

The effect of thermal treatments on recycled alternative aggregates toward concrete properties

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Abstract. The objective of this research was to obtain the physical and chemical characteristics of the recycled waste material such as bricks, roof tiles, and ceramics waste. Chemical composition checked with XRF method. The physical characteristics were obtained by burning the recycled materials at 1000°C with ladle burner machine. SNI 03-2834-2000 was used as guideline in concrete making process. It could be seen that on the recycled materials had silica as their highest chemical composition. The specific gravity of recycled materials increased after the burning process while water absorption decreased after the burning process. Thermal treatment improved the quality of recycled alternative aggregates. Crystallization process started at 1000°C, resulted the decreasing value of material porosity and hardness. The decreasing value of concrete compressive strength was less than 8 % at the 25 % substitution of both ceramics and roof tiles. It showed that the recycled materials could be used as structural concrete based on SNI (Indonesian National Standard)

Keywords : waste material, thermal treatment, chemical content, physic characteristic, compressive strength

1. Introduction

Concrete has the highest compressive strength of all materials, it has high bearing capacity, it endures high temperature and has cheap price of maintenance [1]. Concrete consists of Portland cement, coarse aggregate, fine aggregate and water [2]. However, it still has disadvantages such as high rigidity, difficult to be controlled for its homogeneity, and also high density which burdens the integrity of the foundation where it is installed [3] and also resulting in difficulty of transferring the concrete-based materials [4].

Concrete with its conventional ingredients is relatively expensive quite difficult to be obtained, and not environmentally friendly due to aggressive extraction process to the natural resources [5]. Therefore, it is highly imperative to utilize some alternative materials to save the natural resources, while attempting to reduce the price of concrete. One of the steps to achieve that noble goal is employing recycled waste materials to substitute natural aggregate. As a consideration, the recycled waste materials must be compatible for constructional structures and also do not interfere with chemical reaction during the dehydration of cement in the fabrication of concrete [6]. Some of the promising alternative materials for substitution of natural aggregate are bricks, roof tiles and ceramics



waste. They are adequately good candidate for replacement of coarse aggregate because of the silica content in them, in form of small particles with diameter less than 4 micrometers [7].

One of the most studied alternative materials for natural aggregate substitute is ceramics. When it is mixed with cement to fabricate concrete. It decreases the weight volume of concrete, and gives higher water absorption than that of the concrete with natural aggregates [8]. However, the substitution of natural aggregates with ceramics may sacrifice the compressive strength of the produced concrete by around 25 to 65% (for substitution of 10 to 30% weight) [9]. In order to overcome this problem, the density of concrete is attempted to be increased via burning process. Generally, the burning of concrete may decreases the porosity and the mass through the crystallization of concrete [10]. The burning effect of aggregate would increase the density of the aggregate. When the burning temperature reach 1000°C, crystallization process started [11]. When the temperature becomes higher, then the porosity and the mass of the material decreases [12].

2. Research Methodology

2.1 Aggregate Selection

The waste of bricks, ceramics and roof tiles were used as recycled alternative aggregates. The materials used in this research passed through sieve number 3/4 inch and retained on sieve number 4 (1-2 cm). The shape of aggregate must have sharp angles. Natural and alternative aggregates were washed under flowing water. All materials were crushed manually using hammer. The other component that used in concrete mixture were sand as fine aggregate, water and cement. Fine aggregate should be at zone 2 and the water should have pH value around 6-8.



Figure 1. Natural Aggregate



Figure 2. Roof Tiles



Figure 3. Bricks



Figure 4. Ceramics

2.2 Aggregate Test

Both coarse aggregate and fine aggregate were tested with several standards. Specific gravity and water absorption of fine aggregate using SNI 1970:2008, organic content test of fine aggregate using SNI 2816:2013, and sieve analysis of fine aggregate using SNI ASTM C136:2012. While SNI 1969:2008 was used as standard for specific gravity and water absorption test of coarse aggregate.

2.3 Thermal Treatment of Recycled Alternative Aggregate

Thermal treatment of recycled alternative aggregate was conducted by using ladle burner machine at 1000°C for 40 minutes per material. The effect of thermal demonstrated the physical characteristics changed. The water absorption of the recycled materials became smaller when the pore of each aggregate became smaller due to the thermal treatment.

2.4 Chemical Characteristics Test of Recycled Alternative Aggregate

Chemical tests carried out to determine the similarity of the characteristics of recycled alternative coarse aggregates with natural aggregates. Chemical test was conducted by using XRF (X-ray Fluorescence) whole rock analysis. Samples fused using Lithium Metaborate and analysed by XRF. XRF analysis determined total element concentration which are reported as oxides. XRF was the normal procedure used in rock analysis (by crushing, powdering and pelletizing) [13]

2.5 Sample Preparation and Compressive Strength Method

There were 17 types of variation with 3 samples for each variation. There were 102 samples in total. The variations were 100% substitution of natural aggregate, bricks, roof tiles and ceramics with thermal treatment, 100% substitution of natural aggregate, bricks, roof tiles and ceramics with no treatment, substitution of bricks 15%, 25%, 35%, substitution of roof tiles 15%, 25%, 35% and substitution of ceramics 25%, 30% and 35%. The standard of concrete mixing based on SNI 03-2834-2000. The samples were soaked in the water. Compressive strength tests carried out at 7 and 28 days. Compressive strength test were conducted according to Indonesian national standards SNI 1974:2011.

3. Results and Analysis

3.1 Material Test Result

3.1.1 Water

Based on water pH test, the water pH value was 8, which was acceptable value based on SK SNI-04-1991. It could be concluded that the water could be used as the concrete mixture.

3.1.2 Organic Content Test

Based on organic content test on fine aggregate, the organic content still on the acceptable value. The organic content of material was at level 2, which was acceptable based on the standard. It showed that the fine aggregate was acceptable.

3.1.3 Gradation of Fine Aggregate

Based on the gradation of fine aggregate test standard (SNI ASTM C136:2012), fine aggregate was at zone 2. It showed that the sand could be used as concrete mixture. Because it had coarse grain to fill the void in the concrete mixture.

3.1.4 Chemical Characteristics of Recycled Alternative Aggregates

Table 1 showed the chemical characteristics of recycled alternative aggregates. All recycled alternative aggregates had SiO₂ (Silica) as the highest chemical component. Based on the previous studies, bricks had 64.26 % of SiO₂, 17.29 % of Al₂O₃, 6.4 % of Fe₂O₃ [14] while the ceramics had 60.2 % of SiO₂, 18.322 % of Al₂O₃, 6.23 % of Fe₂O₃ [5]

Table 1. Characteristics of Aggregate

Oxide Composition of Recycled Materials				
	Bricks	Ceramics	Roof Tiles	Natural Aggregate
Al ₂ O ₃	17.1%	18.32%	18.50%	16.00%
Fe ₂ O ₃	6.90%	6.23%	8.48%	7.37%
SiO ₂	64.26%	60.20%	63.56%	53.44%

Table 2 presented the percentage of silica content in each material. The materials burnt at 650°C and 1000°C and the silica content of each material was checked. When the temperature reached 650°C, the silica content of each material increased significantly. The increasing value of silica content was not significant when the temperature increased from 650°C to 1000°C.

Table 2. Silica Content at Different Temperature

Type of Aggregate	Silica Content		
	No Thermal Treatment	Thermal Treatment at 650°C	Thermal Treatment at 1000°C
Natural Aggregate	53.44%	58.80%	59.04%
Ceramics	60.20%	60.74%	60.74%
Brickss	64.26%	69.17%	69.32%
Tiles	63.56%	65.20%	65.28%

3.1.5 Physical Characteristics of Recycled Alternative Aggregates Before and After Thermal Treatment

The specific gravity and water absorption values could be found in Table 3. It could be seen that the natural aggregate had the highest specific gravity value while the bricks had the lowest value. When the thermal treatment reached 1000°C, the specific gravity value of each material decreased. Before the thermal treatment, bricks had the highest water absorption while the natural aggregate had the lowest value because the bricks had bigger pores than natural aggregate. After thermal treatment, water absorption of bricks and natural aggregate decreased due to the expansion of the volume of the material. The pores of bricks and natural aggregate shrunk. This was caused by the reaction of chemical compounds such as silica.

Table 3. Comparison of Recycled Aggregates Before and After Thermal Treatment

Recycled Alternative Aggregate	SNI of GS	Specific Gravity		SNI of WA	Water Absorption	
		Before Thermal Treatment	After Thermal Treatment		Before Thermal Treatment	After Thermal Treatment
Natural Aggregate	1,2-2,8	2.58	2.53	<= 3%	2.5	3.03
Tiles		2.08	2.08		7.51	1.24
Ceramics		2.03	1.94		3.53	4.48
Bricks		1.97	1.76		9.44	5.57

3.2 The Effect of Coarse Aggregate Substitution

Figure 5 a,b,c showed the substitution of coarse aggregate with recycled aggregate (bricks, ceramics and roof tiles). The normal concrete had compressive strength of 25 MPa at 28 days, while the concrete with 15 %, 25 % and 35 % of bricks substitution had the 18.05 %, 24.06 % and 29.32 % decreasing value of compressive strength. Previous study about concrete coarse aggregate substitution with 10%, 30 % and 50 % of bricks showed that the concrete had 25.33 %, 65.15 % and 88.55% of compressive strength decreasing value [15]. It showed that the addition substitution of bricks resulted the lower value of concrete compressive strength.

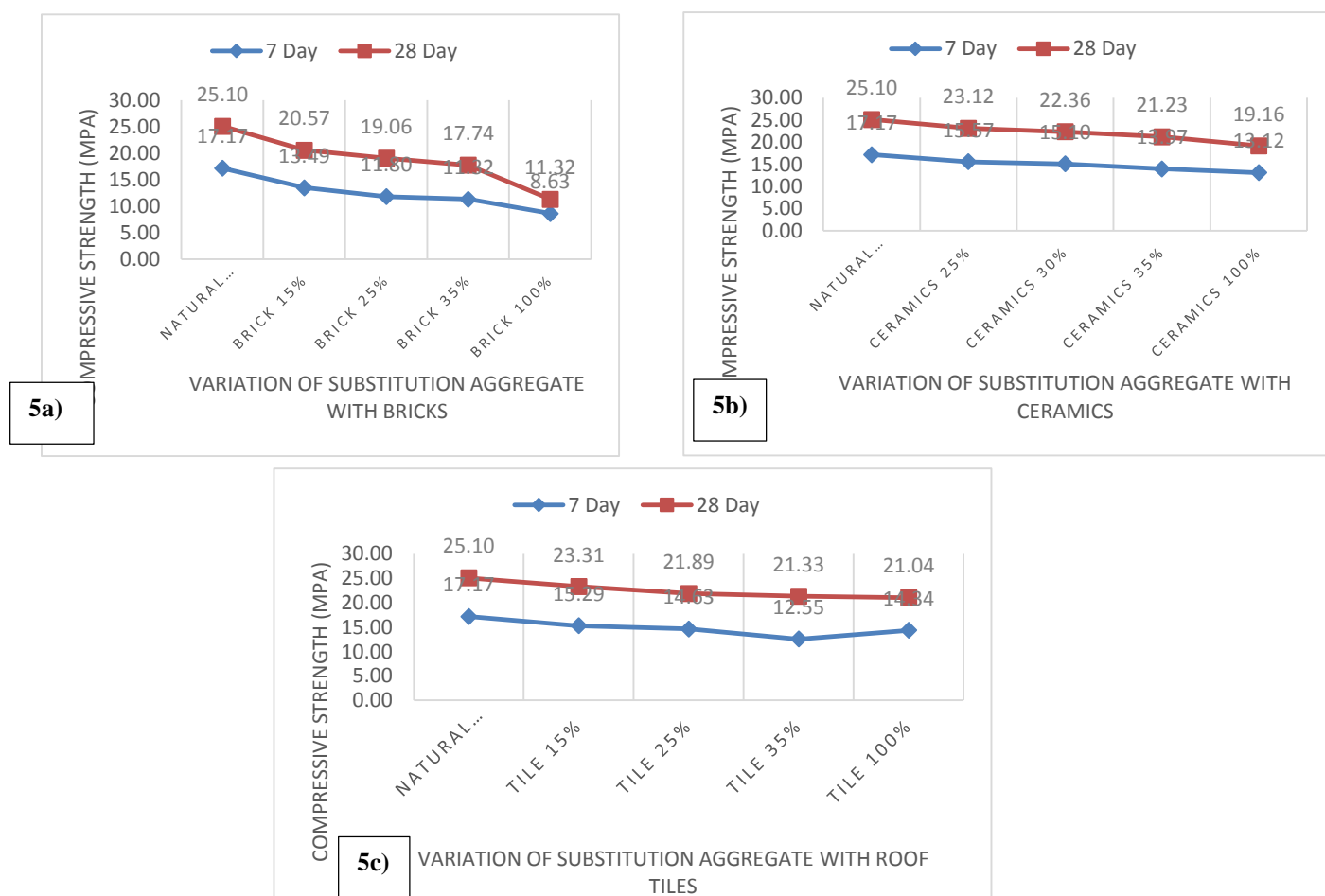


Figure 5 Variation Substitution of Coarse Aggregate (a. Bricks, b. Ceramics, c. Roof Tiles)

If it compared with the normal concrete, the concrete coarse aggregate substitution with 25 %, 30 % and 35 % of ceramics resulted 7.89 %, 10.92 % and 15.42 % the decreasing value of concrete compressive strength. While the substitution of concrete coarse aggregate with 25 %, 30 % and 35 % of roof tiles resulted 7.13 %, 12.79 % and 15.02 % concrete decreasing value. The previous study showed that the decreasing value of concrete compressive strength was not significant if the concrete used ceramics and roof tiles as the coarse aggregate substitution [12]. The maximum 25 % of coarse aggregate substitution with ceramics and roof tiles, both resulted the decreasing value of concrete compressive strength less than 8 %.

3.3 Compressive Strength Before and After Thermal Treatment

In Figure 6, a graph of the effect of thermal treatment on concrete compressive strength of various types of aggregates was presented. The 100 % replacement of concrete coarse aggregate with bricks resulted the decreasing value of 54.9 % concrete compressive strength (11.32 MPa). But if the bricks previously had the thermal treatment, the decreasing value of concrete compressive strength was only 30.44 % (17.46 MPa). It was found that the compressive strength of concrete with bricks as coarse aggregate substitute experienced the largest reduction, followed by those made with ceramics and by those made with roof tiles as the coarse aggregate substitute.[12] The loss 23.67 % and 16.18 % of concrete compressive strength due to the replacement of 100 % coarse aggregate with ceramics and roof tiles could be prevented by thermal treatment. The thermal treatment of ceramics as 100 % of concrete coarse aggregate resulted the decreasing value of concrete compressive strength was only 18.05 %. While the thermal treatment of roof tiles as 100 % of concrete coarse aggregate resulted the decreasing value of concrete compressive strength was only 13.15 %. Thermal treatment improved the quality of recycled alternative aggregates. Crystallization process started at 1000°C, resulted the decreasing value of material porosity and the increasing value of material hardness. [11]

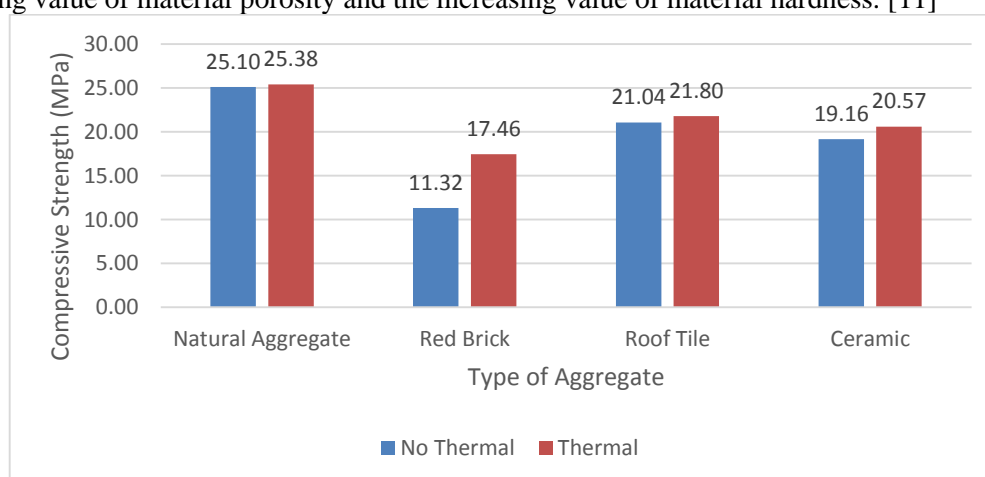


Figure 6 Compressive Strength Before and After Thermal Treatment

4. Conclusion

The decreasing value of concrete compressive strength was less than 8 % at the 25 % substitution of both ceramics and roof tiles. Thermal treatment improved the quality of recycled alternative aggregates. Crystallization process started at 1000°C, resulted the decreasing value of material porosity and the increasing value of material hardness. The concrete with recycled material as coarse aggregate could be used for nonstructural purposes.

The further research could find another alternative of materials as coarse aggregates. The water cement ratio could be varied so it could be found if the optimal compressive strength influenced by the designed of water cement ratio.

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