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The Improvement of Physico-mechanical Properties of MDF with High Frequency Heating Technique*1

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ABSTRACT

This study was carried out to improve the physico-mechanical properties of board products by applying the technique of high frequency heating, and find out the optimum conditions of high frequency heating, compared with the technique of hot platen heating. The possibility of isocyanate resin application to board production was also considered to solve the problem of free formaldehyde emission from urea resin which is generally used in wood industry. For this study, 30 mm thick MDF (medium density fiberboard) with isocyanate resin were manufactured by the techniques of hot platen heating, high frequency heating and the combination techniques of both heating methods, and compared in several point of views.

Keywords : High frequency heating, hot platen heating, waste wood, MDF, isocyanate resin, urea resin, physico-mechanical properties

1. INTRODUCTION

The demand of wood with industrial development and urbanization are more and more increasing, due to the property of natural attraction to human. As a result, the production of waste woods is also rapidly increasing. The small portions are manufactured to the recycled products, and those are still limited to particle board, medium density fiberboard. Therefore, the conversion of valuable recycled products from waste woods can be important subjects and must be attained to high quality material for the economic purpose as well as environmental aspects.

The use of board products produced with waste wood is rapidly expended, because of the easiness in collecting raw material and in process work. This trend would be accelerated for the high quality products made of recycled raw materials. In Korea, the production rate of waste wood are about 40% in proportion to the amount of raw materials of wood used. Therefore, the board production industry would be best wood processing industry.

The representative board products are particle board, medium density fiberboard and hardboard. Among these, the demand of medium

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density fiberboard is rapidly increased. It is known that medium density fiberboard is comparatively expensive, hard to collect raw material, and high in consumption of electricity, but medium density fiberboard also have lots of benefit in superior structure of uniformity, processing performance, and environmental aspect, compared to other board products.

In present, the amount of production in MDF is steadily increasing by 15%. The main products of MDF are thin layer below 20 mm in thickness. MDF is mainly producing by hot platen heating system. For this reason, the products of thick layer have some problems in temperature transfer into the core layer of board, and in taking long forming time.

For the strict environmental regulations, the wood working industry have another big burden for the problem of free formaldehyde emission mainly from synthetic resins during board manufacturing. The free formaldehyde is harmful to human, and forced to change other resins without containing formaldehyde, or to reduce the emission rates of formaldehyde. In other hand, it must be developed new types of resin which has durability, water-resistance, and also harmless to formaldehyde.

Therefore, in this study the possibilities of application in high frequent heating as a heat transferring system and in isocyanate as a harmless resin (Ernst, 1985) were tried for the purpose of improving the physical, mechanical properties of MDF.

2. MATERIALS and METHODS

2. 1 Materials and equipment

2.1.1 Wood fibers

Table 1. Defiberizing conditions of wood chips.

Steaming temperature (°C)	170
Steaming pressure (kgf/cm^2)	7
Presteaming time (min.)	3
Defibrating time (min.)	1

Wood chips from radiata pine (*Pinus radiata* D. Don) were defiberized with defibrator (Valmet Inc. #11133-36, XM-1, Finland) under the conditions of Table 1.

The fiber subsequently conditioned up to the equilibrium of 10% M.C in indoors. The arithmetic mean length and width of fibers were 4506 $\pm$769 ㎛ and 47.654$\pm$6.462 ㎛, respectively.

2.1.2 Resins

PMDI (Polymeric methylene diphenyl diisocyanate) resin was mainly used for manufacturing board, and was compared with urea formaldehyde resin in physical properties of board. The characteristics of resins used were presented in Table 2. The commercial resins were purchased at O. Company, Korea.

Table 2. Characteristics of adhesives.

Characteristics	UF	MDI
Specific gravity	1.203	1.23
Viscosity (cPs)	45~53	100
Solid content (%)	52	91
pH	7.2~7.4	-
-NCO (%)	-	30~32

2.1.3 Equipment for board manufacture

A fiber dispersion apparatus with the size of 340 × 380 × 300 mm was manufactured with acryl plate for defiberizing the agglomerated wood fibers in air-dried state and spraying evenly resin onto the fibers using compressed air of 7~8 atm. A drum blender was manufactured for mixing resins and wood fibers. The combination press equipped with hot platen plate and high frequent oscillator was used for board manufacture. The frequency and maximum output of high frequent oscillator were 13.56 MHz, and 5 kw, respectively. S²PM Series 2000 equipped with noise cleaning condenser was used for the measurement of board temperature.

2.2 Methods

2.2.1 Measurement of internal temperature of board

The temperature differences between core and surface layer of board were measured for controlling the diffusion time of high frequency heating using S²PM Series 2000 (Mescon Technology Inc.). The dimension of board used was 250 × 250 × 30 mm.

2.2.2 Manufacture of board

The board was manufactured with the combination of hot pressing and high frequency heating after forming fiber mat using evenly dispersed fibers mixed with resins. The manufacturing conditions of board were controlled as shown in Table 3.

Table 3. Manufacturing conditions of board.

Target density (g/cm³)	0.4, 0.6
Moisture content of forming mat (%)	10
Hot pressing temperature (℃)	165
Total hot pressing time (sec)	45
Pressing pressure (kgf/cm²)	40
Diffusion time of high frequency heating (min.)	0.5~2.0, 5
Dimensions (mm)	250 x 250 x 30

2.2.3 Physical properties of board

The manufactured board was conditioned in the conditioning room under the temperature of 20±2°C and relative humidity of 65±5% for 2 weeks. The physical properties such as density, moisture content, water absorption, thickness swelling and modules of rupture were measured by the methods described as KS F 3200. Test specimen for MOR was prepared under the dimension of 250 (L) x 50 (W) mm. Screw-withdrawal resistance was measured by Universal Testing Machine (Hounsfield S-Series, Model H50KS), using 3.5 (head width) x 40 (length) mm size of screw in 30 mm screwing depth of board.

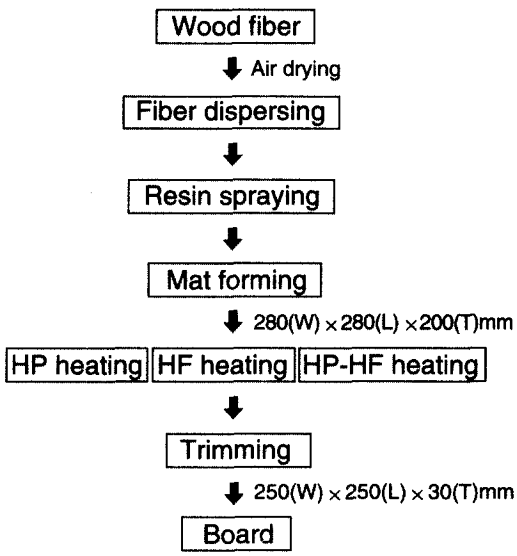

Fig. 1. Manufacturing procss of MDF by hot platen heating, high frequency heating and hot platen-high frequency heating.

3. RESULTS and DISCUSSION

3. 1 Temperature variations of core layer of board

During manufacturing board, one of the important factors in forming fiber mat is proper transfer of heat energy. It is also necessary to measure the temperature variations of core layer of MDF for evaluating the hardening behavior of resin. In the case of high frequency heating process, it is particularly important to know the temperature of core layer of board because heat transferring behaviors from surface to core layers of board are closely dependant on the diffusion time.

In this experimental, a sensor was set on the surface and in the core of board, and temperature variations according to the diffusion time and board density were measured. Results were shown in Figures 2~7.

In hot platen heating method, the temperature variations showed initial rapid increases. The rising time of temperature was faster as pressing pressure and moisture content of board were higher. According to board density, temperature transitions at below 100°C was faster in lower density of board, and at above 100°C in higher density of board. These may be explained as follows; the initial rapid increase of temperature in higher porous structure of board with lower density was due to the easy moisture transition, and the consequent increase of temperature was due to the capability of keeping temperature in higher density board.

When hot platen pressing was ended, the temperature in the core layer of board was between 117~140°C, and in the surface layer was 165°C. These temperature differences were decreased in higher density board.

In high frequency heating method, the rising time of temperature in the core layer up to 80°C was taken within 5 seconds, and up to 165 and

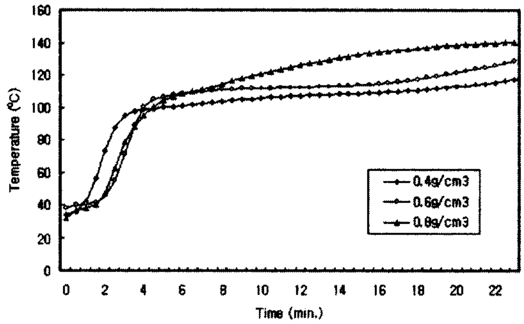

Fig. 2. Temperature variations of core layer of MDF by hot platen heating.

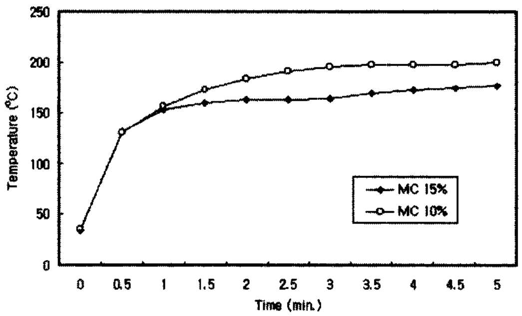

Fig. 3. Temperature variations of core layer of MDF according to moisture content of board.

200°C was taken 70 seconds and 5 minutes, respectively. The temperature transitions in high frequency heating were also much shorter and uniform in any conditions of board density, compared to hot platen heating, byt were slowed in the conditions of board with higher moisture content.

On the contrary of hot platen heating method, the temperature in the core layer of board in high frequency heating method was rapidly increased than that on the top and bottom surface layers contacting hot plate. These results show that the high frequency heating process causes temperature to increase from inner side layer of board and to transfer to outer side of board.

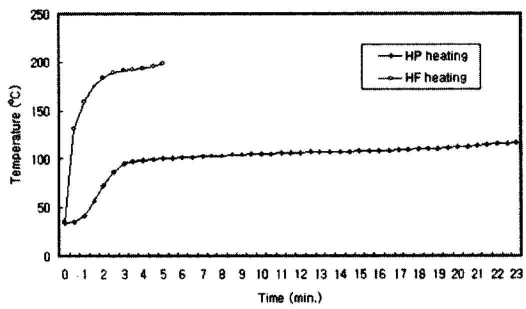

Fig. 4. Temperature variations of core layer of MDF by hot platen heating and high frequency heating (Density 0.4 g/cm³).

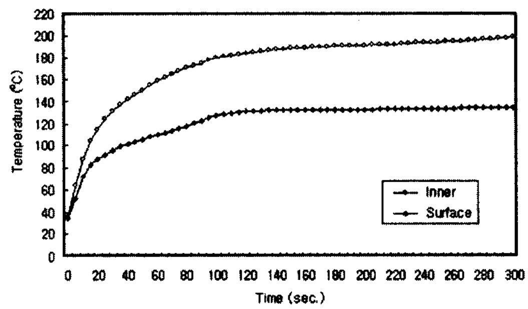

Fig. 6. Temperature differences between core and surface layer of MDF by high frequency heating (Density 0.4 g/cm³).

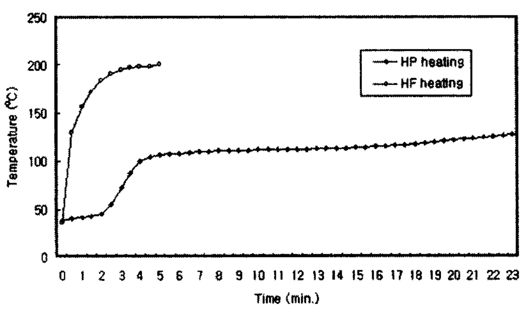

Fig. 5. Temperature variations of core layer of MDF by hot platen heating and high frequency heating (Density 0.6 g/cm³).

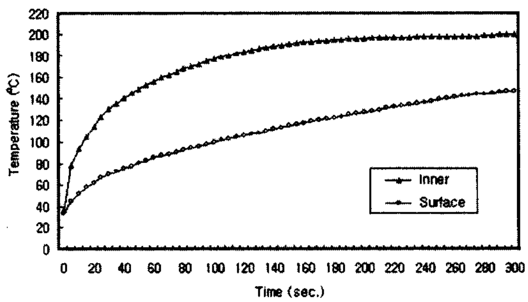

Fig. 7. Temperature differences between core and surface layer of MDF by high frequency heating (Density 0.6 g/cm³).

3.2 Physical and mechanical properties of board

The physical or mechanical properties of board produced by hot platen heating and high frequency heating method were investigated in bending strength, MOR, screw-withdrawal resistance and dimensional stability as described in Table 4.

3.2.1 Density

During diffusion of high frequency heating, lots of dewdrops were formed on the surface of board, due to the outflow of moisture from inside of board by rapid rise of temperature. These factors caused that fiber mat was hardened in the core side of the board, but not hardened on the surface side, due to the fluffy phenomena of wood fibers on the surface of board. Board density showed the similar tendency with hardening effects of board.

In hot platen heating method, density was high on the surface layer of board, and was low in the core layer of board, due to the longer transfer time of heat from surface to core layer by hot plate. In high frequency heating method, the distribution of internal density in the core layer was

Table 4. Physical properties of MDF according to heating types.

Heating type	Normal board specific gravity (g/cm^3)	Resin content (%)	HF irradiation time (min.)	Total heating time (min.)	Actual board specific gravity (g/cm^3)	Moisture content (%)	MOR (kgf/cm^2)	IB strength (kgf/cm^2)	Screw withdrawal resistance (kgf/cm^2)	Water absorption (%)	Thickness swelling (%)
Hot pressing	0.4	10	-	22.5	0.41	6.13	65.98	1.76	82.0	40.8	5.92
	0.6	10	-	22.5	0.62	6.44	146.19	3.08	185.2	18.9	6.08
HP-HF heating	0.4	10	0.5	4.0	0.47	7.76	89.83	1.46	109.0	83.7	12.69
	0.4	10	1.0	4.0	0.40	8.15	91.25	1.58	110.9	97.9	10.11
	0.4	10	2.0	4.0	0.45	7.90	91.80	1.69	125.7	124.8	12.68
	0.6	10	0.5	4.0	0.69	7.51	229.68	2.81	288.8	41.0	8.77
	0.6	10	1.0	4.0	0.70	7.66	241.30	3.06	293.4	54.3	10.75
	0.6	10	2.0	4.0	0.65	7.28	245.40	3.21	298.2	52.1	10.74

* Note; Resin: MDI, resin content: 10%, HP: Hot platen heating, HF: High frequency heating

uniform, but density on the surface layer was relatively low.

From these tendencies of board density, the combination method with hot platen and high frequency heating would improve the physical properties of board by the uniform heating of core and surface layers of board.

3.2.2 Modulus of rupture (MOR)

The MOR properties of board according to the heating types of heating were shown in Figures 8 and 9. The MOR of board produced by the combination method with hot platen-high frequency heating was increased by 36~39%, compared to board produced by hot platen heating, and was also increased by diffusion time of high frequency. In board density of 0.4 g/cm^3, the longer diffusion time of high frequency from 0.5 to 2 min was resulted in the improvement of MOR by 89.83, 91.25 and 91.80 kgf/cm^2. These tendencies were much high in board density of 0.6 g/cm^3, and were agreed with the results of report by Moslemi (Moslemi, 1974).

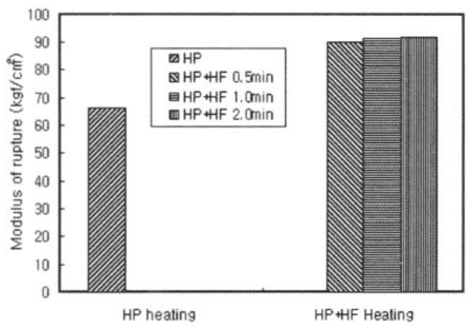

Fig. 8. Modulus of rupture of MDF according to high frequency heating (Density 0.4 g/cm^3).

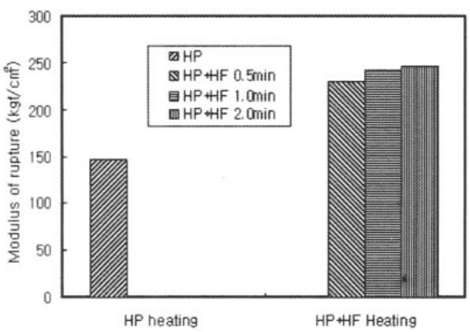

Fig. 9. Modulus of rupture of MDF according to high frequency heating (Density 0.6 g/cm^3).

3.2.3 Screwwithdrawal resistance

The results of screw withdrawal resistance were represented in Figures 10 and 11. The mechanical properties in screwwithdrawal resistance showed very similar tendency with those in bending strength. The application of combination method with hot platen-high frequency heating was resulted in higher screwwithdrawal resistance by 35~61%, compared to heating method with hot platen. In combination method, longer diffusion time of high frequency also directly affected in increase of screwwithdrawal resistance.

This may reflect that the strength improvements in bending and screwwithdrawal resistance were due to the surface hardening effects by high frequency heating (Maloney, 1977). In higher density of board, screwwithdrawal resistance was much increased with longer diffusion time by high frequency heating.

3.2.4 Internal bonding strength

Figures 12 and 13 show the results of internal bond strength of board. It is observed that internal

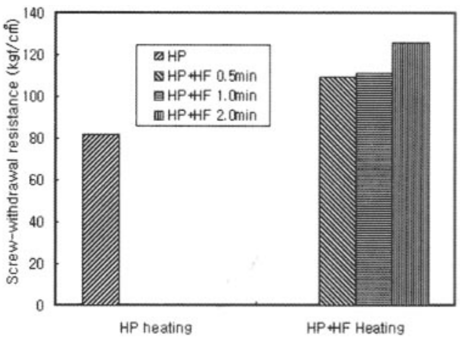

Fig. 10. Screwwithdrawal resistance of MDF according to heating types (Density 0.4 g/cm³).

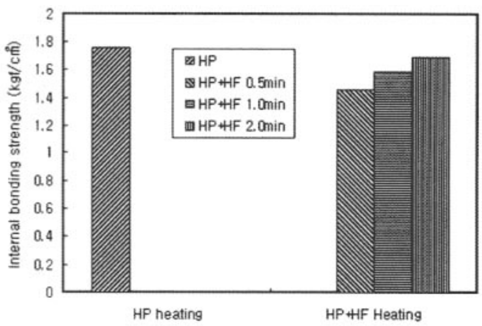

Fig. 12. Internal bonding stength of MDF according to heating types (Density 0.4 g/cm³).

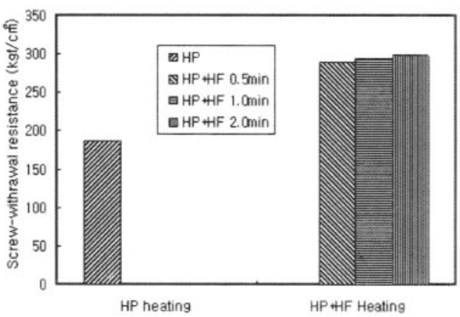

Fig. 11. Screwwithdrawal resistance of MDF according to heating types (Density 0.6 g/cm³).

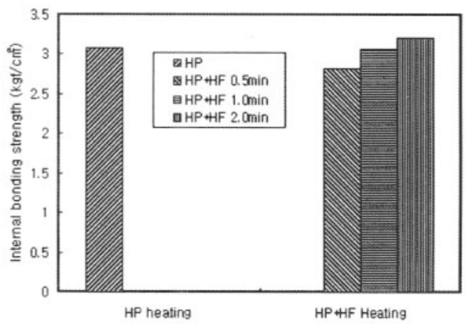

Fig. 13. Internal bonding stength of MDF according to heating types (Density 0.6 g/cm³).

bond strength increases as board density increases. As board density increases internal bond strength also increase more and more. In board density of 0.4 g/cm³, internal bond strength in the combination system of hot platen-high frequency heating was increased, according to longer diffusion time, but internal bond strength in the condition of 2 min diffusion time was decreased. These may be caused by interrupting interal bond of board with longer high frequent heating in lower density of board. In board density of 0.6 g/cm³, internal bond strength was increased by longer diffusion time of high frequent heating.

In board density of 0.4 g/cm³, internal bonding strength was 1.76 kgf by hot platen heating process, and 1.46~1.69 kgf by combination process with hot platen-high frequency heating. In board density of 0.6 g/cm³, internal bonding strength by hot platen heating process was also higher than that by combination process with hot platen-high frequency heating. These may caused by the deterioration of adhesive, due to the foaming resin by rapid increases of temperature in combination process with hot platen-high frequent heating.

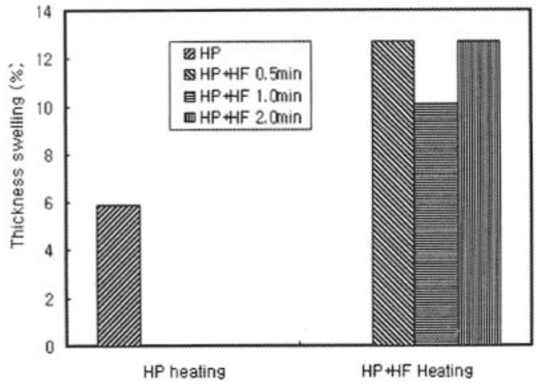

Fig. 14. Thickness swelling of MDF according to heating types (Density 0.4 g/cm³).

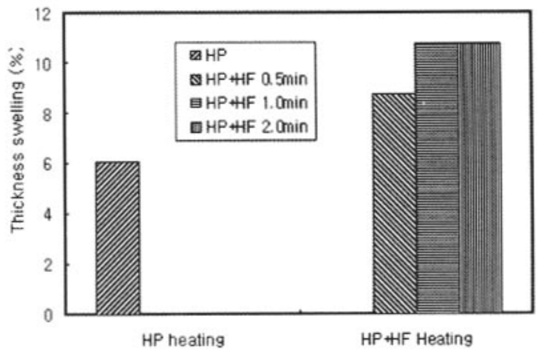

Fig. 15. Thickness swelling of MDF according to heating types (Density 0.6 g/cm³).

3.2.5 Dimensional stability

Figures 14 and 15 show the properties of dimensional stability of board. It is observed that the swelling thickness of board produced by combination method with hot platen-high frequency heating is greater than that of board produced by hot platen heating.

These were similar in the result of internal bonding strength. The results by high frequency heating process could be caused by the deterioration of hardening in the core layer of board, compared to board by hot platen heating process. During applying combination process with hot platen-high frequency heating, the applications of longer time by hot platen heating and of shorter time by high frequency heating caused the increase in bending strength, but the decrease in internal bonding strength. On the contrary, the applications of longer time by high frequency heating and of shorter time by hot platen heating caused the increase in internal bonding strength, but the decrease in bending strength. In this experimental, the increase of hot platen heating time to 6 min showed the improvement in the internal bonding strength and dimensional stability.

Table 5. Change of the amount of free formaldehyde emission according to resin type.

Resin	Density	Resin content (%)	Storage time (7 days)			
			1	2	3	4
Urea	0.6	5	3.53	0.69	0.54	0.31
	0.7	5	6.60	1.15	0.77	0.54
	0.8	5	7.21	1.61	0.85	0.69
	0.6	10	6.67	1.46	1.23	1.00
	0.7	10	13.04	1.53	1.30	1.07
	0.8	10	15.80	1.76	1.37	1.23
Melanin	0.6	5	2.84	0.54	0.38	0.31
	0.7	5	3.76	0.84	0.69	0.39
	0.8	5	5.60	1.23	0.84	0.69
	0.6	10	6.13	1.30	0.81	0.70
	0.7	10	9.89	1.49	0.92	0.61
	0.8	10	11.21	1.69	1.23	1.00

3.3 Formaldehyde emission of board

In wood processing industry, the resins from origin of formaldehyde are inexpensive and relatively good in adhesion performance, but free formaldehydes recently give attention to be harmful to human and natural environment. Therefore, the factors related to the formaldehyde emission are investigated and shown in Table 5.

The emission amounts of formaldehyde in both urea and melamin resin were high in the conditions of higher density of board, higher addition amount of resin and shorter storage time. After 4 weeks of storage time, it was still high in the emission amounts of formaldehyde in both urea and melamin resin, compared to limit amounts of formaldehyde emission described in Korea Industrial Standard.

4. CONCLUSION

In this study, the application of high frequent heating process to board manufacture was tried in order to improve the problems caused in hot platen heating process, and the optimum condition was investigated for the improvement of physical and mechanical properties of board. The possibility of isocyanates in board manufacture was also investigated for solving the problems of free formaldehyde emission.

For this study, 30 mm thick of MDF with isocynate resin and urea resin was produced by using hot platen, high frequent heating process and combination process of both heating methods, and compared in the physical and mechanical viewpoints of board.

The characteristic results obtained are summarized as follow:

1. High frequent heating process caused the temperature to transfer from core to surface layer of board without any profiles of density. The temperature transitions in high frequency heating were also much shorter and even, but were slowed in the conditions of board with higher moisture content.
2. In the application of hot platen heating process, the surface temperature of board was high, and core temperature of board was low. The density on the surface layer of board was higher than that in the core layer of board. The combination process between hot platen and high frequent method, therefore, were

considered to be effective.

3. The total hot pressing times in the combination process of hot platen-high frequent heating were reduced up to 25%, and the physical properties were increased to above 30%, compared to that in hot platen heating process only.

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