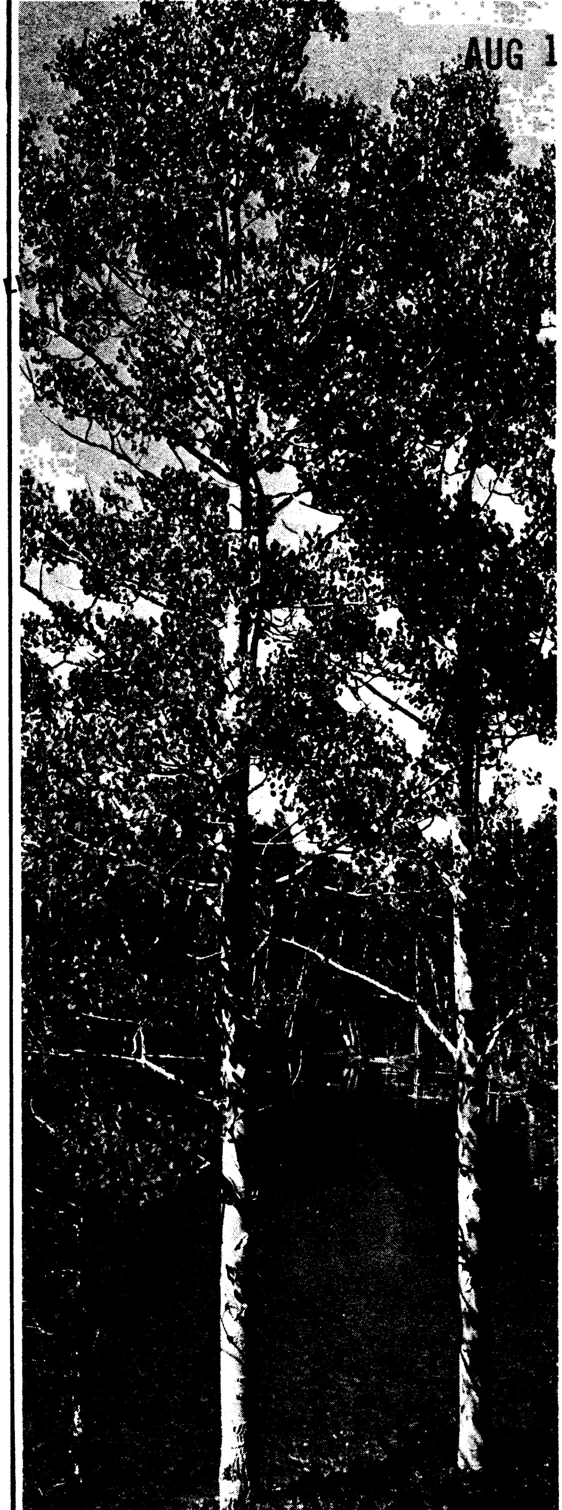
U. S. FOREST SERVICE
RESEARCH PAPER NC-13
JUNE, 1967



ASPEN WOOD CHARACTERISTICS, PROPERTIES, AND USES: a review of recent literature

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Introduction

Aspen is one of the most widely distributed tree species in North America. Its range is transcontinental through Canada, the northern United States, and the western mountain region. Within the Lake States (Michigan, Minnesota, and Wisconsin) it is one of the most abundant species, occupying approximately 30 percent of the commercial forest land and comprising more than 30 percent of the net volume of hardwood growing stock. In Minnesota alone, it contributes about 46 percent of the net annual growth of all growing stock.

Historically, the use of aspen has been small in comparison to its annual growth. Recently, however, much attention has been focused on possible methods of increasing the utilization. But if aspen is to be more fully utilized, information on its characteristics, properties, and suitability for various end uses is essential. Over the past years, numerous articles have appeared containing information pertinent to these topics. These articles, however, are widely scattered in the literature; and in some instances they report conflicting results.

This report, therefore, summarizes present knowledge of aspen properties and uses as an initial source of information for both industrial- and research-oriented individuals and indicates areas where results conflict. It also points out at least some of those areas where additional information would ultimately increase the use of an important forest resource.

The main text is organized into five major sections: (1) Background information, (2) resource data, (3) wood properties, (4) utilization, and (5) summary of recommendations for possible research.

The 42 reports in "Literature Cited" and 73 in "Additional References" constitute a fairly comprehensive bibliography on aspen wood characteristics, properties, and uses.

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Background Information

Description of the Species

Aspen, as referred to in this report, includes *Populus tremuloides* Michx. (quaking aspen), and, to a lesser extent, *P. grandidentata* Michx. (bigtooth aspen). In the Lake States region, quaking aspen is by far the most predominant *populus* species, accounting for 80 to 90 percent of the volume of the entire group.

Quaking aspen is probably one of the most widely distributed tree species in North America (Canad. Dep. Forest. 1963; Fowells 1965; Harlow and Harrar 1950).[1] The range is transcontinental through Canada, the northern United States, and the western mountain region. The species is fast growing, short lived (60 to 80 years), and usually of small size — average height is 50 to 60 feet and diameter 8 to 16 inches. Quaking aspen is exceedingly intolerant and, under competition, develops a long slender bole with a small round crown. The root system is superficial. Being a prolific seeder and possessing good sprouting ability, aspen usually develops in pure stands on logged or burned over areas. In the primeval forest, aspen trees are solitary and widely scattered, usually near water and in sparse cover.

Quaking aspen is a major component of five forest types (Fowells 1965): jack pine-aspen; white spruce-balsam fir-aspen; black spruce-aspen; aspen-paper birch; and aspen. It also forms a minor component of 27 other forest types.

Bigtooth aspen is a medium-size tree, similar in silvical features to quaking aspen; however, it seems to attain a larger size and a longer life span before deterioration (Harlow and Harrar 1950). It is less widespread both in general range and local distribution.

Species-Site Relations

Species-site relations are highly complex, and extensive treatment is not within the scope of this report. The information presented here provides some background material pertinent mainly to properties and uses. The literature cited and additional references listed in the back of the report contain more information on this subject. The effect of site on physical and mechanical properties is discussed in subsequent sections of this report.

Although aspen grows on all types of soils, it is one of the most sensitive species in site requirements (Heinselman and Zasada 1955; Zehngraff 1947). On favorable sites, it develops into a desirable tree; on unfavorable sites it is short and scrubby and deteriorates at an early age. The yield of aspen in well-stocked unmanaged stands in northern Minnesota has been summarized as follows (Zehngraff 1947):

1. Good sites: Trees reach saw log size at a rotation age of about 55 years. Yields of 9,100 board feet or 46 cords per acre and higher are attainable.

2. Medium sites: Small logs and pulpwood are produced at a rotation age of 45 years. Yields are about 5,000 board feet or 32 cords per acre.

3. Poor sites: Aspen seldom reaches more than pulpwood size at a rotation age of about 30 years. Maximum yields may be as much as 18 cords per acre, but they are usually only 5 to 13 cords. Much poor-site aspen is noncommercial under present conditions.

Barth (1942) states that European aspen prefers a light, loose, organic, and particularly lime-containing soil of a fresh, moist nature. On dry poor soils the species does not develop well and is seriously afflicted with heartrot even in young trees. Hard, heavy clay soils or poorly drained soils are also unsuitable. The most desirable is a wet soil where the ground water is in steady motion.

Stone (1966) reported that in Minnesota in 1962 there were 5,451,000 acres in aspen

[1] *Names and dates in parentheses refer to Literature Cited at the back of this report.*

forest type — forests in which aspen comprises the plurality of the stocking. His data separated this acreage by site:

Site	*Site index*	*Percent of total area*
Excellent	76+	11.9
Good	66 - 75	29.2
Medium	56 - 65	34.4
Poor	45 - 55	24.5

In general, the characteristics of aspen growth are (Heinselman and Zasada 1955; Zehngraff 1947): an exceptionally high natural mortality rate; a high cull percentage, especially in older stands; and a natural slowdown in growth with age.

Within the category of species-site relations, the following are areas where additional information is needed or previous data should be reaffirmed:

1. The information on yields from the various site qualities should be reviewed to determine if they are still valid in the light of present stand conditions.

2. Because of aspen's rapid growth, rapid deterioration, and high susceptibility to decay, a guide to growth and stand longevity should be developed to show potential yield and quality of material.

3. Additional information is needed to determine if susceptibility to decay is related to site quality. We know that aspen deteriorates more rapidly on the poorer sites than on the better sites, but we do not know why.

General Characteristics of the Wood

The woods of the two aspen species are indistinguishable from each other in both appearance and properties (Brown *et al.* 1949). The sapwood's whitish to creamy color generally merges gradually into the whitish to light grayish-brown color of the heartwood. The wood has a characteristic disagreeable odor when wet, is odorless when dry, and is without taste. There is a pronounced silky luster to the wood. The growth rings are fairly distinct because of the slightly darker latewood. The rays are fine, scarcely visible with a hand lens. The pores are small and numerous and cannot be seen without a hand lens. Aspen is usually a straight-grained, medium-light-weight wood with a specific gravity of about 0.35 (based on green volume).

As to its mechanical properties, in general aspen is moderately weak in bending and edgewise compression, low in stiffness, and moderately high in shock resistance (Brown *et al.* 1949; U.S. Forest Prod. Lab. 1955).

The wood is moderately difficult to surface because it is prone to chipped or fuzzy grain. It is easy to glue and takes paint well. Although its nail-holding ability is low, it does not split readily.

Volumetric shrinkage is moderate, but natural durability is very poor.

Resource Data

For the Lake States

Timber inventory. — The net volume of aspen timber on commercial forest land in the Lake States in 1963 was as follows (U.S. Forest Service 1965):

State	*Growing stock (million cu. ft.)*	*Sawtimber (million bd. ft.)*
Michigan	2,068	1,445
Minnesota	3,025	2,427
Wisconsin	1,923	773
Total	7,016	4,645

In these States, aspen comprises more than 30 percent of the hardwood growing stock and more than 11 percent of the hardwood sawtimber.

Annual cut for all products. — Horn (1965) reported that the cut of aspen for all products in Michigan, Minnesota, and Wisconsin in 1936 was 1.7 million cords. In 1964 the cut amounted to 2.4 million cords, of which about 1.7 million cords were pulpwood. Although the current annual cut is larger than it was several years ago, the rate of increase has been declining due to smaller annual cuts for products such as fuelwood, fence posts, excelsior, and veneer logs.

Annual cut for pulpwood. — Only the annual cut for pulpwood has generally increased. Data at 10-year intervals are shown below (Horn 1965):

Year	*Aspen pulpwood production (thousand cords)*
1936	94
1946	714
1956	1,397
1964	1,728

From Horn's data (1965), the cut of aspen can be compared to the cut of all species for pulpwood in 1964.

	Pulpwood cut (thousand cords)	
State	*Aspen*	*All species*
Michigan	675	1,321
Minnesota	450	1,062
Wisconsin	603	1,244
Total	1,728	3,627

In 1964, diameters of 7 to 12 inches d.b.h. accounted for two-thirds of the aspen pulpwood production in the Lake States (Horn 1965). The average tree was 9½ inches d.b.h. and 62 feet tall and had a merchantable volume of 11.2 cubic feet. Operable aspen stands in the Lake States yielded about 12 cords per acre.

Annual cut of veneer logs. — Knutson (1965) surveyed the cut of veneer logs in the Lake States. Aspen comprised only a small part of all material cut for veneer logs in 1963:

	Veneer logs cut (thousand bd. ft.)	
State	*Aspen*	*All species*
Michigan	344	15,300
Minnesota	983	9,970
Wisconsin	196	25,203
Total	1,523	50,473

For Minnesota

The data presented here on the growth and production of aspen in Minnesota are summarized from the work of Stone (1966). In Minnesota aspen comprises about 50 percent of the hardwood growing stock volume and contributes 46 percent of the net annual growth of all growing stock. In 1960 the total lumber production was 161.3 million board feet; 90.8 million board feet (56.3 percent) was hardwood with aspen accounting for 37.6 million board feet or 41.4 percent. Nevertheless, the annual cut of aspen is still well below the desirable cut for the State (table 1).

TABLE 1. — *Aspen volume and production on commercial forest land in Minnesota, 1962*[1]

Forest survey unit (see fig. 1)	Annual cut		Desirable cut		Total volume	
	Growing stock	Sawtimber	Growing stock	Sawtimber	Growing stock	Sawtimber
	Million cu. ft.	Million bd. ft.[2]	Million cu. ft.	Million bd. ft.[2]	Million cu. ft.	Million bd. ft.[2]
Lake Superior	14.60	28.18	57.03	74.50	1125.54	884.24
Central Pine	17.43	36.70	52.29	67.00	1318.40	1021.78
Rainy River	6.43	10.56	12.68	17.50	335.35	288.75
Southeastern	1.17	3.05	3.32	6.15	113.08	104.31
Western	1.97	3.63	3.59	4.23	125.79	88.78
Total	41.60	82.12	128.91	169.38	3018.16	2387.86

1/ Summarized from Stone (1966).
2/ International 1/4-inch rule.

The annual mortality of aspen growing stock on commercial forest land in Minnesota in 1962 was 40.3 million cubic feet. This is

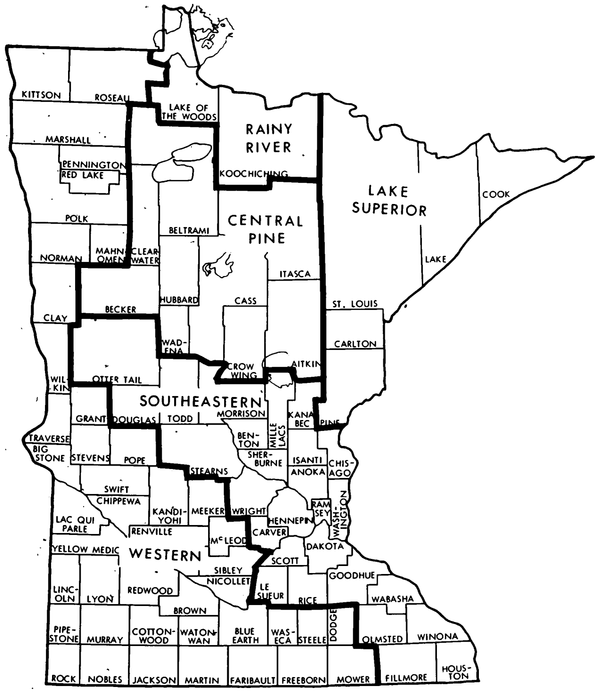

FIGURE 1. — Forest survey units in Minnesota.

approximately equal to the entire volume of aspen timber cut for that year. Fire, insects, disease, and other causes accounted for this destruction (Stone 1966).

The projected supply of aspen in the Lake States has until recently received little attention. Groff (1966) studied this problem for Minnesota and drew the following conclusions:

1. Over the next 10 to 15 years, the volume of aspen in the 8- to 12-inch d.b.h. classes will increase.

2. The projections show no significant increase in the number of large trees (16 inches d.b.h. and over).

3. The total volume in small trees (6 inches d.b.h. and under) will decline as the resource ages.

4. Substantially larger cuts of aspen could probably be made in Minnesota over the next several decades. However, the bulk of the resource will be in material 8 to 12 inches d.b.h.

Wood Properties

Wood Quality

A large amount of the available aspen is of small size (table 2). Because the trees are small, the production of high-quality lumber and its percentage of total lumber output are low. Much of the clear lumber produced is not wide enough or long enough to meet the top-grade specifications of the National Hardwood Lumber Association grading rules (Barth 1942).

Another factor that probably reduces grade yield is the practice in the Lake States of cutting all aspen saw logs to 100-inch lengths without regard to stem form and defect pattern. An especially undesirable characteristic of the wood is the unsound knot, which contributes to the general down-grading of the whole board or log. Such unsound knots (as well as tension wood) are also the chief causes of degrade in veneer-type aspen logs (U.S. Forest Prod. Lab. 1957). The factors of defect pattern, stem form, and end use should all be taken into consideration in the bucking practice.

Paul (1956, 1963), working with five native and hybrid species of the genus *Populus*, found that site quality did not show a constant relation to specific gravity; sites of intermediate quality tended to produce the heaviest wood. Furthermore, specific gravity varied greatly among stands and within sites.

Paul's data also showed that for a combination of the five species specific gravity was inversely related to width of growth rings. This relationship between ring width and

TABLE 2. — *Percentage distribution of number of trees, growing-stock volume, and sawtimber volume of aspen on commercial forest land in Minnesota by diameter class, 1962*[1]

Diameter class (inches)	Percent of-- Number of trees	Cubic feet of growing-stock volume	Board feet of sawtimber volume
3.0 - 4.9	42.1	--	--
5.0 - 6.9	35.4	33.2	--
7.0 - 8.9	14.5	32.4	--
9.0 - 10.9	5.5	20.4	--
11.0 - 12.9	1.8	8.1	55.1
13.0 - 14.9	.6	4.0	28.5
15.0 - 16.9	.1	1.4	11.4
17.0 - 18.9	(2/)	.5	2.9
19.0 - 28.9	(2/)	(2/)	2.1
29.0 - 38.9	(2/)	(2/)	(2/)

1/Summarized from Stone 1966.
2/Less than 0.05 percent.

specific gravity was also reported by Sacre (1963) working with European hybrid poplar. According to Valentine (1962) in a study of quaking aspen in northern New York, specific gravity appeared to have a slight positive correlation with average ring width. Van Buijtenen's work (1962) on quaking aspen showed that fiber length increased with the logarithm of ring age. He also found that the variation in fiber length due to cardinal direction was negligible but that a fair amount of random variation occurred.

Wilde and Paul (1951), working with quaking aspen in Wisconsin, showed a close correlation between rate of growth and nutrient content of the soils. Specific gravity was highest in reasonably fertile soils and lowest in soils deficient in nutrients, but this relationship did not always hold true. Valentine (1962) found that the highest specific gravity occurred in the lower elevations (1,260 feet or less) on abandoned farmland, and the lowest specific gravity occurred in the higher elevations (1,540 feet and higher) on burned-over areas.

The quality of aspen is further influenced by its high susceptibility to heartrot, which may cause a high cull factor in logging (Barth 1942). In over-mature stands, it is usually a very defective tree. The greatest volume of defects found in the aspen of Ontario was caused by brown stain, followed by incipient yellow rot, white spongy rot, yellow-brown stringy rot, and mottled stain (Basham and Morawski 1964). The two prime fungi were *Radulum casearium* and *Fomes igniarius*. In Minnesota, *Hypoxylon pruinatum* is an important canker of aspen. This disease frequently attacks the main stem and may eventually girdle the tree.

Another defect in aspen wood is bacterial wetwood, which is usually darker and has a higher moisture content than the surrounding material. These wetwood areas may promote seasoning defects in lumber and increase bleaching costs in pulping. Little is known about the formation, behavior, and possible methods of preventing bacterial wetwood. In some geographical areas and for certain end products, it can be a serious problem. Additional information on the properties of wetwood will be presented in subsequent sections of this report.

Physical and Mechanical Properties

Four major works present values for the various strength and related properties of small clear specimens of this wood (Irwin and Doyle 1961; Kennedy 1965; Markwardt and Wilson 1935; U.S. Forest Prod. Lab. 1955). Their values for several properties vary considerably (table 3). The variations are such that they cannot be accounted for by differences in specific gravity alone.

An additional study of strength properties is that of Johnson (1947). He does not present any actual strength values but describes the various properties in general terms and ranks the properties of aspen against those of other woods on a percentage basis. His results show that aspen compares favorably with other low-density hardwoods such as yellow-poplar and basswood.

From the literature, the following conclusions can be drawn concerning the

TABLE 3. — *Strength and related properties of small clear specimens of quaking aspen compiled from four sources.*

Source	Condition	Trees sampled	Location of samples	Specific gravity	FSPL	Static bending: Modulus of rupture	Static bending: Modulus of elasticity	Static bending: Work to PL	Static bending: Work to maximum load
		Number			Psi	Psi	1,000 Psi	In.-lb/in³	In.-lb/in³
U.S. Forest Prod. Lab., 1955[1]	Green	11	Wis. - N. Mex.	.35	3,200	5,100	860	.69	6.4
	Air dry, 12%	3	Wis. - N. Mex.	.38	5,600	8,400	1,180	1.53	7.6
Kennedy, 1965	Green	20	N.B. - Man. - Sask.	.374	2,890	5,460	1,310	.37	6.9
	Air dry, 12%	20	N.B. - Man. - Sask.	.408	5,250	9,800	1,630	.99	10.3
Irwin and Doyle, 1961	Green	20	N.B. - Man. - Sask.	.38	2,900	5,500	1,350	.35	6.9
	Air dry, 12%	18	N.B. - Man. - Sask.	.40	4,500	10,100	1,730	1.05	11.0
Markwardt and Wilson, 1935	Green	5	Wis.	.360	2,940	5,280	840	.65	6.9
	Air dry, 5.2%	1	Wis.	.421	7,600	10,770	1,290	2.43	7.3
	Green	6	N. Mex.	.344	3,340	5,000	877	.73	5.9
	Air dry, 7.0%	2	N. Mex.	.372	7,150	10,500	1,410	2.07	9.1

Table 3 continued

Source	Condition	Compression parallel to grain: FSPL	Compression parallel to grain: Max. crushing	Compression perpendicular to grain FSPL	Max. shear parallel to grain	Tension perpendicular to grain	Drop of 50-lb. hammer to failure	Hardness: End	Hardness: Side	Shrinkage: Rad.	Shrinkage: Tang.	Shrinkage: Vol.
		Psi	Psi	Psi	Psi	Psi	In	Lb	Lb	Pct	Pct	Pct
U.S. Forest Prod. Lab., 1955[1]	Green	1,670	2,140	220	660	230	22	280	300	3.5	6.7	11.5
	Air dry, 12%	3,040	4,250	460	850	260	21	510	350			
Kennedy, 1965	Green	1,510	2,350	199	718	441	26	339	324	3.6	6.6	11.8
	Air dry, 12%	3,280	5,270	511	981	607	28	633	482			
Irwin and Doyle, 1961	Green	1,480	2,360	200	[2]755	[2]445	26	370	[2]345	3.6	6.6	11.7
	Air dry, 12%	3,320	5,140	490	[2]1,045	[2]625	26	660	[2]510			
Markwardt and Wilson, 1935	Green	1,600	2,160	203	625	182	28	266	318	3.3	6.9	11.1
	Air dry, 5.2%	4,320	6,440	552	890	380	24	848	420			
	Green	1,720	2,130	239	683	276	18	289	286	3.6	6.6	11.8
	Air dry, 7.0%	--	5,520	718	1,023	239	18	567	338			

[1] Apparently taken from the work of Markwardt and Wilson (1935) since values identical to these appear in a summary section of their publication. The original data of Markwardt and Wilson is shown in table 4. These data were summarized by adjusting the air-dry values to a 12-percent moisture content and averaging first the green and then the adjusted air-dry values over the two separate geographical regions.

[2] Average for radial and tangential.

strength properties of quaking aspen:

1. In general, they compare favorably with those of the other low-density hardwoods and the pines. The wood, however, has a much lower bending strength.

2. Quaking aspen appears to have better toughness and dimensional stability properties than the other species named above.

The natural decay resistance of aspen is low. Untreated posts in direct contact with the soil have a life span of 2 to 4 years. Unfortunately, the heartwood is moderately difficult to penetrate with preservatives; radial penetration in small round posts varies greatly — as much as 1/16 to 1 inch in the same piece (MacLean 1952). Tyloses in both the heartwood and sapwood may explain the irregular penetration (Kaufert 1948). Discolored portions in the heartwood and around knots are at times more durable than either the heartwood or sapwood (Hossfeld *et. al.* 1957). Some of these areas may contain extractives that give added durability.

Haygreen and Wang (1966) found that aspen wetwood has considerably lower strength properties than normal sapwood has. Further tests showed that normal sapwood has a higher specific gravity and a lower volumetric shrinkage than the wetwood.

Aspen is low in nail-holding ability but tends to resist splitting when nailed. The wood's softness and uniform texture will usually permit the use of a nail large enough to hold without an undue hazard from splitting. When green aspen wood is nailed and allowed to dry, its nail-holding ability decreases rapidly to about 10 percent; for example, data on a 7-penny nail driven 1¼ inches into side grain are (Johnson 1947):

Nail-holding ability (pounds)	*Condition when nailed and tested*
194	Nailed dry, tested dry
194	Nailed green, tested green
20	Nailed green, tested dry

The pH of the wood is approximately 6.5. When dry, it has no odor or taste. The average length of fibers is about 1 millimeter, the average diameter about 0.03 millimeter.

The literature on the strength and related properties of quaking aspen shows a need for additional data. Some problems to be studied are as follows:

1. Test for geographical differences in the various strength properties. Table 3 indicates such differences may exist.

2. Refine the various strength values by more intensive and extensive sampling.

3. Define and investigate the factors affecting the strength properties of aspen wood.

Machining Properties

Two reports by Davis (1962) and Cantin (1965) are the major sources of information on the machining properties of aspen (table 4).[2] In general, they show that machining properties of aspen are moderately good when compared to the other low-density hardwoods but only fair to poor when compared to the high-density woods such as maple. Since it is a low-density species, aspen tends to crush or tear rather than cut cleanly when conventional machining methods are used. By cabinet wood standards, the machinability is fair to poor. If proper care is taken, however, it can be worked satisfactorily and will finish well after light sanding.

Many of the machining problems occur when aspen is used in a mixed production run with other hardwoods. Machine settings suitable for the denser hardwoods will not produce a satisfactory finish on aspen. Feed rates, depth of cut, and knife angles must be adjusted to compensate for the softness of the wood (Davis 1962).

Another problem is tension wood, which dulls the cutting tool and causes fuzzy grain (Clark 1958). The numerous small knots, both loose and unsound, cause trouble in surfacing. Even without these problems, aspen wood tends to fuzz when surfacing, especially when the lumber is wet.

Additional information is needed on the

[2] *Apparently the 1962 report by Davis contains the same information he showed in "Machining and Related Properties of Aspen" published in 1947 by the U.S. Forest Service, Lake States Forest Experiment Station, as Aspen Report 8.*

TABLE 4. — *Machining properties of aspen compiled from two sources.*

Item	Source	
	Davis 1962	Cantin 1965
Average specific gravity	0.42	0.41
Samples per test (number)	50	50
Planing, defect-free pieces (percent)	26	58
Shaping, good to excellent pieces (percent)	7	66
Turning, good to excellent pieces (percent)	65	43
Boring, good to excellent pieces (percent)	78	89
Mortising, fair to excellent pieces (percent)	60	67

following points:

1. How well can aspen be machined by the various pieces of equipment and operations?
2. What factors in each operation affect the quality of the finished surface — e.g., in planing what are the recommended cutting angles and feed rates?
3. What properties of aspen wood limit the quality of the machined surface? Can any of these be overcome by different machine settings or machining techniques?

Gluing Properties

Aspen reportedly has good gluing properties and bonds well with a wide range of adhesives under a wide range of conditions. It is usually ranked as a "very easy" to "moderately easy to glue" species (Bergin 1964; U.S. Forest Prod. Lab. 1955). Bergin (1964) reported that aspen glues better with casein and resorcinol than with animal or urea adhesives.

Seasoning

The wood is relatively easy to dry and can be air-dried or kiln-dried without any more degrade than is expected with any other species (Smith 1947). Wetwood, however, is susceptible to collapse, shake, or checks (Kemp 1959); and lumber containing wetwood is subject to degrade if kiln-dried under a normal aspen schedule. Furthermore, the wetwood areas will still have a high moisture content. If the material is then remanufactured into wood components, serious problems in edge gluing, machining, or fabricating can result.

Additional information is required concerning the seasoning of aspen in relation to these wetwood areas.

Present and Possible Uses

Due to aspen's relative ease of machining, low density, light color, and ease of gluing, it is suitable for the following products:

Matches	Containers
Novelties	Excelsior
Toys	Furniture components
Core stock	Interior trim

Aspen is used in furniture (both as core stock and for concealed parts), paneling, and doors. The markets for core stock and wood components could probably be expanded considerably if an adequate supply of graded, well-seasoned, reasonable-quality material of sufficient size were made available. Before this can be achieved, data on yields of cuttings from the various grades of aspen lumber and from aspen logs on a mill run basis are needed.

Aspen is used extensively in the production of excelsior. However, the market for this product is diminishing due to competition from other packaging materials and lack of product demand.

Boxes, crating, and pallets are fabricated from this wood. Its light weight, good strength, and ability to withstand rough handling make it well suited for these products. The lack of odor or taste in dry material permits it to be used in the manufacture of food containers.

Aspen can be rotary cut to produce veneer (Bulgrin *et al.* 1966; Feihl and Godin 1966) for use in baskets and crates, for cores and cross-bands, and in the fabrication of aspen plywood. A relatively high proportion of the lower grades of veneer are produced because of the generally small size of aspen logs and their natural defects. A rotary veneer operation peeling aspen logs must be able to handle small-diameter material, peel to a small core diameter, and have outlets for all grades of veneer.

A large market is open to aspen plywood in painted and unpainted furniture, built-in fixtures, wall paneling, and furniture backs. When an appropriate adhesive is used, the lower grades of aspen plywood are suitable for sheathing and other construction purposes.

Poplar has been tested for use in laminated crossarms for poles (Holmes 1957). Well-chosen, properly laminated material performed well. Aspen, possessing similar properties, may also enter the market for laminated products such as this.

One of the largest uses for aspen is in the manufacture of pulp for paper and fiberboards. It can be pulped by most standard methods and is suitable for a coarse grade of groundwood pulp for fiberboard and a fine grade of groundwood pulp for book and specialty papers and newsprint. Aspen sulfite pulp yield is about 46-54 percent by weight. The pulp is soft, bulky, and easily bleached. It can be used in writing, mimeograph, toweling, and tissue papers. Semichemical (neutral sulfite process) pulp yields are about 70-85 percent by weight, and can be used in fiberboards. Aspen can also be pulped by the soda, cold soda, and kraft processes. The pulps mix well with other pulps for use in fiberboards and cartons. Aspen pulps are most suitable for use in papers requiring softness, bulk, opacity, good formulation, and good printing qualities. They are not well suited for papers requiring toughness, strength, high density, and hard surface characteristics.

The use of aspen for the production of pulp is said to be decreasing. It may be replaced generally by the denser hardwoods, apparently because they yield more fiber per cord. To reverse this trend, information is needed on the pulping characteristics of various mixtures of species in which aspen is used in varying amounts, and on the suitability of the pulp for various end products.

The increasing acceptance of particle board may result in an expanded use of aspen. The species possesses many properties suitable for this product (Hitchcock's Woodworking Digest 1965): (1) light color, (2) ready defiberization, which permits greater flexibility in formulation of mix and in pressing to various densities, (3) low bulk density that permits greater control over mat formulation, and (4) almost neutral pH of 6.5, which permits easier control of adhesive formulation. Machining tests on homogeneous-type aspen flakeboard having a density of 44 pounds per cubic foot showed the following results (Greene 1960):

Planing — good; only slight tear-out and fuzz
Routing — fair; moderate tear-out and fuzz
Shaping — excellent; clean, almost no defects
Sanding — good
Edge drilling — fair

A satisfactory fire retardant particle board can be made from aspen flakes treated with D:P (dicyanidiamide and orthophosphoric acid). Minalith and Pyresote, two other commonly used fire retardants, produced a poor glue bond with urea or phenolic resins. Spray-on zinc borate produced negligible fire retardance (Arsenault 1964).

Aspen should be investigated for its possible application in the field of wood-plastic combinations (WPC). Many of the properties of aspen may be improved by this treatment. However, any commercial use of aspen in this manner will depend on the advantages of WPC over natural wood and on the marketability of WPC products.

Summary of Recommendations for Possible Research

To achieve more complete utilization of aspen, additional information is needed on its properties and suitability for various end products. This section summarizes the problem areas in which more research is needed.

Species-Site Relations

1. Review the data on volume yields from the various site qualities to determine if they are still valid under present stand conditions.
2. Develop a guide to aspen growth and stand longevity which considers the species' rapid growth, rapid deterioration, and high susceptibility to decay.
3. Determine if aspen's susceptibility to decay is related to site quality. We know that aspen deteriorates more rapidly on the poorer sites but the factors that cause this are unknown.

Wood Quality

4. Determine the grade-yield of aspen lumber from saw logs of various diameter classes. The factors of stem form and defect type that affect grade yield need to be defined and investigated.

5. Determine if a relationship exists between specific gravity of aspen wood and the site on which the tree grew. Present information is inconsistent on this point.

6. Investigate the relationship between rate of growth and the various physical properties of aspen wood.

7. Study the formation, behavior, and possible methods of preventing wetwood in aspen.

Physical and Mechanical Properties

8. Refine the present data and develop new information on the strength and related properties of aspen by more intensive and extensive sampling.

9. Investigate whether a geographical difference occurs in the strength and related properties of aspen wood.

10. Define and investigate the factors which affect the various mechanical properties of aspen wood.

Machining Properties

11. Refine present data and develop new information on the machining properties of aspen to determine how well the species performs in relation to the various pieces of equipment.

12. Establish the recommended machine settings, feed rates, and depth of cut that would produce the best surface for each operation.

13. Define the properties of aspen wood that limit the quality of the machined surface and determine methods of overcoming these limitations.

Seasoning

14. Investigate the seasoning of aspen in relation to wetwood and determine methods of preventing its degrading effect.

Utilization

15. Determine the yield of clear cuttings (according to several cutting bills) from the various grades of aspen lumber and from aspen logs on a mill-run basis.

16. Obtain information on the pulping characteristics of various mixtures of species in which aspen is used in varying amounts and the suitability of the resulting pulps for various fiber products. Similarly, the characteristics of particle boards made from aspen in combination with the denser hardwoods should be investigated.

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