



USE OF WASTE MATERIALS IN CONSTRUCTION OF LOW-COST ENGINEERED WOOD

Ali, Sara¹, Zahran, Khaled¹, Assal, Mohamed¹, Sakkari, Moustafa¹, Nasser, Omar¹, Diab, Seif El-din¹, Tageldin, Mustafa¹, Darwish, Mohamed^{2*}, Nassar, Khaled³ and Youssef, Passant⁴

¹Student, American University in Cairo, Egypt

²Lecturer, Ahran Canadian University; Adjunct Faculty, American University in Cairo, Egypt

³Associate Professor, American University in Cairo, Egypt

⁴Teaching and Research Assistant, American University in Cairo, Egypt

*Corresponding Author: mdarwish@aucegypt.edu

Abstract: The waste produced during the process of wood sawing has been a source of pollution and hazards for years. The use of such waste together with different binders in the production of engineered wood products has been studied by researchers for the past three decades. The current study involves performing several mixes of the wastes and the binding materials with different proportions. Standard strength tests are performed on the different mixtures produced to determine the mix having the best properties. Structural analysis and design of wall panels made of the chosen mix are performed. Finally, a parametric study is performed to choose the safe cross-section and dimensions of the panels minimizing the material cost of the wall.

1 INTRODUCTION

The construction market is shifting rapidly towards the dry trade rather than the wet trade and new construction methods are being adopted, the growth of new technologies in the construction industry is expected to have an impact on the way construction is performed in the future, The wood panel walls present a new method to help reduce cost and time during the construction process by applying wood as an alternative for ordinary inner brick walls which is time consuming, relatively expensive and labor intensive and has a low productivity.

The concept of having ready-made wall panels through the use of gypsum boards as an alternative to the brick walls has been adopted in the construction industry; however, Gypsum boards are known of being costly. This discovery triggered the search for a lower cost wall panel alternative. In addition, another aspect factored in while creating an alternative was being environmental friendly, a direction the top firms worldwide are now following.

On the other hand, a group of researchers designed and manufactured a wood-plastic composite pallets to replace the ordinary existing pallets due to its back draws such as degradation due to environmental factors, unreliable performance of the pallets over a period of time due to the method of fastening members of the pallets by nailing or screwing and the forest depletion due to excessive use of trees as well, which is mainly that the pallets are not environmentally friendly (Bahravesh, Rouhani & Zolfaghari, 2009).

Therefore, to overcome such drawbacks and be able to apply this on wall panels is through introducing an alternative way to for the wall panels to be environmentally friendly.

Moreover, Wood Waste was used instead of cutting more trees down to use them in manufacturing, reducing the total cost of internal wall panels compared with using new wood that was never used before. It is also environmentally friendly to use waste instead of disposing them.

Engineered wood nowadays is a trend in manufacturing and they are more recommended as they have better materials properties and performances and the concept of using of engineered wood in this project was introduced due to the advantages of engineered wood than using ordinary brick walls or even using the gypsum boards after comparing some materials properties and advantages of using ordinary brick walls and Engineered wood in construction. From these advantages is that engineered wood products provide high quality products for end users, dimension stability, accuracy and they are also considered more environmentally friendly than ordinary brick walls and gypsum boards. (Jahromi, 2006)

The wood mix design comprised of Eucalyptus wood waste, sawdust and sodium silicate as the binder which has been used before to help resist fire, the results are considered to be promising and could be further developed to reach an adequate product to be used

Different samples with different mix ratios were produced and tested; to test the materials properties; a final sample with the best mix design obtained was produced and underwent different tests according to the ASTM regulations, those tests are static bending test, compressive strength and a full scale test. Moreover, SAP software was used to reach the optimum dimensions and loads.

2 SCOPE AND APPROACH

The scope is to design and manufacture sandwich wall panels from engineered wood that contains two layer of wood and a filler material in between. This filler material is used to reduce the weight of the wall panel which will make these panels more competitive with ordinary brick walls in terms of the weight. The type of wood waste used is Eucalyptus as shown in figure 1. Eucalyptus wood is very abundant; Its produced in huge amounts everyday in arid countries including Egypt.



Figure 1: Eucalyptus wood logs

The binder used to adhere these wood particles with each other is Sodium Silicate, which is a bi-product of the glass industry. It is available in the form of a fluid and also as powder. Each of the two forms whether liquid or powder has its own benefits and drawbacks (Keawthun, 2013). In this paper we used the fluid sodium silicate.

For the internal filler material, Extruded Polystyrene known as XPS was used. It is intended to decrease the weight of the wall panels in addition to providing an insulation barrier as shown in figure 2.



Figure 2: The Extruded Polystyrene after being placed above the lower layer of the panel.

On modeling the structure numerically, the XPS was represented in the SAP model as a hollow core material in order to account for its existence.

3 WORK PROCEDURE

3.1 Pilot Trials

First, the idea started with wood waste produced from factories and how to benefit from this waste in order to prevent the huge amount of disposal since such materials have a huge impact on the environment which will be discussed later on in the report.

A research was conducted to understand which kind of wood waste could be used and to know more about the main wood waste that Egypt produces daily. There are mainly two types of wood waste that factories produce everyday: Eucalyptus and Pine wood. Since Eucalyptus is used in more industries than the Pine wood thus the amount of waste is more than that of the Pine Wood and it's also commercially available. As a consequence, the eucalyptus wood was the one used in the wood mix design.

Secondly, For the binder materials that will be used, Initially Augmen, Urea Formaldehyde, polyvinyl alcohol and Sodium Silicate were the binders choices available based on previous literature report and current ventures ideas; However, based on previous results and cost aspect (5LE/Kilo) Augmen was selected. However, Augmen is not commercially available which will cause a lot of problems in case of mass production of these wall panels.

Then, for the second option Urea Formaldehyde it is commercially available and has had very good results based on previous works. However, after some research it was concluded that its Carcinogenic and banned in multiple countries including Canada and United States. Thus we had disregard it as an option.

Then, polyvinyl alcohol was the final choice and was performed on ten different samples with different binder ratios. However, the samples were very fragile and the results were not promising at all in addition the cost of the material is extremely high which is 25 LE/200ml.

Consequently, Sodium Silicate was the optimum choice for many reasons as its cost was very cheap (2.5 LE / Liter), it was commercially available in addition to being a waste material which increases the eco-friendliness of the final product. Hence, it was used within the different samples; The results were very promising and fortunately this was the material adhered to and used to reach our optimum mix design and optimum Wood/Binder ratio.

3.2 Tests Performed

Tests made in the research included:

- Unit weight test
- Compression test
- 3-point bending test

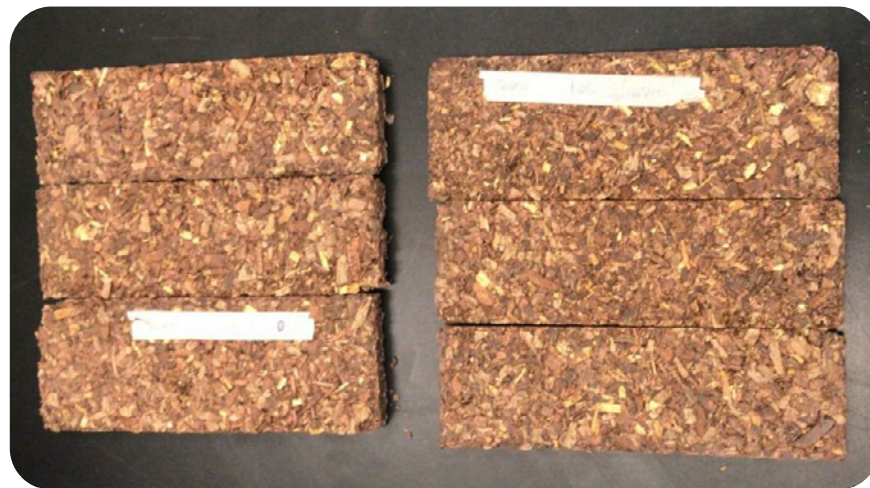


Figure 3: Samples before subjected to bending test

The bending test was performed with dimensions of 250 mm in length and 75 mm in width and a thickness of 10 mm according to the ASTM D1037 method of testing, as shown in figure 3, and each sample was repeated three times to get an average results and to be more accurate.

4 EXPERIMENTAL WORK

4.1 Sample Preparation

This process targeted the preparation of different samples in order to reach the best mixture and its corresponding production process.

4.1.1 Mix design

Produce a mix design for the engineered wood of the panel and test some of its properties. The sample preparation is not just a one easy step like it could appear. The sample preparation started with giving an eye on many literature review related to similar products in the field as well as a price estimate was made from the start of the sample preparation to determine the feasibility of the sandwich wood panels according to the Egyptian market, and compared to other alternative products.

4.1.2 Parametric Study

That involved changing the parameter to reach the optimum mix design. Parameters under study are:

- Particle size
- Wood Binder Ratio
- Sawdust percentages
- Temperature
- Pressure applied during production

4.1.3 Find optimum mix

The optimal mix design is defined as the one having the highest modulus of elasticity while still being light in weight. This was important as this highest modulus of elasticity will ease the design of a panel of a small cross-section however is still stiff enough to carry the design loads.

4.2 Equipment Used

- Steel sheets: Steel sheets are used to cover the sample in the mold and to separate between the mold and the mix so they do not stick at the edges
- Filters: Filters are used with steel sheets to separate between the mixed sample and the mold, as it will be easier for the sample to be removed from the mold
- Mixer: Mixer was used to mix the wood particles with sodium silicate
- Sieves: were used to be able to differentiate between sizes of wood particles
- Compressing machine: The compress machine used in the wood mechanical lab was used to compress the samples for 2 hours with temperature 70 Degrees
- Scale: for measuring the weight of the Samples

4.3 Fabrication

The fabrication process was difficult, it included the mix design, the type of insulator, temperatures of compressing and finally the compressing pressure:

4.3.1 Changing the parameter to reach the optimum mix design:

Table 1: Type of wood and its sizes

Wood Size	Material	Type	Cost
8mm,4mm,Filler	Eucalyptus	Recycled Wood	1200 LE/ton

The wood type used was Eucalyptus with different sizes as shown in table 1 and it's a recycled wood with the cost of 1200 Egyptian pounds per ton.

4.3.2 The Binder:

Table 2: Information about the binder used

Percentage	Material	Type	Cost
30-40%	Sodium Silicate	Water Glass	2.5 LE/Liter

The binder used was the sodium silicate with 30% to 40% of the wood weight as shown in Table 2 and the cost of sodium silicate is extremely low which will benefit us in reducing the whole cost of the wall panel.

4.3.3 Compressing Time and Temperature:

Table 3: Production Variables

Temperature	Load of Compression	Time for Compression
25 °C	50 KN	2 Hours
50 °C	75 KN	
70 °C		

As explained in table 3, the load used for compressing the sample was either 50 KN or 75 KN, limited to 75 KN load because the compressing machine could not maintain higher loads and at the same time the temperature for the compression was between the room temperature, 50 °C and 70 °C. The unheated samples were better in reducing cost. However, the heated ones were better in terms of strength.

Six different samples were produced with the following properties indicated in table 4 and tested them to choose the one with the highest strength and will be discussed in details in the following pages.

Table 4: Table of Mix design

Sample No.	Binder Percentage	Wood Size (mm)	Temp. (°C)	Load (KN)
Sample 1	30	8	50	50
Sample 2	40	8	70	50
Sample 3	30	8	70	50
Sample 4	40	8	Room Temp.	50
Sample 5	30	8	Room Temp.	50
Sample 6	40	4 & 8	70	50

The 3 points bending test was performed by the Universal Testing Machine as shown in figure 4. The test span was 200 mm and the rate of loading was 1 mm/minute.



Figure 4: The Universal Testing Machine with the Sample

4.4 Results

Six different samples were tested with percentages of the binder varying from 30% to 40% and compressed with heat of temperature varying from 50 to 70 degrees Celsius. Three of each sample mix were tested and data was based on the average of the three. The second sample was the most promising as it could withstand the highest load during the test before failure. All the samples were also very ductile since they are still capable carry a load after failure, as shown in Figure 5, unlike brittle materials for example Gypsum board.

4.4.1 Best sample Results

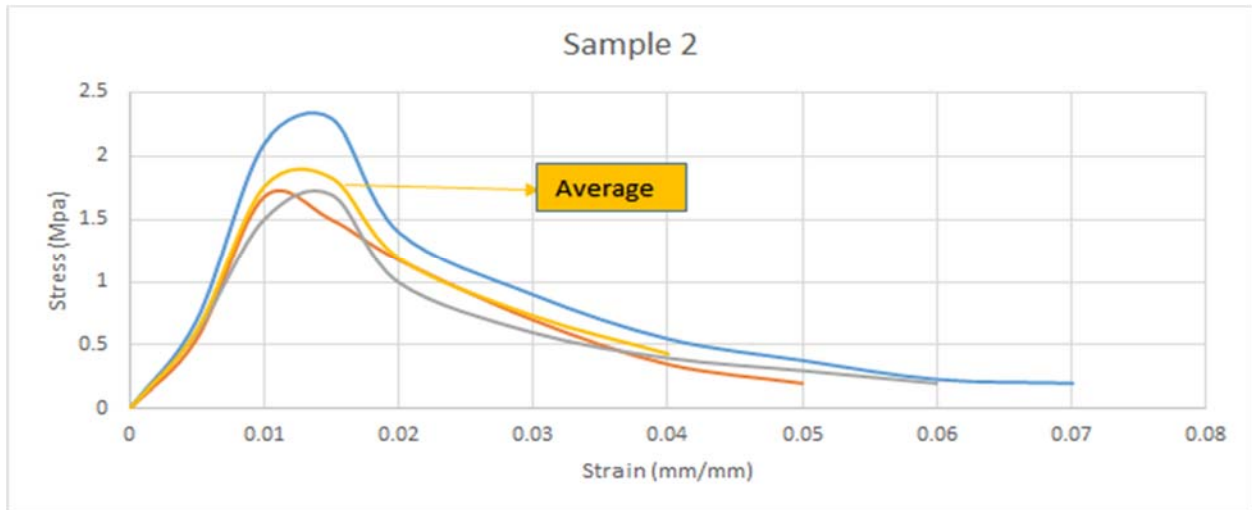


Figure 5: The Stress Vs. Strain Graph for the Second Sample

Table 5: Results of the six tested mixtures

Mixture #	Modulus of Elasticity (MPa)	Bending Strength (MPa)	Unit Weight (kg/m ³)
1	43	0.496	608
2	228	1.83	683
3	192	1.43	621
4	40	0.57	668
5	44	0.33	617
6	30	1.22	708

After performing the 18 bending tests, three of each sample to get more accurate results, sample number two showed the most promising results as indicated in figure 5. As shown in Table 5, the second mix withstood a bending strength of 1.83 MPa and then calculating the modulus of elasticity which came out to be 228 MPa and the sample came out to be very ductile since it was still capable carry a load after failure, as shown in the stress-strain diagram in figure 5 and the failed specimen shown in figure 6.



Figure 6: The specimen at point of failure.

5 STRUCTURAL ANALYSIS

A parametric study was performed on the dimensions of the panel using material properties obtained from the test results above as input to SAP2000 (Computers and Structures Inc., 2017). The target of this process was to reach the design with lowest deflections, lowest weight and lowest cost.

5.1 SAP Model

Four different cases with different dimensions were used in order to reach the design with lowest deflection. The wood elasticity property was entered into the sap model in order to somehow resemble what the real life test deflection would occur. Three-dimensional eight-node elements were used to model the structure. A load equivalent to the wind load in an open-terrain area calculated according to the Egyptian loading code (Housing and Building Research Center, 2012) was applied on the panel. The dimensions shown by arrows in figure 7 were what was varied in order to reach the dimensions with the highest strength.

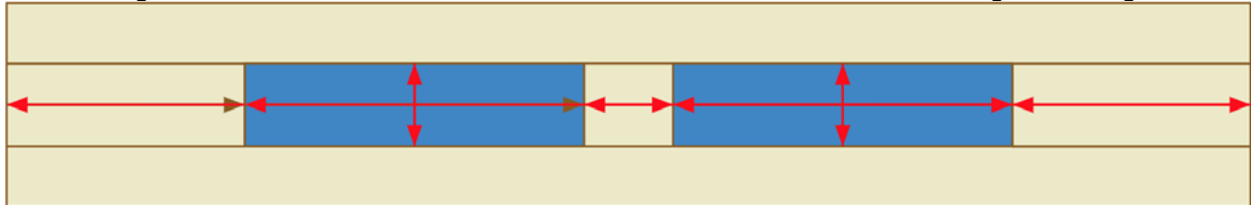


Figure 7: The parameters varied in the SAP2000 model

Different dimensions were used in different models on SAP2000 to reach the optimum dimensions with the highest strength and several iterations was performed till reaching the optimum dimensions.

As shown in figure 8, the 3-dimensional SAP2000 Model was meshed into several elements in order to make the results as accurate as possible. The supports were placed; Hinged Joints. As for the XPS it was resembled in the model as air in order to make account for the weak areas surrounding the XPS on the SAP2000 model. The following model represents the ideal proportions that we researched based on several iterative trials.

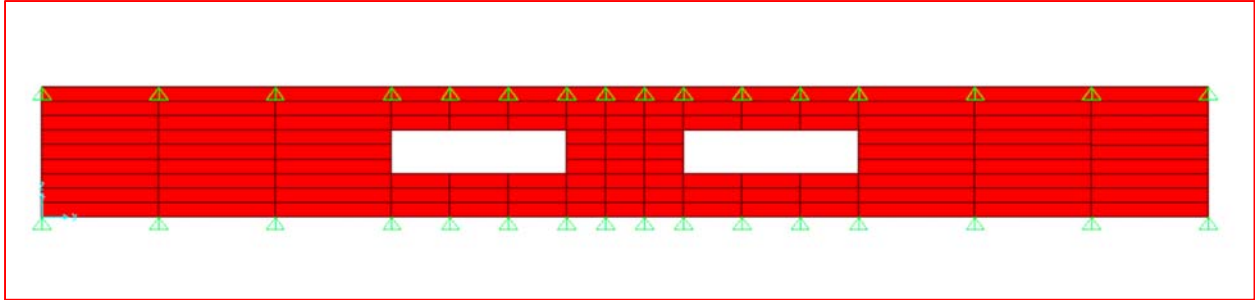


Figure 8: The optimal sample mesh side view

5.2 Results

Finally, the deflection of all the models was calculated using SAP2000, which was used as a caliber to determine the best dimensions. Figure 9 shows the deflected shape of the panel having the optimal dimensions corresponding to the lowest deflection reached from all of the dimensions varied in the parametric study.

The optimal dimensions that was reached resulting in the least deflection were that the total panel width was 1000 mm, the width of the XPS was 150 mm which is repeated twice with a spacing between them of 100 mm and the thickness of the whole panel is 120 mm with a thickness of the XPS of 40 mm and a layer of wood above it and below it of thickness 40 mm also as indicated in the figure below.

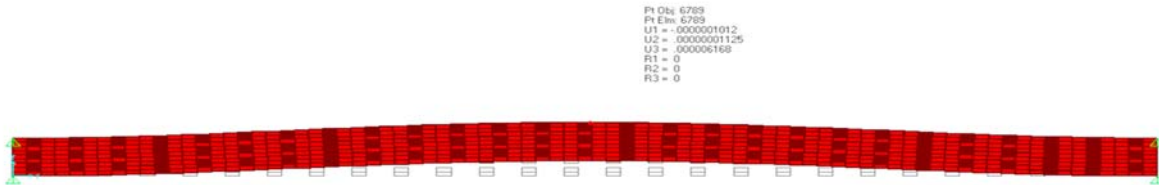


Figure 9: The deflected shape of the panel having the optimal dimensions.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

From the performed tests and analysis, the following conclusions could be drawn:

- The mix reached was made from waste wood and an industrial waste binder.
- The optimal designed mixture had the highest modulus of elasticity of 228 MPa and the highest flexural strength of 1.83 MPa.
- The chosen mixture had a light weight of 683 kg/m³.
- The optimal tested specimen was proven to have a ductile mode of failure.
- The designed panel analyzed numerically withstood the design wind load with minor deflections.
- The optimal dimensions that was reached resulting in the least deflection were that the total panel width was 1000 mm, the width of the XPS was 150 mm which is repeated twice with a spacing between them of 100 mm and the thickness of the whole panel is 120 mm with a thickness of the XPS of 40 mm and a layer of wood above it and below it of thickness 40 mm.

6.2 Recommendations

From the performed tests and analysis, the following recommendations could be drawn:

- Further analysis is needed to study the performance of the newly designed panels during assembly.
- Full-scale structural testing of the designed panels needs to be performed.
- A thorough cost analysis needs to be performed in order to compare the various material, transportation and assembly costs of the designed panels to those of the existing commercially-available panels.

Acknowledgements

The authors would like to thank the assistance of the lab crew and the availability of the lab technicians for long periods of time. Also we appreciate the help the construction engineering department for its support and guidance throughout the research and lab tests.

References

- Computers and Structures Inc. (2017, January). SAP2000. License #3010*178HGQX4P24QLHF. New York, NY, USA: Computers and Structures Inc.
- Housing and Building Research Center. (2012). Egyptian Code for Loads. Cairo: Ministry of Housing and Building - Arab Republic of Egypt.
- Jahromi, Ali. *Development and Evaluation of Composite Insulated Beams*. Lap Lambert Academic Publ, 2011.
- KEAWTHUN, et al. "Conversion of Waste Glasses into Sodium Silicate Solutions." *Trade Science Inc*, 31 Dec. 2013. [DOI:10.1155/2013/1155201311552013](#)
- Soury, E., et al. "Design, Optimization and Manufacturing of Wood Plastic Composite Pallet." *Materials & Design*, vol. 30, no. 10, 2009, pp. 4183–4191., doi:10.1016/j.matdes.2009.04.035.
- "Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials." *ASTM International*, 1999, doi:10.1520/d1037-06a.