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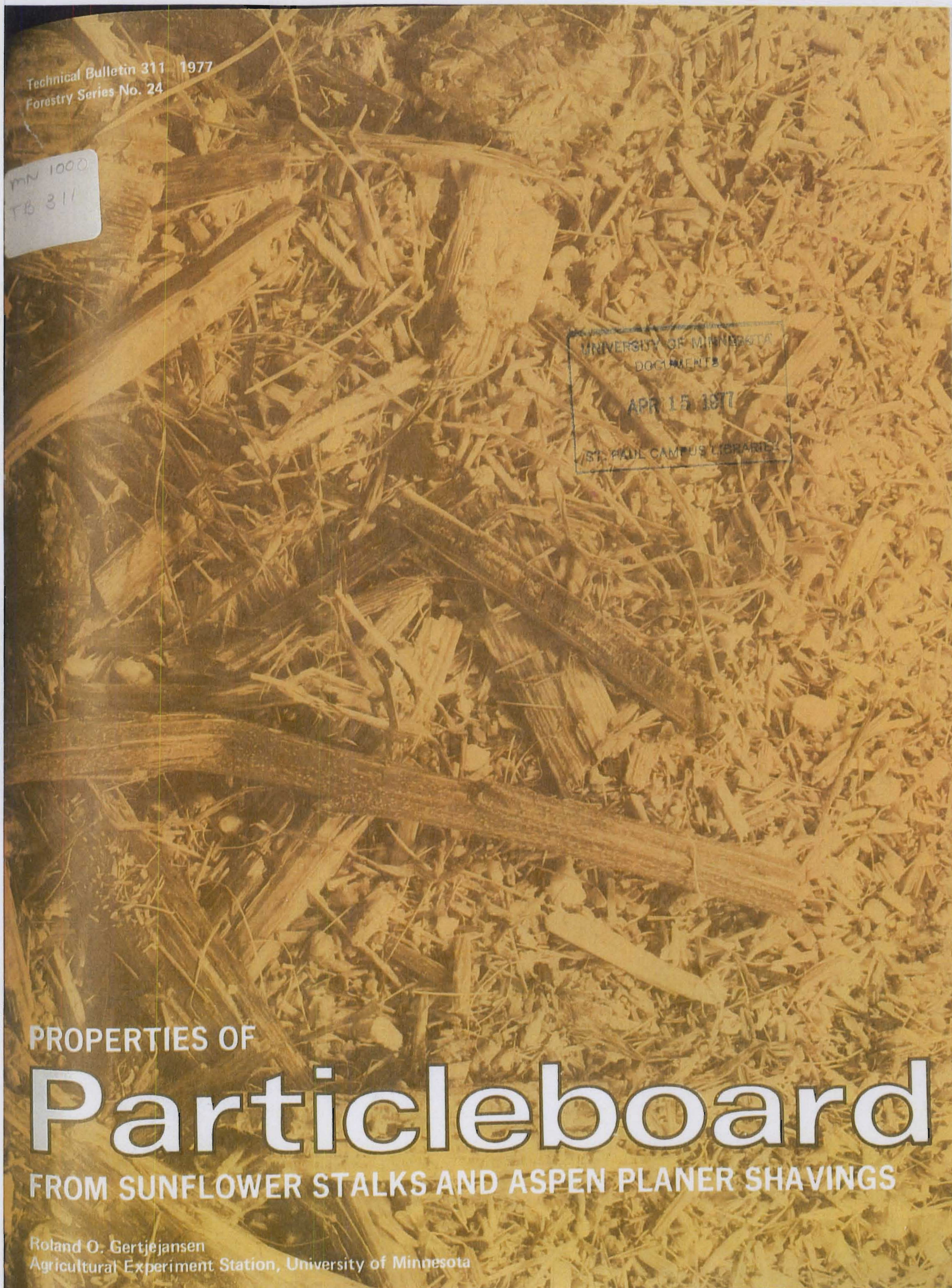

PROPERTIES OF Particleboard FROM SUNFLOWER STALKS AND ASPEN PLANER SHAVINGS

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Abstract

This study dealt primarily with the feasibility of using sunflower stalks as a raw material for particleboard. Three methods of breaking down sunflower stalks into particleboard furnishes were evaluated: hammermilling, disk refining, and ring flaking. Ring flaking was unsatisfactory because of an excessive loss of material as fines. Satisfactory furnishes could be produced by the other two methods, depending on the refiner plate design and plate clearance, size of the hammermill screen, and the moisture content of the stalks.

Laboratory particleboards 18 inches by 18 inches by ½ inch thick were manufactured from four different furnishes: 100 percent sunflower stalks, 50 percent sunflower stalks-50 percent aspen (wood) planer shavings, 100 percent aspen planer shavings, and 100 percent sunflower stalks with the pith removed. Boards were produced at two density levels (42 and 48 pounds per cubic foot) and two phenol formaldehyde resin content levels (5 percent and 10 percent solids based on the oven dry weight of furnish). There were two replications for a total of 32 boards.

The test results showed that modulus of rupture (strength in bending), internal bond strength, thickness dimensional stability, and durability (resistance to exterior exposure) decreased with an increase in sunflower stalk content; while, modulus of elasticity (resistance to deflection in bending) and linear dimensional stability increased with an increase in stalk content. Removing pith from the sunflower stalk furnishes significantly improved modulus of rupture and internal bond strength. Internal bond strength was greatly reduced by the addition of sunflower stalks and greatly improved by the removal of pith. All strength properties increased with an increase in density and resin content. When all properties were considered, it was concluded that sunflower stalks made an acceptable particleboard for interior applications. The low internal bond strength, the most serious deficiency of stalks, was upgraded sufficiently by increasing resin content or density, removing pith, or by adding planer shavings.

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PROPERTIES OF

Particleboard

FROM SUNFLOWER STALKS AND ASPEN PLANER SHAVINGS

Roland O. Gertjejansen*

Introduction

The particleboard industry in the United States relies almost entirely on wood residues (planer shavings, sawdust, plywood trim, etc.) as the raw material for particleboard. Because these residues are relatively inexpensive, the cost of the raw material for board manufacture currently averages only 20 percent of the total manufacturing cost. This has given particleboard a competitive edge in the panel product market. However, the cost of these residues is expected to increase dramatically because of an increased demand by the pulp and paper industry, an increase in use as a fuel, and a decrease in availability because of new sawmill technology (6). The particleboard industry must look for alternative raw material sources and those that appear most promising are bark, logging residues, and certain agricultural wastes.

This study evaluated one agricultural residue—sunflower stalks—as a raw material for particleboard. Possible incentives for removing stalks from sunflower fields include the following: a reduction in rotation time if stalks are removed because certain sunflower diseases are carried over in the stalks; a reduction in soil nitrogen requirements if stalks do not decay in the soil; and last but not least, stalks for particleboard could be a saleable commodity and result in healthy profits for the grower. The average stalk yield per acre is approximately one short ton (2.7 metric tons per hectare).

This study compared the strength, dimensional stability, and durability of laboratory particleboards from 100 percent sunflower stalks (*Helianthus annus L.*) with those from 100 percent aspen (*Populus tremuloides Michx.*) planer shavings. In addition, the effects on board properties of removing pith from the sunflower stalk particles and of mixing stalks 1 to 1 with planer shavings also were evaluated. All boards were bonded with phenol formaldehyde adhesive.

Raw Material.

The stalk particle furnishes were produced from baled stalks of an oil bearing sunflower variety provided by the National Sunflower Growers Association. Tables 1 and 2 and figure 1 show the physical properties and composition of the bales. Three laboratory methods of stalk breakdown were evaluated: hammermilling, disk refining, and ring flaking. Ring flaking was unsatisfactory because of an excessive loss of material as fines[1] even at relatively high stalk moisture contents[2]. Satisfactory furnishes could be produced by the other two methods when a proper combination of operating variables was employed. These variables were refiner plate design and plate clearance, the size of the hammermill screen, and stalk moisture content. Hammermilling resulted in a somewhat lower percentage of fines, but slightly longer particles were obtained with the disk refiner. Hammermilling was chosen as the method of stalk breakdown for this study primarily because it resulted in less fines, but also because of faster processing of material compared with the 12 inch disk refiner and ring flaker.

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1 Fines are defined as all material passing a screen with 1/32 inch diameter circular holes.

Table 1. Percentage composition of sunflower stalk bales

Components of sunflower stalk bales	Percent of total bale weight
Stalk pieces[1]	71.3
Stalk fragments[1]	9.2
Heads	13.2
Straw and weeds	1.0
Dirt and fines	5.3
Total	100

[1]Stalks averaged 15 percent pith by weight. Therefore pith comprised approximately 12 percent of the total bale weight.

Table 2. Average properties of sunflower stalk bales

Property of sunflower stalk bales	Value
Weight (lbs)	47 7
Volume (ft^3)	6.9
Bulk density (lb/ft^3)	6.9
Weight (kg)	21.7
Volume (m^3)	0.19
Bulk density (kg/m^3)	114

Figure 1. Composition of sunflower stalk bales used in this study

2 The percentage of fines produced by either hammermilling of disk refining was reduced approximately 50 percent by increasing stalk moisture content from 12 percent (equilibrium at 50 percent RH) to 29 percent (equilibrium at 90 percent RH). Moisture content is calculated as a percent of the oven dry weight.

Figure 2 shows an overall diagram of materials preparation and manufacture of laboratory particleboard. Baled sunflower stalks including heads, weeds, etc., at approximately 10 percent moisture content were reduced to particles using a 10-inch hammermill fitted with a ¾-inch screen. The particle furnish was screened and all material retained on a ½-inch screen (approximately 10 percent) was rehammermilled and mixed back into the furnish. Fines accounted for 12 percent of the total and were rejected.

Pith was removed from a portion of the hammermilled stalk furnish to determine the effect of its removal on board properties. The pith was separated out quite easily with an air stream because of its lower density compared with other stalk parts. Less than 10 percent of the pith remained using this technique.

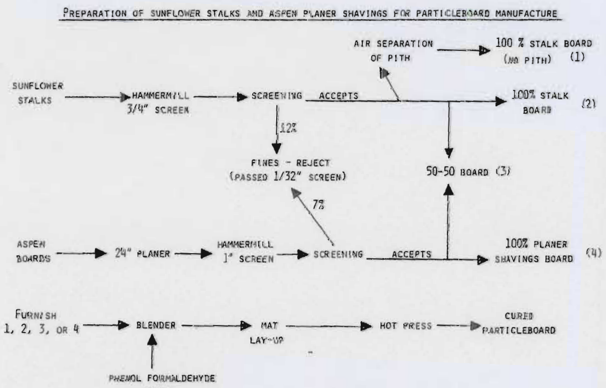

Figure 2. Flow diagram of the manufacture of sunflower stalk and aspen planer shaving particleboards

Aspen planer shavings were produced from dry aspen boards with a 24-inch planer. The shavings were hammermilled (1-inch screen) to break up the large and curled shavings, and the furnish was then screened to remove fines, which accounted for 7 percent of the total weight.

Figure 3 is a sieve analysis of the particle furnishes, and figures 4 and 5 show the appearance of furnishes on a 1-inch (2.54 cm) grid. All three were very similar in size distributions, which indicated that the size distribution of the pith particles of sunflower stalks was similar to that of the other components of the furnish. The stalks had a greater average thickness and a wider range than the shavings. The average thickness of the shavings was 0.027 inch and ranged from 0.009-0.057 inch while the stalks averaged 0.036 inch and ranged from 0.007-0.097 inch.

Experimental Design and Procedure

The following experimental design and manufacturing conditions were employed.

Four board types (raw material compositions):

1. 100 percent sunflower stalks
2. 100 percent sunflower stalks with pith removed
3. 100 percent aspen planer shavings
4. 50 percent stalks, 50 percent planer shavings (1 + 3)

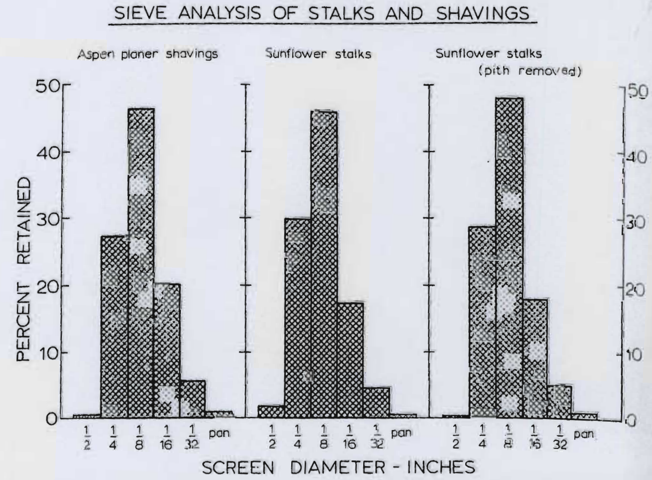

Figure 3. Sieve analysis of sunflower stalk and aspen planer shavings particleboard furnishes

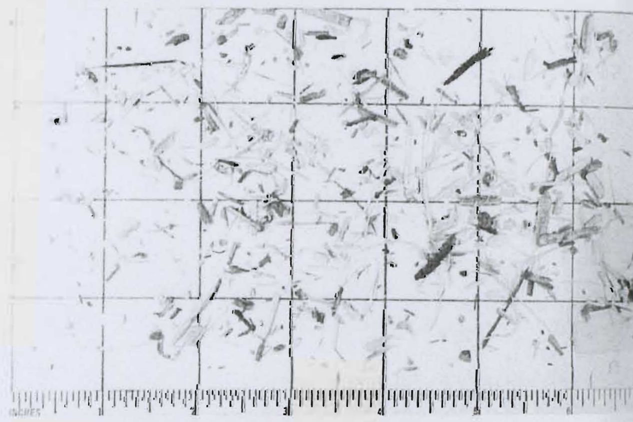

Figure 4. Sunflower stalk particles on a one-inch grid

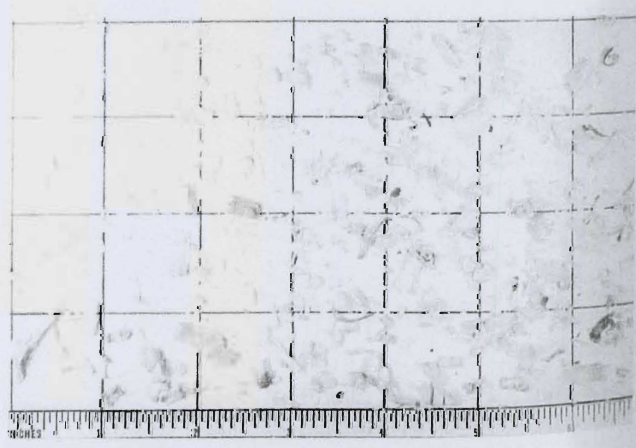

Figure 5. Aspen planer shavings on a one-inch grid

Two board densities (nominal): 42 and 48 pounds per cubic foot (pcf) (670 and 770 kg/m³)

Two phenol formaldehyde resin contents: 5 percent and 10 percent solids (oven dry basis)

Replications: 2 (32 boards manufactured)

Board construction: homogeneous

Board size: 18 inches by 18 inches by ½ inch thick

Resin type: Borden Chemical's PB 65 liquid phenol formaldehyde, 45 percent solids

Press temperature: 375°F (190°C)

Closing pressure: 550 psi (3.8 x 10^6 N/m^2)

Time to ½ inch stops: 30-60 seconds depending on board density and composition

Press time: 8 minutes

Liquid resin at 45 percent solids was applied to the particles by spraying into a rotating drum-type laboratory blender containing the particle furnish. After blending, the particles were hand felted into 18 by 18 inch mats; the mats were prepressed and then hot pressed according to the described conditions. After pressing, the boards were hot stacked overnight to insure complete resin cure and after cooling were edge trimmed to 14 inches by 14 inches. Three 2¾ inch by 14 inch static bending test specimens and three 1¾ inch by 14 inch-linear swelling test specimens were cut from each board. All test specimens were equilibrated at 50 percent relative humidity (RH) and 72°F prior to testing. Board densities (oven dry wt/vol @ 50 percent RH) were determined by oven drying the six test specimens from each board after testing.

Modulus of elasticity (MOE) and modulus of rupture (MOR) were calculated from the static bending tests. The percent linear and thickness swellings in going from equilibrium at 50 percent RH to equilibrium at 90 percent RH and back to equilibrium at 50 percent RH were obtained from linear swell samples. Internal bond strengths (IB) were determined from torsional shear specimens[3] cut from one half of each static bending sample after testing. The remaining halves of the static bending samples were used for a two-cycle vacuum-pressure-soak (VPS) test to determine relative durabilities[4] (resistance to exterior exposure) and thickness swelling.

Regression lines of board properties as a function of density and the standard errors of estimate of the lines were calculated for each resin level and raw material type. Comparisons for significant differences among board types at the 95 percent confidence level were made at 45 pcf (721 kg/m^3) density. Both board density and the property measured were considered to be normally distributed variables; therefore, board types had to differ by plus or minus two standard errors of estimate to be statistically different at the 95 percent confidence level.

Results

Table 3 and figures 6-12 show the experimental results. There were no serious manufacturing difficulties using sunflower stalks although it was found that the higher equilibrium moisture content of the stalks, compared with wood, must be considered or it could result in pressing problems. The stalk boards were similar in appearance to typical wood based particleboards (figure 14), and no obvious differences in sawing or surface sanding were noted.

Figure 6 shows the static bending properties of the four board types at 5 percent and 10 percent resin contents. When compared with the 100 percent planer shavings board (0 percent stalks), sunflower stalk boards had a lower MOR but higher MOE, and, as expected, the 50 percent stalk boards exhibited properties intermediate to the 100 percent stalk and 100 percent planer shavings boards. Removal of pith resulted in a statistically significant increase in MOR at the 10 percent resin level, but had no effect on MOE. The greater stiffness of the stalk particles compared with planer shavings undoubtedly accounted for the higher MOE of the stalk boards. For all board types, both MOR and MOE increased with increased board density.

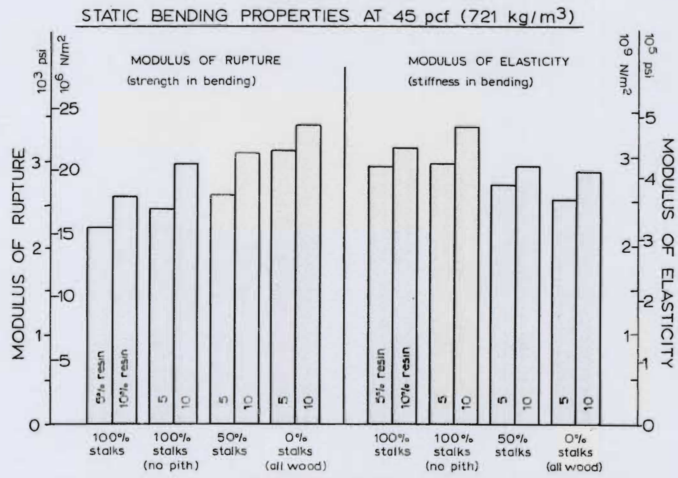

Figure 6. Static bending properties of particleboards from sunflower stalks and aspen planer shavings

Figure 7 shows internal bond strengths (IB) both before and after the 2-cycle VPS durability test. It is evident that sunflower stalks greatly reduced initial IB and caused an excessive loss of IB by the durability test, and these probably are the most serious drawbacks to using sunflower stalks as a particleboard raw material. Removal of pith greatly improved initial IB but reduced the loss of IB only at the 10 percent resin level. Adding planer shavings (the 50 percent boards) was not as effective in improving initial IB as was pith removal, but it resulted in less IB loss from the VPS test. This indicates that the pith was a primary cause of low initial IB, but that the excessive swelling of the stalk particles themselves (figures 8 and 9)[5] probably accounted for the loss of IB by the durability test. The greater the swelling, the greater the degree of bond breakage, and the lower the resulting IB.

Figures 7 and 10 illustrate the importance of resin content in preserving the IB of all four board types due primarily to the reduction in thickness swelling by the additional resin

[3] Internal bond strengths throughout this report are correlated values obtained from the torsional centerline shear strengths of six 1 inch by 1 inch torsion specimens (2).

[4] Two cycle VPS durability test:

1. Test specimens equilibrated at 50 percent RH and 72°F
2. Vacuum of 25 inches Hg applied for 30 minutes
3. Specimens flooded with water under vacuum and then 50 psi pressure applied for 22 hours
4. Specimens oven dried at 105°C for 22 hours
5. Repeat steps 2, 3, and 4
6. Specimens equilibrated at 50 percent RH, 72°F and IB strengths determined.

[5] Figure 8 shows the total and irreversible swellings resulting from two VPS cycles. The total swelling is that percent thickness increase from the original thickness at 50 percent RH to the wet thickness after the second VPS cycles. The irreversible swelling is that percent thickness increase from the original thickness at 50 percent RH after the samples had dried down and equilibrated back to 50 percent RH after the second VPS cycle. No consistent relationship existed between VPS thickness swelling and initial board density.

Table 3. Properties of particleboards manufactured from sunflower stalks and aspen planer shavings. Values not in parentheses are predicted mean values at 45 pcf (721 kg/m³) density. Values in parentheses are plus and minus two standard errors of estimate at 45 pcf.[1]

		Strength properties			After 2-cycle VPS durability test			From equil. @50% RH to equil. @90% RH	
Board type	% resin content	MOR (psi)	MOE (1000 psi)	IB (psi)	IB (psi)	Total thickness swelling (%)	Irrev. thickness swelling (%)	Linear swelling (%)	Thickness swelling (%)
100% stalks	5	2280 (2390-2170)	418 (452-384)	59 (65-53)	15 (20-11)	73.3 (83.8-62.8)	54.4 (65.0-43.8)	0.377 (.433-.321)	16.5 (18.9-14.1)
100% stalks	10	2600 (2760-2440)	451 (479-423)	70 (75-65)	38 (43-33)	44.8 (51.3-38.2)	27.6 (32.8-22.5)	0.316 (.348-.284)	12.9 (14.2-11.6)
100% stalks (no pith)	5	2460 (2700-2220)	426 (452-400)	96 (103-88)	19 (23-16)	73.3 (82.0-64.6)	53.9 (63.2-44.7)	0.309 (.365-.253)	15.0 (16.8-13.2)
100% stalks (no pith)	10	2980 (3120-2850)	485 (515-455)	118 (126-109)	56 (66-46)	41.7 (50.3-33.1)	25.0 (34.0-16.0)	0.268 (.302-.234)	11.6 (13.6-9.7)
50% stalks	5	2610 (2830-2390)	392 (414-370)	81 (90-72)	38 (43-33)	43.2 (48.8-37.6)	29.5 (34.7-24.3)	0.429 (.451-.407)	11.4 (12.4-10.4)
50% stalks	10	3080 (3290-2870)	419 (453-385)	100 (108-92)	67 (78-56)	27.2 (32.2-22.1)	14.5 (19.2-9.9)	0.419 (.453-.385)	11.0 (12.6-9.3)
0% stalks (all wood)	5	3100 (3350-2860)	367 (397-337)	137 (144-130)	103 (110-96)	21.6 (23.6-19.6)	11.4 (13.1-9.6)	0.654 (.668-.640)	8.9 (9.7-8.0)
0% stalks (all wood)	10	3410 (3600-3230)	412 (448-376)	160 (174-146)	147 (172-123)	14.5 (17.6-11.4)	4.8 (7.5-2.1)	0.627 (.683-.571)	7.8 (9.0-6.5)

[1]Board types must differ by plus or minus two standard errors of estimate to be statistically different at the 95 percent confidence level. Differences between the absolute values of plus two and minus two standard errors of estimate are due to rounding.

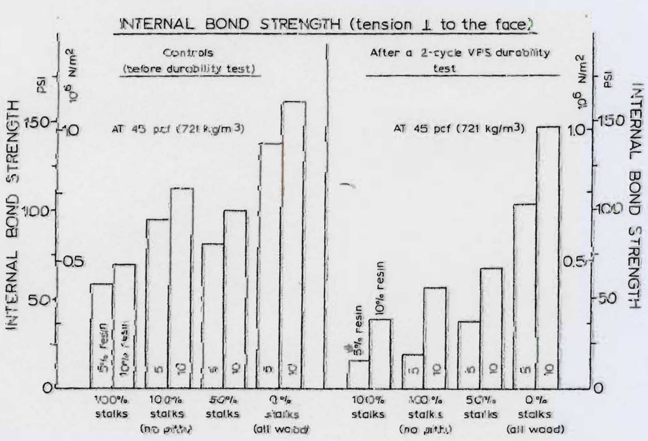

Figure 7. Internal bond strengths both before and after a VPS durability test

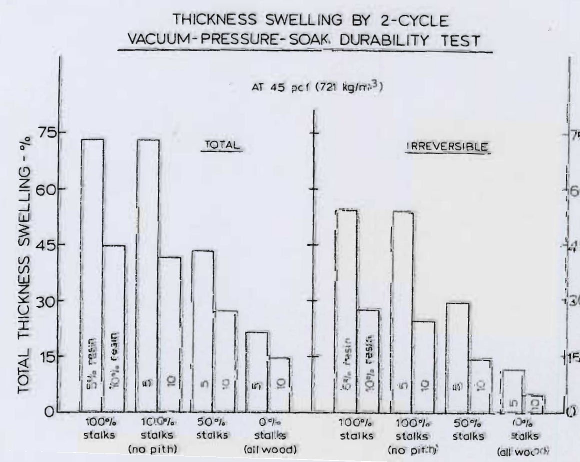

Figure 8. Total and irreversible thickness swelling by a VPS durability test

(figure 8). As with MOR and MOE, initial IB increased with an increase in board density. No consistent relationship existed between initial board density and IB after the VPS test which also was the case for a recent study evaluating logging slash as a raw material for particleboard (1). Because of the excessive loss of IB by the durability test, it appears that particleboards from sunflower should be restricted to interior use only.

Figure 11 shows two other important properties of particleboards: linear and thickness swellings induced by an increase in moisture content from a specified increase in relative humidity. The better linear stability of the stalk boards is evident. Pith removal resulted in an average lower but not statistically significant lower linear swelling. Resin content and board density had little or no effect, which is commonly the case for this range of densities and resin contents (1, 3). The better linear stability of the sunflower stalk boards can be wholly or partly attributed to greater thickness swelling during the corresponding moisture content increase. The linear swelling of the planer shavings boards in this study was greater than normally expected with similar boards. This probably occurred because the planer shavings were manufactured from predominantly flat sawn boards, and this resulted in the shavings having a percent linear cross grain swelling that was greater than the the percent thickness swelling.

Figure 9. Dry thicknesses of the four board types after the VPS durability test. Three samples are shown for each board type to accentuate the differences in irreversible swelling among board types

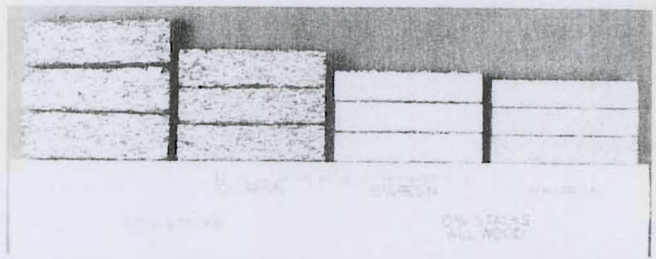

Figure 10. Influence of resin content on irreversible thickness swelling after the VPS durability test

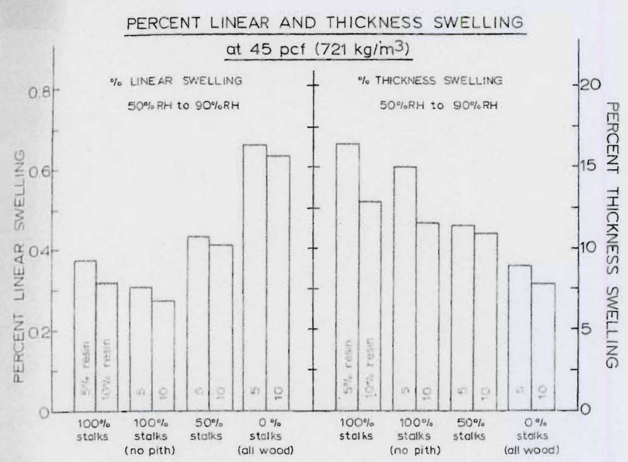

Figure 11. Linear and thickness swelling from equilibrium at 50 percent RH to equilibrium at 90 percent RH

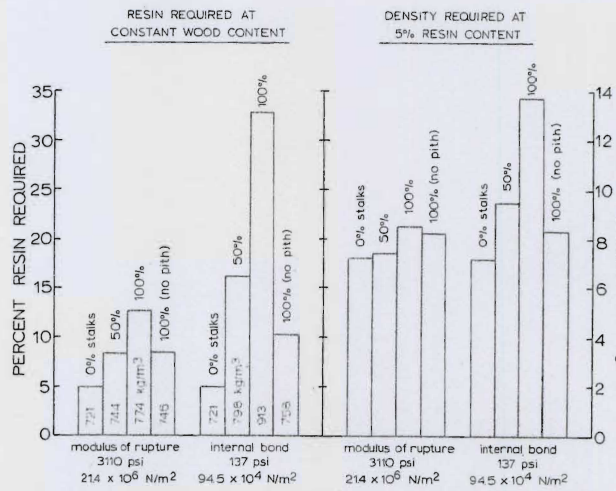

Figure 12. Resin or density increases necessary for particleboards containing sunflower stalks to have the same MOR and IB of 100 percent aspen planer shavings particleboard at 5 percent resin content and 45 pcf (721 kg/m^3) density

Figure 12 shows the resin or density increases that would be necessary for the two 100 percent stalk boards and one 50 percent stalk board to have the same MOR and IB as those of the 100 percent planer shavings boards at 5 percent resin content and 721 kg/m^3 (45 pcf) density. The left half of the figure shows the resin that would have to be added at constant wood weight per unit volume of board to match the properties of the 100 percent shavings boards. The numbers on each bar are the new board densities resulting from the additional resin. Usually a resin content greater than 8-10 percent or a density greater than 800 kg/m^3 (50 pcf) would not be practical. Using these values as a point of reference, a study of figure 11 indicates that the pith probably would have to be removed if a 100 percent stalk board of reasonable density and resin content were to have properties equal to 100 percent planer shavings boards. It is obvious that IB is more limiting than MOR so that if IB could be improved, both density and resin content probably could be reduced. It would seem that the best way to accomplish this would be adding planer shavings to stalk particles containing no pith since the IB of the 50 percent boards (50 percent stalks with pith) was considerably better than that of the 100 percent stalk boards containing pith.

A serious drawback in making comparisons is that the IBs of homogeneous type laboratory particleboards from planer shavings typically are quite high and unrealistic in terms of the IBs of commercial 3 layer or graded density particleboards. For example, the minimum property requirements, particularly IB, specified for 1B1 and 1B2 interior type particleboards[6] are considerably less than the properties of the 100 percent planer shavings boards manufactured in this study. The minimum property requirements for 1B1 and 1B2 boards follow:

	MOR (psi)	MOE (1000 psi)	IB (psi)
1B1	1600	250	70
1B2	2400	400	60

A better comparison appears in figure 13 where the properties of 45 pcf (721 kg/m^3) particleboards from 100 percent stalks, 100 percent stalks with pith removed, and 50 percent stalks + 50 percent planer shavings are compared with the minimum property requirements of 1B1 and 1B2 boards. All three boards compare very favorably with the 1B1 and 1B2 boards and usually exceed the minimum requirements even at 5 percent resin content.

As a supplementary investigation, the holocellulose (total carbohydrate) content of unextracted sunflower stalks was determined (4). The stalks averaged approximately 70 percent holocellulose (dry basis) which compared favorably with typical values for coniferous wood species but 5-10 percent less than that for deciduous species. There appeared to be a relatively large amount of extractives in the stalks so that on an extractive free-basis, the percent holocellulose would be somewhat greater.

6 U.S. Department of Commerce, Commercial Standard CS236-66, Mat Formed Wood Particleboard.

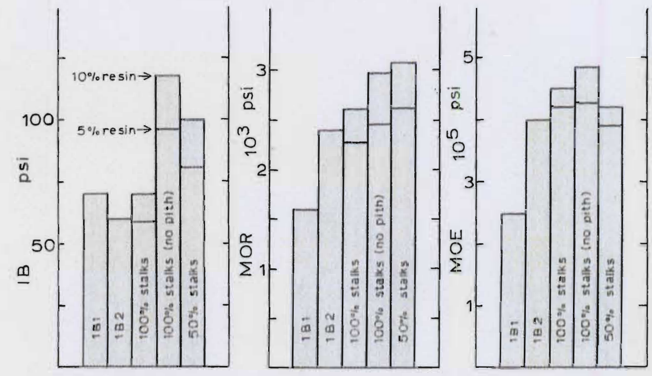

Figure 13. Comparison of Commercial Standard 1B1 and 1B2 particleboard to three sunflower stalk particleboards at 45 pcf and 5 percent and 10 percent resin contents.

Figure 14. Particleboards from sunflower stalks and aspen planer shavings.

Current prices for wood residues (sawdust, planer shavings, and plywood trim) typically used for particleboard manufacture in the United States range from $12-$22 per dry short ton ($13-$24 per dry metric ton). Pulp chips which can be flaked and used for particleboard range from $30-$50 per dry short ton ($33-$55 per dry metric ton). However for reasons stated earlier, these prices are expected to rise dramatically and alternative raw materials will become more attractive to the particleboard manufacturer. According to Vajda (5), the wood cost for a typical particleboard plant in 1975 was approximately 21 percent of the total production costs, but this percentage should rise as wood costs do.

A typical modern particleboard plant requires approximately 120,000 dry metric tons of wood residues per year to sustain its operation. The area of sunflower cropland that would be required to sustain an operation of this size can be approximated if the following are known: the average rotation time for the sunflower crop, the average yield of dry stalks per unit area of cropland, the loss of stalks during processing in the plant, and the percentage of the particleboard furnish that is comprised of stalks.

Summary and Conclusions

General conclusions of the study follow:

1) Sunflower stalks make acceptable particleboards if the pith is removed and/or wood planer shavings are added to the stalks.
2) Because of the excessive swelling of the stalk particles during a durability test, stalk boards appear to be suitable for interior applications only.

Specific conclusions follow:

1) Sunflower stalks increased MOE (stiffness in bending) and linear dimensional stability, but decreased MOR (bending strength), IB (internal bond strength), thickness dimensional stability, and durability (resistance to exterior exposure).
2) Removal of pith increased MOR and IB.
3) Adding planer shavings to stalks increased MOR, IB, thickness dimensional stability, and durability.
4) An increase in resin content generally improved all board properties.
5) An increase in board density increased all strength properties.

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