DEVELOPMENT OF PHYSICAL AND MECHANICAL PROPERTIES OF PARTICLEBOARD AND MEDIUM DENSITY FIBERBOARD WITH PARTICULAR EMPHASIS ON INTERNAL BOND STRENGTH

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ABSTRACT

DEVELOPMENT OF PHYSICAL AND MECHANICAL PROPERTIES OF PARTICLEBOARD AND MEDIUM DENSITY FIBERBOARD WITH PARTICULAR EMPHASIS ON INTERNAL BOND STRENGTH

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The purpose of this study was first to discuss how different factors and process variables influence the physical and mechanical properties of particleboard and medium density fiberboard (MDF) with emphasis on internal bond (IB) strength property, second to evaluate the relationship between IB and density of two commercial particleboards and medium density fiberboards.

Included in this paper are evaluations of some important related properties and discussion and evaluation of different IB test methods.

There were strong correlations between modulus of elasticity and density of both MDF and particleboard. There was a very slight correlation between core density and IB of MDF althougth over a wider range of density IB was a function of density. However, there was a close correlation between core density and IB of particleboard.

It was concluded that there is a possibility of reducing overall density of MDF and saving costs without sacrificing IB. For many application, the resulting reduction of MOE would have little practical significance.

ACKNOWLEDGMENTS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure		Page

Figure		Page

Figure		Page

Figure		Page

LIST OF APPENDICES

Chapter 1

INTRODUCTION

The composition board industry, including hardboard, insulation board, particleboard, strandboard, and medium density fiberboard is of very recent origin. These boards are distinct from solid wood in that they are composed of wooden elements of varying sizes held together by an adhesive. Commercial composition board products have some very desirable characteristics such as availability in large sheets,smooth surfaces, uniformity of properties from sheet to sheet, and freedom from localized defects (44).

A wood particleboard is composed of essentially small dry wood particles that are randomly distributed or oriented, arranged in layers and glued together with a resin binder and pressed into sheet form. The particleboard industry in the U.S. had its start in the 1950's and it was originally established to utilize wood waste. It has grown to be one of the major forest products industries in the U.S. Particleboard has been developed, not solely as a utilizer of wood waste, but as a new product for new uses (32). Particles for the boards can be made from almost any type of wood, whether whole logs or wood residues such as trimmings and shavings from lumber or plywood manufacture.

Particleboard is used by the furniture, kitchen cabinet and store fixture industries, usually in the form of cores in veneered or otherwise overlayed panel material. Particleboard also is suitable for many other applications in furniture, building and other wood using industries. Oriented strand board (OSB) is a type of particleboard which is used in structural applications.

Growing pulp mill demand for low-grade wood waste and increasing utilization of wood waste as fuel are causing some changes in the particleboard industry.

Medium density fiberboard (MDF) is a more recent product in direct competition with particleboard. It can be manufactured from wood waste and low grade woods unsuitable for pulping.

Medium density fiberboard is produced by reducing raw material to fibers in pressurized disk refiners. These fibers are then bonded together with low viscosity, low tack, synthetic resin and formed into a mat. The process offers an opportunity for profitably utilizing wood once considered waste because it tolerates wide variation in raw material such as species composition, geometric configuration and bark inclusions (91, 127).

MDF, according to the common usage of the term, refers to the thick (3/8 to 1 in) medium density fiberboard that is generally sold in the industerial core stock market. Its properties, such as bending strength, modulus of elasticity, internal bond, machinability, and scew holding power, meet the levels required for these applications. Just what these requirement are, in terms of the above properties, is not precisely defined. The furniture manufacturer, in many cases, simply knows from experience that a certain core material is suitable in a given application. The commertial standard simply identifies those materials that can be successfully used for spesific purpose (91).

A unique combination of moderate overall density, suitable density profile, and resin content results in excellent edge machining and edge finishing characteristics, qualities essential to superior furniture stocks. The first MDF plant was built in the U.S. in 1965. MDF-dry successfully competes with particleboard, a lower cost core material, on the strength of its more uniform and solid edges, which allow direct finishing. It is expected that MDF-dry will make further in- roads into the core stock market in the future (91).

Classification of wood composite boards

A general classification of wood composition boards by particle size, density, and process type is shown in figure 1.

In this classification, plywood is also included in wood composition boards in which the particles are veneer

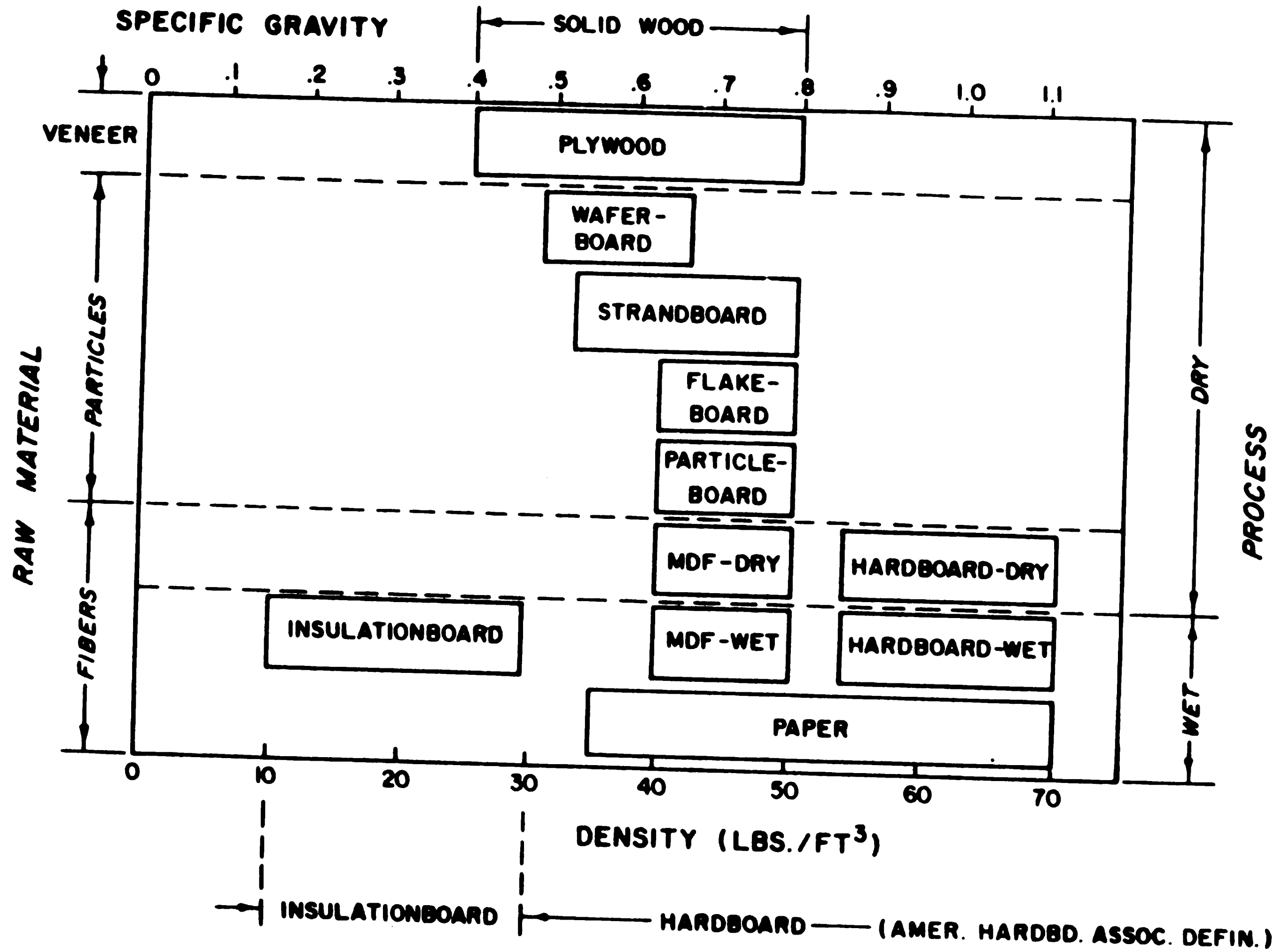


Figure 1.

Classification of wood composition boards by particle size, density, and process type. (Ref. 91) sheets of regular dimensions that can easily and systematically be assembled and laminated without densification.

Particleboard is based on particles that are very small compared with veneer sheets, but many times larger than the wood cell. Waferboard and strandboard are particleboards made from rather large particles and intended for structural applications. Strand board or oriented strand board (OSB) is a particleboard of oriented particles, with the use of particles deliberately manufactured with optimum particle-geometry which can yield materials equalling or surpassing the structural capability and reliability of sawn lumber and plywood.

The term wood particleboard usually refers to a particleboard of random particles (5,44,91).

Fiberboards are made from a furnish consisting of elements with dimensions of the same order of magnitude as those of the wood cells. Insulation board, MDF-dry, MDF wet, hardboard-dry and hardboard-wet fall into the general category of fiberboard. Paper is not a fiberboard but made out of fibers and its process is similar to fiberboard technologies (44,91). A manufacturing diagram of typical composition board is shown in figure 2.

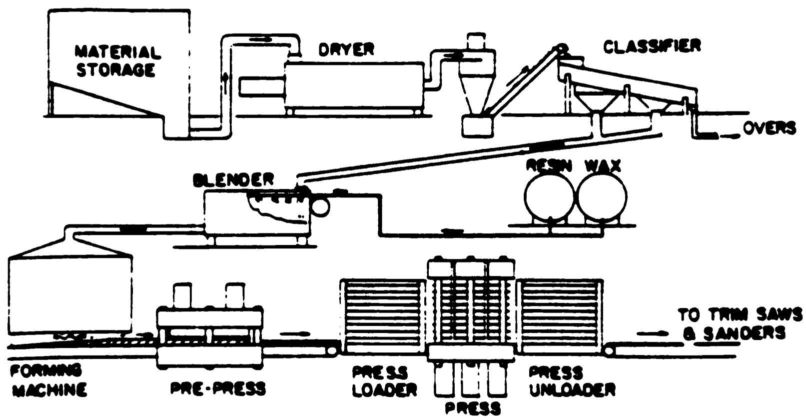


Figure 2.

Manufacturing diagram of typical composite board.
(Ref. 44)

Historic development

Particleboards and fiberboards are of very recent historic origin. A tremendous amount of residual material resulting from the production of lumber and plywood has been used for fuel over the centuries. There is no doubt that people over the centuries have visualized taking the waste material and producing some type of man-made board. However, records show that such developments are of very recent origin.

Maloney (44) summarized a brief history of particleboard and fiberboard which is used as a reference for most parts of the historic section of this paper. The following paragraphes will cover a brief historic development of wet-process fiberboard, platen-pressed particleboard, extruded particleboard, dry-process hardboard and medium density fiberboard. Although fiberboards including insulation board and hardboard wet and dry processes will not be included in this paper, a brief history of these boards will be given for a relatively complete backround of wood composite development and because of the similarity of these processes to the MDF process. See figures 3, 4 for summary schematics of the fiberboard process.

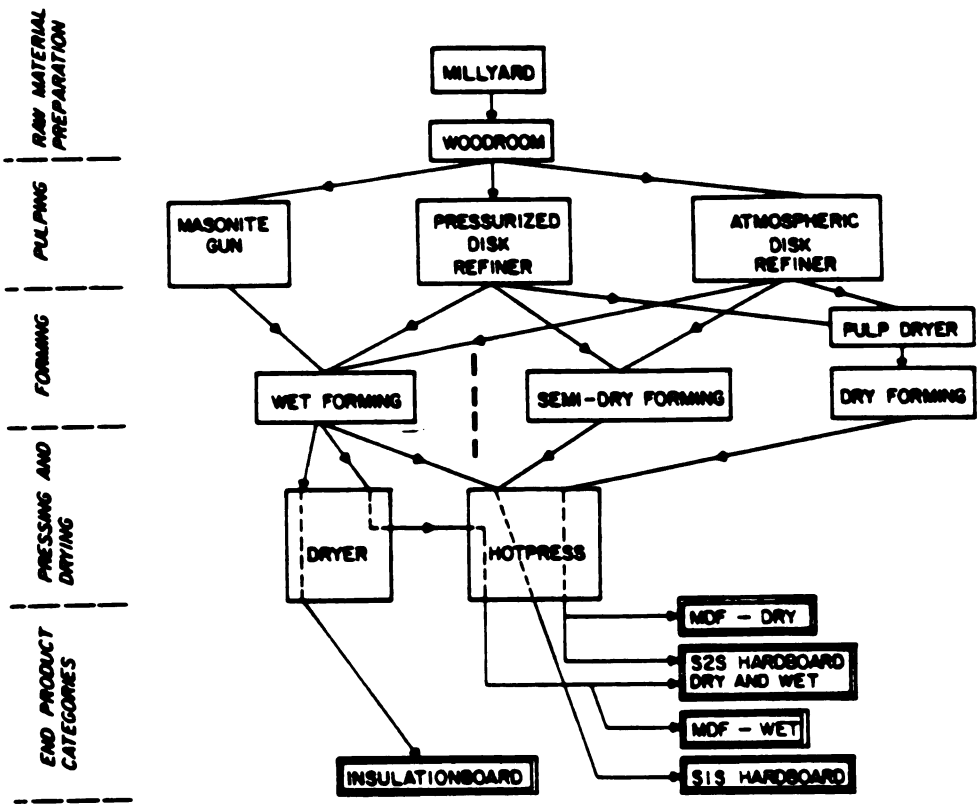


Figure 3.

Summary schematic of fiberboard processing.
(Ref. 91)

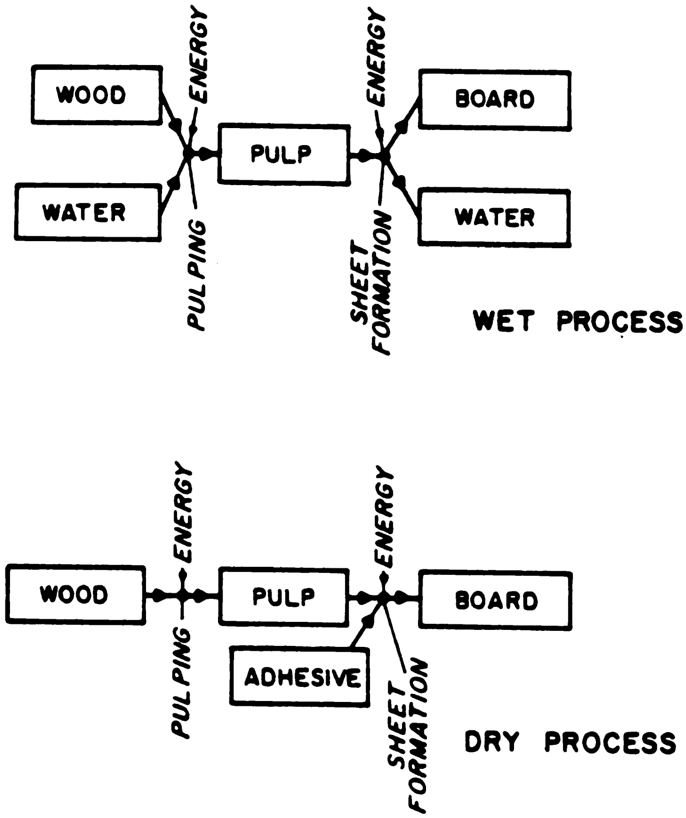


Figure 4.

Simplified schematic of wet and dry fiberboard processes. (Ref. 91)

Wet-process fiberboard

Lyman obtained a United State Patent in 1858 on fiberboard. In 1914, C. G. Muench made the world 's first insulation board out of wood fibers. His idea was a partial adaptation of the process used in making paper. Wood fibers were carried in water from which the fiber slurry was metered out onto a continuously moving screen. The water was drained away through the screen leaving a mat of interlaced fibers. This material was then oven dried, yielding the sheets of board.

Although insulation board has been refined over the years, the key point is that it is a wet process system based on papermaking technology. This type of board ranges in density from 10 to 25 lbs/cu.ft., which is lower than wood and other raw materials from which it is usually made. It is widely used for sheathing, interior paneling, rigid roof insulation, and as a siding. It is a relatively low cost material which requires little, if any, binding agent. It is possible also to densify the insulation board after drying by consolidation in a heated press. This results in higher-density hardboard products (44).

William H. Mason discovered the process of producing wet-process hardboard in 1924 and his discovery established the Masonite Process. To prepare the fiber, chips are subjected to high-temperature steam in a pressure vessel called a gun. The chips are subjected to approximately 600 psi steam pressure for one minute, and then the steam pressure is quickly raised to more than 1000 psi for five seconds. The pressure is suddenly released and the chips are exhausted from the gun. The presure built up within the chips literally explodes them into a coarse mass of fibers. This mass can be further reduced into individual fibers or fiber bundles by means of an attrition mill.

Lignin, in general terms, is nature's glue for binding the wood fibers together. In the steaming operation the lignin bonds between the cellulose fibers are softened, which permits a more improved disintegration of the chips into fiber bundles as compared to grinding unsteamed chips in an attrition mill. After the fluffy masses of fiber are refined, the fiber is washed and the fines and hemicellulose solubles are removed. The remaining stock then goes to a former, somewhat similar to the one for producing insulation board. This type of mat is pressed into its final density in a hot press. A screen is used on the bottom of the mat to allow the moisture to escape during the pressing operation. This results in a smooth-one side (S1S) board. If a smooth-two-side (S2S) board is desired, the wet mat must first be oven dried before it is put into the hot press. Otherwise, the high moisture content of the mat will cause an excessive amount of steam to be generated, which will blow the board apart during or immediately after pressing.

In comparison to insulation board, hardboard must have a density of at least 31 lbs/cu.ft. (44).

Platen-pressed particleboard

Ernst Hubbard in 1887 published the early concept of particleboard process under the title of : Utilization of wood waste. He proposed to manufacture artificial wood from sawdust and blood albumin under application of pressure and heat.

Krammer in 1889 obtained a German patent for a method for gluing planer shavings onto linen cloth and then laying up the cloth layers in a cross-lap construction much like that for plywood.

Watson, an American, in 1905 made thin wood particleboard. This patent shows clearly a flakeboard very similar to some types of board made today. Watson could be called the inventor of the flake type of particleboard.

Backman, a German, in 1918 suggested making a board with chips or wood dust in the center and surface veneers on the outside. This particular formulation is now the basis for a certain structural building panel.

Freudenberg, a German in 1926 talked about utilizing planer shavings with the adhesive available at that time for making a board. He noted that the adhesive level should be between three and ten percent, which, is about the range for the present-day particleboard.

Nevin, an American, in 1933 recommended the mixing of coarse sawdust and waste wood shavings with an adhesive and then forming and compressing them under the application of heat.

A Frenchman, Antoni, in 1933 discussed boards of a mixture of wood fibers and particles and large elements such as excelsior or even metal netting in a board that was to be bonded with phenolic or urea glues.

Carson, an American was awarded a patent in 1936 for which he had applied initially in 1932, for establishing a regular production line for producing particleboard. A binding agent, which was a urea-formaldehyde-condensation product dilutable in water, was to be sprayed onto the wood particles in a rotary-drum blender. Before hot pressing, a prepressing operation was to take place, and he proposed covering the final board with a thermoplastic coating of synthetic resin. Much of what he discussed here will be found in many particleboard plants today.

During 1937-1960 particleboard production gradually appeared throughout the world. Most probably, commercial particleboard was produced after world war II. About 1960 the massive expansion of the United States particleboard industry commenced. Techniques were developed to produce boards with smooth surfaces, and resins were refined to speed up curing times in the press.

Significant efforts are being made to bring particleboard and fiberboard further into the structural building panel market in direct competition with plywood. In the U.S., the greatest usages of structural particleboard are in the underlayment and industrial core stock. Industrial and mobile home decking are using structural particleboard as well.
Structural flake board is approved for use in Canada. Other particleboards are used structurally throughout the world.

The development of this particular segment of the board industry has been phenomenal since world war II. Many different types of board plants have been built around the world, based not only on wood waste and roundwood cut especially for particleboard but also on other lignocellulosic material such as bagasse and flax (44).

Extruded particleboard

The extrusion method of producing particleboard was initially developed in Germany in the years 1947-1949. In the United States, several plants were built in the 1950 's based upon the original concept from Europe as well as on developments by U.S. firms. The plants producing this type of board in the U.S. are relatively small and are captive in the sense that they produce board for use by other parts of their firm 's operations,

notably in furniture factories. Extrusion of particleboard is a different method of production of particleboard.
Particles are forced by an oscillating ram through a die, consisting of two parallel heated plates. The distance between the plates is fixed, and is equal to the thickness of the board (1,44). see figure 5.

The extruded board cannot meet the standard established for platen-pressed particleboard. Particles in this system are randomly oriented in a plane perpendicular to the board surface and hence the boards have very low bending strength and stiffness. They must be overlaid with some other material such as thin particleboard, veneer or a paper or plastic laminate (44).

Dry-process hardboard

The next development in the composition board field was that of manufacturing hardboard by means of a dry process in 1945. In this production process, the chips or other residual materials are conveyed through cooking and grinding units where the fiber is prepared. It is also now normal to apply the resin and wax to the raw material prior to grinding so that the attrition mill simultaneously prepares the fibers and blends the additives with the fibers . In initial experiments and in the early plants, the resin was added

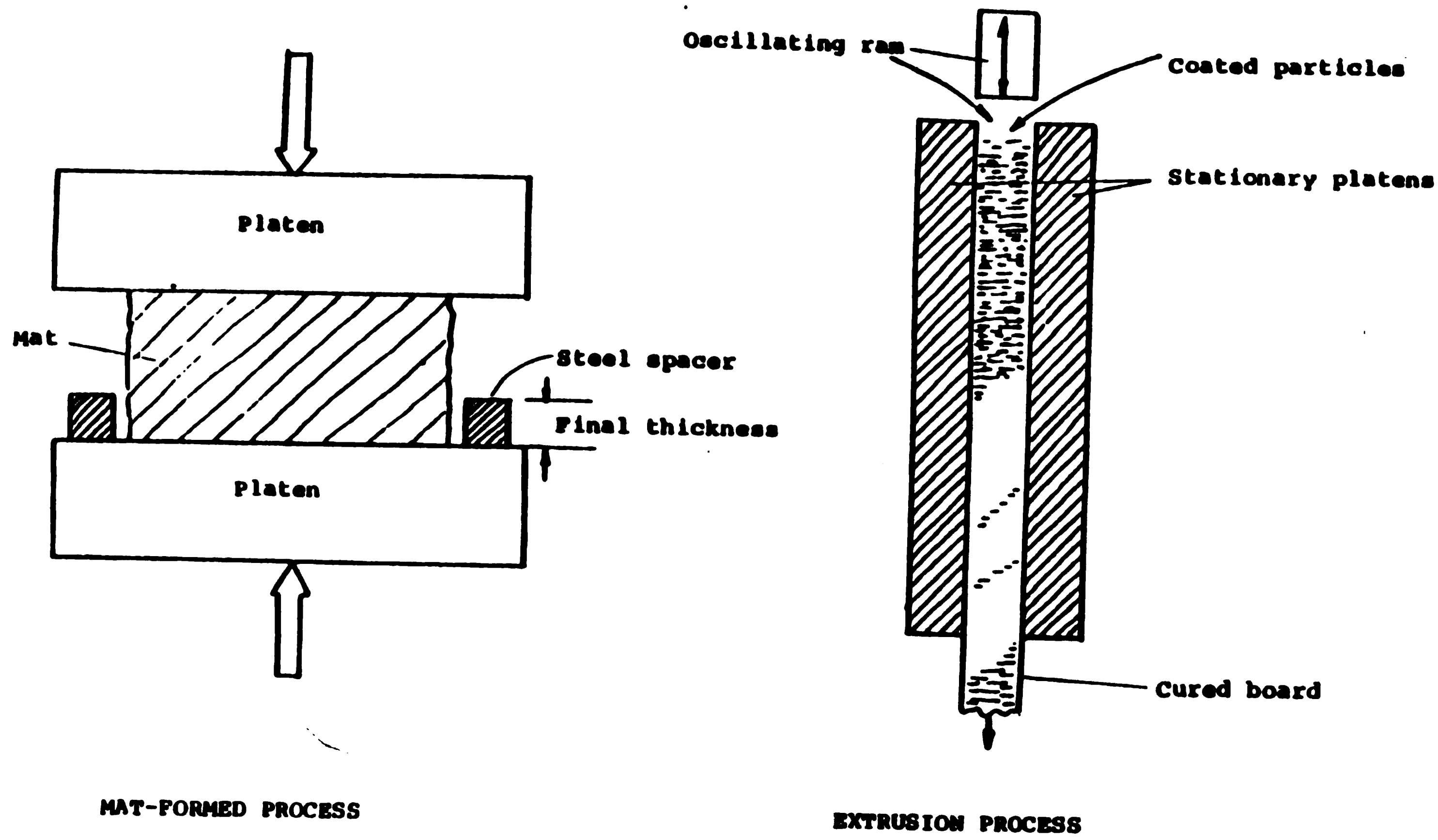


Figure 5.

Principal particleboard manufacturing processes. (Ref. 86) after the fibers were prepared. The mats were then formed using air and mechanical means in a continuous system. This mat, however, did not have the fiber interlocking that is possible when forming mats by the wet process. Because of this lack of interlocking and very low, if any, adhesion that can be obtained by lignin flow and hydrogen bonding in the hot press, the dry-process hardboard is dependent upon an added binder for the development of physical properties. If the mat has a moisture content below 10 percent, it normally is pressed into a smooth-two sides board which has a very light color in contrast to boards prepared by the wet-process system. At moisture contents over 10 percent, it is necessary to use a screen on one side of a mat, much in the same way as pressing a wet-process mat.

The boards manufactured by this method enter the same market as the wet-process board. Some people hold that the wet-process board is somewhat superior in properties because of the self-bonding of the fibers, the intermeshing of the fibers as developed in the wet-forming operation, and the removal of the hemicellulose. The elimination of the massive amounts of water necessary for forming the mat is an advantage of the dry hardboard. However, synthetic resins, which are expensive, must be used as binders in the dry-process board (44).

Medium density fiberboard

In the mid-1960 's the most recent development in the board industry occured. This breakthrough has been called medium density fiberboard. Most of the plants producing this board use the pressurized refiner for generating finer fibers, which have far greater bulk than those produced by atmospheric refiners. This particular board is usually much thicker than the traditional hardboard, and goes to the furniture industry for use as core stock. Much of the recent interest in building new plants has centered on the MDF process (44).

Total Capacity

Particleboard production in the United State is currently nearly four billion sq.ft. per year (1987) as indicated in figure 6 and tables 1,2 (68).

In the South-East region, annual production of industrial board has increased from 635 million sq. ft. in 1976 to its current level of 1.1 billion sq. ft. The West has also seen growth in industrial board production, from 900 million sq. ft. in 1976 to its current level of 1.14 billion sq.ft. However, some products have seen a sharp decline in overall production levels. In the South-East region, for instance, the production of floor underlayment has declined steadily, as have production levels of mobile decking. The West, however, continues to

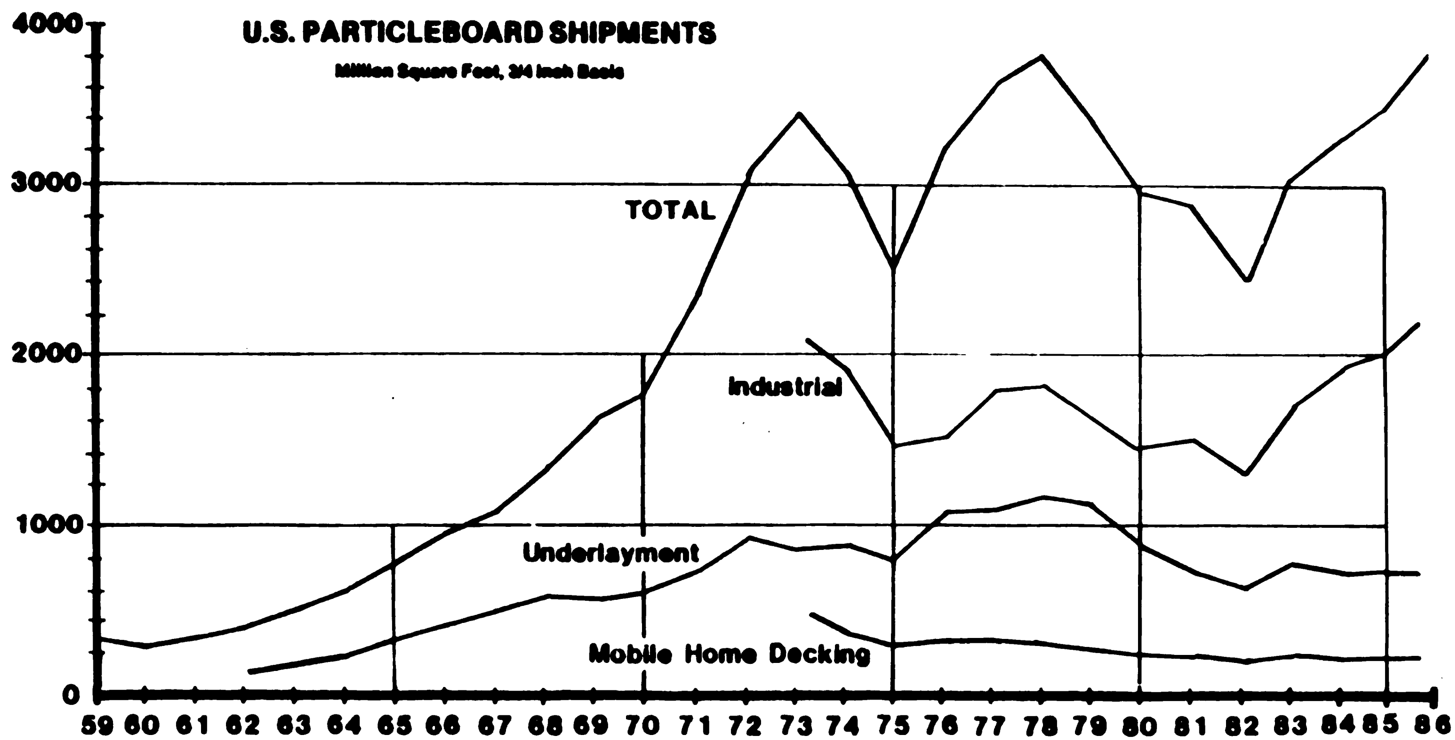


Figure 6.

Historical profile, U.S. particleboard shipments.
(Ref. 68)

Table 1 ***Particleboard and MDF Production, By Region 1976-1986***
(Thousand Square Feet, 3/4" Basis)
(Ref. 68)

Year	Floor Underlay.	Mobile Decking	Shelving	Door Core	Stepping	Industrial Board	MDF
South/East Region							
1976	768,364	188,530	16,135	*	*	634,986	
1977	708,907	198,883	38,246	73,321	*	885,240	
1978	791,656	187,342	16,914	74,160	*	837,488	299,534
1979	746,384	201,487	41,099	53,531	*	768,426	299,542
1980	600,654	176,772	25,355	84,674	135	718,129	307,225
1981	500,336	171,402	*	86,566	*	761,907	329,925
1982	440,375	144,601	15,346	96,677	227	689,217	300,630
1983	525,328	156,167	35,607	105,500	234	892,244	394,753
1984	427,289	132,742	32,909	118,728	*	932,888	405,025
1985	420,031	116,798	32,939	123,181	*	1,003,093	413,823
1986	375,897	128,978	30,472	125,892	*	1,096,903	478,423
Western Region							
1976	323,967	88,468	35,020	*	*	900,727	
1977	387,657	90,271	29,327	69,927	*	940,220	
1978	357,202	86,797	53,458	53,919	*	992,257	208,882
1979	357,611	63,162	55,414	58,290	*	906,480	207,186
1980	285,105	46,658	51,109	52,497	3,091	783,617	185,915
1981	281,151	47,074	*	45,509	*	769,402	186,177
1982	213,353	32,396	23,714	38,902	2,621	617,434	145,527
1983	272,369	33,990	29,539	54,834	5,117	838,085	209,570
1984	302,390	24,811	40,858	62,460	*	1,010,554	228,949
1985	336,741	26,302	44,465	65,770	*	1,012,451	270,770
1986	366,864	25,552	40,958	70,908	*	1,142,343	302,175

*Data withheld to avoid disclosure; fewer than 3 companies reporting

Table 2 ***Historical Profile:***

Shipments and Production of U.S. Particleboard and MDF

1959 to 1986

(Thousand Square Feet, 3/4" Basis)

(Ref. 68)

	Mat-Formed Particleboard				Medium Density Fiberboard	Value of Ship. (Million $)	
Year	TOTAL	Underlayment	Industrial	Mobile Decking		PtBd	MDF
1959	**255,356**						
1960	**231,998**						
1961	**291,327**						
1962	**366,028**	105,667					
1963	**455,813**	118,876					
1964	**591,697**	162,326					
1965	**753,006**	282,556				79.1	
1966	**947,612**	375,948				88.7	
1967	**1,074,195**	456,531				97.1	
1968	**1,391,177**	547,450				141.9	
1969	**1,681,933**	551,855				200.8	
1970	**1,731,451**	596,427				159.4	
1971	**2,359,221**	753,411				206.3	
1972	**3,079,123**	941,353				284.9	
1973	**3,460,450**	890,935	2,107,532	461,983		389.4	
1974	**3,074,535**	901,353	1,859,624	313,558		347.4	
1975	**2,502,580**	784,007	1,492,032	226,541	***215,496***	272.6	31.4
1976	**3,188,911**	1,092,321	1,535,713	276,998	***280,036***	364.9	54.4
1977	**3,569,451**	1,096,564	1,825,460	289,154	***441,354***	484.9	84.9
1978	**3,720,369**	1,148,858	1,829,745	274,139	***508,416***	818.4	114.9
1979	**3,376,488**	1,103,995	1,674,906	264,649	***506,728***	574.8	136.7
1980	**2,949,897**	885,759	1,501,746	223,430	***493,140***	531.1	145.2
1981	**2,869,352**	780,487	1,531,309	218,476	***516,102***	536.6	175.4
1982	**2,393,066**	653,728	1,306,651	176,997	***446,157***	469.2	144.8
1983	**3,009,343**	797,697	1,730,329	190,157	***604,323***	607.0	198.0
1984	**3,195,586**	729,679	1,943,442	157,553	***634,974***	697.4	216.5
1985	**3,330,517**	756,772	2,015,544	159,213	***684,593***	675.9	242.5
1986	**3,602,757**	742,761	2,239,246	154,530	***780,598***	768.1	267.3

Notes:

The production/shipments of one domestic waferboard plant is included in the 1970-1981 figures. This plant's pulput is probably less than 2% of the total production/shipments.

Extruded particleboard is included in the value of shipments and price figures before 1977. Extruded board accounts for less than 10% of the total production between the years of 1963 and 1969, and 2% or **less** of the total production in years 1969 through 1976.

Total figures are based on ***production*** for the years 1959 through 1977, and on ***shipments*** for the years 1978 through 1986.

produce floor underlayment at slightly higher levels than those of 1976, although mobile decking has dropped sharply (68).

As shown in figure 6 and tables 1,2, the production of MDF in the U.S. has grown rapidly in the course of the last ten years, going from just over 215 million sq.ft. in 1975 to a 1986 total of almost 781 million sq.ft. The value of this production has increased even more rapidly, begining at 31.4 million dollars in 1975 to over 267 million dollars in 1986.

General particleboard and MDF processing systems

In this section, the basic particleboard platen type and MDF manufacturing process will be described briefly. Figure 7 shows a typical layout for a platen-pressed board plant.

In the particleboard process, wood raw material in the form of planer shavings, plywood ends, re-cycled particleboard panels, as well as round wood chips, etc are stored in the bins. Usually, finer materials are used to produce faces of panels, and coarser particles are used in the cores of panels.

Screening is an essential part of separating the particles into material to be used for face and core construction.

The screening process is followed by drying. When the particles enter the storage site, their moisture

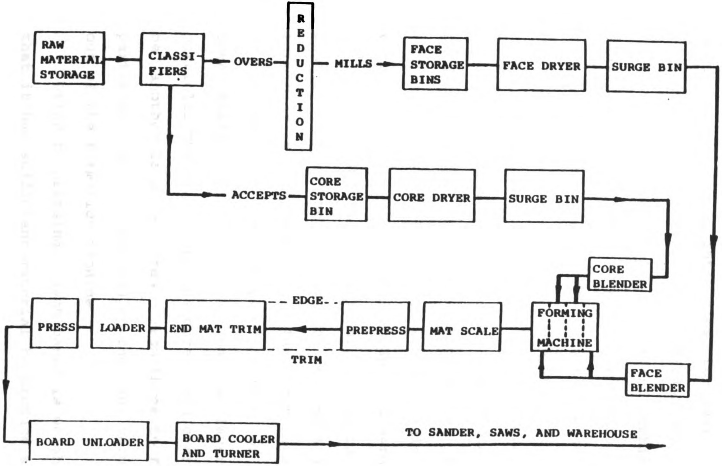


Figure 7.

Typical flow chart of particleboard manufacturing plant. (Ref. 86) content is relatively high depending on the raw material. When they leave the dryers, their moisture content is between 3 and 5 percent. Once out of the dryers, the particles are fed into bins to await the blending process, the next step in particleboard production.

Blending is a complex operation, combining precisely measured quantities of resin and wax with the dry particles. The resin used is mostly urea-formaldehyde, and the wax is used as a moisture inhibitor.

Blending is succeeded by the process of mat formation itself, the process that gives mat formed particleboard , its name. Mat-formation may be done on metal caul plates or screen cauls as in most particleboard plants, or via a caulless method, using a continuous-belt formation line. As the caul, or belt, passes through the forming machine, several layers of particles may be deposited. The first layer may consist of fines that will form one face of the panel. Immediately over these may be a layer of coarser particles that will form the core, and over these would be another layer of fines. From three to five layers of particles may be deposited on the caul before it moves out of the formation machine.

Prior to pressing, each panel is weighed to assure that it has sufficient material to produce an acceptable panel. Underweight and overweight panels are rejected, removed from the production process, and their material fed back into bins to be re-introduced into the production process.

To this point, all of the various processes of the production have been joining together to focus on the heart of the particleboard plant, the presses. Before pressing, prepresing in most of cases is necessary, specially when a caulless system used. Prepressing consolidates a loosely formed mat into a relatively rigid cake which has a certain degree of cohesiveness; the mat is also reduced in thickness so that a press with minimum space between the platen can be utilized.

The hot presses give the board its character. The hot press may be single-opening or multiple opening, with most plants currently employing multiple opening presses. A schematic of a platen press is shown in figure 5.
Into the press are fed the cauls containing the prepared blend of particles. The mats range in size from three to ten feet wide and up to 28 feet long, in most instances. Each press has a press loader, which collects the mats on shelves, one by one, up to the number of openings in the press itself. When the loader is full, it is engaged, and the press fed its full charge of prepared mats, usually from 14 to 24 in number. Inside the press, temperatures of from 300 to 350 degree Fahrenheit combine with pressures of from 300 to 600 psi in compressing the particle mats into the desired thickness and density.

The hot press not only gives shape to the particleboard mat, but it also gives the resin a chance to cure, a process that requires specific amounts of time, depending on the thickness of the panel being produced and the press temperature. Thin boards (1/4 in) will cure in only 2 minutes, while those 1 1/2 in thick require up to 12 minutes for curing.

Following pressing, the panels, are separated from the cauls, which are returned to the production line for additional mats. The panels themselves are off-loaded onto cooling wheels, which turn them and cool them prior to their being sent to saws for final sizing and storage.

The final step in particleboard production is sanding, which assures uniform thickness of the panels and removes precure or soft surfaces from the board assuring a smooth, hard surface and uniform thickness of the panels. At this point panels are graded and banded into units and prepared for final shipment (68).

Medium density fiberboard bridges the gap between fiberboard and particleboard technologies. MDF is based on a pulping process which reduces the wood raw material to fibers or fiber bundles. Its properties are very similar to those of conventional particleboard. While conventional fiberboard products have densities of around 1.0 g/cu.cm.(wet and dry formed hardboard) or around 0.1 to 0.5 g/cu.cm.(insulation board), MDF is manufactured at an average density of 0.75 g/cu.cm.

The ability to develop a satisfactory glue bond between fibers at this density is based on a number of unique features of this process:

Pressurized Refining -- the reduction to fibers of wood chips or other residue occurs in refiners at elevated temperature and pressure. This pulping system produces a pulp with a very low bulk density. This low bulk density offers sufficient resistance during densification in the press to develop adequate bonds between fibers. Bulk densities of one to two lbs/cu.ft. are considered to be an essential requirement for the manufacture of high quality, MDF.

Binder Formulation -- so called in situ resin systems are types of resins which are of low molecular weight, low tackiness and low viscosity. They are condensed after application to the furnish. This type of resin prevents the bulky fibers from lumping together.

Radio Frequency Heating -- during densification in the hydraulic press, the mat is exposed to high frequency heating which causes uniform heating of the mat throughout its thickness (figure 8). This is in contrast to conventional heating of the mat by heat conduction from the heated press platens, causing a considerable temperature gradient in the mat. Certain advantages are ascribed to the high frequency curing of the mat, such as a reduction of the density gradient over the cross

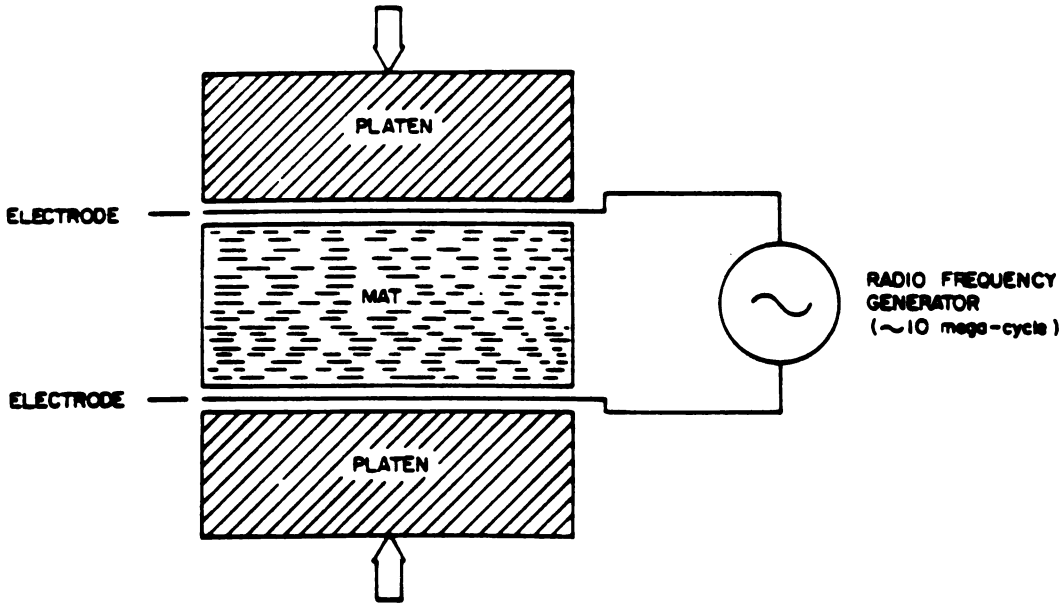


Figure 8.

Principle of radio frequency board press.
(Ref. 86)

section of the board and the elimination of blowing and splitting problems. However, low density gradient or a uniform density over the board cross section is not necessarily always desirable.

MDF is as the name clarifies, distinct from particleboard. The chief difference between the two lies in the treatment of the wood before it is blended and matted. MDF is produced from wood that has been cooked in a moderate pressure steam container. This cooking process softens the wood 's lignin, which is the natural binder holding the wood fibers together. In this process, the wood becomes less brittle and is not easily affected by moisture. In the refining process, these fiber bundles are rubbed apart, as distinct from the breaking or cutting process, characteristic of particle production.

Following this process, the fibers, which are all basically the same size, can be dried and blended without screening, since screening is simply a process of separating particles of different size. Following the refining process, the refined fibers enter a dryer leaving fibers at 2 to 9 percent moisture content. The dried fibers are now ready for the application of the resin binder which resins are either of the in situ type described earlier or they are relatively low tack standard urea resins. Forming and prepressing are the

next step. The fibers are deposited on a screen conveyor by means of a series of vacuum forming heads or vaccum felters. Following the mat formation the loose mat is compressed in a continuous prepress, then it is cut to length and the sides are trimmed. Each mat is weighed to assure proper density of the board. As mentioned before, the use of high frequency heating in the hot press is an important element in MDF manufacture. A press size of 5 by 18. ft. is suitable for high frequency heating.
After pressing, boards are cooled, trimmed, cut to size, and sanded (68,86,91). A typical process flow chart of MDF is shown in figure 9.

Control of properties

The standardized strength properties of composition boards include static bending, tensile strength parallel to the surface, tensile strength perpendicular to the surface, compression strength parallel to the surface, shear strength in the plane of the board, glue line shear, and impact interlaminar shear, and edgewise shear. Properties associated with moisture include water absorption and thickness swelling, linear expansion with change in moisture content, edge thickness swelling, accelerated aging, cupping and twisting. Not all of the above mentioned properties are important for all of the products manufactured. Rather

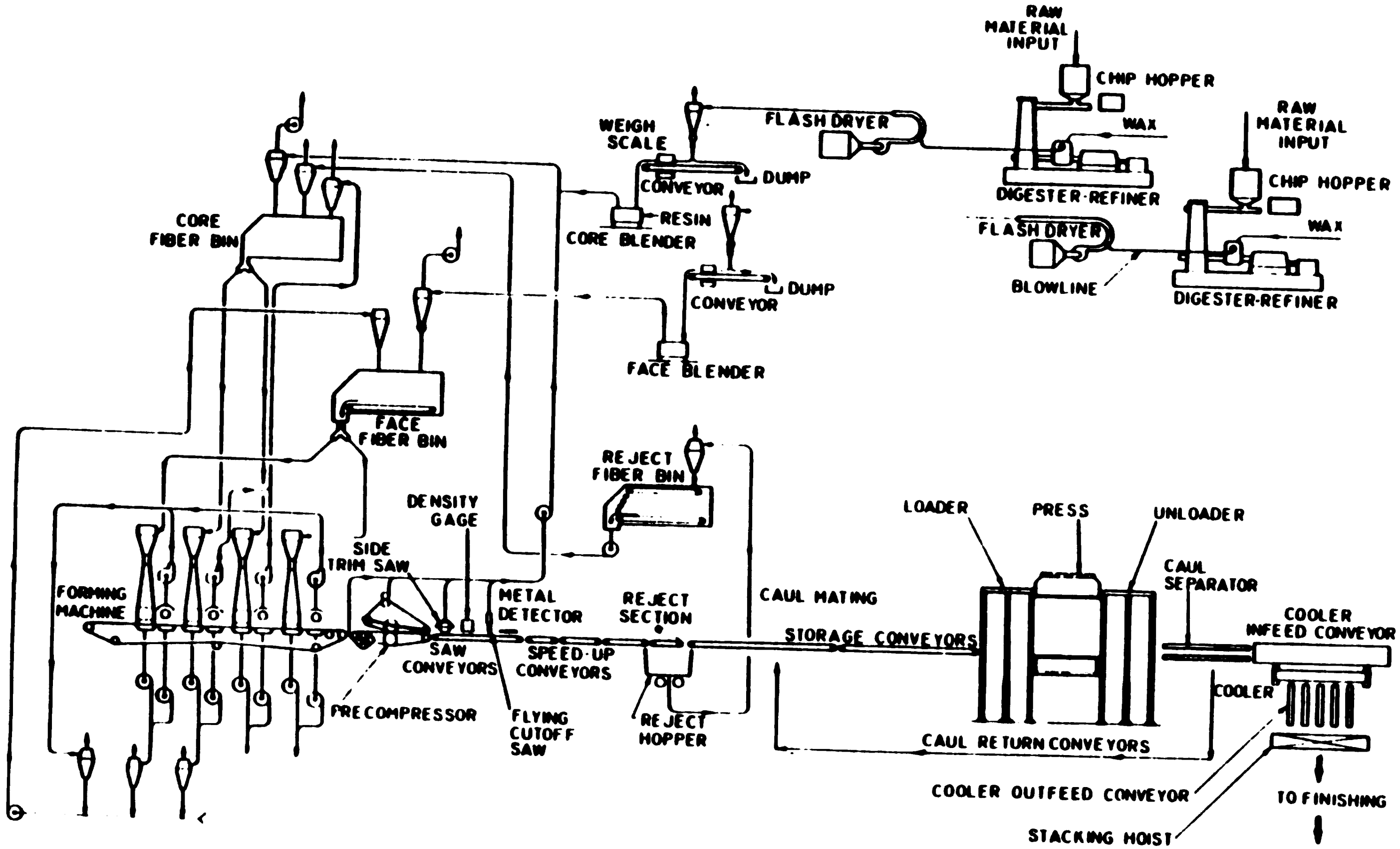


Figure 9.

Typical process flow chart of MDF. (Ref. 91) each product has a particular set of properties which are important because of the intended end use. In general, the physical properties usually evaluated for board products include static bending (which covers modulus of elasticity and modulus of rupture), internal bond, water absorption, thickness swelling, and linear expansion with change in moisture content. Since properties are usually associated with the density of the product, the density is usually determined along with the physical properties.

Measurement of the physical properties of particleboard and fiberboard is generally performed according to the standard methods of evaluating the properties of wood-base fiber and particle panel material (ASTM D 1037) (2). There are of course other accepted standard methods which are used in other countries such as the Canadian Standard (CSA) (9) and the International Standard(ISO) and so forth. Tables 3, 4 show the general properties requirements for particleboard and MDF.

The quality control of particleboard or MDF is associated with testing of these product properties. Many different types of tools can be used in the quality-control effort. These can range from sophisticated instrumentation and computers to micrometers and hand rules. Most plants use statistical quality-control procedures which can provide data on process capability,

Table 3. *Property Requirements of Mat-Formed Wood Particleboard* (Ref. 44)

Density (grade) (min avg)	Class‡	Modulus of rupture (min avg)		Modulus of elasticity (min avg)		Internal bond (min avg)		Linear expansion (max avg)	Screw holding: Face (min avg)		Screw holding: Edge (min avg)	
		(psi)	(MPa)	(psi)	(MPa)	(psi)	(MPa)	(%)	(lbs)	(kg)	(lbs)	(kg)
*Type (use) 1.**												
A. High density, 50 lbs/ft^3 or 0.80 sp gr and over	1	2,400	16.5	350,000	2,413	200	1.38	0.55	450	204.5		-
	2	3,400	23.4	350,000	2,413	140	0.97	0.55			-	
B. Medium density, 37-50 lbs/ft^3 or 0.59-0.80 sp gr	1	1,600	11.0	250,000	1,724	70	0.48	0.35	225	102.3	160	72.7
	2	2,400	16.5	400,000	2,758	60	0.41	0.30	225	102.3	200	90.9
C. Low density, 37 lbs/ft^3 or 0.59 sp gr and under	1	800	5.5	150,000	1,034	20	0.14	0.30	125	56.8		-
	2	1,400	9.7	250,000	1,724	30	0.21	0.30	175	79.5		
Type (use) 2.†												
A. High density, 50 lbs/ft^3 or 0.80 sp gr and over	1	2,400	16.5	350,000	2,413	125	0.86	0.55	450	204.5		
	2	3,400	23.4	500,000	3,447	400	2.76	0.55	500	227.3	350	159.1
B. Medium density, 37-50 lbs/ft^3 or 0.59-0.80 sp gr	1	1,800	12.4	250,000	1,724	65	0.45	0.35	225	102.3	160	72.7
	2	2,500	17.2	450,000	3,102	60	0.41	0.25	250	113.6	200	90.9

* Type 1: Mat formed particleboard (generally made with urea-formaldehyde-resin binders) suitable for interior applications.

† Type 2: Mat formed particleboard made with durable and highly moisture- and heat-resistant binders (generally phenolic resins) suitable for interior and certain exterior applications when so labeled.

‡ Class: Strength classifications based on properties of panels currently produced.

Table 4. Property requirements for MDF. (Ref. 49)

Nominal Thickness	Modulus of Rupture	Modulus of Elasticity	Internal Bond (Tensile Strength Perpendicular to Surface)	Linear Expansion	Screwholding Face	Screwholding Edge
inches	psi	psi	psi	%	lbs.	lbs.
13/16 and below	3,000	300,000	90	0.30[1]	325	275
7/8 and above	2,800	250,000	80	0.30	300	225

[1] *For boards having nominal thicknesses of 3/8 inch or less, the Linear Expansion value shall be 0.35%.*

assist in setting specifications, and help with control decisions.

There are several basically different methods of production of particleboard and MDF and many variables within each method. It is not within the scope of this study to outline those methods of productions or all of the parameters. An effort will be made to investigate some of the basic variables that are always present. These basic variables influence the mechanical and physical properties of particleboard and medium density fiberboard.

Chapter II

OBJECTIVE

The objectives of this study are two fold: The first is to describe the factors involved in the development of strength, stiffness, and density variation in particleboard and MDF. The second is to investigate the relationship between density and internal bond strength of particleboard and MDF.

A number of factors affect and develop the strength properties of the boards. Among the major parameters are wood species, the raw material type, mat moisture level, the resin type and distribution, board density, particle orientation, particle geometry, and pressing cycle variables.

The glue line contact and development of mechanical properties of particleboard and MDF depend significantly on densification.

Almost all of the above mentioned parameters interact with each other in one way or another. A change in any one of these factors will result in a change of the effects of many of the other related factors in the board process and consequently in changes of strength properties. Thus each factor cannot be thought of as an individual entity which can be manipulated easily to control the board process.

However, once it is recognized that there is an interrelationship between a number of factors and how different parameters and process variables influence the strength properties, a more complete grasp of the process can be attained and actual manipulation can be achieved for controlling and modifying the strength property of special interest, namely, internal bond strength and its relations to density.

The subject of internal bond strength property of particleboard and MDF has been investigated by many researchers. However, there is an inconsistency in the results regarding the relationship between IB and density and density gradient. While many workers have found a clear relationship between IB and average density and between IB and core density of particleboard, some workers claim that those relations are not strong and might not exist (18, 70, 71, 97). It is believed that MDF is not similar to particleboard in terms of core density and IB relationship. It is interesting that, if there is no relationship between core density and IB of the board, then it may be possible to reduce the density to some extent and gain the benefits of density reductions.

So, the second objective of this paper is to determine those relationships for two commercial particleboard and MDF and searching for a possibility of density reduction. However, any density reduction would require sacrifices in one or an other of several important board properties, e.g., the density reduction causes a reduction of the bending strength. In order to minimize strength properties, it would be important to know the relationship between overall density, density gradient, face and core densities and the major important strength properties.

The scope of the experiment is limited to only two commercial products. The results, therefore, although they may used as valuable indicators, cannot be extended directly to other commercial particleboard and MDF.

Chapter III

DEVELOPMENT OF PHYSICAL AND MECHANICAL PROPERTIES OF PARTICLEBOARD AND MDF

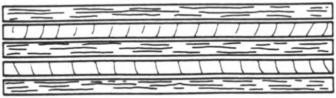
As mentioned previously, there are many factors affecting physical and mechanical properties of particleboard and MDF. Among the major factors are : type of raw material, raw material density, resin type and distribution, press cycle variables and many other factors. In the following sections, the structure of particleboard and fiberboard will be outlined first. The main factors for developing physical and mechanical properties will be discussed next.

The structure of particleboard and fiberboard

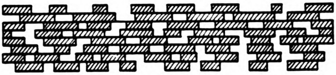
The characteristic feature of woody cells is the special nature of their cell wall.

The layered construction of the cell wall and the organization of the fibrils in the layers have an important bearing on the strength properties of individual fibers, which in turn will be reflected in the behavior of solid wood and wood products (91).

Particleboard can be viewed as a structure consisting of layers like plywood. Each layer consists of a certain amount of wood substance with void spaces interspersed (83), see figure 10.
This structure has an effect on the formation of continuous glue lines. Upon compression of this mat in a



PLYWOOD



PARTICLEBOARD

Figure 10.

Arrangement of particles in the manufacture of plywood and particleboard. (Ref. 91)

hot press, however, the amount of void space is reduced and the total area of contact enlarged.
The discontinuity of the layers may, therefore, be compared with the surface irregulatities of solid veneer sheets in plywood (91).

Major factors developing physical and mechanical properties

Species

Species is one of the most significant factors influencing the physical and mechanical properties of the boards.
Numerous wood species are currently utilized in the manufacture of particleboard and MDF throughout the world. The technology exists for using almost any wood species for the manufacture of particleboard and MDF.

Particleboard manufacturers have a definite preference for softwood because the quality of a softwood board at a given board weight is considerably higher than that of a board made from heavy hardwoods. In other words, hardwood boards must be heavier, to be of the same quality as softwood boards. Aspen and other lower density hardwoods are, of course, exceptions. A wood of low strength properties (aspen) produces a particleboard with higher strength properties than another board made with a wood of high strength at the same board density, see figure 11. This is so because

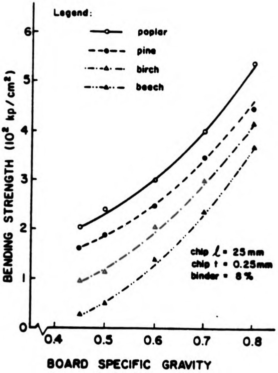


Figure 11.

Example of bending strength of flakeboard affected by both species and board density. (Ref. 5) unit weight of low density wood occupies a greater volume than the same weight of high density wood.

When these volumes of wood are compressed to the dimensions of a board, a higher relative contact will occur in the case of the greater volume of wood and a better glue bond between flakes results (29,82).

Most often the question of species or raw material mix is settled on economic considerations rather than technological ones, although these two are not always independent (47).

Much of the problem of species variation can be handled by constantly subdividing the various types of raw material recieved from various sources and mixing them back together (44).

Resin bond

The two principal and predominant resins used for particleboard manufacture are urea and phenol formaldehyde. The amount of resin used in board manufacture is expressed in one of two ways :

(a) Percent of resin solids based on the oven dry weight of wood furnish.

(b) Amount of resin solids used (in grams or pounds) per unit surface area of the particles.

The amount used in manufacture of particleboard varies over a considerably range . Most often however, the amount of resin used ranges from 5 to 9% for urea formaldehyde resin and from 3 to 6% for phenol formaldehyde. When multi-layer particleboard is intended for furniture manufacture, the resin usage in face layers may be as high as 10-12% , with 6% or higher in the core (47).

Resin efficiency has been defined as the application of a minimum quantity of adhesive to wood particles, with resulting optimum physical properties in a pressed board. Theoretically, resin needs to be applied only to those portions of particles which will come into contact with other particles.

The resin droplets are sufficient to act upon the entire contact area of the particle (8,13, 37,).

Lehmann (37) showed how fine atomization influences strength properties. He noted that at a density of 0.65 g/cu.cm. boards of desired strength level could be obtained with 19.6% to 27.9% less resin with fine atomization than with coarse atomization, see figure 12. However, he pointed out that regardless of resin efficiency, in the density range of the experiment, static bending increases rapidly with increase in resin content from 2 percent to 4 percent. However, those values will not increase significantly with increase in resin content from 4 percent to 8 percent, see figure 13.

The adhesive bonding of wood fibers involves thermodynamic and kinetic parameters and their interactions (99).

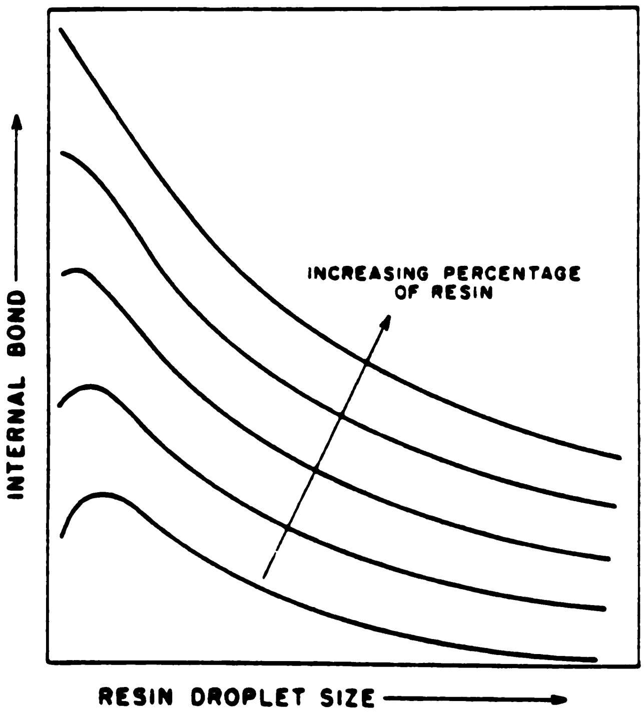


Figure 12.

Resin efficiency in particleboard as function of resin droplet size. (Ref. 100)

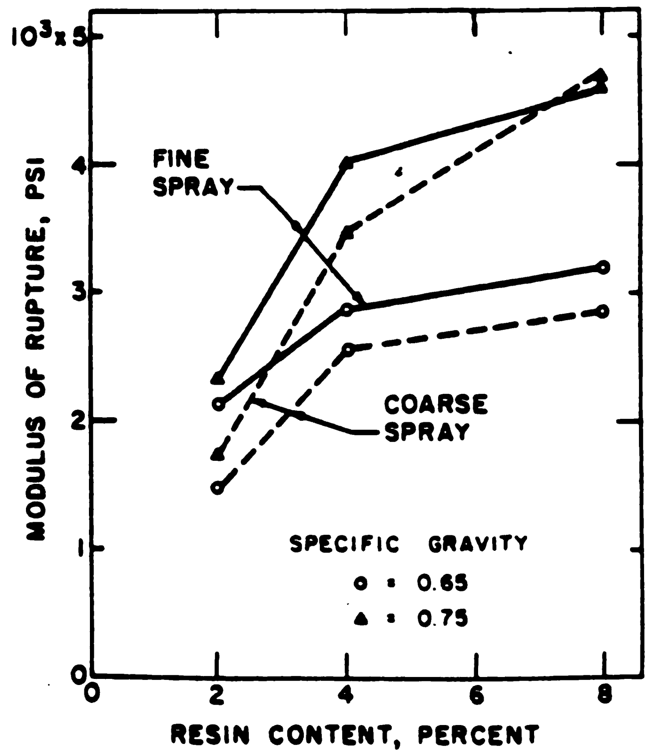


Figure 13.

Example of MOR of particleboard as influenced by resin content. (Ref. 34)

To give the adhesive polymer mobility, it is applied to wood as a solution. As soon as the adhesive solution is applied to the wood, the solvent wets and then penetrates and adsorbs into the fiber, even without pressure, leaving most of the resin solids on the fiber surface. The rate of loss of solvent depends on the moisture content of the wood fibers, roughness of the surface, adhesive concentration and inherent attraction between wood and solvent (99).

Application of pressure to adhesive-laden flakes spreads and transfers the increasingly viscous adhesive and causes bulk flow of adhesive solids and solvent through the wood surface into the large pores and capillaries in the fiber wall, thus reducing the thickness of the film (99).
If too much adhesive penetrates into the fiber structure, the film is discontinuous on the fiber surface (99).

Cure of the adhesive involves two interrelated process: solvent loss and chemical crosslinking. A high solvent content of the adhesive retards crosslinking. Too rapid loss of solvent makes the immobile solids incapable of forming a crosslinking film (99).
Heating increases both solvent loss and crosslinking, although each rate increases differently with temperature (99).

Most of the gluing parameters are affected by time, temperature, pressure, and fiber properties. So, it is possible to manipulate the adhesive property to form a good bond. The thermodynamic processes of wetting and adsorption are less amenable to manipulation than other gluing parameters (99).

Although many wood properties influence bonding, moisture content is most important, see figure 14. When moisture content is high, wetting occurs readily, but the amount of water adsorbed is low. So, at any specific wood moisture content, the assembly time and amount of adhesive are to be adjusted for optimum bond quality (99).

Density also affects gluing in several ways. The glueline may vary in thickness because dense woods are more difficult for adhesives to penetrate and are less conformable under pressure. Because most structural wood adhesives do not fill gaps, thick areas in glulines tend to be weak (99).

Dense woods exert more stress on cured glulines because of changes in wood moisture content. In addition, the greater the wood density, the greater the compression required to consolidate particles and flakes into a board (35,99).

The broad range of densities that may be found within the same piece of wood may create bonds of different quality in a board 99).

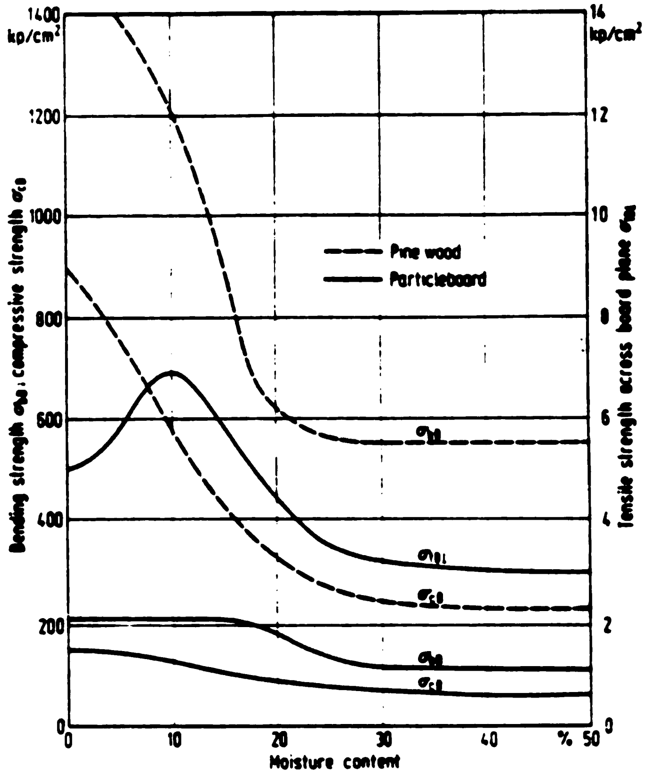


Figure 14.

Example of dependence of some strength properties of solid wood and particleboard on moisture content. (Ref. 31)

Particle geometry

The total range of sizes and shapes of wood elements that could possibly be considered for composition boards are shown in figure 15.

This is a general classification of wood elements starting with the largest element, the log. Smaller element can be defined until the molecular level is reached. Included in this classification, are the typical elements used in particle composites, namely chips, flakes or wafers, strands and particles.

Flakes are particles of predetermined dimensions and are produced by the action of the knives cutting across the grain (either radially, tangentially, or at an angle between) and they are flat, thin particles. In the following, the term flake refers to a special type of particle.

Particle geometry has tremendous effect on mechanical properties.

When considering flake for raw material, two aspect of flake geometry are of significant importance : flake thickness and flake size. The flake thickness relates to the degree of flexibility of each flake when compressed into one layer of particle or flakeboard. The flake size controls the total surface area exposed for resin dispersion. Together, these two aspects of flake geometry influence, to a large extent, the mechanical

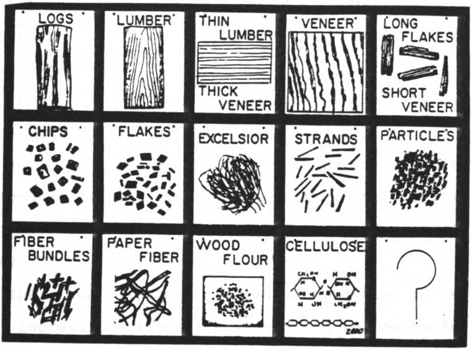


Figure 15.

Most common forms of wood composite elements.
(Ref. 41)

strength of the board, the surface characteristics, the machining properties, and properties such as weatherability and dimensional stability (4).

Suchsland (81) introduced another aspect of flake geometry; the flake length-width ratio. He observed that the area of definite glue line contact between flakes was a function of length-width ratio of individual flakes, and that was a significant factor in developing bending strength.

The ratio of flake length to thickness is another indicator suggested by some workers (6,57).

While modulus of elasticity increases with thinner or longer flakes, internal bond strength improves by using shorter and smaller sizes of flakes (6, 45, 48, 62, 59, 69).

The linear expansion of flakeboard tends to increase with increasing flake thickness and to decrease with increasing flake length (44).

The thickness swell of flakeboard tends to increase with increasing flake thickness except with low board densities (44).

With mixture of particles having widely differing geometrical characteristics, the strength properties tend in general to be intermediate between the properties obtained with the different kinds of particles separately (44).

Densification of boards

Low glue spreads and structural characteristics of the mat require densification. The fundamental variable affecting board properties is the degree of contact between particles. So, densification is the major step developing a good glue bond between particles and developing the strength properties of the loose particleboard mat to produce a relatively strong thin particleboard. This is done by using a hot press.
The common techniques utilized to compress the loose mat into the final thickness consists of using steel bars (stops) whose thickness is equal to that desired for the consolidated boards. In this technique, the press is closed until it reaches the stops. Once the stops are reached, the pressure applied to the densified mat begins to drop.

The densification of the mat involves considerable plastic deformation.

Density

Density is one of the most important and most easily determined characteristics of composition boards. It allows for rough estimate of other physical and mechanical properties.
High insulation values, dimensional stability, and low cost are generally associated with low board densities

whereas, boards of higher densities generally offer higher strength properties, have higher expansion coefficient and are more costly (82).

Density is a measure of compactness of the individual particles. Thus, the two most important factors controlling the average final density of a board are the raw material density and the compaction of the mat in the hot press. Any changes in one of these factors requires an adjustment of the other if the average board density is to remain constant. Either of these factors can also be changed to increase or decrease the average board density (47).

At a given board density an increase in raw material density causes a decrease of particleboard strength properties (4,15,16,40,46,69,95,97).

Most researches have found a positive relationship between particleboard properties and board density.

An increase in board density increases values of modulus of elasticity (MOE), modulus of rupture (MOR), and internal bond strength (IB) (4,24,77,94,95,97).

Density variations in boards

The density of a particleboard is subject to variations both within a board and between boards of a given sample. These variations of the density may be due to the limitations of the manufacturing equipment and variations in the raw material qualities, or they are inherent in the process. The density variations between boards of a given sample are due to the former reason while those within a given board are due to both sources of variations (82).

The density distribution in a homogeneous particleboard has a horizontal and a vertical component. The horizontal density distribution is a direct consequence of the discontinuity of flake layers and is determined by the particle geometry for a given compression ratio while the vertical density distribution is the result of interactions between most raw material and process variables.

The vertical density distribution or density gradient of a board is highly dependent upon the particle configuration, moisture distribution in the mat entering the press, rate of press closing, temperature of the hot press, reactivity of the resin, and the compressive strength of the wood particles.

The effect of temperature and moisture content on mat compressibility is highly responsible for the formation of a density gradient through the board thickness. As the hot press is closed against the mat, vaporized moisture in surface layers migrates toward the more cooler core. This moisture movement facilitates transfer of heat into the board (70,83).

Particle geometry also, influences the rate of moisture migration and therefore the range and the shape of density gradient (14).

The time required to close the press to stops is directly related to the initial pressure; hence, a high initial pressure will cause the mat to reach final thickness before sufficient heat is transferred from the platens to the mat interior. With a lower initial pressure, press closure speed will be slower, thereby allowing the interior to attain a higher temperature and a lower compressive strength before the stops are reached. The slower the press closure speed , the lower will be the vertical density gradient (78,82).

The vertical density distibution has a marked effect on the mechanical properties of the boards (77,82). High bending strength and stiffness are associated with high face densities. Internal bond, shear strength, screw-holding power, and related properties of particleboard are normally functions of the core density (82).

Multi-layer boards

Single layer board or homogenous boards were the first type of particleboard to be developed. They are almost isotropic in strength and physical properties in the plane of the board, due to the random arrangement of the particles. Their strength properties are very closely allied to density (1).

In commercial production, the most common pattern of layer-density is a sandwich construction, or multi-layer board, having the faces of considerably higher density than the core and frequently containing finer particles in the face layer. Because of the larger size of particles in the core, the core cannot consolidate to quite the same degree as the faces, and hence, this core is invariably of a lower density and frequently incorporates a lower proportion of resin than the outer layers.

This type of construction results in a board having adequate bending strength and shearing stiffness for most purpose, but a relatively low tensile strength perpendicular to the plane of the board (1,28, 84).

The mechanics , process techniques and control of three layer boards

Sandwich structure in particleboard is the result of a laminating process in which the manufacture of the laminas and their assembly are combined in one process. The final properties of each individual layer are composite functions of raw material variables and variables of the laminating process.

The properties of the individual layers of a three-layer flake board are functions of their densities. The relations between layer density and overall density is expressed by the following equation (81) :

$$Sl = \frac{St - Sr(1 - x)}{x}$$

Where :

Sl = Layer density, g/cu.cm.

St = Overall density, g/cu.cm.

Sr = Core density, g/cu.cm.

x = Shelling ratio, =

$$\frac{(\text{total thickness} - \text{core thickness})}{\text{total thickness}}.$$

For a given overall density and a given overall thickness, core density, face density, and shelling ratio (a ratio of face thickness to total thickness) can be controlled only indirectly by varying the following factors:

1- Raw material variables affecting the compressibility such as species, flake geometry and initial moisture content.

2- ratio of core weight to face weight.

3- Press cycle (81).

In particleboard structures made up of more than a single layer, a basic characteristic involves the differential strength properties between the face and core layers. This type of differentiation permits densification at surface layers designed to withstand higher bending stresses without undue imposition on cost and product weight.

To obtain the strength differentiation, one or more of these techniques are employed (47, 81) :

-- A higher adhesive content in the face layers.

-- different particles(e.g. smaller, thinner) in the face layers.

-- Lower density wood species in the face layers.

-- Processing techniques which reduce compression strength of the face particles, e.g. , using particles of higher moisture content.

-- Surface particle orientation to achieve higher bending strength in the direction of orientation with other parameters (resin content, particle size, etc.) kept constant.

From the following equation, face modulus of elasticity can be derived, knowing the average MOE, core MOE, and shelling ratio (81) :

$$MOE(f) = \frac{MOE(t) - (1-x)^3 \, MOE(c)}{1 - (1-x)^3} \quad \text{psi}$$

Where :

MOE(f) = MOE of face, psi.

MOE(t) = MOE of total board, psi.

MOE(c) = MOE of core, psi.

x = Shelling ratio.

See figure 16 for an influence of raw material and process variables on the MOE.

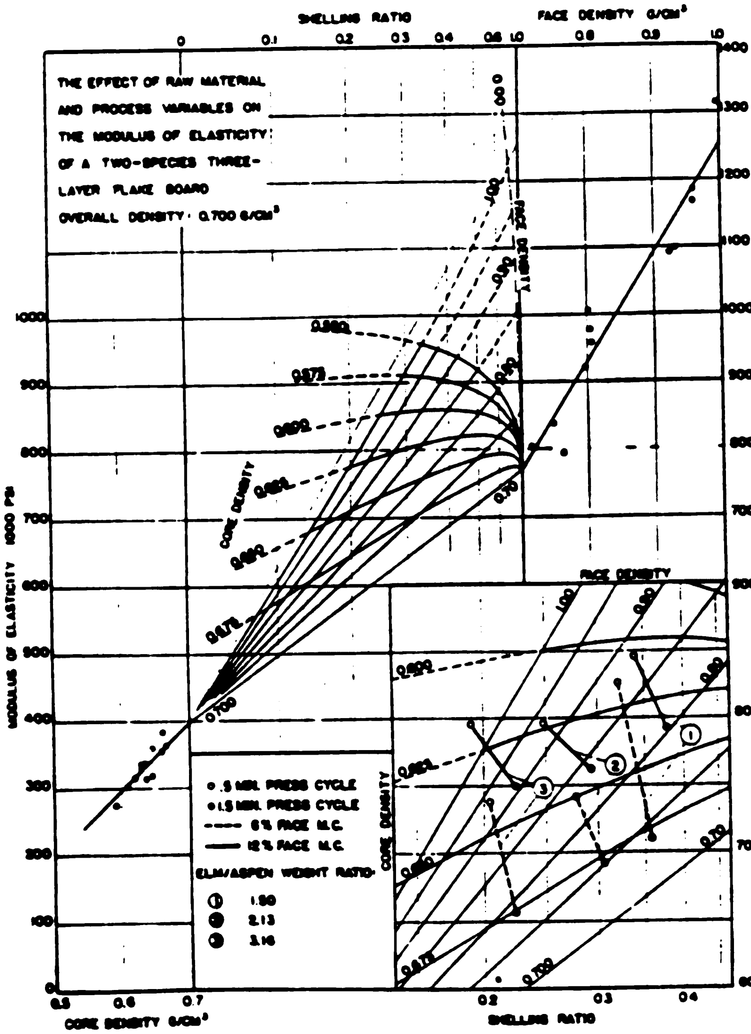


Figure 16.

Example of MOE of three-layer flakeboard as affected by raw material and process variables. (Ref. 81)

The relationship between face density and face MOE and between core density and core MOE of particleboard have been studied by some researchers. Good linear relationships have been found between face density and face MOE and between core density and core MOE (18, 70, 83).

As face density increases the relations become non linear (18).

The relationship between core density and IB is reported by some workers to be linear (10, 11, 81), see figure 17.

Control of density gradient

In general, the linear relations between MOE and core or face densities, and between IB and core density depend only on the density of the species, flake geometry and glue spread. They would only change when one or more of these raw material variables is varied. They do not depend on moisture content or press cycle and can be established independently for any combination of species, flake geometry and glue spread (81).

As mentioned previously, press cycle and closing time have tremendous effect on the strength properties.

The basic function of pressing operation in the manufacture of particleboard is the development of an adhesive bond between individual particles and to densify the mat into the desired thickness.

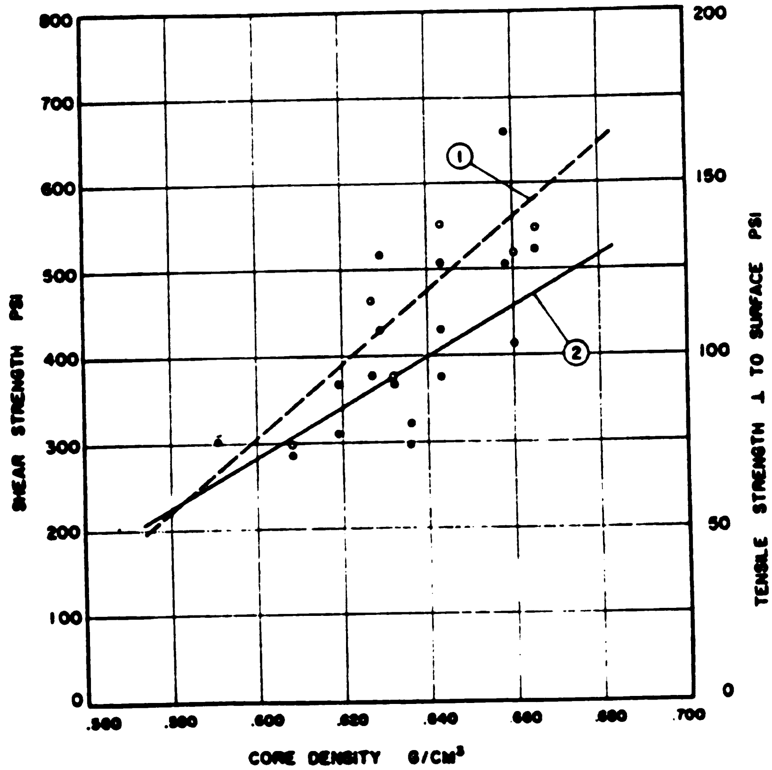


Figure 17.

Example of dependence of IB and shear strength on core density of three-layer flakeboard. (Ref. 81)

The necessity for minimizing press times has been of considerable important in press cycle design and selection of raw material variables although care must be taken to insure that resin is completely cured despite shorter pressing time.

Prepressing and high frequency preheating are possible ways to achieve such a reduction. Factors which affect the time are : temperature required to cure resin, desired board density and wood species used (22).

The most important aspect of the press cycle is closing to position. Closing time refers to the time period between initial pressure application and the moment at which the mat is compressed to the thickness of the stops.

High initial pressures result in short closing time, high face densities and lower core density, see figure 18.

Low initial pressure result in longer closing time and a more uniform density distribution at the same average density (56).

The press closing time not only influences the range of density through the board thickness, but also the shape of the resulting density profile.

With short closing time, the density profile takes on a U-shape. Density would be highest on the surface and then would decrease along a regular gradient to a minimum in the core. As press closing time increases, the density

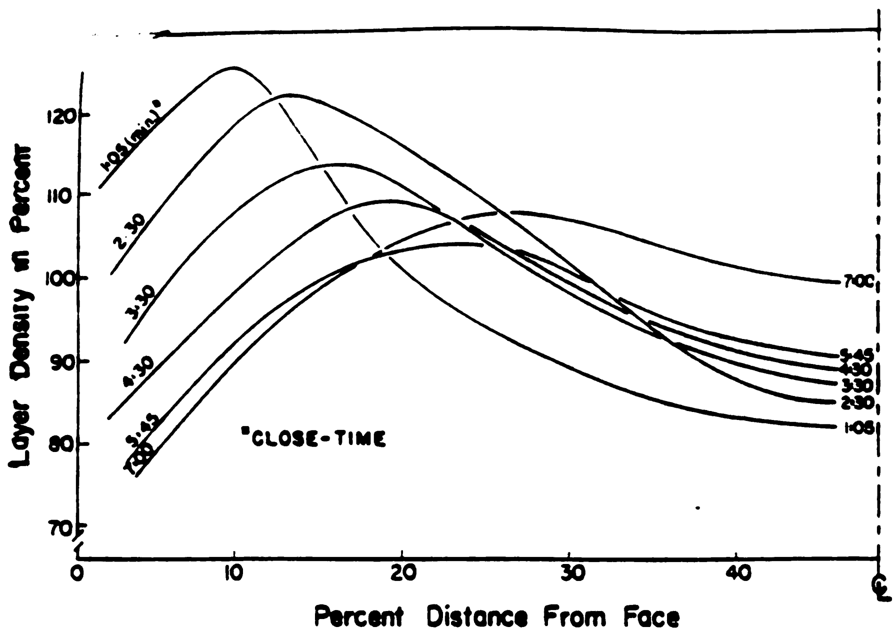


Figure 18.

Example of dependence of layer density of particleboard on press closing time. (Ref. 10) gradient goes through different M-shape configuration, see figures 19-20. Reducing press closing time would lower core density just as it would increase face density (56, 70).

Short closing time would improve MOE and MOR (70, 78, 83).

High densified surfaces increase the bending strength of particleboard but the resultant lower density of the core region normally reduces IB strength (10, 11, 39, 81, 83).

However, some workers reported that short closing time would increase IB strength and core density and internal bond might not have a close relationship (18, 70, 71).

Some special features of MDF

In the previous sections, major factors for developing physical and mechanical properties of particleboard have been disscussed.

MDF has almost similar properties as particleboard in most cases.

Some of the inherent advantages of MDF over conventional particleboard include : higher IB, face screw holding, edge screw holding and better edge machining. In contrast, MOE of MDF is lower than that of particleboard. Comparing the two products, MDF is more costly than particleboard (86).

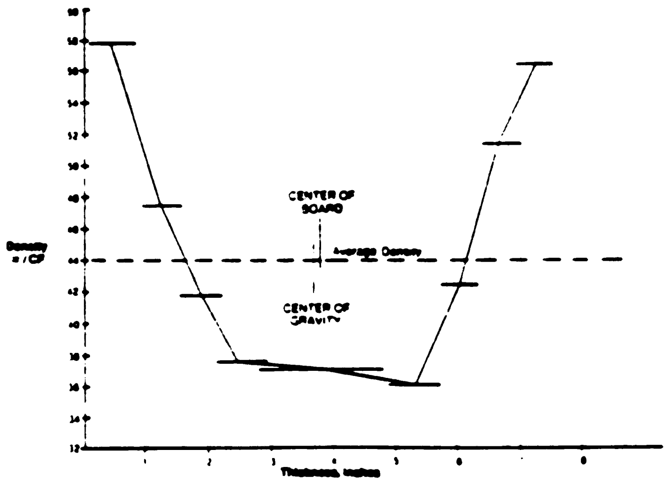


Figure 19.

Example of the influence of short closing time on the shape of density gradient. (Ref. 70)

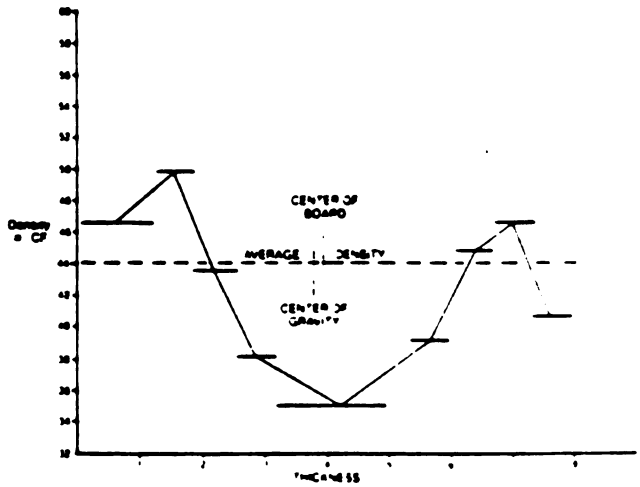


Figure 20.

Example of the influence of long press closing time on the shape of density profile of waferboard. (Ref. 70)

The smaller fiber elements used in MDF result in a much more uniform distribution of the material in the board. This reduces the variations of its properties.

MDF of a good quality can be made from a furnish that contains bark, provided resin distribution is adequate.

By inclusion of bark, IB and other strength properties are reduced to some extent. These losses could be countered by altering the press schedule or by reducing the percentage of fines by screening (103).

Bending strength of MDF similarly to that of particleboard is affected by various factors. Bending strength of MDF at comparable densities would be greater in boards made from raw material of low specific gravity (103).

The density and density distribution directly affect the MOE of MDF (90). This effect is explained in terms of a strong correlation between the MOE and face density of MDF. However, some workers did not find any correlation between MOE and average density of MDF (86).

Unlike particleboard, core density of MDF does not appear to have as strong an effect on the IB strength (86, 89, 90).

The density gradient of MDF is an important variable that can be controlled to a considerable extent during the manufacturing process. An extreme density gradient of

MDF has the advantage of high MOE at a very moderate average density. Its disadvantage might be that the correspondingly low center density could result in low level of IB strength, edge screw holding power and similar properties which rely on the integrity of the center layer of the board (86).

However, a uniform density gradient would produce high IB but poor bending properties (76, 103). This could only be achieved by eliminating the temperature gradient during the compression period, either by heating the mat uniformly throughout its thickness or by pressing the mat at room temperature. The first possibility may be realized by using high frequency heating (76, 89). The second option would be approached by using very high pressure which would bring closing times to a minimum (89).

Like in the case of particleboard, high face density and low core density of MDF are achieved by short closing time, see figures 21-22.

Fiber alignment would improve the bending stiffness in the aligned direction of MDF. Therefore, MDF with properties in one direction equal to those of random boards could be made at lower densities and with less raw material (104).

But fiber alignment does not seem to have a significant effect on IB of MDF (74, 86).

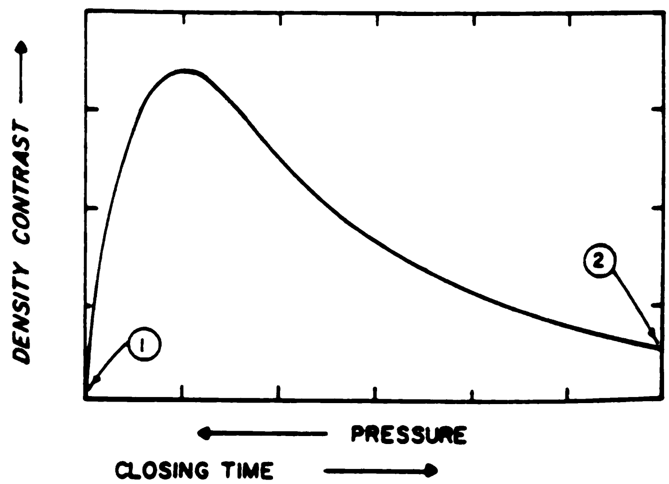


Figure 21.

Example of relationship between pressure or closing time and density profile of MDF. (Ref. 89)

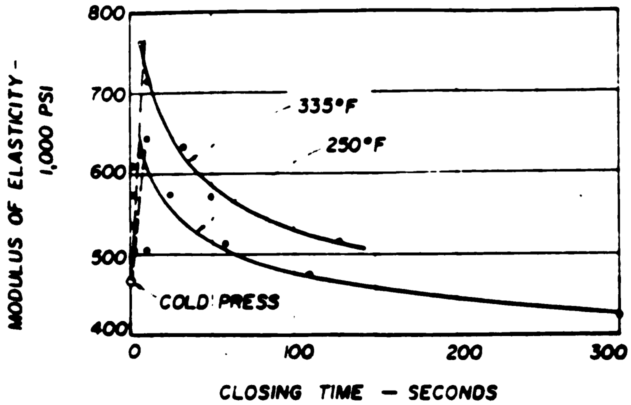


Figure 22.

Example of relationship betwee press closing time and MOE of two press platen temperatures. (Ref. 90)

The measurement of density variation

The measurement of layer density has been extensively used in particleboard and fiberboard research for studying the relation of the board structure to physical and mechanical properties.

Measurement of the density gradient is of use in qualitative evaluations of the manufacturing process and may be accomplished using several techniques.

The normal and traditional method of determining the vertical density gradient is to accurately determine the weight and thickness of a given specimen, remove a thin layer from top and bottom surfaces and accurately determine the weight and thickness of the resultant specimen. The density of the removed layers can then be determined from the weight and volume of materials removed. This is normally referred to as the gravimetric method. Although this method is simple, it is very tedious, is time consuming, has limited resolution, and destroys the specimens. Consequently, it has not been widely used in production control.

Stevens (75) in an attempt to develope a gravimetric method, introduced a slicing apparatus to remove a thin smooth layer, as thin as 0.25 mm. He described the limitation of the surface smoothness and precision of measurement.

Nearn and Bassett (51) examined x-ray

radiography as a means of detecting density variation within a board. In their experiment , x-ray is applied to the cross section of the boards. Dark portions on the exposed film indicated areas of higher density, whereas, light portions indicated areas of lower density. This result can be used as a rough estimate of density variation and does not provide an accurate density profile.

A fast and yet simple non destructive test method for determining the density gradient is the gamma radiation method. The density gradient in this method is determined by incrementally measuring the amount of radiation which passes through a sample (33). The non destructive quality of this measurement allows the correlation of mechanical properties to density gradient characteristics on the same sample and could be used for in-plant quality control, too. This method is not significantly affected by the normal ranges of resin content, changes in wood species and ambient moisture conditions. The cost of this system is relatively low, it was $ 5200 in 1982. The limitations of this method are that only 3 in wide samples can be used in the specimen holder of the stage and the poor resolution in the outer layers.

Winistorfer et al (101, 102) used a direct scanning densitometer based on the gamma radiation technique to measure density profile which may be used for a wide range of specimen thickness.

Chapter IV

IB OF PARTICLEBOARD AND MDF

When the press is closing in the manufacturing of particleboard or medium density fiberboard, the core-zone of the midlle layer compresses least. Therefore, its strength is also the lowest. Thus, it is worthwhile to pay attention to this strength, namely, internal bond.

The internal bond (IB) or the tensile strength perpendicular to the surface of particleboard or fiberboard has been used as an important indication of board quality in both production and utilization. The internal bond test is important for all composites; it provides direct information on the quality of the adhesive bond between wood elements and shows the location of the weakest surface within the board. Thus, the IB test is generally considered the most significant for determining composite board quality. It not only reveals the quality of the glue bond, which in turn allows estimates of related properties, but it is also an important quality control tool, which, in combination with the MOE provides clues to the balance of board characteristics, which is affected, for example, by the press cycle.

The internal bond test methods

The American standard Test for determining the internal bond strength is ASTM D 1037 (2) which is the same as the Canadian Standard (9). It requires 2 in sq. specimens glued between two metal blocks. The glued specimen-block assemblies are pulled apart at a constant rate of strain applied in the direction perpendicular to the surfaces of the board. The specimen is tested to failure and the failing load, which occurs in the weakest planes, is recorded. The IB strength is expressed in psi.

The Japanese-Industry Standard (JIS) has adapted a tensile delamination (push-off) test as a simpler method for evaluating the internal bond of particleboard (25).

The Australian Forest Products Laboratory applies the torsion-shear test for routine determination of torsional properties related to internal bond (42).

The American Standard Test has the advantages that it evaluates the weakest plane in the board, which does not always coincide with the center plane, and that it is equally applicable to thick and thin boards. On the other hand, the necessity of laminating each individual specimen between steel blocks and cleaning the metal block surfaces is inconvenient and time consuming. It also has technological disadvantages such as the dissimilarity of the two materials and the glue lines being subjected to high stresses. Besides, the standard

IB test method is not entirely satisfactory for production quality control work in which a quick result is frequently of primary concern, and it may not be economically feasible for a board user such as a small furniture maker who would have to acquire a relatively expensive testing machine.

Soper and Hann (72) showed that when using the standard method of the IB test, the adhesive and bonding conditions must be carefully selected. The type of adhesive used to glue board specimens to the blocks, how this adhesive is applied, and whether the surface of the board specimen is sanded or unsanded could significantly affect the apparent internal bond strength values obtained. For example, when the surface layers of the board are weak, using an epoxy resin can cause misleadingly high internal bond strength values by reinforcing those surfaces, or the hot-melt adhesive applied at a temperature of 285 F could cause heat deterioration of particleboard, resulting in low internal bond strength.

The need for a speedy, yet reliable method to control quality of particleboard and fiberboard in manufacturing has encouraged many attempts to devise alternative method for determining IB strength. However, each alteration of the standard test might have disadvantages. Most of them either require gluing or restrict failure to a predetermined plane.

Most alternative IB test methods are based on determining torsion strength, shear, torsion shear, or twisting shear strength with good linear correlations between those properties and IB strength derived from standard test.

Knowles (29) described a rapid method determining IB strength in particleboard manufacture. His idea was to organize and simplify the routine of plant hot testing of particleboard for IB. A sample preparation jig which quickly and accurately sizes the test pieces and thin metal tabs (instead of using 2 metal blocks) which cool rapidly provide the means for a rapid test response. It is possible to reduce the response time between sample removal from the line and data evaluation. The benefit of quickly testing IB would be that quality assurance personnel can respond quickly to changing test results by adjusting manufacturing variables.

Following Knowles, Lebens and Hall (34) suggested models of electrically heated hand-held adhesive applicators to speed up gluing of internal bond test specimens.

Lehmann (36) examined two different IB test methods and compared them with standard test. In a modified ASTM test wooden blocks were substituted for metal, the other was a new push-out test. In the push-out test, specimens were prepared by cutting halfway through them from opposite sides with hole saws of two different diameters.

Force was applied at the bottom of each cut until failure occurred in the area between the cuts. Lehmann found a good linear correlation between modified ASTM and ASTM IB test method and between push-out and ASTM test. The push-out IB test method was faster, the modified ASTM was intermediate in terms of time consumed and the standard ASTM test was slowest. However, in the push-out method, failure is forced into the center of the specimens, wheras they could occur in the zone of least strength using the standard test. The strength values obtained with steel blocks were higher than those obtained using wood blocks. These differences between the two methods can perhaps be explained partly by stress concentration induced by the action of yoke arrangement at the edges, see figures 23-24.

Szabo and Gaudert (92) used the idea of Lehmann using wood end blocks instead of metal blocks with eye screw attachments for IB test. They explained that the stress field over the entire block area in an eye screw attachment is more uniform than that of a yoke arrangement.

Lehmann (38) in a recent study, outlined a fast IB test method for both urea and phenol formaldehyde in composite material. This test is based on a simple shear test device and a short exposure to high temperature and humidity in a small pressure cooker. This test does not need gluing and it is a fast test and an accurate one.

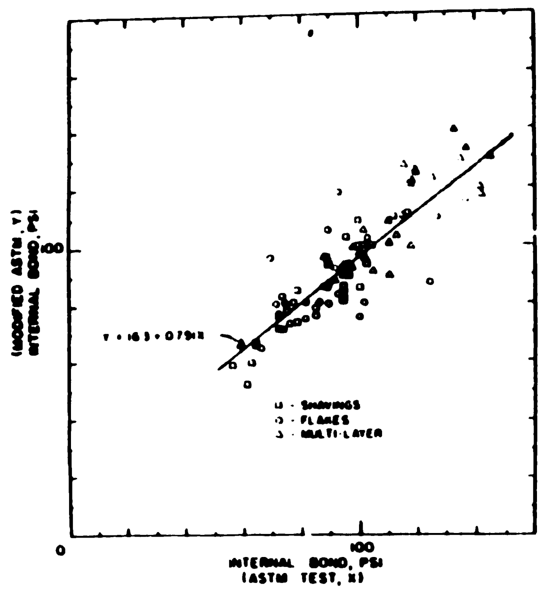


Figure 23.

Correlation between standard IB test and modified standard IB test of particleboard. (Ref. 36)

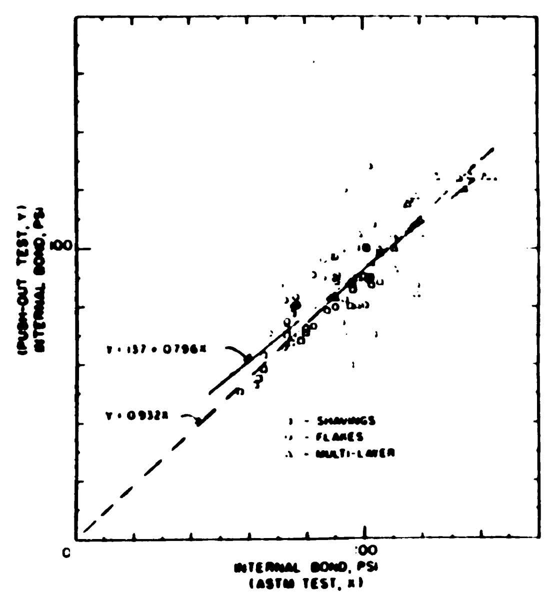


Figure 24.

Correlation between standard IB test and push-out test of particleboard. (Ref. 36)

Shen et al (64,67) introduced a new method for determining IB strength. They found a good relationship between torsion shear and internal bond strength. Their technique is simple, rapid, low cost and does not not involve gluing problems. The speed of testing might be of interest to particleboard manufacturers, and the low cost of the test equipment which includes a precision torque wrench and a pair of modified wrench sockets may be of interest to particleboard users who are not equipped with a conventional testing machine. This test may give erroneous results if the weakest plane does not concide with the center plane of the boards. Besides, it is difficult to test thin specimens using this method. Shen (63) also found a very close correlation between a twisting-shear test and IB.
This method could overcome the difficulties of determining IB using the torsion-shear technique on thin specimens. Again, the limitation of this metod is that failure is forced to occur in the center plane of the board. The other short coming of these methods is that they will not offer the accuracy of a testing machine which is necessary for research studies. Shen and Carroll (65) examined the correlation between layer strength and layer density. They used the same technique of torsion shear to analyse relationship between layer IB and layer density, see figure 25.

Vogt (98) used stress wave analysis to evaluate the

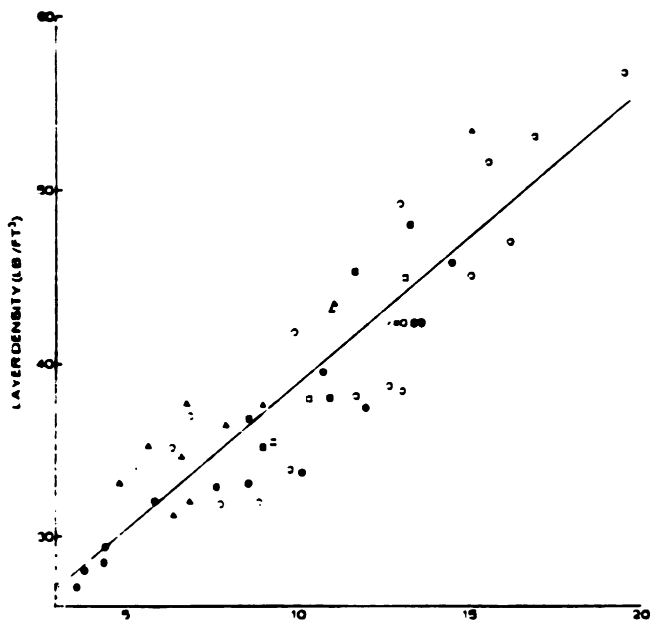


Figure 25.

Example of relation between layer strength and layer density of particleboard. (Ref. 65)

IB strength. That is a non destructive test method can provide useful predictions of IB strength.

Many other workers examined the correlation between torsion strength, shear strength and IB (17,39,53,66,105).

One of the alternative tests based on the well-established high correlation between shear strength in the plane of a particleboard and IB strength, and which is also used in this paper was introduced by Suchsland (85). This alternative test does satisfy the two important advantages of the standard test : evaluation of the weakest plane not necessarly in the center plane, and applicability of the test to thin boards. Suchsland demonstrated that if a particleboard specimen could be oriented so that its center plane concides with the plane of maximal shear stresses in a column, then its shear strength could be determined in a compression test.

Although this method does not require any wooden or metal blocks it does need gluing . The procedure of this method will be described in more details later, see figure 26.

Hall and Haygreen (20,21) developed the " Minnesota Shear Test " which in principle is similar to Suchsland's test in that it utilizes compressive and shear forces. However, by using an apparatus that orients the plane of the specimen at 45 degree to the direction of the compressive load, gluing is not required.

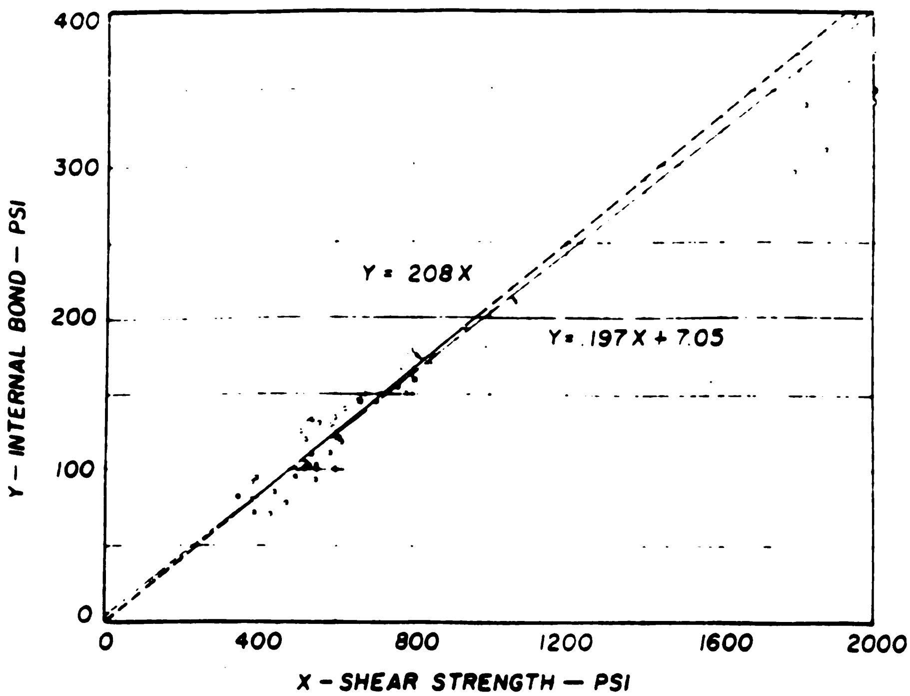


Figure 26.

Example of relationship between standard IB test and shear strength of particleboard. (Ref. 85)

Relationship between IB and density

As pointed out previously, there are many factors influencing the strength development of particleboard and fiberboard. The effects of the main variables on strength properties including internal bond strength were outlined.In this section, the relationship between IB and board density will be described briefly.

The internal bond strength property of composite boards is dependent on many factors such as wood species, board density, density profile, resin type, resin efficiency, resin distribution, particle geometry and press cycle. Efforts are continually being made to improve internal strength by alteration of particle geometry, by altering resin content and method of application (54, 60), by modification of press schedules, by heat treatment (87), by oil tempering (19), by preventing degradation of resins (3,52,61), and by experiments with many other factors (7).

Results of many early researches have revealed that higher IB values occur with increase in board density. Vital et al (97) observed that IB values generally increased linearly with increased board density but these values were not as closely related to board density as were MOR and MOE. Vital et al reported a decrease in IB at constant board density as the compaction ratio increased from 1.2 to 1.6. The IB decrease was attributed to the increased amount of flake damage at the high compaction.

Hse (23) showed that IB was significantly lower for denser species than for other less dense species.

Stewart and Lehmann (77) offered that althougth IB increased with increasing panel density, this increase was not related to species density. In their experiment, they used four different species, three different thicknesses of cross-grain flake, and various board densities. They observed that Red Oak IB values were very high. This high value in IB was due to the furnish having a higher percentage of smaller particles. Red Oak, a ring-porous species, breaks down more compeletly into smaller particles during flake and board manufacture than does a uniformly textured wood .

In general, more uniform horizontal density distribution of particles and the use of smaller particles result in better contact between particles under application of heat and pressure and thus the resulting boards have better bond between particles and have fewer weak points and consequently higher IB strength than boards made from particles not broken down to the same extent.

The internal bond of three-layer boards

The internal bond strength of three-layer boards improve as core particle configuration changes from a long wide flake to planer shavings (6,77,80,93).
Shorter and smaller size of flakes results in better IB.

Hse (24) found a linear correlation between IB and compaction ratio, see figure 27.

Maloney (43) in a study of resin distribution in layered particleboard examined various resin levels of each layer while keeping the total resin content in the board constant at 6 % . He found that high face resin level produced superior MOR values but very low IB properties.
In contrast, with low resin level in the faces, internal bond properties were much higher, but many test failures occurred in the surface. Removing the relatively soft faces of these latter boards by planing shifted the failure location back into the core and further increased the IB strength. Maloney found the optimum percent of resin in both face and core was 6% .

To improve IB of three-layer boards one could increase the core density while maintaining the shelling ratio (the ratio of the face thickness to the total thickness) at the expense of MOE (81). This is

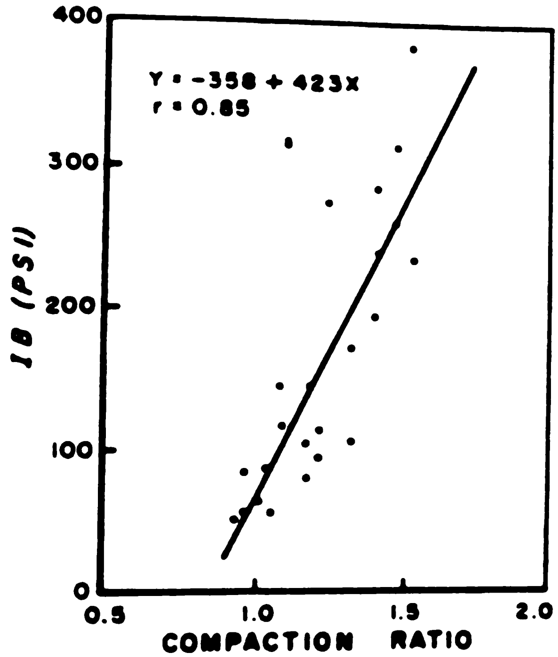


Figure 27.

Example of relationship between compaction ratio and IB strength of flakeboard. (Ref. 24)

possible by manipulating the press cycle.
By changing the press closing time alone, the core density of particleboard of the same overall density could be varied so that the internal bond strength varied as much as 70 percent (10). Again high IB value could not be attained without loss of MOE.

Place (55) in an attempt to make a three-layer particleboard with wood bark as core reported similar results. He found that IB was improved by using higher percentages of resin content. He mentions that in order to get acceptable values for IB, the boards needed more densification in the core at the expense of bending properties.

Inconsistancy in literatures regarding IB and core density relationship

As pointed out earlier, density is one of the most important factors which influence most of the board properties. Reviewing the literature shows that there are many studies on IB strength and its correlation to density and density gradient. Althouth the readers may find many studies which resulted in a positive and strong linear relationship between IB and density and density gradient, yet, there are some reports indicating a non linear correlation betweeb IB and density of particleboard and MDF, see figure 28.

Some workers claim that there is no correlation between center density and IB of MDF (88).
On the other hand, there is no doubt that over a wider range of density, IB is indeed a function of density.

It seems that a definite conclusion with regard to the relationship between core density and IB of MDF cannot be drawn at this time and that the behavior of MDF may differ substantially from that of particleboard.

Therefore, it was decided to investigate these relations in two samples of commercial particleboard and MDF.
This study consists of two parts. In the first part of the experiment, the relationships between density and IB is determined. These relationships are examined over a limited range of density.
Related important properties such as MOE are also considered. In the second part of experiment, those relationships are evaluated over a wider range of density for both commercial boards.

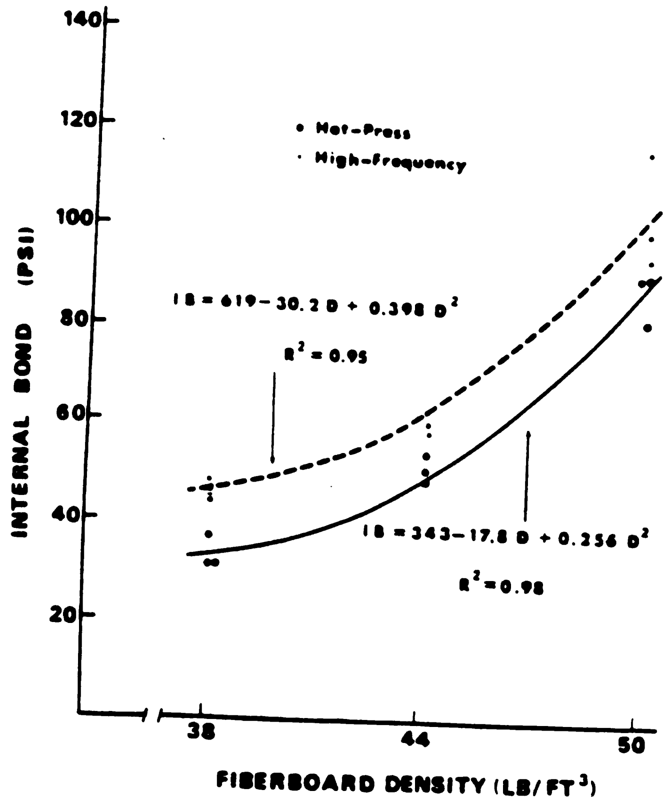


Figure 28.

Example of non linear correlation between IB and density of MDF. (Ref. 76)

Chapter V

EXPERIMENTS : PART I - DETERMINATION OF RELATIONSHIPS BETWEEN DENSITY AND IB OF TWO COMMERCIAL PARTICLEBOARDS AND MDF

Purpose of experiment

It was the purpose of this part of the experiment to investigate the inconsistancies discussed previously and to clear up the relationships between IB and density of the core for both MDF and particleboard. Also to establish whether there are significant differences between MDF and particleboard in this regard.

Preparation of specimens

Rather than trying to obtain commercial boards made at various density levels, the natural variablities of overall and layer densities of boards made at one target density was used as a basis for establishing the desired relationships.

Two 4 by 4 square ft., 0.75 in thick sections of boards were obtained from a southern particleboard mill and two 4 by 5 square ft., 0.75 in thick sections of boards from a southern MDF mill (see board specification in appendix 1).

The two sections of each type are identified in the following as board A and B.

The following properties were determined for each of the two board types:

Vertical density distribution.

MOE of total board.

MOE of core.

MOE of face (derived from core and overall MOE).

IB (overall).

Overall density (determined on MOE specimens).

Core density [determined on MOE (core) specimens].

Core density (determined on IB specimens).

Face density (derived from overall and core densities of MOE specimens).

The overall design and number of specimens used in both parts of the experiment are shown in table 5.

Specimens were cut from board sections as indicated in figure 29. All test specimens were conditioned in a controlled room at 65 deg. F and 50 percent relative humidity.

The moisture content of the conditioned specimens ranged between 6.9 and 7.4 percent.

Density profile testing procedure

For the purpose of this study, since neither board type had clearly defined face and core layers, a

Table 5. The overall design and number of test specimens.

		Particleboard		MDF		Total
		Board A	Board B	Board A	Board B	
MOE, overall density, core density		∥ 18, ⊥ 18	∥ 18, ⊥ 18	∥ 18, ⊥ 18	∥ 18, ⊥ 18	144
IB and core density		36	36	36	36	144
IB and density gradient		25	25	100	100	250
Vertical density distribution	gravimetric method	2	2	2	2	8
	gamma radiation method	6	6	14	14	40
						586

Note : Three of each of the 18 MOE specimens were also used for dynamic MOE test.

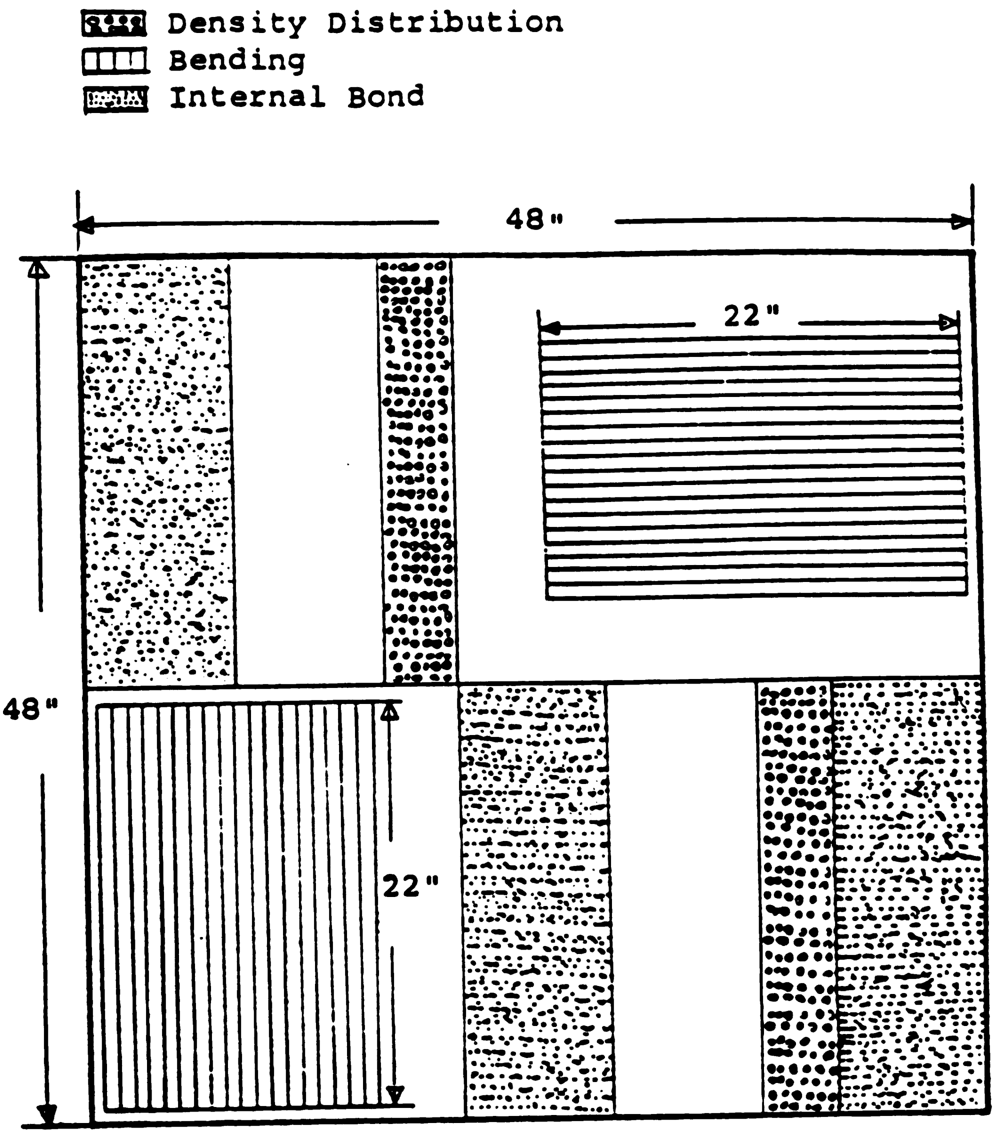


Figure 29.

Diagram for cutting test specimens from 4 by 4 squares ft. boards.

subjective judgement was made as to their relative thicknesses, based on the vertical density distribution. This approximate defining of face and core was based on the average board density in which assuming areas above average board density line as face and areas under average board density line as core. The intersection of average board density and density gradient lines would indicate the thickness of the face of each density profile figure. The average face thickness was 0.32 in and the average core thickness was 0.43 in for both particleboard and MDF.

Two methods were used for the determination of the vertical density distribution, the gravimetric and gamma radiation method.

In the gravimetric method, thin layers parallel to the surface are removed by planing. By weighing and measuring (thickness) of the specimens before and after the removal of each layer, the density of the layers can be calculated :

$$S1 = \frac{St - Sr(1 - x)}{x} \qquad \{1\}$$

Where :

S1 = Layer density, g/cu.cm.

St = density of specimen before layer removal, g/cu.cm.

Sr = Density of specimen after layer removal, g/cu.cm.

$$x = \text{Shelling ratio}, = \frac{\text{total thickness} - \text{core thickness}}{\text{total thickness}}$$

The test specimens, 1 in wide, 22 in long, and 0.75 in thick were weighed to the nearest one hundredth of a gram and the center thickness measured to the nearest one thousandth of an inch. In a given pair of matched strips, material was planed from the top surface of one and the bottom surface of the other. These pieces were then laminated together with the planed surface as the contact area.

Since the planer was preset to a given thickness, initial thickness of all laminated specimens was constant. Thin layers of uniform thickness were now removed from both sides until half the original board thickness had been planed off each side. Layer thickness was 0.050 in and the last layer included the specimen center line. Samples of results are shown in figures 30- 31.

The principle used to measure density gradient using gamma radiatio is simply to pass radiation through a sample of board so oriented that the board surface is parallel to the direction of radiation. The attenuation of radiation is a function of board density. Such tests were conducted on 2 in wide, 10 in long, and 0.75 in thick specimens at the Forest Products Laboratory,

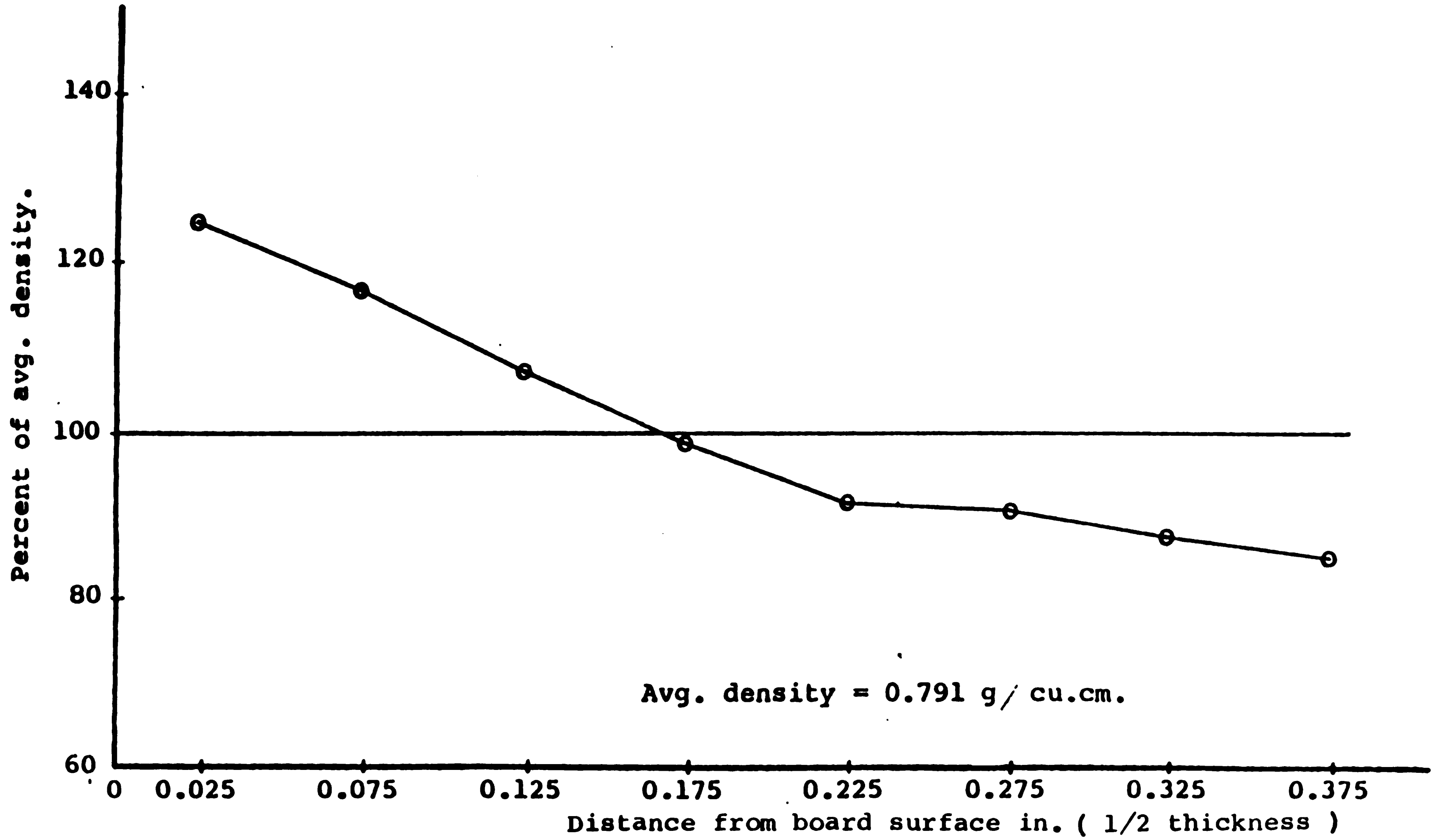


Figure 30.

Density profile for particleboard # PB-E(gravimetric method).

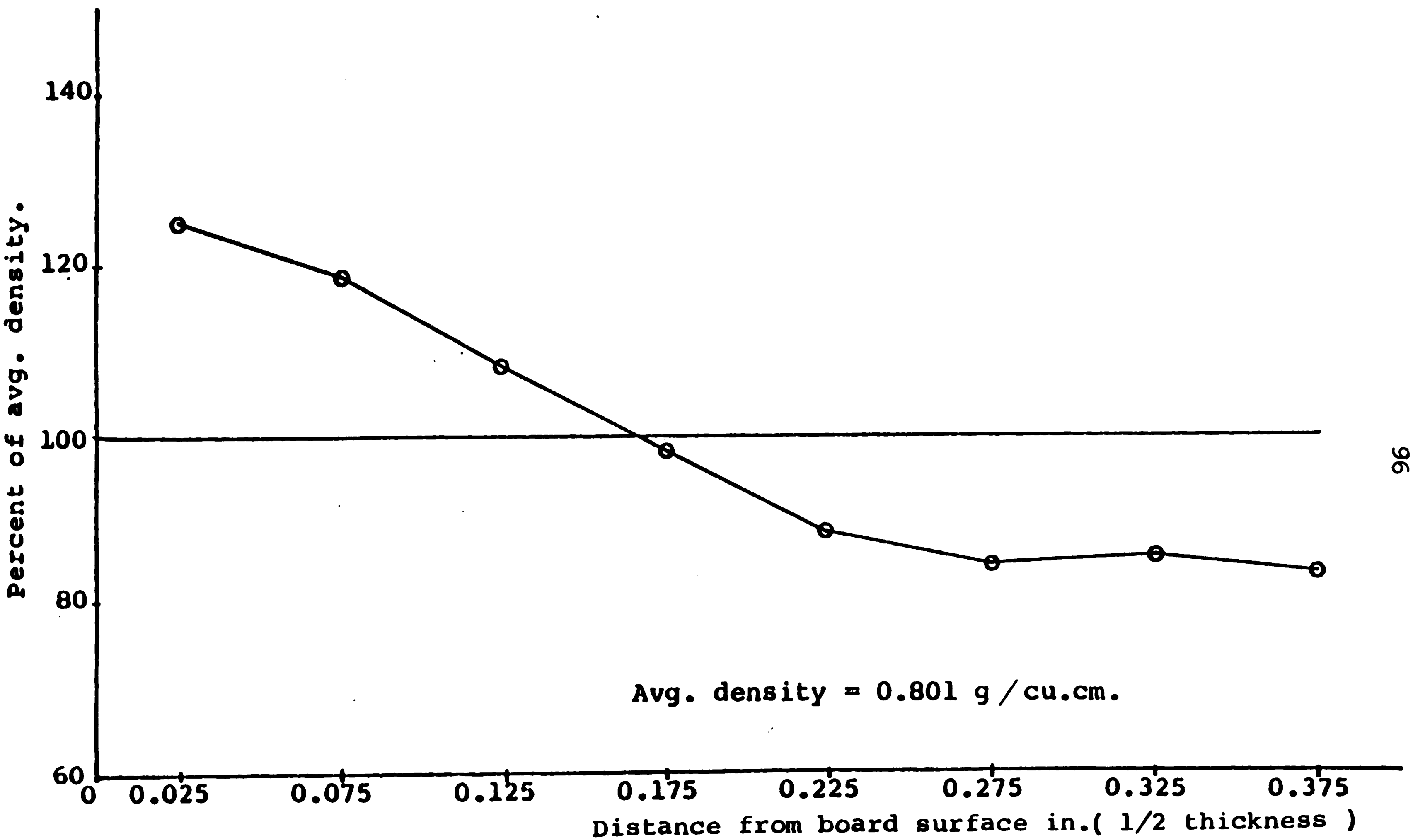


Figure 31.

Density profile for MDF # FB-C (gravimetric method).

Madison, Wisconsin. Each sample had its density profile measured using 0.020 in thickness intervals and in a few cases using 0.0050 in thickness intervals. Samples of results as well as the schematic of the equipment are shown in figures 32-38.

MOE testing procedure

Because it was desirable to determine both face and core moduli on the same specimens, two non-destructive test methods were used, one static, the other dynamic.

The static method consisted of applying two center load increments while determining the change in deflection due to the second load increment of a single supported beam.

$$MOE = \frac{[P(2)-P(1)]L^3}{[Y(2)-Y(1)]4BD^3} \quad \text{psi} \qquad \{2\}$$

Where :

P(1) = First load increment, lbs.

P(2) = Second load increment, lbs.

Y(1) = Deflection after application of first load increment, in.

Y(2) = Deflection after application of second load increment, in.

L = Span, in.

B = Width of specimen, in.

Figure 32. Equipment schematic of gamma radiation method of density profile determination.

Equipment Schematic

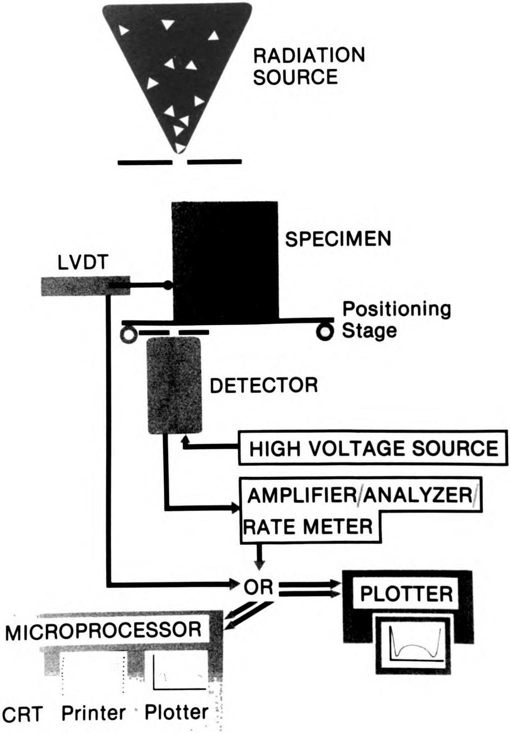


Figure 33. Specimen stage of gamma radiation method.

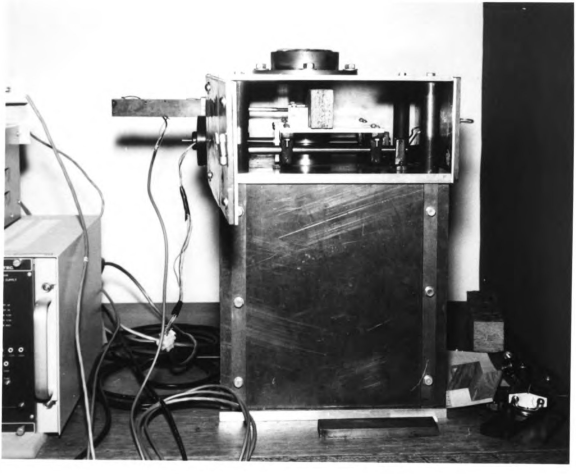
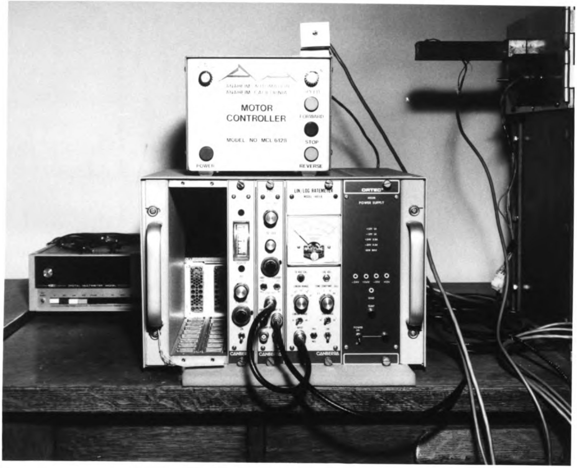


Figure 34. Electrical components of gamma radiation method.


MOTOR
CONTROLLER
MODEL NO MCL 6128
POWER
FORWARD
STOP
REVERSE
LIN/LOG RATEMETER
POWER SUPPLY
CANBERRA
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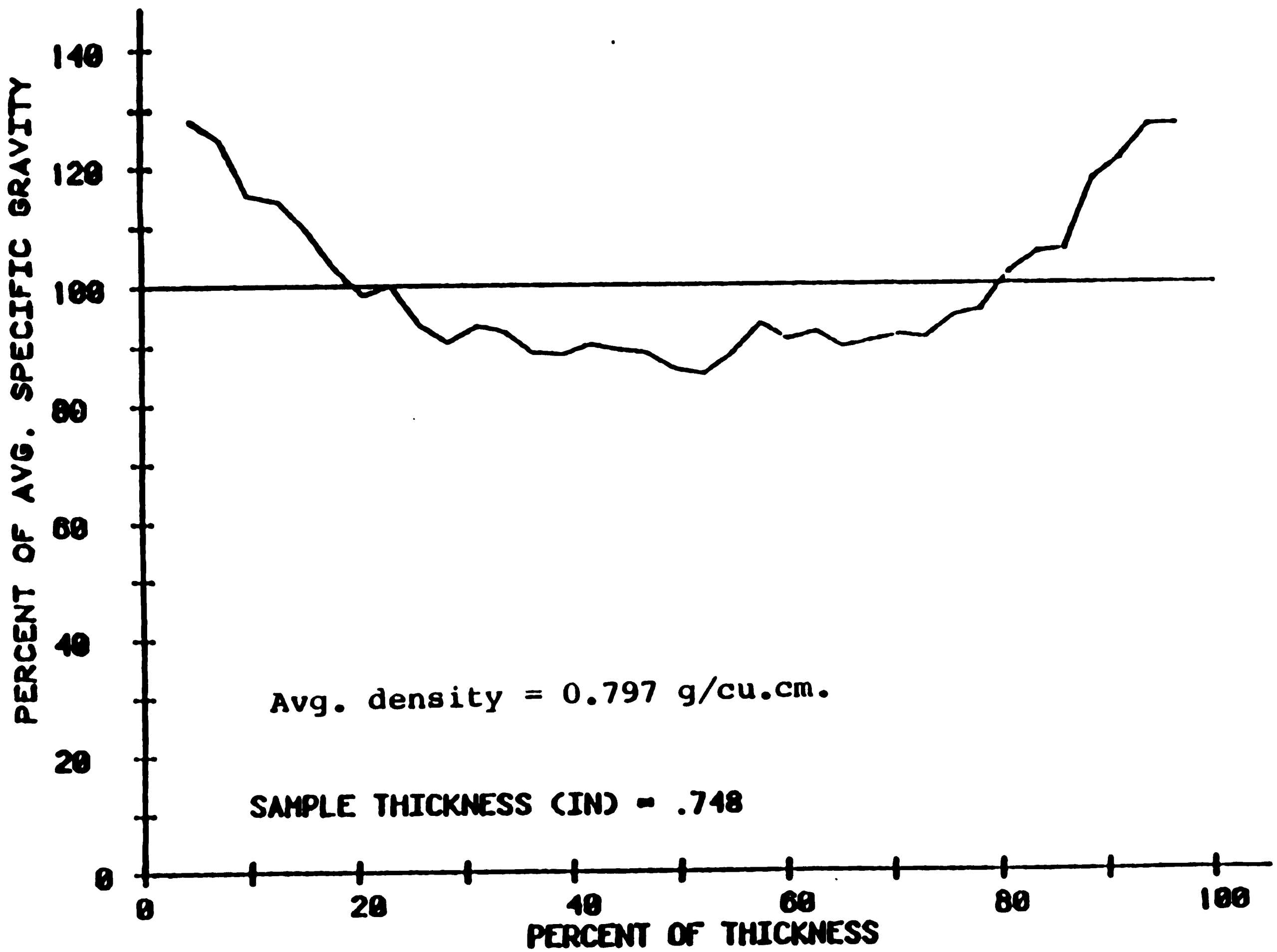


Figure 35.

Density profile for particleboard # PB-E(gamma radiation method using 0.020" interval).

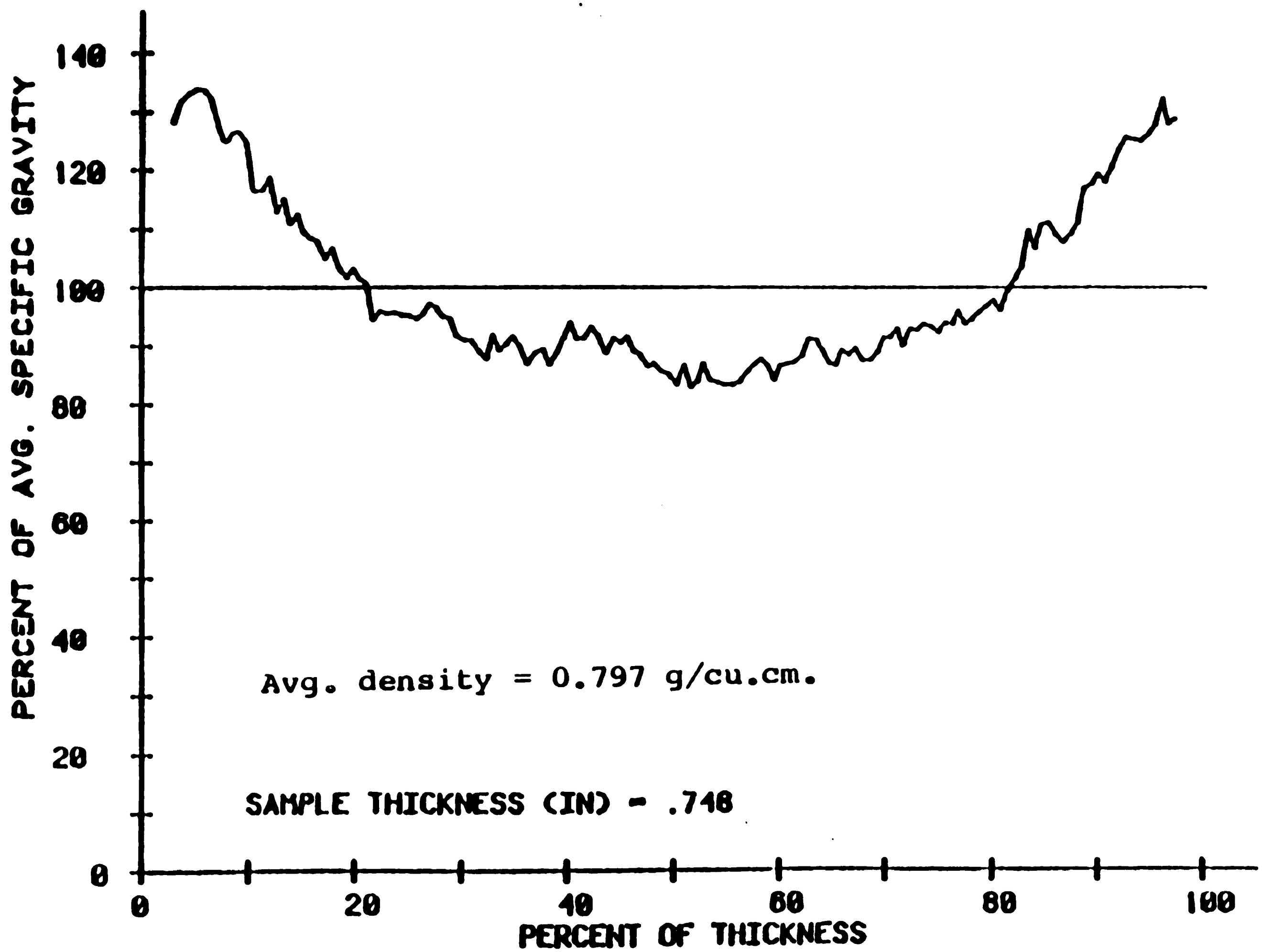


Figure 36.

Density profile for particleboard # PB-E(gamma radiation method using 0.0050" interval).

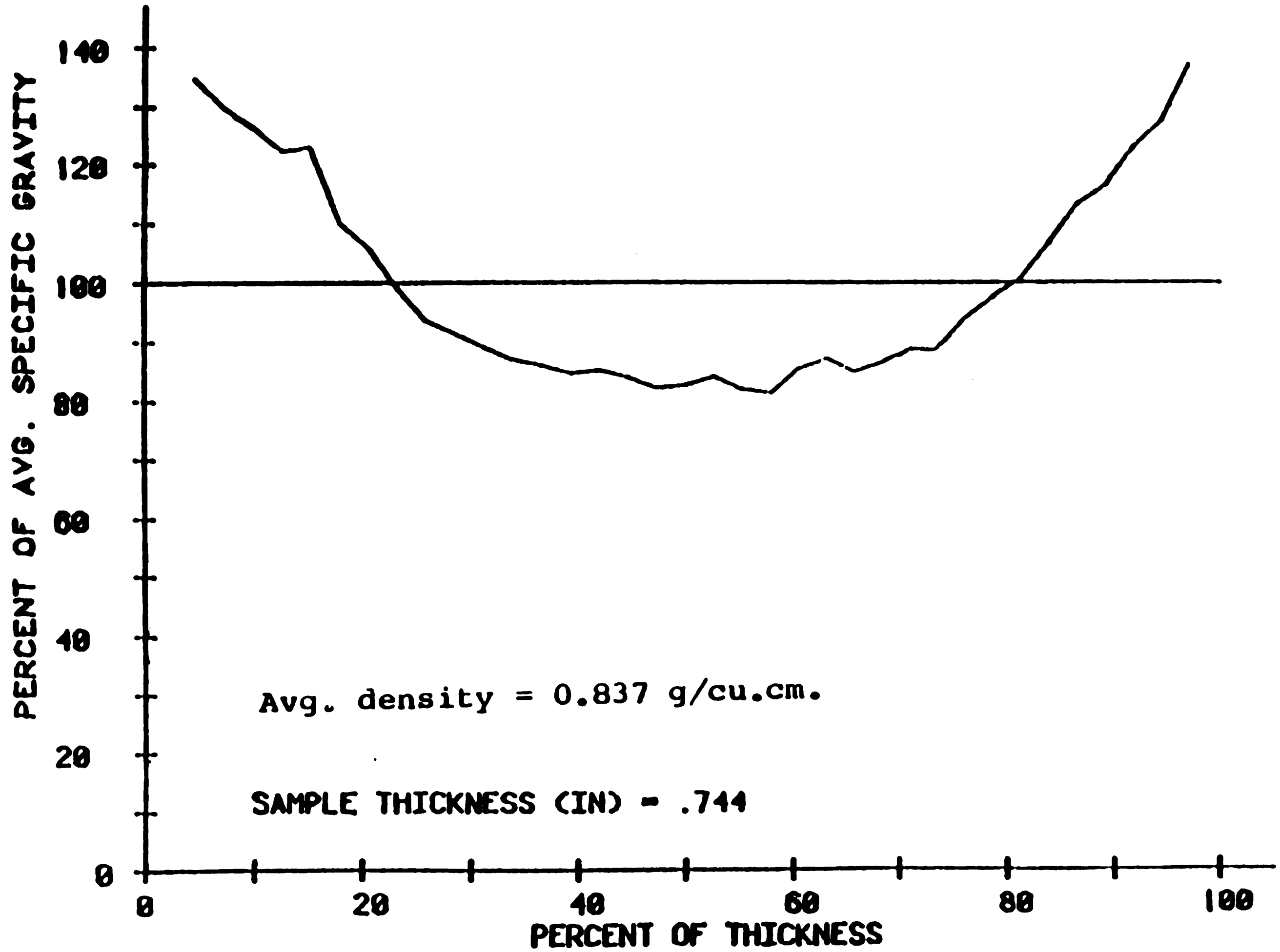


Figure 37.

Density profile for MDF # FB-C(gamma radiation method using 0.020" interval).

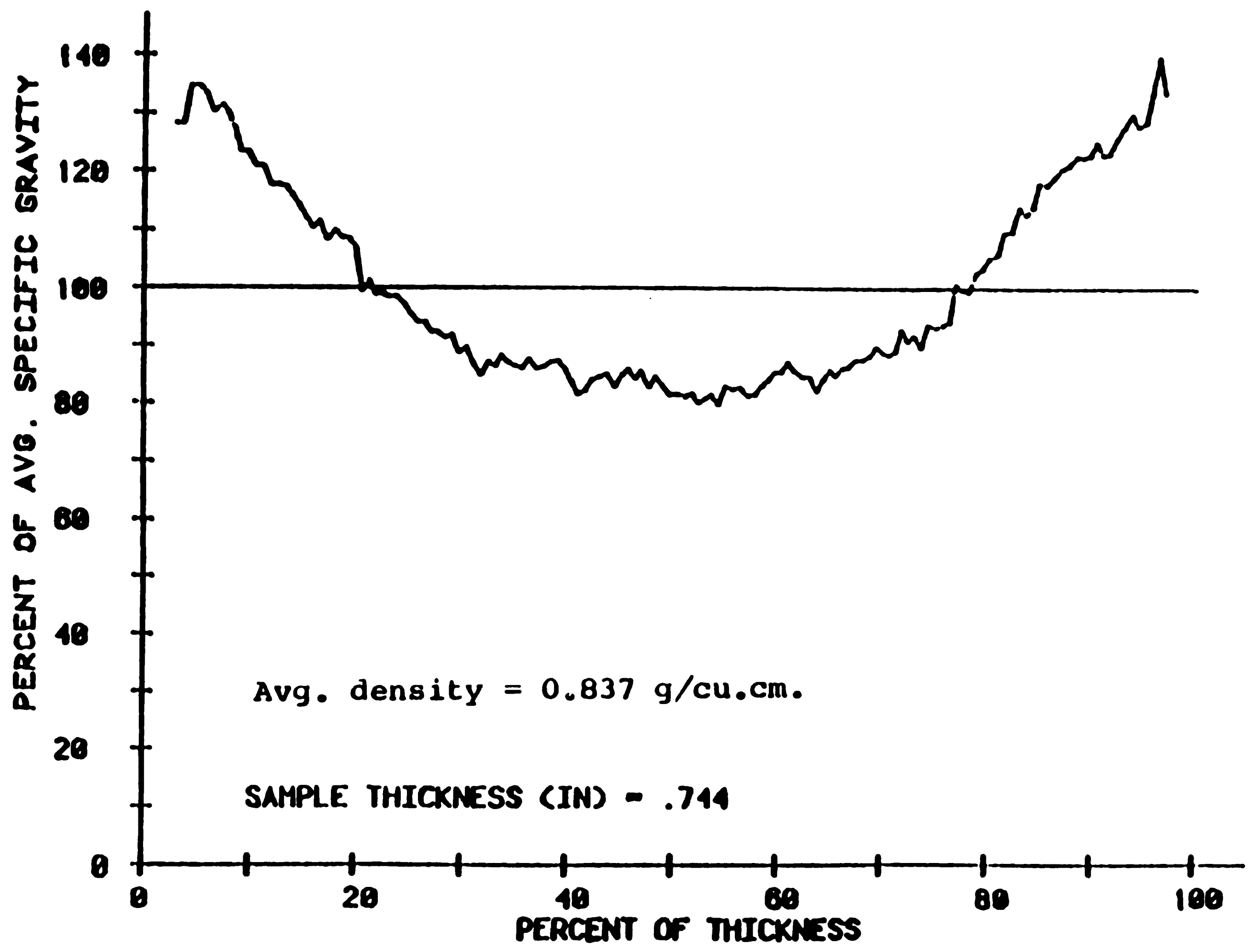


Figure 38.

Density profile for MDF # FB-C (gamma radiation method using 0.0050" interval).

D = Thickness of specimen, in.

[P(2) was well below the porportional limit load, which had been determined by preliminary experiments].

Figure 39 shows the set-up for the static MOE test. Specimens were 1 in wide, 22 in long and the span between supports was 18.2 in (figure 40).

This test was applied first to the complete specimen(face and core) and then to the same specimen after the face layers (0.32 in) had been removed by planing.

From the total MOE and core MOE, the MOE of the faces was derived as follows (81):

$$MOE(f) = \frac{MOE(t) - (1-x)^3\, MOE(c)}{1-(1-x)^3} \quad psi \qquad \{3\}$$

Where :

MOE(f) = MOE of face, psi.

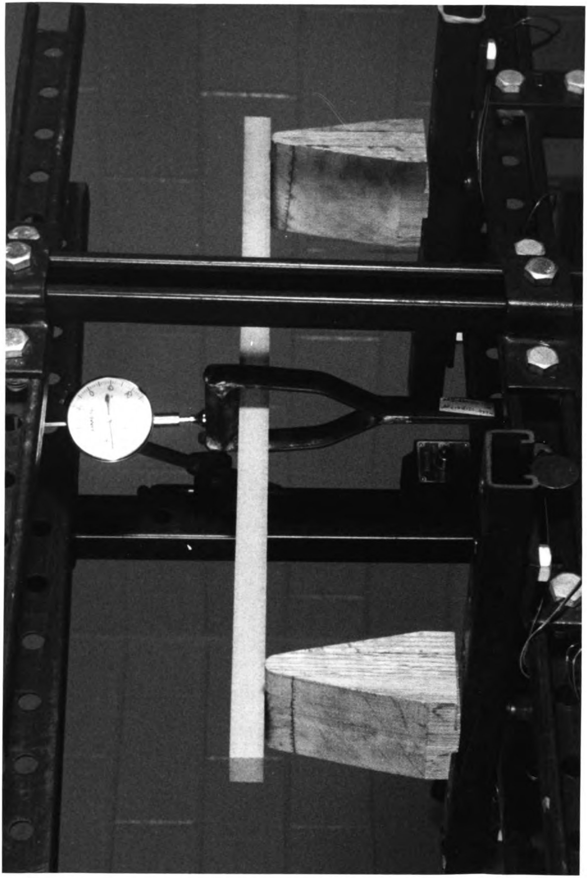
MOE(t) = MOE of total board, psi.

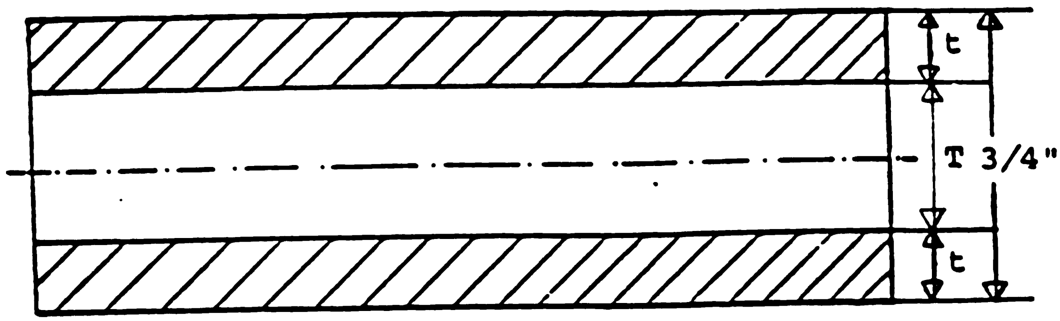
MOE(c) = MOE of core, psi.

x = Shelling ratio.

The above tests were supplemented by a dynamic method employing a stress-wave tester and using the same specimens as used in the static test. The principle of the determination of the dynamic MOE using the stress-wave technique is to measure the time required for a stress wave to travel the length of the specimen. The

Figure 39. Apparatus for measuring static MOE.





A

T = Core thickness.
t = Single face thickness.

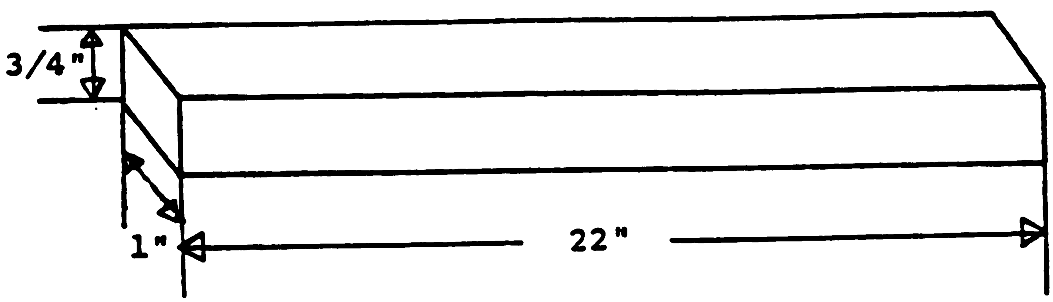


Figure 40.

Cross sectiOn (A) and dimensions (B) of MOE test specimen.

velocity of the stress wave is porportional to MOE (26,30).

Figure 41 shows the dynamic MOE test apparatus.

For all MOE specimen, overall density and core density were determined by weighing and measurement of dimensions. The density of face was derived using equation {1}.

IB testing procedure

Internal bond strength in this part of the experiment was determined by the compression shear test as suggested by Suchsland (85).

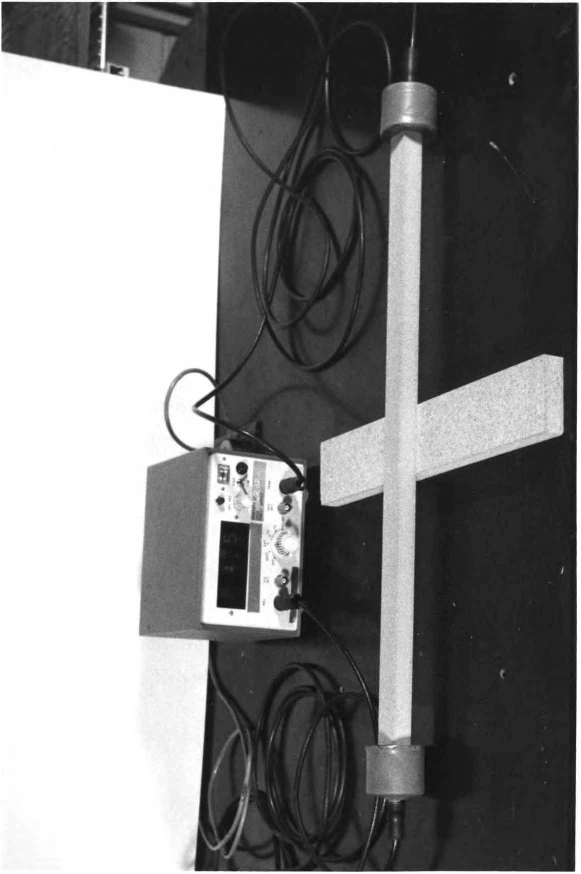
This test involves the lamination of shear strip specimens of 0.75 in by 0.75 in by 24 in between two boards sections and cutting the laminate to yield 12 compression shear test specimens, each 1 in wide, 5 in long and 0.75 in thick (figure 42). The actual shear specimen is now oriented at 45 degrees relative to the direction of the applied axial compression load. The specimens were tested in compression at a crosshead speed (rate of loading) of 0.05 in/min. until they failed in shear (figure 43). The shear strength was calculated as :

$$Tmax = \frac{P}{2A} \qquad \{4\}$$

Where :

Tmax = Shear stress at failure, psi.

Figure 41. Ultrasonic timer for measuring
dynamic MOE test.



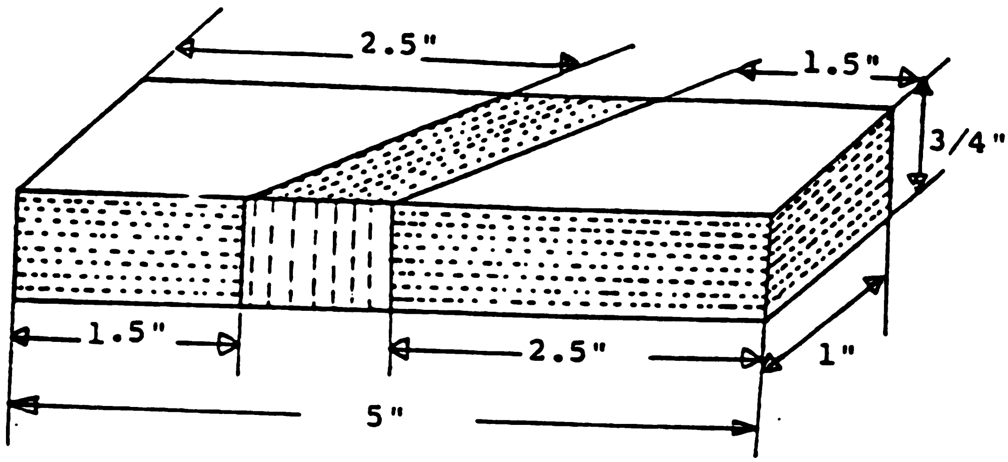


Figure 42.

Dimensions of IB test specimen used in part I of experiment.

Figure 43. Compression shear test specimen undergoing test.

P = Axial load, lbs.

A = Cross sectional area of column, square in.

The values of IB where obtained from the relation:

IB = Shear stress* 0.208.

This is based on statistical analysis of extensive tests by Suchsland (85).

In order to relate internal bond strength to core density, the density of the failure area had to be determined carefully.

This was accomplished by removing thin slices from each side of the shear failure plane and by measuring the resulting weight loss and total specimen length reduction. The thin slices (about 0.10 in thick) were removed from both specimen halves by a carbide tipped milling cutter mounted on a milling machine (figure 44). The specimene were so oriented that the saw cuts were aligned at exactly 45 degrees to the long dimension of the specimens.

The length reduction of the specimen, which is equal to the thickness of the removed slices near the failure area, was determined with a special jig which eliminated the error due to posible slipping along the 45 degrees contact faces when reassemblying the specimen halves for measurement in a straight line. The setup for measuring length reduction is shown in figure 45. Explanation of the length measurement is given in appendix 2.

Figure 44. Carbide tipped milling cutter mounted on a milling machine for removing thin slices of IB test specimen.

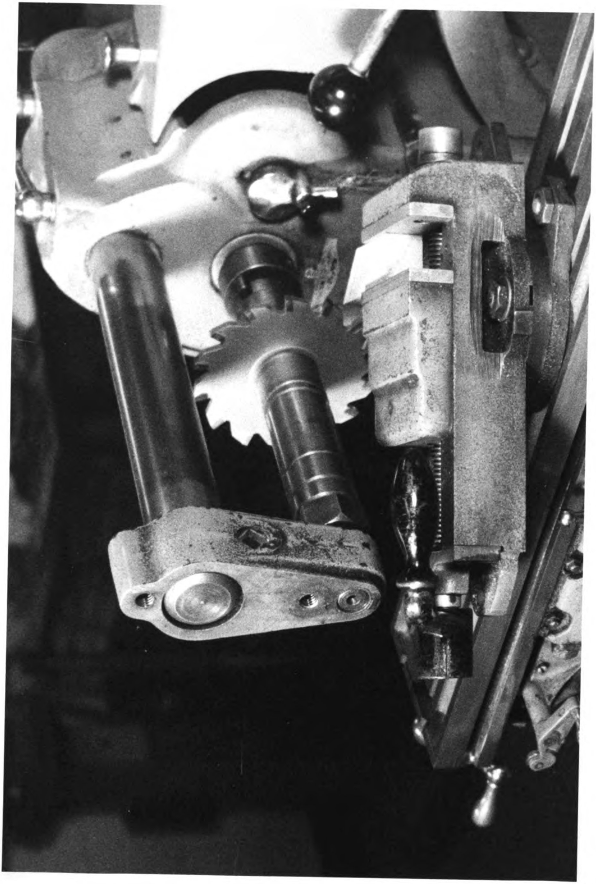
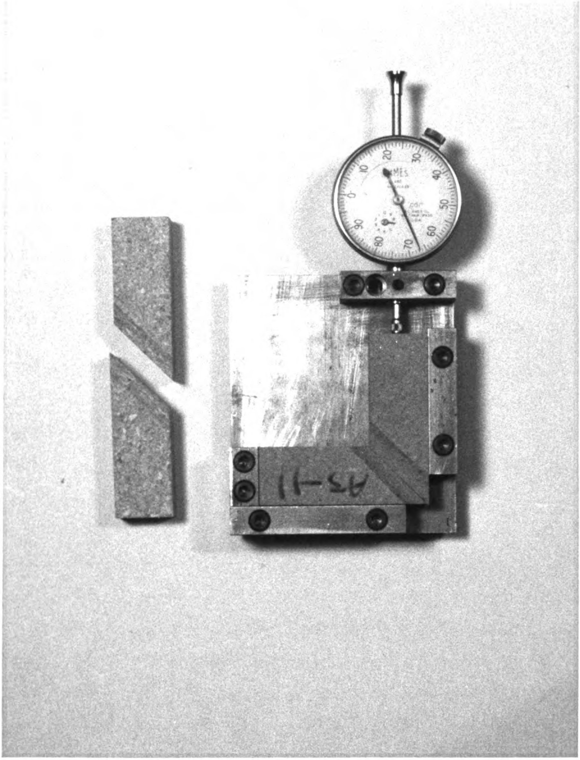


Figure 45. Special jig for measuring length reduction of IB test specimen.



RESULTS (part I)

Tables 6-7 show a summary of the test results as well as statistical analysis of each property. The evaluated properties of particleboard are shown in table 6 while those of MDF are shown in table 7.

Density and Density Profile

Values of overall density ranged from 0.757 to 0.844 g/cu.cm for particleboard and 0.761 to 0.822 g/cu.cm for MDF. The density range of particleboard was about 43% wider than the density range of MDF. Both types of boards had almost the same average density (0.801 and 0.799 g/cu.cm for particleboard and MDF respectively). These results were obtained from MOE test specimens. The average density obtained from the gamma radiation method were 0.811 plus or minus 0.0059 g/cu.cm for MDF and 0.804 plus or minus 0.195 g/cu.cm for particleboard which are very close to the above results.

Samples of the results of density profile determination are shown in figures 30-31 and 35-38.
The face density of particleboard ranged from o.793 to 1.057 g/cu.cm and from 0.888 to 0.967 g/cu.cm for MDF. Here, the range for particleboard was twice that for MDF. The range of the core density values was from 0.686 to 0.757 g/cu.cm for particleboard while those for

Table 6.

Summary of test results : properties of particleboard.

	Mean	Min.	Max.	Range	Std. Dev.	Coeff of Var.%
Overall density of bending test g / cu.cm.	0.801	0.757	0.844	0.087	0.024	3.0
Face density g / cu.cm.	0.920	0.793	1.057	0.264	0.041	4.5
Core density g / cu.cm.	0.719	0.686	0.757	0.071	0.018	2.5
Overall MOE ∥ 1,000 psi	492	433	563	130	37.8	7.7
Overall MOE 1,000 psi ⊥	426	353	494	141	57.0	11.9
Overall MOE average 1,000 psi	459	353	563	210	55.6	12.1
Face MOE 1,000 psi ∥	560	491	639	148	44.3	7.9
Face MOE 1,000 psi ⊥	480	394	560	166	58.6	12.2

Note : MOE was tested in two perpendicular directions. The two results are arbitrarily identified as parallel and perpendicular (∥, ⊥).

Table 6 (cont'd.)

	Mean	Min.	Max.	Range	Std. Dev.	Coeff of Var.%
Face MOE average 1,000 psi	520	394	639	245	65.4	12.6
Core MOE 1,000 psi ∥	234	181	278	97	21.5	9.2
Core MOE 1,000 psi ⊥	216	174	247	73	23.3	10.8
Core MOE average 1,000 psi	225	174	278	104	24.1	10.7
Overall dynamic MOE 1,000 psi	572	481	670	189	55.9	9.8
Core dynamic MOE 1,000 psi	363	315	413	98	30.4	8.4
Internal Bond psi	130	88	165	77	18.8	14.5
Core density of IB test g / cu.cm.	0.747	0.693	0.827	0.134	0.038	5.1

Note : MOE was tested in two perpendicular directions. The two results are arbitrarily identified as parallel and perpendicular(∥, ⊥).

Table 7.

Summary of test results : properties of MDF

	Mean	Min.	Max.	Range	Std. Dev.	Coeff of Var.%
Overall density of bending test g / cu.cm.	0.799	0.761	0.822	0.061	0.016	2.0
Face density g / cu.cm.	0.937	0.888	0.967	0.079	0.020	2.1
Core density g / cu.cm.	0.701	0.671	0.723	0.052	0.014	2.0
Overall MOE 1,000 psi ‖	586	561	619	58	13.3	2.3
Overall MOE 1,000 psi ⊥	547	508	586	78	23.7	4.3
Overall MOE average 1,000 psi	567	508	619	111	27.6	4.9
Face MOE 1,000 psi ‖	647	621	686	65	15.0	2.3
Face MOE 1,000 psi ⊥	603	560	648	88	26.5	4.4

Note : MOE was tested in two perpendicular directions. The two results are arbitrarily identified as parallel and perpendicular(‖ , ⊥).

Table 7 (cont'd.)

	Mean	Min.	Max.	Range	Std. Dev.	Coeff of Var.%
Face MOE average 1,000 psi	625	560	686	126	30.9	4.9
Core MOE ∥ 1,000 psi	345	319	372	53	12.7	3.7
Core MOE ⊥ 1,000 psi	320	269	347	51	15.5	4.8
Core MOE average 1,000 psi	333	269	372	76	18.6	5.6
Overall dynamic MOE 1,000 psi	646	593	692	99	29.1	4.5
Core dynamic MOE 1,000 psi	442	409	467	58	17.0	3.9
Internal Bond psi	129	105	160	55	12.0	9.3
Core density of IB test g/ cu.cm.	0.726	0.679	0.772	0.093	0.019	2.6

Note : MOE was tested in two perpendicular directions. The two results are arbitrarily identified as parallel and perpendicular(∥, ⊥).

MDF ranged from 0.671 to .723 g/cu.cm. Again, the core density range for particleboard was 37% wider than for MDF. Despite the noted differences in average and range of density and density gradient, the two types of boards are remarkably similar in both respects.

Modulus of Elasticity

Values of overall MOE of particleboard ranged from 353,000 to 563,000 psi, while the corresponding values for MDF were 508,000 to 619,000 psi. The average values of MOE were 459,000 and 567,000 psi for particleboard and MDF respectively. Values of face MOE ranged from 394,000 to 639,000 psi with mean value of 520,000 psi for particleboard and from 560,000 to 686,000 psi with mean value of 625,000 psi for MDF. Core MOE range was from 174,000 to 278,000 psi with average of 225,000 psi for particleboard and 269,000 to 372,000 psi with average of 333,000 psi for MDF.

Analyses of variance indicated that there were significant differences between the two directions of the board for MOE values (overall, face and core) in both types of boards.

The results of the relationships between static MOE (overall, face and core) and density (overall, face and core) and between overall MOE and face density are presented in graphical forms in figures 46-48. As

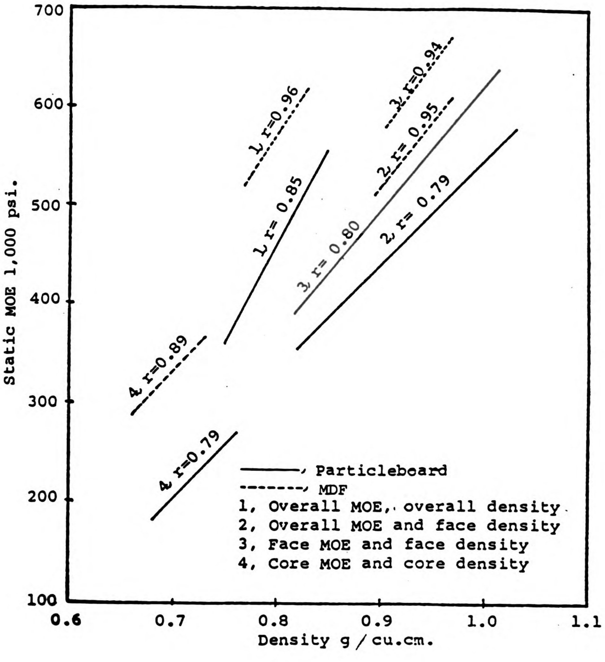


Figure 46.

Regressions of MOE on densities of boards.

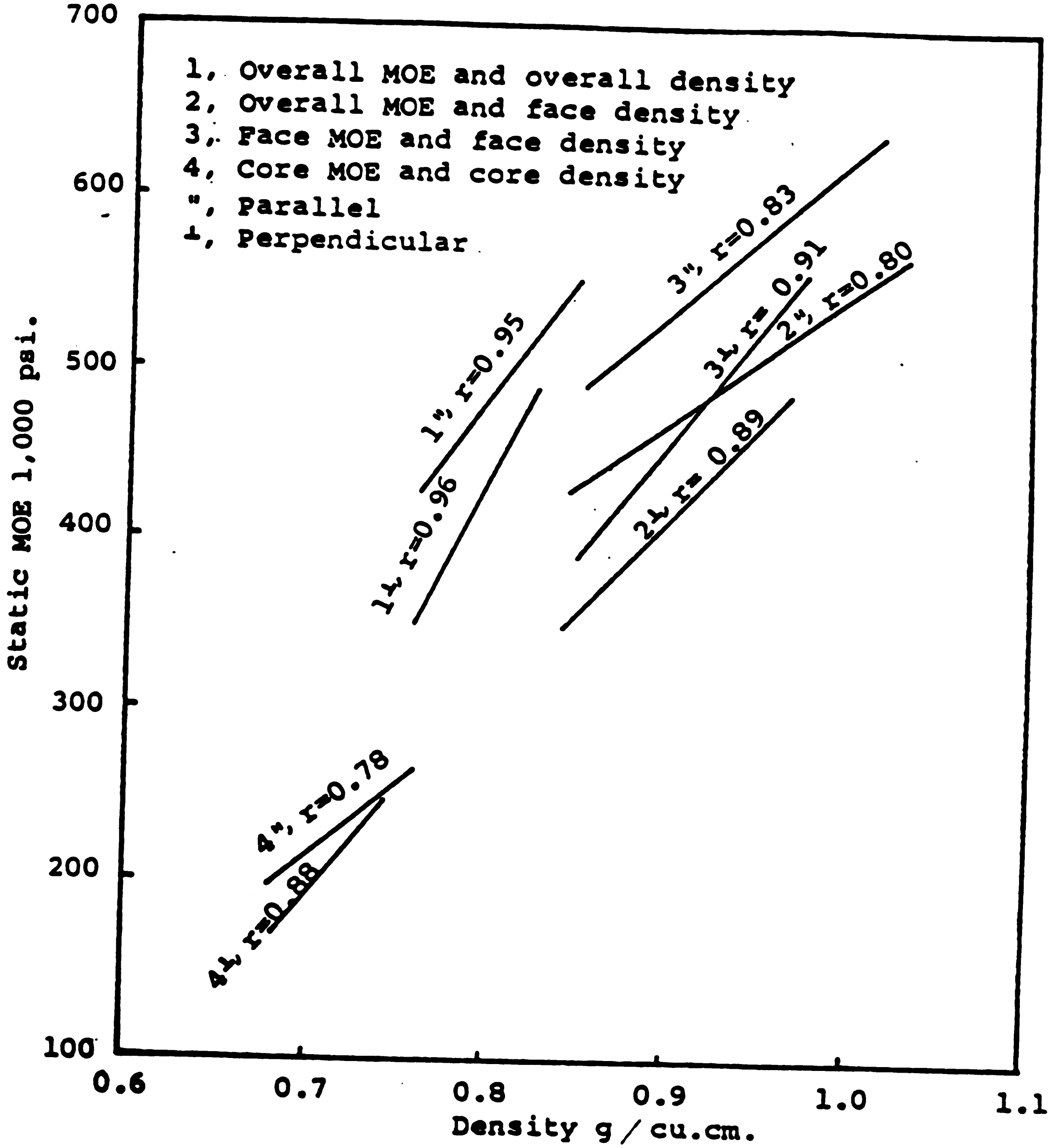


Figure 47.

Regressions of MOE on densities of particleboard (two directions).

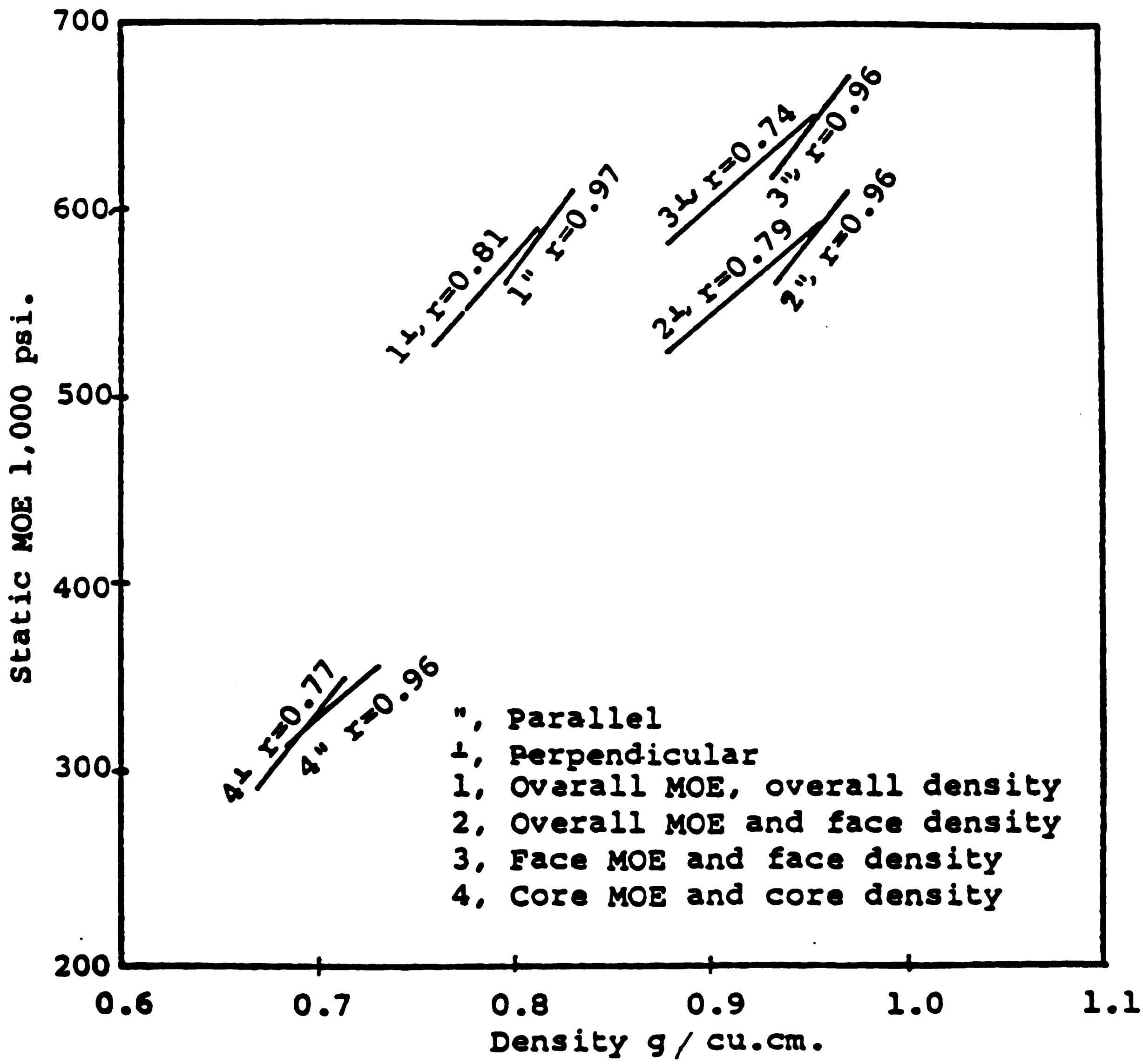


Figure 48.

Regressions of MOE on densities of MDF (two directions).

can be seen in these figures, the MOE is a linear function of density. From analyses of variance for regression (73), the equations for the regression line of MOE (Y) on density (X) of particleboard were determined as follows :

For overall MOE and overall density:

$$Y = - 1{,}117{,}000 + 1{,}968{,}000X$$

with a correlation coefficient of :

$$r = 0.85. \quad (5)$$

For overall MOE and face density:

$$Y = - 528{,}100 + 1{,}073{,}000X \text{ with :}$$

$$r = 0.79. \quad (6)$$

For core MOE and core density:

$$Y = - 529{,}300 + 1{,}048{,}000X \text{ with :}$$

$$r = 0.79. \quad (7)$$

For face MOE and face density:

$$Y = - 653{,}500 + 1{,}275{,}000X \text{ with :}$$

$$r = 0.80. \quad (8)$$

The corresponding equations for the regression of MOE (Y) on density (X) of MDF were determined as follows :

For overall MOE and overall density:

$$Y = - 735{,}300 + 1{,}630{,}000X \text{ with :}$$

$$r = 0.96. \quad (9)$$

For overall MOE and face density:

$$Y = - 682{,}600 + 1{,}333{,}000X \text{ with :}$$

$$r = 0.95. \quad (10)$$

For core MOE and core density:

$$Y = -473{,}700 + 1{,}150{,}000X \quad \text{with :}$$

$$r = 0.89. \quad \{11\}$$

For face MOE and face density:

$$Y = -757{,}300 + 1{,}475{,}000X \quad \text{with :}$$

$$r = 0.94. \quad \{12\}$$

Values of dynamic MOE are presented in tables 6 and 7. These values are higher than static MOE values. The relationship between dynamic and static MOE is shown in the same graph for MDF and particleboard in figure 49. The regression equations of static MOE (Y) On dynamic MOE(X) are :

For particleboard:

$$Y = -62{,}800 + 0.924.701X \quad \text{with :}$$

$$r = 0.90. \quad \{13\}$$

For MDF:

$$Y = 60{,}700 + 0.782{,}527X \quad \text{with :}$$

$$r = 0.92. \quad \{14\}$$

Internal Bond

The results of the first internal bond tests represent the tensile strength of the core alone, since failure occured in the core in all cases. The internal bond values ranged from 88 to 165 psi for particleboard while those values for MDF ranged from 105 to 160 psi. Although both types of boards had the same average IB strength (129 and 130 psi for MDF and

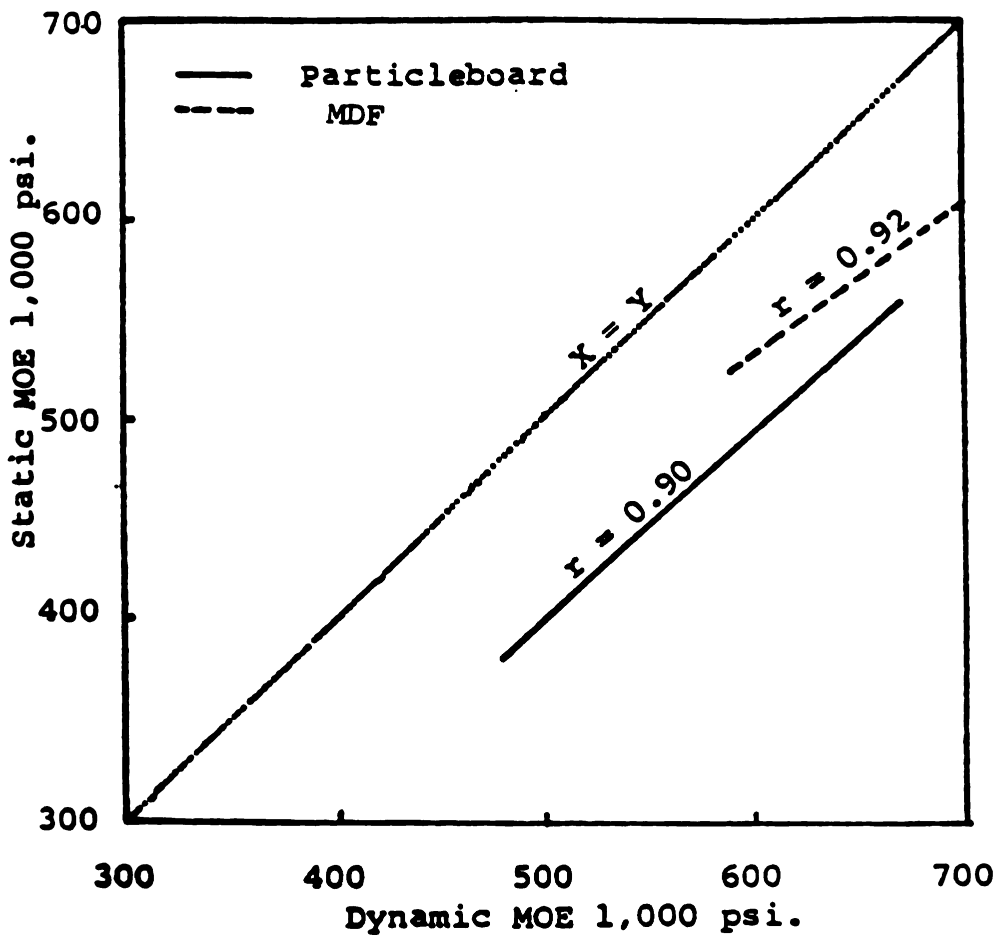


Figure 49..

Regressions of static MOE on dynamic MOE of boards.

particleboard), the IB range for particleboard was 40% wider than that for MDF. Besides, IB variations between boards of particleboard were significant while variations between boards of MDF were not significant.

The results of core density determination at the failure plane of the compression shear test specimens are presented in tables 6 and 7. These values ranged from 0.679 to 0.772 g/cu.cm for MDF and 0.693 to 0.827 g/cu.cm for particleboard. As expected, this range was about 44% greater for particleboard than for MDF. Again, core density variations between boards of particleboard were significant. Core density determined on IB specimens was always higher than that determined on MOE specimens. The reason may be that machining inaccuracies (rough surfaces) would always tend to result in higher density values rather than in lower one.

The relationships between IB and core density at the failure point are presented in graphical form in figure 50 for MDF and particleboard. As shown in this figure, the IB is a linear function of the core density of particleboard. From the analysis of variance for the regression, the equation for the regression of IB (Y) on core density at failure point (X) is :

$$Y = -172.367 + 404.316X \quad \text{with :}$$

$$r = 0.81. \quad \{15\}$$

However, in case of MDF, the correlation between core density and IB was very weak (r = 0.23).

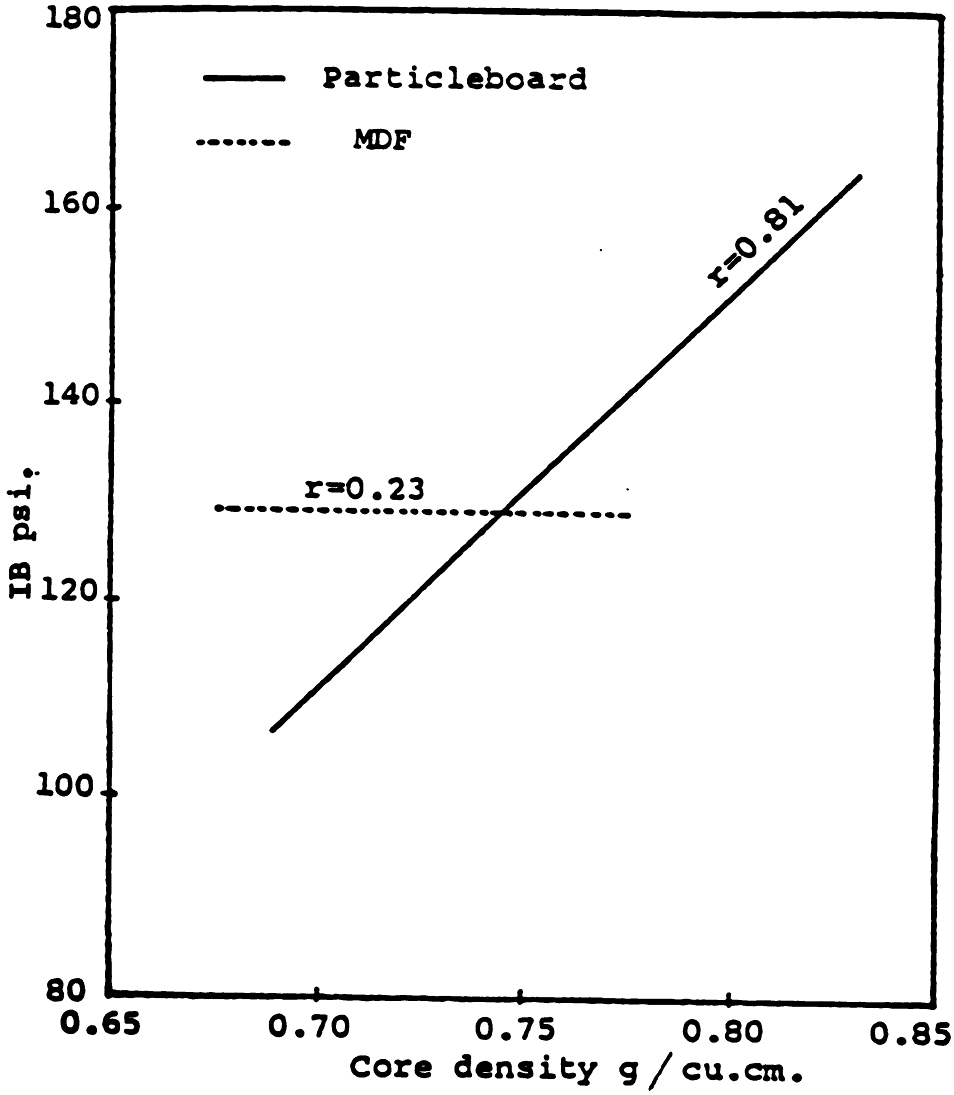


Figure 50.

Regressions of IB on core densities of MDF and particleboard.

Limitation of experiment

As mentioned previously, the length reduction measurement was the difficult part of the experiment in terms of possible error. Although a special jig was used to eliminate such error, the length reduction measurement is subject to error. Another limitation is that since the failure areas are not plane, density determination of the failure area is also subject to error because it might not be representative of the exact failure plane.

Chapter V

EXPERIMENTS : PART II - EXTENSION OF IB TEST TO LARGER RANGE OF DENSITY

Purpose of experiment

In the first part of experiment the relationship between core density and IB of two commercial particleboards and MDF were determined. The results inicated that in a limited range of core density there is a very slight correlation between IB and center density of MDF. But IB was a function of core density of particleboard.

The purpose of this part of experiment was to extend those relations to a larger range of density of particleboard and MDF.

Preparation of specimens

The samples were obtained from the same boards as used in the first part of the experiment. So, the general design and general conditions of this part were similar to first part.

In order to obtain a wider density range for the IB-density relationship, advantage was taken of the vertical density distribution. The IB test was so designed that the failure was forced to occur at various distance from the board surface.

Therefore, two properties were determined : Vertical density distribution and layer internal bond strength.

Density profile testing procedure

Only the gamma radiation test method was used in this part as described earlier.
Samples were chosen so that it was possible to conduct the IB test and density profile determination on the same sample of the boards.

IB layer testing procedure

IB strength was determined at 10 location of each test sample. The standard IB test specimen was modified asin the following explanation :

The thickness of 10 sets of board specimens was adjusted by planing in such a way that their thickness varried from full board thickness by intervals of 0.040 in.
The thinnest set of specimens, thus, had a thickness after planing of board thickness - 0.400 in.
The specimens were then cut to 2 by 2 in square.
Grooves, 1/8 in wide and 0.040 in deep were then milled into the planed face of the specimens. These grooves were cut parallel to the four specimen edges and at a distance from the edges so that their intersections created a 1 by 1 in square in the center of the specimen, see figure 51.
2 by 2 in square aluminum blocks were glued to the back of the specimens and 1 by 1 in square aluminum blocks were glued to the 1 by 1 in square field in the center of the top face of the specimens, see figure 52.
The following IB test therefore evaluated the tensile strength in 0.040 in thick layers of the board at various locations between board surface and board center, see figures 53-57.

The IB of each 0.04 in layer of the board was calculated as :

$$IB = \frac{T}{A} \qquad \{16\}$$

Where :

IB = Internal bond, psi.

T = Axial load, lbs.

Figure 51. MDF and particleboard IB test specimens showing 1 in square area on planed surface created by grooves to which aluminum block will be glued.

Top : Particleboard

Down : MDF

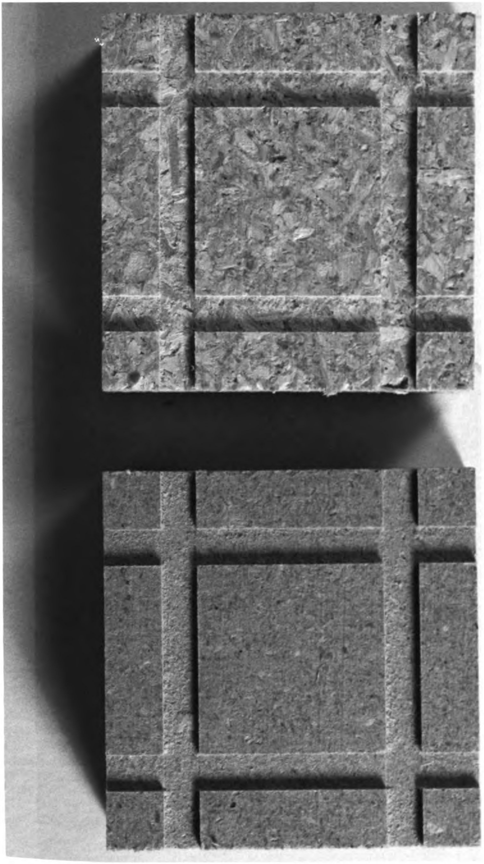


Figure 52. MDF IB test specimen after gluing aluminum blocks to face and back (ready for test).

Figure 53. MDF IB test specimen undergoing test.

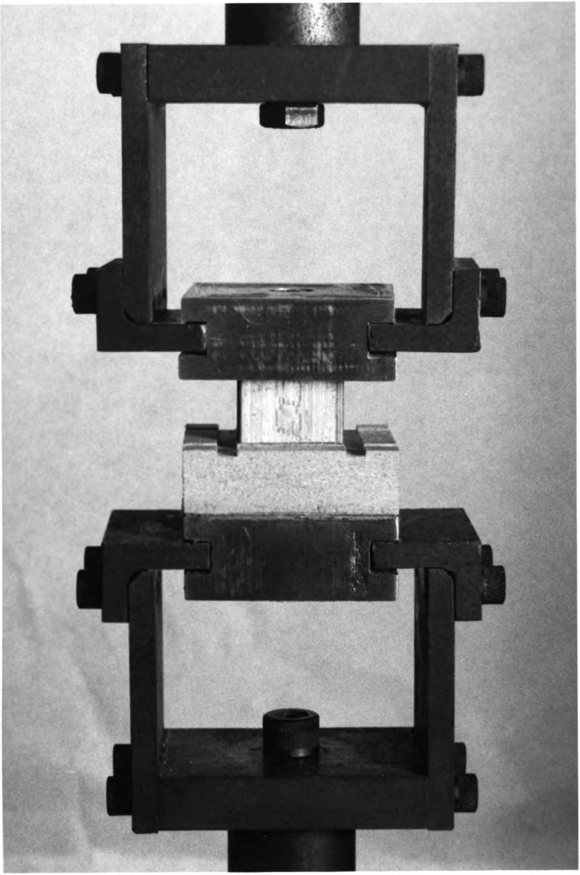


Figure 54. MDF and particleboard IB test specimens showing failure areas at 0.040 in from the surface.

Top : Particleboard

Down : MDF

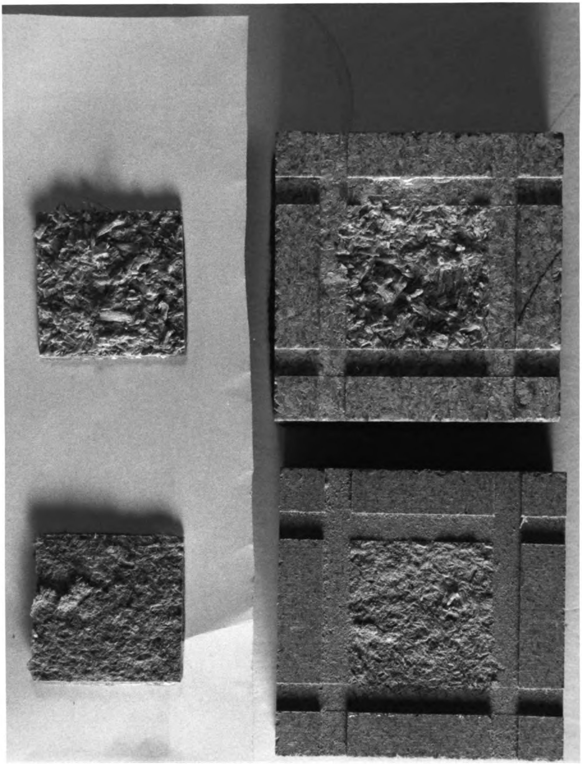


Figure 55. MDF and particleboard IB test specimens showing failure areas at 0.160 in from the surface.

Top : Particleboard

Down : MDF

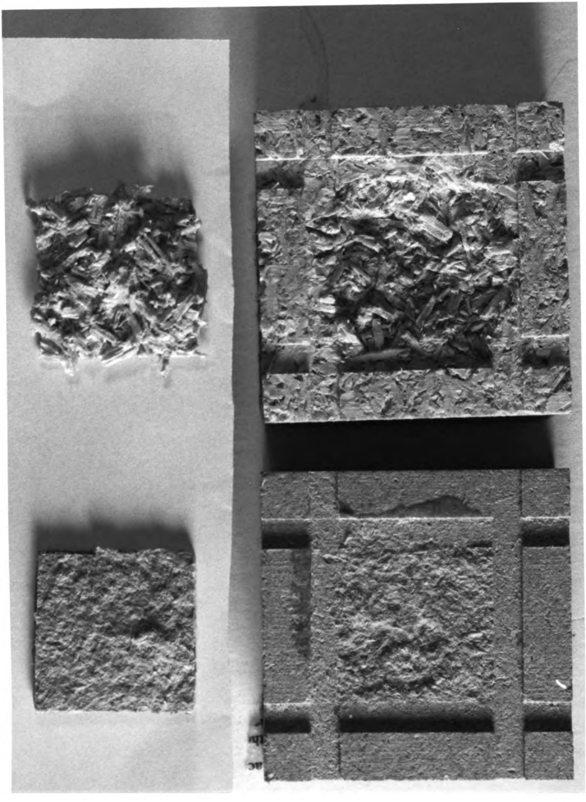


Figure 56. MDF and particleboard IB test specimens showing failure areas at 0.280 in from the surface.

Top : Particleboard

Down : MDF

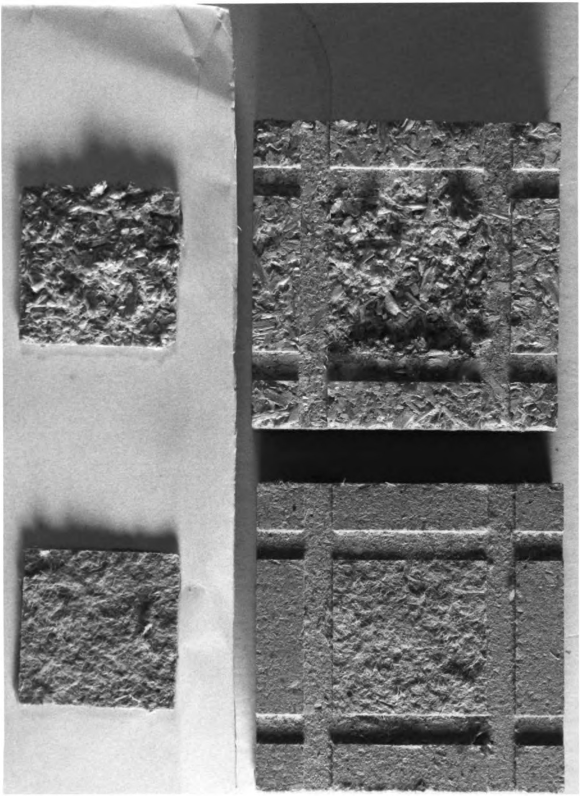
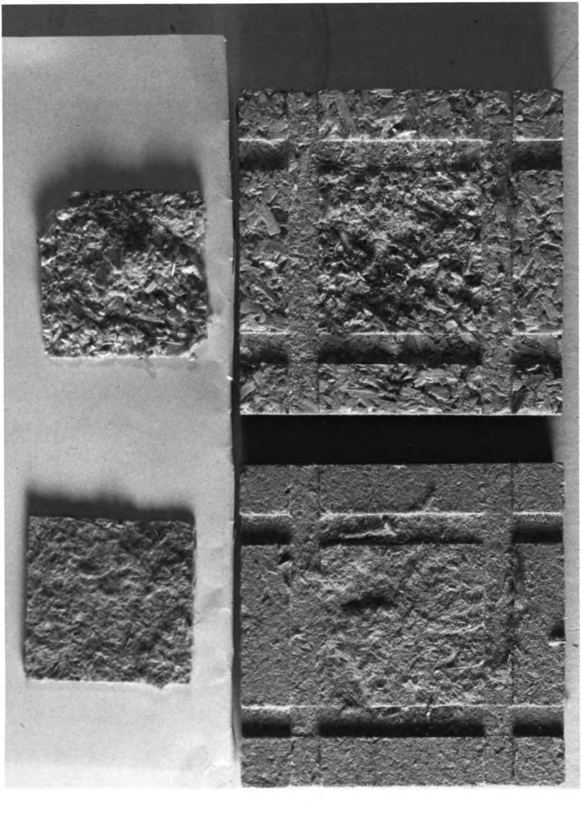


Figure 57. MDF and particleboard IB test specimens showing failure areas at 0.360 in from the surface.

Top : Particleboard

Down : MDF



A = Failure area, equal to 1 in square.

The density of these layers was obtained by the gamma radiation method as described earlier. The experimental data for layer IB and layer density relationships of MDF and particleboard is given in appendix 3.

Results (part II)

Table 8 shows the summary of the test results of the internal bond strength values and densities in different depth of particleboard and medium density fiberboard. The results of density profile determination were discussed in part I. In this part, the results of layer IB test will be described.

Layer IB strength

IB of the layers ranged from 71 psi to 213 psi for MDF and from 107 psi to 256 psi for particleboard.

The relationship between IB of the layers and layer densities is shown in figure 58 for both MDF and particleboard. From the analysis of variance for the regression, the equation for the regression of IB (y) on the density at failure point (x) of particleboard is :

$$y = -104.6 + 333.8x \quad \text{with} \quad r = 0.79 \qquad \{17\}$$

However, the relationship between layer IB and layer densities of MDF was broken down into two line segments

Table 8. Summary of test results : IB of MDF and particleboard as function of distance from board surface.

Table 8.

Board	Depth in	Area in^2	IB (mean) ± psi	Layer density (mean) $\pm g/cm^3$
Fiberboard (MDF)	0.041	1by1	213.1 ± 23.8	1.047 ± 0.013
	0.080	" "	192.0 ± 16.0	0.980 ± 0.012
	0.126	" "	165.6 ± 6.5	0.904 ± 0.011
	0.168	" "	128.6 ± 6.8	0.825 ± 0.011
	0.202	" "	102.1 ± 8.6	0.775 ± 0.010
	0.245	" "	83.1 ± 8.7	0.728 ± 0.008
	0.284	" "	78.0 ± 8.8	0.700 ± 0.008
	0.326	" "	70.9 ± 5.3	0.685 ± 0.008
	0.365	" "	76.4 ± 5.5	0.678 ± 0.007
	0.404	" "	73.9 ± 6.0	0.678 ± 0.007
	Avg. density 0.811 ± 0.006			
Particleboard	0.042	1by1	255.8 ± 41.5	0.974 ± 0.040
	0.084	" "	182.0 ± 8.7	0.954 ± 0.044
	0.125	" "	196.8 ± 11.2	0.874 ± 0.045
	0.166	" "	138.2 ± 15.6	0.805 ± 0.039
	0.203	" "	142.4 ± 25.0	0.767 ± 0.034
	0.244	" "	141.4 ± 15.8	0.728 ± 0.031
	0.282	" "	158.8 ± 28.4	0.717 ± 0.022
	0.325	" "	107.0 ± 11.2	0.710 ± 0.027
	0.363	" "	140.0 ± 25.6	0.694 ± 0.032
	0.405	" "	130.8 ± 20.1	0.684 ± 0.029
	Avg. density 0.804 ± 0.020			

as shown in figure 58. The upper line represents the correlation between layer IB and layer density for the density range of 0.771 to 1.05 g/cu.cm. The corresponding equation for MDF within that range of density is :

$$y = -229.2 + 431.8x \quad \text{with} \quad r = 0.89 \quad (18)$$

The lower line represents the correlation between layer IB and layer density for the density range of 0.67 to 0.77 g/cu.cm. which is about the same range as that of the core density of MDF in the first part of the experiment. Again, within this narrow range of core density, the correlation between IB and density of MDF was found to be very weak ($r = 0.23$).

Both particleboard and MDF show strong overall correlations between IB and layer densities. There appears to be no fundamental difference in the response of MDF compared with particleboard.

Limitation of experiment

Since failure of the IB layer test specimens of particleboard did not occur at the exact predetermined location, and did not have smooth failures, assigning a layer density to the layer IB of particleboard tested is subject to a certain error.

In general, determination of core density and relating it to the internal bond strength at a specific

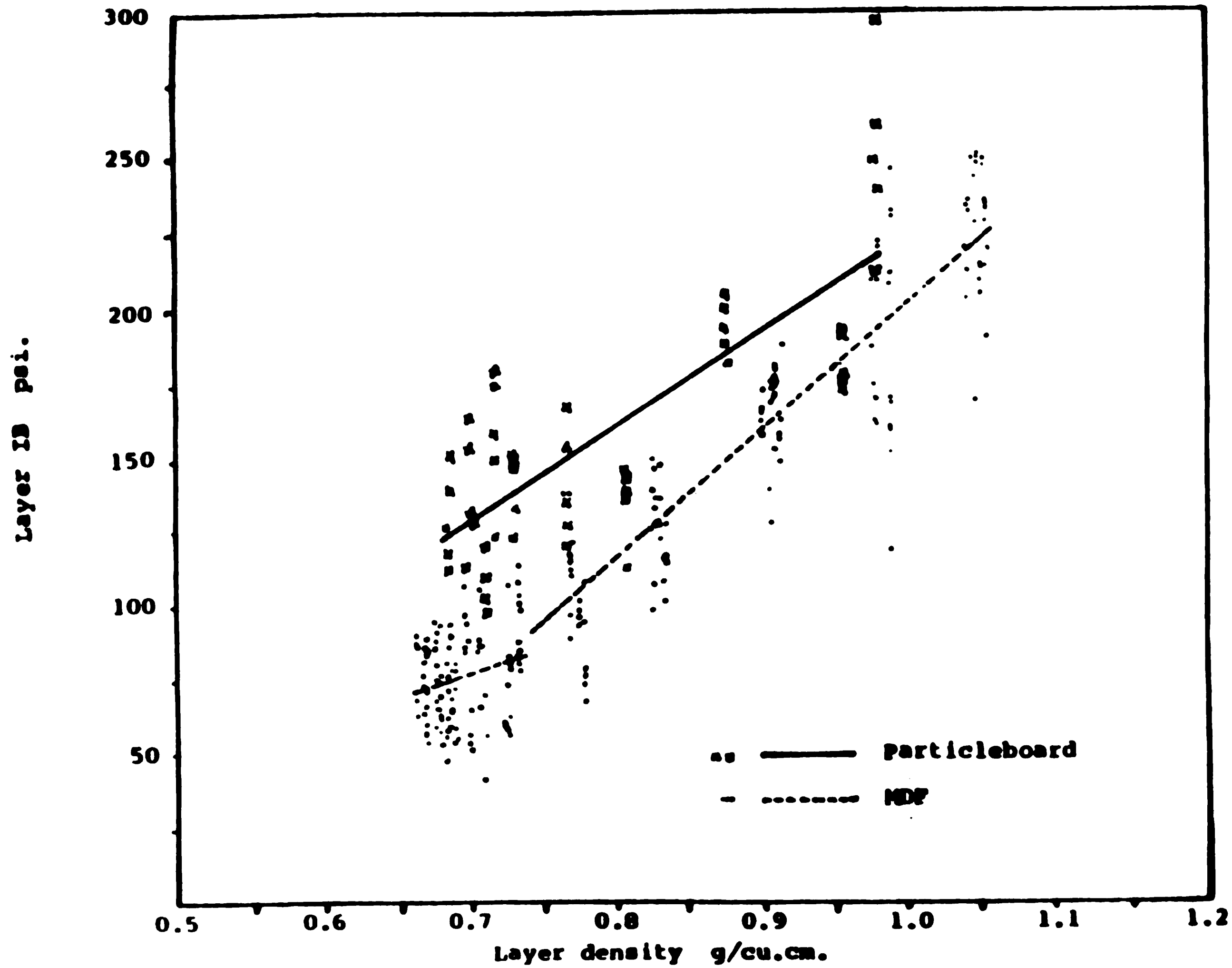


Figure 58.

Regressions of layer IB on layer densities of MDF and particleboard.

location was one of the difficulties of this study in both parts.

Chapter VI

SUMMARY AND DISCUSSION

In the first part of this paper, the important factors developing strength properties of particleboard and MDF were discussed.

Resin efficiency, wood species, board density, temperatyre, particle geometry and press cycle variables are among the major important variables in this regard. However, there are interrelationships between most of the above mentioned factors.

The density distribution in a particleboard or MDF has a horizontal and vertical component. The density gradient can be controlled to some extent by manipulating raw material variables and press cycle.

MOE and IB seemed to have similarities in terms of responding to many factors in the manufacture of both MDF and particleboard . Both properties are sensitive to board density, species, compaction ratio, and flake geometry. Long or thin particle will improve MOE wheras short and small particles in the core region will improve IB. Resin content has a stronger influence on IB than MOE. Press cycle and closing time have opposite affects on MOE and IB. A Short closing time improves MOE at the expense of IB. In contrast, relatively long closing time results in higher IB and lower MOE values. High surface moisture content combined with initial pressure develops significantly superior MOE and reduces the IB. High density gradients normally result in higher MOE and lower IB. Moderate density gradients or uniform density throughout the thickness of the board results in high IB and low MOE. So, manufacturers would have to decide which properties are most important for their products and make the necessary adjustment and trade off between IB and MOE.

In practice, it seems that maintaining the IB strength property is of primary interest because this property cannot be enhanced by fabricators after the board is produced. On the other hand, it is practically possible to reinforce the MOE strength property even after processing simply by adding a thin layer of veneer or other overlay material.

Because of the time consuming, relatively slow and inconvenient glue assembly of IB test specimens according to the standard method, many alternative methods of testing IB strength have been developed. However, not all alternative IB test methods can provide the necessary accuracy and feasibility of the standard test. Again, the manufacturers are to decide which test methods are appropriate for their products in terms of accuracy, cost, speed and suitability for quality control.

The standard requirements of the commercial standard, of course, are based on the standard IB test.

Many researchers have been working on the subject of IB strength and its relation to density and density profile of particleboard and MDF. Because of inconsistancy regarding IB and core density relationships in the results of such studies, the experimental part of this paper includes investigations of those above mentioned relationships for two commercial particleboards and MDF and determination of related properties. This experimental part has two components. In the first part of the experiment, relationships between IB and a limited range of density (core density) of particleboard and MDF were determined . In the second part of the experiment, those relations were investigated over a wider range of density.

The results of the first experimental part confirmed the virtual absence of a core density effect on the IB of MDF, while a relatively strong correlation was found between IB and core density of particleboard. The apparent lack of this correlation in MDF was probably due to the relatively narrow range of the core density.
However, the extension of the experiment in the second part showed that the relationships between IB and density does exist for MDF as well as particleboard.

It may be noted that core and face materials follow the same relationship between MOE and density but at different levels for particleboard and MDF and that MOE is very density sensitive (figure 46).

The dynamic MOE test produces higher values than the static test and appears to be a good predictor of static MOE. This predictability may, however, be limited to individual products only.

Chapter VII

CONSEQUENCES OF REDUCING CORE DENSITY

The results of the first experiment : A very slight correlation between IB and core density of MDF encourage speculation for the possibility of reducing the core density of MDF without suffering undue penalties in terms of properties deterioration.

Some exploratory calculations in this regard were made and are discussed in the following :

Suppose that, the core density of MDF is being reduced from 0.770 to 0.680 g/cu.cm. If the face density was maintained at, say, 1.0, 0.95 or at 0.90 g/cu.cm., the overal density would be determined by using equation (1). These values would be reduced from 0.868, 0.847 or 0.826 to 0.817, 0.795, or 0.774 g/cu.cm. respectively (figure 59). Furthermore, face MOE, core MOE and overall MOE when maintaining such face densities could be calculated by using equations (12, 11, 3) as shown in table 9 example 1. The overall density reductions are

Figure 59. Relations between overall density and core density of MDF when maintaining face density and IB.

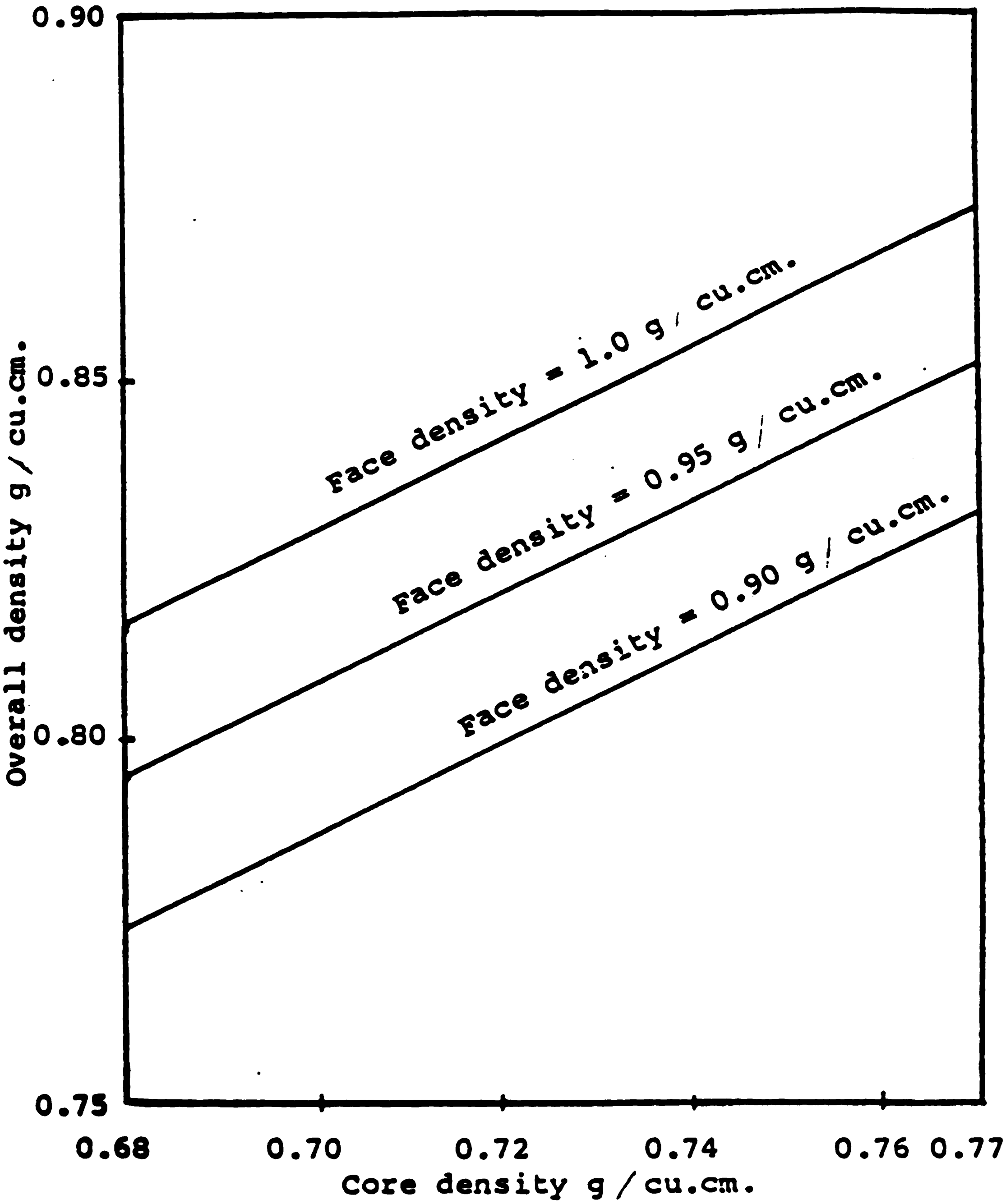

0.90
0.85
0.80
0.75
0.68
0.70
0.72
0.74
0.76
0.77
Overall density g / cu.cm.
Core density g / cu.cm.
Face density = 1.0 g / cu.cm.
Face density = 0.95 g / cu.cm.
Face density = 0.90 g / cu.cm.

Figure 59.

Table 9. Examples of computing density and MOE while reducing core density and maintaining IB of MDF.

Table 9.

Face density (assumption) g / cu.cm.	1.0	1.0	0.95	0.95	0.90	0.90
Core density (range) g / cu.cm.	0.770	0.680	0.770	0.680	0.770	0.680
Overall density (using equation 1) g / cu.cm.	0.868	0.817	0.847	0.795	0.826	0.774
Face MOE (using equation 12) 1,000 psi.	718	718	644	644	570	570
Core MOE (using equation 11) 1,000 psi.	412	308	412	308	412	308
Overall MOE (using equation 3) 1,000 psi.	660	641	600	581	540	521

Example 1.

Overall MOE (assumption) 1,000 psi.	459
Core density (reduced) g / cu.cm.	0.680
Core MOE (using equation 11) 1,000 psi.	308
Face MOE (using equation 3) 1,000 psi.	494
Face density (using equation 12) g / cu.cm.	0.848
Overall density (using equation 1) g / cu.cm.	0.752

Example 2.

5.9%, 6.1%, and 6.3% respectively.

Considering figure 46, which shows that MOE values of MDF are much higher than those of particleboard and that the mean MOE value of particleboard is still higher than the standard requirement (400,000 psi), one might ask, why not reduce overall MOE of MDF to the average MOE value of particleboard (459,000 psi). Here, again, the new face MOE, new face density and finally, new average board density would be obtained simply by using equations {11, 3, 12, 1 } while again reducing core density to 0.680 g/cu.cm. and maintaining IB (table 9 example 2). This would be equivalent to a 5.9% total density reduction.

Of course, even small amounts of density reduction mean cost savings in terms of raw material, press cycle, and transportation.

At the same time, there might result other board quality improvements, as for instance, reduced thickness swelling. There are disadvantages too : Lower edge density, lower screw holding power, etc.

Chapter VIII

CONCLUSION

From the results obtained in this study, the following conclusion may be drawn :

1. Density is a very important and dominating variable affecting physical and mechanical properties of particleboard and MDF.

2. Resin efficiency, densification, particle geometry and press cycle are some of the other important factors developing mechanical properties of particleboard and MDF.

3. Density gradient of MDF or particleboard is one of the important characteristics of these boards which can be manipulated by raw material variables and press cycle.

4. IB and MOE are dependent properties. Measures to increase one may adversely affect the other.

5. MDF and particleboard have different density-IB relationships.

6. IB of particleboard is strongly related to core density.

7. IB of MDF has a very slight correlation with core density.

8. By extension of the range of densities, strong linear correlations were found between IB and density of both board types.

9. It may be possible to reduce the overall density of MDF without sacrificing the IB.

10. The greater homogeneity of MDF is reflected in smaller variations of its properties.

11. There might be other factors besides density

affecting the relationship between layer IB and layer density as tested in our experiment. One such factor might be the change in fiber orientation as function of distance from borad surface.

APPENDICES

Appendix 1. Board specifications.

a: SurPine particleboard specifications :

Raw material	:	Planer shavings, plywood trim,reclaims of Pine.
Resin	:	Urea formaldehyde, 7.5% face and 6.25% core.
Wax	:	0.4% .
Urea	:	0.4%(scavenger).
Press	:	5′ by 16′, with 20 openings.
Pressure	:	500 psi.
Total cycle time	:	6.6 minutes including closingtime and opening.
Sanded	:	0.04 in each side.
Board density	:	48 lbs/cu.ft.

b: Willamette MDF specifications :

Raw material	:	90% Pine planer shaving, 10% hardwood chips.
Resin	:	Urea formaldehyde, about 9% .
wax	:	0.5% .
Urea	:	0.4% or less(scavenger).
Press	:	5′, by 18′, with 13 openings.

Pressure	**:**	**500 psi.**
Total cycle time	**:**	**7 minutes including closing time and opening.**
Board density	**:**	**48 lbs/cu.ft.**

Appendix 2. Determination of machined length of IB test specimen.

The length reduction of the specimen due to the removal by means of a milling cutter of material on both sides of the failure plane can be determined with the help of a special jig, figure 60.

The shaded areas on the sketch are restraining steel bars mounted on a steel base plate.

The distance A is so chosen that it is approximately equal to L1/2 + D/2.

What is shown in the sketch is a hypothetical specimen separated without loss of material along a plane inclined by an angle of 45 degree relative to the long axis of the specimen.

The dial gage measures distance B1. If now this specimen was taken out of the jig, material removed along the 45 degree planes to the dotted lines and placed back in the jig, only part b would shift. Part a would be in exactly the same position it had occupied initially. Part b would shift downward by a distance equal to the length of the arrow which is exactly the reduction in total length (L1-L2) of the specimen. The dial reading is now B2.

Therefore,

$$B1 - B2 = L1 - L2 = \Delta L \qquad (19)$$

Figure 60. Measurement of length reduction of IB test specimen.

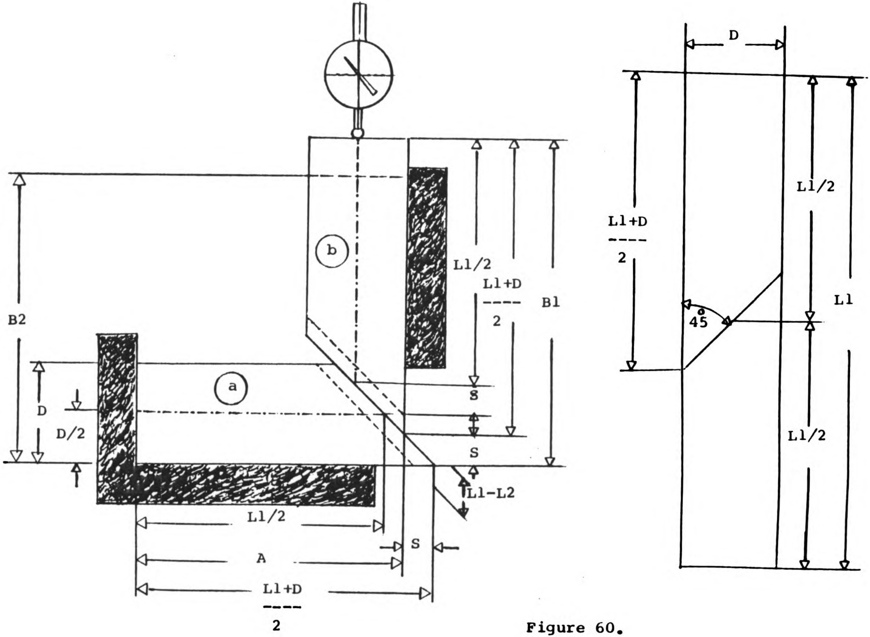


Figure 60.

However, B1 connot be measured and must be expressed in terms of L1 and D, where L1 is the length of the specimen before testing.

One obtains from the sketch :

$$S = L1/2 + D/2 - A \qquad \{20\}$$

$$B1 = L1/2 + D/2 + S \qquad \{21\}$$

$$B1 = L1 + D - A \qquad \{22\}$$

$$\Delta L = B1 - B2 = L1 + D - A - B2 \qquad \{23\}$$

Appendix 3. Experimental data for layer IB and layer density relationships.

Board : MDF

Layer density g/cu.cm.	Layer IB psi	Layer density g/cu.cm.	Layer IB psi
1.051	206	0.974	221
1.051	217	0.974	213
1.051	251	0.974	221
1.051	211	0.907	150
1.051	215	0.907	165
1.054	235	0.907	172
1.054	185	0.907	158
1.054	230	0.907	187
1.054	217	0.903	130
1.054	234	0.903	172
1.047	228	0.903	175
1.047	162	0.903	178
1.047	263	0.903	139
1.047	250	0.905	155
1.047	242	0.905	182
1.036	235	0.905	173
1.036	204	0.905	169
1.036	217	0.905	168
1.036	236	0.901	160
1.036	220	0.901	168
0.987	207	0.901	170
0.987	213	0.901	174
0.987	232	0.901	167
0.987	247	0.828	135
0.987	232	0.828	126
0.988	170	0.828	150
0.988	160	0.828	137
0.988	152	0.828	127
0.988	169	0.822	130
0.988	118	0.822	148
0.974	188	0.822	133
0.974	161	0.822	137
0.974	170	0.822	110
0.974	175	0.831	130
0.974	159	0.831	112
0.974	211	0.831	120
0.974	221	0.831	105

Board : MDF

Layer density g/cu.cm.	Layer IB psi	Layer density g/cu.cm.	Layer IB psi
0.831	117	0.726	80
0.821	130	0.726	108
0.821	153	0.726	83
0.821	100	0.706	42
0.821	130	0.706	56
0.821	141	0.706	83
0.781	67	0.706	71
0.781	83	0.706	85
0.781	96	0.695	55
0.781	116	0.695	66
0.781	78	0.695	89
0.776	100	0.695	52
0.776	101	0.695	56
0.776	98	0.705	90
0.776	76	0.705	106
0.776	92	0.705	66
0.771	120	0.705	87
0.771	110	0.705	84
0.771	97	0.694	107
0.771	90	0.694	87
0.771	142	0.694	85
0.771	108	0.694	95
0.771	123	0.694	98
0.771	116	0.689	56
0.771	116	0.689	83
0.771	112	0.689	81
0.733	100	0.689	74
0.733	80	0.689	61
0.733	103	0.681	65
0.733	116	0.681	57
0.733	90	0.681	68
0.723	61	0.681	63
0.723	57	0.681	55
0.723	59	0.688	70
0.723	59	0.688	59
0.723	75	0.688	81
0.732	72	0.688	66
0.732	78	0.688	91
0.732	78	0.681	70
0.732	103	0.681	70
0.732	112	0.681	96
0.726	66	0.681	74
0.726	82	0.681	78

Board : MDF

Layer density g/cu.cm.	Layer IB psi	Layer density g/cu.cm.	Layer IB psi
0.678	60		
0.678	72		
0.678	70		
0.678	93		
0.678	67		
0.670	72		
0.670	91		
0.670	74		
0.670	70		
0.670	57		
0.685	81		
0.685	75		
0.685	88		
0.685	74		
0.685	57		
0.679	74		
0.679	87		
0.679	91		
0.679	95		
0.679	79		
0.675	75		
0.675	77		
0.675	63		
0.675	86		
0.675	92		
0.677	85		
0.677	81		
0.677	55		
0.677	76		
0.677	62		
0.687	59		
0.687	57		
0.687	50		
0.687	78		
0.687	88		
0.671	68		
0.671	86		
0.671	65		
0.671	86		
0.671	89		

Board : Particleboard

Layer density g/cu.cm.	Layer IB psi	Layer density g/cu.cm.	Layer IB psi
0.974	275	0.694	166
0.974	212	0.694	155
0.974	242	0.694	130
0.974	300	0.694	135
0.974	250	0.694	114
0.954	175	0.684	155
0.954	190	0.684	138
0.954	182	0.684	112
0.954	175	0.684	129
0.954	188	0.684	120
0.874	207		
0.874	195		
0.874	186		
0.874	191		
0.874	205		
0.805	142		
0.805	116		
0.805	144		
0.805	142		
0.805	147		
0.767	129		
0.767	136		
0.767	121		
0.767	156		
0.767	170		
0.728	122		
0.728	135		
0.728	148		
0.728	150		
0.728	152		
0.717	150		
0.717	182		
0.717	160		
0.717	177		
0.717	125		
0.710	105		
0.710	120		
0.710	98		
0.710	112		
0.710	100		

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