The Polymer Brick as Nano-Technology based Material to Support Green Building Construction

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Abstract—**Cement in construction should be reduced because it will increase the emission of CO_2 in the world. In our previous research we introduce foam bricks, while in this research we made polymer brick, a material which is made of plastic and sugar industry waste. Polymer-brick is a new material that reduces the use of cement. The use of cement is replaced by baggase ash released from the sugar mills. In addition, the new material is made of plastic-polymer waste as a raw aggregate and Recycled Concrete aggregate (RCA). In laboratory tests, it is found out that the additional nano-technology will increase compressive strength at about 10,00–24, 57 %.**

Keywords-component; polymer-brick; baggase ash; polymer waste; nano-technology

I. Introduction

Green environment is conserved environment. Green environment has conditions that are free from hazardous waste that corrupted it. In the other hand, construction world is either directly or indirectly contributed to the environmental degradation that results in global warming and climate change [1,2]. One of the examples is the use of cement in the construction of which has been accounted for the second largest CO2 emissions after electricity generation usage [3]. Another issue about the rising price of oil resulted in the construction material products including material such as clay bricks and a number of other construction materials. Therefore, research on Green-material products will meet the challenges of economical and environmental aspects. The use of baggase ash from sugar mills in *Trangkil-Pati*, the city located in northern part of Central Java Province, Indonesia, in previous research had been proven to increase the compressive strength of lightweight concrete because it is similar to fly ash.[4]

Most of plastic waste comes from food and culinary business, one of which is the food around the campus of *Diponegoro* University. Instant noodle stalls spread around the campus and home boarding. Within 1 day of each stall will throw 40-50 packs of instant noodle scar. It can be magined if there are 50-60 instant noodle stalls, then there will be 2500-3000 packets of instant noodles per day are disposed off into the environment. Then, in a month there are 7500-9000 plastics will be thrown. This is so fantastic, because plastic waste will pollute the environment. Therefore the waste plastic-polymer must be processed into something useful for mankind [5].

II. RESEARCH BACKGROUND AND AIM

Global awareness about the environment and climate change in recent years began to rise. The current green movement is not only aimed to protect the natural resources, but also implemented as the efficiency of energy use and minimize environmental damage. It is very beneficial for developing countries, especially Indonesia, which is conducting the equitable and sustainable development. Like Styrofoam, plastic waste is difficult to disentangle. Based on background research, then the plastic waste has been processed into something useful [5].

The purpose of this study is to determine the performance of the polymer-brick, not only of the ability of acoustic but also compressive strength and density reduction.

III. RESEARCH AREA

Lightweight concrete is concrete with lightweight aggregate material that complies with the requirements of ASTM-C.330 [6] and has a unit mass of dry air as determined no more than 1900 kg/cm^3. To achieve its light weight, the coarse aggregate concrete substituted with polymer waste. Bagasse ash is a sugar industry waste. With this substitution material is expected to have a value of green lightweight concrete material, because based on the utilization of waste. Research areas would describe the substitution of material.[5]

Polymer is one of Recycled Concrete Aggregate (RCA) [7]. Polymer of instant noodles is included as the polyurethane. Generally, there are two types of plastic materials consist of thermoplastic and thermoset plastic. Thermoplastics are plastic that can be recycled, such as bottles, styrofoam, plastic packaging and so forth. Whereas thermoset plastics cannot be recycled. Polyprophylene memiliki besaran gravity yang paling ringan sebesar 0,85-0,90 Polyprophylene has the lighest magnitude of gravity at about 0.85-0.90 (Mujiarto, I, 2005) [8]. While the poly acetate has a value of gravity that equal to 1.38. Polymer is a material which is difficult to be destroyed and broken down by the environment.

The use of cement in building construction will add to the effects of greenhouse gases on the environment, because the limestone calcinations and burning coal by the cement industry would result in emissions of carbon dioxide gas (CO_2). Therefore, researchers using bagasse ash for cement substitute.

Bagasse is a side-product (residue) from the processing of sugar cane (*saccharum oficinarum*). Cane is processed to be taken its sap used for the manufacture of sugar. The fresh sugar cane is milled up to several times so that its sap can be issued all. Sugar cane milling process is done until sugar is completely dry of sap [1].

The application of this new material will be discussing about how to contribute the value of OTTV (Overall Thermal Transfer Value) in a sample building if using polymer-brick material when compared with the application of red-brick, and massive concrete brick [9,10].

IV. RESEARCH METHODS

Based on the description of the background and purpose of the study, the research method will be directed towards identifies the technical specifications of this new material. Specifications of the new material to be identified are: compressive strength, density reduction, thermal resistance, acoustic abilities, and Overall Thermal Transfer Value in building using Polymer-Brick.

Research methods of the new material will be described based on the research objectives, as follows:

A. Compressive Strength

In this study, raw aggregate substituted by polymer based on the volume. Muntilan sand is the outcome of natural disasters of Mount Merapi, one of the volcanoes in Muntilan-Indonesia, as a fine aggregate of the foam-brick. The baggase ash substitutes cement in polymer-brick composition. The addition of polymer and baggase ash substitution is expected to produce lightweight concrete with a higher compressive strength. The equation of compressive strength in material is [4]:

$$\sigma = \frac{P}{A} \tag{1}$$

with:

σ : Compressive Strength (kg/cm^2)
P : Compressive power (kg)
A : Cross-sectional area (cm^2)

B. Material Density

The formula below is equation of the specific gravity level on polymer and concrete with baggase-ash [4].

$$\rho = \frac{m}{V} \tag{2}$$

where:

ρ : Density (g/cm^3)
m : The initial weight of spesiment/ sample of material (g)
V : Volume of sample (cm^3)

C. Acoustical Performance

The sound reduction function by a certain material is determined by the value of Sound Transmission Loss (STL) of the material. STL is the ability of a material to reduce noise. Its value has deci Bell (dB) in units. The higher the value of STL, the better the material in reducing noise [11]. For ease in determining the magnitude of the sound insulation of a quantity, it is defined a single Sound Transmission Class conducted from STL measurements with filter 1/3 octave in the frequency range 125 Hz to 4000 Hz.

D. The Application of Polymer-brick in Building and Overall Thermal Transfer Value

The last step in this research method is how the application materials to the building, whether it has a good ability in creating comfort for building occupants. Application polymer-brick on the building will be measured by the extent of OTTV (Overall Thermal Transfer Value) in the building envelope which is achieved by using polymer-brick wall material. OTTV is determined by a variety of variables. While the formula Overall Thermal Transfer Value (OTTV) by Szokolay are as follows [12]:

$$OTTV = \alpha[U_W \times (1 - WWR)] \times TD_{EK} + (U_F \times WWR \times \Delta T) + (SC \times WWR \times SF) \tag{3}$$

with:

OTTV	:	Overall thermal displacement rates on the exterior wall of which has a specific direction or orientation (W/m2).
α	:	Absorption of solar radiation
U_W	:	Thermal transmittance of opaque wall ($W/m^2.K$)
WWR	:	The ratio of the entire wall of windows with an outside outside of the specified orientation
TD_{EK}	:	Equivalent temperature difference (K)
SF	:	Factors of Solar Radiation (W/m^2)
SC	:	Shading coefficient of fenestration systems
U_F	:	Fenestration of thermal transmittance ($W/m^2.K$)
ΔT	:	The plan of temperature difference between the outside and the inside (°C)

The total OTTV of building envelope calculation use the formula as belows:[12]

$$OTTV = \frac{(A_{01} \times OTTV_1) + (A_{02} \times OTTV_2) + ... + (A_{0i} + OTTV_i)}{A_{01} + A_{02} + ... + A_{0i}} \tag{4}$$

V. ANALYSIS

Lightweight concrete as an environmental friendly material is expected to be useful as construction materials in sustainable development in Indonesia. Its density lightweight construction will greatly save computation which ultimately will save construction budget because it will reduce the volume of concrete construction elements such as foundations, columns and beams.

The following analyses of some physical aspects of lightweight polymer brick are described according to the research methods:

A. *Compressive Strength*

The entire test object has been done powerful compress tests at the age of 28 days. The Compressive strength tests used UTM (Universal Testing Machine) ex Hung Ta in Laboratory of materials and structures, Civil Engineering, *Diponegoro University* [13,14,15]. From the compressive strenth test, it was found out the output as seen on table I.

Based on previous research [4] the addition of bagasse ash as a cement substitute with the portion of 15% in concrete can be seen in the table below. It can be seen that the increase in concrete compressive strength is directly proportional to aging concrete.

TABLE I. THE AVERAGE COMPRESSIVE STRENGTH OF POLYMER BRICK [5]

Sample Test	Max. Force (Ton)	Compressive Strength (kg/cm^2)	Compressive Strength average (kg/cm^2)
Raw Agregat-normal 100%	35.0	350.0	400.00
	43.0	430.0	
	42.0	420.0	
Polymer agregate 100% + Nano 0%	12.0	120.0	133.33
	15.0	150.0	
	13.0	130.0	
Polymer agregate 100% + Nano 10%	14.0	140.0	146.67
	15.0	150.0	
	15.0	150.0	
Polymer agregate 100% + Nano 20%	15.0	150.0	166.00
	16.0	160.0	
	17.0	170.0	

On normal concrete, when the material sample given a compressive power between 35,0-42,0 Ton, then compressive strength will be around 400 kg/cm^2. When raw aggregates are replaced with polymers, then the compressive strength of the concrete will be only 133,33 kg/cm^2 (see table I). The addition of 10% nano technology in baggase ash will add compressive strength 10.00%. While the addition of 20% nano technology will add to the compressive strength of 24,57%.

The influence of nano-technology is comparable to the compressive strength [13]. The following image is a High Energy Milling tool owned by integrated Laboratory, Diponegoro University, Semarang, Indonesia (figure 1).

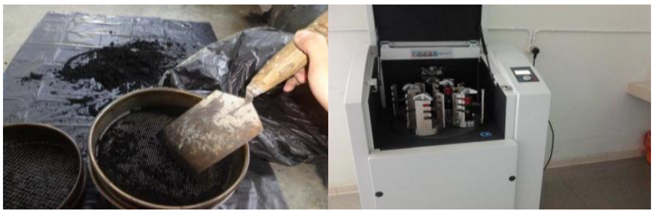

Figure 1. Filtering the baggase ash and High Energy Milling

B. *Material Density*

Obtaining the specific gravity level on polymer and concrete with baggase ash, the Mix design concrete is a method in the design of lightweight concrete. This method is based on the constituent materials of concrete, the raw aggregate, fine aggregate, and cement as composite. The mix design method used in this study is the DOE method. The Mix Design aims to determine the effect of nano-technology to the compressive strength. In this research in the form of gravel in the manufacture of concrete was replaced with polymer to make lightweight concrete. Besides cement as a binder, it will also be substituted with bagasse ash.

The addition of polymer in concrete is directly proportional to the decrease in the unit weight of the concrete. Measurement results on density can be seen in the table below:

TABLE II. THE AVERAGE DENSITY OF POLYMER BRICK

Sample Test	Weight (gram)	Density (g/cm^3)	Average Density (g/cm^3)
Raw Agregat-normal 100%	2,450	2.45	2.44
	2,470	2.47	
	2,390	2.39	
Polymer agregate 100% + Nano 0%	1,730	1.73	1.73
	1,770	1.77	
	1,700	1.70	
Polymer agregate 100% + Nano 10%	1,760	1.76	1.76
	1,750	1.75	
	1,760	1.76	
Polymer agregate 100% + Nano 20%	1,760	1.76	1.76
	1,740	1.74	
	1,770	1.77	

Table II shows that the polymer that replaces the coarse aggregate will lose not only the weight of the concrete but also the density of the concrete. Decrease the weight of the concrete will be very beneficial to the construction of the world, because the lighter the concrete, the lighter thet building structures.

C. *Acoustical Performance*

Noise reduction insulation values (Sound Transmission Loss) of red bricks has range between 35-40 dB [11]. In this study, researcher calculated the value of the polymer brick STL conducted on Acoustic laboratory. The results obtained from testing the value of Sound Transmission Loss (STL) is as follows:

TABLE III. THE ABSORBTION COEFFICIENT OF POLYMER BRICK

	N	Minimum	Maximum	Mean	Std. Deviation	Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error
FREQUENCY	800	8	6400	3204.00	1848.675	-1.200	.173
ABSOBTION COEFFICIENT	800	-.02380	9.19360	.2642946	.37403772	406.855	.173
Valid N (listwise)	800						

Observation on the absorption coefficient of Polymer Brick indicates that from 800 times the measurement by using impedance tube, the average absorption coefficient of polymer brick is 0,26429. The measurement is performed with a scale of 1/3 octave from low-frequency until high-frequency (see table III).

The Data generated by the impedance tube showed that the absorption coefficients of polymer brick is > 0.2 on medium frequency range, 1800 Hz up to 4500 Hz.

For the value of Sound Transmission Loss (STL), researchers did a measurement with impedance tube with 4 microphones. The measurement is done with 1/3 octave filter. And the result is as follows:

TABLE IV. THE SOUND TRANSMISSION LOSS (STL) OF POLYMER BRICK

	N	Minimum	Maximum	Mean	Std. Deviation	Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error
FREQUENCY	3200	2.00	6400.00	3201.0000	1847.80951	-1.200	.087
STL	3200	32.240	57.976	53.90800	2.978746	5.353	.087
Valid N (listwise)	3200						

From the output data of impedance tube with 3200 time measurements, it can be concluded that the average Sound Transmission Loss (STL) of polymer brick is 53,908 dB (see table IV). The output data from the impedance tube described polymer material brick has STL at about 48 dB at frequency of 1000 Hz. Then gradually rose to > 50 db at middle to high frequency. From the data mentioned above, the researchers concluded that polymer material can be applied as a new building brick material from its acoustical capabilities.

D. *The Application of Polymer Brick in Building and OTTV (Overall Thermal Transfer Value)*

To analyze the application of polymer-brick building in achieving optimization of Overall Thermal Transfer Value, the researchers conducted a comparison of other materials in building applications. The sample building that we will discuss is Wijaya Kusuma building at Orthopedic Hospital in Surakarta, Indonesia.

(a) (b)

Fig. 2: Building plan and photograph [7]

Building on the long side direction of the West and East, so most of the openings located on the northern and southern facades (see figure 2)

The table below is the results of calculation of the value of conduction for the brick wall construction materials [9].

TABLE V. CONDUCTION VALUE OF RED BRICK WALL CONSTRUCTION IN A SAMPLE BUILDING [7]

Envelope	**Sqm**	**Sub Total Conduction**	**Conduction W/Sqm**
SOUTH	514,10	7838,87	15,25
WEST	604,17	8839,33	14,63
NORTH	496,33	8007,94	16,13
EAST	337,92	6098,63	18,05
	1952,52	30784,77	15,77

The highest conduction is east wall of the building at about 18,05 W/sqm, and the lowest is 14,63 W/sqm at the west wall (see table V). The average of wall conduction is 15,77 W/sqm, which is calculated from the total conduction and total wall surface.

Brick wall conduction value is then compared with the polymer-brick wall conduction, as follows:

TABLE VI. CONDUCTION VALUE OF POLYMER BRICK WALL CONSTRUCTION IN A SAMPLE BUILDING [9]

Envelope	**Sqm**	**Sub Total Conduction**	**Conduction/Sqm**
SOUTH	514,10	5621,48	10,93
WEST	604,17	7500,41	12,41
NORTH	496,33	5203,35	10,48
EAST	337,92	3671,13	10,86
	1952,52	21996,37	11,27

Thirdly, conduction value of polymer-brick is then compared to the conduction value of massive concrete brick wall construction:

TABLE VII. CONDUCTION VALUE OF MASSIVE CONCRETE BRICK WALL CONSTRUCTION IN A SAMPLE BUILDING [9]

Envelope	**Sqm**	**Sub Total Conduction**	**Conduction/Sqm**
SOUTH	514,10	9141,26	17,78
WEST	604,17	9590,55	15,87
NORTH	496,33	9406,13	18,95
EAST	337,92	7228,37	21,39
	1952,52	35366,31	18,11

Based on the three conduction value table of wall construction above, it can be concluded that the use of polymer-brick material in building construction has a value at the lowest conduction.

TABLE VIII. COMPARISON VALUE VALUE BASED OTTV CONDUCTION WALL

No	Wall Construction	Wall Conduction	OTTV
1	RED BRICK 12 MM	15,767	70,92
2	POLYMER BRICK 12 MM	12,352	68,75
3	MASSIVE CONCRETE 12 MM	18,113	72,88

Conduction value of the wall material will affect the Overall Thermal Transfer Value (OTTV) building envelope of 0.2 - 5%. OTTV value is computed based on the value of the conduction wall material as seen in table VIII.

From the table (V-VIII) it is found out that the use of polymer-brick building wall construction will be lowered the OTTV of building envelope at about 5.256%.

VI. CONCLUSIONS

Based on the description above, in this study we can conclude several statements related to the benefit of foam-brick application in building construction as follows:

1. Polymer brick is a new material made from polymer waste materials that can reduce levels of CO2 production in the earth because it reduce cement usage and increase the value of plastic waste.

2. The additional nano technology in polymer brick can increase compressive strength at about 10,00 – 24,57%.

3. The polymer brick has a good acoustical performance which has 0,26 on absorbtion coefficient and 53,908 dB in Sound Transmission Loss (STL).

4. In the application of polymer-brick, then the value of the building OTTV be lower than the value building OTTV that use red-brick or massive concrete brick walls.

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