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Review of Thickness Swell in Hardboard Siding

Effect of Processing Variables

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Abstract

Medium-density hardboard is used extensively as siding on residential structures. One hardboard behavior that can be measured in the laboratory is thickness swell after exposure to water. This report reviews the literature on processing variables that are known to or likely to influence thickness swell. Where the literature on hardboard is sparse, research on other wood composition materials is cited, with appropriate caveats relevant to hardboard. Initially prepared as technical guidance to the U.S. Department of Housing and Urban Development, this report should be of interest to anyone concerned about thickness swell of hardboard siding.

Keywords: Hardboard siding, thickness swell, process variables

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Review of Thickness Swell in Hardboard Siding

Effect of Processing Variables

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Introduction

According to the *Wood Handbook* (1987), hardboard siding is a medium density, 31- to 50-lb/ft^3 (500- to 800-kg/m^3) board composed primarily of lignocellulosic fiber, which is consolidated by pressing in a heated press. Hardboard siding is usually 7/16 in. (11 mm) thick and is fabricated for application as either panel or lap siding. Virtually all hardboard siding is either factory primed (for subsequent field painting) or factory finished. Surfaces of hardboard siding are either textured or very smooth. Over an approximately 35-year history of commercial production, something in excess of 25 billion ft^2 (2.3×10^9 m^2) of hardboard siding has been shipped (Peterson 1996). These numbers suggest that the generic product has a reputation for at least moderate durability.

Within the past decade, however, the issue of hardboard siding durability has gained significant public attention. The U.S. Department of Housing and Urban Development (HUD) was directed by Congress to develop an acceptance standard for hardboard siding for manufactured housing. In its efforts to develop a standard, HUD has sought input from the USDA Forest Service, Forest Products Laboratory (FPL). This report represents a first step in providing technical input to HUD. The information reported here may be useful to the general public as well.

This report focuses on one behavior of hardboard siding, namely thickness swell, which has apparently become particularly contentious (Eight Penny News 1996). Where field performance problems have occurred with hardboard siding, irreversible thickness swell has been either a common failure mode or a behavior that has contributed to poor performance.[1] A report prepared for HUD (Keplinger and Waldman 1988) and a report from an industry source (Baldwin 1988) suggested that when there are performance problems with hardboard siding, irreversible thickness swell is frequently a contributing factor to or a cause of the problems. The American National Standard for Hardboard Siding (ANSI/AHA 1990) specifies that "substrate weatherability" be evaluated with a test procedure that measures irreversible edge thickness swell after water exposure. Thus, there is apparently general agreement that irreversible thickness swell is a measurable behavior related to hardboard siding performance.

Irreversible thickness swell is recognized as a problematic behavior in hardboard siding for a number of reasons. When irreversible thickness swell occurs to a substantial extent, it occurs unevenly and is thus aesthetically objectionable. In addition, irreversible thickness swell that occurs to a substantial extent typically occurs at board edges, which can result in paint failure there. Kelly and others (1984) showed that hardboard siding that has undergone irreversible thickness swell absorbs liquid water through the swollen edge to a much greater degree than does siding that has not undergone irreversible thickness swell. Both paint failure and irreversible edge thickness swell can accelerate liquid water pickup at board edges. This in turn can lead to panel decay.

The bulk of this report is a review of published literature concerning the influence of processing variables on thickness swell of hardboard. The survey of the research literature was facilitated by four summary reports: Halligan (1970), Kelly (1977), an unpublished internal report on the dimensional stability of particleboard prepared by the Alberta Research Council (1987), and an unpublished report prepared at FPL by J. Dobbin McNatt. Although none of these reports is specifically concerned with hardboard, they all contain references to research on hardboard thickness swell; also, some of the cited papers on particleboard contain information applicable to hardboard. In addition, a bibliography addressing hardboard properties (Youngquist and others 1994) was of some help in preparing this paper.

[1]The FPL does not possess the data with which to back any statement concerning the generic adequacy of hardboard siding. The FPL has not monitored how classes of commercial products perform in the aggregate consumers' experience. However, test fence exposure by an FPL scientist (Feist 1990) indicated that commercial hardboard siding can perform very well in exterior exposure.

Thickness Swell in Wood Composite Products

Wood composite boards have greater instability in the thickness direction than would be expected from the normal shrinking and swelling of their component wood elements (particles or fibers) (McNatt, unpublished report). When a wood composite board at equilibrium with a given set of atmospheric (temperature and relative humidity) conditions is exposed to liquid water or elevated humidity and then reconditioned to the initial set of conditions, some irreversible (or nonrecoverable) thickness swell will be observed.[2] The irreversible thickness swell of wood composites exposed to elevated moisture conditions is recognized as primarily resulting from release of residual (elastic) compressive stresses within the wood component pieces incurred during hot pressing (Kelly 1977). The release of internal compressive stresses is caused at least in part by the failure of bonds between the wood components. Permanent increase in the thickness of individual component pieces and of intercomponent void volumes is logically assumed, although no attempt has apparently been made to microscopically observe this assumed phenomenon. The irreversible thickness swell of wood composites is sometimes referred to as springback.

Irreversible thickness swell is time-dependent. Heebink (1967) found an equal amount of water absorption in a short-term vacuum–pressure–soak (VPS) exposure as in a 30-day soak exposure, but greater irreversible thickness swell in the 30-day test. Liiri (1961) reported that at 95% relative humidity, particleboards reached moisture equilibrium after 30 to 40 days, but that thickness swell continued for an additional 100 days. In neither of these works was reconditioned thickness reported, although additional swelling at no further increase in moisture content is largely nonrecoverable.

Commercial hardboard siding appears to have greater resistance to irreversible thickness swell than do most wood composite materials. In 10 years of outdoor exposure tests, River (1994) found that commercial hardboard siding showed significantly less irreversible thickness swell than did laboratory-made flakeboard or commercial flakeboard or particleboard.[3] Lewis (1968) found substantial differences in irreversible thickness swell of different commercial hardboard siding after exposure to the American Society for Testing and Materials (ASTM) six-cycle accelerated aging test. Biblis (1989, 1991) showed that commercial hardboard siding from different manufacturers had very different irreversible thickness swell values as evaluated by the test procedure in the American National Standard for hardboard siding (ANSI/AHA 1990). Thus, although generically hardboard siding appears to be much more resistant to irreversible thickness swell than are most wood composite materials, it also appears that commercial hardboard siding can vary greatly in resistance to irreversible thickness swell. Table 1 summarizes irreversible thickness swell values in the American National Standard and in various reports on commercial wood-based panels.

Procedures for Evaluating Thickness Swell

Two test procedures commonly used to evaluate thickness swell of hardboard siding are the "substrate weatherability" test procedure in the American National Standard (referred to hereafter as the AHA test) and sections 100 to 106 in ASTM D1037, Standard Methods of Evaluating the Properties of Wood-Base Fiber and Particle Panel Materials (ASTM 1993). These methods differ in two regards. The ASTM D1037 watersoak test is not strictly an irreversible thickness swell test, because specimens are measured in the wet (not reconditioned) condition after exposure. In addition, in the ASTM watersoak test, air trapped within the test specimen[4] can interfere with capillary water absorption (Kelly and others 1984). Kelly and others (1984) and Biblis (1989, 1991) found that differences in thickness swell behavior that were evident in the results of the AHA test were not discernible in the results of the ASTM watersoak test. Kelly and others (1984) also found some correlation between hardboard siding performance in the AHA test and in service. In contrast, no published work shows a correlation between siding performance in the ASTM watersoak test and in service.

Researchers have used a variety of other water exposures to evaluate thickness swell of wood composite (not necessarily hardboard) boards. Among these exposures are sections 118 to 124 of ASTM D1037 (commonly referred to as the ASTM accelerated aging test), vacuum–pressure–soak–drying (VPSD), boil–dry exposures, immersion in water for periods far in excess of 24 h (longer than specified in the ASTM watersoak test), and exposure to elevated humidity. In warm water and steam exposures of the ASTM accelerated aging test, boil–dry exposures, and VPSD, the test specimens become very wet—water penetration is much greater than would occur in siding in normal use. These tests are

[2]This is an oversimplification because a wood composite exposed to elevated humidity or liquid water and then reconditioned to the original set of atmospheric conditions will not return to the original moisture content because of sorption hysteresis. Nevertheless, the difference between initial and reconditioned moisture content is not recognized as a significant contributor to irreversible thickness swell of wood composite products and is ignored by virtually all researchers (except Jorgensen and Odell 1961).

[3]All boards in this study were unpainted. Over time, the siding hardboards became slightly thinner via surface erosion of fibers. It is safe to assume that the particleboards and flakeboards also lost particles or flakes by surface erosion, although all showed irreversible thickness swell. All the particleboards and flakeboards were bonded with phenolic adhesive.

[4]Trapping of air within the test specimen, and subsequent buildup of air pressure within it, can occur when the ASTM D1037 watersoak test is done with the test specimens in horizontal orientation. The ASTM watersoak test can also be performed with the specimens in vertical orientation. When performed in this mode, a hydrostatic pressure head equal to the specimen size comes into play.

Table 1—Irreversible thickness swell values for different wood-based panel products

Reference	Test method	Board type	Irreversible thickness swell (%)
American National Standard	ANSI/AHA	Hardboard siding	20[a]
Biblis (1989)	ANSI/AHA	Hardboard siding	3 to 17
Biblis (1991)	ANSI/AHA	Hardboard siding	2 to 11
River (1994)	10-year test fence	Hardboard siding	– 4 to +1
		Flakeboard and particleboard	3 to 21
		Marine-grade plywood	– 1
Klinga and Back (1964)	Cyclic soak/dry	1/8-in. (3-mm) hardboard	3 to 13

[a]Maximum allowable value.

apparently effective in evaluating the extent to which inter-component bonds are able to resist residual compressive stresses within the wood components. River (1994) did not find particularly strong correlations between thickness swell performance in boil–dry tests and test fence exposures for a data set derived from particleboard, flakeboard, and hardboard. The correlations would likely have been weaker if only commercial hardboard had been included in the data set. The ASTM D1037 watersoak test and the other cited test procedures are addressed here not because they have been empirically related to siding performance but because they were used in virtually all the research on the effect of processing variables on thickness swell of wood composite materials.

Factors That Influence Hardboard Thickness Swell

Wood Raw Material

Steinmetz and Fahey (1971) found that wood species significantly influenced thickness swell of hardboard. Baldwin (1988) stated that some species (and some barks) yield fiberboards with greater resistance to liquid water absorption. Although Baldwin did not specify how this behavior affected thickness swell, Suzuki and others (1976) showed a high correlation between liquid water absorption and thickness swell behavior. Other studies showed that water absorption of hardboard was influenced by species selection (Frashour and Nixon 1956, Liu 1975). Semana and Anderson (1968) indicated that the wax content of pine bark could decrease water absorption of hardboard. Carll and others (1985) found that laboratory boards made from non-debarked small-diameter locust stems showed greater hygroscopicity and greater hygroscopic thickness swell between 50% and 90% relative humidity than did otherwise identical laboratory boards made of locust heartwood.

Fiber Preparation

In the production of pulp, wood chips are exposed to hot and wet conditions, which can result in hydrolysis and extraction of hemicellulose (Spalt 1977, Suchsland and Woodson 1986). The effect of high pressure steaming is widely recognized in the industry as lowering pulp yield and loading process water with wood sugars (Suchsland and Woodson 1986). At least one hardboard producer has sold hemicellulose cattle feed as a commercial byproduct from high pressure steaming of chips (Carll and others 1982).

Spalt (1988) showed that exposure of wood chips to high pressure steam increased hemicellulose extraction and caused a concomitant decrease in hardboard hygroscopicity. In a study by Myers (1982), hardboard produced from low-yield pulps exhibited reduced thickness swell (in cyclic humidity exposures and without heat treatment). Suzuki and others (1976) indicated that steaming pressure influenced liquid water absorptivity of dry process hardboards. Lenic (1973) found that hardboard made from hydrolyzed wood chips (a byproduct of industrial furfural production) had good water absorption and swelling properties, though less than satisfactory strength properties.

The hydrolysis of hemicellulose by high pressure steam was also investigated by Hsu and others (1988) for reducing the thickness swell of particleboard and waferboard. In particleboard or waferboard manufacture, steaming the furnish would constitute an additional processing step, not incidental to production as it is in hardboard.

Thus, research has acknowledged the benefit of low-yield hardboard pulps compared to normally produced particles or wafers in improving thickness swell behavior of wood composite panels.

Heat Treatment

Heat treatment of hardboard reduced thickness swell in water-soak tests (Semana and Anderson 1968, Jansson 1982,

Klinga and Back 1964). In heat treatment, pressed board is exposed to elevated temperatures in the approximate range of 330°F to 410°F (165°C to 210°C) in some type of oven (Suchsland and Woodson 1986), typically soon after the board is pressed in order to use the residual heat.

It is widely recognized that exposure to temperature–time conditions that cause a loss of water of constitution modifies wood hygroscopicity and stabilizes the wood (Stamm 1964). Stamm suggested that these effects are the result of the breakdown of hemicelluloses to furfural polymers of lower hygroscopicity and capillary attraction. Klinga and Back (1964) suggested that crosslinking of carbohydrate chains occurs during heat treatment of hardboard. However, Spalt (1977) provided evidence that heat treatment of hardboard does not result in crosslinking of carbohydrate chains and concluded that the major chemical changes are pyrolytic. Whatever the precise mechanism, chemical modification of wood apparently occurs during heat treatment of hardboard.

The extent to which wood fiber is chemically modified during heat treatment at a given set of time–temperature conditions appears to be influenced by additional factors. Jansson (1982) investigated heat treatment of wet-process hardboard made on a production line where the forming-line water was recycled. She found that with sufficiently long heating times, higher concentrations of dissolved or suspended solids in the forming-line water reduced the water absorption and thickness swell of the board. Moreover, prior research by other authors had shown that aluminum ions would catalyze heat-treatment reactions and improve the water resistance of hardboard.

In addition to chemically modifying the wood fiber, heat treatment may have other effects that result in improved thickness swell behavior of hardboard. Jansson (1982) suggested that oleoresinous materials (which act as sizing agents) are redistributed during heat treatment. According to Spalt (1977), collection of vapors from hardboard undergoing heat treatment showed that sizing wax was being volatilized. Spalt suggested that this process redistributed the wax as a monomolecular layer on all fiber surfaces, with a resulting increase in water repellency. In addition, heat treatment may promote more complete cure of phenolic adhesive, which the hot-pressing operation may not complete (Chow and Steiner 1979, Phillips and others 1991). Suchsland and Enlow (1968) found that heat treatment of phenolic-bonded flakeboard substantially reduced thickness swell, without markedly altering hygroscopicity. They attributed this effect to relaxation of compressive stresses within the panel (see discussion on fiber plasticization in the work reported here), although it is also plausible that the heat treatment resulted in further cure of the phenolic adhesive.

Suchsland and Woodson (1986) suggested that heat treatment of hardboard siding is common industrial practice. If not heat treated, commercial hardboard siding is often hot stacked (American Hardboard Association, personal communication). In hot stacking, panels are stacked (without airspaces between sheets) shortly after hot pressing but they are not placed in an oven. Hot stacking likely provides some of the benefits indicated previously, even if temperatures within the stack are not sufficiently high to result in chemical modification of the wood. Both Spalt (1977) and Hsu (1989) suggested that hot stacking might relax pressing-induced compressive stresses. The benefits of hot stacking may be expected to vary; panels in the center of stacks will experience high temperatures for longer periods than those at the top and bottom of stacks.

Acetylation of Wood Fiber Surfaces

For decades, chemical modification of wood by replacement of hydroxyl groups with acetyl groups has been recognized as an effective means of reducing hygroscopicity, capillary suction, and dimensional movement (Stamm 1964). The process of replacing hydroxyl groups in lignocellulosic materials with acetyl groups is referred to as acetylation.

Klinga and Tarkow (1966) acetylated non-heat-treated wet-process hardboard by a uncatalyzed vapor phase process. The acetylation process resulted in board swelling and surface roughening, but it reduced reversible and irreversible thickness swell in subsequent watersoak exposures. The board swelling and surface roughening were apparently considerable. Subsequent research on acetylation has concentrated on acetylation of fiber or particles prior to panel fabrication.

For hardboard produced from acetylated fibers, Sudo (1979) found that acetylation was very effective at reducing thickness swell resulting from 24-h water immersion. Arora and others (1981) acetylated particles by a catalyzed liquid-phase process and subsequently fabricated phenolic-bonded panels from the treated particles. These authors measured thickness swell of boards made from the treated particles at a series of relative humidity levels, including 100% relative humidity (probably attained by suspending specimens over water in an airtight container). The boards made of acetylated particles showed substantially lower thickness swell at high relative humidities than similar boards not made of acetylated particles.
In the mid-1980s, Rowell and others (1986a, 1989) developed an uncatalyzed liquid-phase acetylation procedure that would allow more economic acetylation of large batches of furnish, and therefore had greater potential for industrial application compared to previous methods. A series of studies followed in which this method (and a few others) were employed to acetylate furnish for wood composite panels (Chow and others 1996, Rowell and others 1986b–d, 1991, Tillman and others 1987, Vick and others 1991, Youngquist and others 1986). In these studies, panels made from acetylated furnish consistently showed lower hygroscopicity and less water absorption and thickness swell in watersoak exposures than did similar panels made of untreated furnish. However, significant improvement in thickness swell appeared to occur at acetyl weight gains in excess of 10% (ovendry wood mass basis). From an industrial standpoint, this is a high level of chemical loading. Furthermore, furnish acetylation as performed in these studies took a few hours (roughly as long as effective heat treatments) and required expensive equipment.

The data of Klinga and Back (1964) suggest that heat treatment can be at least as effective at reducing irreversible thickness swell as can chemical modification of fibers by acetylation. Vick and others (1991) reported that acetylation of flakes to 17% acetyl weight gain reduced irreversible thickness swell of flakeboard (cyclic vacuum soak–elevated temperature drying) from roughly 16% to 8%. By comparison, Klinga and Back (1964) reported that heat treatment for 4 h at 374ºF (190ºC) reduced irreversible thickness swell of wet-process hardboard (cyclic watersoak–ambient temperature drying) from roughly 13% to 3%.

The principal advantages of fiber acetylation as opposed to heat treatment of wood composite boards are (1) acetylation apparently has a less detrimental effect on board mechanical properties and (2) acetylation has been shown to impart decay resistance to boards.[5] Although the first of these advantages is not likely to be of practical importance in siding applications, decay resistance is. Furthermore, and as indicated previously in this paper, thickness swelling behavior can be related to the incidence of decay. Rowell and others (1987, 1988), Tillman and others (1987), and Chow and others (1994) showed that acetylation of flakes, particles, or fiber imparted decay resistance to panels. However, appreciable protection from decay fungi occurred at 10% to 15% acetyl weight gain (Rowell and others 1987). Phenolic adhesive (at 6% adhesive content) also provided decay resistance to flakeboard, although a leaching procedure prior to fungal exposure nullified this protection (Rowell and others 1987). These results suggest that high loadings of fully cured (thus unleachable) phenolic adhesive might provide decay resistance to wood composite materials.

Oil Tempering

Oil tempering is a process whereby a board is roller coated with a drying oil (such as linseed, soybean, tung, or tall) and subsequently baked. Oil tempering is generally recognized to reduce water absorption and thickness swelling, although research literature on this subject is not plentiful. For decades, industry has oil-tempered thin, dense hardboard, primarily to increase surface hardness although bending stiffness is increased as well. Suchsland and Woodson (1986) indicated that oil tempering of hardboard panels used in shower enclosures is standard industrial practice, but siding is rarely oil tempered.

Cured tempering oil probably binds fibers together and acts as a sizing agent, reducing capillary suction. The baking process may furthermore result in some phenomena that occur in hot stacking, although the chemical modifications that occur to wood in heat treatment are not as likely since the temperatures involved in baking generally do not exceed 330°F (165°C). Stewart and Butler (1968) presented data indicating that oil tempering could be very effective at reducing water absorption and thickness swell of high density hardboard in watersoak tests. Nagasawa and Sano (1971) reported similar findings. Kuroki and Tanahashi (1963) investigated the influence of different drying oils and baking conditions on liquid water absorption of hardboard.

Fiber Plasticization

As indicated earlier in this report, the irreversible thickness swell of wood composite materials is caused by the release of elastic residual compressive stresses induced into the component pieces during pressing. If the component pieces were plastically deformed during hot pressing, there would be no residual compressive stresses in the panel and moisture-induced swelling would theoretically be wholly recoverable. Water is a recognized plasticizer of wood.

The plasticizing action of water is aided by elevated temperatures such as those experienced by boards in the hot press. In a review of the particleboard literature, Kelly (1977) cites several works in which higher furnish moisture content reduced thickness swell. Namioka and Anazawa (1981), Liu and McNatt (1991), and Hawke and others (1993) also showed that wood plasticization by the combined effects of moisture and heat during hot pressing could reduce thickness swell of particleboard, flakeboard, and dry-process hardboard, respectively. Chelak and Newman (1991) also indicated that higher furnish moisture content resulted in reduced thickness swell in isocyanate-bonded wood composite boards.

Moisture content near fiber saturation is most effective at plasticizing wood fibers (Stamm 1964). The moisture content of wood fiber mattresses in wet-process hardboard production is substantially in excess of fiber saturation. This would suggest that substantial fiber plasticization should occur during hot pressing of wet-process hardboard. However, Suchsland and Woodson (1986) indicated that although periods of high moisture content and periods of high temperature occur during pressing of wet-process hardboard, these periods do not coincide. This is because one or more "breathing" periods are included in the press cycles for wet-process hardboard. In general, thickness swell behavior of wet-process hardboard is no better than that of dry-process hardboard. Myers (1986) indicated that mat moisture content substantially above fiber saturation was not beneficial in reducing thickness swell of semi-dry process hardboard, apparently because periods of high mat moisture content and high mat temperature did not coincide.

Ironically, coincident periods of high temperature and high moisture content may occur in the press during the manufacture of dry-process wood composite materials. For dry-process board, the press cycle does not include a breathing period to promote drying. If mattress moisture content is high, the board may act as a pressure vessel, and simultaneous conditions of high temperature and high moisture content may occur. In the hot press, such conditions generally result in steam-pressure-induced delamination of the panel when the press is opened. This limits the initial moisture

[5] Heat treatment may also impart some degree of decay resistance to hardboard. In tests conducted by a university for a hardboard manufacturer, heat-treated hardboard was found to have appreciable decay resistance (Fisette 1996). This work is not part of the research literature.

content of the mattress, prior to entering the hot press, to below 12% (based on ovendry wood mass). With the development of isocyanate adhesives, researchers have found that particleboard and flakeboard can be produced at mattress moisture content approaching 20% without steam-pressure-induced delamination when the press is opened. Panels produced in this way have generally had substantially better resistance to edge swelling in watersoak tests (Chelak and Newman 1991, Hawke and others 1993).

Another potential means of plasticizing fiber in dry-process hot pressing is by steam-injection pressing. Thoman and Pearson (1976) showed that irreversible thickness swell of phenolic-bonded flakeboard could be drastically reduced by steam-injection pressing. Hsu (1991) showed similar results, reporting irreversible thickness swell (after 72 h watersoak) of only 3.4% in a steam-pressed waferboard with only 2% phenolic resin content.

Steam post-treatment has also been investigated as a means of reducing thickness swell of particleboard via moisture/temperature plasticization of the wood. Most of the work of Heebink and Hefty (1968) involved steam post-treatment without restraint. The authors reported very substantial reductions in irreversible thickness swell after boil–dry, VPSD, and edge-wicking exposures, with irreversible thickness swell values below 5%. However, I deduce that steam treatment without restraint resulted in relief of internal stresses by thickness swell and that the reported low levels of irreversible thickness swell after test exposure were based on the swollen thickness resulting from steam treatment. Heebink and Hefty mentioned that they investigated steam treatment under restraint. However, the ventilated cauls used for steaming under restraint apparently did not permit sufficient steam access to the panels, and no results of this apparently unsuccessful investigation were reported.

Anhydrous ammonia can be a very effective plasticizer of wood. This suggests that exposure of pressed boards under restraint to anhydrous ammonia might be an effective post-treatment for reducing irreversible thickness swell. Spalt (1988), however, showed that when pressed hardboards were exposed to anhydrous ammonia and subsequently degassed, they showed substantially greater hygroscopicity than did similar boards not so exposed. Spalt attributed this result to a change in the crystalline structure of cellulose by ammonia, which resulted in formerly inactive parts of the cellulose chains becoming active in sorption.

Urea, resorcinol, and phenol–formaldehyde resin of low molecular weight have shown some ability to plasticize wood (Stamm 1964). However, there do not appear to be any published works concerning the feasibility of using these resins as plasticizers during pressing of hardboard panels.

Bulking

Phenolic resin of low molecular weight can penetrate into the wood cell wall, occupy hydroxyl sites, and thereby act as a dimensional stabilizer. Myers (1986) and Haygreen and Gertjejansen (1972) showed that bulking of wood cell walls by phenolic resin can reduce thickness swell of hardboard and flakeboard, respectively. Steinmetz and Fahey (1968) likewise showed that addition of low molecular weight phenolic resin reduced thickness swell of hardboard and was more effective than addition of powdered phenolic resin (of unidentified, but almost certainly higher, molecular weight). By loading flakes with 35% impregnating phenolic resin (ovendry wood mass basis), Talbott (1959) made flakeboard with exceptional resistance to water absorption and thickness swell. Stamm (1977) indicated that furfuryl alcohol resin has potential as a dimensionally stabilizing bulking agent. However, there do not appear to be any published works concerning use of furfuryl alcohol resin as a bulking agent in wood composite products.

Adhesive Type and Amount

Higher adhesive content has been consistently shown to improve thickness swell behavior of particleboard and flakeboard (Beech 1975, Halligan 1970, Lehmann 1974, 1978). However, Stewart and Butler (1968) found that the marginal improvement in thickness swell behavior of wet-process high density hardboard (as evaluated by watersoak testing) was minimal beyond roughly 2% adhesive content. Hiziroglu and Kamden (1995) found that increased adhesive content (in the range of 0% to 2%) reduced thickness swell of wet-process hardboard (as evaluated by watersoak testing), but not to a great extent. Chow and others (1994) likewise found that an increase in adhesive content from 3% to 7% (ovendry wood fiber basis) did not significantly influence thickness swell behavior of dry-process high density hardboard. It thus appears that the benefit of reduced thickness swell obtained from higher adhesive content is substantially less in hardboard than in particleboard and flakeboard.

Waterproof adhesive (usually phenolic) is used in hardboard siding. Urea–formaldehyde adhesive is widely recognized as unsuitable for use in exterior exposure, and furthermore, it would undergo thermally induced breakdown if exposed to the temperatures involved in heat treatment of hardboard (or, for that matter, hot stacking or pressing). Although phenolic adhesive is the most commonly used adhesive in the production of commercial hardboard siding, Galbraith and others (1985) suggest that isocyanate adhesive might be used. There is fairly consistent evidence that in dry-process manufacture of wood composite products, use of isocyanate adhesive can result in superior resistance to thickness swell (Chelak and Newman 1991, Hawke and others 1993, Johns and others 1984).[6] As indicated previously, this resistance is apparently (at least in part) due to the ability of isocyanate adhesives to develop bonds at in-press moisture content of

[6]None of these works specifically concerned hardboard siding. They all concerned products in which embrittlement that might result from heat treatment would be a serviceability issue and in which speed of production at the hot press was an important concern. Although these works show a potential of isocyante adhesive to improve thickness swell behavior of wood composite materials, in my view they do not suggest the superiority of isocyanate to phenolic adhesive for use in hardboard siding.

around 20%, where substantial wood plasticization can occur, which are strong enough to prevent steam-pressure-induced panel delamination when the press is opened.

Wax Sizing

For decades, wax has been used in hardboard to reduce capillary suction of interfiber voids. Wax sizing reduces water absorption and thus thickness swell of panels, as evaluated by watersoak tests. In wet-process hardboard, wax emulsion is often added to the pulp slurry and precipitated onto the fiber. In dry-process hardboard, wax is typically sprayed onto the fiber, suspended in aqueous emulsion. A third option is to add wax to the wood chips before they enter the refiner. Suchsland and Woodson (1986) suggest that the wax content of commercial fiberboard generally does not exceed 0.5% of fiber ovendry weight. Gatchell and others (1966) demonstrated the benefit of wax inclusion at reducing thickness swell of unpainted particleboard in exterior exposure, even though the wax showed no influence on thickness swell in ASTM D-1037 accelerated aging exposure.

Albrecht (1968) indicated that the marginal improvement in water resistance of particleboard, as evaluated by watersoak tests, is negligible beyond 1% wax content. Paraffin waxes are superior to microcrystalline waxes for imparting water repellency to particleboard, although microcrystalline waxes may result in better paintability of panels (Berrong 1968). Microcrystalline waxes are better able to hold oils, which might migrate to board surfaces, in their crystal structure. Microcrystalline waxes (sometimes called petrolatum waxes) are most frequently used in production of hardboard siding, although some plants use paraffin wax (personal communication, American Hardboard Association). The oil content of wax and the ability of the wax to hold the oil and thus prevent it from migrating to board surfaces are factors that influence the choice of wax. The effectiveness of paraffin waxes depends on molecular weight and configuration (Roffael and May 1983). At a given molecular weight, paraffin waxes of linear molecular configuration are more effective at imparting water repellency to particleboard than are branched isomers. Hsu and Bender (1988) found similar results with hardboard.

Fatty acids, tall oil, rosin, and a mixture of paraffin and rosin have also been investigated as sizing additives for hardboard, apparently with mixed results (Sinclair 1964, Sinclair and Drymond 1968, Washizawa and others 1952). These studies reported data on liquid water absorption (but not thickness swell).

Conclusions

The research literature for hardboard indicates that many processing variables influence thickness swell behavior. These findings are augmented by the research literature on particleboard and flakeboard, which strongly suggests that still other variables may affect thickness swell of hardboard. These variables can be broadly categorized as

- processes that chemically modify wood fibers by heat or addition of a chemical additive,
- selection of raw material,
- processes to prevent buildup of residual compressive stresses within panel during hot pressing or relief of these stresses under restraint after hot pressing,
- use of adequate adhesive, and
- use of bulking or sizing additives.

These variables are often interrelated. Specifying one variable or level thereof may influence other variables. Conversely, selecting one level of a variable often does not dictate thickness swell behavior unless specific levels of other variables are also specified. This suggests that it would be very difficult, if not impossible, to promulgate a meaningful prescriptive standard for hardboard siding.

With appropriate selection of processing variables, hardboard can be produced with substantially lower thickness swell than that of most other wood composite materials. Furthermore, appropriate selection of processing variables can result in substantially less thickness swell than the maximum specified in the American National Standard for hardboard siding.

Limitation to Findings

As indicated previously in this report, virtually all the research studies on how process variables influence liquid water absorption and thickness swell involved the use of test procedures that were not empirically related to thickness swell behavior of panels exposed in the field.

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