Screw-holding, internal bond, and related properties of composite board products for furniture and cabinet manufacture: a survey of the literature

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Abstract
This paper discusses selected properties of particleboard, hardboard, medium-density fiberboard (MDF), and plywood related to their use in furniture and cabinet manufacture. Properties covered are screw-holding, internal bond, density profile, and edge appearance. Studies of direct screw withdrawal of panel products indicate that resistance to withdrawal from the edge is 75 to 80 percent of resistance to withdrawal from the face. In all cases, screw-holding powers of these products are considerably less than that of solid wood of the same density. Internal bond strength, density profile, and edge appearance are all related to each other to some degree and are largely governed by press conditions, particle or fiber characteristics, and adhesive content.

A particular panel product can be accepted or rejected for use in furniture and cabinet manufacture for a variety of reasons. In 1968, Suchsland (36) published the results of a survey on the use of panel materials by furniture and cabinet manufacturers. Most frequently mentioned reasons for using particleboard, for example, were: economics, dimensional stability, no telegraphing, no warping, sizes available, and uniform thickness. Reasons given for not using particleboard were: difficult edge treatment, fastening problems, customer objection, and low strength/high weight. Concerning customer objection, one manufacturer commented, "We are using particleboard wherever it is superior to any other material, but we would not like our customers to know about it." It is no surprise then that particleboard used in furniture is disguised.

To a great extent, the results of this survey are still valid. Component joints (especially where screws are used) and treatment of panel edges are still major concerns of furniture and cabinet manufacturers.

This paper discusses screw-holding, internal bond (IB), density profile, and edge appearance of particleboard, hardboard, MDF, and plywood as they relate to performance of these products in furniture and cabinets. Additional important properties are covered in other papers in this proceedings.

Screw-holding: resistance to direct withdrawal
The resistance of particleboard and MDF to direct screw withdrawal is considerably lower than solid wood of the same density (14, 15, 43, 44). This is usually attributed to the reconstituted nature of the products. A limited amount of data available indicates that withdrawal resistance of plywood is also somewhat lower than that of solid wood of the same species.

The standard ASTM method for determining the screw withdrawal resistance of wood-based panels (6) specifies a 1-inch-long, No. 10 wood screw inserted into a 7/64-inch-diameter lead hole to a depth of 2/3 inch. Lead hole diameter is about 90 percent of the screw root diameter. The ANSI standards for particleboard (1) and MDF (2) call for a Type A or AB self-tapping screw instead of a wood screw. Whittington and Walters (43) and Johnson (18) indicate that there is little difference between the withdrawal resistance of self-tapping and wood screws in particleboard and plywood for the same depth of thread penetration.
A comparable expression for MDF face withdrawal is:

$$ F = 3700D^{0.2}(L-D/3)^{0.8}G^3 $$

[3]

A comparable expression for MDF edge withdrawal is:

$$ F = 2860D^{0.2}(L-D/3)^{0.8}G^2 $$

[4]

where:

- $F$ = ultimate withdrawal resistance (lb., at 65% RH)
- $D$ = shank diameter of the screw (in.) ($D$ = 0.06 + 0.013N where N is the screw gauge or number)
- $L$ = depth of embedment of the threaded portion of the screw
- $G$ = specific gravity of the material based on oven dry weight and volume at test

These equations yield an edge withdrawal resistance that is 77 percent of the face withdrawal resistance for both particleboard and MDF. Also for both edge and face withdrawal, predicted resistance values for MDF are 39 percent greater than those for particleboard.

Plywood standards do not include screw-holding requirements. However, the American Plywood Association (APA) has published average ultimate withdrawal loads (5). Comparison of these APA values and those reported by Johnson (18) and Carroll (11) indicates that face withdrawal resistance of Douglas-fir plywood is about 85 percent of the value for side grain Douglas-fir solid wood. Wilkinson and Laatsch (44) reported a withdrawal resistance of 420 pounds for a No. 10, Type A self-tapping screw inserted 3/4 inch into Douglas-fir side grain. Withdrawal resistance perpendicular to the face of Douglas-fir plywood, adjusted for the same depth of penetration, averaged about 385 pounds. In a National Particleboard Association (NPA) study (27), the face withdrawal resistance of A-D plywood was essentially the same as that of core stock particleboards (about 45 pcf, average).

Average ultimate withdrawal resistance from the face of particleboards is predicted by:

$$ F = 2655D^{0.2}(L-D/3)^{0.8}G^2 $$

[1]

and from the edge of a panel by:

$$ F = 2055D^{0.2}(L-D/3)^{0.8}G^2 $$

[2]

A comparable expression for MDF face withdrawal is:

$$ F = 2200D^{0.2}(L-D/3)^{0.8}G^2 $$

[3]

To evaluate edge splitting tendency of fiberboard (hardboard and MDF), particleboard, and spruce plywood (Fig. 1). They found that the edge-splitting tendency decreased as the lead hole diameter increased from 60 to 85 percent of the outer diameter of the screw threads. However, the edge withdrawal resistance decreased. The edge splitting tendency of fiberboard was considerably greater than that of particleboard or plywood.
Increasing resin content has been shown to increase screw withdrawal resistance of MDF and particleboard. Markstrom et al. (23) reported an average increase of about 50 percent for MDF and 25 percent for particleboard when the resin content was increased from 6 to 10 percent. Putting glue in the lead hole before inserting the screw reinforces wood fibers and increases withdrawal resistance. Kelly and Pearson (21) reported a 5 to 10 percent increase in face withdrawal resistance and 35 to 70 percent increase in edge withdrawal resistance for MDF when polyvinyl acetate was put in the lead hole.

All the screw withdrawal resistance data given above are maximum values from short-term tests used for comparisons between materials. They are not meant to be used in design for long-term loading. Design values for particleboard and MDF have not been published. Design values for solid wood (26, 42) are based on wood specific gravity and amount to about 18 percent of average ultimate withdrawal resistance. The same percent has traditionally been used for plywood for normal load duration (5).

**Internal bond strength**

Tensile strength perpendicular to surface (IB) is an important indicator for quality control in wood-based panel manufacture. Internal bond is quite sensitive to a number of raw material and processing variables: particle or fiber characteristics, resin content, panel density, etc. If IB changes very much, something has happened in the manufacturing operation. Although IB is generally not considered to be directly related to performance, insufficient bonding between fibers or particles will quite often show up later as poor performance of the panel in use. For example, low IBs with failures occurring at or near the panel surface indicates resin preure. If not corrected, it can result in delamination if a high pressure plastic laminate is bonded to the core panel with water-based adhesives.

IB requirements in the ANSI particleboard standard (1) vary from a low of 20 psi for a low-density door core grade (1-L-1) to 300 psi for a high-density phenolic-bonded grade (2-H-1). IB requirements for furniture-grade particleboards, 1-M-2 and 1-M-3, are 60 psi and 80 psi, respectively. The ANSI MDF standard (2) requires 90 psi for thinner panels (13/16-in. and below) and 80 psi for thicker panels. The ANSI hardboard standard (3) requires range from 25 psi for industrialite (Class 5) to 130 psi for tempered (Class 1). There are no equivalent strength requirements for plywood. However, River et al. (31) reported an average value of 127 psi in IB tests for samples of 112-inch-thick Douglas-fir plywood. Some unpublished data indicate that plywood IB strength increases with the number of plies for a given panel thickness.

Reported IB values for commercial particleboards range from 45 psi to 450 psi for a specific gravity range of 0.62 to 0.92 (13, 24). In his review of relationships between particleboard processing variables and properties, Kelly (19) noted that most researchers have found higher IB with increasing resin content and increasing press time and temperature. IB also increases as the core particle configuration changes from long, wide flakes (wafers) to planer shavings or slivers (8, 16, 22, 23, 33). Shuler and Kelly (33) and Brumbaugh (8) found that increasing flake thickness increased IB. One explanation for this is that for a given resin content, thicker flakes result in a lower total surface area per panel, and thus more resin
Markstrom et al. (23) and Burrows (9) have shown that increasing the resin content of panels made from wafers from 2 or 3 percent to 5 or percent (increasing resin per unit surface area) will nearly double the IB.

Superfesky and Lewis (41) reported I strengths of 133, 140, and 186 psi for three commercial MDF products with densities of 0.66, 0.68, and 0.78 g/cm³, respectively. Suchsland et al. (37) reported a range of 10 to 282 psi for eight commercial MDF products. IB strength values and failure plan location can be significantly affected by overall board density and differences in density between panel face and core. IB coefficients of variation ranged from 10 to 2 percent for both particleboard and MDF. No published IB values were found for commercial hardboards.

Unlike particleboard, IB of the commercial MDF did not correlate with overall panel density or even core density. The tendency for linear expansion to increase, an thickness swelling to decrease as IB increased suggested a possible vertical component of fiber orientation. Work by Myers (25) indicated that vertical orientation is more likely with shorter fibers.

**Edge appearance and density profile**

Because of the nature of mat-formed particleboard, finishing the edges is considerably more involved than finishing the faces. Porosity of the edges precludes the conventional procedures used on particleboard flat surfaces. In most applications, exposed edges must be banded with veneer or lumber, V-grooved and folded (Fig. 2), or filled with a paint-type material (28, 29). Edgefilling levels out the voids and provides a smooth, sandable surface which can then be finished. Proper edge finishing is particularly important for kitchen and bathroom cabinet doors in order to meet the ANSI performance requirements (4). The amount of filling needed is dictated by the porosity of the panel edge. This in turn depends on such factors as particle size and geometry, panel density, and density gradient through the thickness. Finer wood elements produce tighter edges and reduce the amount of filling needed. Panels produced from fibers have superior edge quality. This is one reason MDF is readily accepted for furniture and cabinet parts (37).

Density gradient produces a nonuniform edge surface which complicates edge treatment. Suchsland and Woodson (38, 39) found that the face density of commercial MDF was as much as 60 percent greater than core density (Fig. 3). Kelly and Pearson (20) found that density gradient in MDF increased as overall density increased from 25 to 42 pcf, and as panel thickness increased from 318 to 314 inch. The time to reach a core temperature of 225°F can be 8 minutes for 1-1/8-inch-thick MDF as compared to 3 minutes for 1/2-inch-thick MDF (7). Shen and Carroll (32) found that density gradient in commercial particleboards also increased as panel thickness increased. Manipulation of press cycle variables can change or essentially eliminate the gradient (17, 38) (Fig. 3).

Stevens and Woodson (35) reported that for medium- (44 pcf) and low- (38 pcf) density boards, the density gradient of high-frequency-cured boards was less than that of hot-pressed boards. At a higher board density (50 pcf) there was practically no difference in density gradient between the two curing methods. Carll (10) found that lower platen temperature and high frequency heating produced 1-inch-thick particleboards with a more uniform vertical density profile.

While edge finishing of hardboard is usually not a consideration in furniture and cabinet manufacture, differences in density profile can affect IB strength levels and failure location. Spalt (34) discussed the density profile of wet- and dry-process hardboard. Based on differences in pressure cycle and heat and moisture transfer in the mat during pressing, he theorized the following differences in density profiles (Fig. 4): 1. Wet-formed/wet-pressed: High density at the smooth surface, decreasing gradually through the panel to a minimum at the screen surface. 2. Wet-formed/dry pressed: Two dense surfaces with lower core density. 3. Dry-formed/dry pressed: Lower face density.
density and higher core density.

However, Spalt did not report any actual hardboard density gradient measurements. Measurements made at FPL on a few samples of 1/4-inch-thick commercial hardboards do not support the above statements (Fig. 5).

Conclusions

Screw-holding, IB strength, and edge appearance are properties of wood-based panels of considerable importance for their use in furniture and cabinet manufacture. An evaluation of published information on these and related characteristics leads to the following conclusions:

1. The amount of torque used to set screws when joining wood-based panels is more important than screw type. There is little difference between torque required to bring the screw flush with the surface and that required to strip the threads formed in the panel.

2. Because of splitting tendency, inserting screws into the edges of wood-based panels should be avoided whenever possible. Resistance to edge withdrawal averages about 70 to 80 percent of face withdrawal resistance.

3. IB strength of particleboard generally increases as pressing temperature and resin content increase. IB also increases as particle type changes from long, wide flakes to planer shavings or slivers. Presence of short fibers in MDF panels with an increased tendency toward vertical orientation leads to increased IB.

4. Edge appearance is influenced by particle type (flakes, shavings, sawdust, fiber), panel density, and density gradient through the thickness. Density gradient can be controlled to a degree by manipulating press cycle variables.

Literature cited

42. USDA Forest Products Laboratory. 1974.