SOME FACTORS AFFECTING RESIN EFFICIENCY IN WOOD FLAKEBOARD

by

CHARLES HENRY BURROWS

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APPROVED:

Redacted for privacy

Associate Professor of Forest Products

In Charge of Major

Redacted for privacy

Head of Forest Products Department

Redacted for privacy

Chairman of Forestry School Graduate Committee

Redacted for privacy

Dean of Graduate School

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INTRODUCTION

Importance of efficiency in resin[1] application as it applies to manufacture of particle board cannot be over-emphasized. This statement is obvious, as cost of synthetic resins ranges from 30 to 60 per cent of total manufacturing cost. The question of how to obtain maximum efficiency from this expensive raw material naturally has been of considerable interest.

Application of a minimum quantity of adhesive to wood particles, with resulting optimum physical properties in a pressed board, would be a suitable definition for resin efficiency. Achieving this goal is not so simple as the definition might suggest. There are many factors that determine extent of resin efficiency, starting with characteristics of the raw materials--that is, wood particles, resin and other additives--and proceeding to the manufacturing process itself.

Lack of basic information has prevented thorough understanding of elements affecting efficiency of resin. Undoubtedly, one reason for this deficiency can be attributed to difficulty in studying the subject. For illustration, one might attempt to answer the question of how to measure, quantitatively or qualitatively, efficiency of resin distribution on wood particles.

The necessity of academic and also practical information is apparent; several prominent researchers on particle board have voiced this. Dr. Wilhelm Klauditz (9) states: "Exact examination

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1 The term resin refers to synthetic resins used as adhesives in the manufacture of particle board. Other terms such as adhesive or binder will be used synonymously throughout this thesis.

of the gluing processes of wood chips in the production of wood chipboards is considered as very purposeful and necessary." Dr. George Kitazawa (8) says: "It is highly desirable that the industry understand the mechanisms operating in the durability of boards, primarily mechanisms relating to inter-particle adhesion."

Objective of the study reported here was to investigate several factors suspected of influencing resin efficiency. Extensive observations were made on the wood particles (flakes), atomization of the synthetic binder (phenol-formaldehyde resin), and glue bond in the pressed board.

Flakes were selected for study because their dimensions could be controlled and their surfaces could be studied easily. Phenol-formaldehyde resin was chosen because, when cured, this adhesive is dark and can be seen plainly.

Flakeboards were tested, and data on modulus of rupture and internal bond were analyzed statistically to evaluate effects of moisture content at time of flaking, degree of resin atomization, and resin content.

LITERATURE REVIEW

Despite the youth of the particle board industry, which started in Europe about 1940, considerable technical information is available in the literature. An excellent reference is the Wood Particle Board Handbook (7). To completely cover all facets of manufacture and to investigate the many factors influencing physical properties of particle board is beyond the scope of this thesis. A brief summary of some research is necessary, however, to acquaint the reader with several general areas of study. In the ensuing discussion, literature of a general nature will be presented first; following this, findings particularly pertinent to the thesis will be examined.

General

Physical properties of particle board have been associated directly with characteristics of the wood raw material. Turner (26, pp. 219-223) investigated effects of size and shape of particles on physical properties of particle board. He studied wood particles in the form of flakes, thin strands, helical ribbons, and cubes. Panels bonded with phenol-formaldehyde resin were made of each kind of wood particle. One general conclusion from his study was that size and shape of particles were strong determinants of both structural qualities and dimensional stability. Panels containing long, flat flakes had exceptional values for modulus of rupture, but strands and ribbons produced panels having dimensional stability superior to that of panels made of flakes. Poorest physical properties were exhibited by panels made from wood cubes.

In another study by Post (21, p. 322), flakes of various lengths and thicknesses were investigated. Resin content was variable. Results of analysis of variance showed that resin content was not so important as flake geometry. Data showed that as flakes increased in length, values for modulus of rupture also increased. Conversely, increasing thickness of flakes caused bending strength to decline; this effect, however, was confounded with surface quality.

German technologists advocate engineered particles for particle board manufacture. Such particles are produced by a cutting or slicing action and are characterized by smooth surfaces, undamaged conditions, and uniform dimensions. Examples of such specially-prepared particles would be flakes or strands. Klauditz (10, pp. 233) supports this German practice mainly on the basis of economics. He states, "In the years 1948 to 1951, it was recognized that the manufacture of wood particle boards using waste from wood working machines, e.g. sawdust and shavings, or even somewhat coarser waste would not yield profitable results or only very limited ones, since the products thereof were too low-grade and the cost comparatively too high. These facts having been recognized, and marketing conditions in Western Europe, especially in Germany, duly considered, the necessity of a basic change in particle board manufacture became obvious. It was necessary to manufacture engineered particles from fuel wood or from available pieces of wood waste."

Although most American manufacturers utilize hammer-milled wood in the form of shavings, splinters, or chips, some emphasis has been placed on engineered particles or flakes. Marra (18, p. 1) describes some advantages of using flakes: dimensions of flakes can be controlled to obtain optimum length-thickness ratio, technique of producing flakes reduces damage to surface and interior, and flakes can be cut so that component fibers parallel the surface, thus contributing increased strength to the board. Marra suggests optimum thickness of flakes to be in the range from 0.005 to 0.015 inch, optimum lengths to range from 3/8 inch to 4 inches, and most desirable widths to be from 1/8 inch to 2 inches.

Ulbrecht (27, pp. 1, 5) further substantiated the importance of thickness of particles on particle board made from pine by showing that as thickness increased from 0.1 mm to 1.0 mm, bending strength dropped from 4180 to 2170 pounds a square inch. Tensile strength dropped off from 2640 to 1120 pounds a square inch. In this work, length of particle (1.18 inches), specific gravity of board (0.55) and resin content (8 per cent urea-formaldehyde) were held constant. Only thickness was varied.

Resin content is another important determinant of physical properties of particle board. In a technical service bulletin issued by American-Marietta Company (1, p. 2), data are provided to show influence of resin content. For chip-type particle boards, strength and dimensional stability both improve with increasing resin content up to 6 per cent, then level off. Both urea-formaldehyde and phenol-formaldehyde resins were examined in this study.

Sears (22, pp. 93-103), while investigating effects of resin content, moisture content, and molding pressure on physical properties of particle board, found that, as resin (powdered phenol-formaldehyde) content was increased from 6 per cent to 9 per cent, flexural strength and specific gravity were increased, and water absorption decreased. This effect of resin content was observed for both ponderosa pine sawdust and a mixture of oak, maple, and birch sawdust. Sawdust was screened to pass a 1/8-inch sieve. Pressing conditions were constant.

Turner (26, pp. 219, 222), in a study described previously, showed a relationship between modulus of rupture and resin content for all of the particle shapes he used. Also, resin content directly influenced springback behaviour; highest resin contents showed lowest degree of recovery. Recovery was measured after two cycles of soaking and drying.

Work by Larmore (14, p. 134) indicated that resin content influenced dimensional stability. Increasing resin content caused change in thickness to decrease. This study was designed to study specific gravity of the wood, resin content, and density of the board.

Several workers have determined the importance of specific gravity on physical properties of particle board. Turner (26, p. 220) found that density of the board was a prime influence in controlling strength. In this respect, properties of the board improved as density was raised.

In a study by Miller (20, pp. 149-151), board density was observed to be an important determinant of such physical properties as modulus of rupture, tensile strength, shear strength, screw holding, hardness, and thickness swelling. All data in this study were based on resin that had been extended from 16 to 31.3 per cent.

Larmore (14, p. 134) pointed out that specific gravity of the wood, as well as density of the pressed board, can be important determinants of physical properties. Boards made of aspen flakes showed better values for modulus of elasticity, work to maximum load, and linear change than did boards made of yellow birch flakes with higher density. This analysis also showed modulus of elasticity to vary directly as density of the board.

Importance Of Wood-Particle Preparation

Quality of wood can be an important contributing factor in acquiring good efficiency from any resin adhesive. In this respect, extent of damage to surface or interior occurring during preparation of wood particles may well be the dividing line between good and poor efficiency of resin. "Engineered" particles in Germany and flake-type particles in this country have been developed to minimize damage to wood raw material. Wood technologists have proclaimed the significance of high-quality wood particles.

Marian (16, p. 176), in suggesting areas for research, mentions a need for more work on preparation of chips. He emphasizes the merits of producing particles that are relatively undamaged. Damage to surfaces appearing as cracks, fissures, and ruptures can cause excessive penetration of resin.

Kollman (11, p. 9) relates poor bonding action to the influence of surface and shape of chip. He states, "Chips broken up by impact have a very irregular shape and surface; therefore, it is difficult to cover their surfaces uniformly with the glue, and a relatively large portion of the expensive binder does not contribute to their cementation."

In describing desirable attributes of wood particles, Marra (18, p. 3) lists smooth, flat surfaces along with optimum length and thickness. Such attributes encourage increased efficiency of resin, according to the author.

Menger and Bock (19, p. 1), in support of their invention involving use of foamed binders in making shaped or molded articles, relate some disadvantages of standard, liquid binding agents when applied to porous materials such as wood dust or shavings. They believe excessive use of binding agent is caused by over-penetration of resin into the particles. Penetration of adhesive into the interior of particles was thought to be detrimental, since particle-to-particle bonding occurs only at the surfaces.

Discussing some factors affecting properties of wood chipboard, Lynam (15, pp. 18-19), points out that moisture content of wood at time of cutting the chips can make the difference between smooth- and rough-surfaced chips, and, similarly, between high and low consumption of adhesive. Particles having smooth surfaces will absorb little resin and promote efficient use of resin, which, in turn, contributes to strength of the board.

Herdey (6, pp. 5, 7) cites histological structure of wood raw material--porosity, density, and cell structure--as being important when selecting type and condition of binder. Also, histological structure, particularly porosity, is very significant in regard to quantity of required binder.

Significance Of Resin Application

Application of binder to the particles is one of the most critical operations in achieving efficiency of binder in manufacture of particle board.

Hadley (5, pp. 20-21) discusses coating of chips with resin and mentions that the goal is to assure complete coverage of each particle with a micro-thin layer of resin. This can be achieved by atomizing the resin and agitating the chips.

In an article by Fehn (4, pp. 4-5), emphasis is placed on the idea that the adhesive should remain on surfaces of particles and not penetrate. Excessive penetration of resin into particles is detrimental to economic application. Also, two disadvantages of applying excessive quantities of binder are cited as making boards too brittle (which affects bending strength), and increasing the density.

A paper by Marra (17) points out the ultimate goal in resin application. This goal is achieved by placing an equal quantity of binder on each wood particle in such a manner as to insure even distribution of resin on surfaces of particles. Marra mentions that this goal is achieved only partially in actual mixing operations, since accomplishment is a matter of statistical chance.

Kollman (13, p. 10) realized the impracticality of depositing a completely continuous layer of adhesive over each chip with present methods and equipment. Even in view of these technological inadequacies, however, he thought that efforts should be directed toward deposition of a continuous, uniform layer of resin of minimum thickness on all wood particles.

When applying resin adhesive to wood particles with a spray, atomization is all-important. During atomization, liquid resin is broken up into numerous small droplets. Surprisingly little research has been devoted to studying atomization and its importance to efficiency of resin.

Marian (16, pp. 172-173) suggests a need for research in resin atomization. Exploratory work has shown that molecular weight of the resin influences atomization; for example, size of resin droplets increased directly with molecular weight of the resin. Synthetic resins used in the manufacture of particle board do not atomize easily to form fine droplets, because of their high molecular weight. To illustrate the process of atomization, Marian describes a jet of liquid resin travelling at a velocity of 100-1000 feet a second being broken up into small droplets. This atomization continues from the time the resin leaves the orifice until the velocity of droplets is virtually zero.

Kollman (12, p. 3) specifies some pressures used in atomization. Liquid glue is pumped to the nozzle at pressures of 1-2 kilograms per square centimeter (about 14.2 to 28.4 pounds per square inch), and air used to atomize the resin is under a pressure of 2-3 kilograms per square centimeter (about 28.4 to 42.6 pounds per square inch).

Other research (25) has indicated that length of spraying time has an influence on modulus of rupture. In this study, five series of particle boards were prepared in the laboratory using various spraying times between 5 and 25 minutes. Resin content and rate of atomizing air were held constant. As a result of this work, the recommendation was made that a study of air-to-resin ratios be made, since this ratio varied with spraying time; that is, reduced spraying time decreased the air-to-resin ratio.

The objective of a study by Suchsland (24, pp. 579-599) was to produce, test, and evaluate the quality of glue bonds similar to those occurring in manufacture of flake boards. This was accomplished by spraying an adhesive on thin squares of veneer, laminating a pair of these squares, and testing the laminated specimens in shear. Variables included glue spread, specific gravity of laminates, moisture content of laminates prior to application of glue, and laminating pressure. Adhesive was sprayed from a gun onto 3-inch squares of veneer. Spray was passed over specimens at uniform speed and distance. Results of this study indicated that for low-density woods (less than 0.5 specific gravity), glue spreads as low as 0.3 grams a square foot produced bonds with shear strength stronger than the wood. For species of higher density, strength of glued joints did not exceed strength of the wood, showing an effect of glue spread on strength of joint.

Some pertinent research conducted by Brumbaugh (2) illustrated the importance of atomization. In this study size of resin particles was varied to produce fine, medium, and coarse spray. This was accomplished by using three nozzles with orifices of different diameters. Rate of spray, air pressure, and other spraying conditions were held constant. A series of flakeboards sprayed with urea-formaldehyde resin and another group containing phenol-formaldehyde resin were pressed and tested. Analysis of test data showed that physical properties, such as modulus of rupture, internal bond, linear expansion, and thickness swelling, declined as size of resin particles increased from fine to coarse. This effect was especially noticeable for modulus of rupture and internal bond.

EXPERIMENTAL PROCEDURE

Douglas-fir, 1- by 4-inch, unseasoned boards (Figure 1) were obtained from a local sawmill. The boards were flat-grained, mostly sapwood, and averaged 12 rings to an inch. Boards were cut into blocks 4 inches square and separated randomly into two groups. One group was stored at conditions for 20 per cent equilibrium moisture content (90 F temperature and 90 per cent relative humidity). Remaining blocks were immersed in water and stored at 35 F. After conditioning for two months, blocks immersed in water averaged 116 per cent moisture content; other blocks averaged 26 per cent.

Blocks were reduced to flakes in a disc-type flaker (Figure 2) at the laboratory of Washington State Institute of Technology, Pullman, Washington. Flakes, cut from the radial edge of blocks, measured a maximum of 1 inch in length and width; they averaged 0.015 inch in thickness. Precautions were taken to assure that knives were consistently sharp, especially when blocks of low moisture content were being sliced. Flakes were kept separate according to moisture content at flaking.

Drying (Figure 3) was accomplished at room conditions. After two months of air drying, moisture content of the flakes had stabilized at about 9 per cent.

Dried flakes were screened on an oscillating chip screen. Only flakes retained on a 2-mesh screen were considered acceptable. Yield of acceptable flakes cut at high moisture content was 56 per cent and for flakes cut at low moisture content, 53 per cent. Differences here were judged insignificant.

Both groups of screened flakes were divided to form four sub-groups. Two of these sub-groups, each representing a different

Figure 1. Douglas-fir, 1-by 4-inch boards selected as raw material for study.

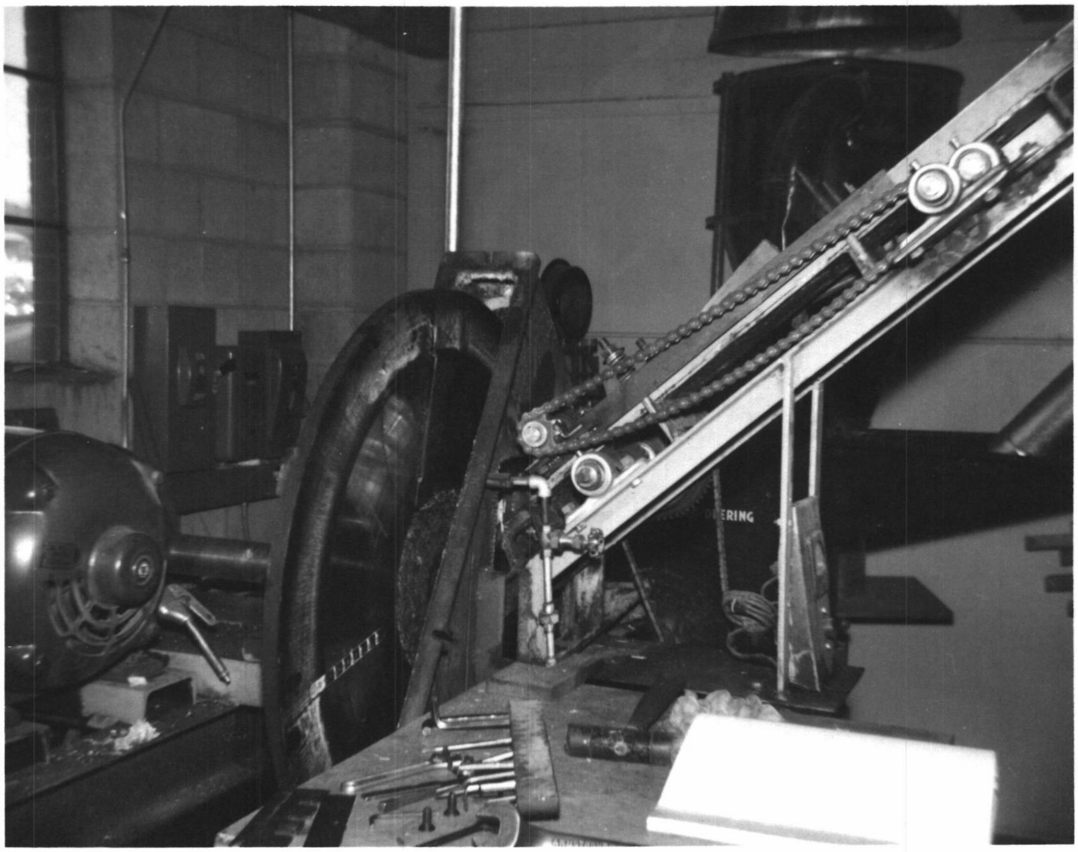


Figure 2. Disc-type flaker used to produce wood flakes.

Figure 3. Drying flakes in the laboratory.

moisture content at time of flaking, were air-dried further from 9 per cent to 6 per cent at 90 F and 22 per cent relative humidity. Drying was accomplished in one month. Purpose of drying flakes to two levels of moisture content was to assure a like moisture content for all mats. With two levels of resin content (2 per cent and 6 per cent), flakes at 6 per cent moisture content were to be sprayed with 6 per cent resin, and flakes at 9 per cent moisture content were to be sprayed with 2 per cent resin. Moisture content of flakes and resin content were so arranged as to achieve uniformity in moisture content for the mats.

Observing Flake Characteristics

An investigation of flakes was made under the microscope. Internal and external structure was observed and evaluated qualitatively according to moisture content at time of flaking, rate of growth and, in some instances, effects of drying.

Microscopic cross sections of flakes were prepared to study degree of internal damage. Unseasoned flakes were softened, then sectioned on a microtome (Figure 4). Flakes with slow and fast growth (more or less than 6 rings to an inch) and two moisture contents at time of flaking are shown in Figure 5. Sections were selected to portray several findings made during microscopic observations.

Internal damage was negligible in all flakes, regardless of rate of growth or moisture content at flaking. In a few flakes, rupture in the summerwood occurred (Figure 5, A and B). Surface damage was apparent, but could not be correlated with moisture content at time of flaking, or rate of growth. Injury at the surface generally

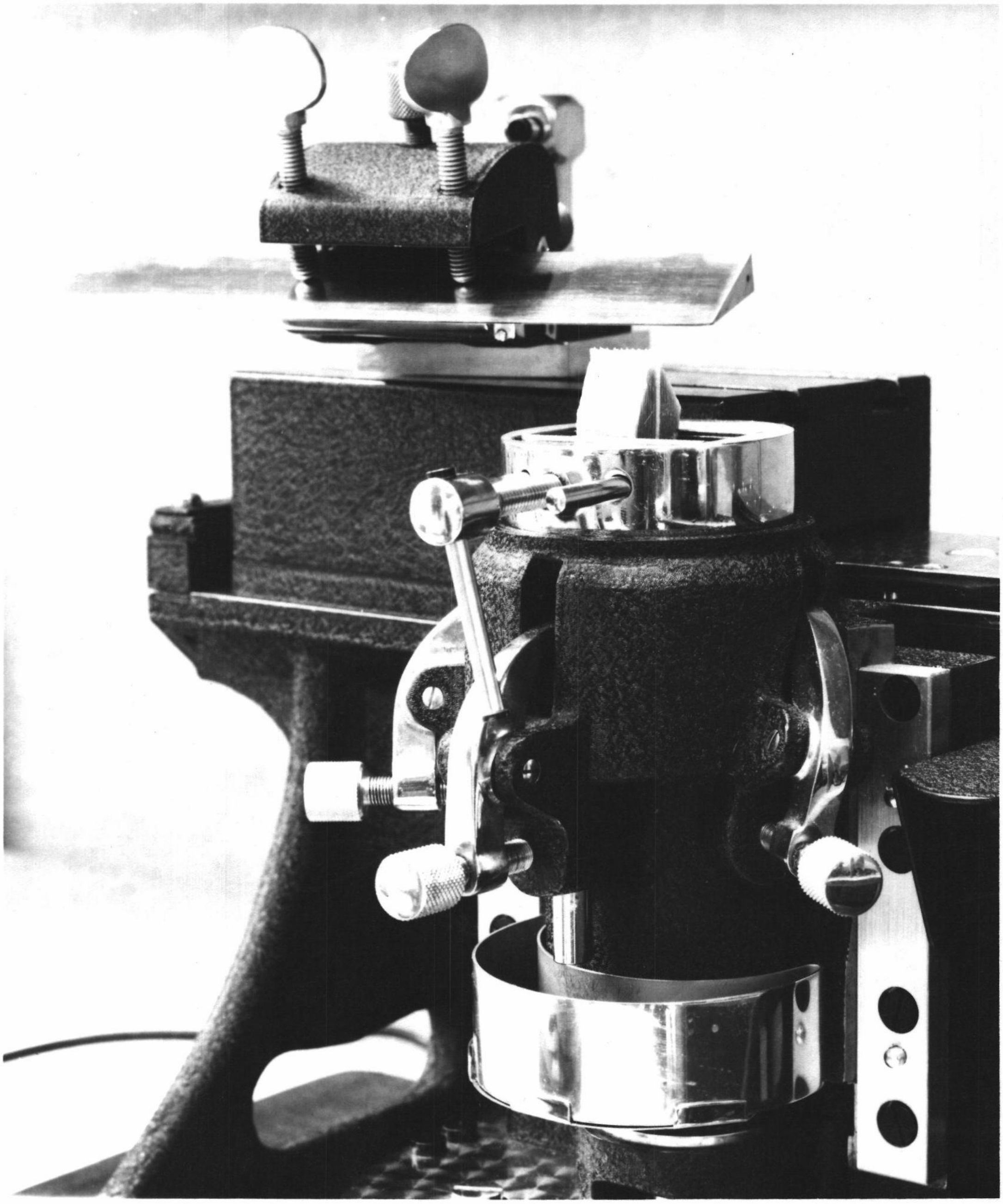


Figure 4. Microtome used to section flakes; flakes were held rigidly between wooden blocks during slicing.

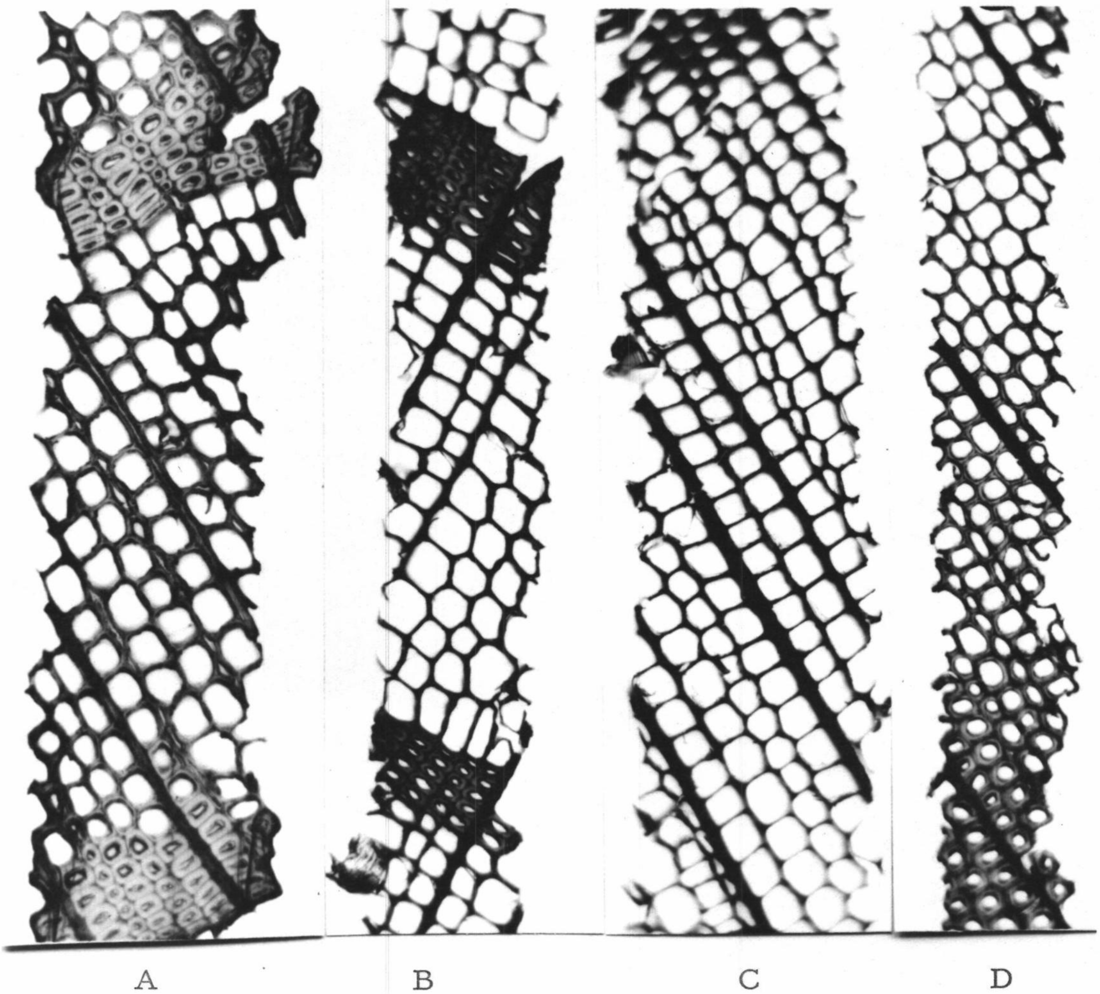


Figure 5. Microscopic cross sections of flakes: A, slow growth flaked at high moisture content; B, slow growth flaked at low moisture content; C, fast growth flaked at high moisture content; D, fast growth flaked at low moisture content. Magnification is 70X.

was restricted to the outermost row of cells, although sometimes it extended into the second row of cells.

Flake surfaces were investigated in several ways. One method, "highlighting", described by Elmendorf and Vaughan (3, pp. 276-277), was used to observe the entire flake surface. By positioning a light source at an angle to the flake, ridges and depressions on the surface were differentiated. Macrophotographs were taken of flakes in an effort to correlate smoothness or roughness with moisture content at time of flaking, rate of growth, and surface changes due to drying. In Figures 6 and 7, several flake surfaces are represented. In each photograph, the bottom half of the flake is undried, and the top half has been dried to 9 per cent moisture content. Major differences in surface quality, due to the three conditions stated above, were anticipated, but were not found. In some instances, flakes cut at lowest moisture content had smoother surfaces than flakes cut at high moisture content, and vice versa. Also, rate of growth appeared to have no connection with surface quality. Contrary to expectations, drying had no obvious effect on profile. Probably, inherent variability of wood flakes was extensive enough to eliminate distinct difference between surfaces.

Another technique employed to observe flake surfaces has been called "light-sectioning". This process is described by Stumbo (23, pp. 123-124) and by Elmendorf and Vaughan (3, p. 276), who call it the light-ribbon test. Procedure is to project a thin ribbon of light on an inclined surface and photograph the display. In this fashion, surface contours can be observed and evaluated. Macrophotographs were taken of flake-surface profiles with light projected across the grain. Several of these light-sections are shown in Figure 8.

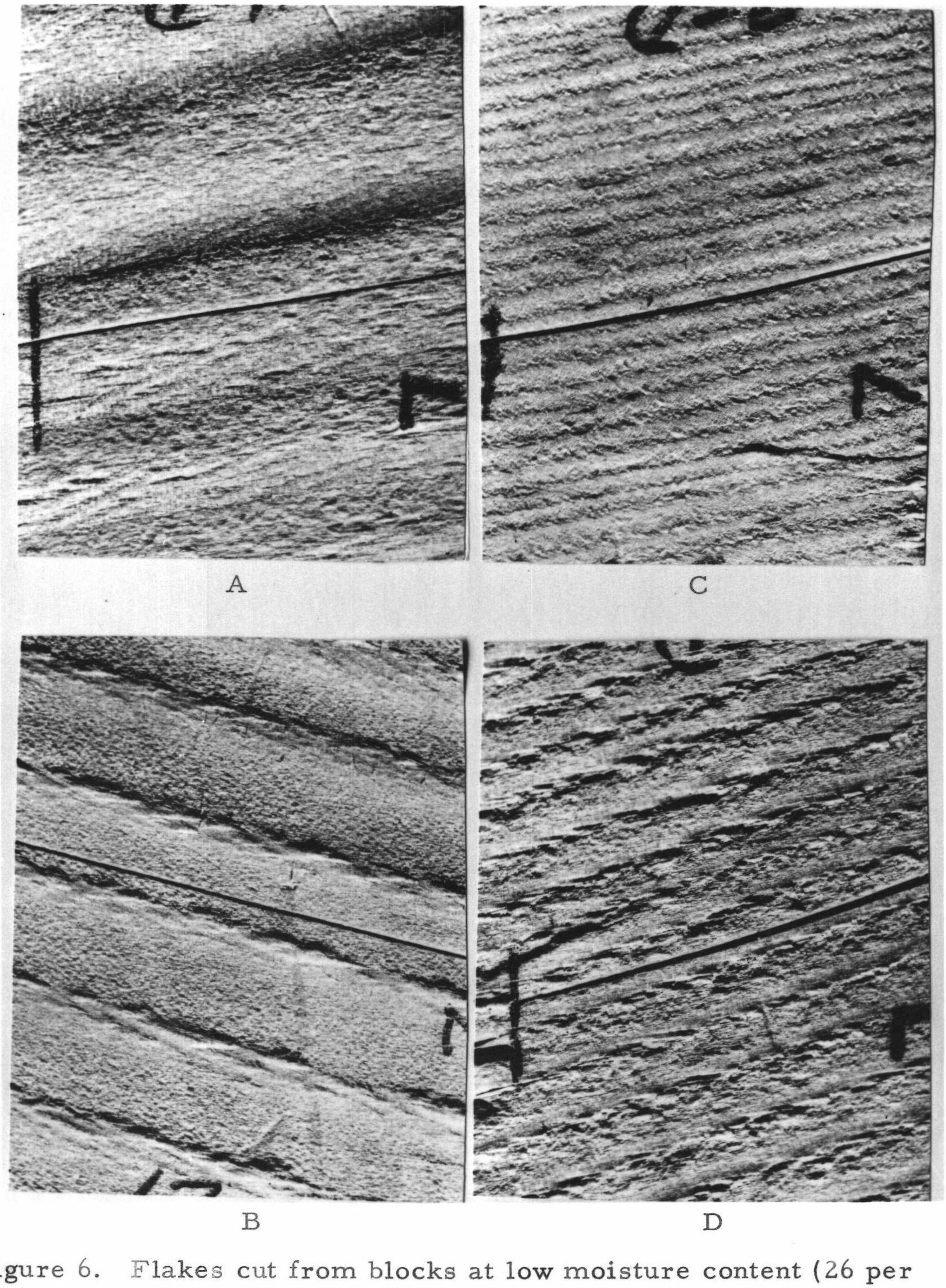
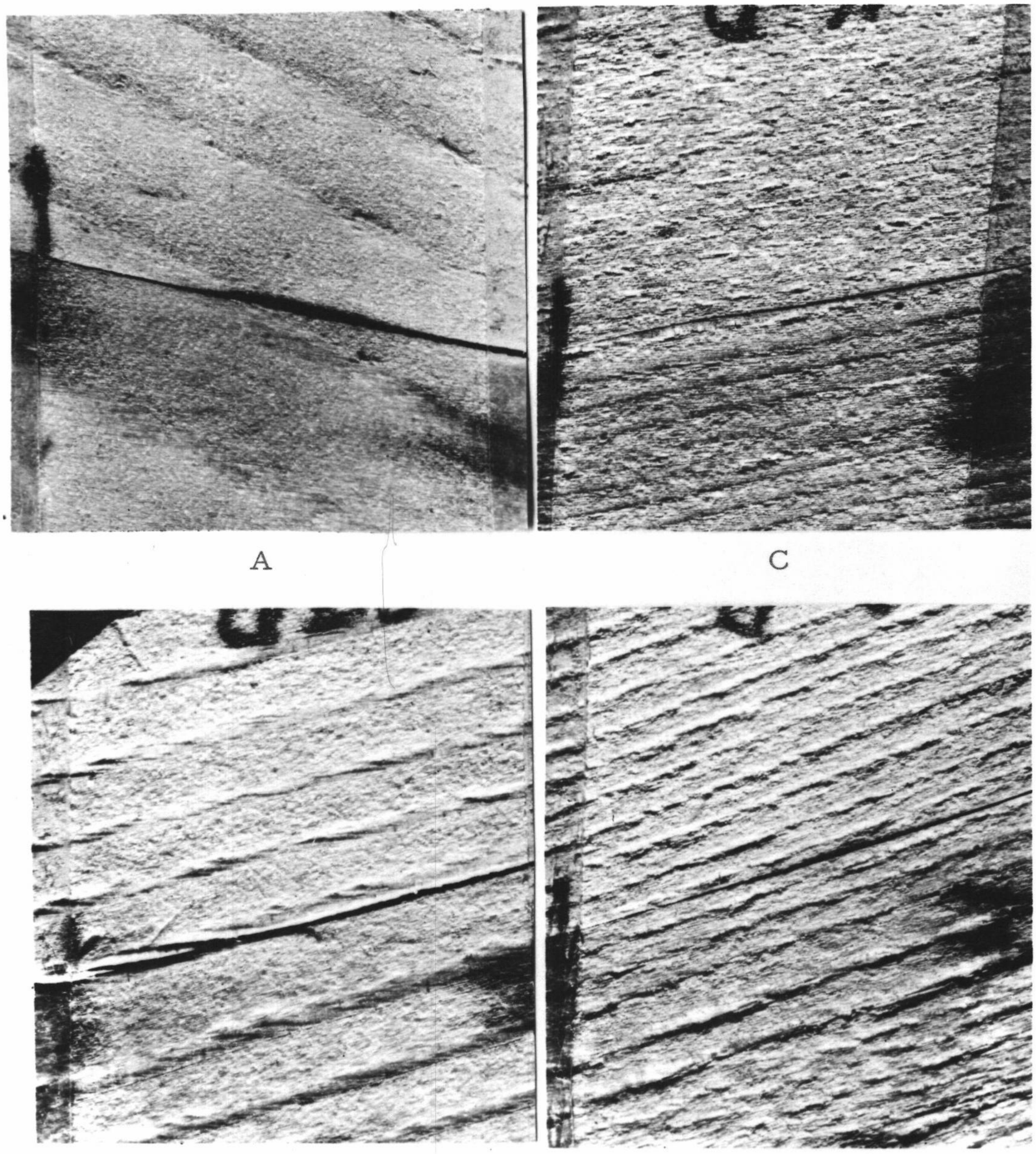


Figure 6. Flakes cut from blocks at low moisture content (26 per cent). Highlighting shows variety of surface profiles: A, fast growth, smooth surface; B, fast growth, rough surface; C, slow growth, smooth surface; D, slow growth, rough surface. Bottom halves of flakes are undried; top halves are dried. Magnification is 5X.



A C

B D

Figure 7. Flakes cut from blocks with high moisture content (116 per cent). Highlighting shows variety of surface profiles: A, fast growth, smooth surface; B, fast growth, rough surface; C, slow growth, smooth surface; D, slow growth, rough surface. Bottom halves of flakes are undried; top halves are dried. Magnification is 5X.

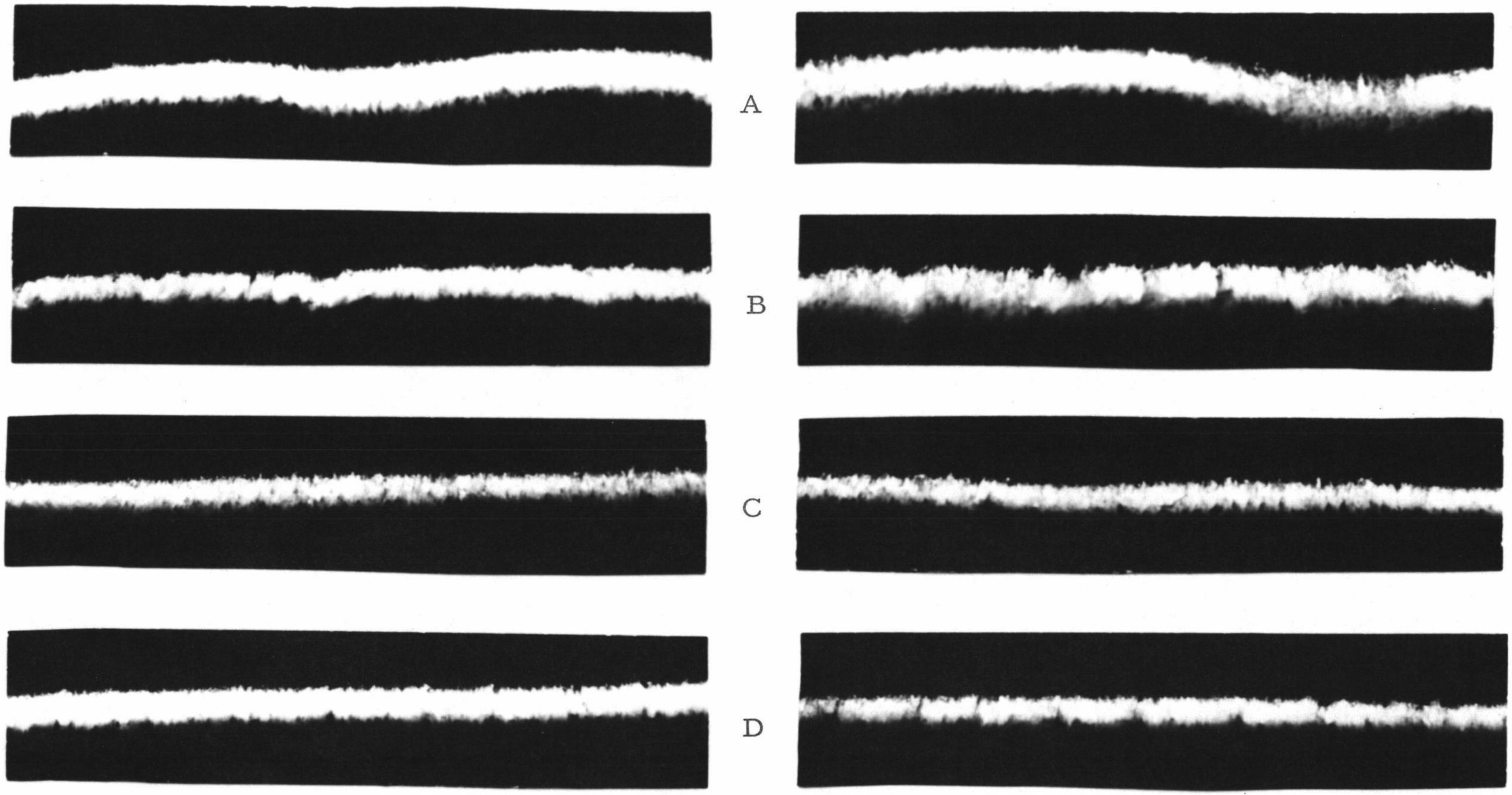


Figure 8. Light sections of flake surfaces: A, fast growth flaked at high moisture content; B, slow growth flaked at high moisture content; C, fast growth flaked at low moisture content; D, slow growth flaked at low moisture content. Sections on right were photographed in undried condition; sections on left are of same flake after drying. Magnification is 4X.

Photographs are arranged in pairs to illustrate flakes in undried and dry conditions; flakes were photographed initially undried, then were dried and rephotographed in essentially the same location. Surface smoothness or roughness was difficult to relate to moisture content at time of flaking, or to effect of drying. Again, as related previously, variability of flakes was thought too great to discern distinct differences in surface quality. Two distinctions were noted relative to rate of growth, however. First, fast-growth flakes (fewer than 6 rings an inch) were nearly all characterized by sine curve profiles; flakes with slow growth did not show this contour (compare Figure 8, A and D). Secondly, surfaces of fast-growth flakes appeared smoother than those of slow-growth flakes (compare Figure 8, B and C).

Preparing Panels

Flakes and resin were mixed in a batch-type mixer (Figure 9). No wax was added. Phenol-formaldehyde resin (Monsanto PF575) was sprayed, undiluted, at 70 F. Resin contents were either 2 or 6 per cent, based on oven-dry weight of the flakes. Rate of resin emission was constant at 20 grams of resin solids a minute. Degree of atomization was varied from fine to coarse by changing atomizing air pressure from 80 to 60 pounds. After blending, moisture contents averaged 10.8 per cent.

Mats were hand-formed (Figure 10), 3 inches thick and measured 18 by 18 inches. Panels were pressed (Figure 11) to 1/2-inch thickness using metal stops; press closing time averaged 2 1/2 minutes. Initial pressing pressure was 250 pounds a square inch, pressing temperature was 330 F and press cycle lasted 12 minutes.

Figure 9. Drum mixer in which resin was sprayed on flakes.

Figure 10. Hand-forming a mat.

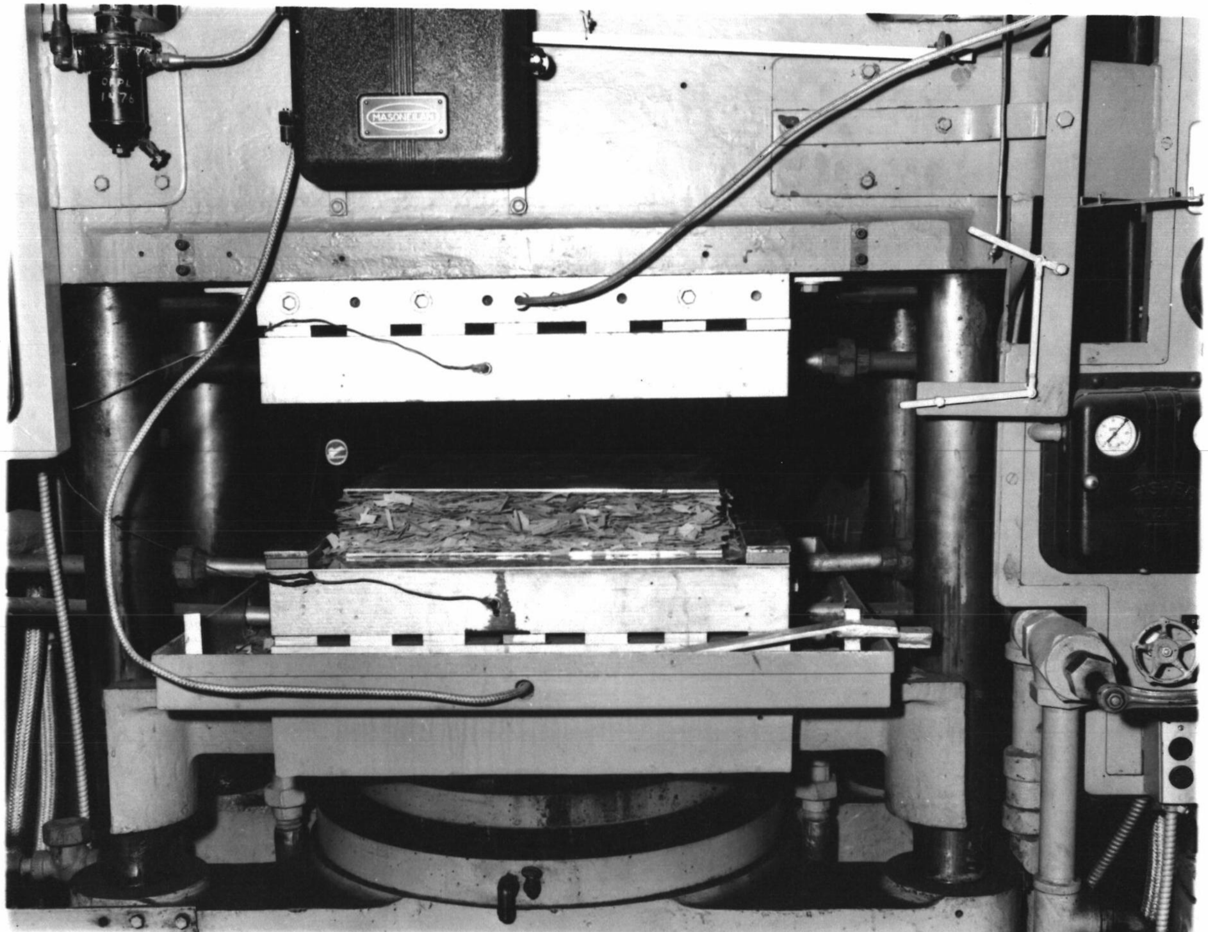


Figure 11. Mat ready for pressing.

To assure complete resin cure, each board was sealed in a plastic sack immediately after pressing and placed in an oven at 150 F for 20 hours. Panels were cooled and trimmed into 15-inch squares preparatory to cutting test specimens. A total of 24 panels was prepared.

Resin Atomization, Distribution, And Bonding

To observe resin atomization, several techniques were tried. When viewed in mid-air (Figure 12) degrees of atomization were distinct, after enlargement as in Figure 13, F and C. In both instances, enlargements were made of the spray area 10 inches from the nozzle, the distance from gun to flakes during mixing. Fine atomization (Figure 13 F) produced smaller droplets than did a coarse spray (Figure 13 C).

To further establish differences in atomization, resin was sprayed onto paper, and the resin droplets were heat-cured to obtain a display. One method involved exposing the paper to a short blast of spray at a distance of 10 inches (Figure 14). A shield was placed between the gun and paper and lifted for a split-second exposure. Results are shown in Figure 15, F and C. By this technique, differences in degrees of atomization could be observed. When inspected closely, spray patterns of coarse atomization typically had more large droplets than did patterns of fine atomization.

Results of another technique to observe resin-spray patterns is shown in Figure 16, F and C. Here, the paper was dropped through the spray (Figure 17), thus simulating the condition that might exist in mixing; that is, free-falling, tumbling flakes passing through the spray. Spray patterns did show differences, mainly in size of resin

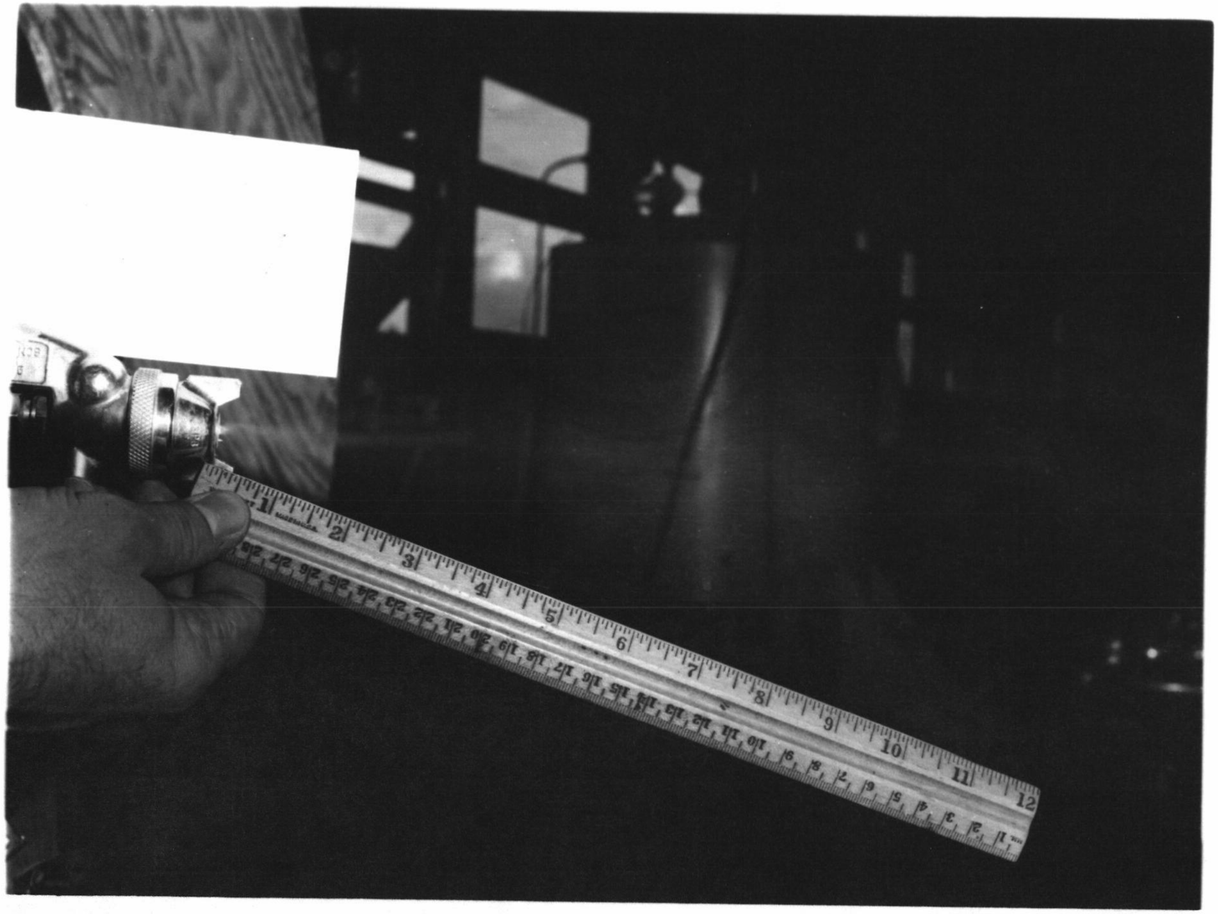
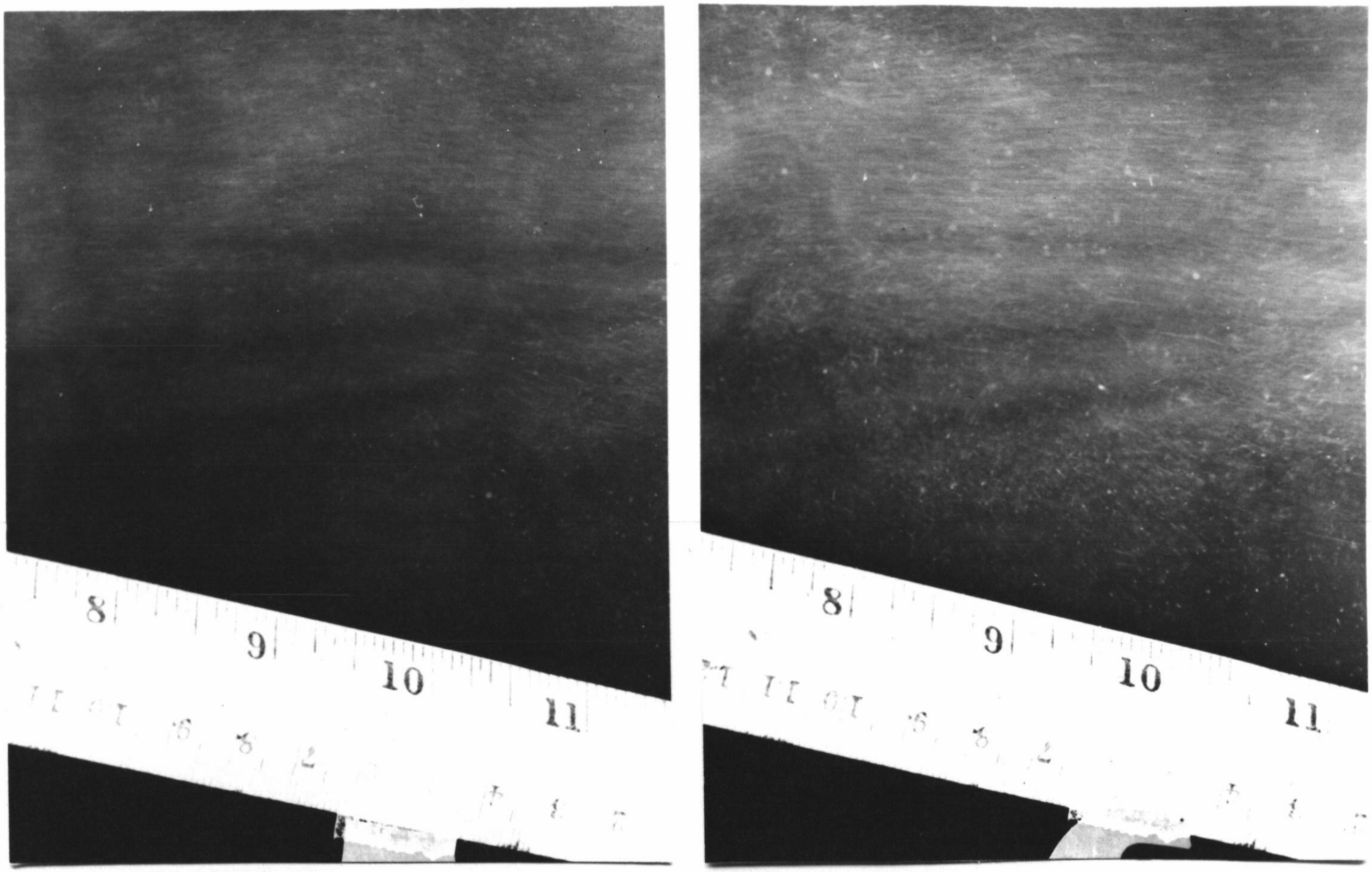


Figure 12. Observing resin spray in mid-air.



F C

Figure 13. Atomization at 10 inches from spray nozzle: F, fine; C, coarse.

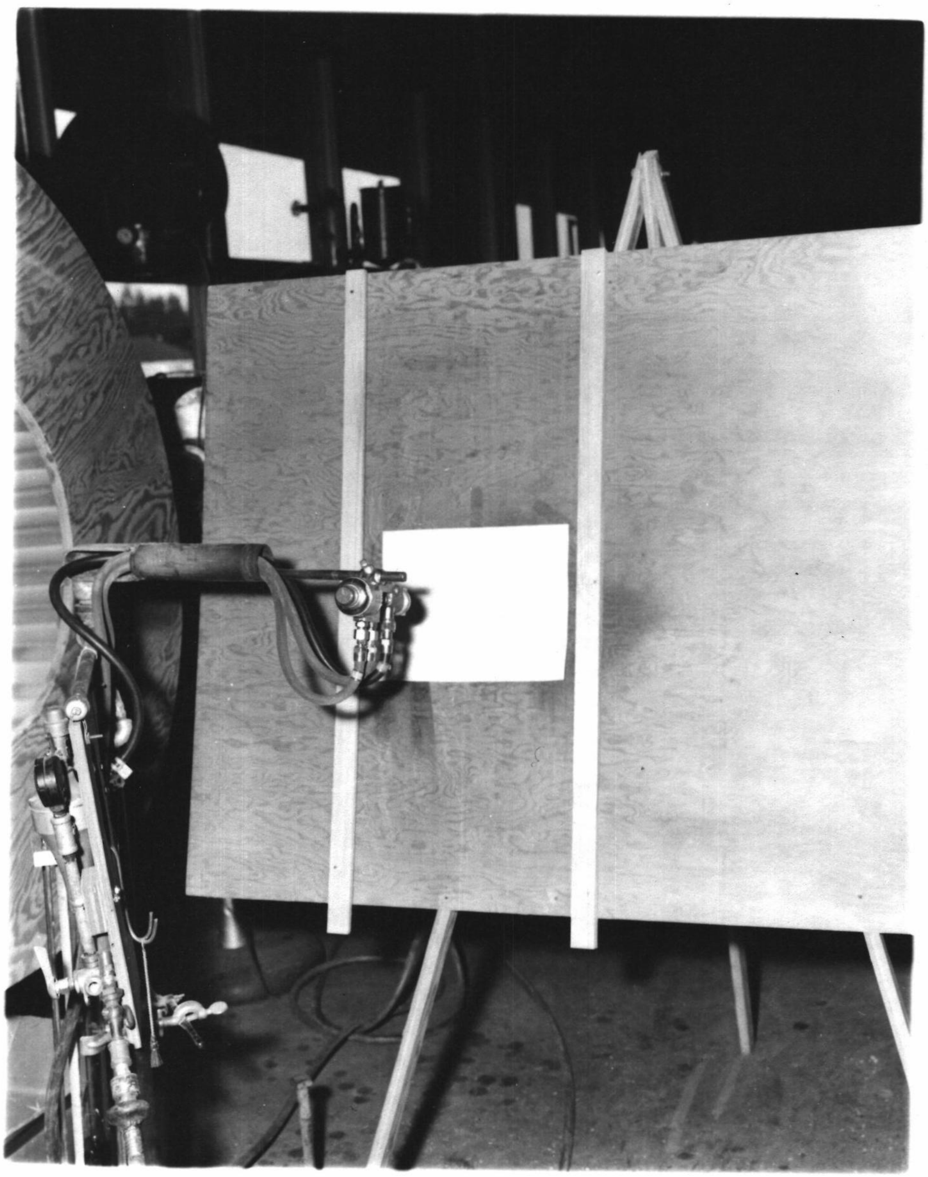


Figure 14. Apparatus to obtain resin spray patterns; the paper was exposed to the spray for a very short time.

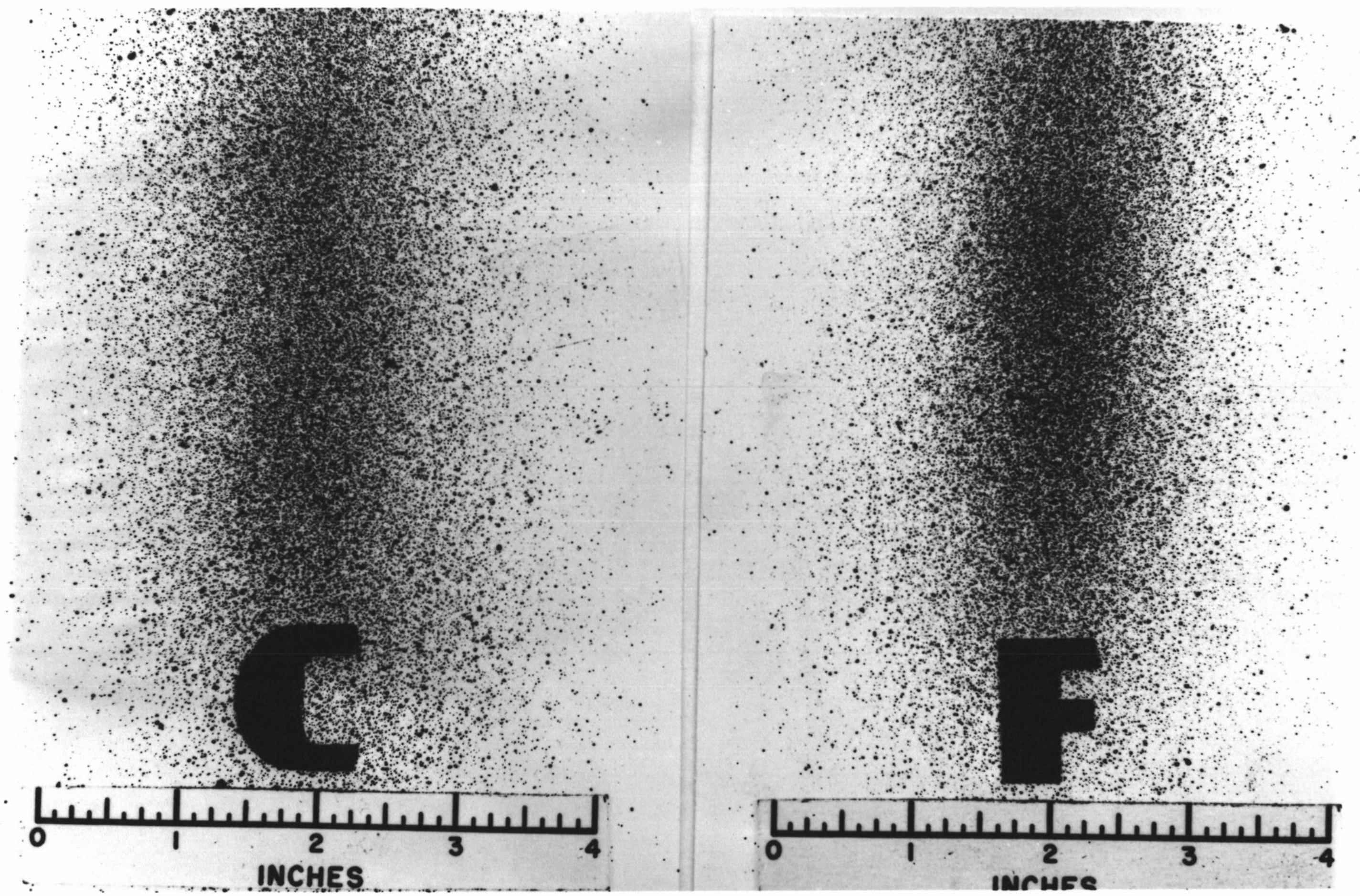


Figure 15. Pattern with spray of short duration: F, fine spray with 80 pounds atomizing air; C, coarse spray with 60 pounds atomizing air.

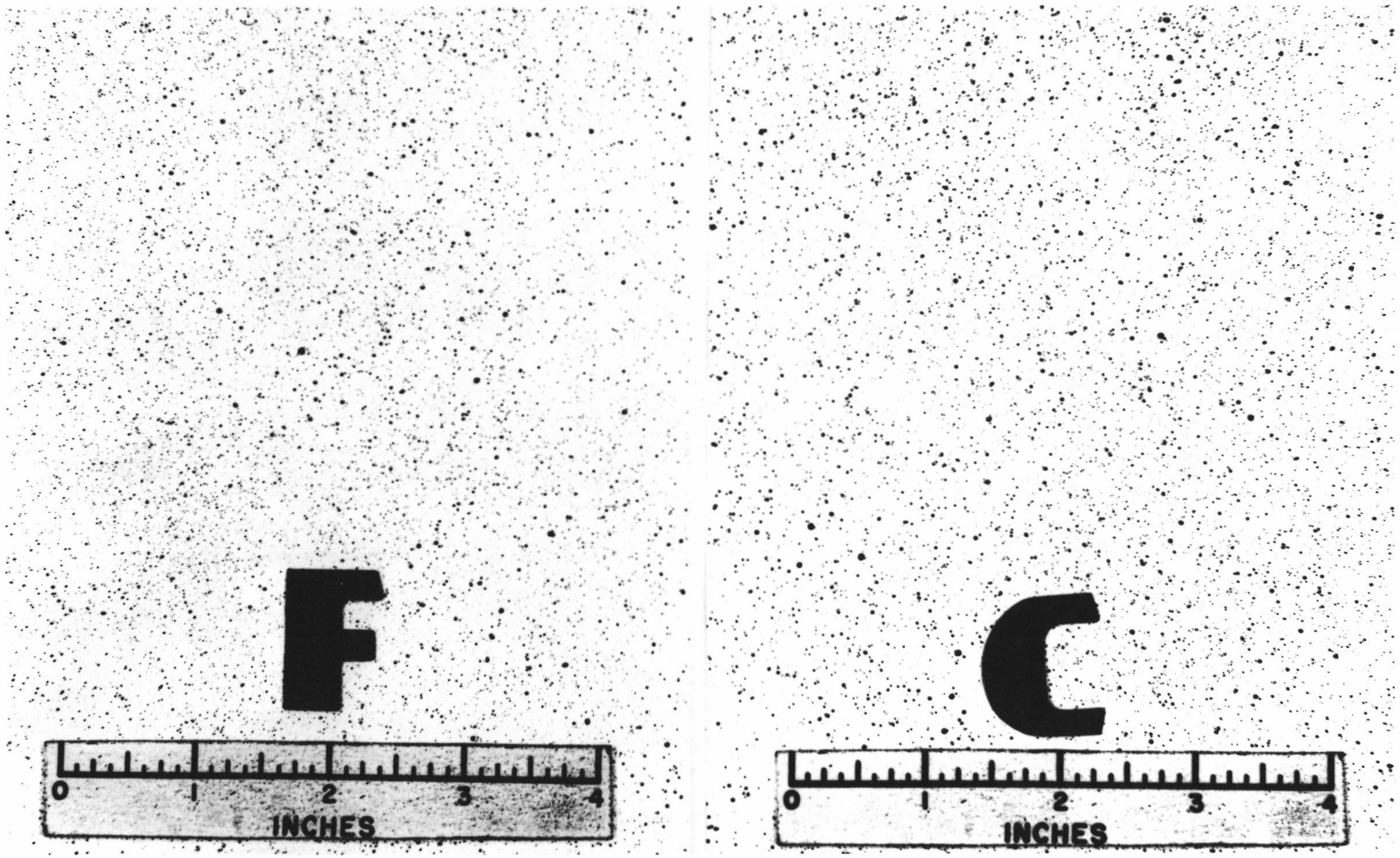


Figure 16. Pattern with paper dropped through spray: F, fine atomization with 80 pounds atomizing air; C, coarse atomization with 60 pounds atomizing air.

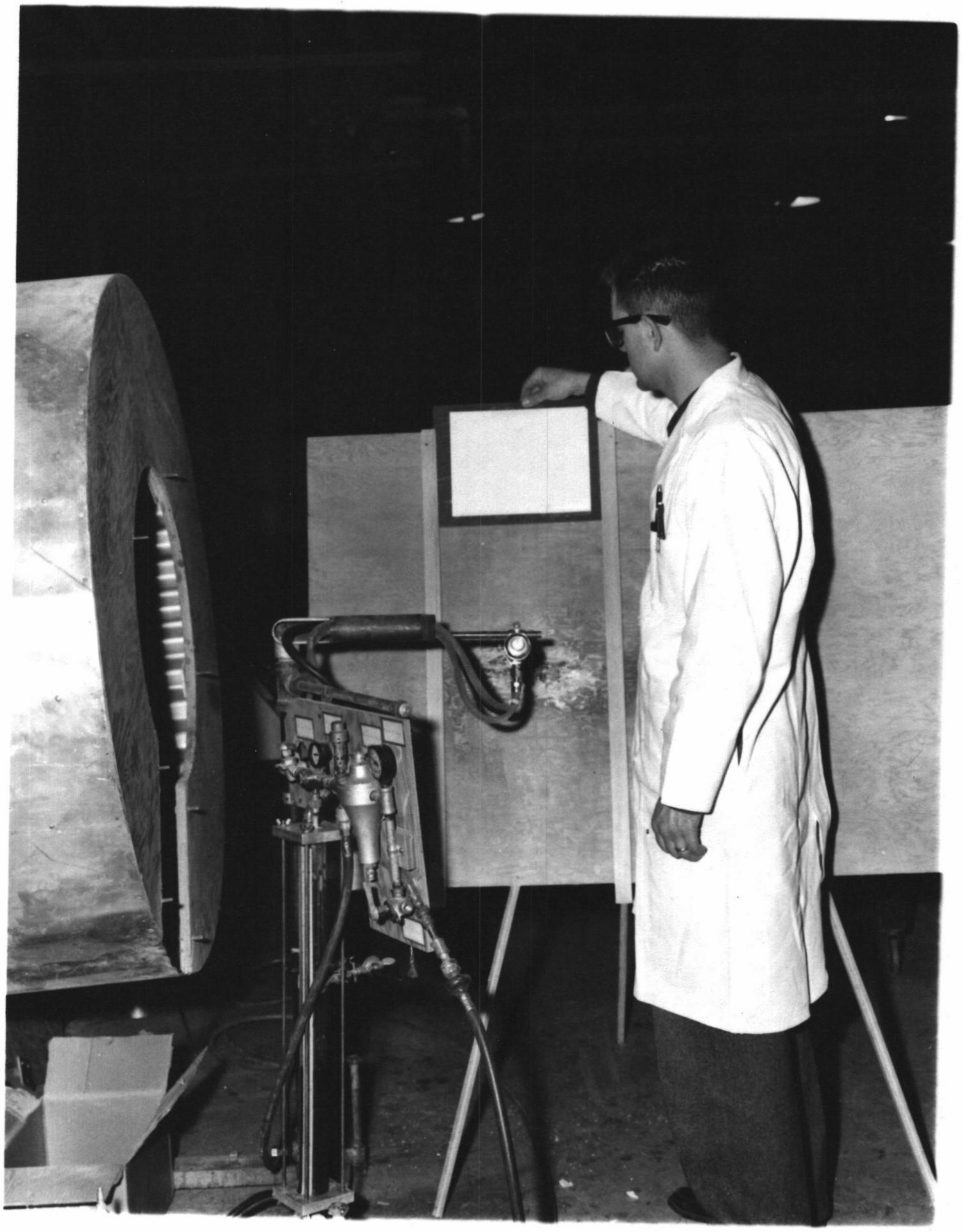


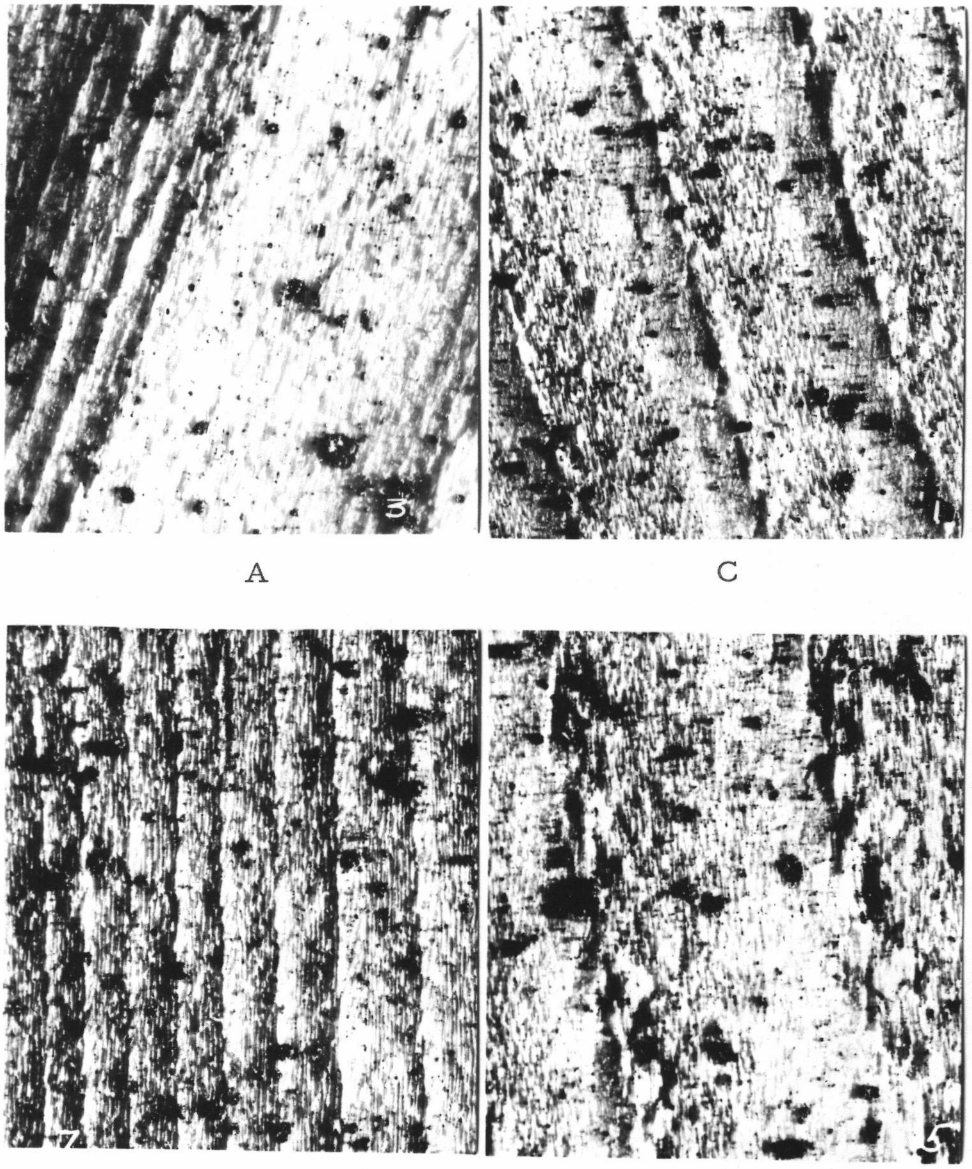
Figure 17. Paper about to be dropped through the spray to obtain a display of resin droplets.

droplets and extent of coverage; fine spray had few large droplets and covered well.

Extensive observations were made of resin-coated flakes. On the basis of resin coverage, flakes sprayed with 2 per cent resin were distinguished easily from those sprayed at 6 per cent. Distinction between fine and coarse atomization was impossible when observing flakes sprayed with 6 per cent resin. To distinguish atomization levels on basis of coverage and size of resin droplets was difficult at 2 per cent resin content.

Macrophotographs of some resin-coated flakes are exhibited in Figure 18. Viewing resin-coated flakes under a binocular microscope, resin droplets were observed to vary in size and shape. Most droplets were on the flake surfaces, but some were found deeply embedded in surface cracks and fissures.

Some observations were made of inter-particle adhesion in the pressed panel. To do this, small pieces of board were split apart with a knife; cleaved sections then were examined. Some of these sections are illustrated in Figure 19. In most instances, the resin apparently had performed a "spot-welding" function. There was evidence of efficient bonding, as many areas showed considerable wood failure (Figure 19, C and D). Resin appeared as amorphous-like blotches in most instances. There were areas, however, where resin undoubtedly had not performed efficiently. In some areas, flake-to-flake contact had not been made. Resin in these locations appeared as droplets and not as blotches (Figure 19 A). In other areas, the resin apparently had been embedded in surface fissures and had not performed its bonding function; this resin appeared also as droplets (Figure 19 B).



A C

B D

Figure 18. Resin droplets on flake surfaces: A, coarse spray and 2 per cent resin; B, coarse spray and 6 per cent resin; C, fine spray and 2 per cent resin; D, fine spray and 6 per cent resin. Magnification is 12X.

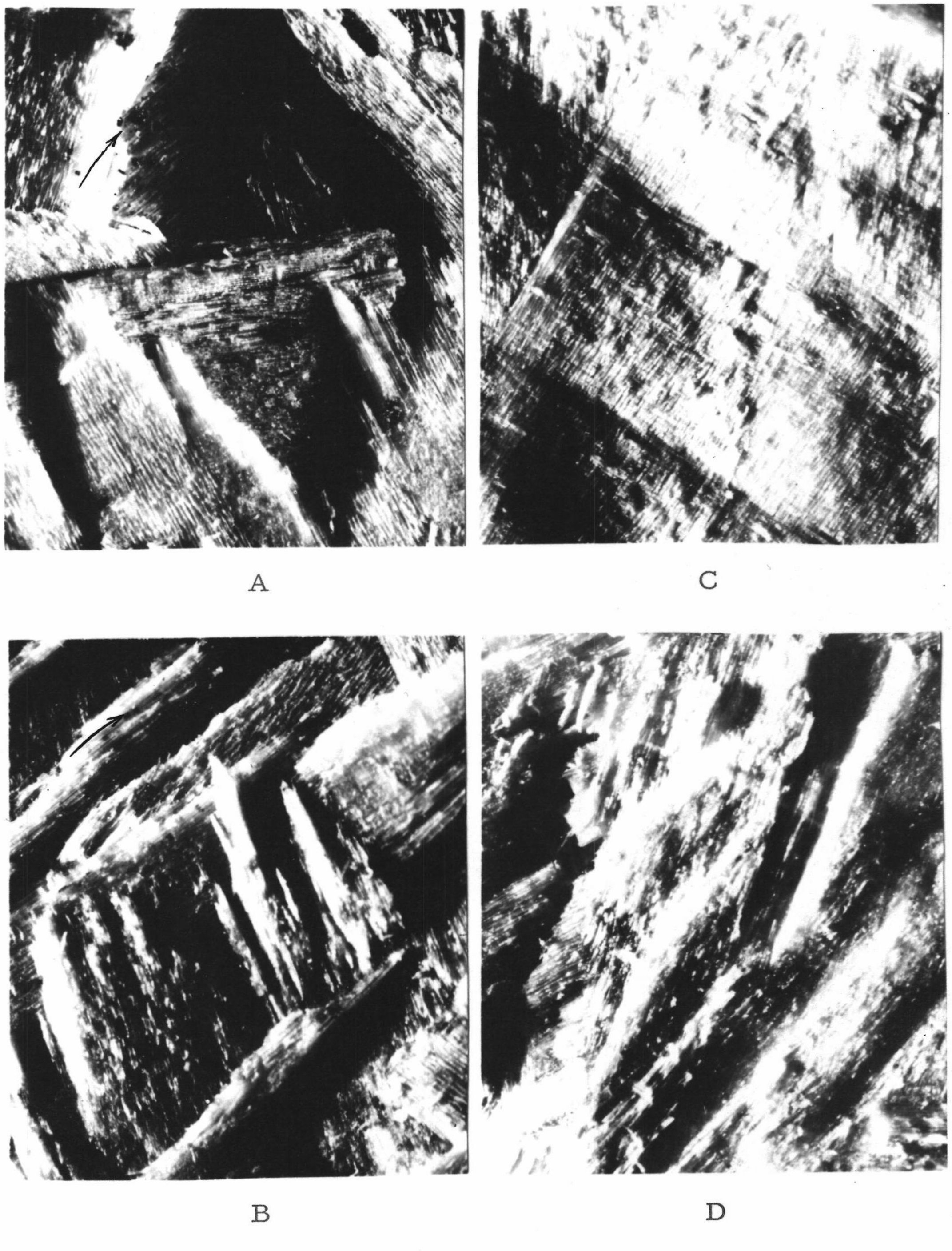


Figure 19. Flake-to-flake bonding observed on surfaces of cleaved board sections: A and B show areas where resin apparently was inefficient (resin droplets in upper left of photos), C and D show areas of considerable wood failure and efficient bonding. Magnification is 12X.

Physical Tests

Specimens to measure static bending and internal bond were cut from each panel as shown in Figure 20. Specimens were stored at conditions for 12 per cent equilibrium moisture content (70 F and 65 per cent relative humidity). After several weeks, they had equalized to an average moisture content of 8 per cent and were ready for testing.

Modulus of rupture was measured in the static bending test. Specimens measuring 3 by 14 inches were loaded at a rate of 0.24 inch a minute over a 12-inch span. Blocks were cut from these specimens after test to measure specific gravity; average for all specimens was 0.67.

Specimens to measure internal bond, 2 by 2 inches square, were tested at a head-speed of 0.04 inch a minute. Procedures for performing this test and the test for modulus of rupture are described in detail in Standard D 1037-56T, American Society for Testing Materials.

Results of physical tests are presented in Table 1.

Figure 20. Manner in which test specimens were cut from 18-inch square flakeboards: S, static bending; I, internal bond.

TABLE 1. RESULTS OF PHYSICAL TESTS.

Specimen	Modulus of rupture	Internal bond	Moisture content at test	Specific gravity †
	Psi**	Psi***	Per cent***	
1LF2*	3286	78	7.7	0.62
1LF6	2923	146	6.8	0.62
1HF2	3095	57	7.8	0.69
1HF6	3848	127	8.1	0.65
1LC2	2505	58	8.9	0.68
1LC6	2945	137	8.9	0.70
1HC2	2935	61	8.9	0.70
1HC6	4100	125	7.9	0.67
2LF2	2846	77	8.2	0.66
2LF6	3825	136	8.1	0.65
2HF2	2662	61	8.1	0.69
2HF6	3592	98	8.6	0.69
2LC2	3073	63	8.7	0.71
2LC6	3833	145	8.1	0.70
2HC2	2721	56	8.6	0.63
2HC6	3977	115	8.1	0.70
3LF2	2898	94	7.7	0.74
3LF6	3662	150	7.6	0.66
3HF2	2506	73	7.8	0.66
3HF6	4291	114	7.4	0.69
3LC2	2858	68	8.3	0.68
3LC6	3511	151	8.4	0.67
3HC2	2431	49	8.0	0.67
3HC6	4298	107	7.9	0.68

* First number indicates replication.
First letter indicates moisture content at flaking: L for low (26%), H for high (116%).
Second letter indicates degree of atomization: F for fine, C for coarse.
Second number indicates resin content: 2% and 6%.

** Each value an average of 3 observations.

*** Each value an average of 2 observations.

† Averages of 2 observations, based on oven-dry weight and volume at time of test.

STATISTICAL ANALYSIS

Data were analyzed with an analysis of variance. Type of experiment was factorial, and design was split-plot. Three factors, each with two levels, were investigated: moisture content at flaking (26 and 116 per cent), resin content (2 and 6 per cent), and degree of atomization (fine and coarse).

Mean values for modulus of rupture (MOR) and internal bond are presented in Table 2. Information presented in this table is general, and interpretation should not be made without consulting the analysis of variance in Table 3. A discussion of significant information based on the analysis of variance follows. Bar graphs have been prepared to show significant interactions. The main effects are not discussed because of significant interactions with other factors.

For modulus of rupture, the interaction between moisture content at flaking and resin content (MXR) was significant (Figure 21). At a resin content of 2 per cent, higher MOR values occurred at the low (26 per cent) moisture content. For 6 per cent resin content, this situation was reversed. At either moisture content, boards with 2 per cent resin content exhibited values for modulus of rupture lower than those of boards with 6 per cent resin content.

A significant interaction between resin content and moisture content at flaking for internal bond is shown in Figure 22. Regardless of resin content, best internal-bond strengths were realized at the low moisture content. Also, at either moisture content, higher internal-bond values occurred with high resin content.

Interaction between resin content and degree of atomization for internal bond is portrayed in Figure 23. This was the only instance where atomization was significant. At 2 per cent resin content, fine atomization resulted in highest value for internal bond. With 6 per cent resin content, however, coarse atomization showed a slight advantage in strength over fine atomization.

TABLE 2. TREATMENT MEANS FOR MODULUS OF RUPTURE AND INTERNAL BOND.

Moisture content	Resin content: 2 per cent MOR*	Resin content: 2 per cent IB**	Resin content: 6 per cent MOR	Resin content: 6 per cent IB
Per cent	Psi	Psi	Psi	Psi
Fine atomization				
26	3010	83	3470	144
116	2754	64	3910	113
Coarse atomization				
26	2812	63	3430	144
116	2696	55	4125	116

* Modulus of rupture.
** Internal bond.

TABLE 3. ANALYSIS OF VARIANCE OF INTERNAL BOND AND MODULUS OF RUPTURE.

Source of variance	Degrees of freedom	Mean squares		F values	
		Modulus of rupture	Internal bond	Modulus of rupture	Internal bond
Total	*	--	--	--	--
Replications	2	91700	99.12	0.51	0.80
Atomization (A)	1	7667	240.67	0.04	1.94
Error (a)	2	179176	124.29	--	--
Moisture content (M)	1	654940	2816.67	1.66	43.12**
Resin content (R)	1	15094765	23814.00	38.17**	364.57**
MXA	1	174739	73.49	0.44	1.13
MXR	1	2555684	400.16	6.46***	6.13***
RXA	1	209412	368.16	0.53	5.64***
MXAXR	1	14936	32.68	0.04	0.50
Error (b)	12	395461	65.32	--	--

* 71 for modulus of rupture, 23 for internal bond.

** Significant at 1 per cent level.

*** Significant at 5 per cent level.

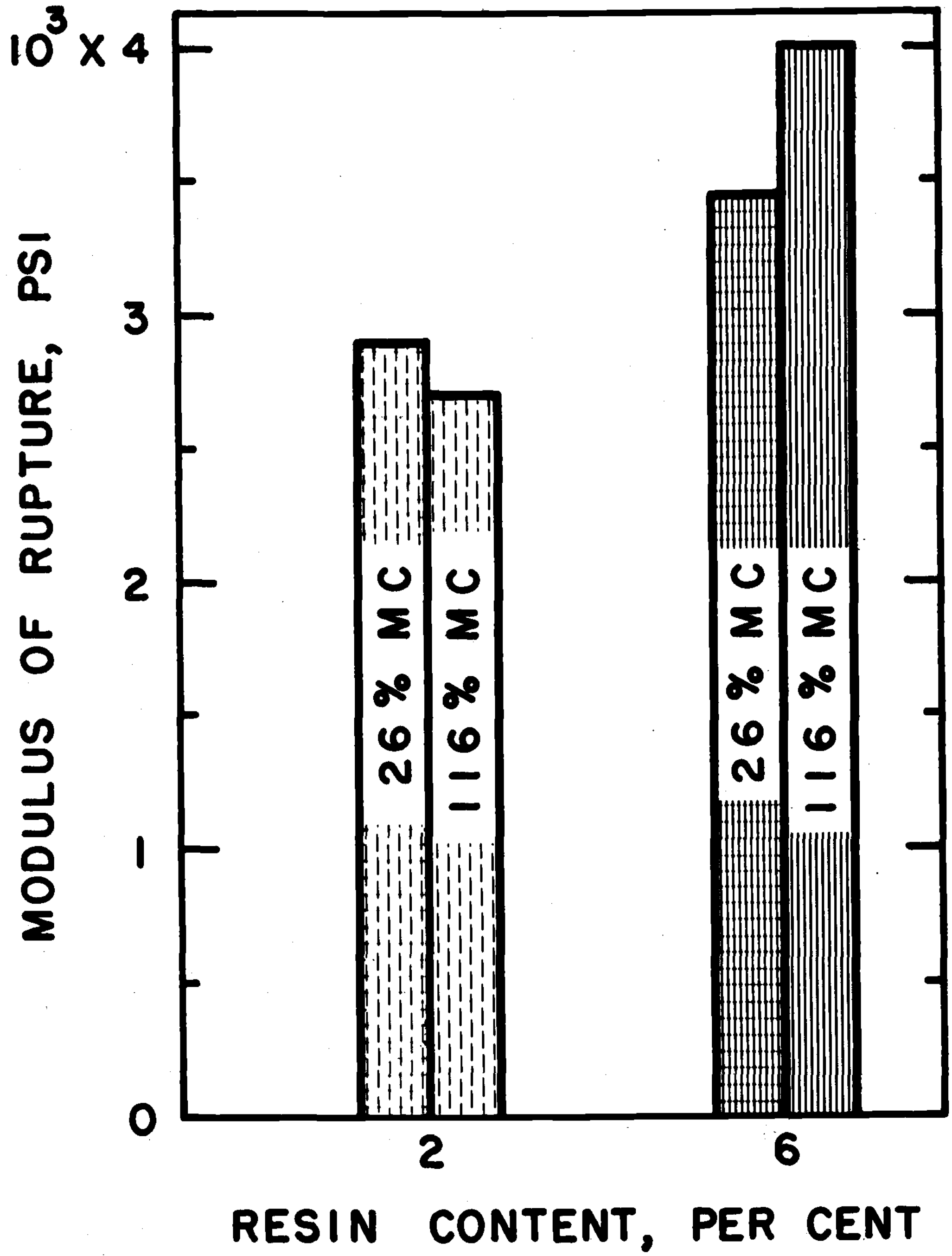


Figure 21. Interaction of resin content with moisture content at time of flaking. Each bar value represents a mean of 18 observations.

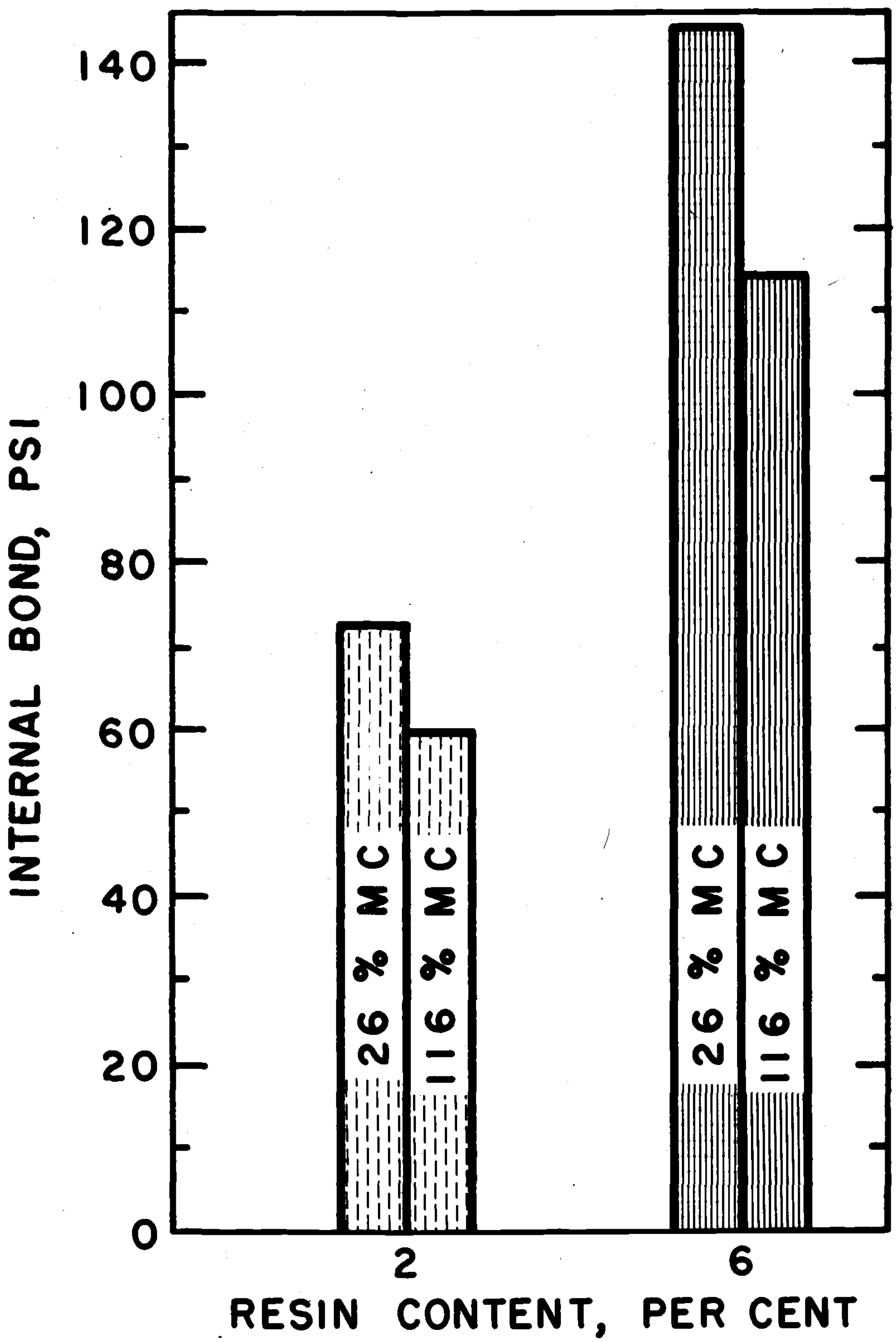


Figure 22. Interaction between resin content and moisture content at time of flaking. Each bar value represents a mean of 12 observations.

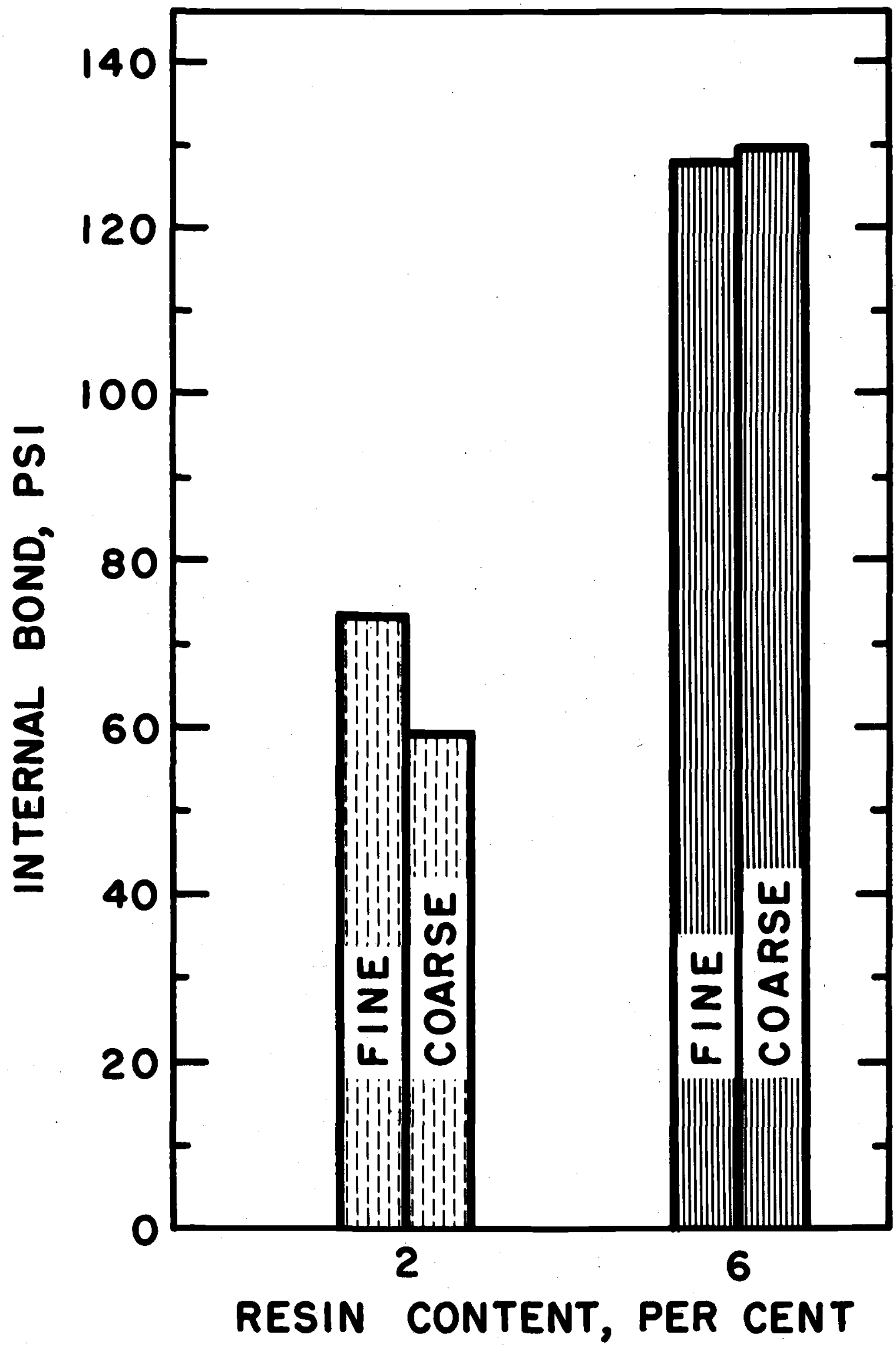


Figure 23. Interaction of resin content and degree of atomization. Each bar value represents a mean of 12 observations.

CONCLUSIONS

Observations and qualitative evaluations illustrated several interesting occurrences. These can be enumerated as follows:

1. Examination of cross sections of flakes showed negligible internal damage, irrespective of moisture content at time of flaking or rate of growth. Damage was restricted to flake surfaces and extended one cell, or sometimes two cell widths, inward.
2. Observations of flake surfaces by two techniques, highlighting and light-sectioning, showed that no distinct differences in roughness of surface or in profile could be established according to moisture content at time of flaking or degree of flake dryness. Using light-sectioning, a discernible difference was noticed, however, for rate of growth. Regardless of moisture content, fast-growth flakes exhibited generally smoother surfaces than did slow-growth flakes. Basing selection of wood for flaking on growth rate, thus, appears important to production of smooth-surfaced flakes.
3. Inspection of the glue bond in the pressed board showed a spot-weld adhesion between flakes. In most instances, resin appeared to be on the flake surfaces, and flake-to-flake bonding seemed adequate. There was evidence, however, that some of the resin was not doing any bonding. Such resin often was embedded in cracks and fissures on flake surfaces, thus emphasizing the importance of smooth-surfaced flakes.

Conclusions based on quantitative measurements of physical properties of the boards may be summarized as follows:

1. Both modulus of rupture and internal bond were sensitive to resin content. In this respect, increasing resin content from 2 to 6 per cent resulted in increased test values.
2. Moisture content at time of flaking affected physical properties significantly. At a resin content of 2 per cent, values for MOR and internal bond were higher at low moisture content (26 per cent). At 6 per cent resin content, this same effect was evident for internal bond. Conversely, modulus of rupture at 6 per cent resin content was higher at the high level of moisture content (116 per cent).
3. Degree of atomization had no significant effect on modulus of rupture. For internal bond, however, test values were highest with fine spray at the 2 per cent level of resin content. Conversely, at 6 per cent resin content, test values were slightly higher for coarse spray.

REMARKS

Several interesting findings have resulted from this study. Reasons for some results are not known entirely; in these instances, logical or reasonable explanations can be advanced. Some conclusions may be considered contradictory to established ideas or practices, but deserve discussion.

Fast-growth flakes appeared to have smoother surfaces than did slow-growth flakes. One explanation that appears reasonable relates directly to the flake-slicing operation. Action of the knife as it proceeds through a block might vary according to the width of annual rings in the block. Under most efficient conditions, slicing action would be smooth and clean. With fast-growth material, this smooth knife-action might be accomplished easily because of long distance between rings. Slow-growth material, with rings close together, actually might set up an undesirable vibrating action detrimental to smooth slicing. In this respect, blade sharpness, speed of the slicing flywheel, and feed rate of blocks into the knives appear to be important factors.

Degree of internal damage resulting from the flake-slicing operation was anticipated to vary according to moisture content of blocks; that is, more damage was expected at the lower moisture content than at the higher. Investigation showed no appreciable internal rupture, however. Precautions taken to insure good flake-cutting conditions were assumed to have eliminated this type of injury. In addition, 26 per cent moisture content probably was not an undesirably low level for slicing.

With one exception (MOR for boards containing 6 per cent resin), test results indicated that flakeboard made from flakes cut at the lower moisture content level, 26 per cent, had superior physical properties. This was an unexpected occurrence, since increased quality in flakes is anticipated from blocks cut at high moisture contents. Also, soaking blocks in water prior to flaking would appear to be advantageous, since this practice supposedly would soften blocks and thus produce fewer damaged flakes. To explain why flakes cut at low moisture content produced superior boards, several ideas may be advanced.

Conceivably, there may be a moisture content for flaking above which quality of flakes declines. In other words, blocks with high moisture content in this study may have become too soft for good slicing. The fact that no noticeable differences in surface quality were observed between flakes cut at both moisture contents does not necessarily mean that differences did not exist. They may not have been discernible or obvious by the techniques used for evaluation.

To obtain desired high moisture content, blocks were immersed in water for about two months. Blocks for producing flakes at the low moisture content were not immersed in water. Certain water-soluble extractives may have been removed during soaking and so changed the chemical characteristics of the wood. A short, investigative study was made on flakes that had been cut from blocks conditioned in both manners. Purpose of this study was to measure pH, realizing that pH often has an effect on resin curing. Flakes were ground into wood meal and placed in distilled water. Slurries were mixed thoroughly, and pH was measured on a standard meter.

Results showed that flakes from blocks with high moisture content were slightly more acidic (pH 4.5) than flakes from blocks with low moisture content (pH 5.0). This small difference led to doubt that pH had any direct effect on gluability.

Flakes also were stained (Ameroid alkalinity indicator) to estimate pH. Results showed differences in pH that paralleled those measured on the meter. During this study of staining another observation was made (see Figure 24). Stain tended to spread outward along the annual rings more extensively on flakes cut from blocks with high moisture content than on flakes from blocks with low moisture content. This blotter-like effect was thought to be an indication of difference in absorptive ability. This could have an effect on gluing, as, for instance, it might cause undue penetration of resin on flakes cut from blocks with high moisture content.

Physical properties of flakeboards were improved markedly by increasing resin content. This procedure may, however, not be in keeping with the idea of resin efficiency which stresses minimum resin content. If resin is to be minimized, factors such as production of high-quality flakes (already discussed) and proper resin atomization become very important. The internal-bond test, which would be sensitive to inter-particle adhesion, showed that fine spray was desirable with 2 per cent resin content. This effect might have occurred at the 6 per cent level of resin content, but perhaps it was masked by the greater quantity of resin added. Nonetheless, if resin is to be used most efficiently, fine atomization apparently should be advocated.

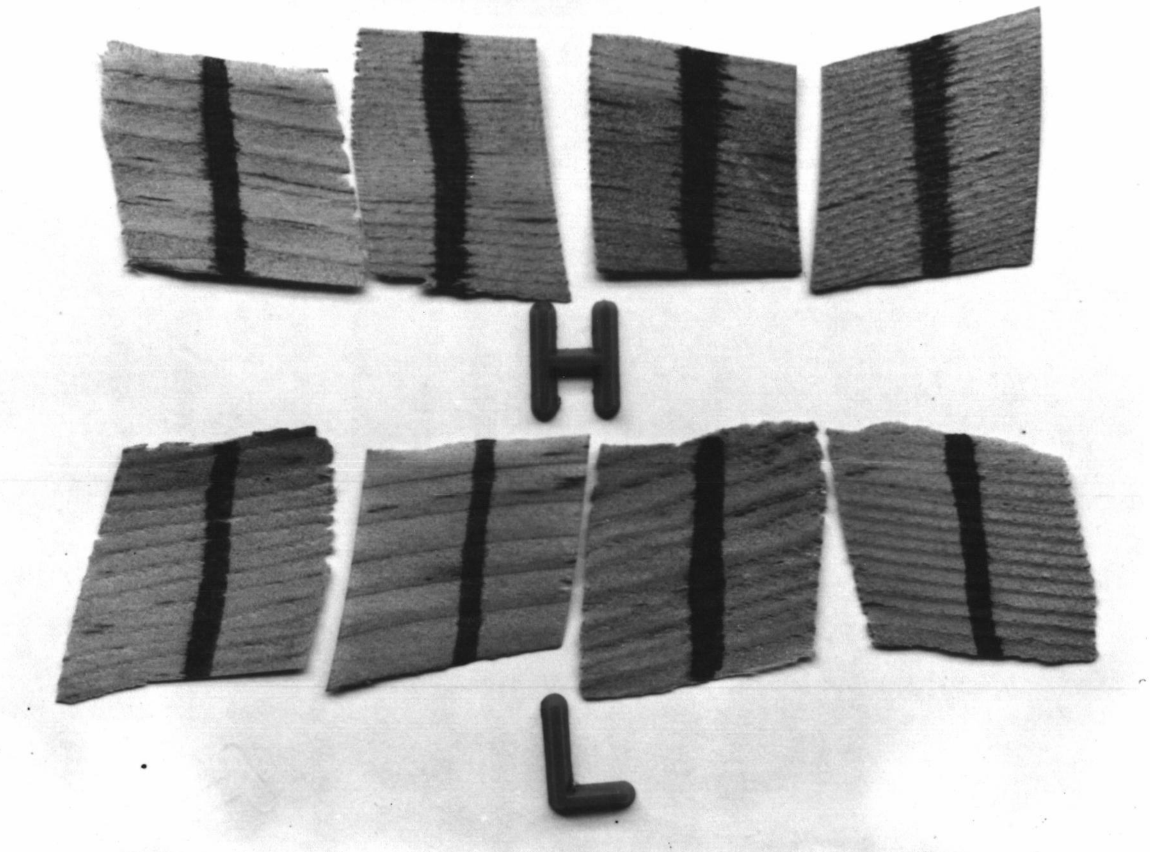


Figure 24. Flakes showing difference in extent of stain spreading: H, flakes cut at high moisture content from water-soaked blocks; L, flakes cut at low moisture content from non-soaked blocks.

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