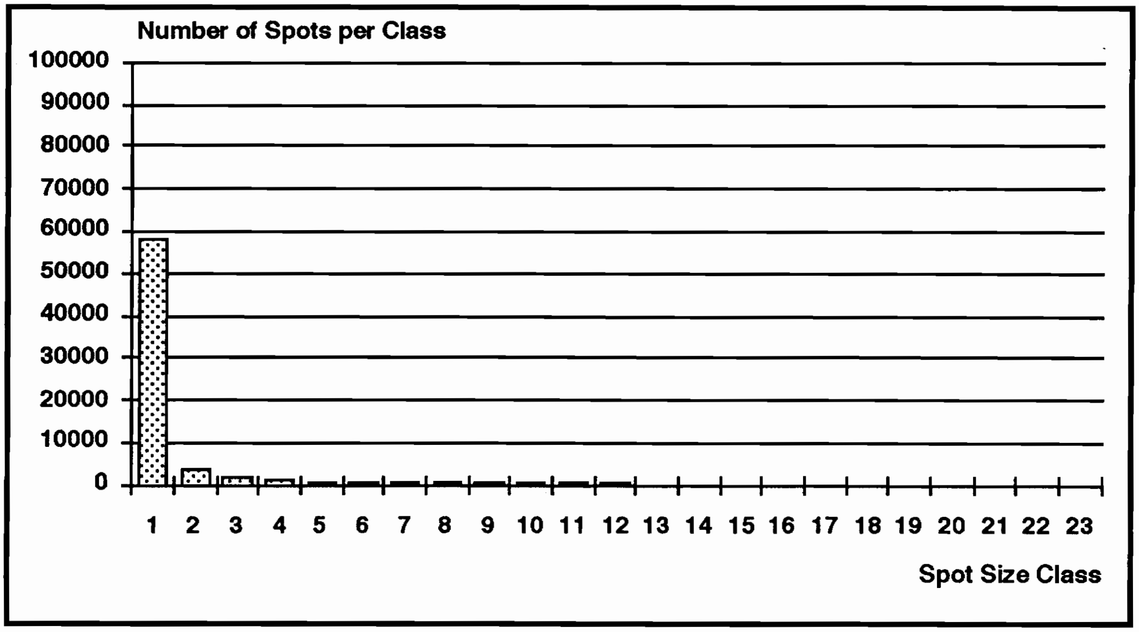


Figure 28 : Number of spots per size class for RLB2.
(for Group 1; 0 to 23,000 μm^2)

Figures 21 through 28 give good descriptions of the Group 1 (0 to 23,000 μm^2) trends between the flake groups present in Figures 13 through 20. As can been seen in these graphs some differences do exist between the various flake groups. For instance, the graphs show that a difference in fractional area covered exists for the smaller spot size classes (classes 1 - 15; 0 to 15,000 μm^2) between groups WLB and RLB, with WLB having a higher fractional area covered in these classes. Generally, both RLB and RLB2 had smaller fractional wax coverage in the smaller classes, than did WLB and WLB2. This information indicates that the presence of resin spots adversely affects the fractional area the smaller wax spots cover, as well as the number of smaller wax spots. This is probably due to the smaller wax spots being covered by resin spots. The distribution differences discussed between WLB and RLB, as well as WLB2 and RLB2 are significant, each having a p-value of 0.0001.

Differences in distribution were also evident between the flake groups with only wax present. The graphs show that WLB2 generally had more area covered by smaller wax spots (classes 1 to 7; 0 to 7,000 μm^2) than the larger wax spots present in the 0 to 23,000 μm^2 size class, when compared to WLB. This observation shows that increasing the wax emulsion application parameters affects the fractional coverage of spot size classes. Statistical tests conducted between WLB and WLB2 confirm that a difference existed between the groups (p-value = 0.0001).

Differences similar to those seen between WLB and WLB2, were also seen between RLB and RLB2. In general, RLB2 had more area covered by smaller wax spots (classes 1 to 7; 0 to 7,000 μm^2) than did RLB. This observation further supports the conclusion made above that the method of wax emulsion application affects the measured spot size distributions (recall, that the fractional area of total wax coverage is directly related to the number and distribution of the wax spot sizes). Statistical tests conducted between RLB and RLB2 confirms the difference observed between the groups (p-value = 0.0001).

Although the figures discussed above give good descriptions of the measured spot sizes distributions, the specific differences that were seen between the respective flake groups are not clearly evident. Refer to **Tables 16 and 17** for a more specific description of the measured distributions.

Table 16: Spot size mean, C.O.V., minimum, and maximum. The minimum spot size is also the smallest area that the system can measure (ie; one pixel).

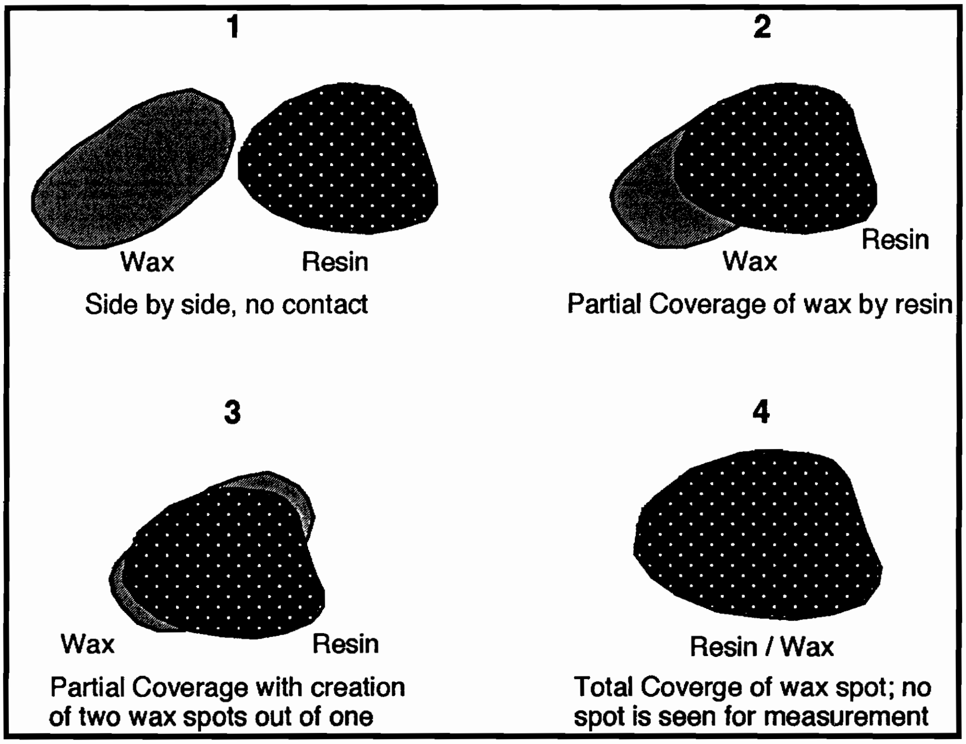
Group	Mean Spot Size (μm^2)	C.O.V	Min. Spot Size (μm^2)	Max. Spot Size (μm^2)
WLB	1026.74	5.19	13.175	321957.00
WLB2	961.35	5.82	13.175	822633.00
RLB	1841.49	6.21	13.175	608566.00
RLB2	1250.68	5.58	13.175	447594.00

Table 17: Total spot count (for all flakes measured) , median, and size range above and below median.

Group	Total Spot Count	Median Spot Size (μm^2)	Range below Median (μm^2)	Range above Median (μm^2)
WLB	106937	118.58	105	321851
WLB2	92316	118.58	105	822527
RLB	80874	92.23	79	608486
RLB2	68274	105.40	92	447501

Tables 16 and 17, document the differences that exist between the respective flake groups. As can be seen in Table 16, the COV of RLB is considerably larger that its respective counterpart. This indicates that the presence of resin spots on the flakes increases the wax spot size variability. However, the COV of RLB2 is less than WLB2. Although at first these observations appear contradictory, closer examination reveals they indicate that changing the emulsion application method (flow rate and air pressure) changes the resin and wax spot interactions that may take place. This in turn affects the wax spot size variabilities. Refer to **Figure 29** for a description of the possible wax and resin spot interactions.

Figure 29 : Resin and wax spots interactions that may have resulted in the formation of different spot size distributions.



As Figure 29 depicts, and investigator observation confirms, several different wax and resin spot interactions could occur, and therefore affect the analysis and variability of the wax spot size distributions. The ideal interaction would be situation **1**, where no interaction occurs, therefore the spot size distribution is unaffected. However, interaction would occur during blending and influence spot size measurement and variability. For example, in situation **3** one wax spot is turned into two by the coincidental presence of a resin spot. This would not only increase the spot size variability, but it would also cause a distribution problem, since what is recorded as two individual wax spots is actually only one.

Table 17 describes the median wax spot size, as well as the spot size ranges both above and below the median of the different flake groups. Any differences present between the groups can be used to describe the regions in the respective distributions where the differences exist. For example, the median value for the WLB and WLB2 groups is 118.575 μm^2. This means that the same number of wax spots exist both above and below 118.575 μm^2 for WLB and WLB2. Therefore if the respective spot size ranges for the two groups are comparable, their distributions will likely be the same. However, for the aforementioned groups this did not occur.

Although the spot size range below the median value was the same for WLB and WLB2, due to the fact that 13.175 μm^2 is the smallest measurable spot, the range above was substantially different. The above median range for WLB2 was 822,527 square microns, approximately 2.5 times larger than that for WLB. This indicates that WLB2 has a broader and different spot size distribution than WLB (which was also seen in the graphs and subsequent discussion). The difference seen between WLB and WLB2 is supported by the graphs discussed above, as well as the statistical analysis, which yielded a p-value = 0.0001.

Similar differences in spot size distributions were also seen between WLB and RLB, and WLB2 and RLB2. For example, the median, as well as the spot size range both above and below the median are different for WLB2 and RLB2, and WLB and RLB, respectively. As a matter of fact, the spot size range above the median for WLB2 is approximately 2 times larger than the range for RLB2, and the above range for RLB is also approximately 2 times greater as the range for WLB. These differences indicate that the presence of resin on the flakes affects the spot size distribution, which is supported by both the statistical analysis (p-value = 0.001, for both paired data sets), as well as the graphs discussed above.

Distribution differences were also seen between RLB and RLB2. In this case, RLB possessed a larger total spot count and range above median, while RLB2 possessed larger median and range below median. These differences indicate that RLB2 possesses a broader spot size distribution below the median value, and that RLB possesses a broader distribution above the median. The differences seen were determined to be significant, and have a p-value of 0.0001. These observations illustrate that the interaction present between the resin and wax spots may be affected by the wax emulsion application.

6.3 Quantification Procedure Evaluation

The quantification procedure worked well throughout the entire testing period. Thresholds were easily established for the majority of flakes measured. The wax spots appeared to have a somewhat characteristic shape, and possessed a typical gray level and surface texture, as well. These observations were useful in distinguishing the wax spots from the background wood regions, as well as some troublesome resin spots that appeared in RLB and RLB2. Refer to **Figures 30** and **31**, for examples of a flake with only wax present and flakes with both wax and resin present.

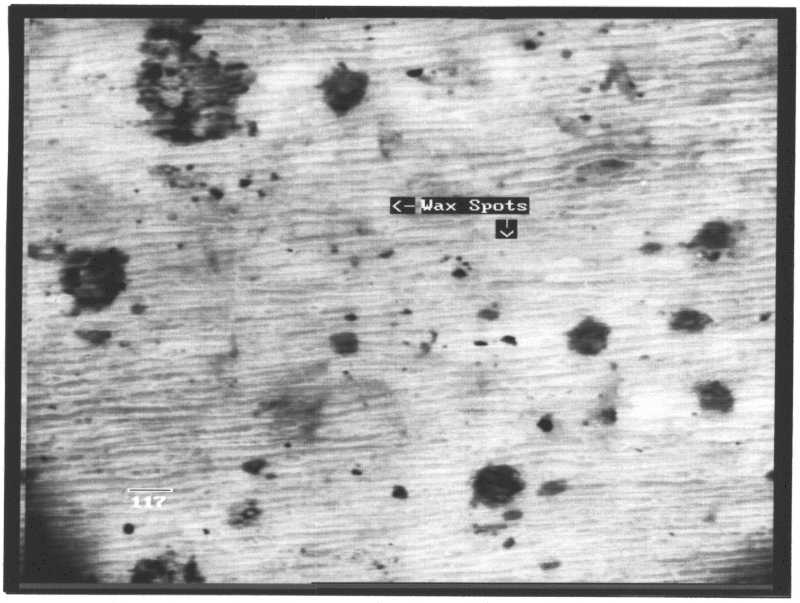


Figure 30 : Flake image with only wax present. (mag = 135x, bar is in μm)

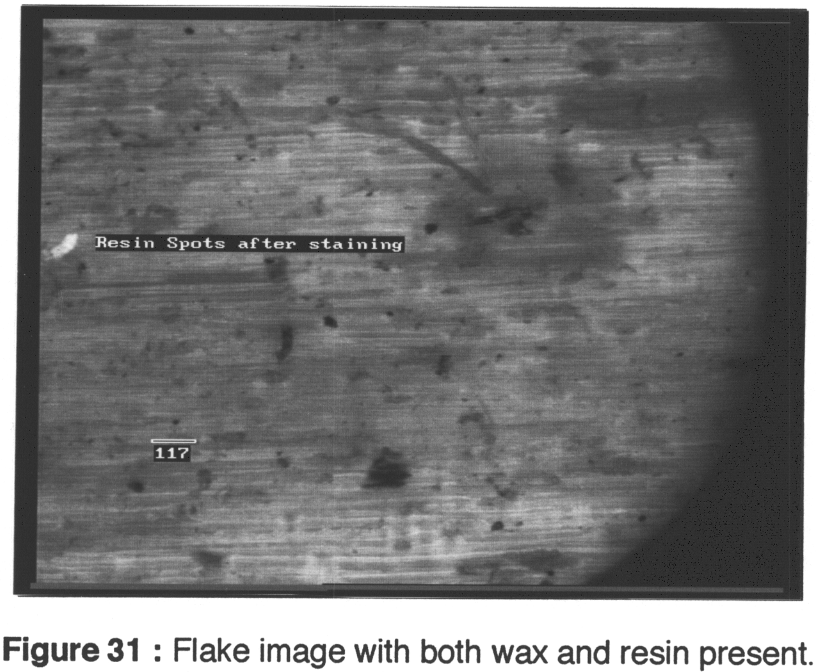


Figure 31 : Flake image with both wax and resin present. (mag = 135x, bar is in μm)

Although no procedural problems were found, several difficulties were encountered. These include wood staining variability, differences in gray level and surface texture between tangentially cut and radially cut flakes, presence of abnormal wood and some dust particles, interference in thresholding by big resin spots, and interaction between resin and wax spots. Although these problems are not directly related to the procedure developed they, along with the associated solutions, should be discussed.

The most recurrent problems encountered concerned flake staining variability and threshold interference resulting from wood anatomical features and abnormal wood. These problems caused contrasting difficulties between the wax spots and the background wood features. For example, the presence of rays, on both radially and tangentially cut flakes, were problems that had to be overcome. Refer to **Figures 32** and **33** for examples depicting these difficulties.

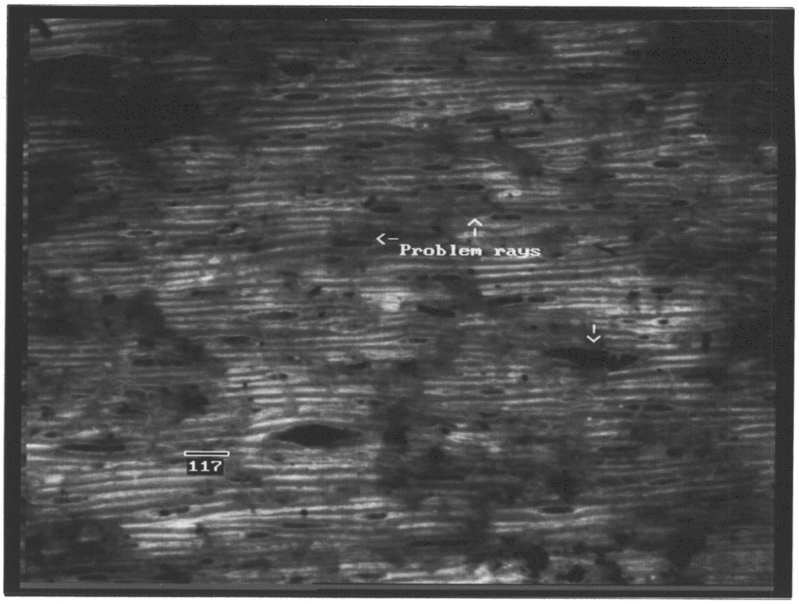


Figure 32 : Staining variability and tangentially cut rays that caused problems. (mag =135x, bar is in μm)

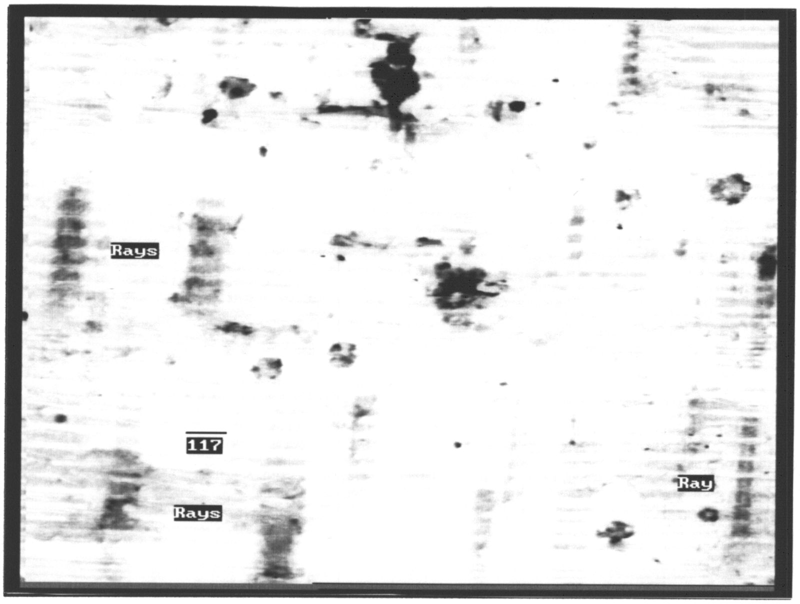


Figure 33 : Rays that caused thresholding problems. These rays are from a radially cut flake. (mag = 135x, bar is in μm)

As can be seen in Figures 32 and 33, the presence of some rays produced places on the flakes appearing to have the same characteristic gray levels as wax spots. The increased darkness of the rays is likely due heavier staining. Since rays tend to be more lignified and may also have extractives present, it is likely that these areas would stain differently. These dark flake areas increased the thresholding difficulty, and had to be dealt with before wax spot quantification could occur. The auto-enhance and paint functions available on the Image 1 system were used to minimize the contrasting problem.

As mentioned in the experimental design section, the auto-enhance function increases an image's contrast by modifying the contrast settings currently being used, while the paint function is used to manually select areas within an image that are undesirable for measurement. Even though a texture difference exists between the rays and wax spots, performing an auto-enhancement of the image improves the contrast and better defines the edges of both the rays and wax spots. This ensures that when dark rays are painted, no wax is painted with them. Refining the contrast is especially necessary when a wax spot and a dark ray spot happen to touch one another. Refer to **Figures 34** and **35**, for a before and after example of an image that has had this type of processing performed.

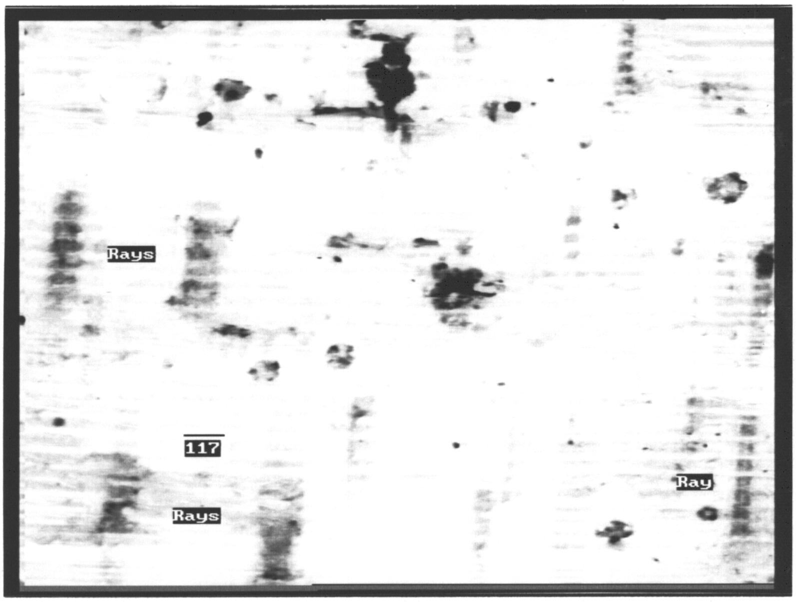


Figure 34 : Image viewed prior to "painting". (mag = 135x, bar is in μm)

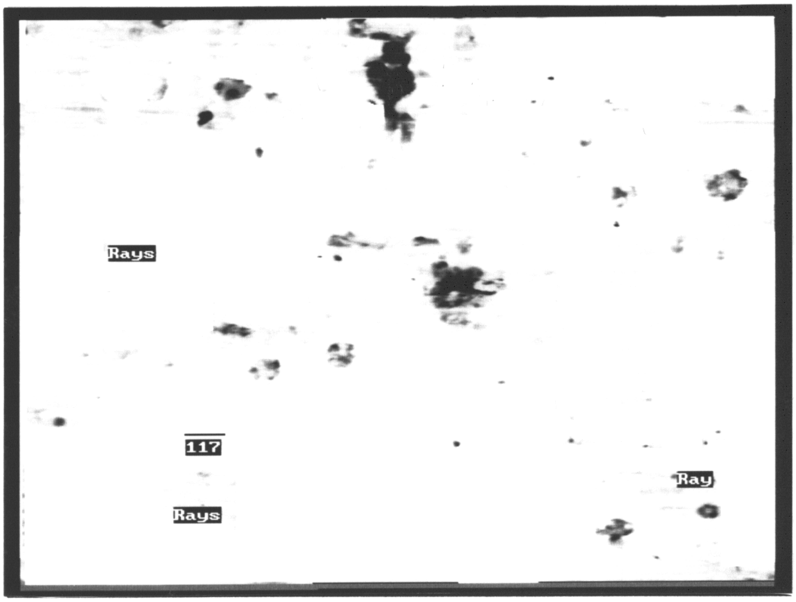


Figure 35 : Figure 34 after "painting". (mag = 135x, bar is in μm)

Other biologically related problems are staining and surface texture variability resulting from wood's heterogeneity. It was noticed throughout testing, that certain flakes tended to stain darker than others, and that some appeared to have a much rougher surface. Since the ideal thresholding situation would be one where the wax spots are dark against a light wood background, and the flake surface is smooth (to avoid any depth of field problems), the presence of the aforementioned variabilities increased the thresholding difficulty. Factors that affected the variability included the species of wood (hardwood versus softwood), the presence of abnormal wood (juvenile, compression, and tension wood), and the way in which the flakes were cut (tangential orientation versus radial orientation).

The species of the flake seemed to not only affect the degree of staining present, but also the variability of staining (within a flake), which was a problem as well. It appeared that good images were normally obtained from flakes cut from diffuse porous hardwoods and gradual early to latewood transition softwoods. Troublesome flakes were mainly hard varieties of the aforementioned species genre, including some ring porous hardwoods and abrupt transition softwoods. Southern yellow pine tended to vary the most in staining, primarily a result of the hard transition between the earlywood and latewood, with the more lignified latewood staining heavy and the earlywood staining lightly. Although troublesome, these staining variabilities were overcome by using different camera functions, and the aforementioned enhancement and paint function combinations.

Since a lighter wood image is the desired image, increasing the brightness of a dark, or variable, image is the first step in improving the image for quantification. Brightening dark images is achieved by using a camera function known as "stretch". Unlike the other image processing functions, stretch is performed on the raw video signal before the image is acquired for measurement. Stretching the image performs a six fold amplification of the gray levels that are present in the image[8]. This helps to lighten the dark wood background, without greatly affecting the wax spots' appearance. Although performing this function greatly increases the video noise, the increased noise can be compensated by increasing the number of frames image is summed. After the image is stretched and acquired, the auto-enhancement and paint functions mentioned above can be used to prepare the image for quantification.

Refer to **Figures 36** and **37** for a before and after view of an image that had a stretch performed.

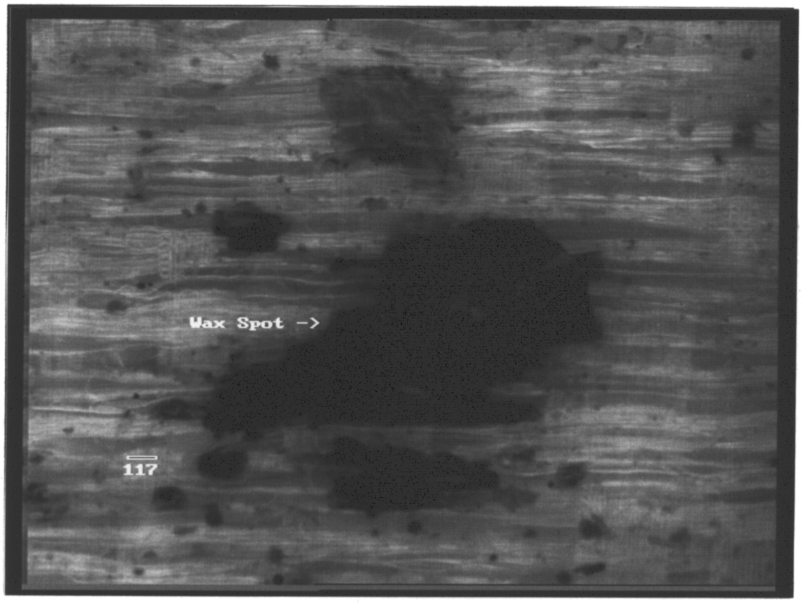


Figure 36 : Image prior to having stretch performed. (mag = 88x, bar is in μm)

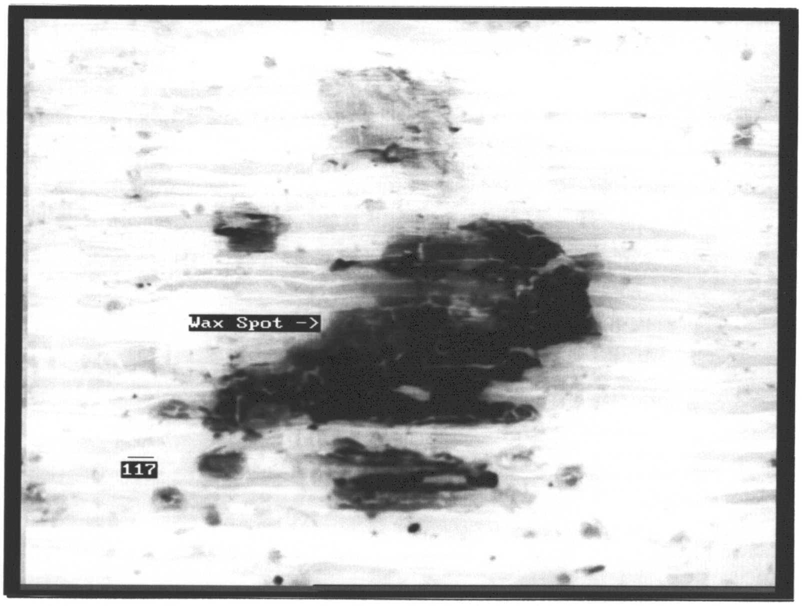


Figure 37 : Figure 36 after having stretch performed. (mag = 88x, bar is in μm)

Another problem noticed during quantification involved flakes where both wax and resin were present. Recall that during the preliminary examination of the Safranin O staining procedure resin spots appeared to disappear, or diminish in gray level, after staining (refer to Figure 7 in the experimental design section). However, during quantification some big resin spots were still apparent on a few of the flakes measured. Although these large resin spots did not physically appear to have the same texture as the wax (the resin spots were smooth, glassy substances that seemed to flow into the wood's surface, while the wax spots were crusty and appeared to sit on the surface) there was not enough gray level difference between the two substances to enable thresholding without some processing being performed on the image. Refer to **Figures 38** and **39** for examples of resin spots seen.

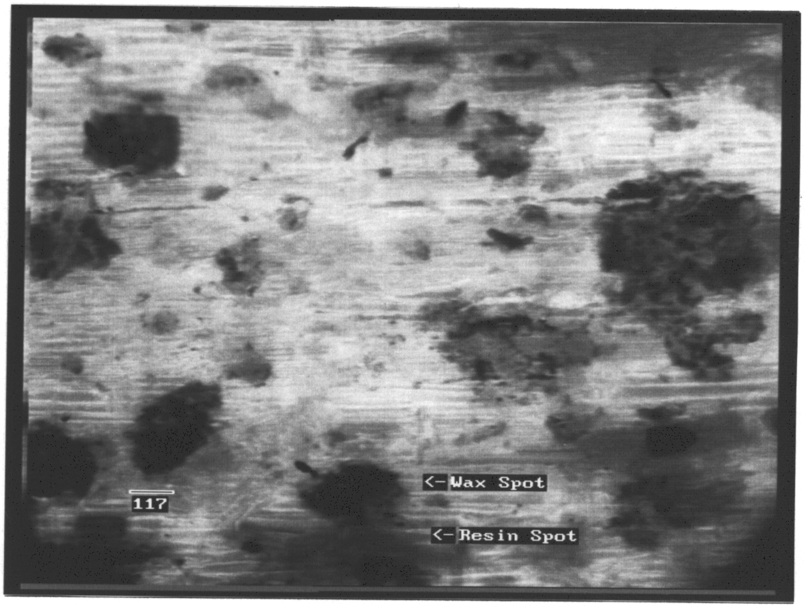


Figure 38 : Example of a visible resin spot. (mag = 135x, bar is in μm)

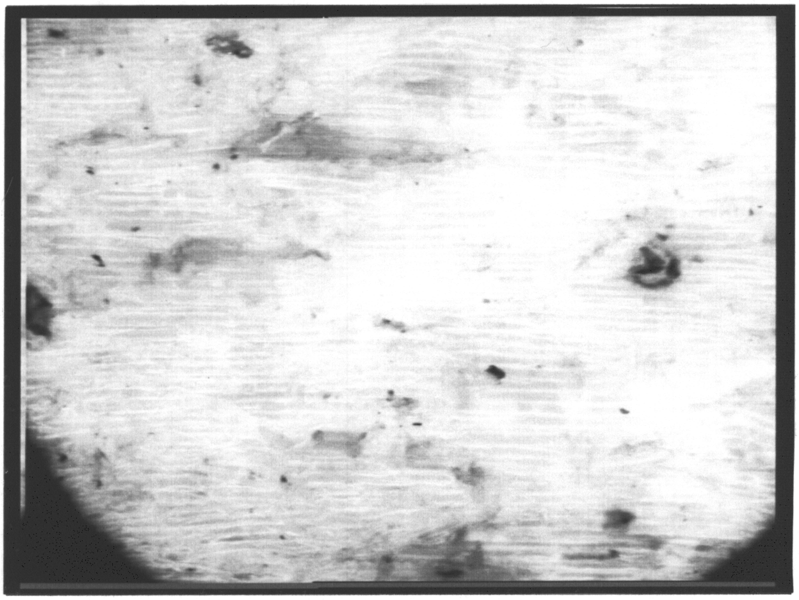


Figure 39 : Example of a visible resin spot. (mag = 135x, bar is in μm)

The auto-enhancement and paint functions were performed on images where the resin spots were still visible. As with the images mentioned earlier, these functions created an image that was easier to threshold and quantify. However, these images was not as easy to paint as the "ray" images (Figures 34 and 35). This was primarily a result of interactions taking place between the resin and wax spots. For example, on some flakes the visible resin spots were touching or slightly covering wax spots. Although distinguishing between the resin and wax spots was not difficult, determining the edges of the wax spots was sometimes difficult and required careful manual painting. The difficulty to precisely identify the wax spot edges, may have added variability into the quantification procedure.

As mentioned in the preliminary investigations, it was determined that staining with Safranin O produced an image where the resin spots were either removed form the image or easily discernible from the wax spots. However, the presence of large visible resin spots was seen on some flakes, where smaller spots were not seen. This leads to the conclusion that the resin spot size may influence the ability to see the spot after staining. Refer to **Figures 40** and **41** for a before and after image depicting the effect that resin spot size may have on the disappearance of the spots.

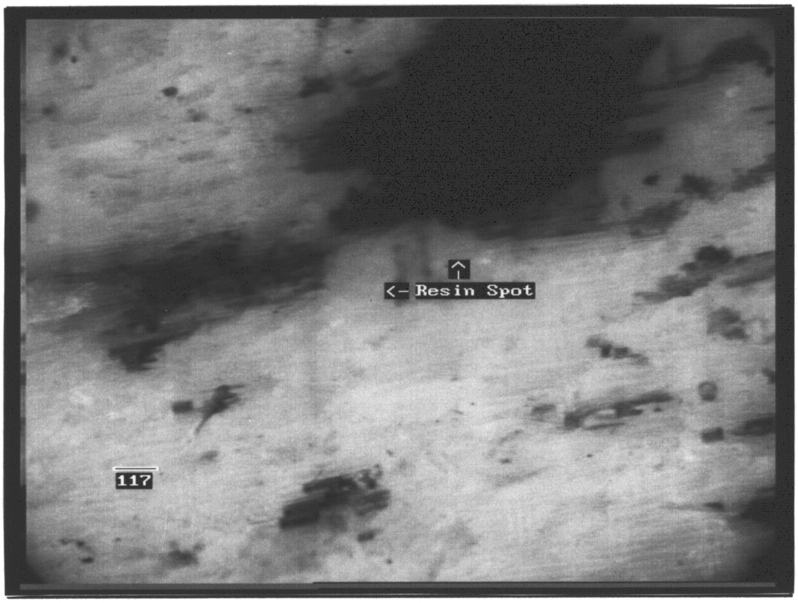


Figure 40 : Wax and resin flake, prior to staining. Notice that small and large resin spots are present. (mag = 135x, bar is in μm)

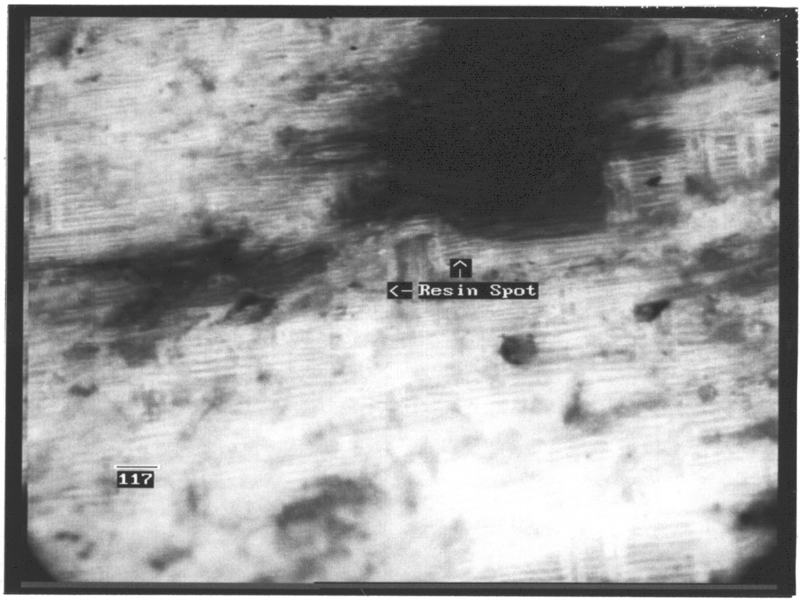


Figure 41 : Wax and resin flake after staining. Notice the smaller resin spots are not seen, while the larger spots are still visible. (mag = 135x, bar is in μm)

Another problem encountered during quantification involved the presence of dust. Recall that to remove any dust present, the flakes were subjected to blasts of air, both before and after the staining procedure. Although this process appeared to work well during the preliminary evaluations, during the actual testing some dust was still seen. This was not a serious problem since the texture and appearance difference between the dust particles and the wax spots was enough to allow dust identification and painting. However, removing the residual dust particles in this manner did introduce some additional variability into the process. For example, in some cases the dust appeared to be slightly joined to the wax spots. This made distinguishing the edges of the dust from the wax spots difficult, and may have resulted in either not enough of the residual dust being removed, or the accidental removal of some wax.

6.4 Recommendation for Future Work

Although the procedure detailed and discussed above performed well, there are several improvements that should be made before it can be used in an industrial setting. These improvements include decreasing the amount of operator input required, developing a better dust removal system, and decreasing the amount of flake staining variability.

The most important procedural change that should be made regards the amount of operator input required. Currently, the operator makes all the decisions regarding feature of interest thresholding, and unwanted feature removal, by painting. Although this process is accurate if the operator is experienced in using the process, it's accuracy is decreased if the operator is inexperienced. Therefore, in an industrial environment (where the operator's experience in using the system may be variable) the amount operator input must be minimized to assure that the data produced is as accurate as possible. There are several ways this can be done.

The first, and probably the best, would be to develop a method where the wax spots appear bright against a dark wood background, instead of dark against a light wood background. This would aid in the distinction between the wax spots, the residual large resin spots and dust particles. This could be done by perhaps using a counter-staining technique, or another type of stain.

Another way to decrease the amount of operator interaction would be to develop a technique where the wax and resin spots appeared as totally different colors or gray levels. This would not only aid in the wax spot thresholding operation but would also allow the resin spots to be measured at the same time. Such a technique could be used to measure the wax and resin distributions simultaneously, and would therefore increase the power and usefulness of the process. A possible technique that would allow this would be to use the inherent fluorescence properties of the cured resin in some manner to increase the gray level difference between the wax and the resin.

The continued presence of dust on the flakes must also be addressed. Although the flakes used in the study were obtained from an industry source, they were blended in a laboratory environment and therefore the amount of dust present was most likely much smaller than the amount that would be present in industry. Since the dust removal techniques used in the study did not appear to work as well as expected in a lab environment, they would probably not work as well in an industrial setting either. For this reason, some other type of dust removal technique should be used. For example, static charge or high powered vacuum may be more effective in removing the dust from the flakes.

Another problem that should be addressed regards wood staining variability, as mentioned in the procedure evaluation section (section 6.3). Staining variability results primarily from lignin content variability existing between species, earlywood and latewood, and between abnormal and normal wood. For example, the increased lignin content of compression wood (softwood reaction wood) results in darker staining and the associated thresholding problems. Since the staining darkness (degree of staining) is controlled by the reaction occurring between lignin and the stain, it is possible that such a problem could be taken care of during the staining process, instead of at the quantification stage of the procedure.

Since staining is a function of both stain solution concentration and specimen soak time, changing either variable would change the degree of staining. For example, either decreasing the stain solution concentration or the amount of specimen soak time would lessen the degree of specimen staining, hence reducing the stained flake's darkness and improving the acquired image. Therefore, the occurrence of staining variability could be reduced by developing specific staining procedures for different flake types. These procedures would be the same basic process, except the staining time and solution concentrations used may be different in order to optimize the contrast between the wax and the wood. The procedures would be classified by species, type of cut (radial, tangential, bastard), presence of abnormal wood (juvenile, tension, compression) and grain transition (gradual vs. abrupt). For example, a softwood flake where a hard transition between the early and latewood exists, decreasing the stain time or solution concentration would decrease the degree of staining and would improve image thresholding. The same is true for flakes that contain abnormal wood.

7.0 Conclusions

7.1 Mechanical and Physical Properties Testing

The method of wax emulsion application (ie; application flow rate and air pressure) was shown to significantly affect the IB strength of flakeboard. Panels made using the standard blender operating parameters (LB) had higher IB strengths than panels where the wax emulsion was applied using increased application parameters (LB2).

The 24 hour thickness swell of flakeboard was also shown to be affected by wax emulsion application. The tests indicated that increasing the application pressure and flow rate increased the 24-hour thickness swell average form 7.05% (LB) to 8.5% (LB2).

Differences between all the board groups (LB, SB, and LB2) were seen in both the 2 hour and 24 hour water absorption tests. This shows that using a soap based emulsion yields a lower 24 hour average percent water absorption, by weight, (15.84%) than does a lignosulfonate based wax emulsion (18.6%). Using the standard operating flow rate and pressure also yields better water absorption characteristics. LB produced an average 24 hour percent water absorption of 18.6%, while LB2 produced an average water absorption of 21.09%.

No difference in linear expansion was seen between the flake groups. This shows that neither using a different wax emulsion type nor different application rates affects the linear expansion characteristics of the flakeboard panels tested.

7.2 Wax Distribution

7.2.1 Percent Flake Area Covered

The percent flake area covered was found to be adversely affected by increasing the flow rate and application pressure of the wax emulsion. WLB had a higher percent flake area covered (3.108%) than WLB2 (2.412%).

Significant differences in wax coverage also exists between flakes with only wax present and flakes with both wax and resin present, indicating that the presence of resin on the flakes affects the measured wax coverage. Similar differences in wax coverage were seen between RLB and RLB2, the flake groups where both wax and resin were present. These differences, along with the differences seen between the wax only and resin/wax flakes, indicate that the application flow rate and air pressure of wax emulsions affect interactions that take place between the resin and wax spots. The data seems to indicate that using a higher application flow rate and pressure decreases the wax and resin spot interactions (due to the fact that the percent flake area covered for WLB2 and RLB2 are similar).

7.2.2 Spot Size Distribution

Significant differences in wax spot size distribution was found between all the flake groups studied. Changing the application flow rate and air pressure of the wax emulsion creates a different wax distribution than the standard application parameters. It was observed that WLB2 had a broader wax spot size distribution, based on the fraction of total wax coverage per size class, than did WLB (when considering the whole wax spot range). WLB2 also seemed to have more area covered by smaller spots (from 13.175 to 7,000μm^2) than did WLB, as did RLB2 when compared to RLB.

The presence of resin was shown to have an influence on the wax spot size distribution (based on the fraction of total wax coverage per size class). Differences were seen between both WLB and RLB and WLB2 and RLB2. Generally, the groups where resin was present had a lower fraction of area covered by the smaller spot sizes (13.175 to 15,000 μm^2). RLB and RLB2 also seemed to have a broader spot size distribution than their wax only counterparts, when the whole distribution range was considered.

7.3 Procedure Performance

The wax distribution quantification procedure developed worked well throughout the quantification process. However, before it can be used on an industry scale several issues must be addressed. These include : the continued presence of dust on the flakes, the amount of human decision making required, thresholding interference caused by darkly stained anatomical features, and the appearance of large resin spots on the flakes after staining. Once these challenges are resolved, the procedure should be able introduced into industry.

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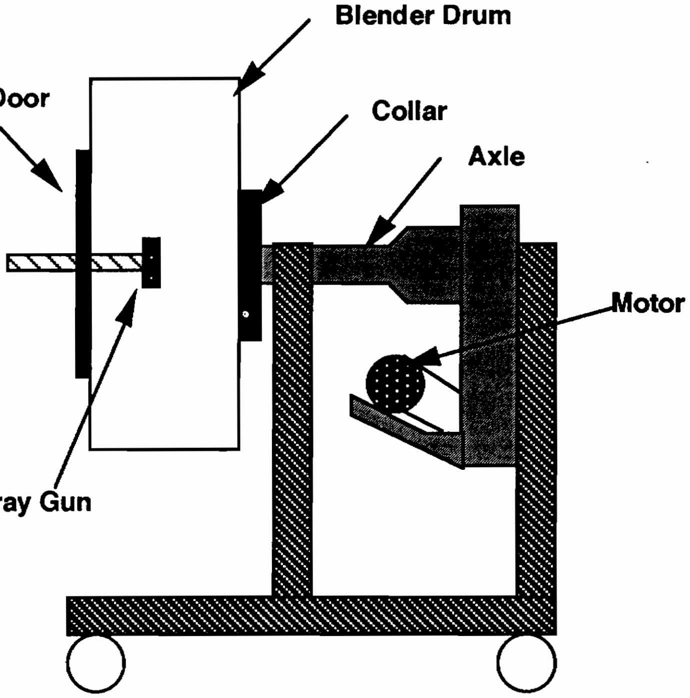
Appendix A

Table A1 : Stains and concentrations investigated.

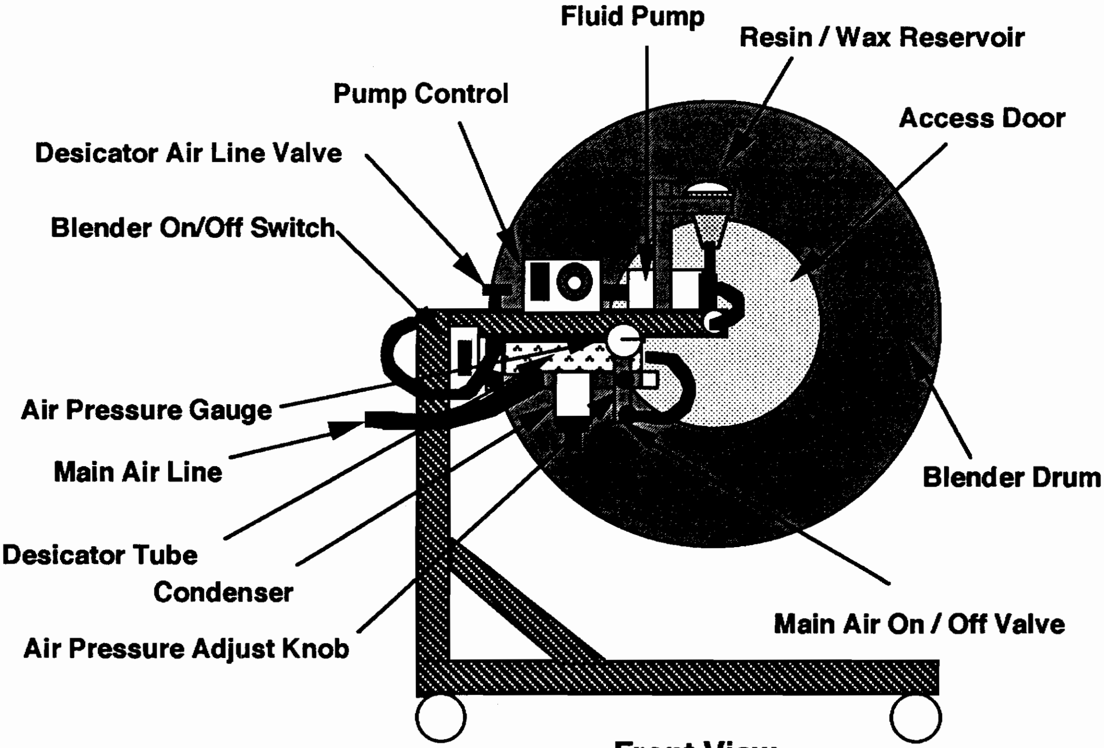
Fluorescent Stain	**Concentrations Used**	**Performance**
Toluidine Blue O[1]	1%	Poor, wax spots not seen
Acridine Orange	1%, 0.2%, 0.5%	Good contrast between wax spots and wood with 0.5% aqueous solution
Rhodamine B	0.5%	Contrast is fair
Rhodamine 6,G	0.5%	Contrast is good
Acridine Orange and Rhodamine B	0.5%	Contrast between wax spots and wood not as good as other combinations
Acridine Orange and Rhodamine 6,G	0.5%	Contrast better than other combinations tried; resin and wax not distinguishable
Acridine Orange and Rhodamine B,O	0.5%	Contrast not as good as 0.5% Acridine Orange and Rhodamine 6G
Safranin O	0.1%, 0.5%	Good contrast with both, **Best** contrast with 0.5%; resin disappears
Fast Green FCF	0.1%, 0.5%	Poor, contrast between wax and wood not improved
Safranin O and Fast Green FCF	0.1%, 0.5%	Fair, image not as good as with 0.5% Safranin O

1. Toluidine Blue O is a fluorescence inhibitor.

AppendixB1



Side View



Front View

Appendix B2

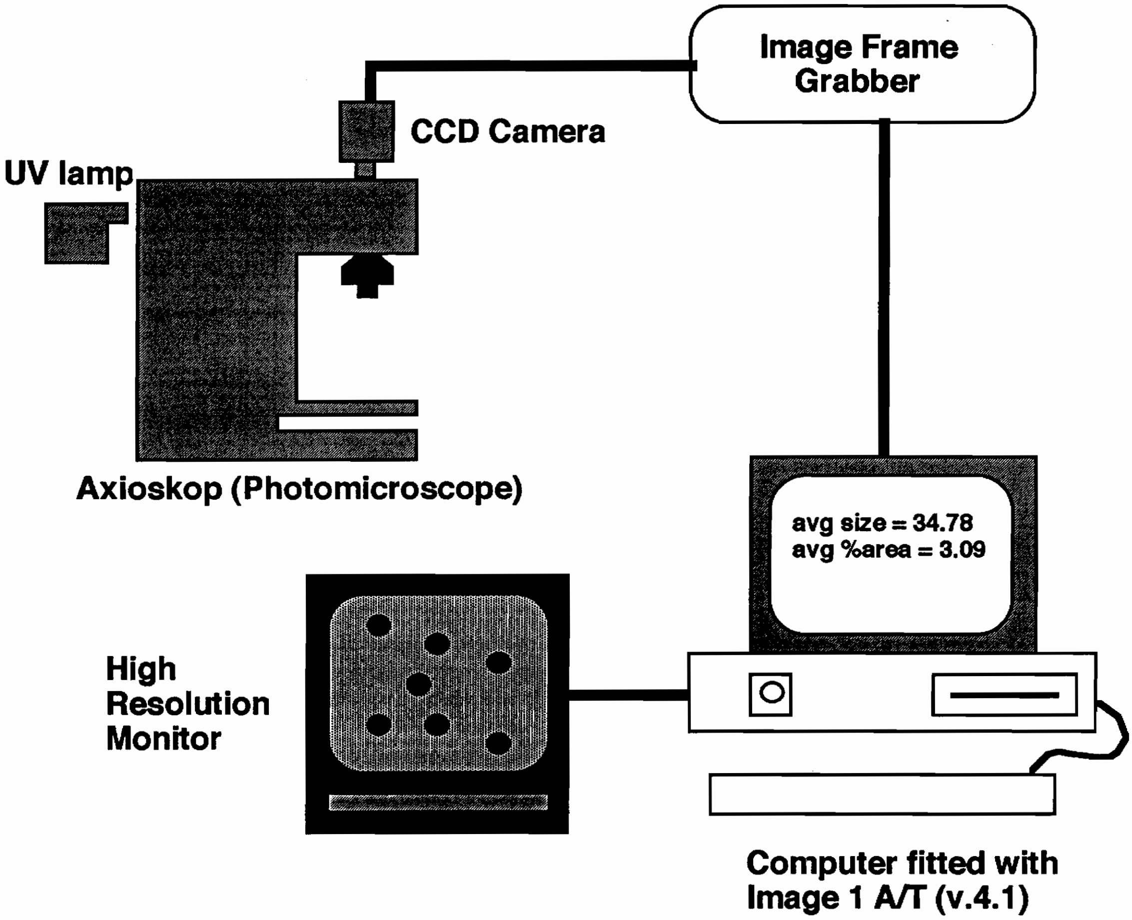


Diagram of image analysis system.

Appendix C

Description of microscope and fluorescence filter sets used during experimentation.

Microscope : Axioskop fitted for both general and fluorescence microscopy. Manufactured by Carl Zeiss, Inc.

Fluorescent Lamp : 50 watt mercury burner

Table C1 : Filter sets used during experimentation, Carl Zeiss, Inc.

Excitation Filter	Dichroic Mirror	Barrier Filter
G 365	FT 395	LP 420
BP 450	FT 510	LP 520
H 546	FT 580	LP 590

Appendix D

Linear Expansion Procedure :

1. Test Specimen

a) Test specimens were 6 inches by 6 inches in size; edges were smooth and square.

b) 0.125 inch diameter holes were machined into the samples at the mid places along each side, 1.0 inch in from the edge. Small copper pipes (with an outside diameter of 0.125 inches) were placed into the holes to ensure constant hole size during soaking. The copper pipes were also machined to sample thickness.

3. Specimen Conditioning

The specimens were conditioned in an environment chamber maintained at a relative humidity of 65+/- 1% and at a temperature of 20 +/- C (68 +/- F).

4. Testing

The test specimens were placed horizontally under 1 inch of distilled water maintained at a temperature of 20+/-1 C (68 +/- F). The specimens were measured at the 2 hour and 24 hour marks.

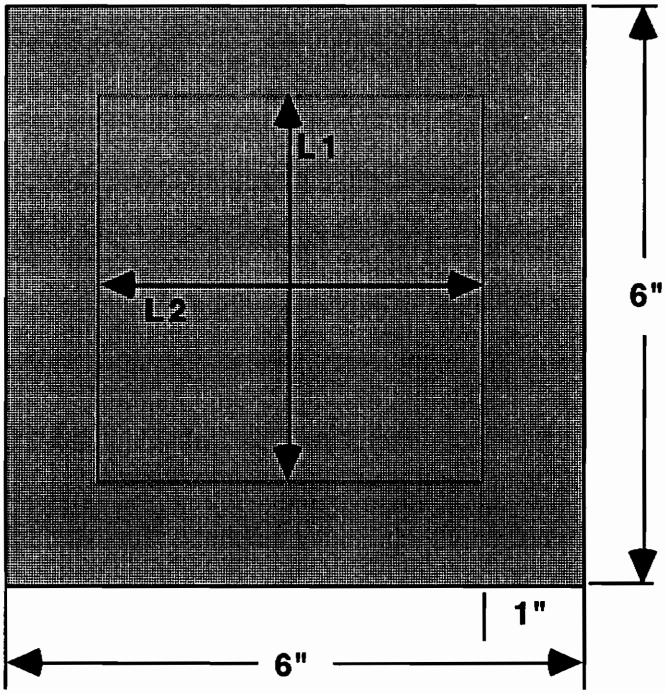
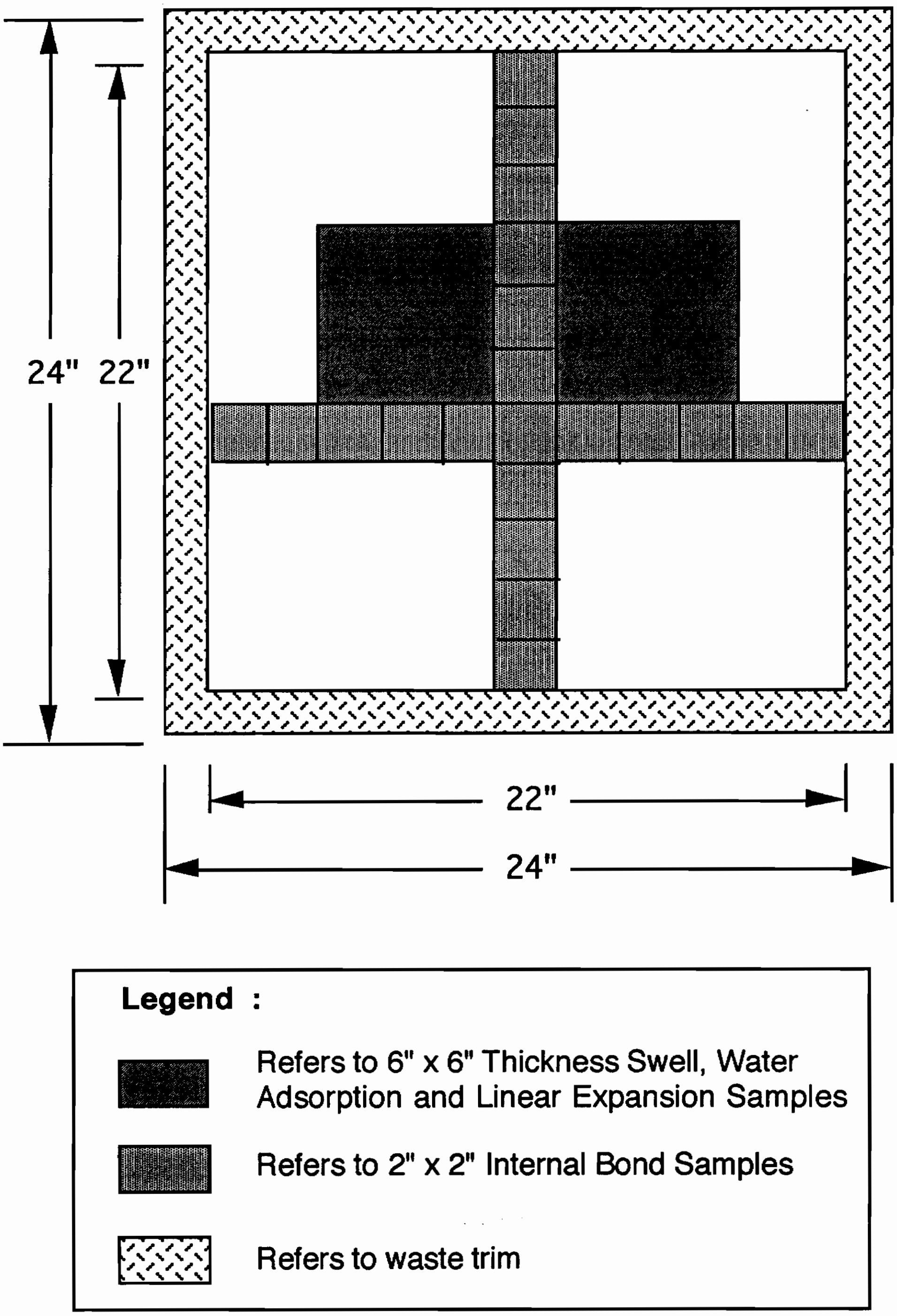


Figure D1 : Linear expansion test specimen showing the L1 and L2 dimensions.

Appendix E



Legend :

■ Refers to 6" x 6" Thickness Swell, Water Adsorption and Linear Expansion Samples

▦ Refers to 2" x 2" Internal Bond Samples

▨ Refers to waste trim

Figure E1 : Panel cut up design.

Appendix F

Table F1 : Size classes used to show the fraction of total wax coverage and the count of spots per class.

Class	A	B
1	0	23,000
2	23,001	46,001
3	46,002	69,002
4	69,003	92,003
5	92,004	115,004
6	115,005	138,005
7	138,006	161,006
8	161,007	184,007
9	184,008	207,008
10	207,009	230,009
11	230,010	253,010
12	253,011	276,011
13	276,012	299,012
14	299,013	322,013
15	322,014	345,014
16	345,015	368,015
17	368,016	391,016
18	391,017	414,017
19	414,018	437,018
20	437,019	460,019
21	460,020	483,020
22	483,021	506,021
23	506,022	529,022
24	529,023	552,023
25	552,024	575,024
26	575,025	598,025
27	598,026	621,026
28	621,027	644,027
29	644,028	667,028
30	667,029	690,029
31	690,030	713,030
32	713,031	736,031
33	736,032	759,032
34	759,033	782,033
35	782,034	805,034
36	805,035	828,035

Appendix F

Table F2 : Size classes used to illustrate the fractional total wax coverage and number of spots per class for the expanded graphs of Class 1.

Class	A	B
1	0	1,000
2	1,001	2,001
3	2,002	3,002
4	3,003	4,003
5	4,004	5,004
6	5,005	6,005
7	6,006	7,006
8	7,007	8,007
9	8,008	9,008
10	9,009	10,009
11	10,010	11,010
12	11,011	12,011
13	12,012	13,012
14	13,013	14,013
15	14,014	15,014
16	15,015	16,015
17	16,016	17,016
18	17,017	18,017
19	18,018	19,018
20	19,019	20,019
21	20,020	21,020
22	21,021	22,021
23	22,022	23,022

Vita

The author was born in Gastonia, North Carolina on March 9, 1969. He grew up in Iron Station, NC with his parents, Mr. and Mrs. Dwight G. Saunders, and his younger brother. He graduated from East Lincoln Senior High in June of 1987.

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