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The effects of pressure and pressing time on the mechanical and physical properties of oil palm empty fruit bunch medium density fibreboard

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Abstract
Processing and performance of medium density fibreboards (MDF) with 12 mm thickness and 700 kg/m^3 density made of oil palm empty fruit bunch fibres (OPEFB) were studied in this project. OPEFB MDFs were made and tested using 12% of urea formaldehyde resin as the binder, 3% ammonium chloride as the hardener and 1% of wax. The samples were produced by using a hot press machine with three levels of pressure (130, 110 and 90 bar) and total pressing time (7, 8 and 9 min). Nine samples of OPEFB MDF were made with two replicates for each different setting of pressure and pressing time. The OPEFB MDF properties evaluated were modulus of elasticity (MOE), modulus of rupture (MOR), internal bond (IB), thickness swell (TS), and water absorption (WA). A good result of MOR, IB and TS occurred at 90 bar of pressure and pressing time of 7 min. Pressure at 110 bar and pressing time of 7 min give the best result for MOE and good result for WA. The effects of changing pressure and pressing time on the press machine were significant in producing OPEFB MDF on the MOE, MOR, IB, TS, and WA.

Keywords: empty fruit bunch, medium density fibreboard, pressure, pressing time

Introduction

Agriculture is an important sector in Malaysian economy. Traditionally, agricultural materials were left useless and disposed of postharvest. Diversification of the agriculture industry is crucial in encouraging economic stability and growth. Value-added processing of agriculture waste would help in agricultural diversification. There are many types of agriculture waste such as pineapple leaves, rice husk, coconut coir, palm oil waste and others that have been studied for value added purpose. One of the huge availability of agriculture waste sector in Malaysia is oil palm empty fruit bunch (OPEFB) or called empty fruit bunch (EFB) that is derived from palm oil industry.

In 2012, plantation area of oil palm in Malaysia is 5.08 million ha, an increase from year 2001 which stood at 3.5 million ha as shown in *Table 1* (MPOB 2012). With the growth of palm oil production in Malaysia, the amount of residues generated also shows a corresponding increase. One hectare of oil palm plantation can produce about 50 – 70 tonnes of biomass residues (Salathong 2006). Therefore, oil palm industry is currently producing the largest

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Table 1. Plantation area of oil palm (ha) in Malaysia from 2001 – 2012

Year	Peninsular Malaysia	Sabah	Sarawak	Total
2001	2,096,856	1,027,328	374,828	3,499,012
2002	2,187,010	1,068,973	414,260	3,670,243
2003	2,202,166	1,135,100	464,774	3,802,040
2004	2,201,606	1,165,412	508,309	3,875,327
2005	2,298,608	1,209,368	543,398	4,051,374
2006	2,334,247	1,239,497	591,471	4,165,215
2007	2,362,057	1,278,244	664,612	4,304,913
2008	2,410,019	1,333,566	744,372	4,487,957
2011	2,546,760	1,431,762	1,021,587	5,000,109
2012	2,558,103	1,442,588	1,076,238	5,076,929

Source: MPOB (2012)

amount of biomass in Malaysia with 85.5% out of more than 70 million tonnes (Hassan and Shirai 2003).

The fresh oil palm fruit bunch contains about 21% palm oil, 6 – 7% palm kernel, 14 – 15% fibre, 6 – 7% shell and 23% empty fruit bunch (Umi Kalsom et al. 1997). At present, these products are not only underutilised but frequently the causes of pollution as well (Husin et al. 1985).

Most wood raw materials are primarily used for sawn lumber products. One of the by-products of palm oil milling process is the empty fruit bunches (EFB). On average, every one tonne of fresh fruit bunches (FFB) produces about 220 kg of EFB as a by-product (Singh et al. 1999). Considering that Malaysia produces 2.8 – 3.0 million tonnes of EFB annually (Kamaruddin et al. 1997), determining ways to reuse the EFB waste is therefore vital.

Using natural fibre to form a new class of materials seems to have a good potential in the future as a substitute for wood-based material. Commercial fibreboards in Malaysia are made from rubberwood. Projections show that in the near future the supply of rubber wood will not meet the demand for making medium density fibreboards (MDF) (Husin et al. 1985). One possible solution is to use the readily available OPEFB instead. However, lack of good knowledge and poor resistance to moisture absorption make the use of natural fibre less attractive. Some authors relate that the strength characteristics of the fibreboards made from various lignocellulosic materials improved with an increase in the levels of resins, forming pressure, curing temperature and duration of curing (Flaws and Palmer 1968; Pandey and Mehta 1980; Pandey and Gurjar 1985). Therefore, this study focused on the effects of processing parameters, which are pressure and pressing time on the physical and mechanical properties of the OPEFB MDF.

Materials and methods

OPEFB fibre was obtained from the Malaysian Palm Oil Board (MPOB), Bangi, Selangor, Malaysia. *Plate 1* shows the bundle of OPEFB fibres. In the manufacturing process of palm fibre, EFB are shredded, separated, refined and dried.

Plate 1. Fibres from empty fruit bunch

Commercially urea formaldehyde (UF) was used as a binder in this project and it was taken from Dynea Malaysia Sdn Bhd. UF resins are most widely used as adhesive for composite wood products especially in fibreboard, particleboard and plywood industries in Malaysia as well as abroad.

Pulps derived from EFB were used in the manufacture of MDF sample. UF, wax and ammonium chloride as a hardener were used in the process. The hardener was added into the glue to harden the UF glue during hot pressing activity. *Table 2* is the parameter of the OPEFB MDF that was used in this process.

The result of calculation of the materials use in manufacturing fibreboard with required condition as in *Table 2* is shown in *Table 3*. Composition fibre (EFB fibre, 12% UF, 1% wax and 3% hardener) was calculated and weighted as in the *Table 3* accordingly and mixed using MDF mixer to homogeneous mixture. The amounts of 1% wax, act to retard the rate of liquid water pick up. This is important when the composite is exposed to moist environment for short periods of time.

OPEFB was prepared to produce 18 panels of fibreboard with size of 340 mm × 340 mm, thickness of 12 mm and at a target density of 700 kg/m^3 as in *Table 2*. While being tumbled in the rotating drum blend (Jaica, Japan), the EFB fibre was sprayed with UF resin together with wax emulsion and hardener (EW 403H, Borden Chemical Inc., Columbus, Ohio) by using local manufactured pneumatic single spray gun applicator.

The homogenous mixture of fibres and resins was transferred manually and spread into the moulding box. The resinated fibres in the molding box were then were transferred and pressed in the cold pressing machine to remove air and stabilise the condition of the mixture before pressing using a hot press machine (Taihi, Japan).

The board pressing conditions were based on the standard to manufacture fibreboard from rubber wood. The sample manufactured can be categorised by three levels of pressure and pressing time as in *Table 4*. A total of 18 boards were made from the change of pressure and pressing time with two replications. At the end of the pressing cycle, manufactured boards were stacked and covered with teflon to hinder the glued fibre stacked on the metal plate. The latter action was to provide conditions for a more gradual cooling of the manufactured boards. The mould was taken out from a hot press machine and undergone the cooling process by exposing to the ambient temperature. After cooling process the product was removed from the mould.

Table 2. Board pressing condition

Board parameter	MDF (UF as binder)
Board length and width (mm)	340 length × 340 width
Board thickness (mm)	12
Target density	700 kg/m^3

Table 3. The weight of material used in fibreboard making

Material	Weight (g)
EFB fibre	971.0
Urea formaldehyde (UF) – binder (12% based on the fibre weight)	182.0
Ammonium chloride (NH_4Cl) – hardener (3% based on UF)	27.3
Paraffin wax emulsion – wax (1% based on oven dried weight fibre)	16.2

Mechanical properties of OPEFB MDF

The Internal bond (IB), modulus of rupture (MOR) and modulus of elasticity (MOE) were the mechanical properties that need to be evaluated on the fibreboard. OPEFB MDF panels were cut into 50 mm × 50 mm pieces for determining of internal bond (IB). MOR and MOE were measured on 340 mm × 50 mm. The mechanical properties which are MOR, MOE and IB were determined according to the EN standard methods (Anon. 1993a; Anon. 1993c) in a Universal Testing Machine model 4204. Prior to mechanical and physical properties testing, the test pieces were conditioned at 65% relative humidity and 20 °C in the conditioning room for 3 days to stabilise the temperature and relative humidity of fibreboard.

Table 4. Parameter for three levels of pressure and pressing time of OPEFB MDF production

Sample	Pressure (bar)	Press time (min)
1	90	7
2	90	8
3	90	9
4	110	7
5	110	8
6	110	9
7	130	7
8	130	8
9	130	9

Physical properties of OPEFB MDF

Thickness swelling (TS) was determined according to the EN standard (Anon. 1993b) from 50 mm × 50 mm pieces of OPEFB MDF and water absorption (WA) properties was determined from the same sample. The OPEFB MDF specimens were immersed in water for 24 h to determine the changes of thickness and weight.

Results and discussion

Properties of OPEFB MDF

All the mechanical and physical properties of the OPEFB MDF were obtained and presented in the *Table 5* with the standard of MDF for thickness of 12 mm according to EN 622-5:1997 (Anon. 1997). These results were based on the MOR, MOE and IB of the sample. The test was conducted with two replications. Statistical software Minitab Version 16 was used to analyse the data.

Mechanical properties

Modulus of rupture (MOR) From the graph of MOR with each of the OPEFB MDF (*Figure 1*) indicated that the combination of pressure of 90 bar and 7 min of press time was to be the highest MOR which is 19.50 MPa. The lowest MOR was obtained by manufacturing with the pressure of 130 bar at 9 min of press time which is 6.03 MPa. The MOR is in low value when processing with the high

Table 5. Mechanical and physical properties of OPEFB MDF

Sample	Pressure (bar)	Time (min)	Mechanical properties			Physical properties	
			MOR(MPa) t1, t2	MOE (MPa) t1, t2	IB (MPa) t1, t2	TS (%) t1, t2	WA (%) t1, t2
1	90	7	19.50,23.00	1887.86,1765.42	0.19,0.17	24.40,23.5	73.39,84.65
2	90	8	9.00,10.12	1487.80,1385.38	0.10,0.11	73.00,75.6	145.60,165.32
3	90	9	6.03,7.15	1118.56,1135.00	0.07,0.06	77.1,8.4	154.10,177.58
4	110	7	1.49,12.00	1821.32,1721.27	0.12,0.13	85.8,75.2	135.30,140.41
5	110	8	14.59,13.45	2045.90,1887.07	0.20,0.21	85.80,84.6	140.9,145.67
6	110	9	12.06,11.16	1741.32,1645.54	0.06,0.05	101.90,105.8	177.1,167.23
7	130	7	8.23,8.21	1510.39,1459.56	0.07,0.06	41.00,51.3	99.20,85.47
8	130	8	13.60,12.65	1657.52,1690.07	0.12,0.15	46.30,58.2	108.50,98.95
9	130	9	7.73,6.69	1427.07,1521.12	0.06,0.05	66.90,70.7	139.69,142.63

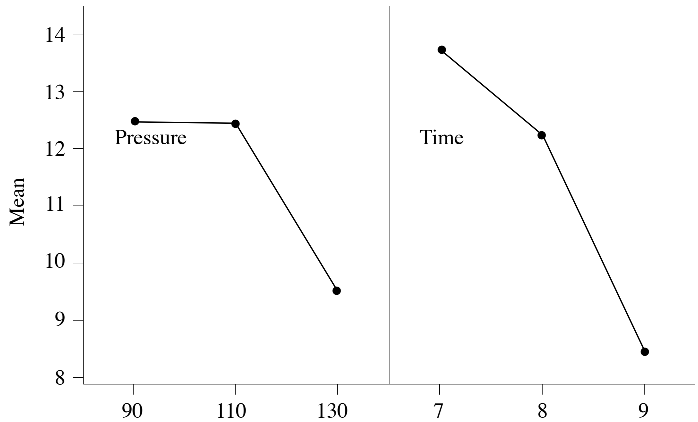

Figure 1. Modulus of rupture (MPa) of OPEFB MDF

Table 6. Result of analysis of variance for MOR, using adjusted SS for tests using Minitab

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Pressure	2	34.673	34.673	17.336	16.33	0.001
Time	2	88.381	88.381	44.191	41.62	0.000
Pressure*Time	4	199.259	199.259	49.815	46.91	0.000
Error	9	9.556	9.556	1.062		
Total	17	331.870				

S = 1.03045; R-Sq = 97.12%; R-Sq(adj) = 94.56%

pressure and longer press time. It was found that the pressure and press time showed significant differences on the result of MOR value. Poor MOR properties shown by the OPEFB MDF were attributed to the weak fibre/matrix bonding. All the trial of OPEFB MDF data on MOR for 12 mm thickness did not meet the requirement of the MDF standard EN 622-5, 1997 (Anon. 1997). In the production of fibreboards, poor MOR is probably due to inadequate compatibility between polar MDF fibres and non-polar PF resins that lead to the weak interfacial regions which might be the Van der Waal interaction. These weak interfacial regions would reduce the efficiency of stress transferred between resin and fibre, thus poor strength properties can be anticipated. The pressure and time are significant to the MOR as the *p*-value is less than 0.05 (*Table 6*).

Modulus of elasticity (MOE) The combination of pressure of 110 bar and 7 min of press time was to be the highest MOE which is 19.50 MPa (*Figure 2*). The lowest MOE was obtained by manufacturing with the pressure of 90 bar at 9 min of press time which is 6.03 MPa similar to MOR result. There is significant effect on MOE at different pressure and press time. It was observed that pressure has to be associated with appropriate press time to produce good performance in MOE because of different pressure to get highest MOE value compared to MOR value which is the highest at pressure 90 bar. In general, there is no pattern of pressure can be seen for highest MOE value but longer press time contribute to low value of MOE. All the trial of OPEFB MDF data on MOE for 12 mm thickness did not meet the requirement of the MDF standard EN 622-5, 1997 (Anon. 1997). The pressure and time are significant to the MOE as the *p*-value is less than 0.05 (*Table 7*).

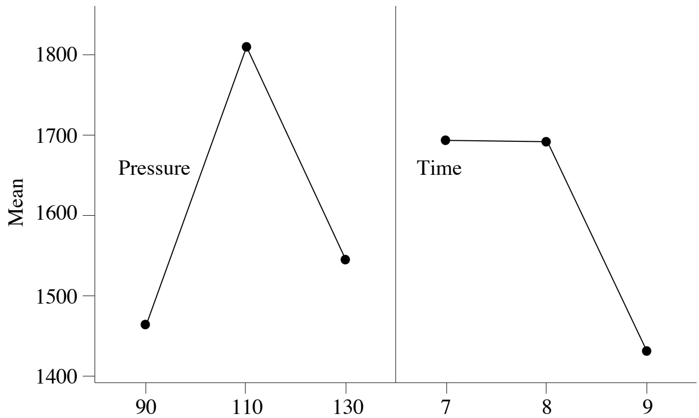

Figure 2. Modulus of elasticity (MPa) of OPEFB MDF

Table 7. Result of analysis of variance for MOE, using adjusted SS for tests using Minitab

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Pressure	2	395612	395612	197806	42.88	0.000
Time	2	274218	274218	137109	29.72	0.000
Pressure*Time	4	347220	347220	86805	18.82	0.000
Error	9	41521	41521	4613		
Total	17	1058572				

S = 67.9225; R-Sq = 96.08%; R-Sq(adj) = 92.59%

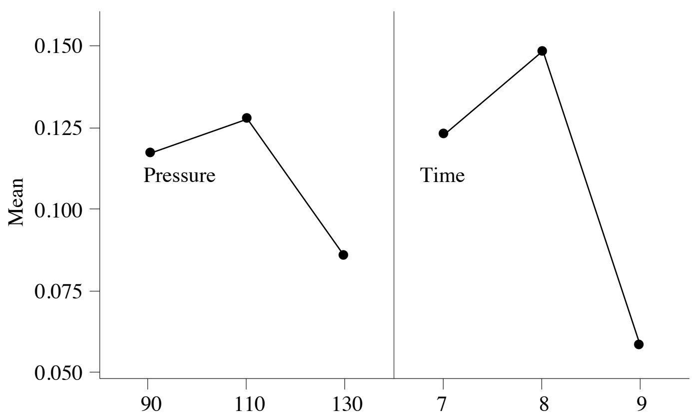

Figure 3. Internal bonding (MPa) of OPEFB MDF

Internal bond (IB) Similar result of IB with MOE was obtained as the highest value of IB (0.19 MPa) was achieved by pressure of 110 bar but at different press time compared to MOR and MOE which is at 8 min (*Figure 3*). The lowest value of IB (0.059 MPa) obtained was similar with MOR value trend which is at combination of 130 bar pressure and 9 min of press time. All the trial of OPEFB MDF data on IB for 12 mm thickness did not meet the requirement of the MDF standard EN 622-5, 1997 (Anon. 1997). The phenomena were caused by better compatibility between fibre and matrix resin surface. Previous study also stated that the internal bond strength depends on the duration of the modification and the size of the fibre used (Wong et al.

Table 8. Result of analysis of variance for IB, using adjusted SS for tests using Minitab

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Pressure	2	0.0056703	0.0056703	0.0028352	23.67	0.000
Time	2	0.0258210	0.0258210	0.0129105	107.79	0.000
Pressure*Time	4	0.0172267	0.0172267	0.0043067	35.96	0.000
Error	9	0.0010780	0.0010780	0.0001198		
Total	17	0.0497960				

S = 0.0109443; R-Sq = 97.84%; R-Sq(adj) = 95.91%

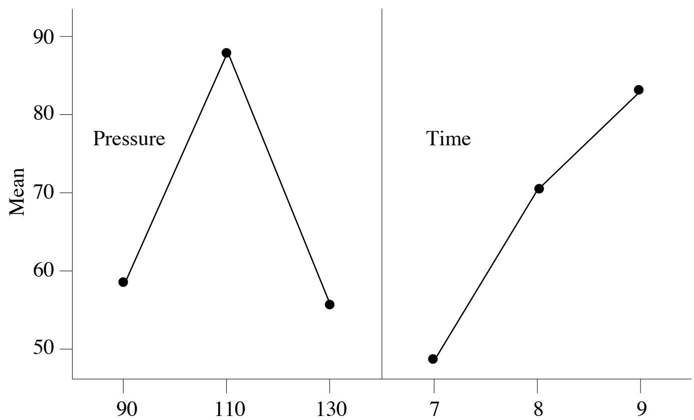

Figure 4. Thickness swelling (%) of OPEFB MDF

2000). When it comes to internal bonding, slightly finer fibres were more favourable. The pressure and time are significant to the IB as the *p*-value is less than 0.05 (*Table 8)*.

Physical properties

Thickness swelling (TS) This test purposely measured the effects of the absorbed water on particle board dimensions after 24 h immersed in water. From the *Figure 4* of the thickness swelling (%) of OPEFB MDF indicated that pressure 130 bar with 7 min of press time resulted in best reduction of TS (24.42%). The highest increase of TS (101.9%) was obtained at pressure of 110 bar and 9 min of press time. There is a significant effect on the pressure and press time on the TS value. All the OPEFB MDF data on TS for 12 mm thickness did not meet the requirement of the MDF standard EN 622-5, 1997 (Anon. 1997). Processing of fibre that improved properties of strength has been proven by Ridzuan et al. (2002) which evaluated the OPEFB MDF with 881 kg/m^3 and achieves the EN 622-5, 1997 standard by the treatment of OPEFB fibre using sodium hydroxide (NaOH). Pre-treatment of the fibre to remove its residual oil significantly improved the MDF performance and eliminated delamination during consolidation of the panels. As expected, using more resin improved the physical and mechanical properties. The pressure and time are significant to the TS as the *p*-value is less than 0.05 (*Table 9)*.

Water absorption (WA)

Water absorption (WA) is defined as the per cent increase in weight of a sample immersed in water for 24 h. Percentages of absorption of water were calculated after 24 h specimen immersed in water by measuring the weight of the specimen. The lowest reduction in WA was found to be at 130 bar with 7 min press (*Figure 5)*. The highest increase of WA was obtained at pressure of 110 bar and 9 min of press

Table 9. Result of analysis of variance for TS, using adjusted SS for tests using Minitab

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Pressure	2	3911.9	3911.9	1955.9	129.95	0.000
Time	2	3658.7	3658.7	1829.3	121.54	0.000
Pressure*Time	4	1282.5	1282.5	320.6	21.30	0.000
Error	9	135.5	135.5	15.1		
Total	17	8988.5				

S = 3.87965; R-Sq = 98.49%; R-Sq(adj) = 97.15

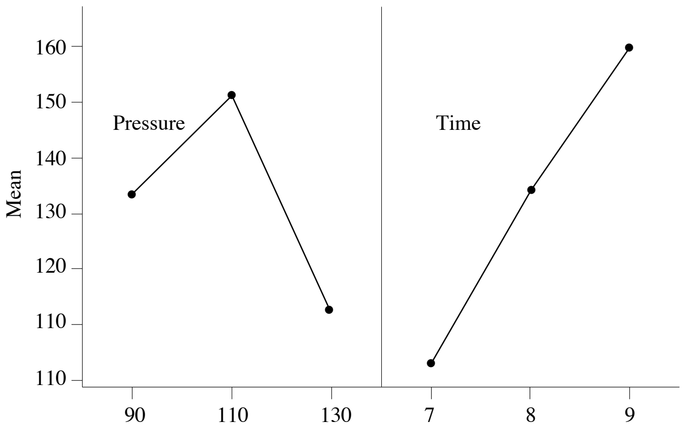

Figure 5. Water absorption (%) of OPEFB MDF

Table 10. Result of analysis of variance for WA, using adjusted SS for tests using Minitab

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Pressure	2	4503.3	4503.3	2251.6	26.99	0.000
Time	2	9658.7	9658.7	4829.4	57.89	0.000
Pressure*Time	4	3304.1	3304.1	826.0	9.90	0.002
Error	9	750.8	750.8	83.4		
Total	17	18216.9				

S = 9.13363; R-Sq = 95.88%; R-Sq(adj) = 92.21%

time. The highest and lowest value of WA pattern is found to be similar with thickness swelling. The pressure and time are significant to the WA as the *p*-value is less than 0.05 (*Table 10)*.

There are many reasons for not achieving the requirement of the MDF standard EN 622-5, 1997 (Anon. 1997) such as nature of the fibre and binder as well as their compositions, the fibre aspect ratio, the types of mixing procedures, processing conditions employed and on the treatment of the fibre with various chemicals, hardener and others.

When OPEFB was bonded with the commercially available UF resin, which is suitable for MDF produced from rubberwood, the boards produced were of poor quality. Moreover, this might be due to certain factor such as the inconsistency in resin distribution in the panel, pre-cure of resin, resin loss and resin penetration into fibres during manufacturing. Hence, both the degree of pre-cure and carbonisation of UF resin during fibre drying contribute to the loss of resin efficiency (Gillah et al. 2000; Xing et al. 2004).

Overall TS and WA showed an increase in water absorption as expected because agricultural fibres are hydrophilic and readily absorb water, which leads to swelling of the fibres. This affected dimensional stability of composites when continuously exposed to high humidity environment. Thus, composites suffered loss of mechanical properties due to deficient wettability fibres and degradation of fibre/matrix resin interaction (Abdul Khalil et al. 2007). The water absorption behaviour of the fibreboards depends on the ability of the fibre to absorb water due to the presence of hydroxyl groups. The hydroxyl groups absorbed moisture or water through the formation of hydrogen bonding.

Conclusion

Pressure and pressing time show relationship as it plays an important parameter in fabricating fibreboard. The study has revealed that from the differences in setting of selected pressure and pressing time, the properties of the OPEFB MDF had changed significantly. Different combinations of pressure and pressing time were resulted in different best parameter for achieving good in MOR, MOE, IB, TS and WA of OPEFB MDF.

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Abstrak

Pemprosesan dan prestasi papan gentian ketumpatan sederhana (MDF) setebal 12 mm dengan 700 kg/m^3 ketumpatan yang dibuat daripada tandan kosong kelapa sawit (OPEFB) telah dikaji dalam projek ini. Papan gentian ketumpatan sederhana tandan kosong kelapa sawit (MDF OPEFB) telah dibuat dan diuji dengan menggunakan 12% urea formaldehid (UF) sebagai pengikat, 3% ammonium klorida sebagai pengeras dan 1% wax. Sampel telah dihasilkan dengan menggunakan mesin tekanan panas dengan tiga tahap pelarasan tekanan yang berbeza (130, 110 dan 90 bar) dan tiga tahap jumlah masa tekanan yang berbeza (7, 8 dan 9 minit). Sembilan sampel OPEFB MDF telah dibuat dengan dua replikasi untuk setiap pelarasan yang berbeza tekanan dan masa tekanan. Sifat OPEFB MDF yang dinilai adalah modulus keelastikan (MOE), modulus kepecahan (MOR), kekuatan ikatan dalaman (IB), ketebalan pembengkakan (TS), dan penyerapan air (WA). Keputusan MOR, IB dan TS yang baik berlaku pada 90 bar tekanan dan pada masa tekanan 7 minit. Pada tahap pelarasan tekanan 110 bar dan masa tekanan 7 minit mencapai keputusan terbaik untuk MOE dan juga untuk WA. Kesan perubahan pelarasan tekanan dan masa tekanan pada mesin tekanan panas adalah signifikan dalam menghasilkan MDF OPEFB terhadap MOE, MOR, IB, TS, dan WA.