MEDIUM DENSITY FIBERBOARD FROM BIOLOGICALLY PRETREATED ACACIA AND GMELINA[⊗]

(MDF dari Kayu Acacia dan Gmelina dengan Praperlakuan Biologis)

Bedyaman Tambunan[1)]

ABSTRACT

Dalam penelitian ini, chips kayu *Acacia mangium* (Acacia) dan *Gmelina arborea* (Gmelina) diberi perlakuan dengan jamur pelapuk *Pleurocybella sp.* sebelum dimasak dengan proses soda. Lama perlakuan bervariasi dari 0 hari sampai dengan 28 hari. Konsentrasi NaOH dalam larutan pemasak adalah 35 g/l dengan nisbah antara chips dan larutan pemasak sebesar 1 : 8. Pemasakan dilakukan selama 2 jam pada suhu 100 °C. Rendemen pemasakan dan energi penggilingan pulp kemudian ditentukan. Pulp yang telah digiling dibuat menjadi *Medium Density Fiberboard* (MDF) dengan kadar perekat 2% dan 250 ml alum 10% untuk membuat adonan ber-pH 5. Tekanan yang diberikan untuk membuat lembaran MDF berturut-turut 25 kg/cm^2 selama 5 menit dan 10 kg/cm^2 selama 10 menit pada suhu 180 °C. MDF yang dihasilkan memiliki ketebalan 10 mm, dan kemudian dikondisikan untuk diuji sifat-sifatnya.

Hasil penelitian ini menunjukkan bahwa rendemen pemasakan dan energi penggilingan pulp menurun menurut lama perlakuan dengan jamur pelapuk. Demikian pula halnya dengan kadar air, *water absorption value*, pengembangan tebal, *internal bond*, dan daya pegang sekrup. Tetapi kerapatan, kekuatan tarik sejajar permukaan, MOR dan MOE dari MDF yang dihasilkan meningkat dengan meningkatnya waktu perlakuan. Sifat fisis dan mekanis MDF dari kayu acacia lebih baik dari sifat fisik dan mekanis MDF dari kayu gmelina.

Kata kunci : MDF, waktu inkubasi, *Acacia mangium*, *Gmelina arborea*, sifat fisis dan mekanis, dan *Pleurocybella sp.*

INTRODUCTION

Medium density fiberboard (MDF) belongs to the group of fiberboard, which is widely used as wall separator, doors and windows, household utensils, and so on. It was developed in the 1960's with density between 0.5 and 0.8 g/cm^3 (Haygreen and Bowyer 1989). These authors were also assumed that adhesives and other additives could be used to improve its properties.

It is considered that MDF has a promising future to be developed based on its increasing demand. In the year of 1985 and 1992, 3.5 and 8.0 million cubic meter MDF was consumed, respectively. It was predicted that 20 million cubic meter will be consumed in the year of 2000 (Anonymous 1994). The low raw material requirement will further promote its development.

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Production of MDF requires large amount of energy, mainly in the fiber preparation process, which depends on wood species. It was found that energy requirement for softwood pulp preparation is higher than that of hardwood (Koch 1985). Regardless of wood species, beating energy is an important factor to be addressed in order to produce an economically competitive MDF. Reduction of beating energy can be approached biologically, in which part of delignification process is carried out through the use of white-rot treatment of wood chips. Even though white-rot attacks both lignin and cellulose (Haygreen and Bowyer 1989), it has long been understood that white-rot mainly prefers to attack lignin more than cellulose (Schmid and Liese 1964, von Aufses 1974, Radtke *et al.* 1981 *in* Fengel and Wegener 1995).

The objective of the present experiments is to examine the influence of the pretreatment of wood chips from *Acacia mangium* and *Gmelina arborea* with *Pleurocybella sp.* on the pulping energy requirement and the strength properties of the resulted MDF.

METHODS

In the present experiments, wood chips were pretreated with 10% (v/w) of fungal inoculum of *Pleurocybella* sp. based on oven dry weight of chips. The pretreatment were carried out for 0, 7, 14, 21, and 28 days. Following fungal treatments, wood chips were pulped with a soda pulping process. The concentration of NaOH in cooking liquor was 35 g/l with wood to liquor ratio of 1 to 8 and cooking time of 2 hours at 100 °C. Cooked chips were then beaten in a Hollander beater to the freeness of about 15 °SR and disintegrated in a stone refiner.

Beaten pulp were made into suspension and then mixed with 2% (based on oven dry pulp) liquid urea formaldehyde adhesive. A 250-ml of alum of 10% concentration was also added into the suspension, and brought about the furnish final pH of 5. It was then put into a deckle box. Sheets formation were carried out by spreading the furnish over a wire. The sheets were subjected to a sequential pressure with an initial pressure of 25 kg/cm^2 for 5 minutes and then of a hot pressure of 10 kg/cm^2 at 180 °C for 10 minutes. MDF sheets with thickness of 10 mm formed were then conditioned for 14 days to eliminate its residual strain.

The mechanical and physical properties of the MDF were determined in accordance with ASTM D 1037 56T and their values were compared with those of FAO standard (1978). Beating energy of pulp beating was calculated following methods developed by Kamajaya (1987). The data were analyzed statistically following nested completely randomized design, in which the incubation time (0, 7, 14, 21, and 28 days) were nested within 2 wood species (*Acacia mangium* and *Gmelina arborea*). Each treatment was carried out in 2 replications. An orthogonal polynomial regression was also performed for the resulted data.

RESULTS AND DISCUSSION

Beating Energy

It is expected that biologically pretreated wood chips of *Acacia mangium* (acacia) and *Gmelina arborea* (gmelina) would require less energy than that of untreated wood chips. In the present experiment energy requirement were based on energy required to beat pulp up to 15 – 16 °SR freeness. The measured beating energy is listed in Table 1.

It can be seen from Table 1 that beating energy of acacia is lower than that of gmelina, in which longer incubation time tends to decrease beating energy. Analysis of variance at 95% confidence level indicated that wood species and incubation time significantly influence the beating energy. A quadratic relationship of $Y = 1535.54 - 38.44X + 0.80X^2$ with coefficient correlation of 0.94 exists between the duration of incubation (X) and beating energy (Y) for acacia. The relationship indicates that the lowest beating energy (1131.04 kcal) is achieved at the 22 days incubation. On the other hand, a linear relationship of $Y = 1465.76 - 6.97X$ with correlation coefficient of –0.72 exists between the incubation time and beating energy of gmelina. The lowest beating energy (1246.20 kcal) is achieved at the 28 days incubation. Figure 1 indicates the curve of the relationship of beating energy and incubation time of acacia and gmelina woods.

It can be seen from Figure 1 that longer biological pretreatment of wood chips with *Pleurocybella sp.* tend to decrease its beating energy. This was probably due to the increasing degradation of lignin along with increasing duration of pretreatment. It has long been realized that lignin is an encrusting substance that bind together cellulose and hemicellulose to form the structural feature of cell wall. Therefore, delignification of wood chips by white-rot fungi (*Pleurocybella sp.*) simultaneously with decaying process (Wilcox, 1968 in Nicholas, 1987) brought about less energy required to homogenize pulp fiber in beating process. The specific gravity of wood may influence the energy required to beat pulp to a certain level of freeness. Thus, higher specific gravity of acacia compared to that of gmelina might be the fact behind its higher beating energy found in the present investigation.

Pulping Yield

Pulping yield was calculated as a percentage of pulp produced from certain oven dry weight of wood chips cooked. Table 2 shows the pulping yield of acacia and gmelina wood chips under investigation.

Table 2 shows that the pulping yield of acacia and gmelina woods are similar. This is assured by statistical analysis, which indicates that wood species did not significantly influence pulping yield. However, it is significantly influenced by the duration of incubation treatment. Longer pretreatment tends to decrease pulping yield.

Table 1. The average beating energy of the pulp of acacia and gmelina.

No.	Wood Species	Duration of Incubation (days)	Beating energy (kcal)
1.	*Acacia mangium*	0 (A0)	1546.20
		7 (A1)	1353.60
		14 (A2)	1152.00
		21 (A3)	1152.00
		28 (A4)	1158.40
2.	*Gmelina arborea*	0 (G0)	1497.60
		7 (G1)	1411.20
		14 (G2)	1353.60
		21 (G3)	1238.40
		28 (G4)	1290.00

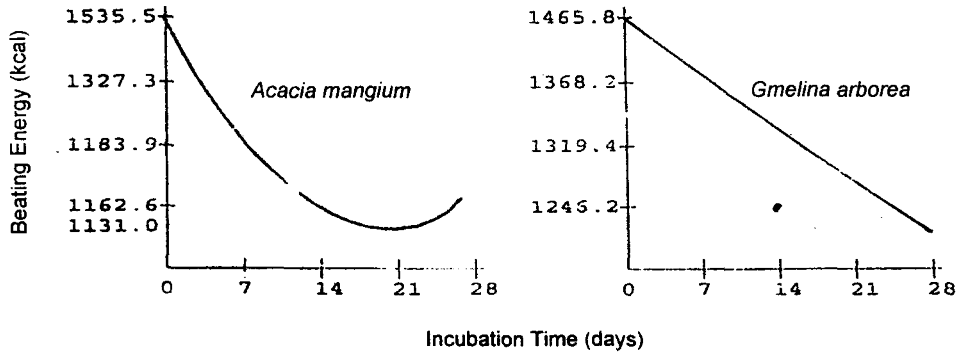

Figure 1. Relationship between beating energy of pulp and incubation time of biologically pretreated acacia and gmelina wood chips.

A linear relationship of $Y = 84.66 - 0.18X$ with a correlation coefficient of -0.67 between yield (Y) and incubation time (X) was found for acacia. Lowest yield (79.53%) occurred at the 28 days incubation. The relationship between yield and incubation time in gmelina is following the linear model of $Y = 88.82 - 0.41X$ with a correlation coefficient of -0.80. The lowest yield also occurred at the 28 days incubation. Figure 2 indicates the curve of pulping yield of acacia and gmelina.

Figure 2 distinctly indicates that pulping yield is decreasing in accordance with longer incubation time. Yield is mainly composed of lignocellulosic wood components. Therefore, degradation of these components will decrease pulping yield. It has been proven that white-rot degrades lignin and to a certain level, cellulose, as well (Schmidt and Leise 1964; Von Aufses 1974; Radthe 1981 in Fengel and Wegener 1995).

Table 2. The average pulp yield of acacia and gmelina wood chips pulping.

No.	Wood Species	Duration of Incubation (days)	Pulping Yield (%)
1.	*Acacia mangium*	0 (A0)	85.79
		7 (A1)	84.30
		14 (A2)	78.40
		21 (A3)	80.92
		28 (A4)	81.07
2.	*Gmelina arborea*	0 (G0)	90.48
		7 (G1)	85.30
		14 (G2)	82.24
		21 (G3)	77.01
		28 (G4)	80.17

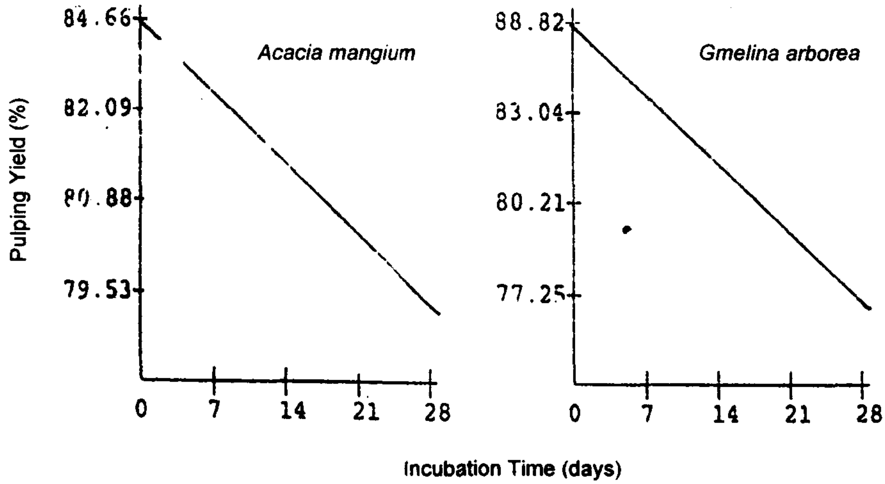

Figure 2. Relationship between pulping yield and incubation time of acacia and gmelina wood chips.

Chemical components of wood, mainly that of cellulose is one of the yield determining factor. Therefore, the similar content of cellulose between acacia (62.72%) and gmelina (64.32%) might be the reason of their yield similarity. Both yield produced in the present investigation are in accordance with that of FAO (1978) requirement, which is between 75% and 90%.

MDF Properties

Series of MDF properties resulted from biologically treated wood chips of acacia and gmelina were examined in accordance with applicable ASTM standards. The properties of MDF in the present investigations are presented in Table 3.

Density. Table 3 shows that the MDF density from acacia decreased from 0 days to 7 days incubation and then increasing up to the 28 days incubation. On the other hand, the density of MDF from gmelina tends to increase with the increasing of incubation time.

Analysis of variance indicated that wood species and incubation time both significantly influencing MDF density at confidence level of 95%. A quadratic relationship of $Y = 0.7480 - 0.0110X + 0.0004X^2$ with correlation coefficient of –0.47 exist between MDF density (Y) and incubation time (X) for acacia. Lowest density (0.68 g/cm^3) was achieved at the 13 days incubation and the highest (0.77 g/cm^3) was occurred at the 28 days incubation. In the case of gmelina, relationship between MDF density and incubation time is linear with $Y = 0.650 + 0.001X$ and correlation coefficient of 0.56. Lowest density (0.65 g/cm^3) occurred at the 0 days incubation and the highest (0.68 g/cm^3) was at the 28 days incubation.

Relationship between MDF density and incubation time for acacia and gmelina is depicted in Figure 3. It can be seen that the density of MDF from acacia decreasing up to the 13 days incubation and then increasing afterward. Meanwhile, the MDF density of gmelina is increasing

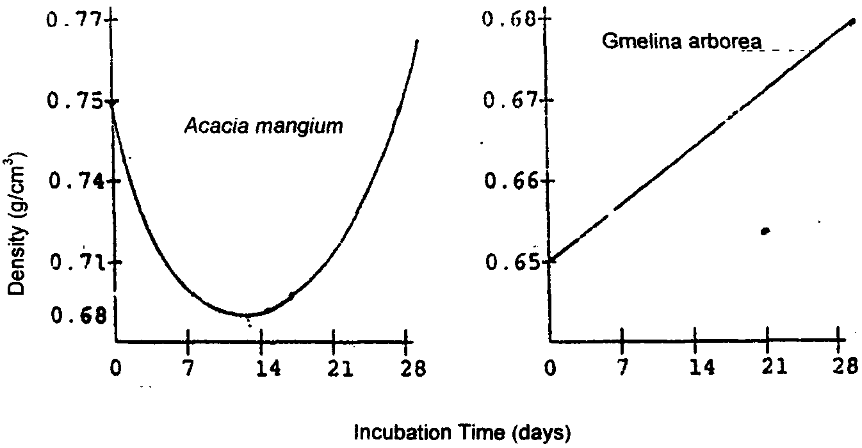

Figure 3. Relationship between incubation time and the density of acacia MDF and gmelina MDF.

with the increase of incubation time. Higher delignification level of biologically delignified wood chips is assumed to produce softer and thinner fiber cell wall (Wilcot 1968 in Nicholas 1987), hence the fiber is more elastic and easily to be flatten during pressing (Haygreen and Bowyer 1982) to produce higher density MDF. Thinner cell wall of acacia may bring about higher density of its MDF as compared to that of gmelina. The cell wall thickness of acacia is 2.24 μ and that of gmelina is 2.55 μ. The density values of both MDF from acacia and gmelina are in accordance with that of FAO requirement, which is in the range of 0.4 – 0.8 g/cm^3.

Moisture Content. It can be seen from Table 3 that the moisture content of MDF from acacia tends to significantly lower than that of MDF from gmelina. However, incubation time did not significantly influence the MDF density.

Thinner cell wall of acacia as compared to that of gmelina may bring about smaller amount of bound water presence in it, as Haygreen and Bowyer (1989) have explained it. Furthermore, the relatively unchanged cellulose crystallinity of biologically treated wood as compared to that of untreated may be the cause of their moisture content homogeneity. Kirk (1970) in Nicholas (1987) has explained this.

Water Absorption Value. Table 3 indicates that water absorption values of MDF from acacia tend to increase up to the 7 days incubation and then was decreasing afterward. Water absorption values of MDF from acacia are significantly different to those of MDF from gmelina. However, incubation time did not significantly influence water absorption values of MDF from both of the wood species.

Water absorption value is influenced by the presence of additives (adhesive and wax), pressing temperature and pressure level (Kollman 1975). These were given the same during the formation of MDF sheets both from acacia and gmelina. Therefore, it is not astonishing that the

Table 3. The properties of MDF from biologically pretreated acacia and gmelina wood chips.

No.	Wood Species	Incubation Time (days)	Density (g/cm^3)	Moisture Content (%)	Water Absorption Value (%)	Thickness Swelling (%)	Tensile Strength Parallel to Surface (kg/cm^2)	Modulus of Rupture (kg/cm^2)	Modulus of Elasticity (kg/cm^2)	Internal Bond (kg/cm^2)	Screw Holding Power (kg)
1.	*Acacia mangium*	0 (A0)	0.75	12.33	61.95	28.40	78.25	141.02	8992	4.75	111.90
		7 (A1)	0.64	13.07	73.24	29.34	54.36	77.85	4819	4.94	112.80
		14 (A2)	0.69	14.48	68.06	31.96	60.72	123.65	9096	5.49	116.40
		21 (A3)	0.76	11.88	64.76	27.50	80.46	185.11	14559	6.04	118.20
		28 (A4)	0.76	12.48	58.09	28.67	81.89	181.67	14086	5.01	112.20
2.	*Gmelina arborea*	0 (G0)	0.66	14.53	54.84	23.47	47.75	81.85	3210	4.10	97.70
		7 (G1)	0.66	15.20	63.14	28.83	43.10	97.38	3705	5.87	97.80
		14 (G2)	0.67	13.20	61.37	23.98	45.60	84.23	4294	4.33	98.05
		21 (G3)	0.68	14.30	52.55	21.95	53.08	122.59	5045	4.97	96.70
		28 (G4)	0.69	14.40	54.46	25.52	60.29	125.26	7909	5.20	96.20

water absorption values were relatively homogeneous. The water absorption values found in the present experiments did not correspond with that of FAO (1978) requirement, which is in the range of 6 – 40%.

It is suggested that the high water absorption values found in the present investigation were due to the influence of pulp beating process. Beating process increases the surface area of pulp fibers and chemically it is more hydrophilic due to the raise of hemicellulose unto the pulp surface, as has been explained elsewhere by Pasaribu (1985).

Addition of wax to the fiber furnishes can reduced water absorption value, since hydrophobic properties of wax will protect the MDF from absorbing more water (Haygreen and Bowyer 1989). Higher pressing temperature (205 – 210 °C) was suggested to reduce water absorption value and thickness swelling of fiberboard, as well (Kollman 1975).

Thickness Swelling. It was found that thickness swelling of acacia and gmelina MDF tends to increase with the increase of incubation time. In contrary with incubation time, wood species significantly influence the thickness swelling of the MDF. Additives (adhesive and wax), pressing temperature and pressure level affect thickness swelling, (Kollman 1975). These were given in the same amount when MDF sheets were formed and it was thought causing the incubation time was insignificantly influencing the thickness swelling of the MDF. The same suggestion applied for reducing water absorption value can be followed to reduce thickness swelling.

Tensile Strength Parallel to Surface. It can be seen from Table 3 that the tensile strength parallel to surface of MDF from acacia tends to be higher than that of MDF from gmelina, in which increasing tensile strength were found with the increase of incubation time. Further statistical examination showed that wood species and incubation time were both significantly affecting tensile strength parallel to surface of MDF at 95% confidence level.

A quadratic relationship of $Y = 73.62 - 2.14X + 0.09X^2$ with correlation coefficient of 0.618 were found between tensile strength parallel to surface (Y) and incubation time of acacia. The equation indicates that the lowest tensile strength (61.35 kg/cm^2) was occurred at the 12 days incubation and the highest (87.17 kg/cm^2) was at the 28 days incubation. On the other hand, a linear relationship of $Y = 42.35 + 0.53X$ with correlation coefficient of 0.80 were found for gmelina. In this case, the lowest tensile strength (42.35 kg/cm^2) was occurred at the 0 days incubation and the highest (57.18 kg/cm^2) was at the 28 days incubation. However, by no means of MDF tensile strength resulted in the present investigation is in accordance with that of FAO (1978) requirement, which ranged between 85 kg/cm^2 and 321 kg/cm^2. The curves of both equations are depicted in Figure 4.

It can be seen from Figure 4 that the tensile strength of MDF from acacia tends to decrease up to the 12 days incubation and increasing afterward. A different trend is indicated in the case of the tensile strength of gmelina MDF, in which an increasing tensile strength occurred with increasing incubation time. The trends are in accordance with those of MDF density (Figure 3).

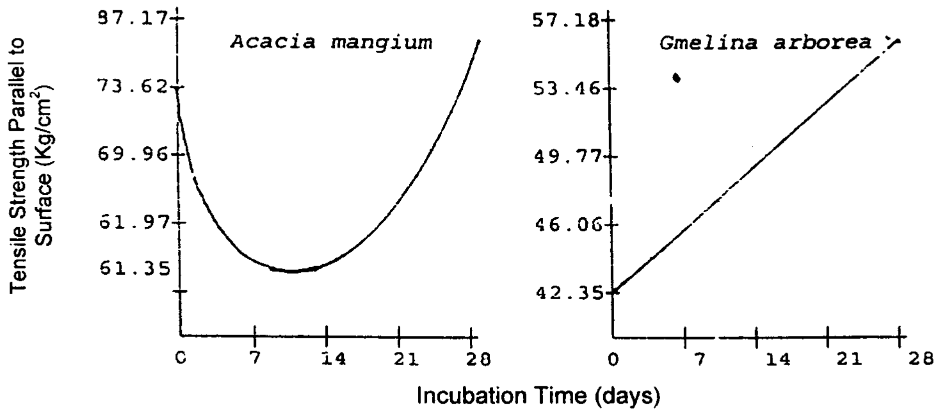

Figure 4. Relationship between tensile strength parallel to surface and incubation time of MDF from acacia and gmelina.

Tensile strength of MDF is strongly influenced by its density (Kollman 1975). Thus, in comparison to the tensile strength parallel to surface of gmelina MDF, higher density of acacia MDF may bring about higher tensile strength of its MDF. Specific gravity of its original wood is also thought to influence the tensile strength of the resulted MDF. The specific gravity of gmelina is higher than that of acacia. It has been explained (Koch 1985) that wood with high specific gravity will result in a high fiber bulk density. This will bring about low compaction ratio in hot pressing and less favorable interfiber bonding will be formed. Lack of interfiber bonding will bring about low fiberboard strength.

Modulus of Rupture (MOR). MOR of acacia MDF is higher than that of gmelina MDF and they increased with the increase of incubation time. It is influenced by MDF density and the specific gravity of wood in the same way to that of tensile strength parallel to surface. Both wood species and incubation time were significantly ($\alpha = 0.05$) affected the MOR of MDF.

A cubic relationship of $Y = 138.4470 - 0.5210X + 0.3341X^2 - 0.0093X^3$ with correlation coefficient of 0.72 present between MOR (Y) and incubation time (X) of acacia MDF. The lowest MOR (138.25 kg/cm^2) from the equation is for 1-day incubation and the highest was for 22 days incubation. On the other hand, a linear relationship of $Y = 79.86 + 1.72X$ with correlation coefficient of 0.80 exist for gmelina MDF. In this case, the lowest (79.86 kg/cm^2) and the highest (128.07 kg/cm^2) MOR were occurred at the 0 and 28 days incubation, respectively. The MDF MOR resulted from 21 days incubation for acacia and from 28 days incubation for gmelina is in accordance with these of FAO (1978) requirement, which is between 105 kg/cm^2 and 280 kg/cm^2. Figure 5 depicted relationship between MOR and incubation time for acacia and gmelina.

Modulus of Elasticity (MOE). Table 3 indicates that MOE's of acacia MDF are higher than those of gmelina MDF, in which MOE tended to increase with the increase of incubation time. Further statistical evaluation indicated that MOE were significantly influenced by wood species and incubation time at $\alpha = 0.05$.

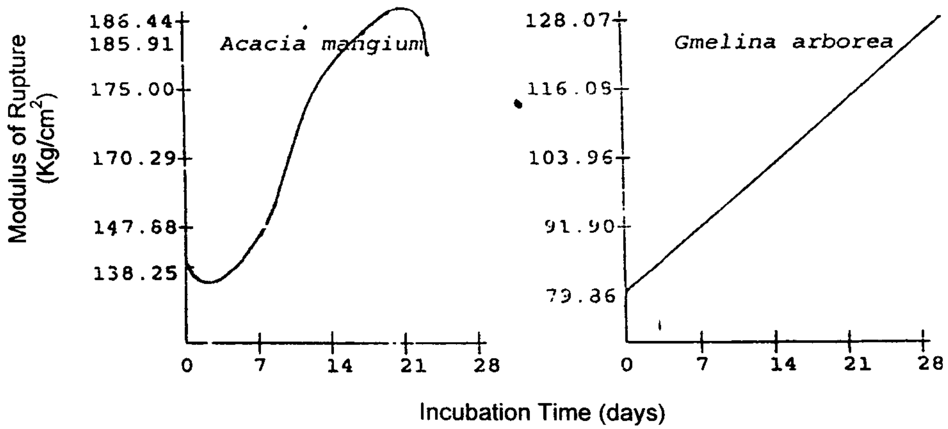

Figure 5. Relationship between MOR and incubation time of the MDF of acacia and gmelina.

A cubic relationship of Y = 9879.00 – 1124.90X + 120.49X2 – 2.68X3 with correlation coefficient of –0.760 exist between MOE (Y) and incubation time (X) of acacia MDF. From the equation can be calculated that the lowest (6888.36 kg/cm^2) and highest (15187.75 kg/cm^2) MOE were occurred at the 6 days and 25 days incubation, respectively. On the other hand, a quadratic relationship of Y = 3393.76 – 54.72X + 7.43X2 with correlation coefficient of 0.95 was found for gmelina MDF. The lowest (3296.04 kg/cm^2) and the highest (7686.61 kg/cm^2) MOE of gmelina MDF were achieved at the 4 days and 28 days incubation, respectively. MDF density and wood specific gravity influence the value of MOE in the same way to that of MOR, in which higher wood specific gravity bring about weaker fiberboard (Koch 1985).

The curves of the relationship between MOE and incubation time for acacia MDF and gmelina MDF are depicted in Figure 6. It shows that highest MOE for acacia MDF and gmelina MDF are occurred at 24 days and 28 days incubation, respectively. The MOE of acacia MDF was in accordance with that of FAO (1978) requirement. However, the MOE of gmelina MDF found in the present investigation did not fulfill FAO (1978) requirement, which is between 14000 – 49000 kg/cm^2.

Internal Bond (IB). The data of IB in Table 3 indicates that IB of MDF tends to increase with increasing incubation time. However, statistical evaluation indicated that wood species and incubation time did not significantly influence them. The IB values in the present investigation do not fulfil FAO (1978) requirement, which is between 7.24 kg/cm^2 and 19.83 kg/cm^2. IB value could be increased by the use of higher amount of adhesive (Nurkolik 1990).

Screw Holding Power. It can be seen from Table 3 that incubation time seem not to effect screw holding power of MDF. Further statistical evaluation has proven it. However, significantly different screw holding power between acacia MDF and gmelina MDF was found at α = 0.05. The screw holding power found in the present experiments did not fulfill FAO (1978) requirement, which is between 130 and 170 kg.

In comparison to screw holding power of acacia MDF, higher specific gravity of gmelina could bring about its MDF higher screw holding power. Influence of wood specific gravity on fiberboard strength properties has been explained elsewhere by Koch (1985).

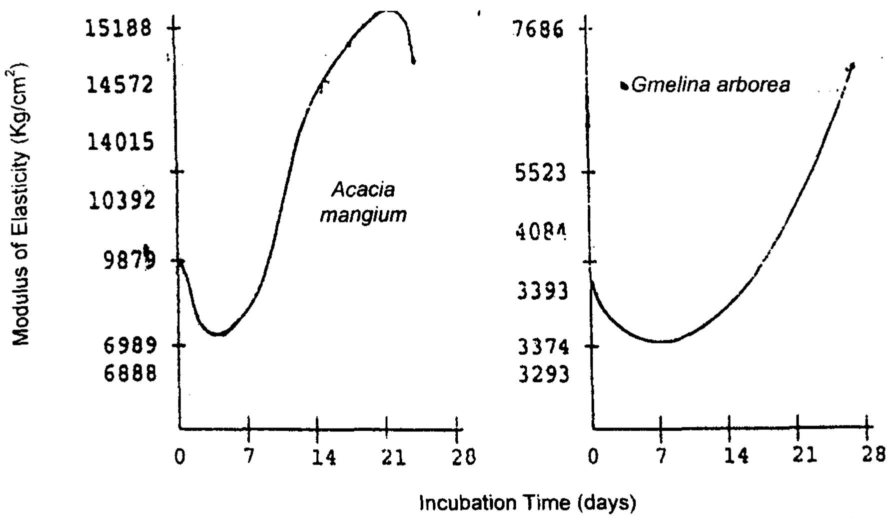

Figure 6. The relationship of MOE and incubation time of acacia MDF and gmelina MDF.

CONCLUSIONS

Treatment of wood chips from acacia and gmelina with *Pleurocybella sp.* decreased beating energy of their pulp, in which lowest beating energy were achieved at the 22 days and 28 days incubation, respectively. A decreasing pulping yield was also observed along with longer incubation time.

The physical and mechanical properties of acacia MDF were higher than that of gmelina MDF, however its beating energy was lower. The density, tensile strength parallel to surface, MOR, and MOE of acacia and gmelina MDF increased with increasing incubation time. In contrary, their moisture content, water absorption value, thickness swelling, internal bond, and screw holding power were decreasing.

The density, MOR and MOE of acacia MDF and density and MOR of gmelina MDF were in accordance with these of FAO (1978) requirement.

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