GLUABILITY OF SANDED LUMBER

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Introduction

Reasons for Sanding Lumber

The spread of sanded lumber technology in the softwood lumber industry took place in the late 1970's with implementation of lumber sanders in four western ponderosa pine sawmills. Two Weyerhaeuser Douglas-fir sawmills followed with lumber sander installations in 1980 before the economy curtailed further introduction of the technology into the industry.

The initial incentive for sanding lumber was to capture the benefits of improved manufacturing; i.e., increased productivity (more board feet processed), improved recovery (reduced target sizes, less trimming) and increased grade yield (less manufacturing damage). Introduction of sanded lumber into the market place produced a fourth benefit: a customer preference for sanded lumber due to its improved appearance (no machine marks or grain tear). There have been several problems in the development of this technology, but, with the exception of its gluability, they have all been manufacturer related and have not affected the user.

Gluability

While the gluability of sanded surfaces was examined in 1944 by Maxwell (3), it was not until the mid-1970's that several research groups such as the U.S. Forest Products Laboratory, the American Institute of Timber Construction, the ASTM Wood Adhesive Subcommittee, Weyerhaeuser Company and others, felt the gluability of sanded surfaces should be evaluated to determine if structural, long-term durability could be obtained.

Jokerst and Stewart in 1976 (2) determined that glue lines made with 36-, 60- and 80-grit sanded Douglas-fir and southern pine have:

1. Dry shear strengths equivalent to glue lines made with knife-planed lumber.
2. Dry wood failure values slightly higher than glue lines made with knife-planed lumber.
3. Lower resistance to glue line separation upon accelerated aging than glue lines made with knife-planed lumber.
4. Damage to surface and subsurface fibers (especially early wood) not seen in glue lines made with knife-planed lumber.

Jokerst and Stewart reported that Tom Brassel of AITC found more checking in and near the glue line of sanded laminated members after exposure to accelerated aging than was found for knife-planed members.

Weyerhaeuser Company began preliminary evaluation of the gluability of sanded lumber in 1972 and commenced detailed evaluations in 1976. This publication will report on several detailed laboratory and mill trials conducted between 1976 and 1982 to determine any gluability problems and possible technical solutions. In addition to Douglas-fir and southern pine which are used for laminated beams, ponderosa pine is often used to make laminated decking, and will also be discussed.

Materials and Methods

Lumber

Attempts were made to always evaluate matched knife-planed lumber with the sanded lumber. Since this study involves several trials over a six-year period with the sanding being done on four different sanders at four locations, it has been assumed that the data obtained in 1976 can be averaged and compared with that obtained through 1982. During the six years of conducting trials, it was learned that the following variables should be controlled and recorded as the lumber is sanded:

1. Lumber species.
2. Lumber density.
3. Lumber grain pattern.
4. Lumber grain angle.
5. Belt grit.
6. Belt type (open or closed).
7. Belt grit material.
8. Belt speed.
9. Belt age.
10. Lumber feed speed.
11. Amount of wood removed.
12. Belt pressure.
13. Lumber moisture content.

For the work reported here, 1x4 or 1x6 flat grain lumber was hand selected.

Sanders

Surface damage produced by each belt is usually removed by the following sanding step. This means that only surface damage caused by the last sanding step in a series was considered.

Most of the work in this study was done on the Kimwood single-head experimental sander at Cottage Grove, Oregon. Samples were also obtained from the Weyerhaeuser Klamath Falls and Springfield, Oregon and Longview, Washington production lines, which use Kimwood four-stage mill sanders.

One hundred grit and coarser belts were of the open-coat type. All work with grits above 100 used closed-coat type belts. All belts were silicon carbide, except the 220-grit, which was aluminum oxide. The transition between open and closed belts (100- to 120-grit) was not detectable in the test data.

Sanding

Boards were normally sanded first on a mill production line for thickness control. This provided an identical sanding surface on both sides. The boards were then either taken to the laboratory for evaluation or taken to Kimwood for sanding with the grits not available on the mill sander. The Kimwood single-head experimental sander only sanded one surface at a time. In the process of sanding, both to obtain the desired thickness and final sanding finish, the board often underwent several passes through the conveyor rolls and sander. For experimental purposes an attempt was made to record the amount of material removed on the final sanding step. The Kimwood experimental sander was run at 2286 m/min belt speed and 60 m/min lumber throughput speed.

Gluing

After sanding, all boards were taken to the laboratory for gluing:

1. The boards were cut into 20 cm lengths.
2. Any 20 cm length which had an obvious defect (knot, pitch pocket, etc.) or extremely high or low density, was discarded.
3. Specimens were conditioned at 65% relative humidity, 23°C until the next test step. (The exception to this was the southern pine, which was glued within 18-48 hours of surfacing.)
4. Twenty 20 cm boards of each grit treatment were selected to bond 10 two-ply lay-ups.

   Adhesive - Typical phenol-resorcinol two-component laminating adhesive
   Spread Rate - 330 gm/m^2
   Open Assembly Time - 5-10 minutes
   Closed Assembly Time - 15-24 minutes
   Clamp Time - Overnight (about 16-20 hours)
   Clamp Pressure - 1050 kPa
   Cure Temperature - 23°C

   Glued specimens were aged at least one week at 65% relative humidity, 23°C prior to testing. Tests run were:

1. ASTM D 905 - Standard Test Method for Strength Properties of Adhesive Bonds in Shear by Compression Loading.
2. AITC 110 - Water soak under vacuum followed by water soak under pressure. The blocks are sheared wet, then dried to read wood failure.
3. ASTM D 3434 - Standard Practice for Multiple-Cycle Accelerated Aging Test (Automatic Boil Test) for Exterior Wet Use Wood Adhesives. This test consists of 20 boil-dry cycles per day for 800 cycles.
4. ASTM D 2559 - Standard Specification for Adhesives for Structural Laminated Wood Products for Use Under Exterior (Wet Use) Exposure Conditions (Section 13-Delamination After Water Soak and Steam Cycles).

Hubert Roughness Test

A Hubert Roughness Tester was used to provide a numerical value of roughness prior to gluing. The principle of operation is to place a 2.5-cm diameter probe on the surface to be rated and measure the rate of air leakage. The rougher the surface, the faster the air leakage.

Microscopic Evaluation

Early wood and late wood areas were removed from selected boards both prior to, and in some cases, after gluing, embedded in plastic and cross sectioned on a sliding microtome. An estimate was made of gross surface roughness (undulation in the surface) in millimeters and depth of cellular damage in terms of number of cells. Cellular damage was determined in terms of completely collapsed (i.e., torn, distorted and crushed) cells at the surface and partially collapsed cells below the surface. Surface cells include those at the surface and any cells directly attached to those cells. Subsurface cells are those down in the interior of the specimen and not part of the surface cells.

Results and Discussion

Automatic Boil Test

Figures 1, 2 and 3 and Table 1 show the automatic boil test results for evaluating glue lines made with lumber sanded with belt grits between 24 and 100. The original 1976 work and much of the work since then has used this range of sanding grits since they represent what is being used in mill production.

Caster (1) describes the use of automatic boil test data in predicting durability of glue lines. Sanded Douglas-fir and southern pine produced glue lines which performed well below the knife-planed controls (Figures 1, 2). The 24- to 100-grit range appeared to produce glue lines for sanded Douglas-fir and southern pine at about the same performance level. Figure 3 shows that sanded and knife-planed ponderosa pine essentially produce glue lines of similar quality.

General Surface Characteristics

Figures 4 and 5 illustrate the typical surface appearance of sanded and knife-planed Douglas-fir early wood. The 80-grit sanded surface has a layer of completely collapsed cells (torn, distorted, crushed), about two to four cells deep, and a definite gross surface roughness. The knife-planed surface lacks the completely collapsed cells and demonstrates a definite gross surface smoothness. The surface of sanded (Figure 6) and knife-planed late wood is relatively undamaged, undoubtedly due to the thicker walls of the late wood cells. Sanded and knife-planed southern pine and ponderosa pine (Figures 7 and 8) appear similar to Douglas-fir, except that ponderosa pine is a more uniform wood with only a narrow band of dense late wood as compared to a much wider band of dense late wood in Douglas-fir and southern pine. This probably results in ponderosa pine yielding a smoother, more uniform surface for gluing than either of the other two species. Sanding and planing can produce a certain amount of partially collapsed cells below the surface, dependent on the pressure applied and the condition of the wood. This agrees with the observations of Stewart and Crist (6). Planing may (Figure 5) or may not (Figure 8) produce this partial collapse.

Glue Line Durability of Douglas-fir

The following comments are generally true of southern pine as well as Douglas-fir. Ponderosa pine is treated in a separate section.

Dry shear strength was found not to be a meaningful measure of glue line performance differences between sanded and knife-planed lumber. This agrees with Jokerst and Stewart (2) and River, Murmanis and Stewart (5).

The difference in glue-line performance between sanded and knife-planed lumber shows up in several other ways.

1. The glue line shear strength values with sanded lumber for an accelerated aging soak test (AITC 110) are lower than for knife-planed values (Table 2, Figure 1). A determination of the ratio of AITC 110 shear strength/dry shear strength was found to be a simple evaluation procedure (Figure 9). A ratio less than or equal to 0.6 was obtained for sanded Douglas-fir surfaces which are not gluable; a ratio greater than 0.6 was obtained for knife-planed Douglas-fir, which yielded good glue bonds. River, Murmanis and Stewart (5) indicate that the soak test shear value is "generally 30-50%" of the dry value for sanded Douglas-fir. A large number of specimens must be tested to give statistical reproducibility for the 0.6 value to be useful.
2. Sanded lumber, after AITC 110 soak cycling, tends to give high percent wood failure values for sheared glue lines, but the wood failure is very shallow as compared to knife-planed lumber. The crushed cells at the surface may prevent adhesive penetration down to the undamaged cells. The adhesive bonds to the crushed cells, which pull loose very easily, giving low shear strength but the appearance of high percent wood failure. Measuring the depth of wood failure, therefore, becomes a possible method for detecting glue lines produced from sanded lumber. An arbitrary scale of 1 to 5 has been established for measuring depth of wood failure by visual examination of the sheared surface. A value of 1 is a normal, deep wood failure as obtained with knife-planed lumber. A value of 5 represents the extreme, shallow wood failure noted for sanded lumber. A value of 3 is recorded when there is a mixture of deep and shallow wood failure or the depth of wood failure is not obviously a 1 or 5. For each variable evaluated, at least 10 shear blocks are examined for depth of wood failure, the depth of wood

failure being read at a 1, 3 or 5. The average of these depths is then used as the depth of wood failure. Figure 10 and Table 3 provide the correlation found for depth of wood failure versus grit size. This approach is meaningful for only those samples sheared after the soak test.

3. Microscopic examination indicated the presence of completely collapsed cells on the surface of sanded lumber. Observations by Murmanis, River and Stewart (4) and River, Murmanis and Stewart (5) have indicated that the S_1 layer of these cells has been ruptured, allowing the thicker S_2 layer to shrink and expand with changes in moisture content. Unrestrained swelling of the cell wall and the internal stress from the overall swelling of the densified crushed cells break the S_2 layer and other layers apart. The current study indicated there also is a certain amount of gross surface roughness, which is more readily apparent when using the coarser 24-grit (Figures 11 and 12) as compared to the 80-grit (Figures 4 and 6). Knife-planed lumber has neither the completely collapsed cells at the surface nor the gross surface roughness. The completely collapsed cells may prevent adhesive penetration while the gross surface roughness probably leads to overpenetration by entrance through surface checks (Figure 12) and inadequate closeness of two surfaces for bonding. In any case, the completely collapsed cells are weakened so that when the adhesive bonds to these weakened fibers, the resulting bond has a low AITC 110 wet shear strength but a high percent wood failure value, with the wood failure being very shallow (see above). As already mentioned, collapsed cells occur more readily in the early wood (Figures 4 and 11) than in the late wood (Figures 6 and 12, Table 4). Knife-planed lumber with partially collapsed cells at the surface (Figure 5) did not appear to result in an AITC 110-wet cycle-shear strength loss. The role of subsurface partially collapsed cells (Figure 12) in gluability was not investigated but it is felt that it would be dependent on the degree of collapse. Severely or completely collapsed subsurface cells may very well cause a problem.

Glue Line Durability for Ponderosa Pine

1. Table 2 and Figure 9 show that ponderosa pine presents a completely different pattern than Douglas-fir or southern pine when the AITC 110 shear strength/dry shear strength ratio is compared for sanded and knife-planed surfaces. The ratio is generally much higher for ponderosa pine. Also, the AITC 110 shear strength and dry shear strengths are essentially equal for sanded and knife-planed ponderosa pine surfaces.
2. Table 3 and Figure 10 show that sanded and knife-planed ponderosa pine produce similar depth of wood failure

patterns for both the dry and AITC 110 soak shear tests.

As already indicated, cellular damage in ponderosa pine appears to be similar to that in Douglas-fir. However, due to a more uniform wood structure, it may yield less gross surface roughness when sanded, which could improve its gluability over Douglas-fir. Within certain grit ranges, it could be that gross surface roughness may be a more significant gluability factor than cellular damage. Also, the high proportion of dense late wood in Douglas-fir could result in less overall adhesive penetration, and hence poorer bonding, than in ponderosa pine.

Attempts to Improve Gluability of Sanded Douglas-Fir

Since sanded Douglas-fir produces substandard glue lines in normal lamination processes, several sanding variables were examined to try to reduce or eliminate the problem.

1. Since each sander belt removes the surface damage produced by the previous belt in the series, it was thought that using very light pressure on the final 80-grit step (thereby removing a minimum of material) would do less damage than the 0.15 mm normally removed on the final 80-grit step. Removing as little as 0.07 mm with an 80-grit belt gave equal appearance, roughness and gluability as 0.3 mm removal. Unfortunately, removing such a small amount also leads to "skipping" in production operations; i.e., incomplete sanding over the surface of the board.
2. Combinations of the following variables were examined in an attempt to find optimum values and combinations which would improve gluability.

Variable	Range
Grit Size	24, 36, 60, 100
Feed Speed	45, 60, 137, 203 m/min
Belt Speed	2286, 2900, 3660 m/min
Age of Belt	New to several hours

   No gluability improvement could be detected by varying the above parameters, either individually or in combination. River, Murmanis and Stewart (5) indicate there was no significant difference in bond strength among six combinations of feed speed and depth of cut for Douglas-fir specimens.
3. The moisture content of the lumber at time of sanding does appear to be a variable which can affect the surface damage and therefore gluability. Lumber sanded at less than 10 percent M.C. (preferably less than eight percent M.C.) appeared to provide better glue line performance than that sanded at 12-22 percent M.C. Additional work is needed to validate this opinion.
4. Based on previous work and fundamental adhesion theory, it was felt that very fine grits might cause less cell damage and less gross surface roughness, and therefore produce a more suitable bond. An experiment was

designed to evaluate 120-, 150-, 180-, 220- and 240-grit sanding belts. The results are shown in Tables 2, 3 and 4 as well as Figures 9, 10, 13 and 14. The 120- to 220-grit sanded material produced glue line performance and cell damage similar to that from the 24- to 100-grit. The 240-grit sanded Douglas-fir yielded data and surface cell structure very similar to that obtained for knife-planed Douglas-fir. The 240-grit sanding was repeated six months later to determine reproducibility. The conclusions were identical. In the grit sequence from 80 to 240 (Table 4 is based on limited sampling at each grit size), subsurface damage in the form of partially collapsed early wood cells seemed to be minimal (0-1 cell) at 80- and 240-grit sizes and reach a maximum (6-8 cells) at 150-grit. The need for further examination of surface versus below surface damage is emphasized by the work of Stewart and Crist (6).

Although controlled laboratory tests have identified a 240-grit surface as producing an acceptable glue line, there still remains the implementation of this solution. The 240-grit would first require confirmation by checking its performance under normal production variables.

Even if the 240-grit performed acceptably under production conditions, the implementation of this solution into an existing production operation appears impractical. The production use of fine grit belts would be complicated by poor belt performance, belt loading and reduced stock removal capability.

The finer grit belts perform poorly because they are not as durable as coarser grit belts and are more prone to mark the lumber. Fine grit belts are generally made of a weaker fabric backing which makes them susceptible to tearing, folding and edge damage. There is also a greater tendency to score the lumber with burns from belt loading, belt splice marks and machine revolution marks.

The smaller the grit, the more susceptible the belt is to loading. This will result in belt life being reduced. Tests have shown that off-line cleaning systems will clean the loaded belts and on-line cleaning systems appear to help resist loading. For four-stage batch machines, cleaning systems are cost prohibitive at $25k to $100k per sander.

A fine grit finish belt would require a different grit sequence in a four-stage sander. The overall result would be lower stock removal capability at normal production speeds. The normal stock removal requirement could be met by reducing machine feed speed but this would have a negative effect on production.

Quality Control Procedures

Microscopic evaluation of sanded surfaces in terms of gross surface roughness and cellular damage (Table 4) can be used to predict gluability of sanded lumber in the laboratory; however, it is desirable to have a quality control procedure for use at a high-speed production surfacing facility to determine if damage was being produced at the lumber surface in such a manner as to affect gluability. Measuring the surface roughness with a Hubert Roughness Tester Model W4 was the approach used. The results obtained on the Hubert Roughness Tester for several independent trials are shown in Figure 15. The plots of roughness value versus grit used show some general trends but did not agree between trials. It is not known why there is such an order of magnitude difference in the roughness between trials when glue line performance data correlated exactly with grit size used for sanding. No morphological characteristics of the wood surface were readily apparent to explain the differences obtained and no instrument problems could be detected.

Conclusions

Based on automatic boil test data, the ratio of AITC 110 shear strength/dry shear strength, depth of wood failure and microscopic analysis:

1. Douglas-fir will not produce structural, wet use glue lines when sanded with 24- through 220-grit belts.
2. Southern pine will not produce structural, wet use glue lines when sanded with 36- through 100-grit belts (24-grit and 120- through 240-grit belts were not evaluated).
3. Ponderosa pine will produce structural, wet use glue lines when sanded with 24- through 100-grit belts.
4. Douglas-fir will produce structural, wet use glue lines when sanded with 240-grit belts under highly monitored conditions. Further testing is necessary to validate this approach under mill conditions.

The new ANSI/AITC A190.1 - 1983 American National Standard for Structural Glued Laminated Timber, Section 4.4.5, requires separate qualification for sanded lumber gluing than used for knife-planed lumber gluing.

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TABLE 1 - AUTOMATIC BOIL TEST DATA

Species	Independent Runs	Grit	No. of Shear Blocks At Each Data Point	Dry Shear SS[A] (kPa)	Dry Shear WF[B] (%)	AITC 110 Shear SS (kPa)	AITC 110 Shear WF (%)	Automatic Boil Test: 20 Cycle SS (kPa)	20 Cycle WF (%)	40 Cycle SS (kPa)	40 Cycle WF (%)	100 Cycle SS (kPa)	100 Cycle WF (%)	200 Cycle SS (kPa)	200 Cycle WF (%)	400 Cycle SS (kPa)	400 Cycle WF (%)	800 Cycle SS (kPa)	800 Cycle WF (%)
Douglas-fir	4	24-40	8-32	7742 ±809[C]	94 ±5	3500 ±1062	97 ±4	3326 ±310	99 ±1	3084 ±210	100 ±1	2898 ±109	99 ±1	2757 ±289	94 ±3	2116 ±154	93 ±3	1860 ±437	99 ±1
Douglas-fir	3	60	32	7686 ±902	96 ±2	3617 ±1385	97 ±3	2993 ±813	95 ±3	2765 ±1160	97 ±2	2476 ±846	99 ±2	2450 ±1202	97 ±3	3316 ±549	96 ±2	2881 ±182	95 ±3
Douglas-fir	6	80	60	8160 ±1297	94 ±7	4167 ±1764	96 ±6	-	-	-	-	-	-	-	-	-	-	-	-
Douglas-fir	3	100	10-26	7594 ±815	95 ±3	3837 ±1257	99 ±2	3157 ±673	98 ±2	2539 ±652	100 ±1	3119 ±631	98 ±3	2312 ±386	97 ±2	2367 ±1150	97 ±3	2506 ±803	97 ±3
Douglas-fir	6	K.P.	12-60	8221 ±1158	90 ±7	6221 ±1491	90 ±8	5012 ±922	88 ±8	4635 ±1381	97 ±3	4114 ±992	94 ±3	4146 ±368	86 ±7	4257 ±276	90 ±2	2740 ±585	79 ±7
Douglas-fir	-	24-100	-	7796 ±815	95 ±3	3780 ±1152	97 ±3	3159 ±491	97 ±3	2796 ±574	99 ±2	2831 ±478	99 ±2	2506 ±526	96 ±3	2600 ±621	95 ±3	2416 ±485	97 ±2
Douglas-fir		Normal[D] Required	-	7590	80	5313	70	-	70	-	70	-	70	-	70	-	70	-	70
Southern Pine	2	60	20	9544 ±1953	97 ±2	4934 ±345	100 ±1	4020 ±137	95 ±3	3105 ±1463	100 ±1	2105 ±1125	100 ±1	1001 ±538	100 ±1	840 ±462	100 ±1	-	-
Southern Pine	1	K.P.	10	9108	-	6141	-	6762	-	5969	-	6003	-	4761	-	4361	-	-	-
Southern Pine	-	Normal[D] Required	-	9040	-	6300													

TABLE 1 - AUTOMATIC BOIL TEST DATA
(CONTINUED)

Species	Independent Runs	Grit	No. of Shear Blocks At Each Data Point	Dry Shear SS (kPa)	Dry Shear WF (%)	AITC 110 Shear SS (kPa)	AITC 110 Shear WF (%)	Automatic Boil Test: 20 Cycle SS (kPa)	20 Cycle WF (%)	40 Cycle SS (kPa)	40 Cycle WF (%)	100 Cycle SS (kPa)	100 Cycle WF (%)	200 Cycle SS (kPa)	200 Cycle WF (%)	400 Cycle SS (kPa)	400 Cycle WF (%)	800 Cycle SS (kPa)	800 Cycle WF (%)
Ponderosa Pine	1	40	16	6741 ±490	96 ±1	7452 ±690	93 ±3	4002 ±400	-	3416 ±346	-	3623 ±98	99 ±1	3298 ±420	99 ±2	2884 ±480	95 ±3	3140 ±531	76 ±6
Ponderosa Pine	1	60	16	6127 ±766	97 ±1	6493 ±911	92 ±5	4865 ±586	-	4037 ±437	-	3968 ±262	99 ±1	3802 ±420	98 ±1	2953 ±373	96 ±3	3146 ±193	85 ±2
Ponderosa Pine	1	80	10	7145 ±1550	92 ±3	7343 ±1598	94 ±4	3781 ±339	93 ±4	3988 ±524	95 ±3	3893 ±421	94 ±2	3562 ±412	92 ±7	-	-	-	-
Ponderosa Pine	1	100	16	7335 ±538	96 ±1	6748 ±380	91 ±1	5003	-	4140	-	3988 ±345	96 ±1	3712 ±690	97 ±2	3416 ±690	91 ±5	3278 ±221	89 ±1
Ponderosa Pine	2	K.P.	58	7444 ±373	90 ±2	7069 ±550	92 ±2	4928	88	4176	86	4254 ±89	89 ±4	3686 ±387	89 ±4	3236 ±269	91 ±3	3312 ±152	83 ±6
Ponderosa Pine		-40-100	58	6837 ±776	95 ±2	7009 ±463	93 ±3	4413 ±484	93 ±4	3895 ±408	95 ±3	3868 ±259	97 ±1	3594 ±432	97 ±3	3084 ±458	94 ±4	3188 ±277	83 ±4
Ponderosa Pine	-	Normal/D Required	-	6280	80	4400	70												

/A Shear Strength.

/B Wood Failure.

/C ± indicates one standard deviation.

/D Normal required refers to values normally used for knife-planed standards (dry strength/wood failure ASTM D 2559).

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TABLE 2 - RATIO OF AITC 110 SHEAR TO DRY SHEAR, FOR VARIOUS GRIT SIZES

Species	Grit	Dry Shear (kPa)	AITC 110 Shear (kPa)	Ratio AITC 110 Shear / Dry Shear
Douglas-fir	24-40	7742 ±809 /A	3500 ±1062	0.45
Douglas-fir	60	7686 +902	3617 +1385	0.47
Douglas-fir	80	816C ±1297	4167 ±1764	0.51
Douglas-fir	100	7594 ±815	3837 ±1215	0.51
Douglas-fir	24-100	7796 ±815	3780 ±1152	0.48
Douglas-fir	K.P.	8221 ±1158	6221 ±1491	0.76
Douglas-fir	Normal Required/B	7590	5313	0.70
Douglas-fir	120	8866 ±1131	3624 ±2121	0.41
Douglas-fir	150	9158 ±2832	4201 ±1633	0.46
Douglas-fir	180	6411 ±1464	3284 ±1756	0.51
Dougls-fir	220/C	8169 ±1650	4120 ±1496	0.50
Douglas-fir	240	7781 ±1057	5146 ±1076	0.66
Douglas-fir	240	7872 ±1172	5353 ±1279	0.68
Douglas-fir	240	7689 ±1869	4938 ±1655	0.64

TABLE 2 - RATIO OF AITC 110 SHEAR TO DRY SHEAR, FOR VARIOUS GRIT SIZES (CONTINUED)

Species	Grit	Dry Shear (kPa)	AITC 110 Shear (kPa)	Ratio AITC 110 Shear / Dry Shear
Southern Pine	60	9544 ±1953	4934 ±345	0.52
Southern Pine	K.P.	9108	6141	0.67
Southern Pine	Normal Required/B	9040	6300	0.70
Ponderosa Pine	40	6741 ±490	7452 ±690	1.11
Ponderosa Pine	60	6127 ±766	6493 ±911	1.06
Ponderosa Pine	80	7145 ±1550	7343 ±1598	1.03
Ponderosa Pine	100	7335 ±538	6748 ±380	0.92
Ponderosa Pine	40-100	6837 ±776	7009 ±463	1.03
Ponderosa Pine	K.P.	7444 ±373	7069 ±550	0.95
Ponderosa Pine	Normal Required/B	6280	4400	0.70

/A ± indicates one standard deviation.

/B Normal required refers to values normally used for knife-planed standards (dry strength/wood failure ASTM D 2559).

/C 220-grit belt was aluminum oxide; all others silicon carbide.

TABLE 3 - DEPTH OF WOOD FAILURE FOR VARIOUS GRIT SIZES

Species	Grit	Depth of Wood Failure: Dry Shear Test	Depth of Wood Failure: AITC 110 Shear Test
Douglas-fir	24	2.0	4.0
	36	2.1	4.3
	60	1.9	2.7
	80	1.7 ± 1.0/A	3.1 ± 0.4
	100	2.3 ± 1.2	2.4 ± 0.7
	120	3.3 ± 1.1	3.2 ± 1.2
	150	2.8 ± 1.1	2.9 ± 0.5
	180	3.3 ± 0.8	3.3 ± 0.9
	220	2.0 ± 1.0	2.5 ± 0.9
	240	2.1 ± 0.9	1.9 ± 0.7
	K.P.	2.3 ± 1.1	1.6 ± 0.7
Southern Pine	36	-	3.6
	60	-	2.8
	100	-	2.3
	K.P.	-	1.6
Ponderosa Pine	80	2.3 ± 0.5	2.5 ± 0.1
	K.P.	1.7 ± 0.5	1.7 ± 0.5

/A ± indicates one standard deviation.

TABLE 4 - REPRESENTATIVE MICROSCOPIC OBSERVATIONS ON SANDED DOUGLAS-FIR

Sample Preparation /A	Description	Hubert Roughness Tester Reading /B	Gross Surface Roughness (mm)	Cellular Damage in Depth of Cells /C
Springfield 80-grit	Early Wood	814 ± 30	.067	1-3 0
	Late Wood		.013	1/2-1 0
Kimwood 100-grit	Early Wood	1486 ± 203	.026	2-3 2-3*
	Late Wood		010	1/2-1 2-3* (Early Wood)
Kimwood 120-grit	Early Wood	2037 ± 256	-	1-2 2-3*
	Late Wood		-	1/2-1 5* (Early Wood)
Kimwood 150-grit	Early Wood	1944 ± 380	-	1 6*
	Late Wood		-	1/2-1 8* (Early Wood)
Kimwood 180-grit	Early Wood	1937 ± 137	-	1 3*
	Late Wood		-	1/2-1 0
Kimwood 220-grit	Early Wood	2131 ± 254	-	1 2*
	Late Wood		-	1/2 2* (Early Wood)
Kimwood 240-grit	Early Wood	5757 ± 652	-	1/2-1 1*
	Late Wood		-	1/2 1* (Early Wood)

/A All samples sanded with 80-grit for size prior to final sanding step.

/B ± represents standard deviation; not possible to get separate reading for early wood and late wood.

/C * indicates cells are only partially collapsed, rather than more or less completely collapsed (i.e., torn, distorted and crushed); upper value - at surface, lower value - below surface.

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FIGURE 1 - ACCELERATED AGING EVALUATION
SANDED DOUGLAS FIR

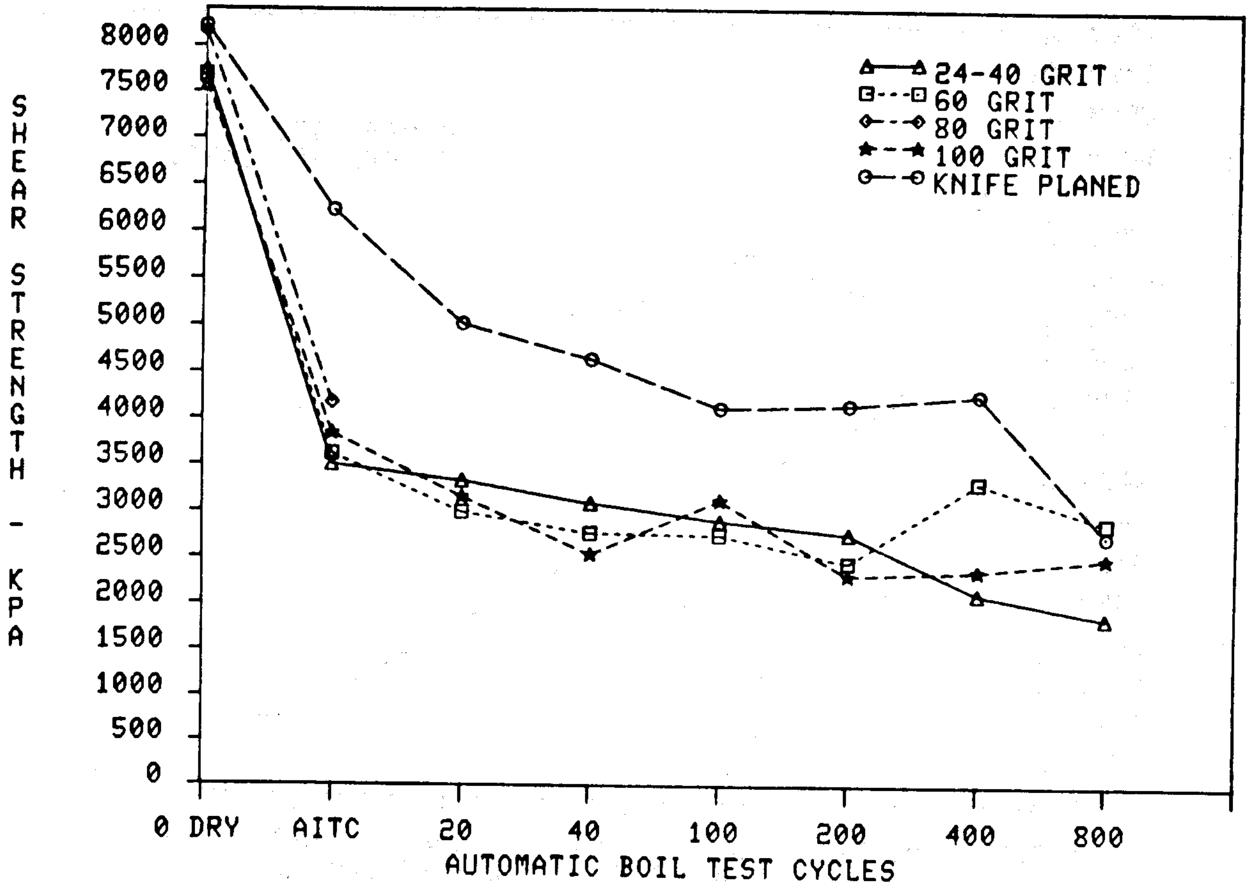


FIGURE 2 - ACCELERATED AGING EVALUATION
SANDED SOUTHERN PINE

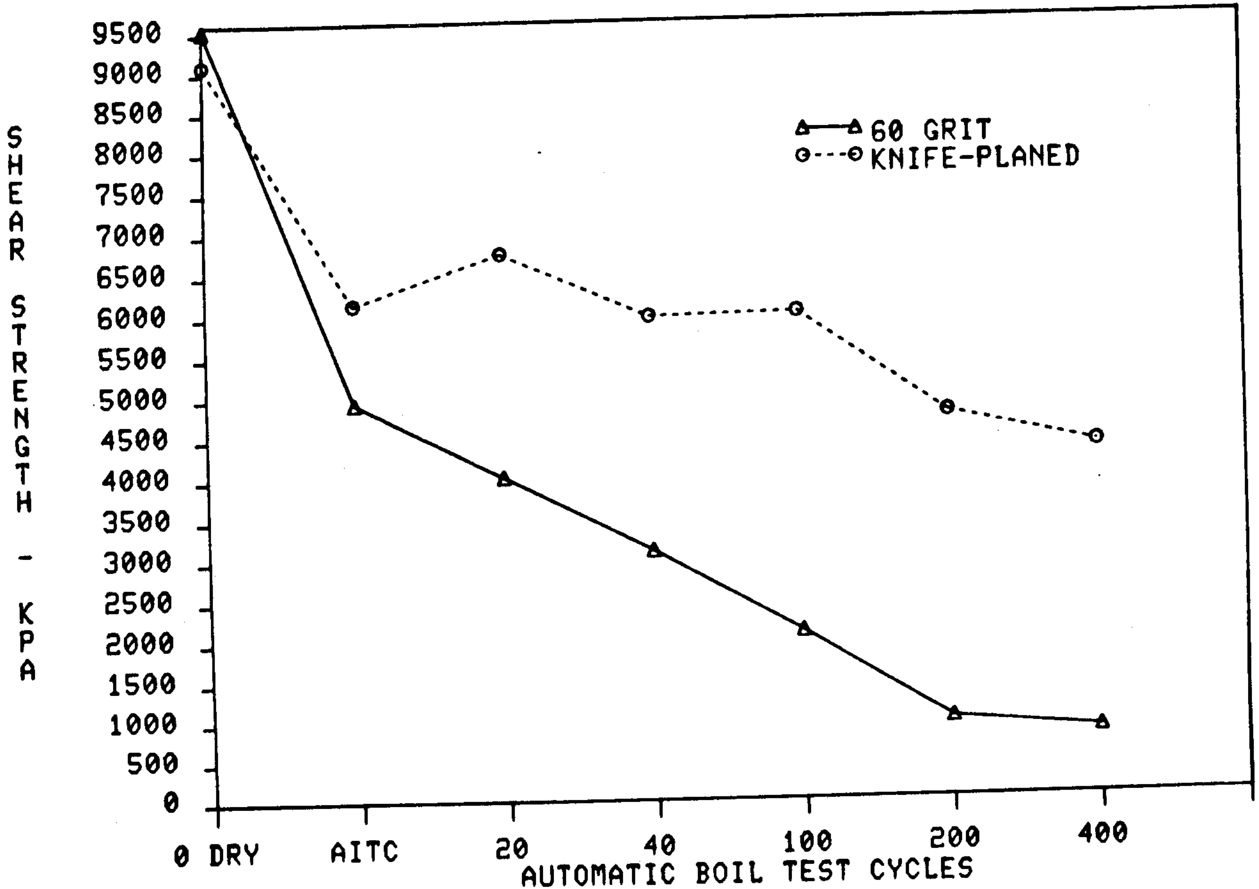
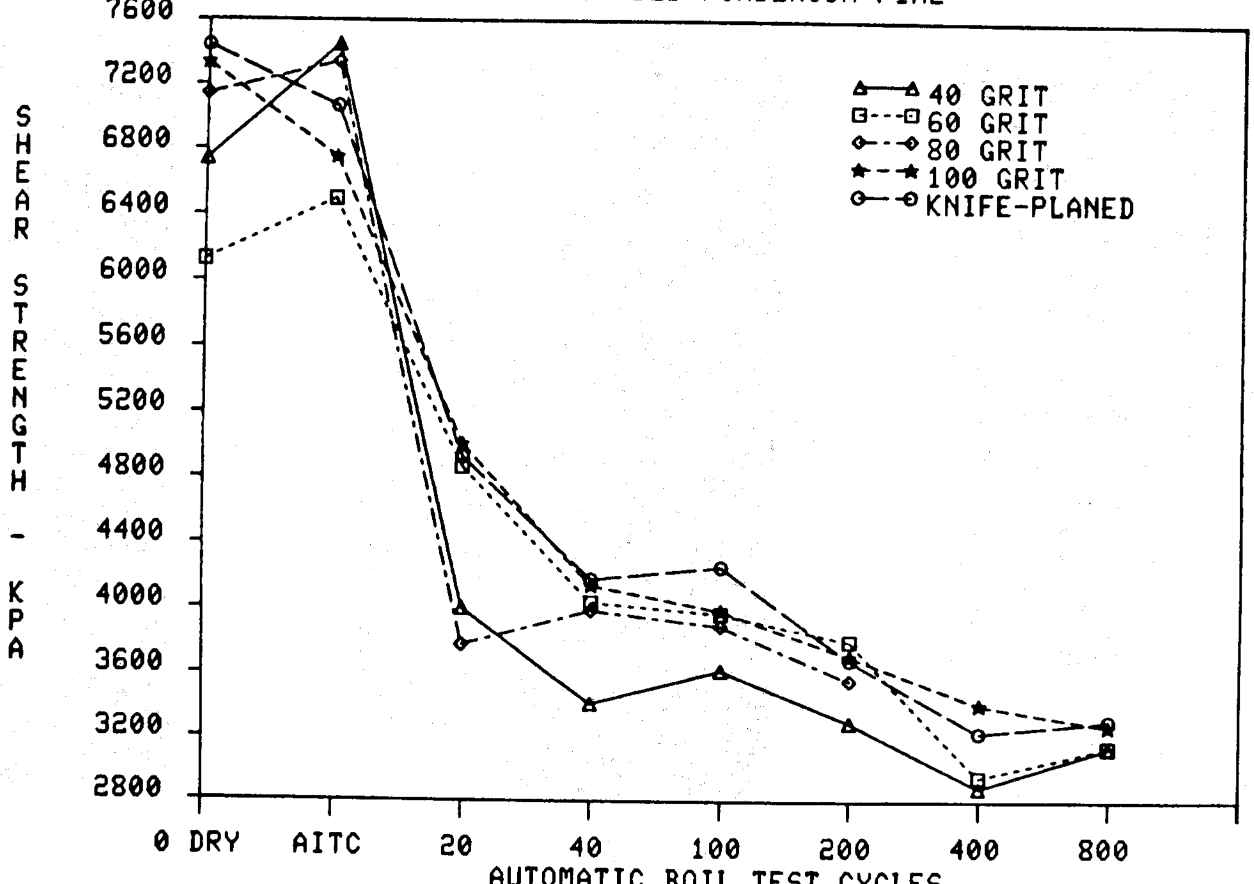


FIGURE 3 - ACCELERATED AGING EVALUATION
SANDED PONDEROSA PINE



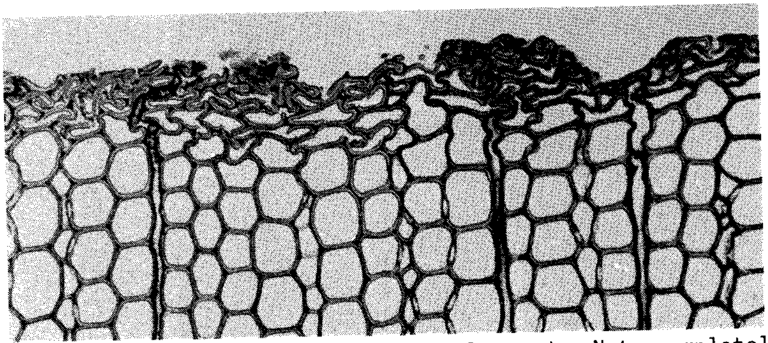


Figure 4. 80-grit sanded Douglas-fir early wood. Note completely collapsed cells at surface and gross surface roughness. 150X

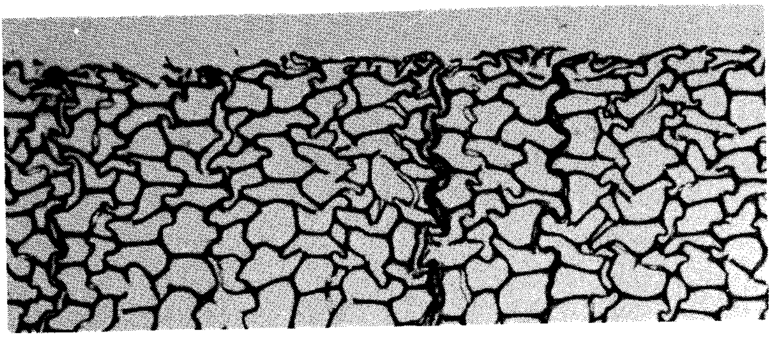


Figure 5. Knife-planed Douglas-fir early wood. Note lack of completely collapsed cells at surface and gross surface smoothness. Partly collapsed cells present below surface may or may not be present in knife-planed lumber, depending on pressure applied during planing. 150X

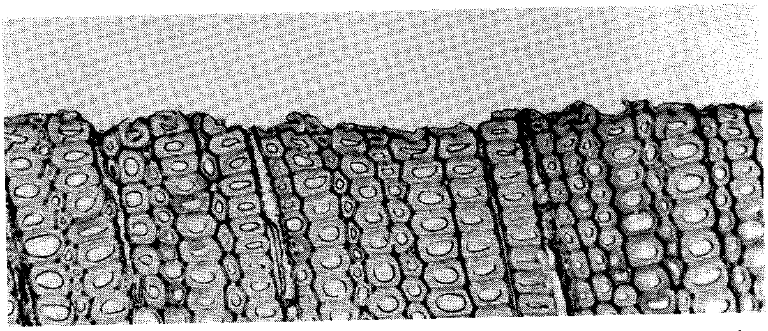


Figure 6. 80-grit sanded Douglas-fir late wood. Note relatively undamaged surface as compared to early wood (see Figure 4, Table 4). 150X

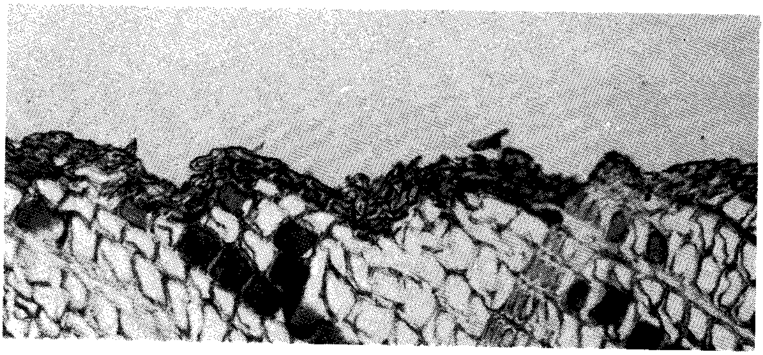


Figure 7. 100-grit sanded ponderosa pine. Note completely collapsed cells at surface and gross surface roughness. 120X

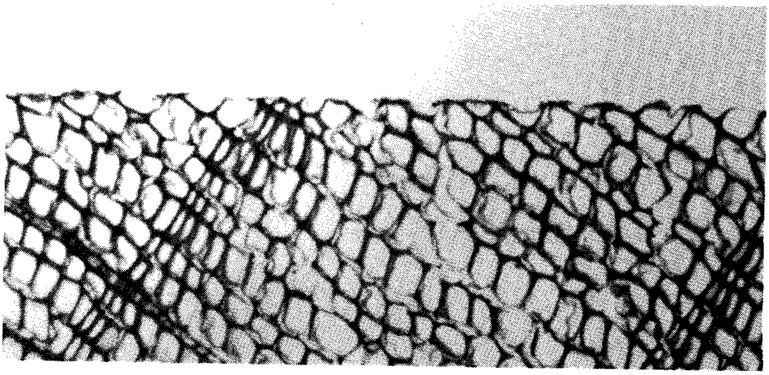


Figure 8. Knife-planed ponderosa pine. Note lack of completely collapsed cells at surface and gross surface smoothness. No partly collapsed cells below surface which can occur in knife planing (see Figure 5) or sanding. 120X

FIGURE 9 - RATIO OF AITC 110 SHEAR/DRY SHEAR VERSUS GRIT OF FINAL SANDING STEP

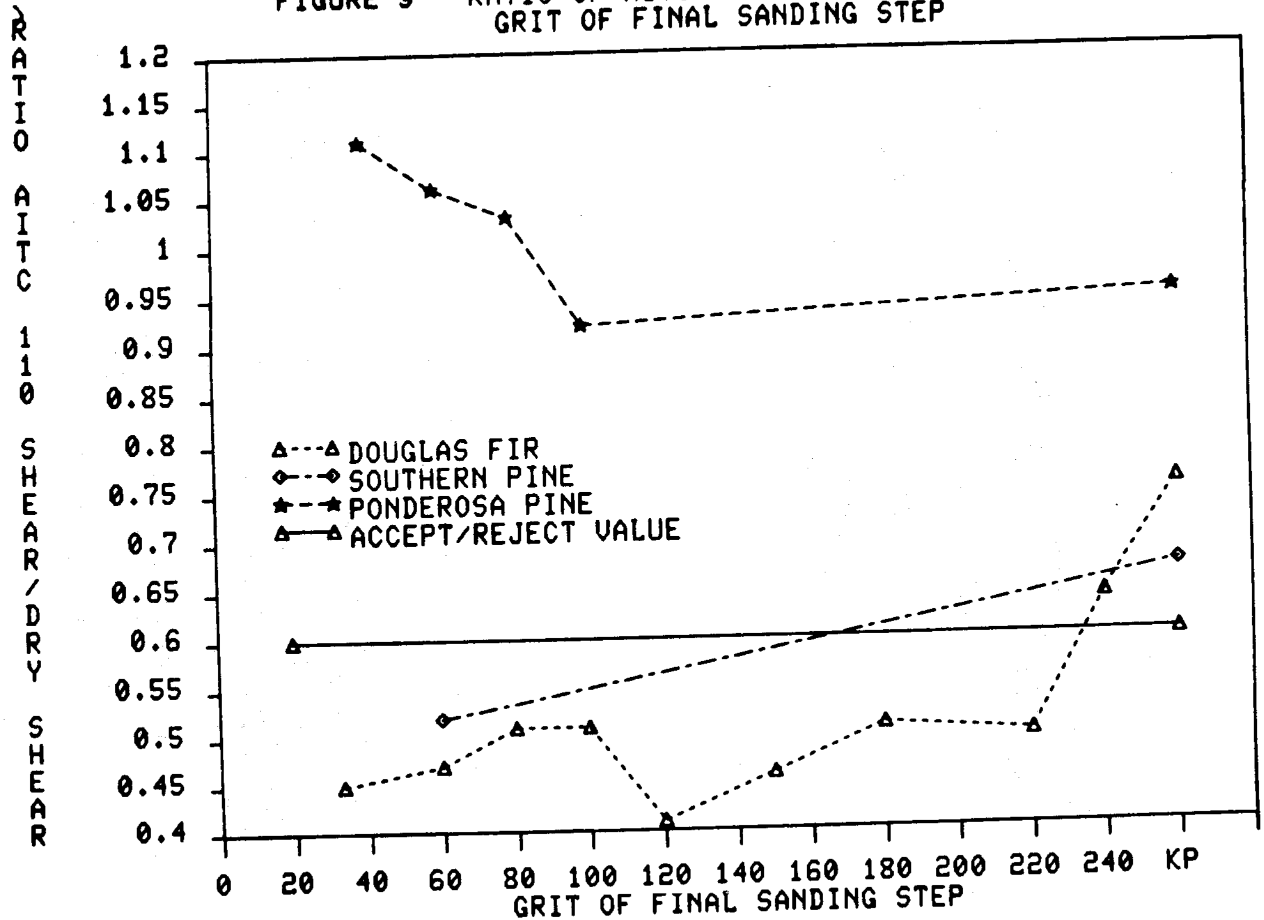
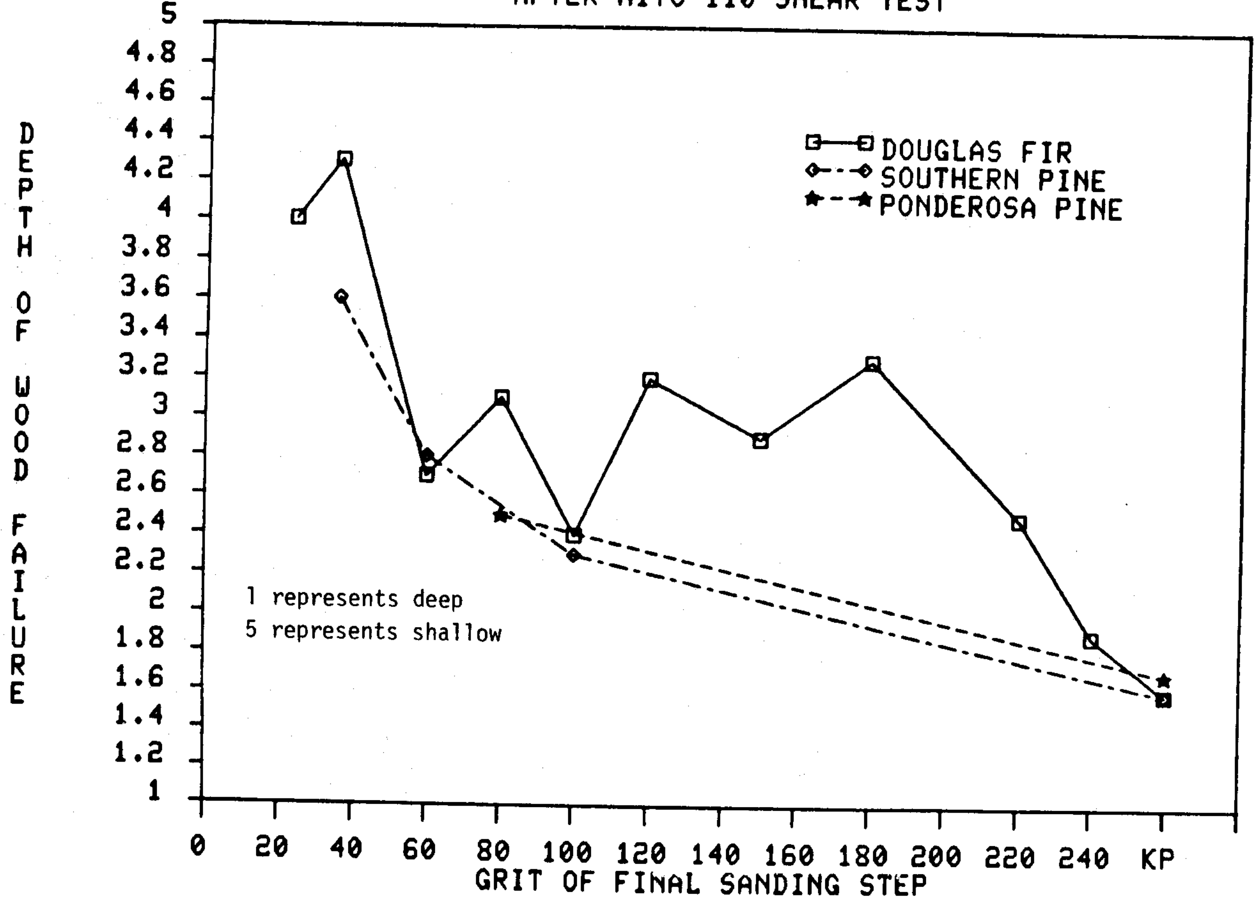


FIGURE 10 - DEPTH OF WOOD FAILURE FOR VARIOUS GRIT SIZES AFTER AITC 110 SHEAR TEST



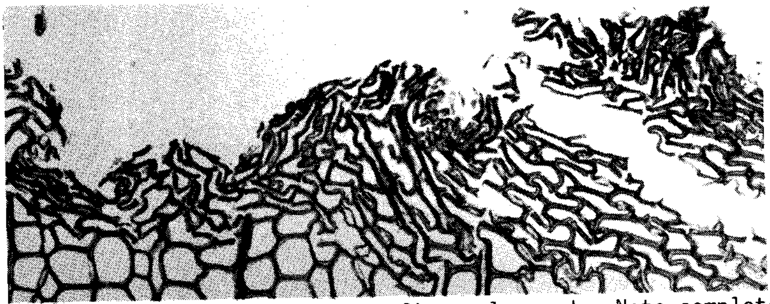


Figure 11. 24-grit sanded Douglas-fir early wood. Note completely collapsed cells at surface and extreme gross surface roughness. 150X

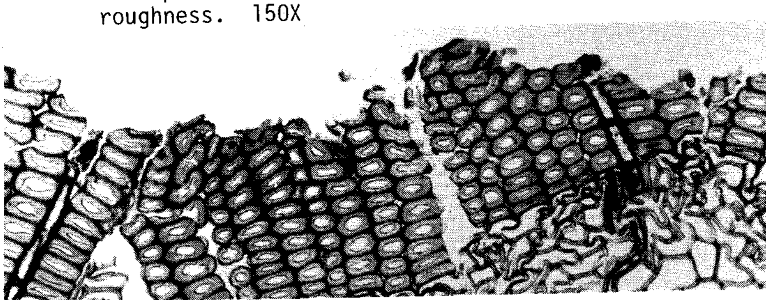


Figure 12. 24-grit sanded Douglas-fir late wood. Note relatively uncollapsed late wood cells at surface as compared to early wood cells (see Figure 11) and extreme gross surface roughness. Subsurface cells (early wood) partly collapsed. 150X

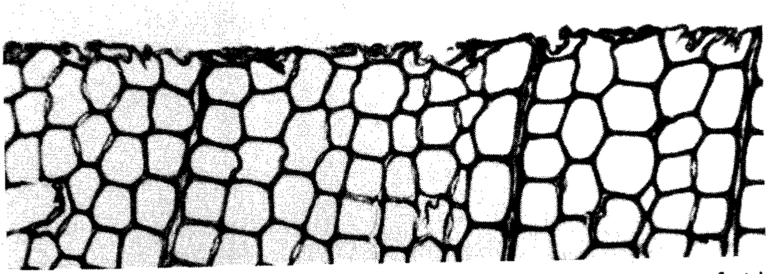


Figure 13. 240-grit sanded Douglas-fir early wood. Note relatively few (see Table 4) completely collapsed cells at surface and gross surface smoothness. 150X

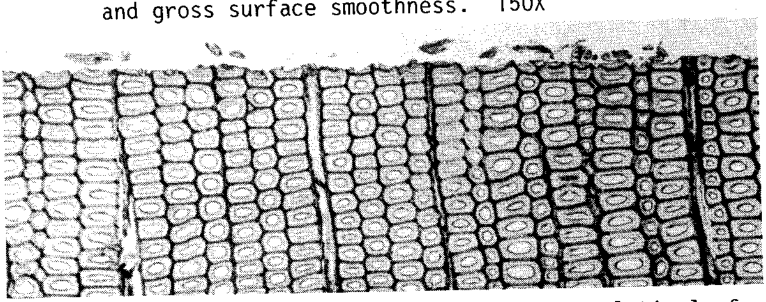


Figure 14. 240-grit Douglas-fir late wood. Note relatively few (see Table 4) completely collapsed cells at surface and gross surface smoothness. About one partially collapsed cell (early wood) below surface. 150X

FIGURE 15 - HUBERT ROUGHNESS TEST VALUES SANDED DOUGLAS FIR