Forintek Canada Corp.
Western Division
2665 East Mall
Vancouver, B.C.
V6T 1W5

Machining, Laminating, Fastener Withdrawal and Finishing Properties of Hybrid Poplar

by

Derek Williams

prepared for

Ministry of Forest Research Branch
Kalamalka Research Station
Vernon, B.C.

March 1998

Acknowledgements

For their contribution to the planing and sanding testing the author wishes to acknowledge the FRBC Valued-Added Skills Centre, Abbotsford, for use of their facilities, equipment, and support from Skills Centre staff, including Peter Vogt, Norbert Milota, and Stewart Buckman. For their work in the fastener withdrawal tests, strength tests and determination of density and ring counts the author wishes to acknowledge Jules Gardy, Rollie Wakeman and Roy Abbott of the Wood Engineering Department of Forintek Canada Corp. For their work with the laminating properties the author wishes to acknowledge Axel Andersen of the Composites Department and Elias Mucha of the Value Added Technology Transfer Program at Forintek Canada Corp. Finally, the author wishes to acknowledge Stu Eaton and Ed Santella of Cloverdale Paints Ltd. and Dave Lick, chief instructor at BCIT's Painting and Decorating Trades Department for their contribution to the paint and furniture finishing testing and evaluations.

Table of Contents

Appendix

List of Tables

List of Figures

---

1 Introduction

This study examines the utility of using hybrid poplar in typical woodworking processes. The following three processes were considered: machining (including fastener withdrawal), laminating and finishing. In addition the effects of kiln drying on shrinkage and warp and general strength properties of hybrid poplar were also evaluated.

The machining operations studied were those encountered in commercial secondary wood processing (value-added) plants, including planing, sanding, boring and shaping. The machining tests were conducted according to American Society for Testing and Materials (ASTM) D 1666-87: *Standard Methods for Conducting Machining Tests of Wood and Wood-Based Materials*. The fastener withdrawal tests determine the force necessary to withdraw two types of fasteners (nail and screw) from a number of samples. The fastener withdrawal tests were conducted according to ASTM D 1761-88: *Standard Test Method for Mechanical Fasteners in Wood*. Density (or specific gravity) and ring per inch were determined for approximately half of the boards used in the machining tests. Knowing these values may lead to insights on how variability in these parameters affects the machining, laminating, finishing and strength properties of hybrid poplar.

The laminating tests study the performance of hybrid poplar when four different types of adhesives are used in conjunction with three different types of glue press systems: cold set press, hot platen press and a radio frequency press used in laminating sample blocks. The resulting samples were tested for delamination and shear strength of the glued joint according to the ASTM D 1101: *Standard Test Methods for Integrity of Glue Joints* and D 905: *Standard test Method for Strength Properties of Adhesive Bonds* respectively.

The finishing properties of hybrid poplar were evaluated using three types of finishes: paint, furniture type of finishes and wax finishes. The paint tests are typical paint industry tests for the adhesion of the coating to a substrate and a gloss test. The following ASTM test procedures were used: D 4541 *Test Method for Pull-Off Strength of Coatings Using Portable Adhesion-Tester*, D 3359 *Test Method for Measuring Adhesion by Tape Test* and D 523 *Test Method for Specular Gloss*. The tests for furniture type finishes follow no formal test procedure as none exist; however, the applicability of using hybrid poplar in typical furniture finishing was subjectively evaluated by applying six different types of stains in combination with four types of sealers and six clear finish coats. The wax finish tests again follow no formal test procedure other than following the instructions provided by the wax finish manufacturer and use of subjective evaluation to judge the results.

The lumber used for the above and following tests had to be kiln dried at Forintek as a matter of course. Hence the opportunity presented itself to perform shrinkage and warp evaluations on the hybrid poplar lumber as supplied. Shrinkage and warp can affect the utility and of a wood species for particular products and depending on the grading rules used its grade determination and value. The evaluation was based on comparing the degree of shrinkage and warp prior to after kiln drying with the latter results being evaluated against standard warp tables found in *NLGA Standard Grading Rules for Canadian Lumber*.

The general strength properties evaluated were modulus of rupture (MOR) and modulus of elasticity (MOE). The test procedure followed to determine MOR and MOE was ASTM D 143 *Standard Methods of Testing Small Clear Specimens of Timber* .

It was felt that the results of these tests could be made more meaningful if hybrid poplar could be compared to other wood species or general standards if possible. As the author has recently completed a wood machining study of 15 B.C. wood species, comparing hybrid poplar with five similar species provides a sense of the relative properties of hybrid poplar. The five species selected were trembling aspen, red alder, black cottonwood, western white pine and lodgepole pine. In the laminating tests the same five species were tested along with hybrid poplar for the block shear strength values. No comparison could be made for the various finishing tests due to the lack of comparative data.

2 General Procedures

The lumber to be tested was supplied directly from Rouck Bros. Sawmill in Lumby as green lumber in two thickness sizes (1 and 2 inch), in widths ranging from 4 to 8 inches and in lengths ranging from 4 to 9 feet, the majority being in eight to nine foot length. The lumber was marked with identifying colours on the ends: red, white and blue to signify the size of log from which it was sawn. Refer to Appendix I for a list of the sizes of lumber in each colour category received. Of note was the fact that a lot of lumber (with green ends) was sent to Forintek inadvertently as it came from pulp grade logs. However not to miss out on an opportunity to test this lumber, it was agreed that if funding permitted both MOE and MOR tests would be performed on this lot of lumber as a comparison with lumber from saw logs. All the lumber once received was immediately stickered and stored indoors for a period of one month to await kiln drying.

As in the case for the hardwood tested in the previous machining study the moisture content targeted for the hybrid poplar lumber was 9%. The kiln schedule used can be characterized as being very gentle (low air velocity, low dry bulb final temperature and long duration). This schedule was used to limit drying defects such as checking, as only a limited amount of lumber was available for the other tests.

Once dried lumber from saw logs was marked for the cuttings to be made, stamped with a four-digit number for identification and sawn into pieces. Every attempt was made to obtain cuttings from each of the three coloured board ends though this was not always possible especially for the blue end boards, as they were too narrow and short.

The cuttings were stored in a conditioning chamber set at relative humidity of 65% and a temperature of 20° C to maintain a moisture content of 9%. Samples were kept in the conditioning chambers until a machining test was ready to commence. Refer to Appendix II for a cross-reference list of board number to part number. Small sections were cut from each of the 50 boards to determine specific gravity and number of rings per inch. Oven-dry weight over oven-dry volume as measured by water displacement was used to determine the specific gravity for each board.

The planer samples were further sanded to make them ready for the finishing test, which require a finer finish. The laminate samples were taken from boards used in the machining tests and from previously unused boards though no sanded surface could be used in the tests.

3 Specific Gravity and Rings per Inch

The mean and standard deviation of the specific gravity values of 27 hybrid poplar samples was calculated to determine how it compared to the specific gravity for the two species from which this hybrid poplar is derived, namely western black cottonwood (*Populus Trichocarpa*) and eastern cottonwood (*Populus deltoides*). The mean value of specific gravity obtained for hybrid poplar was 0.375 with a standard deviation of 0.043. The published means for both types of cottonwood are 0.334 and 0.386 respectively. The hybrid poplar samples tested clearly fell between these two values with a tendency of having a specific gravity closer to that for eastern cottonwood. Higher specific gravity values are always superior to lower values for strength considerations alone.

The mean and standard deviation for the number of rings per inch were also determined. Refer to Appendix III for a table showing specific gravity (or relative density) and rings per inch for various part numbers. Similar data from the previous machining study show western black cottonwood, red alder and trembling aspen having ring per inch mean values in the 10 to 15 range. It is evident that this hybrid poplar is a very fast growing tree with 1.48 rings per inch.

4 Wood Machining Tests

The test procedures followed the tool and machine settings as prescribed in ASTM D-1666 whenever possible. However, some settings were modified in the interest of obtaining the best possible surface quality. These modifications are discussed separately under the "Procedure" heading for each test.

The wood machining tests were performed on two different samples cut from each board, as specified in the ASTM standard though this became difficult to accomplish with narrow boards. The planer test samples were each 36 in. long and 4 in. wide. The shaping test samples were each 12 in. long and 3 in. wide. The boring tests were performed on the same piece of wood as the shaper test.

The tests examine the surface quality of the machining operations and this was done both visually and by touch. The ASTM D1666 standard uses five quality grades based on the amount and severity of defect present, as follows:

- Grade 1 -- excellent / defect free
- Grade 2 -- good
- Grade 3 -- fair
- Grade 4 -- poor
- Grade 5 -- very poor.

Table 1 lists each machining test and the quality grades used in determining overall performance.

Table 1 Quality Grades Used in Determining Overall Performance for each Machining Test

Machining Test	**Performance Criteria**
Planing	Grade 1
Sanding	Grade 1
Boring	Grades 1 and 2
Shaping	Grades 1 and 2

The practice of using different grades or combination of grades for each test may appear to be inconsistent. However, the grade combinations are those that are considered suitable for most purposes found in secondary wood processing. Samples of each grade and type of defect were kept for reference.

4.1 Planing

Planing is second to sawing as the most important machining operation in a wood processing plant, since all lumber has to be dressed to size and/or surfaced prior to further use. Accordingly, this study has placed more emphasis on the planing test than the other machining tests. Planing provides an excellent opportunity for adding value to a product. This machining process can be performed by a planer or the more versatile moulder.

4.1.1 Equipment

The planing test was conducted on a Weinig through-feed moulder with five spindles. Only the top spindle was used in the planing tests. The machine had a variable feed rate with a spindle rotation speed of 6000 rpm.

Two hydraulically clamping cutter heads were used: one with a 12° hook angle (also known as the rake or cutting angle) and the other with a 20° hook angle. The corrugated back knives were cut from individual bar stock, balanced to within 0.2 grams, and aligned within the cutter head. All knives were the industry standard high speed steel (HSS), M-3 type. Each knife was carefully ground using an aluminum-oxide wheel to a consistent cutting circle on a profile grinder. The knives were ground to an extremely keen edge through several lapping passes. The planing tests compared two hook angles and four numbers of knife marks per inch (KMPI).

4.1.2 Measurement of Surface Quality

The number of KMPI is often used as a measure of surface quality in planing. It is determined by the feed speed, spindle rpm and number of knives making the final cut. As the latter two parameters were not varied during the tests, altering the feed speed was the only way of changing the number of knife marks per inch. Table 2 shows the number of knife marks per inch typically found in various wood products:

Table 2 Comparison of Knife Marks per Inch by End Use

Product	KMPI
Lumber	4 to 8
Exterior Wood Products	8 to 12
Millwork	12 to 16
Furniture	16 to 20

4.1.3 Procedure

Five passes were made with each sample having a 0.1 inch (2.5 mm) depth of cut under different sets of conditions. The first four runs used a 20° hook angle cutter with four feed speeds that yielded 8, 12, 16 and 20 knife marks per inch. The fifth run used a 12° hook angle cutter that produced 20 knife marks per inch. The number of knife marks per inch was determined by running a few test pieces through the moulder, and adjusting the feed rate until the desired number was repeatedly measured. Table 3 lists the machining parameters for each planing test. All the samples were run butt to butt to eliminate the occurrence of snipe and related feeding problems that can result in burn marks and subsequent overheating of the knife edges. All specimens of a common thickness were run one after another, and then the machine height setting was changed to accommodate thinner stock.

Samples were graded for the presence of fuzzy grain, raised grain, torn grain and chip marks. The sense of touch was found to be an efficient method for determining the presence and severity of raised and fuzzy grain.

Table 3 Machining Parameters for the Planing Tests

Run	Hook Angle	KMPI	Feed Speed (Ft/min)*
1	20°	8	63
2	20°	12	42
3	20°	16	31
4	20°	20	25
5	12°	20	25

* Note: Non-jointed cutter block -- only one of the knives produced the final cut

4.1.4 Planing Properties

Comparison of the planing properties was based on the percentage of defect-free samples in each species. Each of the five runs was evaluated separately. Table 4 provides a summary of the results for each planing test runs and an average for all five runs.

The best results for planing hybrid poplar occurred with a 20° hook angle at a feed speed of approximately 31 feet per minute which yielded 16 knife marks per inch. The most prevalent defect at all feed speeds was fuzzy grain though the severity was in nearly all the cases, grade 2 (good) and it could be considered as being light fuzzy grain. However, the fuzzy grain was completely removed by sanding. If the criteria for evaluation hybrid poplar was to include good to excellent samples (defect free), the average number of samples pieces in each run meeting the standard would have been 93%. These results would indicate that hybrid poplar can be planed successfully if the tooling is kept sharp and it has a hook angle between 12º and 20º and that light sanding is required afterwards to remove minor fuzzy grain.

Table 4 Summary of Planing Tests - Percentage of Defect-Free Samples

Species	Run 1	Run 2	Run 3	Run 4	Run 5	Average
	%	%	%	%	%	%
Lodgepole Pine	100	100	100	92	94	97
W. White Pine	90	74	86	94	96	88
Black Cottonwood	72	49	32	26	58	47
Red Alder	80	96	92	96	88	90
Trembling Aspen	66	90	46	96	100	80
Hybrid Poplar	69	53	72	57	62	63

Run 1: 20° Hook Angle, 8 KMPI
Run 2: 20° Hook Angle, 12 KMPI
Run 3: 20° Hook Angle, 16 KMPI
Run 4: 20° Hook Angle, 20 KMPI
Run 5: 12° Hook Angle, 20 KMPI

4.2 Sanding

Sanding is a method of preparing the wood surface for the application of a finish coating (e.g., sealer, stain, oil, and lacquer). Sanding wood properly is the first step in applying a first class finish. Mistakes made in sanding often show up after the finish is applied.

Sanding is an abrasive action that leaves a scratch pattern on the wood surface, and is directly influenced by the grit size of the sandpaper. To remove excessive scratch patterns, progressively finer grit sandpaper is used until the desired surface smoothness is reached.

4.2.1 Equipment

This test was conducted on a CEMCO wide belt sander with two heads. The belt sequence was a 80 grit, cloth-backed aluminum oxide belt on the first head and a 120 grit, cloth-backed aluminum oxide belt on the second head. The feed rate was adjusted to 20 ft/min (6.1 m/min).

4.2.2 Procedure

The planing samples were used for the sanding tests though they were not cut down to a 12 inch length as recommended in the ASTM standard but left in the 3 foot length as they were to be used in the finishing tests as well. In order to use the whole width of the belt, the sanding specimens were staggered across the belt.

4.2.3 Sanding Properties

The basis of comparison for sanding properties was the percentage of fuzzy grain present in each sample. The percentage of defect free-pieces samples was 96 % with the remaining 4 % of the samples being in grade 2 or good category. Figure 1 shows how well hybrid poplar did when compared to the other five species. It is evident that hybrid poplar sands well.

4.3 Shaping

Shaping is similar to planing with respect to cutting action and type of tooling. The major difference is the shaper's ability to profile curved pieces of wood, whereas the moulder/planer can only profile straight lumber. A shaper is a versatile machine and can produce a variety of cuts (grooves, rebates, profiles, dados, etc.).

4.3.1 Equipment

The shaping test was conducted on a SCM T120C single spindle shaper operated at a spindle speed of 7200 rpm. The tooling used was a six pocket (wing) cutter head with removable HSS knives though only three of the pockets contained a knife (this was a specially ordered cutter head with three 10° and three 20° pocket angles). Each pocket in the cutter head was numbered as were the knives and corresponding gibs. Shaping tests were conducted using the 10° knives on the hardwoods and 20° knives on the softwoods. The knives were ground to the same profile shown in the ASTM standard.

A jig was designed to hold the sample in place while shaping. The jig was similar to that described in the ASTM standard, with the addition of toggle clamps to help secure the workpiece. The workpiece was fed by guiding the jig against a bearing mounted underneath the cutter head. This set-up produced duplicate curved patterns with every pass.

4.3.2 Procedure

Prior to being shaped, each sample was bandsawn to a pattern using a template. Two passes were made on the shaper: a preliminary pass that removed a lot of material followed by a second pass that removed the required 1/16 inch (1.6 mm) of material. This was accomplished by placing a 1/16th inch strip of veneer between the sample and the jig's base. All the cutting action was against the grain as is the usual way of operating a shaper safely.

All samples were examined visually and by touch. Samples were graded for the presence of fuzzy grain, raised grain, torn grain and end grain tear out. As in the evaluation of planing pieces, the sense of touch was found to be a more efficient method of determining the presence and severity of raised and fuzzy grain.

4.3.3 Shaping Properties

Shaping properties were based on the percentage of good to excellent samples present. For hybrid poplar, the value was 96% which indicates that it is a good species to shape however, this must be qualified to some extent. It was observed that no appreciable shaping defects occurs in the straight portion of the cut but as the cut started to go across the grain in the curved portion rough end grain appeared. This defect was categorized as being to a slight degree (grade 2) but it occurred in 60% of the samples. Fuzzy grain was the next most prominent defect occurring in just 12% of the samples again to a slight degree. The percentage of defect-free samples was 17%. Figure 2 shows how hybrid poplar compared to the other five species. It is on par with alder and greatly exceeds the performance of black cottonwood.

4.4 Boring

Boring like shaping is performed extensively in furniture and other woodworking plants. Boring is performed to create holes for the insertion of dowels or attachment of metal hardware

Boring holes into wood can serve two purposes: (1) to receive dowels and (2) to pre-drill "pilot" holes for insertion of screws or other type of fastener. The bored hole must be round without any noticeable distortion and have an inner surface conducive for good glue bonding (free of torn and crushed grain). Dowels serve to (1) reinforce the joint and (2) accurately position adjacent parts, thereby allowing fast assembly. Boring is extensively used in the manufacture of RTA furniture.

Two bits were used in the boring tests: (1) a single twist, solid-centre point bit (referred to as *single twist bit* from here on) as stated in the ASTM standard, and (2) a brad and lip point bit (referred to as *brad point bit* from here on). The single twist bit was similar to an auger style bit. The brad point bit differed from the single twist bit in that it had two flutes (twists) instead of one, and two lips ground into the ends of its flutes. The lips in the brad point bit act as spurs severing wood fibres before they are cut. Both styles are common in use however, the brad point bit is normally regarded as producing a more accurate and clean hole. The brad point bit was added to the test, as it was more representative of current industrial practices in B.C.

Adaptations to the ASTM recommended test procedure were necessary, since the recommended spindle speed of 3600 rpm was found to cause burning of the wood and overheating of the boring bits. Furthermore, the recommended single twist bit was found to be too aggressive in cutting (its threaded centre-point pulled the wood into the bit too fast). After a number of trials, a spindle speed of 1200 rpm was found to be satisfactory for both bit types. The removal of threads by grinding reduced the pulling tendency of the single-twist bit.

The boring tests were conducted after the shaping test using the same samples.

4.4.1 Equipment

The boring machine used was an Ashina bench drill press with a ½ hp motor. The feed rate was approximately 1 inch in 6 seconds.

4.4.2 Procedure

The brad point bit was used to bore the first hole into each of the wood samples. This hole was placed at the pointed end of each sample. A jig was made so that the holes were placed in approximately the same location for each specimen. A removable wooden base board was used under the test pieces, which was replaced when worn.

The same procedure was replicated using the single twist bit. The two holes were spaced at least 2 inches (50 mm) apart and away from any edges.

All samples were examined with the aid of a magnifying glass. The bored holes were graded for the presence of crushed, fuzzy, or torn grain, and general smoothness of cut.

4.4.3 Boring Properties

Comparisons of boring properties using the two types of boring bits were based on the percentages of excellent and good samples present in each species. The brad point bit outperformed the single twist bit by a wide margin, 68% to 4% respectively for defect-free samples and 80% to 8% respectively for defect-free and good samples. This performance improvement is due to the cutting action of the brad point bit's two lips that sever the wood fibres with a shearing cut before the cutting edges remove the chip.

The most common defect for the brad point bit was tearing of the fibres followed closely by fibres being crushing up against the inside of the hole. For the single twist bit the most common defect by far was grain crushing followed by grain tearing. Crushing of the fibres can present problems if glue is to be inserted into the hole as the glue will adhere to fibres that are not firmly attached, hence failure is likely. Figure 3 shows how hybrid poplar did when compared to other species. Hybrid poplar performed the best when the brad point bit was used though with the single twist bit its performance was the poorest.

4.5 **Comparative Summary of Machining Properties**

Table 5 presents a comparative summary of the results of the four machining tests performed with hybrid poplar and the other five species. It can be seen that hybrid poplar exceeds only black cottonwood in the planing test however, it must be pointed out that when the good to excellent results are considered hybrid poplar scores in the high 90's. The sanding properties of hybrid poplar are on par with the other wood species. The single twist boring results can be considered insignificant as the type of boring bit is seldom used by industry. However, it can be seen that hybrid poplar responds well to an improvement in tooling with the brad point bit. Here it scored the highest. In the shaping test hybrid poplar scored in the high 90's and it is comparable with some of the better wood shaping species from B.C.

Table 5 Summary of Comparative Machining Properties

Species	Specific Gravity	Planing Good to Excellent Ave.	Planing Good to Excellent Best	Sanding Defect-free	Boring Good to Excellent Single Twist	Boring Good to Excellent Brad Point	Shaping Good to Excellent
		%		%	%		%
Hybrid Poplar	0.38	69	72	96	8	80	96
Black Cottonwood	0.39	47	72	80	10	29	33
Red Alder	0.49	90	96	100	25	67	94
Trembling Aspen	0.47	80	100	96	55	73	98
Lodgepole Pine	0.46	97	100	98	19	44	86
W. White Pine	0.43	88	96	96	57	65	100

5 Fastener Withdrawal

The fastener withdrawal tests provide quantitative data on the force required to withdraw nails and screws. The screw test measured the maximum withdrawal force required to pull two screws from either flat or vertical grain samples (chosen at random), whereas the nail test measured the maximum withdrawal force required to pull two nails from each of the three grain orientations (tangential, radial, or end grain).

All tests were conducted on a Tinius Olsen Universal Testing Machine. This machine had an accuracy of ± 1%. A specially designed gripping device shaped to fit the base of the two types of fasteners was used to permit accurate sample placement and true axial loading. A clamping assembly was used to hold the wood sample to one platen of the machine.

5.1 Screw Withdrawal

The screw withdrawal test determined the maximum force required to withdraw a screw fastener driven in at right angles to the wood surface. Screws were randomly driven into either the tangential or radial face.

5.1.1 Equipment

Fifty samples were tested, each measuring 2 in. by 6 in. with their depth at least equal to the length of the screw. The tests involved standard one inch, No. 10 gauge, flathead, low-carbon steel wood screws. A screwdriver was used to insert the screw into a pre-drilled hole bored on a drill press at right angles to the surface. Each screw was only used once.

5.1.2 Procedure

The samples were pre-drilled to a depth of ½ inch using a #39 drill bit (0.1 inch diameter). The location of the holes was within an area ¾ inch from the edge and 1-½ inch from the ends and at least 2-½ inch apart. Samples were tested within the prescribed one hour period after driving of the fasteners. The screws were driven by hand using a screwdriver to a depth where the threads were no longer visible. This permitted the gripper to firmly secure the screw head.

Each sample was placed in the clamping assembly, the gripper secured around one of the screw heads and aligned axially. A uniform platen withdrawal rate of 0.1 inch per minute was set for the universal testing machine. The maximum force in pounds was measured for each screw.

5.1.3 Screw Withdrawal Properties

Table 6 shows the wood specific gravity and screw withdrawal force for hybrid poplar and the other five species. There is a reasonably good relationship between increasing specific gravity and required force for screw withdrawal.

Table 6 Relationship between Specific Gravity and Screw Withdrawal Force

Species	Specific Gravity	Average Force (lb)	Standard Deviation
Hybrid Poplar	0.38	395	73.1
Black Cottonwood	0.39	302	52.9
White Spruce	0.40	347	49.8
Lodgepole Pine	0.46	435	58.8
Trembling Aspen	0.47	482	79.9
Red Alder	0.49	518	54.5

Figure 4 shows a comparison of the average force required to withdraw a screw from hybrid poplar and five other species. It is clearly on par with the other hardwood species in this group and it even surpasses one of the pine species.

Figure 4. Comparative Screw Withdrawal Force

5.2 Nail Withdrawal

The nail withdrawal test determined the maximum force required to withdraw a nail driven in at right

5.2.1 Equipment

The nails tested were the 6d plain-shank, diamond-point, round-wire, low-carbon-steel type. Each nail was only used once. Fifty samples of hybrid poplar were tested. Each sample measured 6 in. long and 2 in. wide and high.

5.2.2 Procedure

Six nails were driven by hand with a hammer to a total penetration of 1 ¼ in.; two nails in the tangential face, two in the radial face, and one in each end. A jig was designed to ensure that ½ in. of nail shank remained above the surface. Nails were driven least ¾ in. from the edge, 1-½ in. from the ends, and no closer than 2 in. apart. Nails driven into the end grain were not placed in line with each other. Testing was completed within one hour after the nails were driven. The testing machine along with the gripping device and clamping assembly were the same as used in the screw withdrawal test. The maximum withdrawal force in pounds was measured for each nail.

5.2.3 Nail Withdrawal Properties

Table 7 shows the wood specific gravity and nail withdrawal force for hybrid poplar and the other five species. The highest results were obtained from nails driven into the tangential and radial faces (tangential being slightly higher on average). As expected, the end grain face produced the lowest values though the end grain face values for hybrid poplar were only about 15% lower whereas for the other species the end grain values were about 1/3 lower. Figure 5 shows a comparison of the average force required to withdraw a nail from the tangential, radial and the end grain faces for hybrid poplar and five other species.

Table 7 Relationship between Specific Gravity and Nail Withdrawal Force

Species	**Specific Gravity**	**Average Force (lb.)**		
		Tang.	**Radial**	**End**
Hybrid Poplar	0.38	98.3	94.9	82.2
Black Cottonwood	0.39	108.5	100.7	70.8
White Spruce	0.40	110.7	100.8	69.1
Lodgepole Pine	0.46	131.6	116.1	85.2
Trembling Aspen	0.47	165.8	169.8	102.4

Red Alder	0.49	198.7	190.5	153.1

Figure 5 shows a comparison of the average force required to withdraw a nail from the tangential, radial and the end grain faces for hybrid poplar and five other species.

6 Laminating Tests

The laminating tests determine the applicability of using hybrid poplar in glued wood products when delamination and shear strength are taken into consideration in the evaluation of a glued joint. In order to given a broader answer to the question of how well hybrid poplar performs as a glued wood product, four adhesives typically used in the secondary wood processing industry were tested in conjunction with three different types of glue presses.

The four types of adhesives used in the test were as follows: polyvinyl acetate (PVA), polyvinyl acetate with a crosslinking agent added (PVAc), urea formaldehyde (UF) and phenol resorcinol formaldehyde (PRF).

PVA is white glue typically found in woodworking applications like furniture making. PVAc and UF represent adhesives that provide better moisture resistance than PVA. They are used for furniture and non-structural building components and require mixing of two components prior to use. These adhesives can be cured at room temperature but are commonly used with heated platens or radio frequency curing to increase production rates. PRF is a high end adhesive that would probably not be used with this wood species but it is an adhesive that can provide exterior exposure durability with the capacity for room temperature curing. Like the PVAc and UF this adhesive requires mixing of two components and has to be used within a certain time period.

The three types of glue presses used were as follows: a hot platen, a cold set press and high frequency press. The hot platen press uses heat to cure the glue joint by transferring heat from the metal platen (top and bottom) to the glue joint. This type of press is well suited for plywood and veneer and thin lumber stock but it is limited in use for very thick stock as wood is a good insulator. The second type of press uses the normal room temperature to cure the glue joint providing that the temperature is in the 18 to 20° range. A clamp carrier or glue reel is an example of this type of press. This type of press is the most inexpensive and simplest to use and operate. The last type of press uses electrical energy in a wave form to cure the glue joint in a relatively short period of time depending on the size of the generator and surface area of glue line to be cured. Though this type of press promises quick curing, tight control of wood moisture content is critical if arcing problems are to be avoided. Ideally, the moisture content should not go above the 12 to 13 % range.

The two ASTM standards used to test the glued joints are D 905 and D 1101. The first test determines the shear strength of the glued joint and the second test determine the extent of delamination of the glue joint when subjected to wet and dry cycling. The shear tests determine the maximum force necessary to fracture the glue bond when a shear force is applied in compression. An examination was also made of the bonded surface and specifically how much of the joint failure was a result of wood failure and conversely, glue failure.

The force necessary to break the glue bond is influenced by three factors working in conjunction with each other. These factors are the inherent strength of the adhesive, how well the adhesive interacts with the surrounding wood fibre and the strength of the surrounding wood fibre. To give an indication of the relative shear strength of hybrid poplar in compressive shear loading, it was decided to perform a secondary test in which samples of hybrid poplar would be compared to the five selected species mentioned above. Though the shear test would be done with solid wood and not along a glue line.

The delamination test on hybrid poplar unlike the shear test was not comparative. This test determines the accumulated percentage of delamination along the glue line for each batch of samples. To be considered a good glue joint the percentage of delamination should be no more that 10% of the overall length of all the glue joints hence comparing to other wood species was not necessary.

Glued wood samples were prepared in five lots with each lot comprised of five glued blocks. The wood that made up the glue blocks were previously planed on both wide faces, then sawn in the middle so that each block would in effect be glued to itself. The first lot used a PVAc cured in a hot platen, the second lot a PRF cured by cold set, the third lot a PVA cured by cold set, the fourth lot a UF cured by radio frequency and the final lot, a PVAc cured by radio frequency. Each glued block was further divided into five smaller pieces— three to be used for the shear test, one to be used in the delamination test and one spare piece. A total of 75 shear samples and 25 delamination samples were tested.

6.1 Shear Test

The shear test as stated in the ASTM standard is intended primarily as an evaluation of adhesives for wood; however, it is often used to evaluate the strength of a glued wood joint as in this case. In a shear test the true indication of a good bond is if there is wood failure present in the fracture area. The amount of wood failure was recorded by judging the percentage of the surface area of the joint that exhibited fibres torn away from the opposing surface.

6.1.1 Equipment

A Tinius Olsen Universal Testing Machine was used to apply a shear force in compression. Fitted to the machine was a shear tool with a self-aligning mechanism to ensure uniform lateral distribution of the load.

6.1.2 Procedure

To test the shear strength of the hybrid poplar glue line each of the glue blocks were cut into five pieces measuring exactly 2 by 1½ inches. Each smaller sample was accurately knotched by a bandsaw in such a way that a ¼ inch segment was removed from diametrically opposite ends of each lamination. This way the shear force could be concentrated along the glue joint.

All sample pieces were numbered to keep a track of which adhesive and glue curing system was used in their construction.

The shear load was applied with a rate of load of 0.15 inch/minute to failure. The shear stress at failure was calculated in pounds-force per square inch of glue line area between the two laminations.

To test the shear strength of a solid piece of hybrid poplar relative to the five other wood species, the samples were cut in exactly the same manner. Samples from the five other species were conveniently available with planed surfaces ready for gluing. Only the shear stress at failure was recorded.

6.1.3 Shear Test Results

The results for block shear for hybrid poplar with glue joints appear in Table 8. Due to the low shear values obtained for UF adhesive using the RF glue press it was decided to use a urea with a thickening agent or filler to increase its viscosity thereby reducing the flow of urea into the wood fibre before curing can occur. Unfortunately testing a UF with filler with a RF press was not possible however, the thickened form of UF was tested using the hot platen and the cold set method and the results can also be seen in the last two columns in Table 8.

Table 8 Comparative Shear Results Using Different Glue/Press Combinations

	Hot Platen	Cold Set	Cold Set	RF	RF	Hot Platen	Cold Set
Part #	**PVAc**	**PRF**	**PVA**	**Urea**	**PVAc**	**Urea**	**Urea**
B23	1708						
W15	1649						
W16	1776						
W17	1570						
W18	1220						
Average	**1585**						
B25		2046					
B21		1751					
R5		1377					
R21		1598					
W2		1245					
Average		**1603**					
B22			1543				
B24			1875				
R10			1803				
R11			1862				
W4			1569				
Average			**1731**				

R6				859			
W19				682			
R12				1493			
R7				1115			
R9				1145			
Average				**1059**			
R14					2210		
R13					2032		
W3					1443		
W8					1490		
W20					1824		
Average					**1800**		
B6						1572	
W10						1622	
R11						1806	
R24						1457	
R24B						1894	
Average						**1670**	
B6							1608
W10							1591
R11							1877
R24							1400
R31							1786
W34							1965
Average							**1705**

*Note: Sample number denotes source board number and hence colour of board end marking.

Excluding the UF values using the RF press it can be seen from the above table that all of the adhesives used were capable of providing a satisfactory shear strength no matter what type of glue press was used. Filled UF provided good shear strength whereas un-filled UF, which provides a colorless glue line, could not provide an adequate shear load. The tests conducted with un-filled UF clearly show that hybrid poplar does not work well with low viscosity adhesives.

The shear test results for solid wood blocks (with no glue joint) appear in Table 9.

Table 9 Block Shear Results for Solid Wood Samples

Species	Shear Force (lb.)
Black Cottonwood	1350
Western White Pine	1359
Trembling Aspen	1675
Lodgepole Pine	1716
Hybrid Poplar	1876
Red Alder	2037

The results in Table 9 show that hybrid poplar is only exceeded by red alder in compressive shear loading. It must be emphasized that the number of samples used in this test was small hence the data may not be that representative.

A comparison can also be drawn between the value for the solid wood shear test for hybrid poplar and the average of the glue joint shear tests in Table 8. It can be seen that the glued joint shear tests (except for the UF radio frequency samples) range from being 16% to 4% below the strength of solid hybrid poplar which is an indication of how well hybrid poplar glues.

6.2 Delamination Test

This test method determines the resistance to delamination of wood laminations typically used in exterior applications. It is, in effect, an accelerated means of measuring the effects of exterior exposure. Similar test procedures are employed in other countries to test glued wood bonds though, in practice, the number of wet and dry cycles is reduced to one rather than the three stipulated in the ASTM standard. This test requires the evaluations be done in two stages: after one complete wet-dry cycle and then following a second wet-dry cycle.

6.2.1 Equipment

Equipment requires includes a pressure vessel similar to the ones used in paint finishing lines where both a vacuum and elevated atmospheric pressure can be applied, a water aspirator system to create a vacuum of between 25-30 inches of mercury, and a convection oven capable of heating air up to 153 ° F and capable of circulating air at 500 feet per minute.

6.2.2 Procedure

Test sample pieces were cut from the larger glue blocks mentioned above to a size of approximately 2 by 2 inches and then weighed. With weighed down samples in the pressure vessel warm water was added to cover the samples and a vacuum of between 20 to 25 inches of mercury was drawn for five minutes which was followed by a pressurization period of one hour at 75 psi. Upon completion of wet cycling, the samples were dried in an oven for 10 hours at 160 ° F at an air velocity of 500 feet per minute. The end grain glue joints were placed directly parallel to the air stream. Upon reaching 115% (i.e. at 15% moisture content) of the initial dry weight the samples were examined for delamination of the end grain joints only.

All delamination lengths were totaled and expressed as a percentage of the total length of glue joint in all the samples of a lot. A second wet-dry cycle was then completed as before with the delamination recorded as before for each lot.

6.2.3 Delamination Test Results

The first wet-dry cycle yielded the following results as found in Table 9:

Table 10 Delamination Test Results after first wet-dry cycle

	Hot Platen	Cold Set	Cold Set	RF	RF
Part #	**PVAc**	**PRF**	**PVA**	**Urea**	**PVAc**
B23	0.0%				
W15	56.0%				
W16	13.0%				
W17	0.0%				
W18	5.0%				
Average	**14.8%**				
B25		0.0%			
B21		0.0%			
R5		0.0%			
R21		72.0%			
W2		0.0%			
Average		**14.4%**			
B22			0.0%		
B24			0.0%		
R10			26.0%		
R11			0.0%		
W4			13.0%		
Average			**7.8%**		
R6				53.0%	
W19				65.7%	

R12				100.0%	
R7				100.0%	
R9				62.0%	
Average				**76.1%**	
R14					4.0%
R13					28.0%
W3					7.0%
W8					0.0%
W20					52.0%
Average					**18.2%**

*Note: Sample number denotes source board number and hence colour of board end marking.

Excluding the UF results, it can be seen that every test batch had at least one sample that had high delamination values though 65% of the samples had values below 10%. The very high values account for 25% of the values which is significant. Only the cold set PVA batch had delamination results that were below the 10% level. The PRF had the one 'wild' result but other than that it faired well as would be expected with this waterproof, structural adhesive.

The second wet-dry cycle yielded the following results as found in Table 10:

Table 11 Delamination Test Results after second wet-dry cycle

	Hot Platen	**Cold Set**	**Cold Set**	**RF**	**RF**
Part # *	**PVAc**	**PRF**	**PVA**	**Urea**	**PVAc**
B23	0.0%				
W15	29.0%				
W16	55.0%				
W17	47.0%				
W18	47.0%				
Average	**35.6%**				
B25		0.0%			
B21		0.0%			
R5		7.0%			
R21		72.0%			
W2		38.0%			
Average		**23.4%**			
B22			0.0%		

B24			0.0%		
R10			37.0%		
R11			0.0%		
W4			79.0%		
Average			**23.2%**		
R6				79.0%	
W19				100.0%	
R12				100.0%	
R7				100.0%	
R9				63.0%	
Average				**88.6%**	
R14					15.0%
R13					45.0%
W3					8.0%
W8					28.0%
W20					13.0%
Average					**21.8%**

*Note: Sample number denotes source board number and hence colour of board end marking.

The second delamination test produced higher average delamination rates as expected with more than 60% of the samples (excluding the UF values) having values above 10%. In two instances the delamination values are seen to have decreased from the first to the second wet-dry cycle tests. This would appear impossible however, the explanation has to do with added swelling of the open joint after the second test hence less of the open joint was visible for measuring.

When both delamination tests are taken into consideration the results were not completely satisfactory as none of the adhesives gave consistently satisfactory results. Upon examination of the joints it was evident that the majority of the delamination failures appeared to show starved glue lines despite the fact that all of the adhesives were applied with the manufacturer's recommended spread levels. While some of the wood substrate tested consisted of juvenile wood which is commonly more porous; the general trend in the test data is that the wood species should be used with higher glue spread levels or limited to the use of high viscosity adhesives.

7 Finishing Tests

The finishing tests determine the applicability of finishing hybrid poplar when a typical paint type coating, a furniture type coating and a wax coating is applied. Finishing is a key process if the maximum value is to be extracted from hybrid poplar or any other wood fibre. Paint type finishes are opaque and as such they can hide a lot of defects in the wood substrate as well as offer a relatively high degree of protection. Furniture type coatings involve the uses of a stain, a sealer and a top coat that is applied to enhance the wood grain and to offer it protection. A wax coating is similar in principle to the furniture-type finishes in that it enhances the wood grain, but it offers the least amount of protection.

Nine paint type finishes were tested: four of which are intended for interior application and five for exterior application. The paint type finishes consist of the following:

- interior varnish
- interior stain/water-based varnish
- interior alkyd primer/enamel top coat
- interior lacquer primer/lacquer top coat
- exterior semi-transparent stain
- exterior solid color oil stain
- exterior solid color acrylic stain
- exterior clear finish
- exterior elastomeric acrylic latex

Two of the ASTM standards used to evaluate these coatings look primarily at how the coating adhered to the wood substrate. The other ASTM standard evaluates the light reflectance of the surface coating.

Furniture type finish tests involved the use of six stains, four sealers and six top coats used in combination though not all the combinations were evaluated. A total of 33 samples were produced for evaluation. To determine the effect of using a wash coat (a pre-stain treatment to equalize the penetration of stain into the wood fibre), the same combination of stains, sealers and top coats was applied over a wash coat; this was performed on the back face of the samples to give a total number of finished surfaces at 66.

The stains used were the following:

- Sheriton Mahogany Penetrating Stain
- Antique Oak Penetrating Stain
- Oil Stain - Walnut
- Penetrating Stain Concentrate - Green
- Water Stain - Walnut
- Alcohol Stain - Walnut.

The sealers used were the following:

- Shellac
- Acrylic Waterborne Sealer
- Lacquer Sanding Sealer
- Nitrocellulose/ Alkyd Sealer (Catalyzed).

The clear top coats used were the following:

- Alkyd Semi-Gloss Varnish
- 45 degree Acrylic Waterborne
- Semi-Gloss Lacquer
- 45 degree Nitrocellulose/Alkyd Clear
- Acrylic/Urethane Waterborne (stain)
- Two Component Polyurethane (high gloss).

The evaluation of the finish is not aided by the use of any test protocol as none exists on account of the subjective nature of evaluations of this type. To assist in the evaluations the opinion of an expert was sought. His opinions, as such, cannot be readily quantified hence it is impossible to create a scale ranking the best to worst finish system used.

Wax coating is a very old method of applying a finish to a wood surface that has fallen out of favour. In Europe it is used more extensively than in North America. Its level of use in Europe can in part be attributed to its low impact on the environment. The wax coating test was a straight forward application of a wax finish (wax with colour as opposed to a wax polish) onto a finely sanded wood surface. Four colours were supplied by the manufacturer for testing. Evaluation was based on the final appearance after burnishing (buffing the wax coating to a shine).

7.1 Paint Tests

The paint tests investigated how well standard industrial types of paint coatings adhered to hybrid poplar. Poor adhesion of a coating to a wood substrate is influenced to a great extent by the ability of the coating to wet the wood substrate surface. Evidence of poor wetting can be found in the adhesion data and in the surface appearance such as craters and pin hole presence. Another factor that can influence surface preparation of the wood substrate. The surface preparation for the test samples consisted of sanding on a wide belt sanding machine with a 150 grit sanding paper. A number of different types of paint coating systems, representing a broad range of commercially available paints, along with some stains were used in the tests.

The second type of paint test involved one of the appearance attributes of a paint coating namely, gloss retention. The properties of the substrate may have an influence on the degree of light reflectance that comes off a painted surface.

All coatings were applied by conventional spray and allowed to dry at ambient conditions for 7 days prior to testing. Except for the exterior semi-transparent stain two coats were applied for each of the other coatings.

7.1.1 Adhesion Tests

The adhesion tests provide quantitative data on the suitability of hybrid poplar as a wood substrate for most common painting systems. One test involved the use of tape that is adhered to a knife scored (in a hatch pattern) painted surface. The tape is then pulled off and the resulting surface is examined for removal of coating material from either the substrate or the previous underlying coat. The percentage of the hatched area that remained on the tape is calculated by visual examination of the tape by holding it up to the light.

The second test looks at the pull-off strength required to pull of a section of a painted surface. An adhesion tester is used to apply a normal tensile force to the paint surface via a load fixture. A high strength adhesive is used to adhere the fixture to the paint surface. The force is applied until failure occurs and the force required is recorded.

7.1.1.1 Equipment

The tape test used a multi-blade cutter to score cuts into the paint surface. The tape used was a one inch wide semi-transparent pressure-sensitive tape available from a specialty tape supplier specializing in quality tape. For the pull-off test an adhesion tester with detachable loading fixture or plug was used to apply the tensile force to the paint surface.

7.1.1.2 Procedure

For the tape test a multi-blade cutter is used to score lines 1mm apart ¾ inch long through to the wood substrate. The surface is cleaned of any small fragments. The first two complete laps of tape are discarded then a length of tape is cut that will cover the hatched marks. To ensure good contact the tape was rubbed with the eraser end of a pencil. Within a time period 90 seconds after application of the tape, the tape is rapidly pull back upon itself at close to a 180 º angle as possible. Though the test procedure calls for the inspection of the grid area, better visibility was obtained by examining the tape against the light for paint fragments. The tape test was performed once for each of the samples.

For the pull-off test a special metal plug was glued to the coating using an epoxy adhesive and allowed to cure. Constant pressure was applied to the plug during the setting and curing of the adhesive. The adhesion tester was attached to the glued in plug and aligned over top of the plug and set to zero. A ring was turned by hand until the failure occurred and the force required exerted at failure was recorded. This was repeated at another location along the sample piece. An examination of the failure area to determine at what interface the failure occurred.

7.1.1.3 Adhesion Test Results

Table 12 presents the results for two paint adhesion tests for various paint coating systems.

Table 12 Paint Adhesion Test Results

Part #	**Coating**	**Tape Test Adhesion***	**Pull-Off Test (psi)**	**Failure Interface**
3629	interior varnish	100%	375	Substrate
3612	interior stain/ water-	100%	385	Stain-Clear

	based varnish			Interface
3602	Interior alkyd primer/ enamel top coat	100%	100	Primer
3614	interior lacquer primer/lacquer top coat	100%	300	Primer
3636	exterior semi-transparent stain	100%	400	Substrate
3628	exterior solid color oil stain	100%	90	Coating
3620	exterior solid color acrylic stain	100%	245	Coating
3635	exterior clear finish	100%	190	Coating
3627	exterior elastomeric acrylic latex	100%	290	Coating

* Percentage of coating remaining on the wood substrate

All the coating performed well with regard to the tape test. With respect to the other adhesion test two coating exhibited low values: part numbers 3602 and 3628. The reason for their low pull-off strength values can be attributed to paint product design or formulation. These two coatings have higher proportion of pigments added to promote intercoat adhesion and less of the stronger binders. This comes at the expense of film integrity and adhesion to the substrate as the test results show.

7.1.2 Gloss Test

Paint being opaque covers a wood substrate completely hence its visual attributes are colour and gloss provided that the paint contains a gloss additive. Gloss is associated with the capacity of a surface to reflect more light in one direction than another. The gloss test is a comparative test in which samples are tested for their gloss values and compared to the gloss value of the coating when it is applied to a black glass block. All reflectancy values are compared to the value obtained when the glossmeter is calibrated using a polished black glass plane at the 60 ° incidence angle. This value is 100 on the scale.

7.1.2.1 Equipment

The standard equipment used to measure gloss values is the Parallel-Beam Glossmeter. This device projects a light beam at set incidence angles at a surface of a sample and a photodetector receives the light at the same angle once it has been reflected.

7.1.2.2 Procedure

When applying a coating to each of the sample pieces an identical set is made using black glass as the substrate. The glossmeter is set to a beam axis of 60º and it is calibrated using the black glass plane. A number of readings are taken for each of the wood substrate samples pieces with an average being taken for each one and a reading is taken for each of the black glass substrate pieces. The reading taken are recorded.

7.1.2.3 Gloss Test Results

The results of the gloss test on the various paint coatings are presented in Table 13.

Table 13 Paint Gloss Test Results

Part #	**Coating**	**60º Gloss on Wood Substrate**	**Standard 60º Gloss on Black Glass Substrate**
3629	interior varnish	39.0	40
3612	interior stain/ water-based varnish	81.0	80
3602	Interior alkyd primer/ enamel top coat	35.0	50
3614	interior lacquer primer/lacquer top coat	65.0	90
3636	exterior semi-transparent stain	4.6	Low
3628	exterior solid color oil stain	0.5	Low
3620	exterior solid color acrylic stain	0.9	Low
3635	exterior clear finish	6.3	Low
3627	exterior elastomeric acrylic latex	11.0	13

The variance in gloss level between the standard and the wood test pieces is a good indicator of gloss holdout or porosity of the substrate. This indicates that hybrid poplar can be sealed effectively by the paint systems used.

The above test results would indicate that hybrid poplar is a suitable wood substrate for most common painting systems. No difficulties are foreseen using this wood for interior applications.

7.2 Furniture Finish Tests

Tests for furniture type finishes, for the most part, are concerned with the properties of the topcoat such as its resistance to chemical stains, moisture and abrasion. There are no testing protocols to evaluate the appearance of a finish as this attribute is subjective and hard to describe in words let alone apply a numeric value to appearance factors.

The combination of stains, sealers and topcoats used on in these tests are representative of what is available from finishing suppliers in B.C. They range from traditional solvent based treatments to the newer, more environmental friendly water-borne treatments as well as a washcoat treatment on one side of each board all with varying degrees of success. Different colour treatments, ranging from light to dark were used to explore the range of possible furniture type finishes for use on hybrid poplar.

7.2.1 Equipment

All stain, sealer and topcoat coatings were applied with the use of an air spray system. Sand paper used on the sealer was 180 grit aluminum oxide.

7.2.2 Procedure

All samples were supplied to the finish consultant sanded by a wide belt sander to 150 grit. Finish system sample pieces in the furniture industry are called step panels where a small 2 inch section across the wide of a sample piece is masked off so that it will not be coated by the next layer of coating material. This way the colour build up of the finish can be seen from start to finish.

The number of processes or steps used in the hybrid poplar test samples number five for one side of each sample piece and six for the back side. The steps were as follows: stain, sealer, sealer sanding and two topcoats. The additional step used for the back of each sample was the application of the initial washcoat. A washcoat is a highly thinned finish like shellac that slows down stain penetration and helps to reduce splotching. The finished sample pieces show only four steps as sealer sanding is never shown and the topcoat is shown in its aggregate form this time with two coats.

The finish consultant, using his expertise, evaluated each sample according to industry norms.

7.2.3 Furniture Finish Test Results

General Observations as provided by the finishing consultant:

- hybrid poplar finishes very much like maple
- addition of the washcoat step before staining worked well to eliminate blotches and uneven colour
- lighter stains did not require a wash coat
- water stains do not work well with or without the washcoat as water stain penetrated too deeply and produced a muddy dark colour.
- washcoat used under the water stain produced a faded and incomplete colour
- the best finishing system was the nitrocellulose/alkyd catalyzed sealer and a topcoat over a penetrating stain
- the new acrylic water-borne finishes worked well and may in the future replace the solvent based system.

A complete listing of the furniture finish results appears in Appendix IV.

7.3 Wax Finish Test

As in the case of the furniture finish tests there are no test protocols to evaluate wax finish. Compared to a typical furniture finish a wax finish does not offer the same protection to the wood; in fact it offers the least amount of protect of any coating. Regardless of these disadvantages it does have it uses in interior applications such as interior furniture that receive little in the way of contact and interior doors. Wax finishes do offer the benefit of being the simplest and require little in the way of an expensive finishing line.

7.3.1 Equipment

To apply the wax a number of application techniques can be used but woven steel wool of the 0000 grade (very fine) was found to best.

7.3.2 Procedure

Each of the sample pieces was sectioned off using masking tape so that different treatments could be tried. One section was left with the original 150 grit sanding where the other section was block sanded by hand with a 180 grit and finally a 400 grit finish. This left the surface very smooth. Each of the four wax finish colours were applied to four samples in both treatment areas by the using the woven steel wool as an applicator. The wax coating was allowed to penetrate the wood surface for a moment before being wiped off and left to dry. This was repeated a second time. Upon being left to dry for one hour the wax finish was buffed with a clean cotton cloth until it was shiny.

7.3.3 Wax Finish Test Result

The wax finishes produced a very attractive finish considering what went into the process. Minor surface checks had a tendency to fill up with wax hence these areas show up a small dark lines. Most minor surface checks do this with just about any type of finish applied. As expected the surface that received the 400 grit sanding treatment produced a better finish from a feel perspective though there was no difference in appearance from the 150 grit and 400 grit sanding treatment. Hybrid poplar performed well when a wax finish is applied and it is worth considering as a finishing technique for the type of product that will not receive much contact while in service. A table showing the results for each of the colours tested appears in Appendix VI.

8 Drying Evaluation

The kiln drying was performed using a small 2000 fbm research kiln equipped to dry either by conventionally means (forced air with a steam spray) or by using the dehumidification system. The former method was selected to dry the hybrid poplar. The drying schedule followed was long and gentle by industry standards as the goal was to get the moisture content down to 9% with as little in the way of drying defects as possible. The drying schedule appears in Appendix VII.

The evaluation covered the degree of shrinkage and warp that developed as a result of kiln drying. Measurements were taken before and after kiln drying to determine the shrinkage and after kiln drying to determine the type and degree of warp. Shrinkage was determined by measuring the thickness and width of each board. The four types of warp measured were crook, bow, twist and cup. Warp values were evaluated against the warp standard tables found in the NLGA rulebook.

8.1 Equipment

Shrinkage and warp were measured using digital calipers. A moisture meter was used to determine the initial and final moisture content of the hybrid poplar lumber.

8.2 Procedure

Prior to drying the width and thickness of each board was measured with digital calipers at three set points along its length and these points were marked for later reference. All boards were numerically coded to identify source colour grouping and board number. Any warp present at this stage was also recorded. Upon being loading into the kiln each board was weighed. The lift of lumber had weight restraints piled on the top to prevent excessive movement in the lumber. The kiln schedule used was a low temperature, low air velocity and lengthy one so that little in the way of drying defects would occur. This was not an exercise to determine an optimal kiln schedule.

8.3 Results

The following results must be regarded as not being representative on hybrid poplar lumber in general but only applying to the actual lumber dried. Hence these results give a general indication of what to expect with hybrid poplar with regard to the effects of kiln drying.

8.3.1 Shrinkage Results

A summary of the shrinkage results by board colour grouping is presented in Table 14.

Table 14 Shrinkage Results by Board Colour

Board Colour	Shrinkage %		
	Thickness	**Width**	**Volume**
Red	3.44	3.14	6.66
White	2.53	3.71	6.40
Blue	0.9	1.2	2.20

The results presented above reflect shrinkage after some initial air drying had occurred prior to the first measurements being taken hence this does not give a true indication of the percentage of shrinkage that would be encountered from green to kiln dry. The one interesting feature of the figures presented above concerns the ratio between the percentage shrinkage in width and thickness dimensions. Normally shrinkage in width (tangential shrinkage) is about twice that of the thickness (radial shrinkage) for most wood species. However, for black cottonwood and eastern cottonwood these values are over two times as much as published in *Strength and Related Properties of Woods Grown in Canada*. Hybrid poplar exhibited a much lower ratio than ratio than its two 'parent' species. A lower ratio is preferred as less stress will developed along a glue line during the normal cycling that wood products go through from one season to the next.

8.3.2 Warp Results

The warp results are presented by board colour grouping in Table 15.

Table 15 Warp Results by Board Colour

	Crook			**Bow**		**Twist**			**Cup**	
Red	None	8	16%	5	10%	None	41	80%	11	22%

	V. light	2	4%	39	76%	Slight	3	6%	29	56%
	Light	23	45%	7	14%	Medium	3	6%	11	22%
	Medium	13	25%	0	-	Heavy	4	8%	0	-
	Heavy	5	10%	0	-					
White	None	7	19%	2	5%	None	28	76%	6	16%
	V. Light	0	-	33	90%	Slight	7	19%	21	57%
	Light	20	54%	2	5%	Medium	2	5%	7	19%
	Medium	8	22%	0	-	Heavy	0	-	3	8%
	Heavy	2	5%	0	-					
Blue	None	2	12%	3	18%	None	12	71%	9	53%
	V. Light	0	-	14	82%	Slight	1	6%	8	47%
	Light	6	35%	0	-	Medium	4	23%	0	-
	Medium	7	41%	0	-	Heavy	0	-	0	-
	Heavy	2	12%	0	-					

Warp can often be reduced or eliminated in lumber by further processing though material is loss through saw kerf or by being planed off and not to mention the cost of the labour to perform the corrective work.

Crook appears to the type of warp that had the greatest percentage of occurrence in the medium to heavy categories with bow having the least occurrence in these categories. Twist had the highest percentage of none present for all three board colours. With respect to the percentage of all the boards that had heart centre present especially for the red and white boards, hybrid poplar warp characteristics can be regarded at being moderate. If typical cut up operations are to be performed (cross cut, rip cut and planing) on the lumber then the effects of warp will be minimized.

9 Strength Tests

Static bending strength tests were used to determine modulus of elasticity (MOE) and the modulus of rupture (MOR). The static bending tests are a method of determining the strength of wood. The resulting value is expressed in pounds per square inch or psi. MOE is basically a measure of the flexibility of a material in the materials elastic range— a range in which the material will completely recover from the effects of an applied load. MOR is the maximum load applied at failure of the material and it is expressed in psi as well. Specific gravity readings were also taken for each of the samples tested.

As mentioned in **Section 2 General Procedures,** two lots of lumber were tested for their respective MOE and MOR values. This provided a basis for comparison between sawlog grade and pulp grade hybrid poplar lumber. Comparisons can also be drawn between hybrid poplar and other wood species as listed in tables found in *Strength and Related Properties of Woods Grown in Canada*.

9.1 Equipment

Static bending test apparatus with a computer data capture acquisition system was used in the test. A yoke to measure deflection at the neutral axis was used to obtain a more accurate MOE.

9.2 Procedure

The sample pieces were all cut from 2-inch lumber as the size requirement for this test was for samples to be 2 by 2 by 30 inches with no knots or other strength-reducing defects present. Representative samples were cut from all colour groupings, if available, and from a cross section of the pulp (green coloured) lumber.

Each sample was mounted in the test machine and tested for MOE first. This was followed by the test for MOR. All results were captured on the data acquisition system.

9.3 Test Results

Table 16 presents the results of the MOE, MOR and specific gravity values for red, white and blue (sawlog) and green (pulp log) coloured lumber samples, an aggregate of the sawlog lumber and an aggregate of all the hybrid poplar lumber (sawlog and pulp log).

Table 16 Selected Mechanical Properties of Hybrid Poplar

Category/ Samples	MOE		MOR		Specific Gravity	
# Samples	Mean (10^6 psi)	Std. Dev.	Mean (psi)	Std. Dev.	Mean	Std. Dev.
Red lumber (11)	1.085	0.273	8585	1155	0.378	0.046
White lumber (16)	1.113	0.219	8700	1109	0.374	0.027
Blue lumber (1)	1.006	N/A*	7943	N/A*	0.321	N/A*
Green lumber (28)	1.085	0.106	7884	1115	0.317	0.023
Sawlog lumber (28)	1.111	0.234	8628	1095	0.373	0.036
All hybrid poplar lumber (56)	1.098	0.181	8256	1158	0.345	0.041

* Note: Standard deviation cannot be determined with only a sample size of one.

Within the sawlog grouping (red, white and blue), it can be seen that the MOE values are close together with an average of 1,111,000 psi. The MOE value for the pulp grade samples are also very close to the overall sawlog value however, the standard deviation of the sawlog values was twice that of the pulp grade log value. A difference starts to occur when the MOR values are taken into consideration. The MOR values for the pulp logs when compared to the sawlog values were 8.6 % lower though the standard deviation was comparable in this case. Turning to the specific gravity values, a significant difference can be seen between the sawlog grouping and the pulp grade samples. The sawlog grouping had a specific gravity value that was 15 % higher.

Table 17 shows hybrid poplar (sawlog grade) in comparison with similar species for MOE, MOR and specific gravity values. Data for the other species derived from *Strength and Related Properties of Woods Grown in Canada*.

Table 17 Mechanical Properties of Hybrid Poplar in Comparison with Similar Species

Species	MOE (10^6 psi)	MOR (psi)	Specific Gravity

Hybrid Poplar	1.111	8628	0.373
Trembling Aspen	1.630	9800	0.424
Black Cottonwood	1.280	7140	0.334
Lodgepole Pine	1.580	11020	0.455
Subalpine Fir	1.490	8000	0.351
White Spruce	1.440	9090	0.393

10 Conclusion

Hybrid poplar machined moderately well when compared to a selected group of other wood species; its performance in the all important planing test was below average as it encountered light fuzzy grain however, this defect was easily removed by sanding. If not for this defect hybrid poplar would have performed as well the other species it was compared too. It is interesting to note that hybrid poplar far exceeded the performance of black cottonwood in all the machining tests.

With respect to its strength properties hybrid poplar when compared to the other wood species, produced results that were about average in the screw withdrawal and MOR tests but had the lowest results in the nail withdrawal and MOE tests. This can be attributed to the fact that hybrid poplar had the lowest specific gravity along with exceedingly large growth rings. It is fair to say that hybrid poplar probably does not have a future in structural applications when these results are considered.

Hybrid poplar can be glued using commonly available adhesives found in the wood processing industry though adhesives with low viscosity (thin glues) should be avoided. Delamination results were inconsistent hence indications are that hybrid poplar should only be used in applications where wetting is not likely to occur.

Finally, hybrid poplar performed very well with regard to finishing. It takes paint, stain/lacquer and wax coatings well and had a pleasing appearance. Considering how much of the lumber supplied included heart centre the results indicate that properly selected lumber would make attractive furnishings that present no problems in finishing.

11 References

American Society for Testing and Materials. 1993. ASTM D 1666-87: Standard methods for conducting machining tests of wood and wood-based materials. Annual Book of ASTM Standards. Philadelphia, PA: ASTM. Vol. 04.09. p. 257.

American Society for Testing and Materials. 1993. ASTM D 1761-88: Standard test method for mechanical fasteners in wood. Annual Book of ASTM Standards. Philadelphia, PA: ASTM. Vol. 04.09. p. 300.

American Society for Testing and Materials. 1993. ASTM D 1101-92: Standard test methods for integrity of glue joints. Annual Book of ASTM Standards. Philadelphia, PA: ASTM. Vol. 15.06. p. 59.

American Society for Testing and Materials. 1993. ASTM D 905-89: Standard test method for strength properties of adhesive bonds. Annual Book of ASTM Standards. Philadelphia, PA: ASTM. Vol. 15.06. p. 26.

American Society for Testing and Materials. 1994. ASTM D 4541-93: standard test method for pull-off strength of coatings using portable adhesion testers. Annual Book of ASTM Standards. Philadelphia, PA: ASTM. Vol. 06.02. p. 344.

American Society for Testing and Materials. 1994. ASTM D 3359-93: Standard test methods for measuring adhesion by tape test. Annual Book of ASTM Standards. Philadelphia, PA: ASTM. Vol. 06.01. p. 432.

American Society for Testing and Materials. 1994. ASTM D 523-89: Standard test method for specular gloss. Annual Book of ASTM Standards. Philadelphia, PA: ASTM. Vol. 06.01. p. 68.

National Lumber Grades Authority. 1990. Standard Grading Rules for Canadian Lumber. Vancouver, B.C.

American Society for Testing and Materials. 1994. ASTM D 143-83: Standard methods of testing small clear specimens of timber. Annual Book of ASTM Standards. Philadelphia, PA: ASTM. Vol. 04.10. p. 24.

Jessome, A.P. 1977. Strength and Related Properties of Wood Grown in Canada.

Forintek Canada Corp., Ottawa. Forintek Tech. Report 21.

Appendix I

Hybrid Poplar Lumber Sizes

Red Lumber - lumber input (Lumber grade)

- 2x8 1/5, 2/9 feet
- 2x6 1/8, 2/8.5, 21/9 feet
- 1x6 1/5, 21/9 feet

White Lumber - lumber input (Lumber grade)

- 2x8 2/9 feet
- 2x6 16/9, 2/8.5, 1/4 feet
- 1x6 4/10, 4/9.5, 2/7, 1/6, 1/5 feet

Blue Lumber - lumber input (Lumber grade)

- 2x6 1/9 feet
- 1x4 5/9.5, 9/9, 1/6.5, 1/6 feet

Green Lumber - lumber input (Pulp grade)

- 2x6 36/9 feet
- 2x4 14/9 feet
- 1x6 23/9, 2/9.5 feet
- 1x4 25/ 9 feet

Appendix II

Cutting and Cross Reference List

Part #	Planing	Sanding	Shaper	Engineering	Screw & Nail	Density	Board #
3601	x	x	X	X	x	x	B01
3602	x	x	X	X	x	x	R05
3603				X			R04
3604		x	X		x	x	R03
3605				X			R20
3606				X			W01

3607	x	x	X		x	x	W02
3608				X			W03
3609	x	x	x	X	x	x	R07
3610	x	x	x		x	x	R01
3611	x	x	x		x	x	R02
3612				X	x	x	R12
3613	x	x	x	X	x	x	W20
3614	x	x	x	X	x	x	W21
3615				X			W07
3616	x	x	x		x	x	W04
3617	x	x	x	X			W05
3618	x	x	x	X			W06
3619	x	x	x	X	x	x	R09
3620	x	x	x	X	x	x	R08
3621				X			R23
3622				X			R19
3623				X			R14
3624	x	x	x		x	x	R18
3625				X			R17
3626				X			R16
3627	x	x	x		x	x	R15
3628	x	x	x		x	x	R10
3629				X	x	x	R25
3630	x	x	x	X	x	x	W08
3631				X			W09
3632				X			W10
3633				X			W11
3634	x	x	x	X	x	x	W12
3635	x	x	x		x	x	W14
3636	x	x	x		x	x	W15
3637				X			W16
3638				X			W17
3639	x	x	x	X			W13
3640				X			W19

3641	x	x	x		x	x	R43
3642	x	x	x		x	x	R35
3643	x	x	x		x	x	R29
3644	x	x	x		x	x	R48
3645	x	x	x		x	x	R28
3646	x	x	x		x	x	R30
3647	x	x	x		x	x	R42
3648	x	x	x		x	x	R40
3649	x	x	x		x	x	R39
3650	x	x	x		x	x	R32
3651	x	x	x		x	x	W25
3652	x	x	x		x	x	W24
3653	x	x	x		x	x	R47
3654	x	x	x		x	x	R44
3655	x	x	x		x	x	R4
3656	x	x	x		x	x	R38
3657	x	x	x		x	x	R37
3658	x	x	x		x	x	B02
3659	x	x	x		x	x	W22
3660	x	x	x		x	x	W30
3661	x	x	x				B11
3662					x	x	B08
3663	x	x					B12
3664			x		x	x	B15
3665	x	x	x				W26
3666					x	x	W36
3667	x	x					W37
3668			x		x	x	W33
3669	x	x	x				R51
3670					x	x	R49
3671	x				x	x	R49
3672		x	x				R36
3673	x	x	x				W28
3674					x	x	W27

3675	x				x		B07
3676		x				x	B10
3677	x	x	x				W35
3678					x	x	W31

Appendix III

Specific Gravity and Ring Count per Inch

Part #	Relative Density	Rings per inch
3601	0.3348	1.3
3602	0.468	1.2
3607	0.3506	2
3610	0.3882	1.2
3616	0.4058	1.6
3620	0.4043	1.2
3623	0.3822	1.7
3627	0.3894	1
3629	0.3946	1.7
3630	0.3227	1.5
3634	0.3897	1.8
3636	0.3471	0.8
3641	0.3153	1.3
3643	0.3239	1
3645	0.3681	1.7
3646	0.394	1.3
3648	0.4271	1
3650	0.3552	1.8
3651	0.3121	1.2
3652	0.4137	1.5
3654	0.3345	2

3656	0.3326	1.6
3657	0.3563	1.4
3659	0.3447	2
3660	0.3847	1.7
3664	0.4264	1.5
3674	0.4598	2
Average	0.375	1.48
Std. Dev.	0.043	0.3

Appendix IV

Furniture Finish Test Results

Finishing Sample # /Part # *	Stain/Sealer/Topcoat Combinations	Comments
1 / 3601	Sheriton Mahogany Penetrating Stain/ Shellac/ Alkyd Semi-Gloss Varnish	Good results, stain took will, finished well
1W / 3601	Sheriton Mahogany Penetrating Stain/ Shellac/ Alkyd Semi-Gloss Varnish with a washcoat	Stain took well even with the wash coat. System could be used in field operations
2 / 3607	Sheriton Mahogany Penetrating Stain/ Acrylic Waterborne Sealer/ 45 degree Acrylic Waterborne	Some grain raising but acceptable results. Environmentally friendly waterborne system
2W / 3607	Sheriton Mahogany Penetrating Stain/ Acrylic Waterborne Sealer/ 45 degree Acrylic Waterborne with washcoat	Good results even with the wash coat. Environmentally friendly finishing system
3 / 3604	Sheriton Mahogany Penetrating Stain/ Lacquer Sanding Sealer/	Fast drying finishing system. Low film build produces a grainy

	Semi-Gloss Lacquer	appearance.
3W / 3604	Sheriton Mahogany Penetrating Stain/ Lacquer Sanding Sealer/ Semi-Gloss Lacquer with washcoat	Fast drying finishing system. Low film build produces a grainy appearance
4 / 3609	Sheriton Mahogany Penetrating Stain/ Nitrocellulose/ Alkyd Sealer (Catalyzed)/ 45 degree Nitrocellulose/Alkyd Clear	Excellent fast drying system. Good film build and a smooth finish
4W / 3609	Sheriton Mahogany Penetrating Stain/ Nitrocellulose/ Alkyd Sealer (Catalyzed)/ 45 degree Nitrocellulose/Alkyd Clear with washcoat	Excellent fast drying system. High build produces a smooth finish. Less blotches in the stain using the washcoat.
5 / 3610	Sheriton Mahogany Penetrating Stain/ Nitrocellulose/ Alkyd Sealer (Catalyzed)/ Acrylic/Urethane Waterborne (satin)	Hybrid system (solvent based stain and sealer with waterborne topcoat) with good results. Satin sheen hides some of the wood texture.
5W / 3610	Sheriton Mahogany Penetrating Stain/ Nitrocellulose/ Alkyd Sealer (Catalyzed)/ Acrylic/Urethane Waterborne (stain) with washcoat	Hybrid system (solvent based stain and sealer with waterborne topcoat) with good results. Satin sheen hides some of the wood texture. Washcoat evens out the colour.
6 / 3611	Sheriton Mahogany Penetrating Stain/ Nitrocellulose/ Alkyd Sealer (Catalyzed)/ Two Component Polyurethane (high gloss)	Extremely durable, high gloss exterior finish. The high gloss does magnify some of the wood texture.
6W / 3611	Sheriton Mahogany Penetrating Stain/ Nitrocellulose/ Alkyd Sealer (Catalyzed) Two Component Polyurethane (high gloss) with washcoat	Extremely durable, high gloss exterior finish. The high gloss does magnify some of the wood texture. The washcoat evens out the colour
7 / 3613	Antique Oak Penetrating Stain/	Extremely durable, high gloss

	Nitrocellulose/ Alkyd Sealer (Catalyzed)/ Two Component Polyurethane (high gloss)	exterior finish. The high gloss does magnify some of the wood texture. Stain worked well.
7W / 3613	Antique Oak Penetrating Stain/ Nitrocellulose/ Alkyd Sealer (Catalyzed)/ Two Component Polyurethane (high gloss) with washcoat	Extremely durable, high gloss exterior finish. The high gloss does magnify the wood's defects and texture. Because the stain is light there is no advantage to using the washcoat.
8 / 3616	Antique Oak Penetrating Stain/ Nitrocellulose/ Alkyd Sealer (Catalyzed)/ Acrylic/Urethane Waterborne (stain)	Hybrid system (solvent based stain and sealer with waterborne topcoat) producing good results. Sheen hides some of the wood's texture. Stain took well.
8W / 3616	Antique Oak Penetrating Stain/ Nitrocellulose/ Alkyd Sealer (Catalyzed)/Acrylic Urethane Waterborne (stain) with washcoat	Hybrid system (solvent based stain and sealer with waterborne topcoat) producing good results. Sheen hides some of the wood's texture. Washcoat is not necessary because the stain is light.
9 / 3717	Antique Oak Penetrating Stain/ Nitrocellulose/ Alkyd Sealer (Catalyzed)/ 45 degree Nitrocellulose/Alkyd Clear	Excellent fast drying system. Produces a smooth, tough finish. Stain works well.
9W / 3617	Antique Oak Penetrating Stain/ Nitrocellulose/ Alkyd Sealer (Catalyzed)/ 45 degree Nitrocellulose/Alkyd Clear with washcoat	Excellent fast drying system. Produces a smooth, tough finish. Washcoat is not required because the stain is light.
10 / 3618	Antique Oak Penetrating Stain/ Lacquer Sanding Sealer/ Semi-Gloss Lacquer	Fast drying system. Low film build produces a grainy texture.

10W / 3618	Antique Oak Penetrating Stain/ Lacquer Sanding Sealer/ Semi-Gloss Lacquer with washcoat	Fast drying system. Low film build produces a grainy texture. There is no need for the washcoat because the stain is light.
11 / 3619	Antique Oak Penetrating Stain/ Shellac/ Semi-Gloss Lacquer	Good results. Can be a brush applied finish if needed.
11W / 3619	Antique Oak Penetrating Stain/ Shellac/ Semi-Gloss Lacquer with washcoat	Good results. Wash coat is not necessary because the stain is light
12 / 3624	Antique Oak Penetrating Stain/ Acrylic Waterborne Sealer/ 45 degree Acrylic Waterborne	Almost a complete waterborne system except for the stain. Results are good with a smooth finish with minimal texture.
12 W / 3624	Antique Oak Penetrating Stain/ Acrylic Waterborne Sealer/ 45 degree Acrylic Waterborne with washcoat	Almost a complete waterborne system except for the stain. Results are good though there is no need for a washcoat because the stain is light.
13 / 3630	Oil Stain – Walnut/ Acrylic Waterborne Sealer/ 45 degree Acrylic Waterborne	Almost a complete waterborne system except for the stain. Finished product is smooth with minimal texture.
13 W / 3630	Oil Stain – Walnut/ Acrylic Waterborne Sealer/ 45 degree Acrylic Waterborne with washcoat	Almost a complete waterborne system except for the stain. Washcoat makes little difference except for a little less blotchiness.
14 / 3634	Oil Stain – Walnut/ Shellac/ Semi-Gloss Lacquer	Good results with very little grain raising. Slow dry nature of the stain and varnish may suit field application only. Can be applied with a brush.
14 W / 3634	Oil Stain – Walnut/ Shellac/ Semi-Gloss Lacquer with washcoat	Good results with very little grain raising. Slow dry nature of the stain and varnish may suit field application only. Can be applied with a brush. Washcoat provides minimal improvement as the oil stain is light.

15 / 3641	Oil Stain – Walnut/ Nitrocellulose/ Alkyd Sealer (Catalyzed)/ Acrylic/Urethane Waterborne (satin)	Very smooth finish with a waterborne topcoat. Satin finish hides some of the natural texture of the wood. Stains well.
15 W / 3641	Oil Stain – Walnut/ Nitrocellulose/ Alkyd Sealer (Catalyzed)/ Acrylic/Urethane Waterborne (stain) with washcoat	Very smooth finish with a waterborne topcoat. Washcoat not required because the stain is light in colour.
16 / 3642	Oil Stain – Walnut/ Lacquer Sanding Sealer/ Semi-Gloss Lacquer	Fast drying system except for the stain. Low solids in the lacquer produces a grainy finish.
16 W / 3642	Oil Stain – Walnut/ Lacquer Sanding Sealer/ Semi-Gloss Lacquer with washcoat	Fast drying system except for the stain. Low solids in the lacquer produces a grainy appearance. A washcoat under the stain has little advantage.
17 / 3643	Oil Stain – Walnut/ Nitrocellulose/ Alkyd Sealer (Catalyzed)/ 45 degree Nitrocellulose/Alkyd Clear	Fast drying with a very smooth finish. Minimal texture through this system.
17 W / 3643	Oil Stain – Walnut/ Nitrocellulose/ Alkyd Sealer (Catalyzed)/ 45 degree Nitrocellulose/Alkyd Clear with washcoat	Fast drying with a very smooth finish though there was minimal texture. Washcoat has no advantage with such a light oil stain.
18 / 3647	Oil Stain – Walnut/ Nitrocellulose/ Alkyd Sealer (Catalyzed)/ Two Component Polyurethane (high gloss)	Very durable, exterior high gloss finish. Can magnify defects and texture.
18 W / 3647	Oil Stain – Walnut/ Nitrocellulose/ Alkyd Sealer (Catalyzed)/ Two Component Polyurethane (high gloss) with washcoat	Very durable, exterior high gloss finish. Defects and texture can be magnified with this sytem. Washcoat has no appreciable advantage because the oil stain is light.
19 / 3648	Penetrating Stain Concentrate – Green/ Acrylic Waterborne Sealer/ 45 degree Acrylic Waterborne	Almost a complete waterborne system except for the stain. Results are smooth with minimal texture. Stain is dark and somewhat

		blotchy.
19 W / 3648	Penetrating Stain Concentrate – Green/ Acrylic Waterborne Sealer/ 45 degree Acrylic Waterborne with washcoat	Almost a complete waterborne system except for the stain. Washcoat definitely improves the uniformity of the stain.
20 / 3654	Penetrating Stain Concentrate – Green/ Shellac/ Semi-Gloss Lacquer	Good results. Slightly yellow because of the varnish. Slow drying nature of the varnish makes this system better suited for the field. Brushable product.
20 W / 3654	Penetrating Stain Concentrate – Green/ Shellac/ Semi-Gloss Lacquer with washcoat	Good results. Slightly yellow because of the varnish. Washcoat improves the uniformity of the stain. Slow drying nature of the varnish makes this system better suited to the field.
21 / 3655	Penetrating Stain Concentrate – Green/ Nitrocellulose/ Alkyd Sealer (Catalyzed)/ 45 degree Nitrocellulose/Alkyd Clear	Excellent fast drying system. Stain concentrate is sometimes dark and blotchy. Washcoat is required.
21 W / 3655	Penetrating Stain Concentrate – Green/ Nitrocellulose/ Alkyd Sealer (Catalyzed)/ 45 degree Nitrocellulose/Alkyd Clear with washcoat	Excellent fast drying system. Stain concentrate is sometimes dark and blotchy. Washcoat is required.
22 / 3657	Penetrating Stain Concentrate – Green/ Lacquer Sanding Sealer/ Semi-Gloss Lacquer	Fast drying system though the low solid produce a grainy texture. Stain is dark and somewhat uneven. Washcoat is required.
22 W / 3657	Penetrating Stain Concentrate – Green/ Lacquer Sanding Sealer/ Semi-Gloss Lacquer with washcoat	Fast drying system though the low solid produce a grainy texture. Stain is dark and somewhat uneven. Washcoat improves the stain uniformity.
23 / 3658	Penetrating Stain Concentrate – Green/ Nitrocellulose/ Alkyd Sealer (Catalyzed)/ Acrylic/Urethane Waterborne	Hybrid system using solvent based stain and sealer with a waterborne topcoat. Low sheen of the topcoat hides some of the wood texture.

	(satin)	Stain is dark and somewhat uneven. Washcoat is required.
23 W / 3658	Penetrating Stain Concentrate – Green/ Nitrocellulose/ Alkyd Sealer (Catalyzed)/ Acrylic/Urethane Waterborne (satin) with washcoat	Hybrid system using solvent based stain and sealer with a waterborne topcoat. Low sheen of the topcoat hides some of the wood texture. Washcoat evens the colour of the stain.
24 / 3659	Penetrating Stain Concentrate – Green/ Nitrocellulose/ Alkyd Sealer (Catalyzed)/ Two Component Polyurethane (high gloss)	Very durable, exterior high gloss finish. The high gloss shows some of the wood's natural texture. Stain is dark and uneven. Requires a washcoat
24 W / 3659	Penetrating Stain Concentrate – Green/ Nitrocellulose/ Alkyd Sealer (Catalyzed)/ Two Component Polyurethane (high gloss) with washcoat	Very durable, exterior high gloss finish. The high gloss shows some of the wood's natural texture. Washcoat improves the uniformity of the stain.
25 / 3660	Water Stain – Walnut/ Nitrocellulose/ Alkyd Sealer (Catalyzed)/ Two Component Polyurethane (high gloss)	Very durable, exterior high gloss finish. The high gloss shows some of the wood's natural texture. Stain is dark and muddy. Water stain not recommended.
25 W / 3660	Water Stain – Walnut/ Nitrocellulose/ Alkyd Sealer (Catalyzed)/ Two Component Polyurethane (high gloss) with washcoat	Very durable, exterior high gloss finish. The high gloss shows some of the wood's natural texture. Washcoat prevents the water stain from penetrating well. Washcoat not recommended.
26 / 3651	Water Stain – Walnut/ Nitrocellulose/ Alkyd Sealer (Catalyzed)/ 45 degree Nitrocellulose/Alkyd Clear	Fast drying finish system. Sealer and topcoat work well but the stain is dark and muddy. Water stain not recommended.
26 W / 3651	Water Stain – Walnut/ Nitrocellulose/ Alkyd Sealer (Catalyzed)/ 45 degree Nitrocellulose/Alkyd Clear with washcoat	Fast drying finish system. Sealer and topcoat work well. Washcoat prevents stain penetration. Washcoat not recommended.

27 / 3661	Water Stain – Walnut/ Nitrocellulose/ Alkyd Sealer (Catalyzed)/ Acrylic/Urethane Waterborne (satin)	Hybrid finishing system. Solvent based sealer with a waterborne stain and clear topcoat. Sealer/topcoat system produces a smooth durable finish. The stain is dark and muddy. Water stain not recommended.
27 W / 3661	Water Stain – Walnut/ Nitrocellulose/ Alkyd Sealer (Catalyzed)/ Acrylic/Urethane Waterborne (stain) with washcoat	Hybrid finishing system. Solvent based sealer with a waterborne stain and clear topcoat. Sealer/topcoat system produces a smooth durable finish. Washcoat prevents the stain from penetrating. Washcoat not recommended under a water stain.
28 / 3665	Water Stain – Walnut/ Lacquer Sanding Sealer/ Semi-Gloss Lacquer	Fast drying finishing system. Low solids of the lacquer produces a grainy appearance. Water stain is dark and muddy. Water stain not recommended.
28 W / 3665	Water Stain – Walnut/ Lacquer Sanding Sealer/ Semi-Gloss Lacquer with washcoat	Fast drying finishing system. Low solids of the lacquer produces a grainy appearance. Washcoat prevents the penetration of the water stain. Washcoat not recommended.
29 / 3667	Water Stain – Walnut/ Acrylic Waterborne Sealer/ 45 degree Acrylic Waterborne	A complete waterborne system. Sealer and topcoat work well. Stain is dark and muddy. Water stain does not work well because of the porosity of the wood.
29 W / 3667	Water Stain – Walnut/ Acrylic Waterborne Sealer/ 45 degree Acrylic Waterborne with washcoat	A complete waterborne system. Sealer and topcoat work well. Washcoat prevents the penetration of the water stain. Washcoat not recommended
30 / 3669	Water Stain – Walnut/ Shellac/ Semi-Gloss Lacquer	Slow drying system. Shellac and varnish combination work well together but the water stain

		produces a dark and muddy colour. Water stain not recommended.
30 W / 3669	Water Stain – Walnut/ Shellac/ Semi-Gloss Lacquer with washcoat	Slow drying system. Shellac and varnish combination work well. The washcoat prevents the water stain from penetrating. Washcoat not recommended under a water stain.
31 / 3673	Alcohol Stain – Walnut/ Lacquer Sanding Sealer/ Semi-Gloss Lacquer	Fast drying system. Alcohol stain is light and hard to apply evenly. The low solids of the lacquer allows the natural texture of the wood to show through.
31 W / 3673	Alcohol Stain – Walnut/ Lacquer Sanding Sealer/ Semi-Gloss Lacquer with washcoat	Fast drying system. Alcohol stain is light and hard to apply evenly. The low solids of the lacquer allows the natural texture of the wood to show through. Washcoat prevents penetration of the alcohol stain. Washcoat not recommended under a alcohol stain.
32/ 3675	Oil Stain – Walnut/ Acrylic Waterborne Sealer/ 45 degree Acrylic Waterborne	Hybrid finishing system. Solvent based stain with waterborne sealer and topcoat. Waterborne sealer/topcoat work well and produce a smooth finish. Oil stain produces a light colour that is even.
32 W / 3675	Oil Stain – Walnut/ Acrylic Waterborne Sealer/ 45 degree Acrylic Waterborne with washcoat	Hybrid finishing system. Solvent based stain with waterborne sealer and topcoat. Waterborne sealer/topcoat work well and produce a smooth finish. Washcoat produces no advantage with this oil stain. As long as the oil stain is a light colour there is no need for a washcoat.
33 / 3677	Alcohol Stain – Walnut/ Shellac/ Semi-Gloss Lacquer	Slow drying finishing system. Shellac/varnish combination works well. The alcohol stain is hard to

		work with and can produce uneven colour.
33 W / 3677	Alcohol Stain – Walnut/ Shellac/ Semi-Gloss Lacquer with was	Slow drying finishing system. Shellac/varnish combination works well. The washcoat effects the penetration of the alcohol stain. Washcoat not recommended under a alcohol stain.

*** Note: The W signifies washcoat.**

Appendix V

Wax Finishing Results

	Sanding with 150 grit with 1 coat of various wax finishes applied with steel wool		Sanding with 400 grit with 2 coats of various wax finishes applied with steel wool	
Board #	**Smoothness**	**Evenness of Colour**	**Smoothness**	**Evenness of Colour**
3614	1	1	1	1
3602	1	1	1	2
3612	1	1	1	1
3620	1	1	1	1
3627	1	1	1	1
3628	1	2	1	1
3629	1	1	1	1
3635	1	2	1	1
3636	2	N/A	1	N/A
3644	1	1	1	1

3645	1	1	1	1
3646	1	N/A	1	N/A
3649	1	1	1	1
3650	1	1	1	1
3652	1	1	1	1
3656	1	1	1	1
3663	1	1	1	1
3671	1	1	1	1

Scoring:

- **1 - excellent**
- **2 - good**
- **3 - fair**
- **4 - poor**

Appendix VI

Hybrid Poplar Kiln Schedule

The following kiln schedule was used to dry hybrid poplar after it was air dried inside for approximately one month.

Step	Time (hrs)	Dry Bulb Temp. F	Dry Bulb Temp. C	Wet Bulb Temp. F	Wet Bulb Temp. C	Relative Humidity	EMC
1	8	135	57.2	135	57.2		
2	12	135	57.2	130	54.4	87	16.1
3	12	140	60.0	133	56.1	82	14.1
4	12	145	62.8	135	57.2	76	11.9

5	12	150	65.5	135	57.2	66	9.5
6	114	160	71.1	135	57.2	51	6.7
7	6	160	71.1	150	65.5	77	11.6