HOLLOW-CORE FLUSH DOORS

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FOREST PRODUCTS LABORATORY
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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

HOLLOW-CORE FLUSH DOORS[1]

Forest Products Laboratory,[2] Forest Service
U. S. Department of Agriculture

Introduction

Flush doors have been used for many years. In recent years, however, a new type, the hollow-core flush door, has seen extensive use. The hollow-core door is an application of the stressed-skin principle, in which relatively thin skins or covers contribute importantly to the strength and stability of the whole. Hollow-core flush doors are light in weight and, at the same time, strong and stiff. The flush surfaces, whether in natural or painted finish, have a simplicity and pleasing appearance in harmony with today's trends in home styling. An important percentage of the doors in new residential construction are now of the hollow-core flush type.

In contrast to the solid core, which contacts the covers of a door continuously, the hollow core contacts the covers only intermittently. Points of contact may be a fraction of an inch up to 2 or 3 inches apart. Bulk densities of hollow cores are generally from a few pounds up to about 10 pounds per cubic foot. In contrast, the typical solid-wood core weighs about 30 pounds per cubic foot.

Hollow-core doors are widely used by many builders, and now have an extensive and generally satisfactory record in interior service. They have had much less extensive exterior use.

The hollow-core door could not have attained its wide acceptance in competition with other types of doors unless its performance in service was essentially superior in some of its properties to other doors. It follows, of course, that all hollow-core doors have not proved wholly satisfactory. The same may also be said of other types of doors. Some of the problems that arise during fabrication and that are cause for rejection at the time of inspection are: warp, twist, or cup; delamination or separation of veneer or plywood; pattern of core visible on surfaces; and openings or separation at joints of plywood facings. Doors that have passed inspection may develop the same defects in service occasionally because of some exposure involving unbalanced moisture content conditions.

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[1]This report is prepared through the collaboration of members of the Forest Products Laboratory staff, including Don Brouse, R. F. Luxford, L. W. Wood, and L. V. Teesdale. Original report prepared June 1954.

[2]Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

The purpose of this report is to answer some of the questions that arise in connection with the design, fabrication, testing, and use of hollow-core flush doors and to discuss some of the reasons why their performance is not always satisfactory. Although there has been much research on doors, it has been related more to applications than to principles. For this reason, information presented is somewhat generalized and, in some instances, incomplete. Nevertheless, it is believed that a summary of present knowledge will have value to the many people who are now making, distributing, or using hollow-core flush doors.

Design Factors in Doors

Core Materials

The center layer of a hollow-core door consists of a frame, formed by the stiles and rails, and inside of the frame a noncontinuous arrangement of material that provides support for the other layers or facings. Several different materials may be used in the space between the stiles and rails, and this material may be laid up or arranged in any one of several patterns or designs. The pattern or arrangement of this core material depends in part on the thickness of the facings; the core should provide sufficient support to the facings to eliminate objectionable depressions or irregularities in the facings of the finished door.

One widely used core consists of a lattice of wood strips about 3/16 inch thick so arranged that the openings are about 2 inches by 4 inches with the edge of the lattice forming the support for the facings. Frequently the lattice is set into the framing. In another type that is very similar, strips of fiberboard about 3/8 inch thick are used to form the lattice. This construction may be termed mesh core, or grid core, as well as lattice core.

In place of a lattice, strips may be laid either horizontally or vertically to form the core. In some cases, the strips are let into the framing to insure uniform positioning. In case the strips are not uniformly positioned, faulty glue bonds between the strips and the facings may result and permit the strips to loosen and fall out of position. Like the lattice cores, the strip cores may be either of wood or of fiberboard. This construction is often termed a ladder core.

In addition to the fiberboard mentioned above, paper products in other forms may be used for cores. One manufacturer makes use of sections of paper tubes about 3 inches in diameter with walls about 3/16 inch thick. The tube sections are positioned, by the use of a pattern board, to provide the necessary support for the facings. The term, "implanted blanks core," is sometimes used to designate this type.

Veneer may also be used for cores. In one form, veneer in the order of 1/16 or 1/20 inch thick is spot-glued and expanded so that it resembles in form the expanded paper product often seen in Christmas bells and the like. The core may also be formed of veneer glued and bent in other forms, as resembling a figure 8, so that it is stiff enough to permit forming a glue bond between the veneer edges and the facings.

Cores may also be of the honeycomb type formed of paper that has been treated or impregnated with phenolic resin. Such core stock may be produced by corrugating the treated paper, bonding the corrugated sheets parallel node to node, and resawing to form short sections resembling natural honeycomb. The corrugated paper may also be bonded with the corrugations in successive layers at right angles and then may be resawed at right angles to the planes of the sheets, with the resulting sections being used as core stock. This construction is not so resistant to crushing as the true honeycomb, but it may offer some advantages in heat transfer.

Figure 1 shows typical cores of lattice, ladder, tube, and honeycomb types.

Framing

The stiles and rails, or the framing of the core, are usually of softwood. Several manufacturers favor ponderosa pine. The exposed edges of the stiles are usually free from knots, pitch pockets, and other defects for a depth of at least 1/2 inch from the outside edge along the entire length of the stile. Since the stability of the door in service depends in part upon the strength of the frame, the width of the stiles and rails is of importance in the design of a serviceable door. For interior and exterior doors of standard sizes, Commercial Standard CS 171-58, "Hardwood Veneered Doors," requires that stiles be at least 1-1/8 inches wide and rails at least 2-1/2 inches.

The thickness of the stiles, rails, and core depends, of course, upon the total door thickness desired and upon the thickness of the facings. The total thickness of interior and exterior hollow-core doors is usually 1-3/8 or 1-3/4 inches, that of dwarf doors 1-1/8 inches, and that of cupboard doors 1-1/8 inches or thinner. The exposed edges of the stiles are sometimes covered with an edge strip, primarily to match the appearance of the facings.

Unless the stiles are unusually wide, blocks are ordinarily glued to the inside of the stiles at midpoint to provide support for locks and catches. Commercial Standard CS 171-58 requires that these lock blocks be 20 inches or more in length, and the combined width of the block and stile be not less than 4 inches. Where glazed openings are made in doors, suitable blocking should be provided for support around the edges of cutouts.

Facing Materials

The material most commonly used for facings of hollow-core doors is plywood two or three plies thick. Hardboard is used to some extent and, more rarely, other sheet materials, such as aluminum or sheet plastics. The thickness of the facings depends in part on the stiffness of the facing material and in part upon the dimensions of the voids in the core. The facings should be stiff enough to span the gaps in the core without showing irregularities in the surface or "telegraphing" the locations of the core supports. Plywood facings should be not less than 1/10 inch thick before sanding.

When applied to hollow-core doors, the term "grade" usually pertains to the quality of veneer visible on the surfaces of the door before finish is applied. The higher grades, called "Premium" and "Good" in Commercial Standard CS 171-58, are intended for natural finishes. It is often required that the face veneer be of one piece selected for pleasing grain and color or, if of more than one piece of veneer, that the sheets be matched for grain and color. If the door is intended to be finished with paint or enamel, unmatched veneers or other characteristics of the wood that can be covered with two coats of paint are acceptable, and the grade is called "Sound" in Commercial Standard CS 171-58.

Types of Glue

The serviceability of a hollow-core flush door depends to a very large degree upon the quality and permanence of the glue bonds. Consequently, it is very important that the gluing be well done and that the glue selected be suitable for the service intended.

In addition to the property of maintaining permanently a high bond strength in the dry condition, the glues used for interior doors should have a degree of water resistance sufficient to prevent damage from dampness and accidental wetting during shipping, storing, and handling incidental to moving from the place of manufacture to final installation. Casein and urea-resin glues have been widely used for interior doors. They have a moderate degree of water resistance and, over a period of years, have proved suitable for the normal service of interior doors. Polyvinyl-resin glues have been used recently to a limited extent for interior doors, but their record of service is insufficient to demonstrate with certainty their suitability for the purpose.

Fully exposed exterior doors should be glued with weatherproof glues. Of this type, the phenol or phenol-resorcinol-resin types are often used. If the exterior doors are protected, as by a porch, and the top and bottom edges are kept well painted, a fully weatherproof bond may not be required. In this case, the melamine-urea-resin blends should prove suitable.

Fabrication

General

The general procedures and equipment used in fabricating hollow-core doors closely resemble those used in the production of lumber-core plywood. In both are involved selection of stock, control of moisture content at the time of fabrication, selection and preparation of the glue, control of the gluing operation, and observance of suitable conditioning schedules after gluing.

Selection of Stock

The face veneers are selected on the basis of the figure, color, characteristics, and defects desired or permitted in the grade produced. If the facings are each of three-ply plywood, the back ply of each plywood panel should be matched with the face ply, in species, grain direction, and thickness, but it need not be a high-appearance grade. The center ply of the facing panels should be uniform in texture, straight-grained, and preferably of a species medium to low in specific gravity and low in shrinkage characteristics. The panel, in itself, should remain flat; and the panel on one side of the door should be of the same species and should match in shrinkage characteristics that on the other side, so that the door, as a whole, may be balanced and remain flat. If the facing material is two-ply plywood, the plies on one side of the door should closely match the corresponding plies on the other side in species, thickness, and grain direction. The framing members should be straight and free from grain or structural characteristics that would result in warping the door. The size and quality of the members should be such as to provide the necessary strength to the door and the desired appearance of visible parts. Since the serviceableness of the flush-type doors depends so largely upon the quality of the glue bond, it is important that the stiles and rails be well surfaced and that the stiles, rails, and core material be finished accurately to the same thickness so that the gluing pressure may be equally effective over the entire area of bond.

Hardboard is sometimes used for the facings of doors intended for interior service. To increase the resistance to puncture from accidental impacts, the thickness is sometimes more than that of a plywood facing for equivalent use.

Control of Moisture Content of Stock

The moisture content of the stock at the time of gluing has an important effect on the stability and appearance of the door in service. Consequently, the moisture content of the stock should be carefully equalized and adjusted on the basic principle that the moisture content when increased by the water added by the glue should equal the average moisture content of the door in normal service. The moisture content of doors in normal service varies with the season of the year and also depends on the geographical location as well as upon their location in the building. The moisture content of interior doors in service may, in extreme cases, be as low as 4 percent in midwinter in the colder sections of the country, or it may be as high as 12 or 13 percent in the warm, moist areas. In the north central area of the country a change from about 5 or 6 percent in the winter to some 10 or 11 percent in the summer may be expected each year. Consequently, no one moisture content can be expected to be perfectly adapted to all conditions of service. However, a moisture content of about 8 percent in the stock for interior doors at the time of fabrication may be considered a desirable level. For exterior doors an average moisture content of about 10 percent is desirable.

Gluing and Pressing

As mentioned previously, the glues should be selected to fit the service for which the doors are intended. Depending upon the glue selected, the gluing may be done entirely at room temperatures in a cold press or the glue may be cured by heating between platens of a hot press.

If three-ply plywood is used for facings, the veneers are usually glued to form the plywood in one operation and the plywood facings are glued to the frame and core in a second operation. Frequently, the plywood facings are produced in a plant manufacturing only plywood, and the second operation, of gluing the facings to the core and frames, is done by the door manufacturer.

If the facings are of two-ply plywood, the gluing of the veneers to form the plywood and the gluing of the plywood to the frame and core are occasionally carried out in one pressing operation. When this technique is followed, rather exacting attention must be given to the details of gluing to obtain an adequate and uniform bond between the veneers without crushing the core. Gluing the two-ply plywood in a separate operation is considered the better practice.

Conditioning

Gluing operations almost always involve a gain or loss of moisture in the wood. In cold-press gluing, water is added with the glue, and, consequently, the wood is wetter when the gluing operation is completed than it was when the stock was delivered to the glue spreader. In hot-press gluing, water is usually added with the glue, but some is driven off by the heating, and the wood, after hot-pressing, is usually drier than it was before spreading the glue.

Consequently, hollow-core doors, like most other glued products, should be conditioned after gluing to adjust the moisture content to the average expected in service and to insure that the moisture is uniformly distributed throughout the door. This conditioning is sometimes accomplished by stacking the doors in stickered piles, covering and weighting the top of the pile, and storing for a brief period, as 1 or 2 days, in a room or kiln where temperature, relative humidity, and circulation can be adjusted and maintained at suitable levels.

Ventholes are often provided in the top and bottom rails to relieve pressure from vapor formed during hot-pressing. Whether these ventholes should remain open after the door is in normal service is not established. For exterior doors and others exposed to unusually severe moisture conditions, it is considered good practice to plug the holes, and to coat, at least the bottom edge, after it is trimmed to fit with water-repellent preservative and two coats of paint to reduce the absorption of moisture at this critical area.

The finished doors should be flat and true, not only for satisfactory appearance but for easy installation and operation of hinges, latch, and stops. Commercial Standard CS 171-58 provides a warp or twist allowance of 1/4 inch on a door of normal size and specifies how warp and twist are to be measured. The outline of the core structure and of the stiles and rails should not be obvious on casual examination. A narrow beam of light directed at a low angle is helpful in detecting small raised or sunken areas in the surface of the door.

Causes of Warping

Warping is a term used to mean any distortion in the door and includes cup, bow, and twist. Cup refers to a distortion across the width of the door and is seldom troublesome. Bow is a curvature along the length of the door. Cup and bow can readily be measured by means of a straightedge. As a general rule, twist is attributable to differences in the grain direction in the plywood facings. If the grain direction of any ply of one face does not match the grain of the corresponding ply on the other side, the door may twist. Twist is that form of warp in which the four corners of the door are not in the same plane.

Warping is caused by stresses set up when the door tends to swell or shrink as its moisture content changes. If the stresses developed on one side of the door are not balanced in direction and magnitude by stresses on the other side, warping of some type may be expected.

Lengthwise expansion and contraction of normal straight-grained wood with changes in moisture content is so small that for most purposes it may be neglected. Irregular grain, such as occurs near knots, will increase lengthwise shrinkage. In cutting strips for stiles and rails, some irregular grain may occur in some part of a piece and, if such a piece changes in moisture content after it is assembled in a door, some distortion may appear.

Though dimensional change along the grain in plywood is small percentagewise, it is greater than in solid straight-grained wood. The crossband in plywood attempts to expand and contract across the grain but is restrained to a large extent, but not entirely, by the face plies. If there is an increase in moisture content of the plywood on one face of the door without a corresponding change on the other, the face with the higher moisture content will tend to elongate, causing the door to bow. The stiles offer some resistance to the bowing. It follows that the greater the thickness and the greater the width of the stiles, the greater the resistance to bowing. It is, of course, important that the plywood faces on opposite sides of the door have the same moisture content at the time of assembly.

Perhaps the type of bowing most commonly observed in service occurs in exterior doors where, during cold weather, the inside face is exposed to warm, relatively dry air and the outside face to a relatively high humidity. The resulting difference in moisture content causes a slight expansion on the outside face and a contraction on the inside face which cause a slight bow with the concave face on the warm side. Hinges restrain bowing on one side of the door. Where 2 hinges are used, some bowing may occur, but where 3 hinges are used, practically no bowing will develop in the hinge side. Restraint of bowing on the hinge side where 3 hinges are used will also offer some resistance to bowing on the latch side.

The door latch holds the door tight to the door frame at the latch, but bowing may develop above and below the latch. Since the latch is below the center of the door, there appears to be more bowing above the latch than below. With more bowing on the latch side than on the hinge side, the face of the door takes on a degree of twist.

The cutting away of the stiles to hold the mortise lock weakens the stile and affects the restraint it may offer to bowing. The tubular type of lock that requires a minimum of cutting of the stiles will have less weakening effect than the mortise type of lock set.

Protecting exterior doors during cold weather with storm doors on the cold side will materially reduce the potential difference in moisture content between the warm and the cold sides, and this, of course, will reduce the tendency to bow. Maintenance of protective coatings on the ends and sides, as well as on the faces of exterior doors, will retard moisture changes and thus tend to reduce the amount of bow.

Inside doors will generally have approximately the same temperature and humidity on one side as on the other. Even though there will be some seasonal change in moisture content, the change will be approximately the same on both sides and there should be no bowing. Sometimes a door separates an unheated space from a heated space, in which case some bowing may develop.

In exceptional cases, seasonal moisture content changes may make a door bow due to irregular grain in some part of the plywood or even in one of the stiles. Generally, however, the presence of irregular grain as described causes distortion that will appear during manufacture and before final inspection.

Improper storing or handling may well cause troublesome warping. If doors intended for normal service are fabricated at the desirable moisture content of about 8 percent, the doors should be stored and handled in such a way that moisture changes are held to a minimum. This care should extend from the time of fabrication until normal occupancy conditions are established in the customer's building. For example, if doors were stacked solid and stored in a damp location, the ends and sides and the exposed side of the top panel would pick up moisture rapidly, while the parts in the center of the pile would change very slowly. The stresses developed by such unequal changes in moisture content would tend to cause the top panel to bow upward and the other doors to twist.

Likewise, if doors are fitted and hung before the building is completed, some may be exposed to comparatively high temperatures on one side and low temperatures on the other, or to high humidities on one side and low humidities on the other. If these differences are great, warping may be expected.

Performance Tests and Requirements

As new types of hollow-core flush doors have appeared, there has arisen a need for performance tests. Performance testing affords a means for predicting service behavior where records from service are lacking. The Housing and Home Finance Agency and the National Woodwork Manufacturers' Association have sponsored research at the Forest Products Laboratory directed toward the development of performance test methods and test requirements.

Much of the performance testing has been related to doors for interior service in houses, but glue-bond testing has been directed toward both interior and exterior doors. The test methods fall into two general groups: those for strength, and those for moisture resistance. The work on glue-bond testing has led directly to the glue-bond requirements included in Commercial Standard CS 171-58. No provisions for strength tests are contained in CS 171-58, but strength and stability characteristics were probably considered when minimum widths of stiles and rails and minimum thicknesses of facings were established. Any well-made, hollow-core flush door with framing and facings adequate for stability and moisture resistance, and facings thick enough for puncture resistance, will show good strength properties.

Performance requirements related to these tests apply directly to flush doors of wood or wood-fiber construction. Although the same tests have been made on panel doors, it is still an open question whether or not the performance requirements should be the same. Applicability to doors of metal or other nonwood construction is not known.

Strength Tests

Strength tests at the Forest Products Laboratory include racking parallel to the plane of the door, racking perpendicular to the plane of the door (twisting), impact by falling ball, and impact by swinging sandbag. Other laboratories have developed tests by repeated slamming. Moisture tests at the Labotory include soaking, humidity-exposure cycle, and moisture differential (warping).

In the racking-parallel test, the door is supported along one long edge in a vertical position, as when hung in service. Load is applied to the opposite edge, and the deformation is measured (fig. 2). Almost any well-made flush door will withstand this kind of service load without structural damage or significant deformation. Some of the tests have shown that, with increased loads, the hinge fastening may fail before the door does. For these reasons, the test is not critical on flush doors.

The twisting or racking-perpendicular test has been performed by two methods. Originally, the door was held down in a flatwise position by ties at two diagonally opposite corners, and an upward pull was applied at the third corner while load was measured at the fourth corner. That method has been varied by giving upward support to the two diagonally opposite corners, holding down the third, and loading the fourth. More recently, the test has been made by supporting two diagonally opposite corners and loading the other two opposite corners (fig. 3). All of these methods of test are essentially equivalent.

Because of the one-piece faces and the glued construction of flush doors, they are very resistant to this kind of test. A well-made hollow-core flush door was bent about 2 inches with a test load of 200 pounds. There was no structural damage, and the deformation was entirely recovered when load was removed. Tests have not been carried to destruction, as forces of this kind in service are not likely to exceed 200 pounds. It would seem that a door should withstand that load without structural failure, and that the deformation should be recovered when the load is removed.

Doors placed flatwise have been tested by drops of a 2-inch steel ball from various heights. This is primarily a test of the resistance of the facing to accidental impacts. It can be made on the whole door or on a small square section cut from the door. Such drops make small dents, and the higher drops cause structural failure. Small dents are more objectionable on polished or highly finished surfaces than on dull or matte finishes.

Impact with a 10-pound sandbag is more general in its effect. In this test, a door is placed upright, with the long edges backed by stops 1/2 inch wide. The 10-pound bag is dropped pendulumwise from various heights (fig. 4). A well-made hollow-core flush door withstood repeated drops from heights up to about 10 feet before failure occurred. A requirement to withstand five 6-foot drops has been proposed. Damage from this test is not always seen at the point of impact; it may appear at a joint or on the opposite face of the door.

Both the steel-ball and the sandbag impacts are made against the point on the door that is most vulnerable to damage. Some exploratory drops may be necessary to locate that point. Doors are more vulnerable to sandbag impact if struck near a framing member or other unyielding support.

In a common type of slamming test, the door is hinged horizontally and allowed to fall repeatedly from the vertical to the horizontal position, where it strikes a stop. The test can be actuated mechanically by a cam-and-lever arrangement, with thousands of repetitions if desired. The severity of the test increases with the weight of the door, other things being equal. The general effect on the door is somewhat like that from sandbag impact.

Moisture-Resistance Tests on Glue Lines

Evaluation of glue joints in hollow-core doors should include those between the facings and the stiles, rails, and cores, as well as those in the facings.

Commercial Standard CS 171-58 recognizes two types of glue bonds. Type I requires a fully waterproof bond that will withstand, without failure, exposure to the weather or other severe service conditions. Type II requires of the glue bonds a modest degree of moisture resistance that would insure satisfactory service of interior doors under normal use conditions.

For Type I bonding, the standard for hardwood veneer doors (CS 171-58) requires that a door without finish be selected at random, and from the door so selected 10 plywood shear specimens and 4 6-inch-square corner sections are cut. All specimens are boiled in water for 4 hours, dried 20 hours at 145° ±5° F., again boiled for 4 hours and cooled in water. The plywood specimens are then tested wet by standardized plywood test methods (ASTM D805-52). The wood failure that develops must be not less than that specified in table 5 of Commercial Standard CS 35-56, "Hardwood Plywood."

The 6-inch-square specimens are examined for delamination after the completion of the boiling-drying cycle. If no delamination is greater than 2 inches in length or more than 1/8 inch in depth at any point, the sample is considered adequately bonded. If the plywood specimens and three of the four 6-inch-square sections meet the requirements, the door is acceptable together with the lot from which it was selected.

For Type II bonding, CS 171-58 requires that an unfinished door be selected at random, as for Type I. Four 6-inch-square corner sections are cut from the door to include stile, rail, and core material. The specimens are submerged in water for 4 hours and dried at temperatures between 70° and 80° F. for 20 hours. The cycle is then repeated until all specimens have failed, or until 15 cycles have been completed. The specimen is considered to have passed if no delamination exceeds 2 inches in length or 1/8 inch in depth. If the specimen successfully withstands an average of 10 cycles, the door is considered acceptable, along with the lot from which it was selected.

These requirements are essentially equivalent to those for Type I and Type II plywood in Commercial Standard CS 35-56, "Hardwood Plywood."

Tests on the corner sections also provide a qualitative measure of workmanship in gluing, because if errors are made in the preparation of the stock for gluing or during the gluing operation, those errors are likely to be disclosed by defective glue joints at or near the corners.

Moisture Tests on Whole Doors

Wood doors are assembled with the grain of adjoining parts at right angles. Because wood shrinks much more across than along the grain, doors are put under stress by changes in moisture content. A humidity-exposure-cycle test has been made by conditioning the door in a dry atmosphere, then in a highly humid atmosphere, and finally reconditioning in the original dry atmosphere. Under humidity, the door increases in length, width, thickness, and weight. When redried, there may be face checking or separation of parts. Where glues are not waterproof, there may be some failure of glue joints. Two or three weeks' time is required for full conditioning each time the door is moved into a different atmosphere.

The test has been made on interior doors with the moisture content of the door about 10 percent more in the humid than in the dry atmosphere. With such a test, there should not be structural damage or excessive warp or twist. Excessive increases of length and width are also objectionable. Well-made hollow-core flush doors increase about 1/4 percent in length and width and remain essentially free of structural damage or warp.

The moisture-differential or warping test is made by placing the door without surface coating into the side of a cabinet with humid air maintained on the inside and dry air on the outside. The side exposed to the humid air becomes larger, and the door becomes bowed or cupped, with the damp side convex and the dry side concave. A common humidity differential is about 90 percent relative humidity on one side and 25 percent on the other. Since warping from differential moisture content is generally not a serious problem in interior doors, a somewhat smaller differential, such as 30 to 80 percent, might be used. About 2 or 3 weeks are required for the moisture differential to become fully effective.

Well-made doors became bowed lengthwise 1/4 to 1/2 inch with this test treatment. When the humidity differential was removed, most of the bow was recovered. Where one side of the test door was restrained by two hinges, the hinge side developed about half as much bow as the free side.

While the performance tests described were developed mainly for interior doors, the same or similar methods are applicable to exterior doors. Any of the group of strength tests can be made on exterior doors. Requirements for strength and impact resistance in these tests can be made about the same or perhaps somewhat higher than for interior doors.

The moisture test methods for whole doors should be more severe for exterior than for interior doors. Where a moisture content difference of 10 percent is used for the humidity-exposure cycle on interior doors, 14 percent may be used on exterior doors. In the warping test of an exterior door, a higher humidity differential, such as 30 to 97 percent, might be used.

Actual exterior exposures of test doors in a northern climate have been made. Doors were hung on a heated building under observation for about a year and observed monthly for structural damage, warping, and change of dimension or weight. Results indicated that such a natural exposure has slightly more severe effects than those resulting from the moisture-differential or warping test. In an experiment with door-sized panels having interior facings of hardboard and exterior facings of aluminum, it was noted under winter conditions that thermal contraction of the outer facing was offset by the reduced dimension caused by low moisture content in the inner facing, so that bowing was quite small.

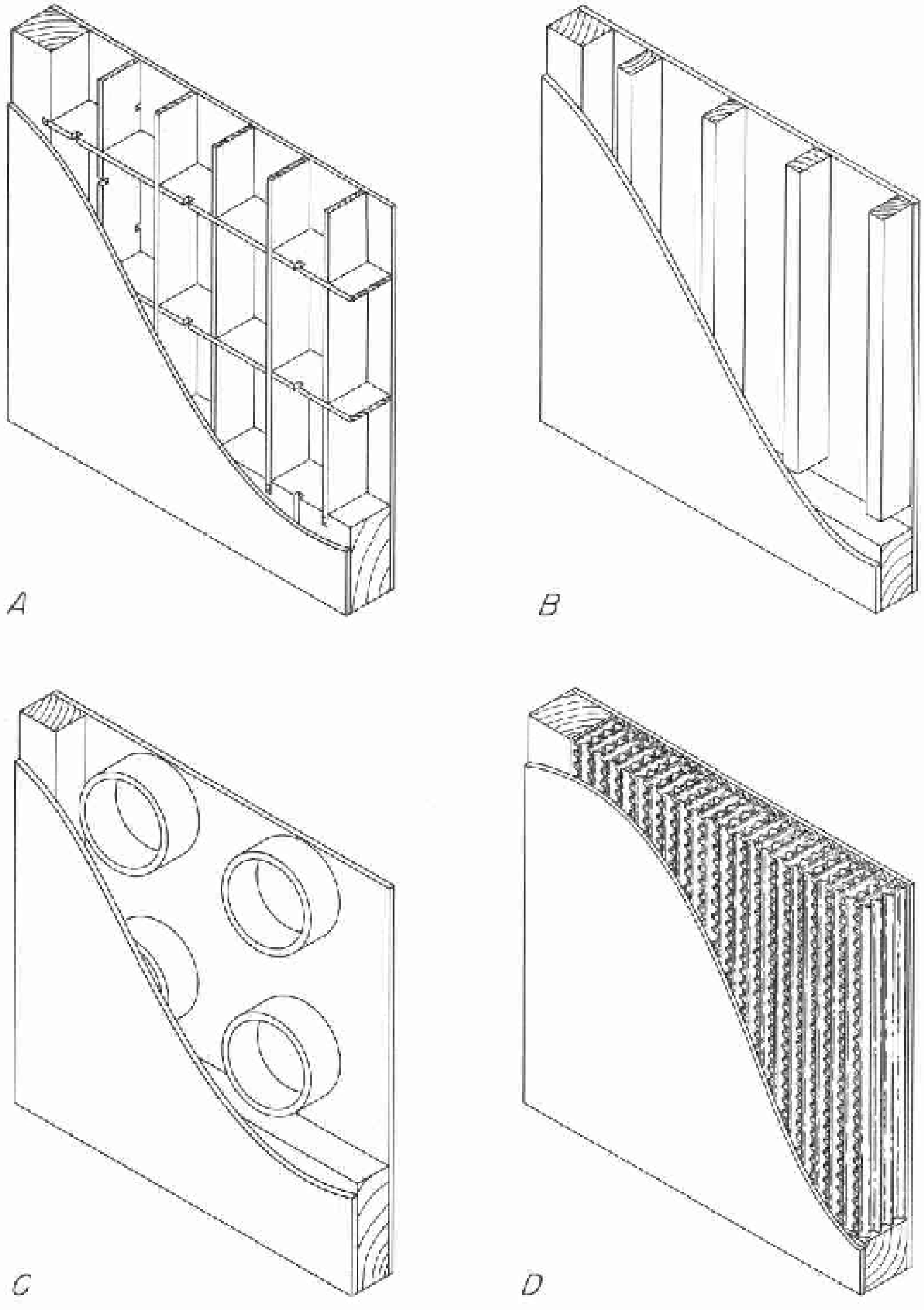

Figure 1. --Sketches of typical cores of: A, Lattice; B, ladder; C, tube; and D, honeycomb types used in hollow-core doors.

Z M 96381 F

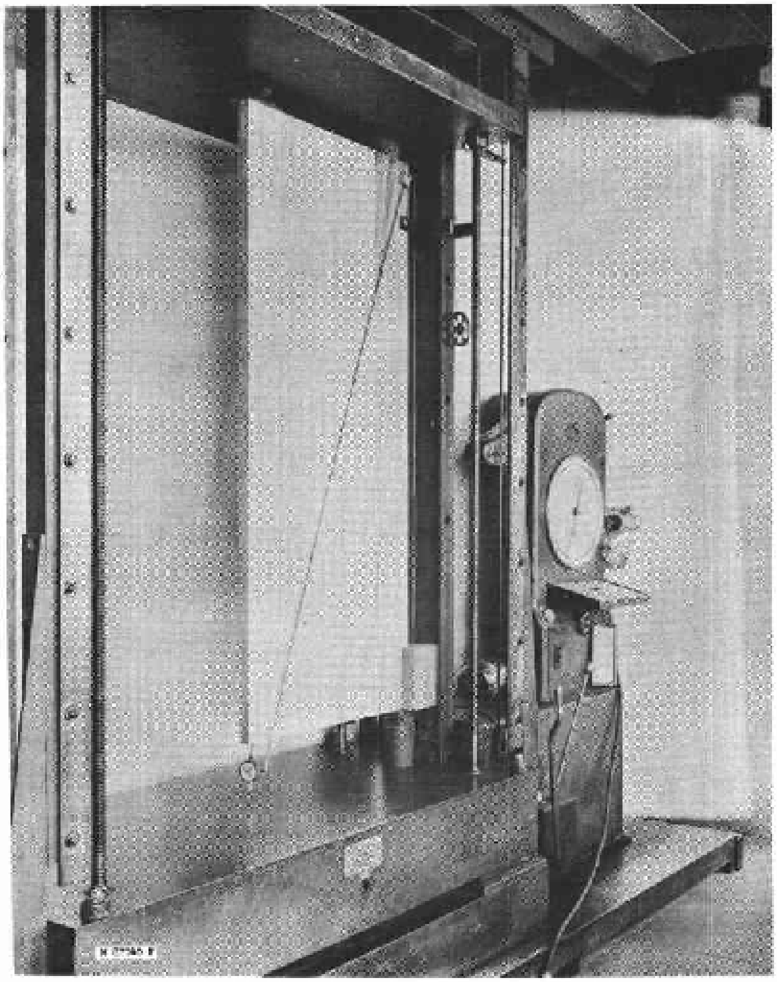

Figure 2. --Racking-parallel test of a hollow-core flush door.

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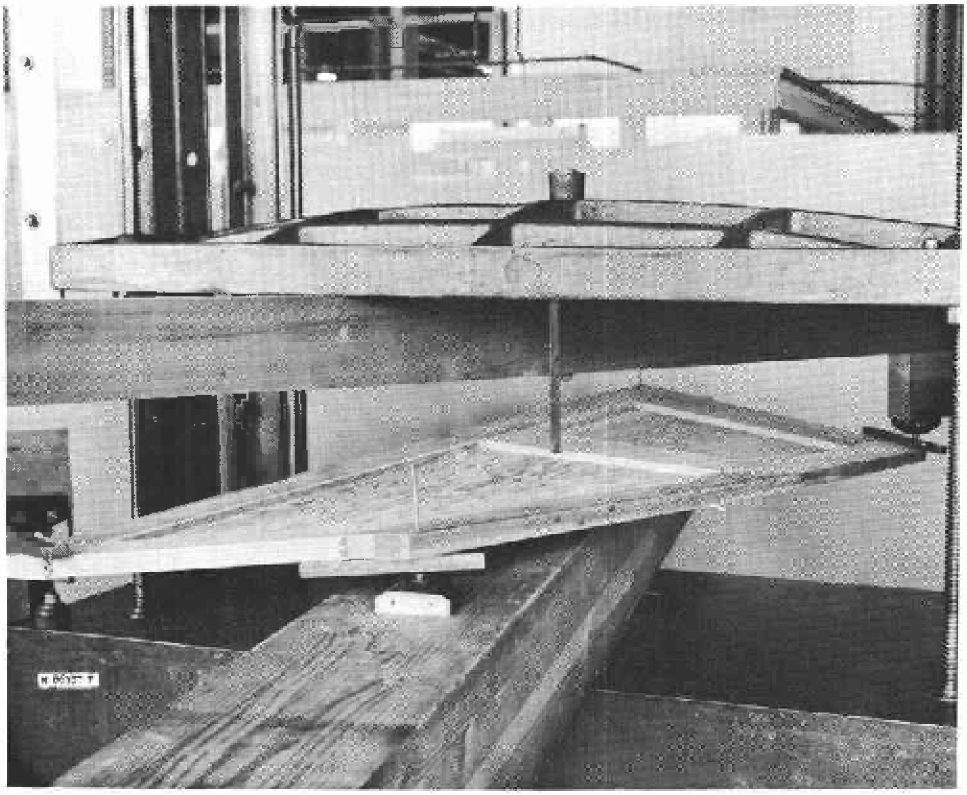

Figure 3. --Racking-perpendicular test of a panel-type door. Hollow-core flush doors are tested by the same method.

ZM 86357 F

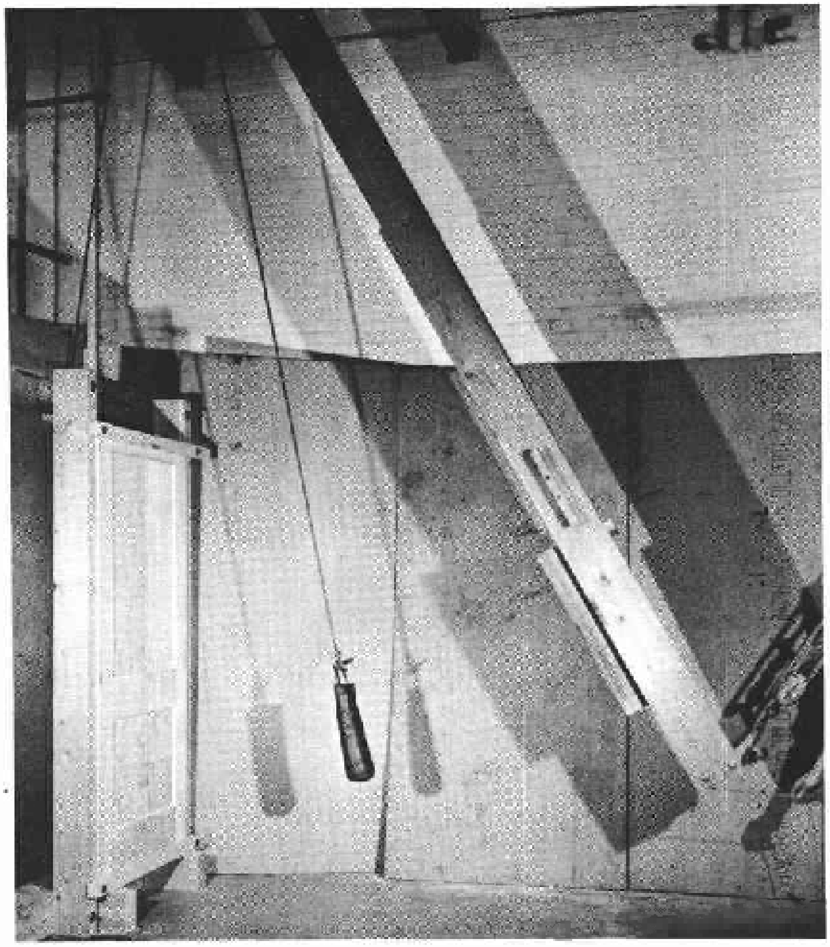

Figure 4. --Sandbag impact test on a panel-type door. Hollow-core flush doors are tested by the same method.

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