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MDPI

Article

Experimental Investigation of Vertical Density Profile of Medium Density Fiberboard in Hot Press

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Abstract: This research investigates the performance of medium density fiberboard (MDF) with respect to hot press parameters. The performance of the board, type of glue, and production efficiency determine the optimum temperature and pressure for hot pressing. The actual temperature of the hot press inside the MDF board determines the properties of the final product. Hence, the optimal hot press parameters for the desired product are experimentally obtained. Moreover, MDF is experimentally investigated in terms of its vertical density profile, bending, and internal bonding under the various input parameters of temperature, pressure, cycle time, and moisture content during the manufacturing process. The experimental study is carried out by varying the temperature, pressure, cycle time, and moisture content in the ranges of 200–220 °C, 145–155 bar, 260–275 s, and 8–10%, respectively. Consequently, the optimum input parameters of a hot-pressing temperature of 220 °C, pressure of 155 bar, cycle time of 256 s, and moisture content of 8% are identified for the required internal bonding (0.64 N/mm^2), bending (32 N/mm^2), and increase in both the core and peak density of the vertical density profile as per the ASTM standard.

Keywords: medium density fiberboard; bending; internal bonding; vertical density profile; hot-pressing temperature; pressure; moisture content; cycle time

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1. Introduction

Medium density fiberboard is a wood board manufactured under optimal hot press conditions using wood fibers and applying the urea formaldehyde resin. MDF boards have several indoor and outdoor applications but are mainly used in the furniture industry as a replacement for solid wood [1]. There are three types of production lines in MDF manufacturing,

- Single daylight press.
- Multi-opening press.
- Continues line press.

Figure 1 shows an overview of all the major processes involved in MDF manufacturing. This includes raw material collection, chipping, defibrating, forming, pressing, product finalizing, and shipment to the market [2]. With the introduction of industrial wood-based panel manufacturing, most researchers initially focused on the technical and economical optimization of both processes and products [3]. Nowadays, customer demands for sheets are steadily increasing. There are two ways to meet such needs: either by performing various experiments on MDF boards or by developing model simulation [4]. The variation in density at different positions in the fiber mat is of major concern because of the consequent variations in mechanical properties. Input temperature, pressure, cycle time, and moisture content in hot pressing determine the physical and mechanical properties of the manufactured MDF board [5]. A large number of boards (nearly 10–15%) or about one hundred thousand cubic meter per year are rejected in the market due to defects, such as weak internal fiber arrangement, low bending and internal bonding, sides looseness, delamination problems, and rough surfaces [6]. The major reason for these defects is the lack of appropriate understanding of the inter-relationship during the hotpress process among the initial process parameters, such as temperature, moisture content, platen pressure, and its impact on the properties of the board [7]. Consequently, the process optimization of MDF is important to overcome all of these issues. A viable solution is to develop a relationship between the hot press process parameters and its output results [8]. A number of researchers have examined the parameters of hot pressing during operation, while our study focusses on the parameters in the hot press only. In this research, the experiments are performed on 16 mm MDF board [9]. To perform the experiments, a long piece of 8 × 4 feet MDF board is taken, and it is further divided into smaller pieces according to the requirements of lab tests. Furthermore, the vertical density profile (VDP) is a critical factor that determines the strength and quality of MDF panels [10]. The concept of the ratio of the modulus of bending of one layer to the sum of the modulus of bending of all layers in the previous time step, as previously given by Suo and Bowyer [11], is redefined according to the latest published findings. The equation given by Carvalho et al. is used to calculate the modulus of elasticity of different layers of the fiber cake. This model gives an improved relationship between the peak and core densities at a low hot press platen temperature at 160 °C but with an increase in hot platen temperature to 198 °C, where the rise in peak density is comparatively high [12]. The results of laboratory studies indicate that the vertical density profile of MDF is made from a combination of processes that occur both during compaction and also after the press has reached its final position [13]. Medium density fiberboard's strength, hardness, and other important properties are determined by its vertical density profile, which is one of the most important factors that is determined in laboratory tests of MDF performance. This factor is the combination of the results of many process parameters [14]. During hot pressing, the internal condition of the sheets, temperature, and moisture content continuously change with time [15]. A one-dimensional computer model depends on fundamental analysis, which shows the relationship between process parameters and density profile arrangement. Such parameters are important board characteristics that correlate with the properties of the MDF board [16]. MDF boards with appropriate VDPs are created with careful determination and accurate pressing plan. Existing MDF in the wood market faces issues in regard to moisture, dampness, primary execution, and toughness [17]. Producing quality MDF products that satisfy customer requirements will definitely result in a notable increase in profit for the industry as well as enhancement of the credibility from the perspective of customers [18]. In the last few decades, many researchers have worked on MDF board properties, i.e., bending, thickness swelling, internal bonding, and occurring chemical changes, but only a few studies have examined the vertical density profile of MDF board mathematically. The aims of this study are to increase the bending and internal bonding strength of MDF board, to experimentally study its vertical density profile under varying hot press parameters, and to determine how its peak and core densities are affected by various hot press parameters.

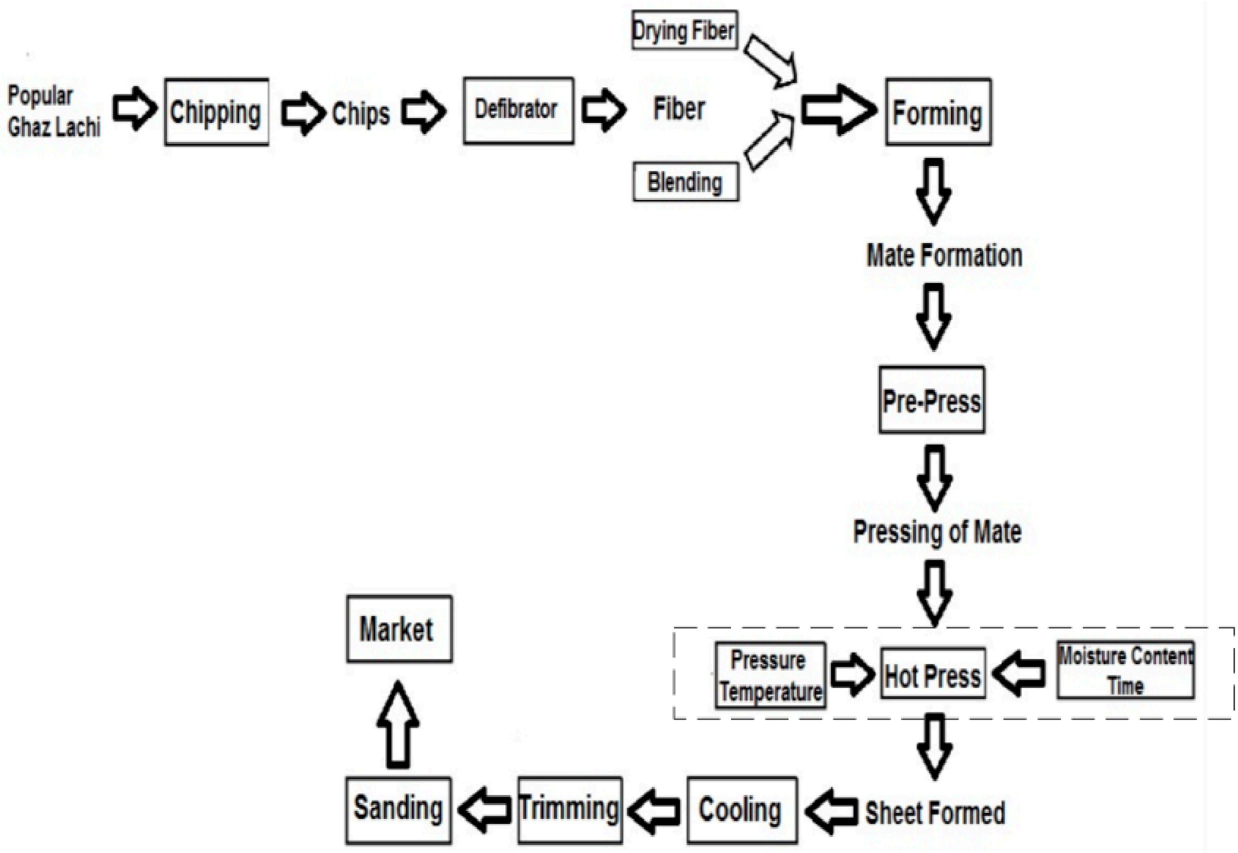

Figure 1. Medium density fiberboard manufacturing process.

2. Materials and Methods

The raw material used for the production of MDF is wood and glue. Generally, three types of wood are used with different percentages: popular (Populus caspica) with 60%, Ghaz (Tamarix aphylla) with 20%, and lachi (eucalyptus) with 20%.

For the required binding of the board, gluing is a crucial step in the manufacturing of MDF board. Other factors that depend on the glue content are board looseness, area roughness, bending, and internal bonding [19]. The glue used is procured from various certified suppliers, and it is comprised of urea and a formaldehyde mixture. The glue is applied through nozzles with diameters from 2 mm to 3 mm with respect to the ratio of fiber/pulp; i.e., if the pulp is transferring in the blow line of 25 kg, then 15 kg glue is applied.

The process of hot pressing in MDF involves applying pressure in a specified pattern with respect to time, with the platens being heated up to the optimal temperature [20]. A pressure versus time graph in hot pressing is shown in Figure 2.

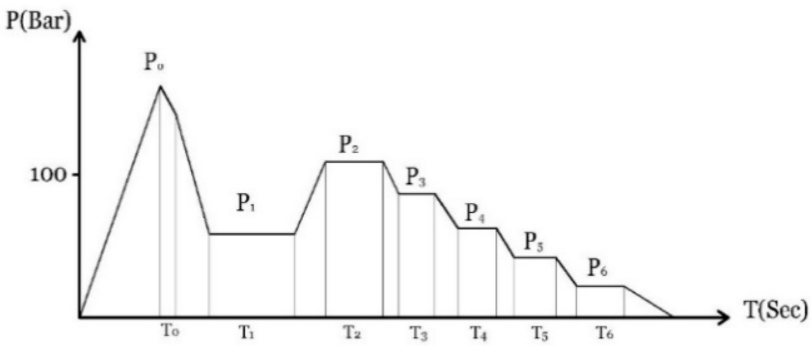

Figure 2. Hot press cycle graph.

Experiments were carried out on 16 mm medium density fiberboard with variations in hot press parameters the ranges specified in Table 1.

Table 1. Process parameters for hot pressing.

S.No.	Parameters	Value
1	Temperature	200–220 °C
2	Pressure	145–155 bar
3	Time	260–275 s
4	Moisture contents	8.00–10.00%

Afterwards, the density profile test, bending test, internal bonding test, and vertical density profile or X-ray graph test were performed on the sample of the 16 mm board.

2.1. Density Profile Test

The density profile test illustrates changes in thickness, reflecting the density of the panel. Equal distribution leads to a better quality of medium density fiberboard. The experiment was performed using twelve sample pieces, with six pieces with dimensions of 100 × 200 mm at the left side and six pieces with dimensions of 100 × 200 mm at the right side. The weight and thickness of each work piece were measured to obtain the density profile.

2.2. Bending and Internal Bonding Test

This test measures the bending of MDF boards. Five pieces with dimensions of 50 × 400 mm were used in the wood testing machine for the internal bonding and bending test. The maximum applied uniform load with a consistent speed toward the point of convergence of MDF prior to failure measured the bending and internal bonding [21]. For internal bonding critical tests, five work pieces with dimensions of 50 × 50 mm were used. Figure 3 shows the wood testing machine used for the bending test, while Figure 4 depicts the internal bonding test.

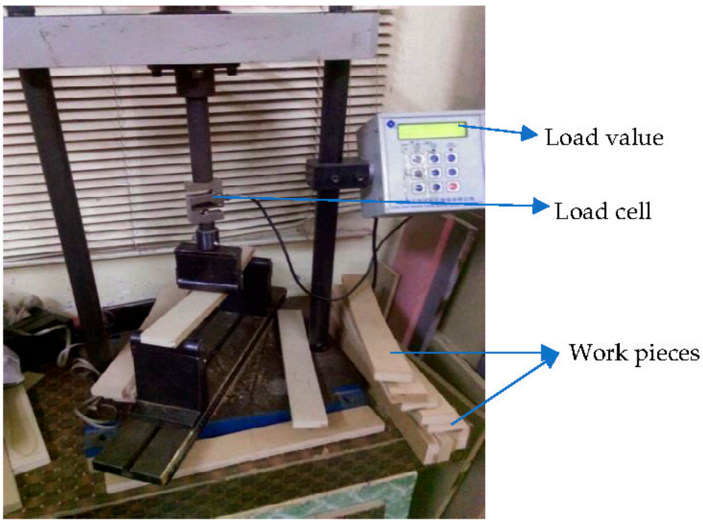

Figure 3. Wood testing machine.

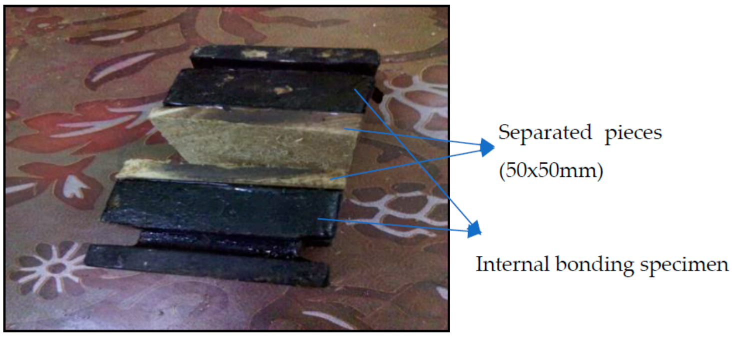

Figure 4. Internal bonding specimen.

2.3. Vertical Density Profile or X-ray Graph

The vertical density profile is generated as result of the input process parameters in hot pressing. Applying pressure on the fiber mat in the presence of a high temperature and the required moisture content creates a vertical density profile. This VDP across the board thickness relates to the bending, internal bonding, and other MDF mechanical properties [22]. An electronic wood X-ray machine as shown in Figure 5 was used to generate X-ray profile of samples used in the experiment. Five work pieces' samples with dimensions of 50 × 50 mm was considered for the X-ray graph. The X-ray graph represents the point-to-point density as well as the density at the edges and center of the samples [23].

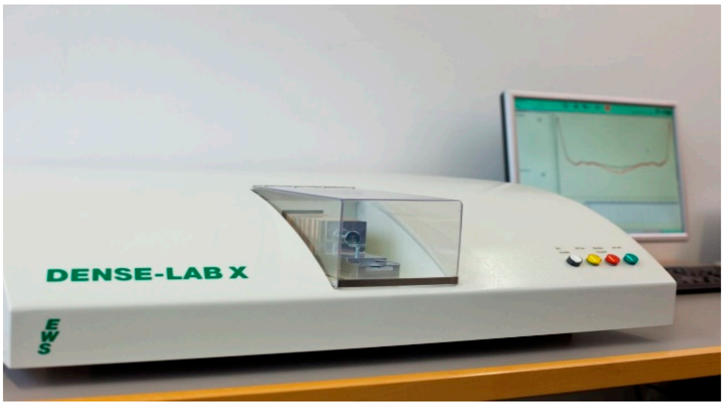

Figure 5. X-ray graph apparatus.

2.4. ISO and ASTM Standards for Statistical Testing Methods

ISO 16895:2016 (en) is international standards used for fiberboard, dry fiber, wood-based panels, medium density fiberboard, and dry-process fiberboard testing. According to ISO/IEC directives, this document is listed as an international standard of fiberboard testing (ISO 16895:2016 (en) ISO/TC 89 array). In addition, another standard for fiberboard testing marked as ASTM D-1037—12(2020) is listed as a standard for methods of evaluating properties of wood-based fiber and the material density of fiberboards.

3. Results and Discussions

Several tests were performed on MDF board by varying the hot press parameters, i.e., temperature, pressure, cycle time, and moisture content. Temperature was varied from 200 to 220 °C, pressure from 145 to 155 bar, cycle time from 260 to 275 s, and moisture content from 8 to 10%. The experimental results are shown in Table 2.

Table 2. Experimental data results.

S.No.	Temperature °C	Pressure Bar	Cycle Time S	Moisture Content %	Bending N/mm^2	Internal Bonding N/mm^2
1	195	145	260	8.00	12	0.25
2	200	145	260	8.00	24	0.56
3	200	153	268	8.80	16	0.40
4	202	152	265	9.50	17	0.38
5	205	155	270	10.00	22	0.46
6	206	154	266	9.75	19	0.41
7	207	147	260	8.70	18	0.39
8	210	150	265	8.50	28	0.55
9	211	148	263	8.20	15	0.44
10	213	150	270	9.20	14	0.42
11	215	155	275	9.00	26	0.58
12	218	145	275	10.00	21	0.43
13	220	155	265	8.00	32	0.64
14	225	155	272	8.00	20	0.39

From the experimental data presented in Table 2, the input values of pressure, temperature, cycle time, and moisture content are determined based on the output of bending and internal bonding. According to the experimental data, the maximum value of bending is 32 N/mm^2, corresponding to the maximum internal bonding of 0.64 N/mm^2. These are achieved by applying a pressure of 155 bar with a temperature of 220 °C, cycle time of 265 s, and moisture content of 8%.

Figure 6 demonstrates the effect of variations in process parameters on bending and internal bonding through a 3D graph of experimental data.

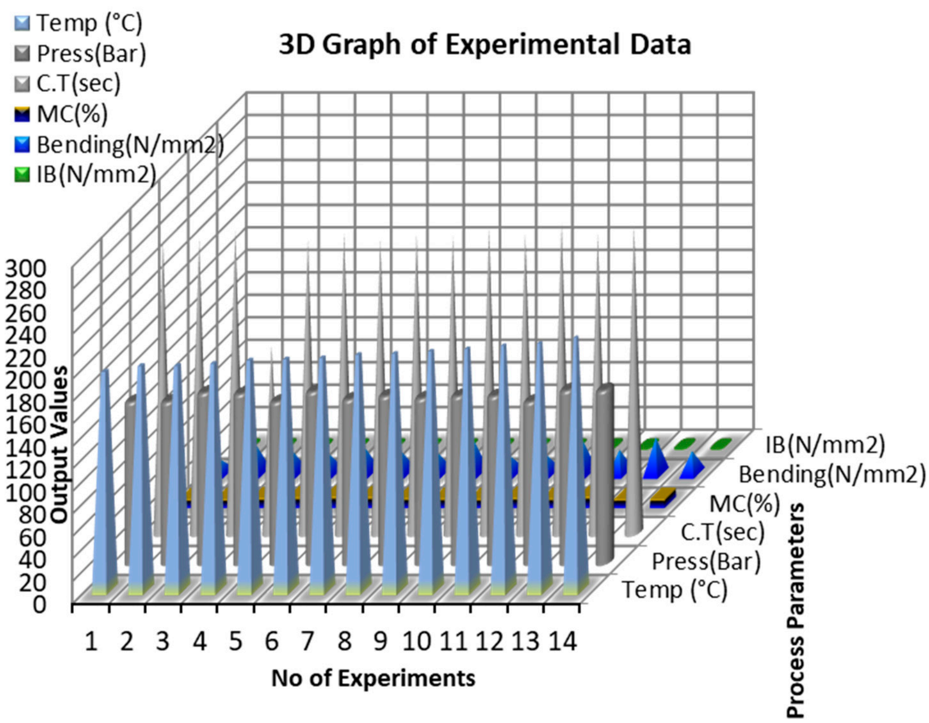

Figure 6. Three-dimensional graphical representation of experiments.

Figure 7 shows the percentage representation of mediumdensity fiberboard parameters. Some of the data are selected from the experimental data in Table 3 for further analysis. To obtain the peak and center densities of the specimen, vertical density profiles are generated.

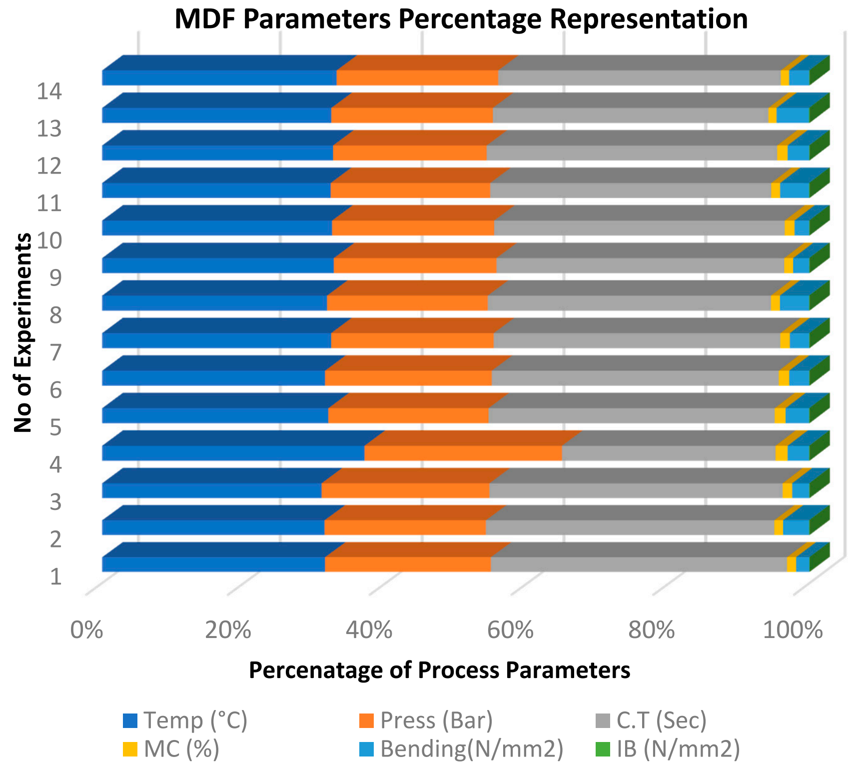

Figure 7. MDF parameter percentage representation.

Table 3. Selected experimental data.

S.No.	Temperature °C	Pressure Bar	Cycle Time S	Moisture Content %	Bending N/mm^2	Internal Bonding N/mm^2
1	200	145	260	8.00	24	0.56
2	205	155	270	10.00	22	0.46
3	210	150	265	8.50	28	0.55
4	215	155	275	9.00	26	0.58
5	220	155	265	8.00	32	0.64

3.1. Experiment No. 1

Figure 8 shows the vertical density profile of X-ray graphs in 1st specimen, whereas Tables 4–7 illustrate the detailed experimental data at temperature = 200 °C, cycle time = 260 s, pressure = 145 bar, moisture content = 8.00%.

Table 4. Density profile across thickness.

S.No.	Density Kg/m^3	Piece No	Weight (g)	Length (mm)	Width (mm)	Thickness (mm)
1	744	L1	261.14	200	100	17.56
2	713	L2	249.16	200	100	17.48
3	710	L3	250.34	200	100	17.64
4	715	L4	250.65	200	100	17.52
5	712	L5	250.66	200	100	17.61
6	714	L6	250.76	200	100	17.56
7	709	R6	249.34	200	100	17.59
8	710	R5	250.66	200	100	17.65
9	711	R4	251.11	200	100	17.66
10	711	R3	252.43	200	100	17.75
11	713	R2	251.56	200	100	17.65
12	739	R1	260.34	200	100	17.61

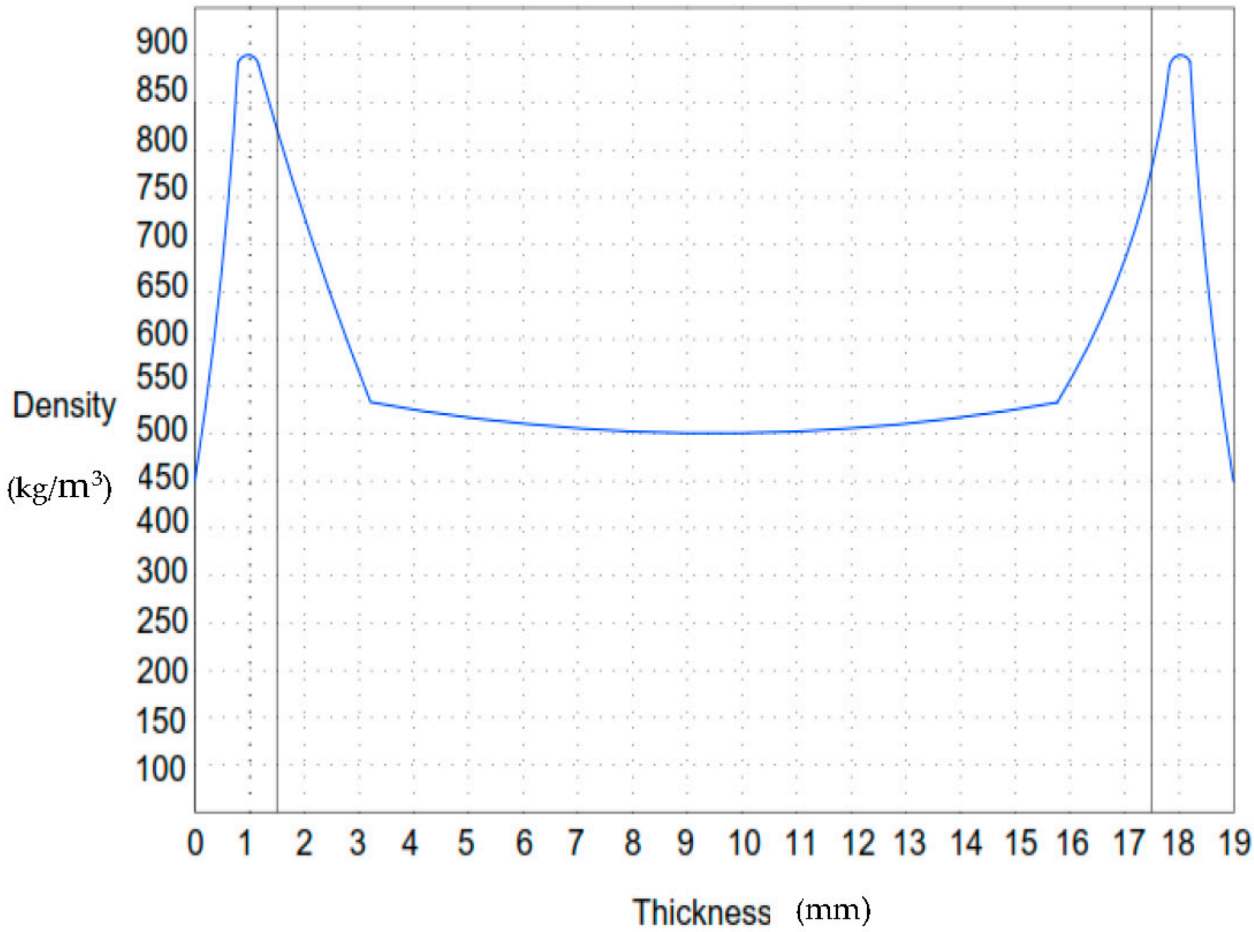

Figure 8. X-ray vertical density profile of 1st specimen.

Table 5. Bending tests.

Sample	P.max N	Strength N/mm^2	Span mm	Sample weight (g)	Density kg/mm^3
Middle M1 of right	641	24.04	320	198.24	670
Middle M2	653	24.49	320	195.66	661
Middle M3	648	24.30	320	194.35	657
Middle M4	655	24.56	320	196.41	664
Middle M5	648	24.30	320	199.12	673
Average		24.34			665

Table 6. Internal bonding test results.

Sample	P.max N	Strength N/mm^2	Sample weight (g)	Density kg/mm^3
Middle M1 of right	1523	0.61	26.85	671
Middle M2	1411	0.56	26.44	661
Middle M3	1278	0.51	26.31	658
Middle M4	1352	0.54	26.13	653
Middle M5	1466	0.59	27.26	682
Average		0.56		665

Table 7. Experimental data of 1st sample.

Density	Average		850	kg/m3
	Min.	Valve	652	kg/m3
		Position	5.392	mm
	Max. Left	Valve	849	kg/m3
		Position	0.560	mm
	Max. Right	Valve	851	kg/m3
		Position	0.713	mm
Ratio	Min./Avg		81.10	%
Gravimetric Valve	Width		50	mm
	Depth		50	mm
	Weight		29.21	g

3.2. Experiment No. 2

Figure 9 shows the vertical density profile of X-ray graphs in 2nd specimen, whereas Tables 8–11 illustrate the detailed experimental data at temperature = 205 °C, cycle time = 270 s, pressure = 155 bar, moisture content = 10.00%.

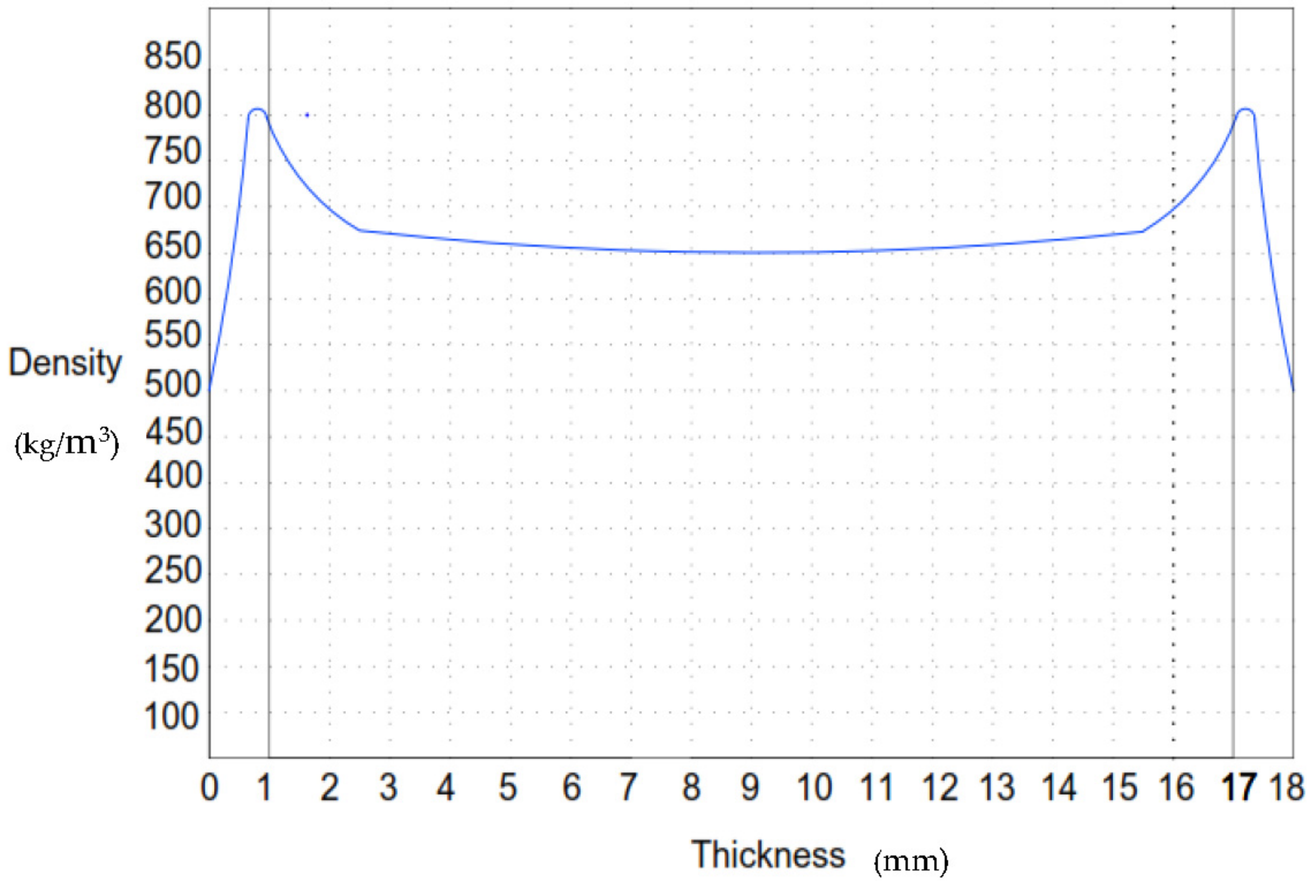

Figure 9. X-ray vertical density profile of 2ndspecimen.

Table 8. Density profile across thickness.

S.No.	Density Kg/m^3	Piece No	Weight (g)	Length (mm)	Width (mm)	Thickness (mm)
1	687	L1	256.66	200	100	18.68
2	655	L2	245.13	200	100	18.71
3	654	L3	244.23	200	100	18.66
4	653	L4	243.67	200	100	18.65
5	657	L5	244.54	200	100	18.61
6	663	L6	245.98	200	100	18.56
7	657	R6	244.45	200	100	18.59
8	659	R5	243.98	200	100	18.52
9	659	R4	244.45	200	100	18.55
10	658	R3	244.98	200	100	18.61
11	661	R2	246.56	200	100	18.64
12	688	R1	257.76	200	100	18.72

Table 9. Bending tests.

Sample	P.max N	Strength N/mm^2	Span mm	Sample Weight (g)	Density kg/mm^3
Middle M1 of right	600	22.50	320	201.14	680
Middle M2	556	20.85	320	198.46	670
Middle M3	582	21.83	320	196.33	663
Middle M4	599	22.46	320	197.67	668
Middle M5	614	23.03	320	200.56	678
Average		22.13			672

Table 10. Internal bonding test results.

Sample	P.max N	Strength N/mm^2	Sample Weight (g)	Density kg/mm^3
Middle M1 of right	1167	0.47	26.26	657
Middle M2	1219	0.49	26.01	650
Middle M3	1075	0.43	25.56	639
Middle M4	1200	0.48	25.98	650
Middle M5	1115	0.45	26.11	653
Average		0.46		650

Table 11. Experimental data of 2ndsample.

Density	Average		898	kg/m3
	Min.	Valve	550	kg/m3
		Position	6.921	mm
	Max. Left	Valve	895	kg/m3
		Position	0.495	mm
	Max. Right	Valve	899	kg/m3
		Position	0.623	mm
Ratio	Min./Avg		79.92	%
Gravimetric Valve	Width		50	mm
	Depth		50	mm
	Weight		27.52	g

3.3. Experiment No. 3

Figure 10 shows the vertical density profile of X-ray graphs in 3rd specimen, whereas Tables 12–15 illustrate the detailed experimental data at temperature = 210 °C, cycle time = 265 s, pressure = 150 bar, moisture content = 8.50%.

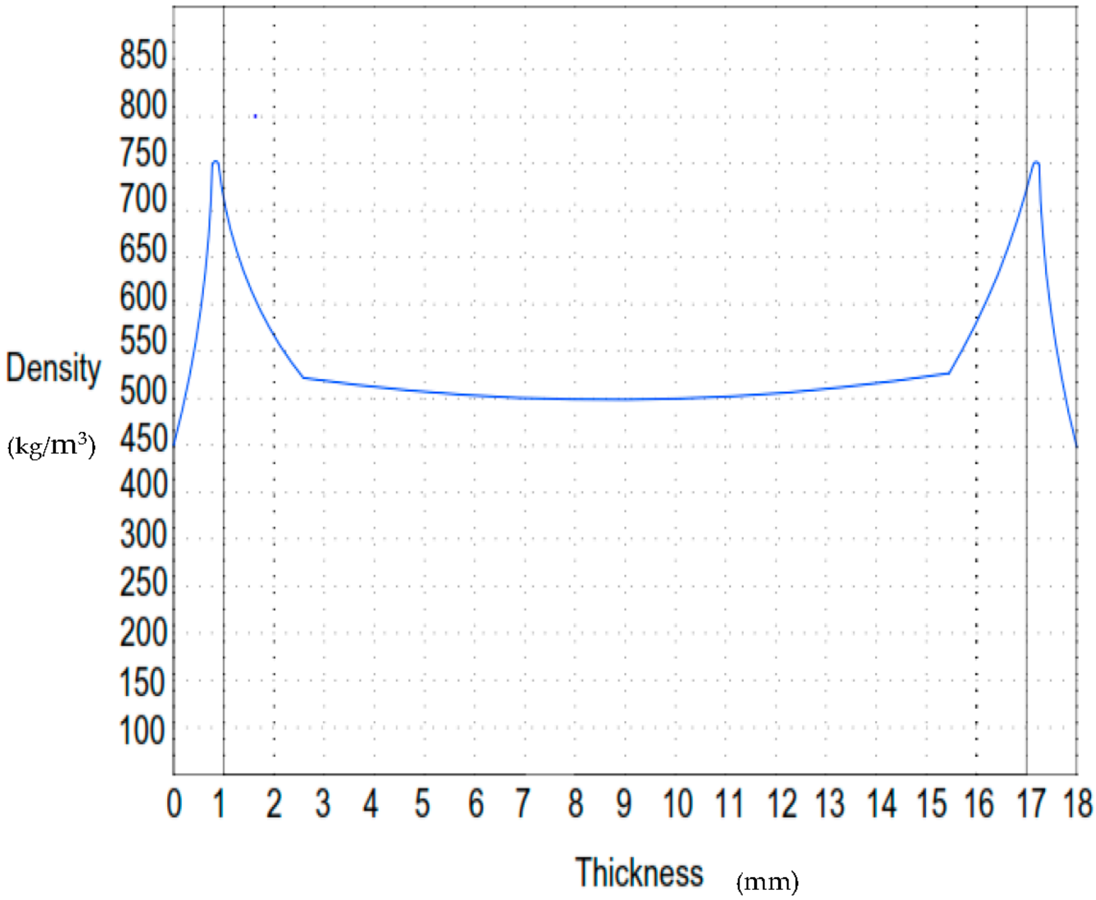

Figure 10. X-ray vertical density profile of 3rdspecimen.

Table 12. Density profile across thickness.

S.No.	Density Kg/m^3	Piece No	Weight (g)	Length (mm)	Width (mm)	Thickness (mm)
1	728	L1	262.56	200	100	18.03
2	707	L2	255.44	200	100	18.06
3	705	L3	254.19	200	100	18.02
4	706	L4	253.91	200	100	17.99
5	704	L5	254.03	200	100	18.05
6	710	L6	255.71	200	100	18.01
7	709	R6	254.54	200	100	17.96
8	709	R5	254.98	200	100	17.99
9	708	R4	255.45	200	100	18.04
10	711	R3	255.98	200	100	18.01
11	711	R2	256.56	200	100	18.05
12	734	R1	263.63	200	100	17.97

Table 13. Bending tests.

Sample	P.max N	Strength N/mm^2	Span mm	Sample Weight (g)	Density kg/mm^3
Middle M1 of right	715	26.81	320	205.76	695
Middle M2	756	28.35	320	203.12	686
Middle M3	781	29.29	320	200.34	677
Middle M4	736	27.60	320	202.75	685
Middle M5	709	26.59	320	205.61	695
Average		27.73			688

Table 14. Internal bonding test results.

Sample	P.max N	Strength N/mm^2	Sample Weight (g)	Density kg/mm^3
Middle M1 of right	1387	0.55	27.55	689
Middle M2	1468	0.59	27.23	681
Middle M3	1254	0.50	26.15	654
Middle M4	1345	0.54	25.35	634
Middle M5	1477	0.59	27.86	697
Average		0.55		671

Table 15. Experimental data of 3rdsample.

Density	Average		798	kg/m^3
	Min.	Valve	652	kg/m^3
		Position	7.020	mm
	Max. Left	Valve	790	kg/m^3
		Position	0.569	mm
	Max. Right	Valve	800	kg/m^3
		Position	0.758	mm
Ratio	Min./Avg		77.75	%
Gravimetric Valve	Width		50	mm
	Depth		50	mm
	Weight		26.52	g

3.4. Experiment No. 4

Figure 11 shows the vertical density profile of X-ray graphs in 4th specimen, whereas Tables 16–19 illustrate the detailed experimental data at temperature = 215 °C, cycle time = 275 s, pressure = 155 bar, moisture content = 9.00%.

Table 16. Density profile across thickness.

S.No.	Density Kg/m^3	Piece No	Weight (g)	Length (mm)	Width (mm)	Thickness (mm)
1	723.0	L1	265.21	200	100	18.34
2	694.4	L2	254.29	200	100	18.31
3	701.3	L3	256.13	200	100	18.26
4	695.1	L4	255.11	200	100	18.35
5	693.9	L5	254.23	200	100	18.32

Table 16. *Cont.*

S.No.	Density Kg/m^3	Piece No	Weight (g)	Length (mm)	Width (mm)	Thickness (mm)
7	695.3	R6	255.45	200	100	18.37
8	693.3	R5	254.32	200	100	18.34
9	701.1	R4	256.76	200	100	18.31
10	692.3	R3	254.34	200	100	18.37
11	694.0	R2	255.67	200	100	18.42
12	728.5	R1	266.76	200	100	18.31
6	700.0	L6	257.87	200	100	18.42

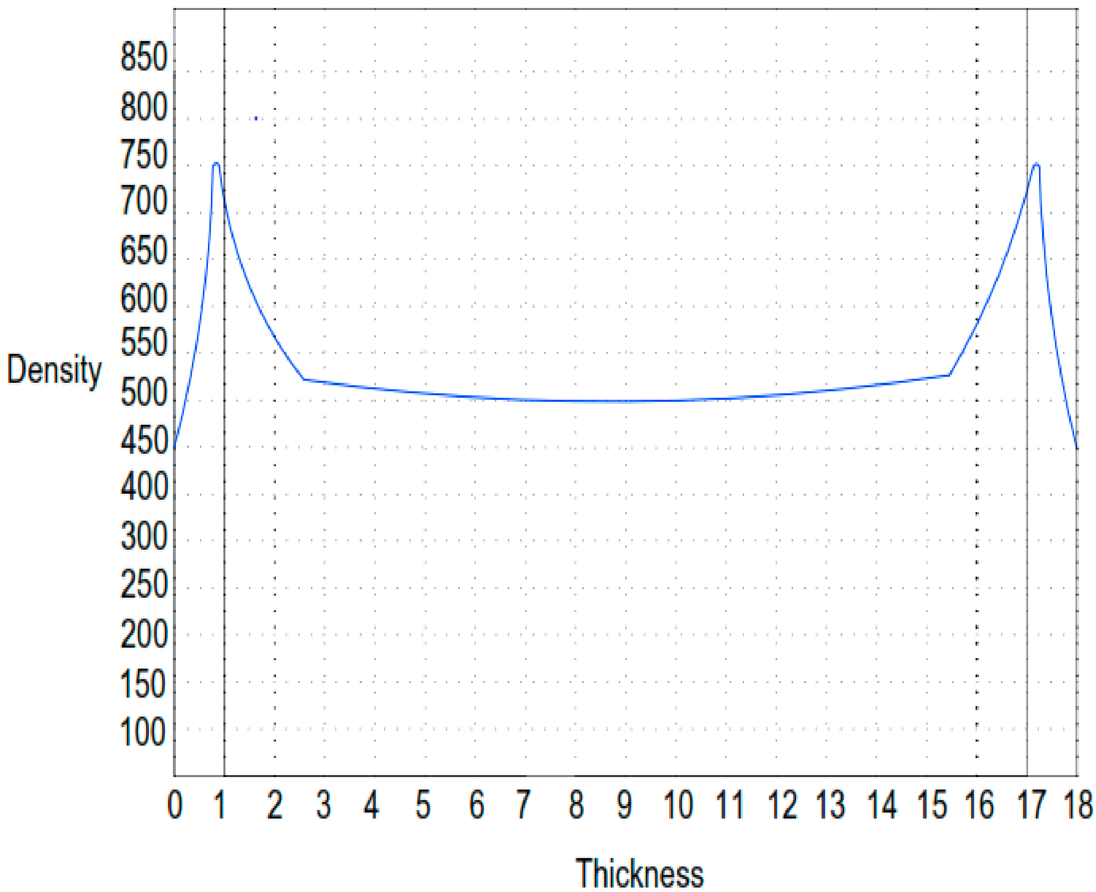

Figure 11. X-ray vertical density profile of 4thspecimen.

Table 17. Bending tests.

Sample	P.max N	Strength N/mm^2	Span mm	Sample Weight (g)	Density kg/mm^3
Middle M1 of right	687	25.76	320	201.13	679
Middle M2	676	25.35	320	197.52	667
Middle M3	695	26.06	320	195.63	661
Middle M4	703	26.36	320	198.98	672
Middle M5	707	26.51	320	200.23	676
Average		26.01			671

Table 18. Internal bonding test results.

Sample	P.max N	Strength N/mm^2	Sample Weight (g)	Density kg/mm^3
Middle M1 of right	1456	0.58	27.12	678
Middle M2	1515	0.61	26.52	663
Middle M3	1378	0.55	26.13	653
Middle M4	1404	0.56	25.54	639
Middle M5	1511	0.60	27.76	694
Average		0.58		665

Table 19. Experimental data of 4thsample.

Density	Average		750	kg/m^3
	Min.	Valve	525	kg/m^3
		Position	7.052	mm
	Max. Left	Valve	755	kg/m^3
		Position	0.461	mm
	Max. Right	Valve	746	kg/m^3
		Position	0.836	mm
Ratio	Min./Avg		82.4	%
Gravimetric Valve	Width		50	mm
	Depth		50	mm
	Weight		28.78	g

3.5. Experiment No. 5

Figure 12 shows the vertical density profile of X-ray graphs in 5th specimen, whereas Tables 20–23 illustrate the detailed experimental data at temperature = 220 °C, cycle time = 265 s, pressure = 155 bar, moisture content = 8.00%.

Table 20. Density profile across thickness.

S.No.	Density Kg/m^3	Piece No	Weight (g)	Length (mm)	Width (mm)	Thickness (mm)
1	744	L1	268.24	200	100	18.03
2	721	L2	260.11	200	100	18.05
3	726	L3	261.56	200	100	18.01
4	725	L4	260.78	200	100	17.98
5	724	L5	261.31	200	100	18.05
6	721	L6	259.78	200	100	18.02
7	721	R6	260.04	200	100	18.03
8	725	R5	260.98	200	100	17.99
9	724	R4	260.64	200	100	17.99
10	725	R3	261.25	200	100	18.01
11	724	R2	260.65	200	100	18.01
12	750	R1	269.78	200	100	17.99

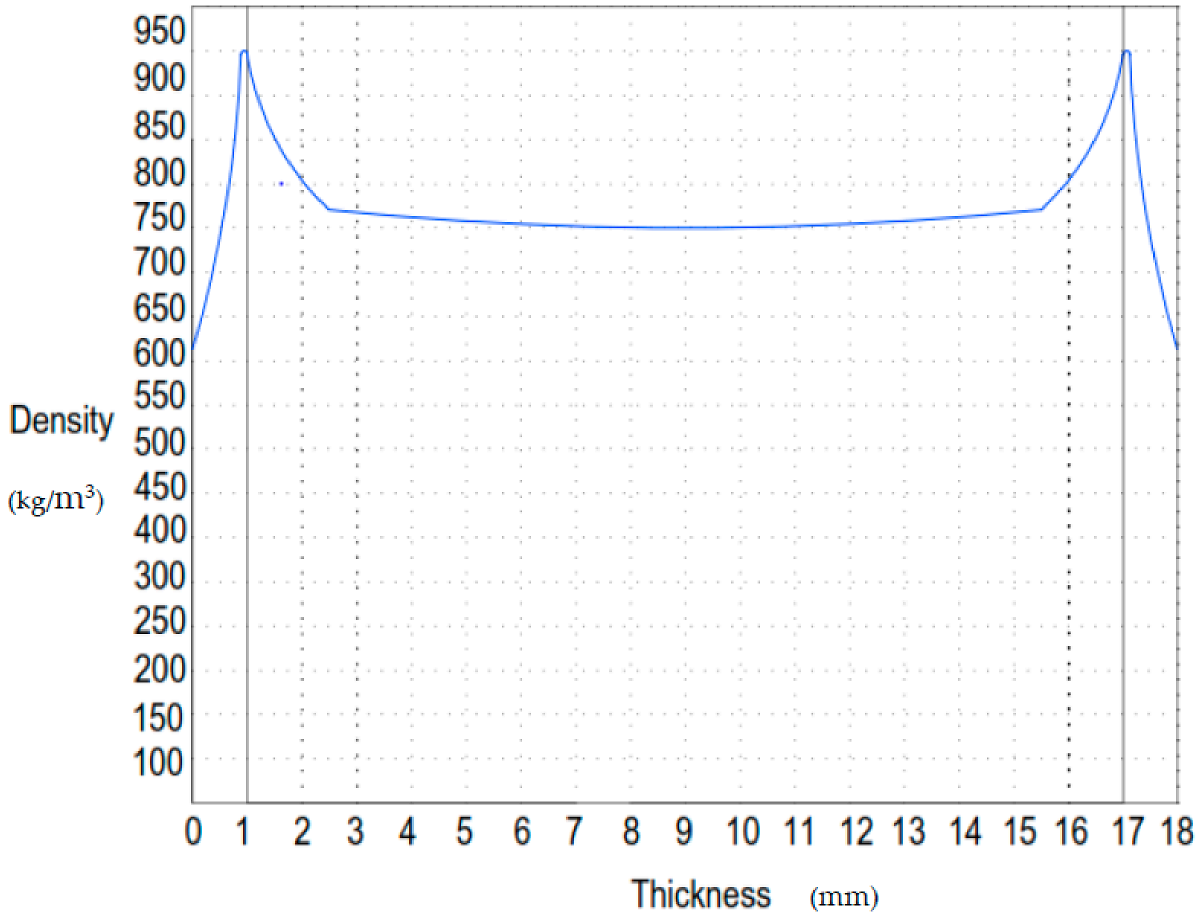

Figure 12. X-ray vertical density profile of 5thspecimen.

Table 21. Bending tests.

Sample	P.max N	Strength N/mm^2	Span mm	Sample Weight (g)	Density kg/mm^3
Middle M1 of right	827	31.01	320	207.53	701
Middle M2	856	32.10	320	205.11	693
Middle M3	898	33.68	320	203.68	688
Middle M4	861	32.29	320	207.09	700
Middle M5	854	32.03	320	208.65	705
Average		32.22			697

Table 22. Internal bonding test results.

Sample	P.max N	Strength N/mm^2	Sample Weight (g)	Density kg/mm^3
Middle M1 of right	1698	0.68	27.76	694
Middle M2	1587	0.63	27.98	700
Middle M3	1476	0.59	27.11	678
Middle M4	1523	0.61	27.31	683
Middle M5	1654	0.66	27.64	691
Average		0.64		689

Table 23. Experimental data of 5thsample.

	Average		950	kg/m^3
Density	Min.	Valve	752	kg/m^3
		Position	8.201	mm
	Max. Left	Valve	942	kg/m^3
		Position	0.593	mm
	Max. Right	Valve	947	kg/m^3
		Position	0.792	mm
Ratio	Min./Avg		89.2	%
Gravimetric Valve	Width		50	mm
	Depth		50	mm
	Weight		32.2	g

Five samples of medium density fiber board were produced at various temperatures, pressures, cycle times, and moisture contents. In the first sample, the temperature was 200 °C with a pressure of 145 bar, cycle time of 260 s, and moisture of 8.00%. In this experiment, all of the parameters were taken at the minimum conditions, but the result of bending and internal bonding were not good (compared to standards).

In the second sample, a minor increase in all process parameters was observed, with a temperature of 205 °C, a pressure of 155 bar, cycle time of 270 s, and moisture of 10.00%, and, as a result, the bending and internal bonding decreased. In third sample, we observed a further increase in temperature (210 °C) with pressure (150 bar) and cycle time(265 s) and a decrease in moisture (8.50%) with respect to the previous experiments' moisture content. The results of bending and internal bonding were notably better than those of the previous experiments.

In the fourth sample, we observed an increase in temperature (215 °C) with pressure (155 bar) and cycle time (275 s) as well as an increase in moisture (9.00%) with respect to the results of the previous experiments. The bending and internal bonding also increased. In the fifth sample, the highest value of temperature at 220 °C and a pressure of 155 bar were observed with normal cycle time of 265 s and low moisture content of 8.00%. The results were in accordance with our expectations, with bending and internal bonding values reaching the requirements of the standards.

4. Comparative Analysis

4.1. Vertical Density Profile

A temperamental, one-dimensional PC model dependent on central examination, which can assist with understanding the connection between handling boundaries and density profile arrangements, was created in the current study]. The vertical density profile, representing board density, has for quite some time been distinguished as one of the significant load-up qualities that relate well with internal bonding, bending, and other properties of MDF sheets [24].

Starting with the initial X-ray graphs, and after optimization, it can be observed that the graphs do not follow the standards. The board is hard at the center but loose at the sides. In the second and third graphs, the same situation can be observed in the sheets, as they contain loose sides and only their center is hard and has high density, while the density of their center is normal. After optimization, the graphs present the standards of X-ray graphs. Rendering the sheet results in the density being the same across the board, which means that by increasing the temperature to optimize the pressure, proper use of a wood recipe and maintenance of the dampness content will result in reaching the level of an MDF manufacturing plant.

4.2. Density Profile

The most significant test in the industry is the density profile test, which allows one to examine the combination of density and thickness. From this test, the density profile and weight distribution of a fiber mat can easily be determined. The test before optimization shows that the density in the right side of the board is low, resulting in it not meeting the requirements. In the same case, the second graph shows that the density of the left side is also low due to the low-density range, high weight, and high density of the sheet. In the third graph, both the sides are low, and this must be determined by examining the forming section [25].

After optimization, the density of the fiber mat arrangement in the board whose sides are equal in the sheet is in the desired range. If the density is in not in this range, then various issues can occur. Notably, with the help of the profile test, this problem can be resolved with mat arrangement in the mat or board. The use of a vacuum suction blower can help in suctioning the mat from the pen duster, thereby ensuring the correct fiber mat arrangement in the board.

4.3. Internal Bonding and Strength of the Sheet

The use of tests allows for the strength of sheets and the ways by which they resist external force to be determined. Multiple industries perform bonding tests to standardize final sheets. Prior to optimization, we used an iron pattern, but this consumed a lot of time in the heating process and in conducting the test. Now, however, we use a steel pattern, which speeds up the heating process and is less time consuming.

Several authors have worked on medium density fiberboard properties in many ways, but this study experimentally investigates the properties of MDF board by examining the effect that changing the various process parameters has on bending, internal bonding, and the vertical density profile. IN a previous study, Arun Gupta et al. worked on the modeling of the development of the vertical density profile of MDF during hot pressing [26]. Paul M. Winistorfer et al. worked on modeling and provided a comparison of vertical density profiles. There is various MDF manufacturing plant types, such as single daylight opening plants, multi-opening plants, and continuous production plants [27].

The results show that the internal bonding and strength of the sample before optimization are lower than the standards, which means that the sheet can easily be rupture at the center and also from the side. In contrast, by setting the press parameters of pressure, temperature time, and dampness content, internal bonding reaches its highest level of quality.

5. Conclusions

This research illustrates the effect of hot press input parameters on the characteristics of manufactured medium density fiberboard. Optimum MDF with maximum bending and internal bonding as well as the desired vertical density profile is achieved through careful experimentation and its validation with standards. Five experiments are successfully conducted, where the last experiment provides the desired results. The hot-pressing process with a temperature of 220 °C, a bar pressure of 155, a cycle time of 265 s, and a moisture content of 8%produces the required MDF output. Increasing the hot-pressing temperature improves the bending stiffness and internal bonding and allows for the optimum values of 32 N/mm^2 and 0.64 N/mm^2, respectively, to be achieved.

For future work, the quality of MDF board can be improved by considering different suitable combinations of raw wood. Similarly, the used resins can be changed, and the manufactured MDF can be analyzed in terms of its bending, internal bonding, and vertical density profile.

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