STUDY ON THE FABRICATION, EVALUATION OF MECHANICAL AND PHYSICAL PROPERTIES OF PARTICLEBOARD MADE FROM GIANT REED (*ARUNDO DONAX L.*) AND APPLICATION

Saw Win[1], Win Win Nu[2], Myint Sandar Win[3]

Abstract

Single-layer experimental particleboards were made from internode of giant reed culms with different particle sizes (4 mm, 2 mm, 1 mm, 500 µm, 250 µm) of particles bonded with urea-formaldehyde resin. Urea-formaldehyde resin (25 %) was mixed with 2 mL of 0.4 % ammonium sulphate hardener and 1 mL cashew nut shell liquid for each panel to improve strength and other properties. The panels were tested for mechanical properties including modulus of rupture (MOR), impact strength, hardness, tensile strength and physical properties such as density, moisture content (MC), water absorption (WA) and swelling thickness (ST) according to the procedures defined by British Standard and Indian Standard methods. The overall results showed that most panels fulfilled FAO (2013) standard for MOR, WA and ST. The surface fracture of PBS4 (500 µm) is more uniform and fibers are not pull out from the surface. This tend to be more enhanced the MOR, less WA and ST of particleboard. PBS4 (500 µm) had the highest MOR, the lowest WA and ST values. Particle size was found to have a profound effect on the board properties.

Keywords: Giant reed, urea-formaldehyde, cashew nut shell liquid, particle size, particleboard, mechanical properties and physical properties

Introduction

The demand for composite wood products, such as plywood, oriented strand board, hardboard, particleboard, medium-density fiberboard, and veneer board products has recently increased substantially throughout the world (Youngquist, 1999, Sellers, 2000). According to a report from Food and Agricultural Organization (FAO) of the United Nations, the worldwide demand of particleboard panels were 56.2 Mm^3 in 1998 (Youngquist and Hamilton, 2000). The feasibility of using fast-growing trees and agricultural residues as raw materials for particleboard production has been explored by a number of researchers. Particleboard can be considered as a common product of wood industry. Particleboard is widely used around the world in furniture manufacturing and house construction (Youngquist, 1999). The production of particleboard involved compression of wood particles with other lignocelluloses materials and adhesive at high pressure. The adhesive used to bind the wood particles made from natural or synthetic products (Bono *et al*., 2011).

In the last decade, European agricultural research has focused much attention on the research for new, non-food crops with regard to their industrial utilization. The grass *Arundo donax* L. (giant reed) (Poaceae) has been considered as one of the more-promising crops (Shatalov and Pereira, 2005). Giant reed is a perennial herbaceous species growing in grasslands and wetlands, and is an invasive, riparian plant and potential bioenergy crop (Lewandowski *et al*., 2003, Graziani and Steinmaus, 2009). Giant reed is thought to have originated from Asia, but

[1] Dr, Associate Professor, Department of Engineering Chemistry, West Yangon Technological University
[2] Dr, Associate Professor, Department of Botany, Myeik University
[3] Dr, Professor (Head), Department of Engineering Chemistry, West Yangon Technological University

it is also considered as a native species in the countries surrounding the Mediterranean Sea (Lewandowski *et al*., 2003). In the Southeast of Spain, giant reed was used as a building material (walls, frameworks, roofs, fences) for livestock and housing and for erosion control until the beginning of the 20th century. Giant reed has consumed water from the river that is needed for agricultural use. Large clumps alter stream flow patterns, increase flood damage (Frandsen and Jackson, 1994, Moran and Goolsby, 2009), and displace populations of native plants and animals (Bell 1997, Herrera and Dudley 2003). Physical (burning), mechanical (mowing or mulching, and chemical control (Tracy and Deloach, 1999) are the methods commonly used to solve these problems, but they do not have sufficient impact. Giant reed has been grown at the bank of the stream, river, in grasslands and wetlands of almost regions except hilly regions in Myanmar. In this research giant reed culms were used to manufacture particleboard panels in order to give added value to the residue. Some physicochemical properties of giant reed are shown in Table 1.

Table 1 Physicochemical Properties of Internode of Giant Reed Culms (Stems)

Component	Shatalov Values* 2001	Ververis Values** 2004
Ash (%)	6.14	4.53
Lignin (%)	21.31	-
α-Cellulose (%)	32.93	36.27
Hemicelluloses (%)	28.48	-
Fiber (%)	33.90	-
Fiber Length (mm)	1.20	1.22
Fiber width (μm)	14.60	-
Fiber wall thickness (μm)	4.60	4.40
Fiber diameter (μm)	-	17.30

* Shatalov *et al.,* (2001)
**Ververis *et al.,* (2004)

At the present time, the majority of particleboard manufacturer employs formaldehyde-based adhesive such as phenol-formaldehyde (PF), urea-formaldehyde (UF), and melamine-urea-formaldehyde (MUF) as the main adhesives (Bono *et al*., 2011). Urea-formaldehyde (UF) is chemically known as urea-methanol, non-transparent thermosetting resin. UF is obtained by heating urea and formaldehyde in the presence of ammonia or pyridine as catalyst. UF was first synthesized in 1884 by Holzer. It is a great resin for bonding particle. UF is the commercial resin popularly used for wood-based panel product (Lee *et al*., 2011).

Cashew nut shell liquid is used to reduce urea-formaldehyde resin, formaldehyde and volatile organic compounds emission (Kim, 2009). It is also used to reduce biodegradability (fungicity and insect). Cashew nut shell liquid improves water resistance, corrosion and insulation resistance (Bisanda *et al*., 2003). Particleboard having the best physical properties such as water absorption and swelling thickness was made of ammonium sulphate hardener and small chips. (Mohsen, 2011). The presence of hardener enhances the cross linking between the resin and hardener thus increases the tensile strength (Sulaiman *et al*., 2008).

The objectives of this study are to use particles from giant reed culms, of different sizes, as a raw material for laboratory made particleboard panels and to test the properties of such boards to determine if they are comparable to particles made from other species.

Materials and Methods

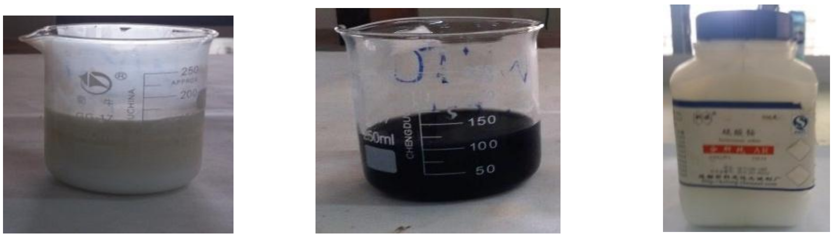
Materials

Giant reed culms (*Arundo donax* L.), were collected from West Yangon Technological University Campus, Hlaing Tharyar Township in Yangon (Myanmar) and were dried for 2 months under ambient conditions, to 6.3 % moisture content, before use. The average culm height, diameter, and thick of wall 550 cm, 1 cm and 0.5 cm, respectively. After removing any remains of pulms and leaves, the culms were manually cut into slices (ca. 3 cm long) and crushed or blended in Henser Mixer about 10 minutes. The particles were then classified using a Horizontal Screen Shaker with sizes of 4 mm, 2 mm, 1 mm, 500 μm and 250 μm to remove oversize and undersize (dust) particles. A sample of the different sizes of the particles can be seen in Figure 1.

4 mm 2 mm 1 mm 500 μm 250 μm

Figure 1 Giant reed particles with different sizes

Particles were blended with urea-formaldehyde (UF) resin with the solid content of 58 % at the level of 25 % based on the weight of particles (6.3 % moisture content). As a hardener, 0.4 % of ammonium sulphate and 1ml of cashew nut shell liquid, based on the weight of particles (6.3 % moisture content), was used. Urea-formaldehyde resin was purchased from Watayar Glue Factory in Yangon, Myanmar. Cashew nut shell liquid was collected from Myeik, Tanintharyi Region, Myanmar. The ammonium sulphate was produced from Chengdu Kelong Chemical Reagent Factory, China. Urea-formaldehyde, cashew nut shell liquid and ammonium sulphate are shown in Figure 2.



(a) (b) (c)

Figure 2 (a) Urea-formaldehyde, (b) cashew nut shell liquid and (c) ammonium sulphate

Procedure for Preparation of Particleboards

The five types of particleboard panels were made. Pre-weighed 120 g classified size (4 mm, 2 mm, 1 mm, 500 μm and 250 μm) raw material giant reed particles was placed into a Hensel Mixer. Before spraying the UF adhesive, the hardener ammonium sulphate was dissolved at 0.4 % concentration in water and fungicide cashew nut shell liquid 1 mL was blended and immediately mixed with the adhesive, the glue mixture was then sprayed onto the particles and blended for 5 min at ambient temperature in the Hensel mixer to obtain a homogenized mixture. The mat configuration was one layer. Boards measuring (6" x 6" or 15 cm x 15 cm) were manually formed and pressed in a hydraulic hot press at 2200 psi at 120 °C for 15 min.

The experimental design for preparation of one-layer particleboards is shown in Table 2.

Table 2 Production Parameters of One-layer Particleboards

Parameter	Value
Press temperature (°C)	120
Pressing time (min)	15
Press pressure (psi)	2200
Dimensions (cm)	15x15
Thickness (cm)	0.46 - 0.56
Number of boards of each type	2

Two replicate panels were made for each board type. After pressing, the particleboards were conditioned at ambient temperature about one week in vertical position (Figure 3). The finished particleboards were trimmed to avoid edge effects to a final size of 14.8 cm x 14.8 cm, and then cut into various sizes for properly evaluation according to BS 1811 (1961) and IS 3087 (1965) methods as shown in Figure 4.

Figure 3 Finished particleboards during conditioning at ambient temperature

Figure 4 Particleboards samples stored after the assessment

Some mechanical and physical properties of panels were determined in accordance with their respective methods as shown in Table 3.

Table 3 Tests and Test Specimen Sizes and Number

Test	Specimen size (cm × cm)	Specimen per panel	Method and Equipment
Modulus of rupture	14.8 × 2.5	3	BS:1811-1961
Impact strength	7.5 × 2.5	3	ASTM D – 256 Qualitest Impact 50
Hardness	1.7 ×1.7	3	Wallace Hardness Micro Tester
Tensile strength	14.8 × 2.5	3	Electrohydraulic Tensile Tester
Thickness	14.8 × 2.5	3	Veneer clipper
Density	14.8 × 2.5	3	BS:1811-1961
Moisture content	1.7 × 1.7	3	MOC. 63 U Moisture Analyzer
Water absorption*	2.5 × 2.5	3	IS:3087-1965
Swelling thickness*	2.5 × 2.5	3	IS:3087-1965

*After soaking period 24 h

Results and Discussion

The five types of particleboard (PBS1-PBS5) were prepared by using 25 % urea-formaldehyde, 2 mL (0.4 %) ammonium sulphate, 1 mL cashew nut shell liquid and various particle sizes of giant reed fiber (4 mm, 2 mm, 1 mm, 500 μm and 250 μm).

The mechanical and physical properties of prepared particleboards are shown in Table 4.

Table 4 Mechanical and Physical Properties of Prepared Particleboards

Properties	PBS1	PBS2	PBS3	PBS4	PBS5	Reference **Reported
Modulus of rupture (psi)	8468.8	7013.5	9817.8	10603.9	8611.9	-
Modulus of rupture (kg cm$^{-2)}$	234.9	194.5	272.3	294.1	238.9	100-500
Impact strength (kj m^{-2})	107.7	78.2	68.4	52.3	28.6	-
Hardness (Shore D)	95	95.75	96.5	97.0	98.0	-
Tensile strength (lb)	7	7	7	7	6.5	-
Thickness (cm)	0.56	0.52	0.48	0.46	0.50	-
Density (g cm^{-3})	0.95	0.96	0.98	1.01	1.0	0.40 - 0.80
Moisture content (%)	4.63	5.12	5.16	5.24	5.50	-
Water absorption*(%)	36.74	31.70	31.04	30.01	22.84	20-75
Swelling thickness*(%)	23.21	22.80	20.84	20.23	4.00	5-15

Pressing temperature = 120°C pressing time = 15 min
Pressing pressure = 2200 psi Fiber type = giant reed (internode)
Adhesive type = UF Hardener = ammonium sulphate
Fungicide = CNSL
* = after soaking period 24h
** = FAO (2013)
FAO = Food and Agriculture Organization
PBS1 = particleboard with 4 mm particle size
PBS2 = particleboard with 2 mm particle size
PBS3 = particleboard with 1 mm particle size
PBS4 = particleboard with 500 μm particle size
PBS5 = particleboard with 250 μm particle size

The values of MOR ranged from (194.5 – 294.1) kg cm^{-2}. The particleboards made from five types of particle sizes had MOR values that are sufficiently high to meet the requirements for FAO (2013) standard. Panel (PBS4) having the greatest density gave the greatest values of MOR, suggesting, that the particleboard density plays a very important role on the bending strength, as expected (Figure 5).

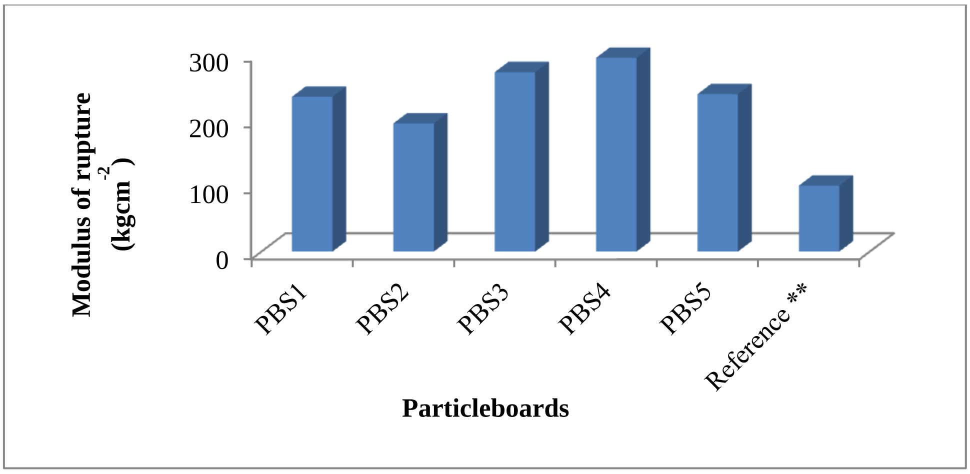


Figure 5 Modulus of rupture of particleboards

From the observation of impact strength of prepared particleboards, it is envisaged that as the size of particles becomes bigger, greater original interaction between the fibers in the particle. Impact strength of particleboard decreases as the particle size of fiber used for particleboard decreases as expected. PBS4 (4 mm) with biggest particle size had the greatest impact strength (Figure 6).

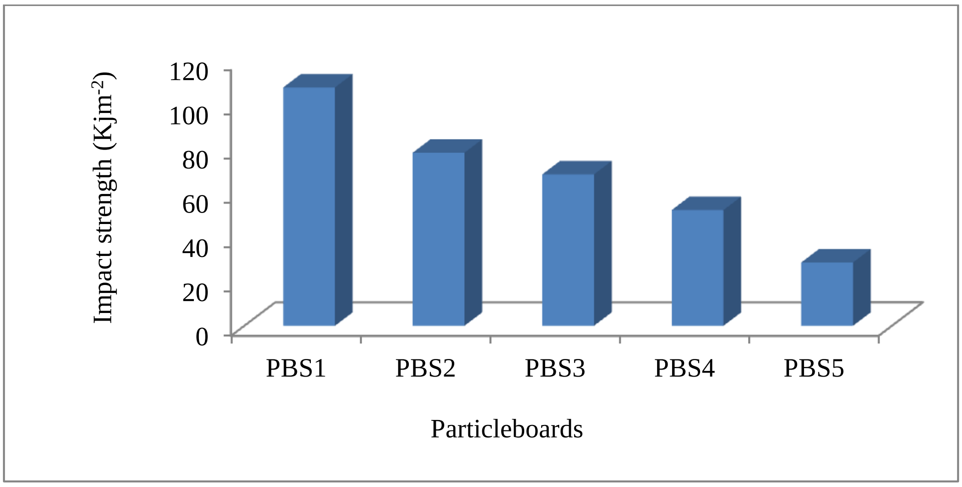


Figure 6 Impact strength of particleboards

It is observed that particleboards with particle sizes (4 mm, 2 mm, 1 mm, 500 μm) have constant tensile strength (7 lb) and decreasing bending period but particleboard with particle size 250 μm has the lower tensile strength (6.5 lb) than that of other four boards.

Hardness of prepared particleboards is gradually increasing from 95 to 98 Shore D. It suggested that particle size of fibers is inversely proportional to the hardness of board formed.

The thickness of the produced particleboards ranges from 0.46 to 0.56 cm. The density ranged from 0.95 to 1.01 gcm^{-3}. Panel PBS4 had the lowest thickness and the highest density, was prepared with the particle size (500μm). It was suggested that these properties may be attributable to an insufficient application of pressure during the compressing. Increasing particle size may be increased thickness and decreased density of board. Kelly (1977) reported that a higher pressure was required to reach a desired specific gravity for narrow and thicker flakes as opposed to wider and thinner flakes

The water absorption values of particleboards after 24 h soaked in water were 22.84 to 36.74 %. The results fulfilled to FAO (2013) standard. The water absorption values decreased with increasing the board density and decreasing particle size. It was suggested that increasing (WA) of larger particle size panel due to the voids and moistures among the particles.

Particleboards should have a maximum swelling thickness (ST) value of 15 % for 24 h immersion in water (FAO, 2013). Average (ST) of panels following a 24 h immersion ranged from 4.00 to 23.21 %. Panels PBS5 were found to 4 % with swelling thickness value and had the smallest particle size. The ST values decreased with decreasing particle size, because of lesser voids between the particle (Figure 7).

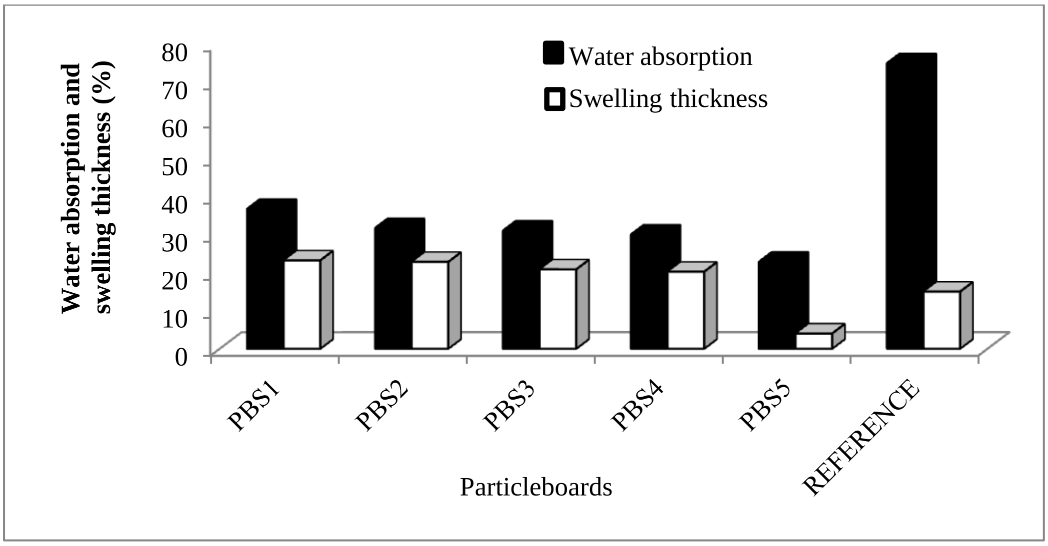
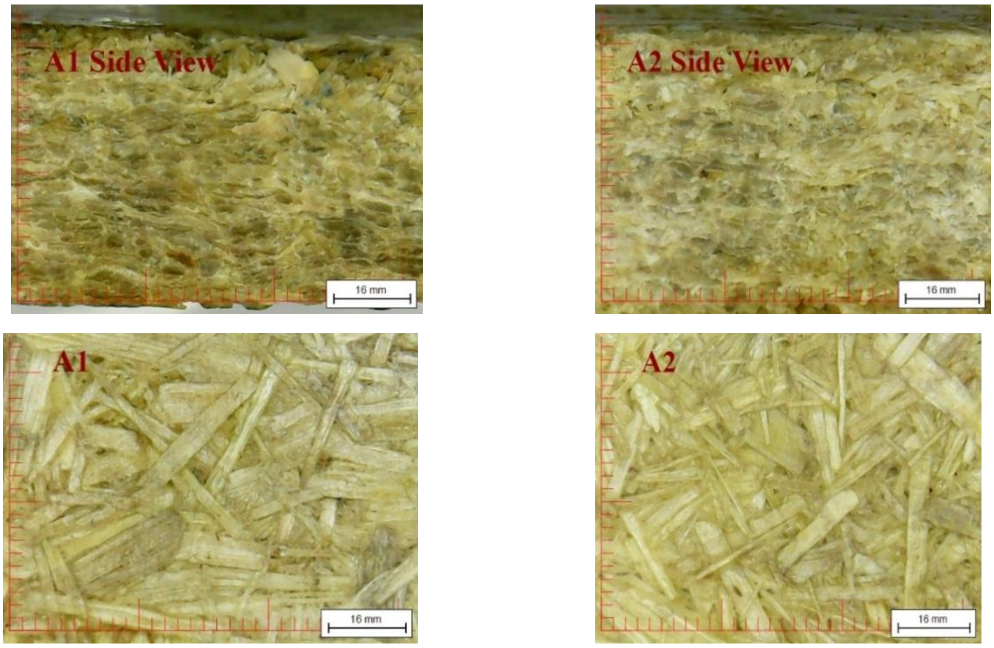


Figure 7 Water absorption and swelling thickness of particleboards

Moisture content of panels ranged from 4.63 % to 5.50 %. The moisture content of particleboard increased as the particle size decreased of fiber due to the greater surface area of particle contact with moisture. The moisture content necessary for fungi growth on the surface of board is 16 % (Burmester, 1974). So, moisture content of board should be reduced to the least as possible.

Surface Morphology of Selected Prepared Particleboards

Surface morphology of particleboards was analyzed by Digital Microscope (50x-500x), China. The micrographs from side view and over view of PBS3 (1 mm) and PBS4 (500 μm) are shown in (Figure 8). It was found that the surface fracture of PBS4 (500 μm) is more uniform, compatible and fibers are not pull out from the surface that is PBS4 has less micropores and microcracks on the surface. This is tend to be more enhanced the MOR, less WA and ST values of particleboard.



PBS3 (1 mm) PBS4 (500 μm)

Figure 8 Surface micrographs of PBS3 and PBS4 (300x Mag)

Application of the Prepared Particleboards

The finished particleboards were prepared by using giant reed fiber, UF, ammonium sulphate and cashew nut shell liquid to protect the fungi growing on the surfaces. The surface of finished particleboards could also be made attractive by using sun mica laminates. The surface finished particleboards were found to be successful in making of household articles such as ceiling boards, wall partitions and floor underlayment. (Figure 9) shows the photographs of various household articles.

Figure 9 Photographs of household articles

Conclusion

The results presented suggest that it is completely feasibility to manufacture acceptable or high-quality particleboard using giant reed as an alternative lignocellulosic raw material. Since particleboards produced with particle sizes from 4 mm to 250 μm had the most desirable quality and so the production of 500 μm and 250 μm particle sizes are recommended for milling of the culms due to their highest MOR, hardness, density and lowest, thickness, water absorption and swelling thickness which are fulfilled to FAO (2013), standard. Particle size was found to have a great effect on the properties of UF-bonded giant reed particleboards manufactured from giant reed particles of five different sizes.

Since particleboards are considered quality grade, cost effective and long-life products, could be manufactured for household articles. The use of renewable giant reed fiber for manufacturing particleboards could help to alleviate the scarcity of raw material for the particleboard industry. The present work will contribute to the technological needs for our country: reducing the non-biodegradable pollutants, giving added value of the giant reed culms, preserving potentially the forest depletion and reducing the greenhouse gases emission and creating green world.

Acknowledgement

The authors would like to express their profound gratitude to the Department of Higher Education (Lower Myanmar) Ministry of Education, Yangon, Myanmar for provision of opportunity to do this research.

References

Bell, G.P.(1997). “Ecology and Management of *Arundo donax*, and Approaches to Riparian Habitat Restoration in Southern California”, In: Brock, J. H., Wade, M., Pysek, P. and Green, D. (eds.), *Plant Invasions: Studies from North America and Europe,* Blackhuys Publishers Ledien, The Netherlands, pp.103-113

Bisanda, E.T.N., Ogola, W.O. and Tesha, J.V. (2003). “Characerization of Tannin Resin Blends for Particleboard Applications Cement and Concrete Composites”. *J. Polym. Mater*., vol. 25, pp. 593-598

Bono, A., Nur. M., Anisuzzaman, S.M., Sualah, S. and Chiew, H.K. (2011). The Performance of MUF Resin with Palm Kernel as Filler. *Advanced Materials Research*, vol. 3, pp. 233-235

Burmester, A. (1974). Simple Methods of Improving Dimensional Stability. (2) Treatment of Wood-based Materials, Technology, Economics. *Holz und Kunststoffverarbeitung,* vol. 9(9), pp. 610-617 (in German)

FAO. (2013). Characteristic Mechanic of Polyester Composite Particleboard with Filler Particle of Areca Nut Fiber, http://www.fao.org/3/a-i4441 e.pdf (Accessed 8 June2013)

Frandsen, P. and Jackso, N. (1994). “The Impact of *Aurndo donax* on Flood Control and Endangered Species”, In Jackson, N. E., Frandsen, P and Duthoit, S. (Compliers), *Arundo donax* Workshop Proceedings, 19 November 1993, Ontario, California, USA. Team Arundo and California Exotic Pest Plant Council, Pismo Beach, CA, pp.13-16

Graziani, A. and Steinmanus, S.J. (2009). “Hydrothermal and Thermal Time Models for the Invasive Grass, *Arundo donax*”. *Aquatic Botany,* vol. 90, pp. 78-84

Herrera, A.M. and Dudley, T.L. (2003). “Reduction of Riparian Arthropod Abundance and Diversity as a Consequence of Giant Reed (*Arundo donax*) Invasion”. *Biological Invasions,* vol. 5, pp.167-177

Kelly, M.W. (1977). “Critical Literature Review of Relationships Between Processing Parameters and Physical Properties of Particleboard”, Gen.Tech. Rept. FPL-10. USDA Forest Serv., Forest Prod.Lab., Madison, Wisconsin, USA

Kim, S. (2009). “Environmental-friendly Adhesive for Surface Bonding of Wood-Based Flooring using Natural Tannin to Reduce Formaldehyde and TVOC Emission”. *Journal of Hazardous materials,* vol. 100, pp. 744-748

Lee, J.H., Jeon, J. and Kim, S.(2011). “Green Adhesives using Tannin and Cashew Nut Shell Liquid for Environment- friendly Furniture Materials”. *Journal of the Korea furniture Society*, vol. 22(3), pp. 219-229

Lewandowski, I., Scurlock, J.M.O., lindvall, E. and Christou, M. (2003). "The Development and Current Status of Perennial Rhizomatous Grasses as Energy Crops in the US and Europe". *Biomass Bioenergy*, vol. 25, pp. 335-361

Mohsen, S.(2011). "Effect of Hardener Type and Particle Size on Formaldehyde Emission Pollution". *International Conference on Environment Science and Engineering* IPCBEE, vol. 8, pp. 242-244

Moran, P.J. and Goolsby, J.A. (2009). "Biology of the Galling Wasp *Tetramesa romana*, a Biological Control Agent of Giant Reed". *Biological Control,* vol. 49(2), pp. 169-179

Sellers,T. (2000). Growing Markets for Engineered Products Spurs Research. *Wood Technology*, vol. 127(3), pp. 40-43

Shatalov, A. A., Quilho, T and Pereira, H. (2001). " *Arundo donax* L. Reed: New Perspectives for Pulping and Bleaching -1. Raw Material Characterization". *TAPPI J.* vol. 84 (11), pp. 1-12

Shatalov, A.A. and Pereira, H. (2005). "Kinetics of Organosolv Delignification of Fiber Crop *Arundo donax* L*". Ind.Crops Prod,* vol. 21(2), pp. 203-210

Sulaiman.S., Yunus, R., Ibrahim, N.A. and Rezaei, F. (2008). "Effect of Hardener on Mechanical Properties of Carbon Fiber Reinforced Phenolic Resin Composites". *Journal of Engineering Science and Technology,* vol. 3(1), pp. 79-86

Tracy, J.L. and Deloach, C.J. (1999). "Suitability of Classical Biological Control for Giant Reed (*Arundo donax*) in the United States", In Bell C., (ed.), *Arduno* and *Saltcedar* Management Workshop Proceedings, 17 June, 1998, California. University of California Cooperative Extension, Holtville.

Ververis, C., Georghiou, K., Christodoulakis, N., Santas, P. and Santas, R. (2004). "Fiber Dimensions, Lignin and Cellulose Content of Various Plant Materials and Their Suitability for Paper Production". *Ind. Crops Prod*, vol. 19, pp. 245-254

Youngquist, J.A.(1999). Wood-based Composites and Panel Products. In: Wood Hand book: Wood as a Engineering Material. Gen. Tech. Rept. FPL-GRT-113. USDA Forest serv., Forest Prod. Lab., Madison, WI, pp. 1-31

Youngquist, J.A. and Hamilton, T.E. (2000). A look at the World's Timber Resources and Processing Facilities. In: Proceedings of the XXI IUFRO world congress 2000, Sub-plenary sessions, Kualalumpur, Malaysia, vol. 1, pp. 183-190