Vol. 9 · March 2019 · ISSN 2449-4399
International Peer Reviewed Journal
This journal is produced by the International Association
of Scholarly Publishers, Editors and Reviewers, Inc.
Registered in the Philippines' Securities
and Exchange Commission (CN201433407)

Compressive Strength Properties of Rice Straw Composite Board using Cementitious Materials

MARIA CRISELLA D.C. PELAEZ
https://orcid.org/0000-0002-2442-5383
kreezdcpelaez@psau.edu.ph
Pampanga State Agricultural University
Magalang, Pampanga, Philippines

ABSTRACT

As the world responds to solving climate change issues, the construction industry still looks for sound strategies, not just structures, to provide construction materials in which the utilization of agricultural wastes is one of the many techniques that promote green engineering through technological approaches. Rice straw fibers are among the common agricultural wastes burned in the fields for easy disposal that bring health hazards to the community. The utilization of this agricultural waste into a valuable construction material prompted the interest in investigating its properties. This experimental study focused on the compressive strength characterization of rice straw composite board as a result of variations of cementitious materials. Cementitious materials used were gypsum powder, cement, and tile grout in different design mixtures. Results show that the optimum design was attained at 70% gypsum powder, 15% cement and 15% tile grout mixture with 3.57 MPa tested at 28 days with water-cementitious ratio of 0.43 and fiber-cementitious ratio of 0.05. The results gathered from the study demonstrated the potential of rice straw composite board as a substitute for a decorative drywall panel.

KEYWORDS

Civil Engineering, rice straw, fiber-cementitious ratio, water-cementitious ratio, compressive strength, Philippines, Asia

INTRODUCTION

Agricultural waste, as defined from Article 3 of Republic Act 9003 or the Ecological Solid Waste Management, is a waste generated from planting or harvesting of crops, trimming or pruning of plants and wastes or run-off materials from farm or fields.

The Philippines is primarily 47% agricultural land, and rice straw is one of the most common agricultural wastes (Zapar, 2015). As mentioned in PhilStar (2006) in the article "Burning of Rice Straw: Agri waste threatens the environment,"200 kilograms of rice straw are burned per ton of rice produced.

Padin (2015) stated that the Philippines is the 8th largest rice producer in the world and according to Allam, Garas, and El Kady(2011), the easiest and less expensive way to reduce or eliminate volumes of rice straw wastes is burning. It is the quickest manner to eliminate wastes and clear the fields in preparation for the next planting season. However, agricultural residues burning is not environmentally acceptable because of health hazard reasons. It boosts air pollution and serious human health problems due to the emission of carbon monoxide (Allam, Garas, & El Kady, 2011). In addition, incomplete combustion processes like the burning of the fields produce dioxins which are highly toxic and carcinogenic pollutants. According to Irina Ize of the Commission for Environmental Cooperation, "Burning agricultural waste creates non-specific sources of pollutants for the atmosphere and takes place over vast areas. It is therefore difficult to measure and to regulate the resulting emissions" (CEC, 2014).

On the other hand, the continuous rise in the price of construction materials is very evident. The Philippine Statistics Authority, as mentioned by Valencia (2018), reported that there was a rise in the wholesale price index of construction materials from 8.4% to 8.8% in June 2018 which influences the cost of government projects. In the study conducted by the National Association of Home Builders inJanuary 2018, building material prices ranked number 2 among the problems faced in 2017 (Chaluvadi, 2018).

Bolden, Abu-Lebdeh, andFini (2013) mentioned that replacing raw materials with recycled materials reduces the dependency on raw materials in the construction industry. Recycling of wastes into more useful construction materials is not a new concept to solve issues on environmental concerns of waste production and pollution.

In consideration to Republic Act 10068 (Organic Agriculture Act of 2010) which aimed "to promote, propagate, develop further, and implement the practice of organic agriculture that will cumulatively condition and enrich the fertility of the soil and increase farm productivity ("Status of Agricultural Waste and Utilization", 2018) ; reduce pollution and destruction of the environment; prevent the depletion of natural resources; and to protect the health of farmers, consumers and the general public" (Tacio, 2018) the need to use agricultural wastes is a challenging task to researchers.

Munshi, Dey, and Sharma (2013) stated that to decrease the cost of construction materials and raise environmental concerns, considerable efforts to improve the performance of construction is by the utilization of local waste and byproduct materials. Innovative technologies such as utilization of agricultural waste into a new building material are one of the best approaches to meet the growing demand of the construction industry for building materials (Patel, Salla and Pitroda, 2013). The application of agricultural waste as a sustainable construction material is a means to provide a solution to the current problems.

According to Coutts and Warden, as cited by Shawia, Jabber and Mamouri (2014), developing natural fibers as composite-based products is a trend to substitute traditional engineering materials. All over the globe, different researches were conducted on the possibilities of using natural fibers such as bagasse, cereal straw, corn stalk, cotton stalk, kenaf, rice husk and rice straw for the production ofhardboard and particle board (Domke&Mude, 2015). Furthermore, wood-cement boards were found to be heat-resistant, fire-resistant, lightweight, has sound-isolating capabilities, eco-friendly and cost-effective (Mohammadkazemi, & Doosthoseini, 2015).

Rice straw, like any other natural fibers used as a substitute for construction materials, can also be utilized into something useful and economical. Studies have shown that rice straw contains high silica content of about 74.67% which can be compatible with cement (Lim, Manan, Alwi& Hashim, 2012). It has also been discovered by Munder, Karaj, Gummert, Haefle, and Muller (2012), and Guillemot, Bruant, Pasquiou, and Boucher (2014) that rice straw contains a high value of ash that resembles silica fume in terms of high silica content (Morsy, 2011). Therefore, this agricultural waste has a very high potential in producing secondary raw materials mainly due to high silica content and relatively low cost. Hence, this study was carried out to determine the optimum design mix that can be used in the production of a rice straw composite board with cementitious materials as binders and to evaluate the compressive strength properties of the rice straw composite board that will positively show the impact of utilizing agricultural wastes in Magalang, Pampanga as an advantageous construction material that deserves technological improvements.

FRAMEWORK OF THE STUDY

Many researchers believe that natural fibers reinforced composites are better replacement for conventional synthetic fibers reinforced polymers. The research idea was established from the issues involved which focused mainly on climate change issues which is one of the reasons why innovation of materials in the construction industry has been put into practice.

Figure 1 shows the block diagram used for the trial mix designs while Figure 2 shows the production process of the rice straw composite board.

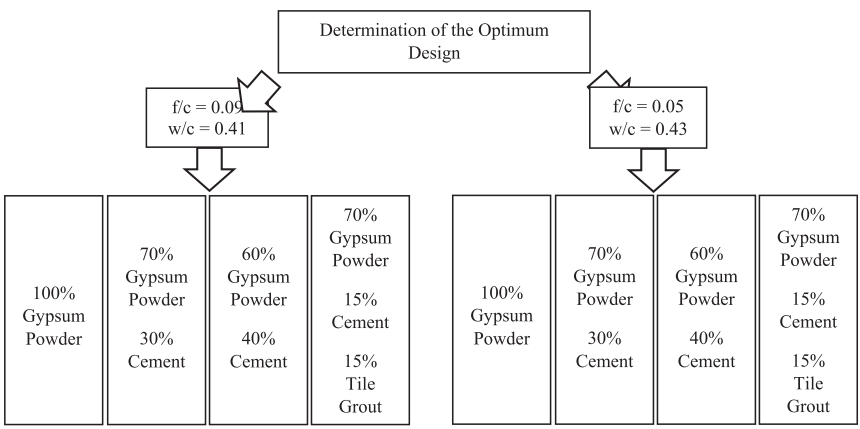

Figure 1. Block diagram for the trial mix designs

The figure describes the step by step procedure to materialize the conceptual framework. The gathering and selection of materials were conducted directly from the rice fields that are within the vicinity of Magalang, Pampanga and followed by the preparation of the rice straw. As shown in Figure 1, four variety of mixtures of the cementitious materials were applied to two variations of fiber-cement and water-cementitious material ratios. The samples were fabricated and cured and were subjected to compression test at 7, 14 and 28 days after which the optimum design was determined based on the results of the testing.

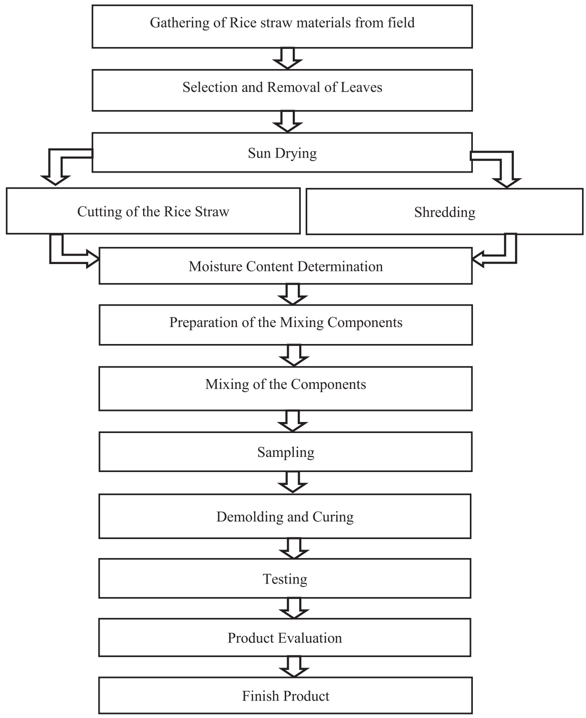

Figure 2.Production process of the rice straw composite board

METHODOLOGY

The materials used for the production of the rice straw-cementitious bonded composite board were composed of rice straws collected from barangays Sta. Cruz, and Mandani, Magalang, Pampanga, ordinary Type I Portland cement (OPC), gypsum powder, tile grout, acrylic polymer and acrylic latex. Rice straw was the main lignocellulose material used as filler. Gypsum powder, cement and tile grout served as the binding agents while acrylic polymer (mortar admixture) served as the admixture and the fresh water was used to dissolve the powder compositions. The acrylic latex was only used for the finishing touches to give a glossy effect to the product and to act as sealant or laminating agent of the board to avoid powdering.

Before the rice straw was mixed with other materials, the leaves of the rice straw were removed from the stem. Isolation of the damaged parts as well as removal of the leaves was done prior to sun drying. The rice stalks were then sun-dried to remove some water content such as dew and were cut into the sizes of 10 mm. All rice straw materials have undergone sun drying to measure its moisture content, as adopted from Shawia et al. (2014). The advantage of sun drying for different wastes is the low operating cost and little expertise is required (Muruganandam et al., 2016). The rice straw materials were kept in a storage area, covered and intact in a sack to avoid wetting.

However, to determine the optimum moisture content, the "Bone Dry" procedure was conducted. The bonedry procedure, according to licensed Agricultural Engineers from Pampanga State Agricultural University, is determining the exact moisture content of the fibers. In the book "Quality Management of Cement Concrete Construction" (Gahlot and Gehlot, 2009), in the condition of bone dry, the moisture from all permeable pores is completely evaporated.

In the bone dry procedure, the fibers were weighed with an initial amount of 50 grams and placed inside an aluminum foil. The purpose of placing the fibers in the aluminum foil is to maintain the heat being absorbed by the fibers. The fibers were placed inside an oven with a consistent temperature of 105°C. Hourly, the weight of the fiberswas taken and recorded and it was done consistently for 24 hours, though the mass of the fibers became consistent in reading upon reaching the oven-drying for 12 hours beyond. The moisture content was measured after the conduct of the dry bone procedure.

In determining the optimum design mix, there were eight mixtures prepared in the variations of the percentage of the cementitious materials, fiber-cementitious(*f/c*) ratio, and water-cementitious(*w/c*) ratio.

From the first design mixture, a fiber-cementitious ratio of 0.09 and water-cementitious ratio of 0.41. There were four variations of compositions made. The variations were composed of 100% gypsum powder, 70% gypsum powder with 30% cement, 60% gypsum powder with 40% cement and 70% gypsum powder with 15% cement and 15% tile grout. Each variation was sampled on a 50 mm x 50 mm x 50 mm steel mold and there were 9 samples prepared per variation. A total of 36 samples were prepared for testing at 7 days, 14 days, and 28 days. The second design mix used was a fiber-cementitious ratio of 0.05 and water-cementitious ratio of 0.43. The same variations of mixture were made to be compared with the previous design. Similarly, there were also a total of 36 samples prepared for 7 days, 14 days, and 28 days testing. The conduct of both trial mixes was done at the Department of Public Works and Highways Regional Office in the City of San Fernando, Pampanga. Table 1 and Table 2 reflect the trial mix designs.

Table 1. Trial Mix Designs (Length of Rice Straw = 10 mm.)

Fiber-cementitious ratio (f/c) = 0.09 Water-cementitious material ratio (w/c) = 0.41	Gypsum Powder (%)	Cement (%)	Tile Grout (%)	Admixture (%)
Mix 1	100	-	-	3
Mix 2	70	30	-	3
Mix 3	60	40	-	3
Mix 4	70	15	15	3

Table 2. Trial Mix Designs (Length of Rice Straw = 10 mm.)

Fiber-cementitious ratio (f/c) = 0.05 Water-cementitious material ratio (w/c) = 0.43	Gypsum Powder (%)	Cement (%)	Tile Grout (%)	Admixture (%)
Mix 6	100	-	-	3
Mix 7	70	30	-	3
Mix 8	60	40	-	3
Mix 9	70	15	15	3

The exploratory research method was used to observe the performance of the specimens. This is used to obtain new ideas relating to the research problems. In determining the optimum design mix, the specimens were observed and tested on 7 days, 14 days and 28 days. The specimenswere sampled, cured, and tested according to American Society for Testing and Materials (ASTM) procedures. ASTM C109 (Standard Test Method for Compressive Strength of Hydraulic Cement Mortars Using 2-in. or [50 mm.] Cube Specimen) was followed. Since there were replications made and the test was conducted at 7, 14, and 28 days, the Analysis of Variance (ANOVA) was used to determine the significant difference between the samples tested from 7 days to 28 days.

RESULTS AND DISCUSSION

The final product of the rice straw composite board was fabricated with dimensions of 300 mm x 300 mm x 10 mm. It was made from a mixture of 70% gypsum powder, 15% cement, and 15% tile grout combined with 5% rice straw fiber and 3% acrylic polymer. The cementitious materials served as a binder, the rice straw fiber as filler, and the acrylic polymer as an admixture. It has a unit weight of 1.45 kg., and with a variety of colors, depending on the color of the tile grout used. It has a rough texture due to the presence of rice straw fibers that served as a decorative design to the composite board and it is odorless.

Determination of the Optimum Design

The data presented in Figure 3 is the result of the compressive strength obtained at 7 days, 14 days, and 28 days using f/c = 0.09 and w/c = 0.41.

In the figure, the results of the mixture of 70% gypsum powder, 15% cement and 15% tile grout dominated the other mixtures with a compressive strength of 2.34 MPa at 14 days.

However, it decreases at the 28th day. According to Dai, Wood, and King(2004), the strength development in a structure is not uniform. The temperature of the specimen may vary due to the exothermic reaction of hydration while the concrete gain strength. The room temperature where the specimenswere placed during its hydration and curing may have affected the behavior. Therefore, the location of the specimens must have a uniform temperature though it could not be consistently maintained due to humidity. Room temperature can be considered.

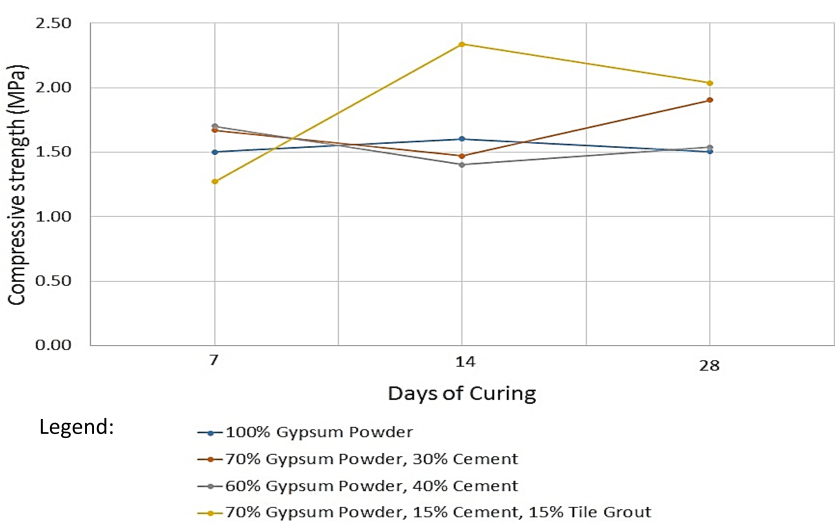

Figure 3. Results of Compression Test of the Specimen with f/c = 0.09 and w/c = 0.41

In consideration of the foregoing data, the results gathered from f/c = 0.05 and w/c = 0.43 was reflected in Figure 4.

It was observed that the same behavior was obtained by the mixture of 70% gypsum powder, 15% cement and 15% tile grout. The compressive strengths varied from 2.34 MPa to 3.5 MPa at 7 days to 28 days that means there is an increase in the strength by 33%.

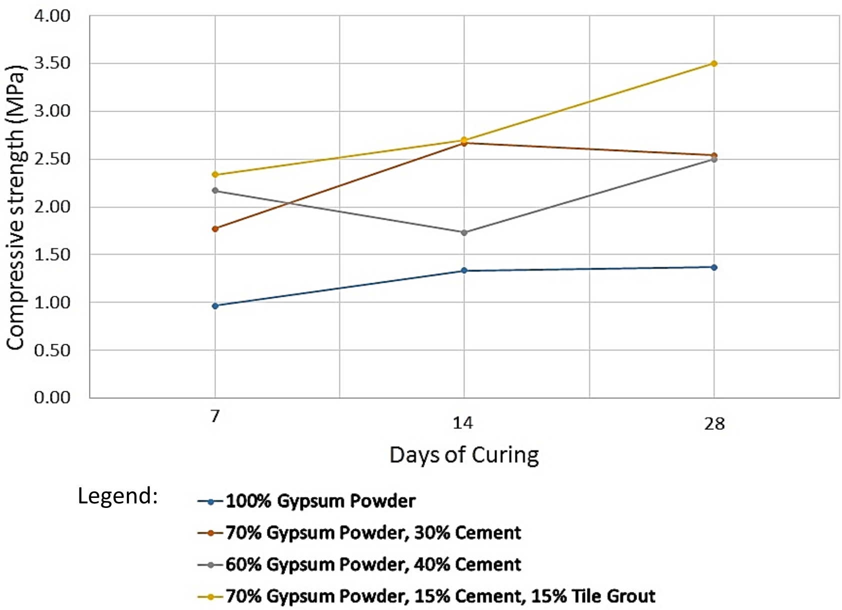

Figure 4. Results of Compression Test of the Specimen
with f/c = 0.05 and w/c = 0.43

The other mixtures showed inconsistencies in their compressive strength except for the mixture of 100% gypsum powder. However, its obtained strength was not as high as the combination of 70% gypsum powder, 15% cement and 15% tile grout. Also, a slight increase in the strength occurred at 14 days and 28 days which means that the development in the optimum strength of the specimen was already obtained during the 14 days.

Table 3. Result of the ANOVA test on the compressive strengths of the specimens with f/c = 0.09 and w/c = 0.41.

		F	Significance
	Between Groups	22.585	**.003**
Day_7	Within Groups		
	Total		
	Between Groups	3.481	.113
Day_14	Within Groups		
	Total		
	Between Groups	3.408	.116
Day_28	Within Groups		
	Total		

Table 3 shows the result of the ANOVA test on the compressive strengths of the specimens with f/c = 0.09 and w/c = 0.41. It appears that a significant difference in the compressive strength of the samples exists during the 7th day curing. This can be attributed to the effect of hydration of cement since the w/c used was lower.

Thisis supported by the principles of cement-based materials that the rate of gain of strength with continued hydration is faster at the start and gets reduced with age (Abd&Metwally, 2014). Also, the least significant difference was found on the use of the 60% gypsum powder and 40% cement combination implying that the amount of cement used in the mixture affects the f/c and w/c ratios. However, even if there is a difference between the compressive strengths at 7 and 14 days of different variations, this means that it may happen 11% at a time that implies several factors may have affected the results of the compressive strength. It can be attributed to the room condition, the sampling procedures and the curing process.

The Analysis of Variance for f/c = 0.05 and w/c = 0.43 is shown in Table 4. As revealed, there is a significant difference in the compressive strength of the samples from 7 days to 28 days using the variations of the cementitious materials. This further implies that the reduction of the fibers in the volume has affected the compressive strength of the composite board as it has a greater bonding effect with cement.

Also, each of the variations of the cementitious materials affects the behavior of the specimen during its curing period that may be a result of careful sampling and proper curing.

Table 4. Result of the ANOVA test on the compressive strengths of the specimens with f/c = 0.05 and w/c = 0.43.

		F	Significance
Day_7	Between Groups	7.950	0.000
	Within Groups		
	Total		
Day_14	Between Groups	18.451	0.000
	Within Groups		
	Total		
Day_28	Between Groups	21.008	0.000
	Within Groups		
	Total		

The percentages of cementitious materials were greatly affected by the f/c and w/c ratios in its compatibility with the rice straw fibers.

Comparing the f/c ratios between the design mixtures, the study related to the concept that the volume of fibers affects the behavior of the rice straw composite board. Studies conducted by Bae, Choi, Lee, and Bang (2016) narrated that the compressive strength tends to increase linearly with the increasing proportions of fibers. In particular, the correlation between compressive strength increase and fiber content tends to decrease with increasing design compressive strength. However, in the case of using natural fibers such as rice straw, experts believe that rice straw can impair the workability of the mixture and its compaction condition. Pickering, Efendyand Le (2016) stated that interfacial bonding between fiber and matrix has an important role in the development of the mechanical strength of natural fiber composites. Since the rice straw composite board is a plant-based composite, it may have limited interaction between the fiber and the matrix that will lead to poor interfacial bonding limiting its compressive strength. On the other hand, the rice straw used in the study was untreated and according again to Pickering, Efendyand Le (2015), the strength and stiffness of natural fibers are generally low. Therefore, the attained compressive strength of the experimental board may not be significantly as high as those with treated natural fibers.

(a) (b) (c)

Figure 5. (a) Sample of rice straw fibers cut in 10-mm. size,
(b) The ASTM standardsize steel mold used to sample specimens for compression test,
(c) a sample finished product in 300 mm. x 300 mm. x 10 mm. dimensions

The mixture that produced the highest compressive strength among the eight variations is the 70% gypsum powder with 15% cement and 15% tile grout, with f/c = 0.05 and w/c = 0.43, which was the basis for the design mix in determining the other properties of the experimental board.

CONCLUSIONS

The optimum design mix for the production of the rice straw composite board shall composed of 70% gypsum powder, 15% cement and 15% tile grout with fiber-cementitious material ratio of 0.05 and water-cementitious material ratio of 0.43. The highest compressive value acquired is 3.57 MPa at 28 days tested under ASTM C109.

RECOMMENDATIONS

It is further recommended to consider extending the curing age of the composite board to determine the deterioration age of the compressive strength. Also, it is recommended to explore on the use of treatments on the rice straw fibers and other binders to determine its effect on the compressive strength properties of the rice straw composite boards.

ACKNOWLEDGMENT

The researcher would like to acknowledge the Pampanga State Agricultural University, Commission on Higher Education, Department of Public Works and Highways, Department of Science and Technology, Bureau of Research Standards, and all the people who made this research possible.

LITERATURE CITED

Allam, M., Garas, G., & El Kady, H. (2011). Recycled Chopped Rice Straw-Cement Bricks: Mechanical, Fire Resistance & Economical Assessment. Australian Journal of Basic and Applied Sciences, 5(2), 27-33. Retrieved on January 26, 2017 from https://bit.ly/342jQQV

Bae, B. I., Choi, H. K., Lee, B. S., & Bang, C. H. (2016). Compressive behavior and mechanical characteristics and their application to stress-strain relationship of steel fiber-reinforced reactive powder concrete. Advances in Materials Science and Engineering, 2016. Retrieved on March 17, 2017 from https://www.hindawi.com/journals/amse/2016/6465218/abs/

Bolden, J., Abu-Lebdeh, T., & Fini, E. (2013). Utilization of recycled and waste materials in various construction applications. *American Journal of Environmental Science*, 9(1), 14-24. Retrieved on January 26, 2017 from https://pdfs.semanticscholar.org/d993/8ffedb4b7352cc9a8aff77df85ee519f371b.pdf

Chaluvadi, Ashok (2018). National Association of Home Builders. "Building Materials Prices and Labor Access Top Challenges for 2018." Retrieved on DATE from http://eyeonhousing.org/2018/01/building-materials-prices-and-labor-access-top-challenges-for-2018/

CEC (2014). Burning Agricultural Waste: A source of dioxins. 1-6. Montreal, Canada: Commission for Environmental Cooperation. pp.6.

Domke, P. & Mude, V. (2014). "Natural Fiber Reinforced Building Materials." IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN:2278-1648, p-IISN:2320-334x, Volume 12, Issue 3, Ver. II (May-June 2015) pp.104-107 DOI: 10.9790/1648-1232104107. Retrieved on March 17, 2017 from www.iosrjournals.org

Mohammadkazemi, F., & Doosthoseini, K. (2015). Rice Husk and Old Corrugated Container Cement Boards: Performance of Nano-SiO2 on Strength and Dimensional Stability. Iranian Journal of Chemistry and Chemical Engineering (IJCCE), 34(3), 91-98. Retrieved on January 26, 2017 from http://www.ijcce.ac.ir/article_14755_2075.html

Gahlot, P.S., Gehlot, D. (2009). Quality Management of Cement Concrete Construction. Retrieved on April 18, 2017 from https://www.abebooks.com/book-search/title/quality-management-cement-concrete-construction/author/gahlot/

Dai, J., Wood, C. R., & King, M. (2004). The Use of the Concrete Maturity Method In the Construction of Industrial Facilities: A Case Study. Retrieved on June 14, 2017 from https://www.flir.com/globalassets/discover/instruments/concrete-curing/fieldtrials-concretematurity-intellirock-case-study.pdf

Guillemot, A., Bruant, R., Pasquiou, V., & Boucher, E. (2014). Feasibility study for the implementation of two ORC power plants of 1 MW each using rice straw as a fuel in the context of a public-private partnership with the institutions PhilRice and UPLB. *ENERTIME.*

Lim, J. S., Manan, Z. A., Alwi, S. W., & Hashim, H. (2012). A review on utilization of biomass from rice industry asa source of renewable energy. *Renewable Sustainable Energy Review, 16*, 3084-3094. Retrieved on May 18, 2017 from https://www.sciencedirect.com/science/article/abs/pii/S1364032112001451

Abd elaty, Metwally. A. A. (2014). Compressive strength prediction of Portland cement concrete with age using a new model. HBRC journal, 10(2), 145-155. Retrieved on May 18, 2017 fromhttps://www.tandfonline.com/doi/full/10.1016/j.hbrcj.2013.09.005

Morsy, M. I. (2011). Properties of Rice Straw Cementitious Composite. *PhD Thesis*. Technische Universität, Darmstadt. Retrieved from on April 26, 2017 from http://tuprints.ulb.tudarmstadt.de/2847/1/Dissertation_Morsy_2011.pdf

Munder, S., Karaj, S., Gummert, M., Haefele, S., & Müller, J. (2012). Improving thermal conversion properties of rice straw by briquetting. *International*

Workshop on the innovative uses of rice straw and rice husk. Los Baños : University of Hohenheim. Retrieved from on May 18, 2017 from http://www.stiftung-fiat-panis.de/images/DF/DF537.pdf

Munshi, S., Dey, G., & Sharma, R. P. (2013). Use of rice straw ash as pozzolanic material in cement mortar., 5 *IACSIT International Journal of Engineering and Technology* (5).Retrieved on DATE fromhttp://ijetch.org/papers/626-C3005.pdf

Muruganandam, L., Ranjitha, J., Harshavardhan, A. (2016). A Review Report on Physical and Mechanical Properties of Particle Boards from organic Waste. International Journal of ChemTech Research CODEN (USA): IJCRGG ISSN: 0974-4290 Vol.9, No.01 pp 64-72, 2016

Padin, M.G. (2015, July 23). PHLWorld's 8th Biggest Rice Producer by 2016 - World Bank. Business Mirror. Retrieved on March 5, 2017 fromhttps://businessmirror.com.ph/phl-worlds-8th-biggest-rice-producer-by-2016-world-bank/

Patel, A., Salla, S., & Pitroda, J.K. (2013). Patel, A., Salla, S., & Pitroda, J.K. (2013). A study on utilization of Agro-Waste as an Innovative Material in Indian Context. *International Journal of Scientific Research. International Journal of Scientific Research, Vol. 2, Issue 2, 119-224.*

Pickering, K. L., Efendy, M. A., & Le, T. M. (2016). A review of recent developments in natural fibre composites and their mechanical performance. Composites Part A: Applied Science and Manufacturing, 83, 98-112.Retrieved on February 14, 2017 fromhttps://www.sciencedirect.com/science/article/pii/S1359835X15003115

Shawia, N. B., Jabber, M. A., & Mamouri, A. F. (2014, April). Mechanical and physical properties of natural fiber cement board for building partitions. *Physical Sciences Research International, 2*(3), 49-53. Retrieved on April 26, 2019 from http://www.netjournals.org/pdf/PSRI/2014/3/14-021.pdf

Valencia, C. (2018). "Prices of building materials continue to rise in July 2018 - PSA". PhilStar Global. Retrieved on August 23, 2018 fromhttps://www.philstar.com/business/2018/08/23/1844918/prices-building-materials-continue-rise-july-2018-psa

Zafar, S. (2015, March 22). *Agricultural Wastes in the Philippines*. Retrieved from BioEnergy Consult: Powering Clean Energy Future. Retrieved on May 18, 2017 from https://www.bioenergyconsult.com/agricultural-resources-in-philippines/