UNIVERSITI PUTRA MALAYSIA

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MOHAMAD AMARULLAH

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FORMALDEHYDE EMISSION AND PROPERTIES OF PHENOL FORMALDEHYDE-TREATED OIL PALM WOOD

By MOHAMAD

AMARULLAH

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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DEDICATION

To my *beloved parents, Rd. Hanny Kusumawati Pdk.and Fawzul Kabir, and* my *sisters, Aulia Fabia and Aulia Nikmah, for their love, support, patience, understanding, and encouraged* me *throughout this journey.*

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

FORMALDEHYDE EMISSION AND PROPERTIES OF PHENOL FORMALDEHYDE-TREATED OIL PALM WOOD

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October 2010

Chairman : Associate Professor Edi Suhaimi Bakar, PhD

Faculty : Forestry

It is known that impregnation of oil palm wood (OPW) with low molecular weight phenol formaldehyde (Lmw-PF) resin significantly improved the strength, dimensional stability, durability, and machining characteristics of the material. This treatment has shown a great potential to expand the usage of OPW for high-grade furniture and housing materials. However, the treated OPW releases high amount of formaldehyde emission (FE), i.e. more than 30 mg/L which is considered as mammalian hazardous. If this material is to be used for indoor application, its FE should be reduced to threshold limit of 0.1 mg/L or less. The main objective of this study was to determine the level and reduce the FE from phenol formaldehyde-treated OPW which was manufactured at different processing variables. The physical properties such as density percent gain, weight percent gain, water absorption, thickness swelling, density profile, and mechanical properties such as modulus of elasticity (MOE), modulus of rupture (MOR), compression strength, shear strength, and hardness of the treated OPW were also assessed.

In this study two approaches were carried out to reduce the FE. Firstly, by improving the curing state of the resin through a modification of compression step and adopting a post treatment drying after the manufacturing. Secondly, incorporating urea in the treating solution (as formaldehyde catcher). Samples were treated with 15% *w/w* Lmw-PF using vacuum pressure. After treatment, the samples were dried with industrial microwave until reach moisture content of 50%. The samples were then hot pressed at 150°C for 45 min to a compression ratio 50% (from 40 to 20 mm thick) using various compression steps (12.5%-25%-50%, 12.5%-37.5%-50%, and 25%-50%). The compression steps were varied in combination with various post treatment drying (0, 24, and 48 h) in an oven at 103 ± 2°C. The compression step of 12.5%-25%-50% produced the sample with the lowest FE, and it was choosen as the optimum compression step which would be used in the second study. For the second approach, the treatment with the optimum compression step (12.5%-25%-50%) was combined with addition of various concentration of urea granule (5, 10, and 15% based on solid weight of phenol) in the treating solution as formaldehyde catcher.

The results showed that implementation of post treatment drying and modifying compression step significantly ($P < 0.05$) reduced FE level of the treated OPW from 30 to 9 *mg/L.* It is acknowledged that the post treatment drying gave more effect on reduction of FE than that of modifying compression step. The sample treated using combination of compression step of 12.5%-25%-50% and post treatment drying of 48 h emited the lowest FE of 9 *mg/L.* Meanwhile the addition of urea was not significantly ($P > 0.05$) reduces the FE level of the samples.

In term of physical properties, it was found that the three type treatments (altering compression step, post drying treatment, and addition of urea granule) imparted various positive and negative effects on the properties of the treated OPW. In general, there was no significant effect ($P > 0.05$) of the compression step and post drying treatments on the density gain, but the additions of urea granule on the PF resin liquid increased the sample density gain. The compression step gave more effect on the resin load than the post treatment drying, and the addition of urea granule on the PF liquid only increased the resin load. The microwave pre-heating prior to the hot-pressing densification resulted in the better (shallower) density profile of the treated OPW than that of many particleboards. The thickness swelling (TS) and water absorption (WA) values of the treated OPW were not affected by the three treatments.

In term of mechanical properties, the three treatments also imparted various positive and negative effects on the properties of the treated OPW. Both the compression step and post treatment drying gave significant effects ($P < 0.05$) on bending strength (MOE and MOR) values of the treated OPW samples, in which the former gave more significant effects than the later. Combination of the compression step of 12.5%---+25%---+50% and post treatment drying of 48 h gave the highest MOE value (14,980 MPa), and compression step of 12.5%---+25%---+50% and post treatment drying of 0 h gave the highest MOR value (121.08 MPa). The post treatment drying gave irregular effect of the MOE but it has negative effect on MOR due to cellulose degradation caused by long heating treatment. Whilst, addition of urea granule on the resin liquid gave no significant ($P > 0.05$) effect on both the MOE and MOR values of treated OPW. The compression strengths were mainly affected by post treatment drying, and there was a tendency that the longer post treatment drying gave the higher compressive strength. The post treatment drying gave a positive effect, but urea granule addition gave negative effect on the shear strength of the treated OPW. All the three treatments gave no significant effect ($P > 0.05$) on the hardness of the treated OPW. Compare to the untreated OPW, the impregnation treatment of the OPW with Lmw-PF resin increased the MOE for 5.5 times (from 2,157 MPa to 11,954 MPa), MOR for 6.1 times (from 15.9 MPa to 97.4 MPa), compression strength parallel to the grain for 5.6 times (from 15.7 MPa to 88.1 MPa), and shear strength for 5 times (from 2.0 MPa to 10 MPa).

Finally, It can be concluded that implementation of post treatment drying and modifying compression step significantly reduced the FE level and increased the physical and mechanical properties of OPW. The modified impregnation treatment can be applied to effectively modify low quality OPW into highgrade OPW that can be used as value added furniture and other high grade interior/exterior applications.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains

EMISI FORMALDEHIDA DAN SIFAT-SIFAT KAYU SAWIT YANG DIRAWA T DENGAN PHENOL FORMALDEHIDA

Oleh

MOHAMAD AMARULLAH

Oktober 2010

Pengerusi : Professor Madya Edi Suhaimi Bakar, PhD

Fakulti : Perhutanan

Telah diketahui bahawa impregnasi kayu kelapa saw it (KKS) dengan fenol formaldehiQ resin berat molekul rendah (Lmw-PF) secara signifikan mempertingkatkan kekuatan, kestabilan dimensi, ketahanan, dan ciri pemesinan bahan tersebut. Rawatan ini telah menunjukkan potensi yang besar untuk memperluaskan penggunaan KKS untuk perabot bermutu tinggi dan bahan perumahan. Walau bagaimanapun KKS yang dirawat membebaskan formaldehid pada kadar tinggi, iaitu lebih dari 30 *mg/L* yang dianggap sebagai tidak sihat kepada mamalia. Jika bahan ini akan digunakan untuk kegunaan dalaman, tahap pembebasan formaldehid (FE) mestilah dikurangkan kepada tahap selamat, iaitu 0.1 *mg/L* atau kurang. Tujuan utama kajian ini adalah untuk menentukan tahap FE dan mengurangkan FE daripada KKS yang dirawat melalui pengubahsuaian pembolehubah proses pembuatan. Sifat fizikal seperti pertambahan peratus

ketumpatan, pertambahan peratus berat, penyerapan air, pengembangan ketebalan, profil ketumpatan, dan sifat mekanik seperti modulus kenyalan (MOE), modulus pecah (MOR), kekuatan mampatan, kekuatan ricih, dan kekerasan daripada KKS yang dirawat juga dinilai.

Dalam kajian ini dua pendekatan dilakukan untuk mengurangkan FE. Pertama, dengan mempertingkatkan tahap pematangan resin melalui pengubahsuaian langkah mampatan dan menggunakan rawatan pasca pengeringan selepas proses pembuatan. Kedua, menambahkan urea ke dalam cecair perawat (sebagai penangkap formaldehid). Sampel dirawat dengan menggunakan 15% *bIb* Lmw-PF menggunakan proses vakum mampatanan. Selepas rawatan, sampel dikeringkan dengan gelombang mikro industri sehingga kandungan lembapan mencapai 50%. Sampel kemudian dikenakan mampatan panas pada 150°C selama 45 min kepada nisbah mampatan 50% (dari ketebalan 40 mm kepada 20 mm) dengan langkah mampatan yang pelbagai (12.5%-+25%-+50%, 12.5%-+37,5%-+50%, dan 25%-+50%). Langkah mampatan yang berbeza-beza digabungkan dengan pelbagai perlakuan pasca pengeringan yang perbagai (0,24, dan 48 jam) di dalam oven pad a suhu 103±2 °C. Langkah mampatan 12.5%-+25%-+50% menghasilkan sampel dengan FE terendah, Langkah ini dipiJih sebagai optimum yang digunakan dalam kajian kedua. Untuk pendekatan kedua, perlakuan dengan langkah mampatan optimum (12.5%-+25%-+50%) yang digabungkan dengan penambahan butir urea dengan pelbagai kepekatan (5, 10, dan 15% berdasarkan berat pepejal fenol) ke dalam cecair rawatan sebagai penangkap formaldehid.

Keputusan menunjukkan bahawa pelaksanaan rawatan pasca pengeringan dan mengubahsuai langkah mampatan signifikan ($P < 0.05$) dapat menurunkan kadar FE dari KKS dirawat dari 30 *mg/L* kepada 9 *mg/L.* Hal ini diakui bahawa rawatan pasca pengeringan memberikan kesan yang lebih kepada pengurangan FE dibandingkan dengan mengubahsuai langkah mampatan. Sampel yang dirawat dengan menggunakan gabungan antara langkah mampatan 12.5%-25%-50% dan rawatan pasca pengeringan 48 jam memberikan pembebasan FE terendah pada 9 *mg/L.* Sementara itu penambahan urea tidak secara signifikan ($P > 0.05$) mengurangkan kadar FE sampel.

Dalam hal sifat fizikal, didapati bahawa tiga jenis perlakuan (pengubahsuaian langkah mampatan, rawatan pasca pengeringan, dan penambahan butiran urea) memberikan pelbagai kesan positif dan negatif terhadap sifat KKS yang dirawat. Secara amnya, tiada kesan signifikan ($P > 0.05$) dari pembolehubah langkah mampatan dan rawatan pasca pengeringan pada pertambahan ketumpatan, tetapi penambahan butir urea pada cecair resin PF meningkatkan pertambahan ketumpatan sampel. Langkah mampatan memberikan pengaruh yang lebih pada pembebanan resin daripada rawatan pasca pengeringan, dan penambahan butir urea pada cecair PF hanya meningkatkan pembebanan resin. Pemanasan gelombang mikro sebelum pemadatan panas pada KKS yg dirawat menghasilkan profil ketumpatan yang lebih baik (lebih dangkal) berbanding profil ketumpatan daripada kebanyakan papan serpai. Nilai pengembangan ketebalan (TS) dan penyerapan air (WA) dari KKS yang dirawat tidak dipengaruhi oleh ketiga rawatan tersebut.

Dalam hal sifat mekanik, tiga rawatan ini juga memberikan pelbagai kesan positif dan negatif terhadap KKS yang dirawat. Kedua-dua langkah mampatan dan rawatan pasca pengeringan memberikan pengaruh yang signifikan ($P < 0.05$) terhadap nilai kekuatan lenturan (MOE dan MOR) sampel KKS dirawat, dimana langkah mampatan lebih memberi pengaruh daripada rawatan pasca pengeringan. Kombinasi langkah mampatan 12.5%-25%-50% dan rawatan pasca pengeringan 48 jam memberikan nilai MOE tertinggi (14,980 MPa), manakala langkah mampatan 12.5%-25%-50% dan rawatan pasca pengeringan 0 h memberikan nilai MOR tertinggi (121.08 MPa). Perlakuan pasca pengeringan memberikan kesan yang tidak sarna terhadap MOE, tetapi memberikan kesan negatif terhadap MOR kerana disebabkan penguraian selulosa akibat pemanasan yang lama. Sementara itu, penambahan butir urea granula di dalam cecair resin tidak memberikan kesan signifikan ($P > 0.05$) terhadap nilai MOE dan MOR dari KKS yang dirawat. Kekuatan mampatan terutama dipengaruhi oleh rawatan pasca pengeringan, dan ada kecenderungan bahawa perlakuan pasca pengeringan lagi memberikan nilai kekuatan mampatan yang lebih tinggi. Perlakuan pasca pengeringan memberikan pengaruh positif, sedangkan penambahan butir urea memberikan kesan negatif pada kekuatan ricih dari KKS yang dirawat. Semua tiga perlakuan tidak memberikan pengaruh yang signifikan ($P > 0.05$) terhadap kekerasan KKS yang dirawat. Apabila dibandingkan dengan KKS tidak dirawat, rawatan pemadatan dari KKS dengan resin Lmw-PF mampu meningkatkan MOE sebanyak 5.5 kali ganda (dari 2,157 MPa kepada 11,954 MPa), nilai MOR sebanyak 6.1 kali ganda (dari 15.9 MPa kepada 97.4 MPa), kekuatan mampatan selari ira sebanyak 5.6 kali ganda (dari 15.7 MPa kepada 88.1 MPa), dan kekuatan ricih sebanyak 5 kali ganda (dari 2.0 MPa kepada 10 MPa).

Akhirnya, dapat disimpulkan bahawa pelaksanaan rawatan pasca pengeringan dan mengubahsuai langkah mampatan secara signifikan boleh mengurangkan kadar FE dan meningkatkan sifat fizikal dan mekanikal KKS. Rawatan pemadatan diubahsuai dapat diterapkan secara berkesan mengubahsuai KKS berrnutu rendah menjadi KKS bermutu tinggi sehingga boleh digunakan untuk pernbuatan perabot yang bernilai tinggi samada untuk kegunaan dalarnan ataupun luaran.

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I certify that a Thesis Examination Committee has met on 29 October 2010 to conduct the final examination of Mohamad Amarullah on his thesis entitled "Formaldehyde Emission and Properties of Phenol Formaldehyde-Treated Oil Palm Wood" in accordance with the Universities and University College Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The committee recommends that the student be awarded the Master of Science.

Members of the Thesis Examination Committee were as follows:

Mohd Hamami bin Sahri, PhD Professor
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Professor an~Deputy Dean School of Gr
uate Studies Universiti Put a Malaysia

Date: 22 February 2011

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