Palm-shell Waste Treatment as a Coarse Aggregate for Environmentally Friendly Lightweight Concrete

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ABSTRACT: *Palm-shell is a waste produced by the palm oil industry. Palm-shells can be used as a substitute for natural coarse aggregate since palm-shells meet the requirements of aggregate gradation criteria which are rough surface, square shape, and hard. In addition, the density of palm-shell is±600 kg/m^3 so that it can produce lightweight concrete. The drawback of using palm-shell is the oil contained on its surface. An experimental study was employed by carrying out three methods of treatment towards palm-shells. Fly-ash content substitution on cement was also studied to obtain optimum levels of fly-ash which produced maximum compressive strength. Fly-ash substitution varies from 0%, 15%, 20%, and 25%.The results show that the concrete average density is 1749 kg/m^3, so it can be classified as lightweight concrete. The use of 1.2% super plasticizer reduces water usage which can adjust water-cement ratio from 0.61 to 0.23. Increasing fly-ash content from 0% to 20% increases the concrete's compressive strength. The treatment on shell aggregate affects the concrete's compressive strength in which without the treatment the highest compressive strength is 15.58 MPa; the first treatment produces 19.26 MPa, and the second treatment produces 27.97 MPa.*

Keywords-*compressive strength, fly-ash, lightweight concrete, palm-shell, treatment*

I. Introduction

Nowadays, Indonesia is promoting the construction of low-cost housing for residence by utilizing locally available materials to reduce house prices. Another reason is that Indonesia is in an active earthquake zone, the effect of earthquake forces on building structures needs to be considered. In order to reduce an inertial force arising from earthquake acceleration, there must be reduction on building mass or weight.

The nature of concrete is strongly influenced by the composition and quality of its constituent materials, namely aggregates as fillers, as well as hydraulic cement and water as binders. Aggregate as filler, fills70% of the concrete volume which consists 30% fine aggregate and 40% coarse aggregate. Coarse aggregates that are commonly used are natural coarse aggregates, namely gravel in which its exploration will greatly damage the nature. Whereas there may be alternative substitutes such as palm-shells.

At present, lightweight aggregate concrete can be produced using a variety of lightweight aggregate. Lightweights can originate from either natural materials, like volcanis pumice; thermal treatment of raw materials like clay, slate or shale; manufactured from industrial by-products, such as fly-ash; or processing of industrial by-products, such as slag. Well produced lightweight aggregate concrete shall have strength equivalent to normal weight concrete. Towards achieving sustainable environmental, many plant based waste material resources have been researched as potensial to be aggregates in the production of lightweight concrete. One such material is oil palm shell which is treated as waste. To further enhance the compressive strength of the lightweight concrete produced, the oil palm shell is further treated prior to potential use as an aggregate.

According to the data of Indonesian Plantation of Palm Oil Commodities Statistics 2014-2016 [1], oil palm plantations (Elaeis guineensis Jacq.) are the largest plantations in Indonesia, reaching 10,668,425 hectares spread out in almost all regions of Indonesia. While the palm oil productivity in 2015 reached 31,284,306 tons or 3 tons/hectare/year. Palm-shell is one of the palm oil industry wastes that can be used as an alternative to coarse aggregate since it is hard, tough and durable due to its high lignin and silica dioxide content like hard wood species, but its cellulose is low so it does not easily rot. It also meets the requirements for aggregate gradation without breaking process which has a thickness of 2-4 mm and a maximum width of 15 mm. Having a lightweight volume of ±600kg/m^3 is another advantage which will produce lightweight concrete with a density less than 1850 kg/m^3[2].

Fly-ash is solid waste produced by coal burning in power plants and is categorized as hazardous and toxic waste material (*limbah bahan berbahaya dan beracun*, B3). Production of Fly-ash and Bottom Ash (FABA) from power plants in Indonesia continually increases every year which is estimated reaching 3.3 million tons per year in 2009 [3]. If the fly-ash is not utilized wisely, it will become an environmental pollution problem. Fly-ash is a pozzolanic material with its highest chemical content is silica oxide (SiO2) and its grains is almost the same as cement, so that it can fill the pores. Therefore, optimizing fly-ash as an alternative additive is expected to produce higher quality concrete and reduce environmental pollution.

II. Literature Review

Earthquake forces on a structure are strongly influenced by mass distribution, building shape, stiffness and ductility of buildings. The aspect which is directly affected by the material is building mass. Earthquake loads can be reduced through building mass reduction that can be achieved by using lightweight aggregate concrete.

Concrete is a mixture of fillers called aggregates which are bound by a binder in the form of hydraulic cement and water mixture to form a solid material. This mixture is expected to receive loads on the structure. The nature of concrete is strongly influenced by the composition and quality of its constituent materials. Therefore, the planned concrete must have an optimum ratio between aggregate and bonding material according to the desired mixture needs.

2.1 Lightweight Concrete

Concrete has disadvantages that must be considered such as its large weight. In order to overcome this drawback, the concrete weight can be reduced by using lightweight aggregates which produce lightweight concrete weighing less than 1850 kg/m^3 [2]. Natural lightweight aggregates are easily obtained from pumice, lava, and tufa. Artificial lightweight aggregates such as slate, clay, or fly-ash, are made through a combustion process. High-performance lightweight concrete is lightweight concrete with compressive strength greater than 34.5 MPa [4].

2.2 Compressive Strength of Lightweight Concrete

Concrete's quality is measured by the ability of concrete to bear compressive stress. While other stresses are stated as functions of compressive stress. The compressive strength of concrete is strongly influenced by characteristics of coarse aggregate, water-cement ratio, level of density, time and treatment quality, and other factors such as the use of additives. Lightweight coarse aggregate which fills almost ±40% of the concrete volume has a significant influence on the compressive strength of concrete, especially some of its characteristics such as specific gravity and density, surface texture, raw materials and aggregate gradation distribution [4].

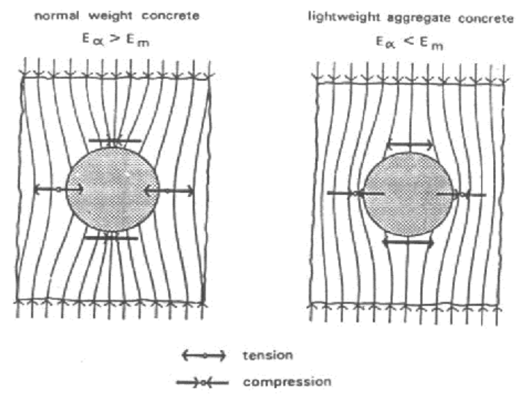

Figure 1. Phenomenon of crack on normal and lightweight concrete due to compressive forces [4]

According to FIP [4], the compressive strength of lightweight concrete is closely related to the stress-strain relationship between aggregate and mortar around aggregate in concrete. Unlike in normal concrete, there is an unpredictable phenomenon of stress around the mortar and aggregate when lightweight concrete receives compressive loads. Having different strength when receiving external loads, the outer surface of light coarse aggregates receives tensile stress while normal aggregates receive compressive stress, as shown in Fig. 1, this causes the strength of lightweight aggregate concrete is lower. Aggregates with high absorption have interconnected airspace structures which make the strength low. In addition, the formation of contact zone between aggregate and cement in a form of a space (void) where will be filled by absorbed water (absorptive and bleeding water) causing low compressive strength.

Unlike in normalweight concrete, the strength development in lightweight concrete is high at first but after 14 days it shows a small increase (low strength hardening) and tends to be flat. This is the result of stresses around the mortar and aggregate as well as the inaccuracy of absorbed water supply of lightweight coarse aggregate when cement hydration process occurs. This increase is in accordance with the cement hydration process speed which generally increases sharply in the first one to two weeks, and it is only cement hydration improvement afterwards. Generally, the shape of stress-strain curve for normal and lightweight concrete is the same but the initial curve shape for lightweight concrete is sloping due to lightweight concrete's elastic modulus value is smaller, as shown in Fig. 2 [4].

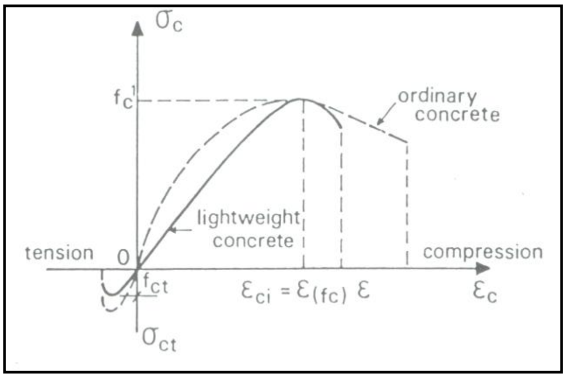

Figure 2. Stress-strain relationship of normal and lightweight concrete

2.3 Palm-shell Coarse Aggregate

Palm-shell is a hard coating with a 2-4 mm thickness in which its hard nature is caused by the large amount of silica (SiO2). Besides, the shell also contains a lot of lignin, while the methoxyl content is almost the same as wood. The palm-shell natures which are hard, ductile, high silica content, less hygroscopic, thick, and relatively small width (20-30 mm) are expected to be utilized as a substitute for coarse aggregate in concrete. Besides, the shell's density is lighter so that it can produce concrete with lighter weight, or so-called lightweight concrete.

2.4 Related Research

Titik P. Artiningsih's research [5] used a palm-shell as a substitute for coarse aggregate to produce lightweight concrete. The results showed that the palm-shell can be used as a substitute for aggregate in lightweight concrete with the average concrete densitywas1760 kg/m^3. The result of the compressive strength test showed that the planned compressive strength was not achieved because there was a slip between aggregate and mortar due to the presence of oil content on the aggregate's surface. Bee Chin Ang, et al. [6] conducted a study and filed a patent on a treatment method for palm-shells as coarse aggregates. The treatment was carried out by heating shells at a 50ºC-200ºC for 0.5 - 1 hour until the surface turned black, then coated thereafter.

III. Research Methodology

3.1 Research Limitation

Research limitations in a plan of making specimens are as follows:

a. Material used consisted of coarse aggregate of Dura palm-shells, natural fine sand aggregate, type 1 Portland cement, class F fly-ash.
b. Three treatments were conducted on the palm-shell, namely the first treatment was a trial without treatment as a comparison. The second treatment is immersed in water for 24 hours, and the third treatment is by immersing in hot water, so that the oil comes out and comes off.
c. Fly-ash substitution for cement varied between0%, 15%, 20%, and 25% according to cement weight.
d. 156 pieces of cylinder-shaped specimens with a diameter of 150 mm and a height of 300 mm.
e. Tests conducted were compression and splitting test.

3.2 Research Methods

The research employed experimental study which the first step was testing physical material properties. The results of the material properties test were used for mix design calculations; Further more conducted palm-shell treatments consisting of treatment-0 (T-0), treatment-1 (T-1) and treatment-2 (T-2). Shells produced from treatments were used to make cylinder specimens; The compressive strength test of the specimens was conducted at the age of 7, 14, 21, and 28 days, while the tensile strength test was conducted at the age of 28days. Compressive strength test at various time phases was conducted to determine the history of compressive strength concrete development, which then be compared with the history of normalweight concrete compressive strength.

3.3 Material Inspection

Physical material inspection was only conducted on palm-shells coarse aggregates and natural sand fine aggregates, while Portland cement (PC), fly-ash (FA), and super plasticizer (SP) were based on manufacturer specifications. Material inspection of palm-shells coarse aggregate properties and natural fine sand aggregate was conducted at ITB's Structure and Material Laboratory, including gradation, specific gravity, absorption, density, water content, and destruction rate, which can be seen in TABLE 1.

Table 1. Physical properties of palm-shell and natural sand

INSPECTION TYPE	Sand	Palm-shell
Apparent Specific Gravity	2.674	1.478
Bulk Dry Specific Gravity	2.489	1.093
Bulk Specific Gravity SSD	2.558	1.353
Water Absorption [%]	3.306	23.84
Mud Content	5.043	-
Water Content [%]	7.81	5.70
Solid Density [Kg/L]	1.455	0.673
Density[Kg/L]	1.272	0.602
Fineness Modulus	2.941	-
Wear [%]	-	23.25

3.4 Concrete Mix-design

Based on the result of physical properties inspection, a mix-design was made using ACI 211.2-91 method [7], with calculation results as shown in TABLE 2.

Table 2. Material compositions per $m^3$of concrete mix-design

Material	Mass [kg]	Volume [m^3]
PCC	354.33	0.12
Coarse Aggregate	450.91	0.33
Fine Aggregate	790.43	0.31
Water	216.55	0.22
Air	-	0.03
Fly-ash	0%, 15%, 20%,25%	
Super plasticizer	1.20%	

Based on the mix-design above, various mixture variations are made, namely:

- **Mix-design T0** is a mixture of concrete with palm-shell without treatment (treatment-0), w/c = 0.61, without using super plasticizer (SP), fly-ash(FA) content varies from 0%, 15%, 20%, and 25%.
- **Mix-design T1** is a mixture of concrete with palm-shell treated by treatment-1 which is immersed in water for 24 hours, w/c = 0.32, using SP 1.2%, FA content varies from 0%, 15%, 20%, and 25%.
- **Mix-design T2** is a mixture of concrete with palm-shell treated by treatment-2 which is washed with hot water and immersed for 24 hours w/c = 0.23, using SP 1.2%, FA content varies from 0%, 15%, 20%, and 25%.

3.5 Specimen

Three cylinder-shaped specimens with a diameter of 150 mm and a height of 300 mm for each variation were used for compressive strength test, which were tested at the age of 7, 14, 21, and 28 days. Three specimens for each variation were used for tensile strength (splitting) test and only tested at the age of 28 days. The number and type of test objects can be seen in TABLE 3.

Table 3. Variation and number of test objects

Code	Description	Compressive Test	Tensile Test	Total
T0-610000	treatment-0 w/c 0.61; SP 0.0%; FA 0, 15, 20, 25%	12	3	60
T0-610015		12	3	
T0-610020		12	3	
T0-610025		12	3	
T1-321200	treatment-1 w/c 0.32; SP 1.2%; FA 0, 15, 20, 25%	12	3	60
T1-321215		12	3	
T1-321220		12	3	
T1-321225		12	3	
T2-231200	treatment-2 w/c 0.23; SP 1.2%; FA 0, 15, 20, 25%	12	3	60
T2-231215		12	3	
T2-231220		12	3	
T2-231225		12	3	
TOTAL		144	36	180

3.6 Specimen Testing

- Compressive strength test was conducted to obtain a compressive stress-strain relationship curve of concrete, using Universal Testing Machine (UTM) by following testing procedures by ASTM standards [8] in which cylindrical specimens were vertically placed and given uniaxial loads incrementally until it collapsed, and the ultimate loads were recorded. The amount of concrete compressive strength was calculated by the equation:

$$f_c^{'} = \frac{P}{A} \quad (1)$$

Where, f_c' is compressive strength of concrete, P is compressive load, and A is specimen surface area

- Tensile strength test (splitting) test was conducted to obtain a tensile stress-strain relationship curve of concrete, using UTM by following procedures by ASTM standards [8], in which cylindrical specimens were horizontally placed and applied loads incrementally until the cylinder was split, and the ultimate loads were recorded. The amount of concrete tensile strength was calculated by the equation:

$$f_{sp} = \frac{2P}{\pi L D} \qquad (2)$$

Where, $f_{sp}$is split tensile strength, L is specimen length, and D is specimen cross section diameter.

IV. Results and Discussions

4.1 Slump Test Results

Slump measurement results show that in mix-design without SP (T0 mix-design), water usage can still be reduced since the slump value is greater than planned. In order to reach the slump plan, the amount of water must be reduced in the T1 mix-design since the mixture of 1.2% SP and treatment-1 makes humidity increases. This causes a correction for w/c ratio from 0.61 to 0.32. In the T2 mix-design, the mixture of 1.2% SP and treatment-2, the amount of water must be reduced again, and it corrects w/c ratio to 0.23 because the results of hot water immersing treatment cause the pores to close so that aggregate absorbs less water. The results of slump measurements and water correction can be seen in TABLE 4 below.

Table 4. Fresh concrete slump-test

Code	w/c ratio		Fly-ash	Slump
	initial	correction	[%]	[cm]
T0-610000	0.61	0.62	0	13.50
T0-610015	0.61	0.62	15	12.50
T0-610020	0.61	0.62	20	11.50
T0-610025	0.61	0.62	25	10.50
T1-321200	0.61	0.32	0	7.50
T1-321215	0.61	0.32	15	7.50
T1-321220	0.61	0.32	20	7.50
T1-321225	0.61	0.32	25	7.50
T2-231200	0.61	0.23	0	7.50
T2-231215	0.61	0.23	15	7.50
T2-231220	0.61	0.23	20	7.50
T2-231225	0.61	0.23	25	7.50

4.2 Density of Concrete Specimens

The results of density measurements can be seen in TABLE 5 below. The density of palm-shell aggregate concrete is 1700-1800 kg/m^3, with an average of 1749 kg/m^3, thus classified as lightweight concrete. The increase levels of SP cause a water content reduction and make the concrete becomes solider, resulting in density increased.

Table 5. Specimen density

Code	Fly-ash [%]	Weight [kg]	Density [kg/m3]
T0-610000	0	9.02	1700.74
T0-610015	15	9.28	1749.76
T0-610020	20	9.04	1704.51
T0-610025	25	9.17	1729.02
T1-321200	0	9.23	1740.34
T1-321215	15	9.53	1796.90
T1-321220	20	9.35	1762.96
T1-321225	25	9.36	1764.85
T2-231200	0	9.46	1783.70
T2-231215	15	9.44	1779.93
T2-231220	20	9.27	1747.88
T2-231225	25	9.18	1730.91
Range of Density			1701-1797

4.3 Compression Test Result

The calculation results of compression strength development history from ages 7, 14, 21, and 28 days are shown in TABLE 6 below. In the mix design T0, T1 and T2, the increase of FA content from 0% to 20% makes the compressive strength increased, but at 25% the compressive strength decreases. Concrete with treatment-2 in which it is washed with hot water and immersed for 24 hours produces the highest compressive strength. Treatment-1 also increases compressive strength when compared to treatment-0 (without treatment).

Table 6. History of specimen compressive strength at the age of 28 days

Code	FA	Compressive Strength [MPa]			
	[%]	7	14	21	28
T0-610000	0	7.1838	10.4364	12.1616	12.8687
T0-610015	15	8.4000	11.3980	14.0000	14.3960
T0-610020	20	9.2202	12.5293	14.8485	15.5838
T0-610025	25	7.6929	10.6343	12.7556	13.7172
T1-321200	0	7.1838	10.4364	12.1616	12.8687
T1-321215	15	8.4000	11.3980	14.0000	14.3960
T1-321220	20	9.2202	12.5293	14.8485	15.5838
T1-321225	25	7.6929	10.6343	12.7556	13.7172
T2-231200	0	8.7960	12.1899	14.1980	15.4141
T2-231215	15	10.6061	14.2828	16.4606	17.3091
T2-231220	20	11.5960	15.5838	17.9313	19.2606
T2-231225	25	9.4747	13.1798	15.0465	16.0929

4.4 Collapse Pattern

The result of observing collapse pattern turned out to be a splitting failure. Generally, the splitting failure occurs in high-quality concrete. But in fact, the concrete compressive strength is achieved does not show as high-quality concrete. This happens because the destruction occurs at the aggregate interface due to a slip between the aggregate and the mortar. Aggregate stiffness fulfils the requirements which is shown by the absence of aggregate destruction due to compressive test.

In shell aggregate concrete without treatment, the compressive strength achieved is low because there is a slip between the aggregate and the mortar. This happens since aggregate surface contains residual oil from palm oil processes. There is a compressive strength increase on shell aggregate with treatment-1which is immersed for 24 hours. Aggregate with treatment-2 which is washed by hot water and immersed for 24 hours increases the compressive strength of concrete compared to aggregate with treatment-1. This happens because washing by hot water releases more oil.

4.5 Splitting Test Results

Split tensile test was conducted on 28-days-old concrete. The results of the tensile strength test can be seen in TABLE 7 below. Similar with the compressive strength, the greatest tensile strength occurs in the T2 mix-design at 20% FA content.

Table 7. Tensile strength (splitting) of specimens for each mixture variation at the age of 28 days

Code	w/c ratio	SP [%]	Fly-ash [%]	Tensile Strength [MPa]
T0-610000	0.62	1.2	0	1.1525
T0-610015			15	1.1737
T0-610020			20	1.3081
T0-610025			25	1.2515
T1-321200	0.32	1.2	0	1.3293
T1-321215			15	1.4354
T1-321220			20	1.6051
T1-321225			25	1.4000
T2-231200	0.23	1.2	0	1.4424
T2-231215			15	1.5626
T2-231220			20	1.7182
T2-231225			25	1.4990

V. Conclusion

Based on the results of the study, several conclusions can be drawn as follows:

1. Palm-shell coarse aggregate is a material that easily absorbs water. This can be seen from the amount of water absorption which is around 24%. The strength of palm-shell aggregates used in the research is quite good as seen in wear testing which is 21% in dry condition, while ASTM [8] required a maximum of 32%. Aggregate gradation also qualifies, but the maximum aggregate size is only 12.5 mm.
2. The use of water in mixing fresh concrete must be considered because the specific gravity of the shell is quite small, so that the use of excessive water will cause palm-shell floating, especially in mixture using SP. Bentonite powder is used in order to make the shell does not float.
3. Slump exceeds the plan, so that the slump is maintained according to plan (75 mm) when using SP. This causes a considerable water correction which is seen in the w/c change from 0.61 to 0.32 in the mix-design T-1 and 0.23 in the T-2 mix-design. This happens because the water content in the palm-shell is high due to 24 hours immersion.
4. The density of the palm-shell aggregate concrete is 1700-1800 kg/m^3, and the average is 1749 kg/m^3, thus classified as lightweight concrete. Enhancing SP usage will increase density because it will reduce water content which causes density increased. When density increases, the densityand compressive strength also increase.
5. The result of compressive strength test shows that increasing the FA level from 0% to 20% will increase the strength, but at 25% the strength decreases again.
6. Treatments towards shell aggregate affect the concrete compressive strength. In the T-0 mix-design, the highest compressive strength is 15.58 MPa, in the T-1 mix-design is 19.26 MPa, and the T-2 mix-design is 27.97 MPa. Therefore, it can be claimed that treatment by washing aggregate using hot water and immersing it for 24 hours will increase strength by 80%
7. Destruction on compressive tests occurs between the mortar and the aggregate interface. This happens because the bond between the aggregate and the mortar is not good. Whereas the shell aggregate does not split which proves that palm-shells can replace natural coarse aggregates.

VI. Acknowledgements

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