The use of solar energy for the curing of ferro-geopolymer elements in the semiarid region

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Abstract. Kupang City in Timor Island of Indonesia, as a semiarid area, has abundant solar energy sources. Based on climatology data of Kupang City in 2013-2015, the minimum and maximum average temperatures in Kupang City range from 19.3-34.8^{o}C. Besides, dry seasons last for about 8 months (April-November). This abundance of solar energy is a potential energy resource for the manufacturing of environmentally friendly ferro-geopolymer elements. Based on previous research, the production of geopolymer material can be done optimally with dry curing treatment at 60-80^{o}C for less than 48 hours. Therefore, in this paper, a low-cost, energy efficient oven operated by a solar energy collector was developed. This paper describes a feasibility study of the use of solar energy for curing ferro-geopolymer elements. The ferro-geopolymer elements made were beams with length 600 mm, width 100 mm and height 100 mm. Wire meshes with 6x6mm of opening were used in 5 layers. The solar energy collector system used as an oven was a zinc coated drum which was painted black outwardly and was covered by a glass plate. Using this oven, it was possible to increase the ambient temperature by 1.62 to 2,37 times. Furthermore, this oven can also increase the flexure strength of ferro-geopolymer elements about ± 25.34%. This paper shows good potential use of solar energy in the manufacturing of ferro-geopolymer elements in the semiarid region.

1 Introduction

The research on geopolymer materials has shown significant improvement over the years [1-2]. Nevertheless, the application of geopolymer material technology, either as a precast product or an in situ product, is still very limited. According to geopolymer precast material technology, one of the reasons for the limitation of the application is the need for dry curing treatment to make optimal geopolymer precast products [2]. Meanwhile, according to previous research on geopolymer material, it was recommended that optimal dry curing was within a temperature of 60-80^{o}C with a duration of about less than 48 hours [3-4].

Due to the high cost of energy nowadays, there should be a consideration to use the low-cost dry curing method. Therefore, it is necessary to use solar energy as sustainable energy. This is because of an abundance of solar energy in the semiarid area.

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Kupang City located in Timor Island of Indonesia is included as a semiarid region. Based on the climatology data of Kupang City in 2013-2015, the minimum and maximum average temperatures in Kupang City range from 19.3-34.8^{o}C. Besides, dry seasons last about eight months (April-November) [5]. This abundance of solar energy should be used for the manufacturing of environmentally friendly geopolymer elements.

Based on that background, this paper presents the preliminary feasibility study of the use of solar energy in the semiarid region to make ferro-geopolymer elements. To get the optimum dry curing method from solar energy, it is necessary to develop the low-cost solar energy collector as the low-cost oven. So, the temperature produced is also required for the range of 60-80^{o}C. Furthermore, the feasibility of a solar energy collector as the low-cost oven was evaluated on the making of Ferro-geopolymer elements. Finally, two types of ferro-geopolymer elements which were cured inside and outside of the oven were compared on their flexure strengths.

2 Materials and methods

The method of the research will present the raw material used, the composition of mortar geopolymer, manufacture of the low cost of solar energy collector as an oven, manufacture of the ferro-geopolymer element, and testing of the flexure strength. It will be described as follows.

2.1 Materials

The material used consisted of: (1) Class F Fly Ash from Power Plant Bolok Kupang Indonesia, (2) sodium silicate, (3) sodium hydroxide, (4) sand from Takari Kupang as fine aggregate, and (5) welded wire mesh with openings 0.6x0.6cm and diameter 1 mm.

Table 1. Oxide compositions of fly ash by XRF (X-Ray Fluorescence) testing.

Oxide	MgO	Al_2O_3	SiO_2	SO_3	K_2O	CaO	TiO_2	MnO	Fe_2O_3
Wt (%)	8.27	17.78	43.18	4.13	0.96	8.46	3.08	0.25	13.89

Class F Fly Ash used had oxide compositions as shown in Table 1. It had CaO 8.48%. Meanwhile, the amount of $SiO_2 + Al_2O_3$ was about 60.96%. This indicated that the class F fly ash was a good silica-alumina rich material to make geopolymer material. Based on XRD (X-Ray Diffraction) pattern in Fig. 1, the minerals of fly ash were (1) Quartz, (2) Hematite and (3) Magnetite.

The mixture composition of geopolymer mortar was fly ash : alkaline activator solution: sand = 1:2:3. Alkaline activator solution was a mixture of 12 M sodium hydroxide solution with natrium silicate solution = 1:1. Fine aggregate used was the sand of Takari Kupang with fine modulus of 2.226 and zone 3 of sand category according to Indonesia Standard.

2.2 Manufacture of low cost of solar energy collector as an oven

The low cost of the solar energy collector was made like an oven to make a ferro-geopolymer element. This oven was created by cutting a metal drum vertically, cleaning the inside of drum thoroughly, measuring and cutting three pieces of zinc sheet for the inner

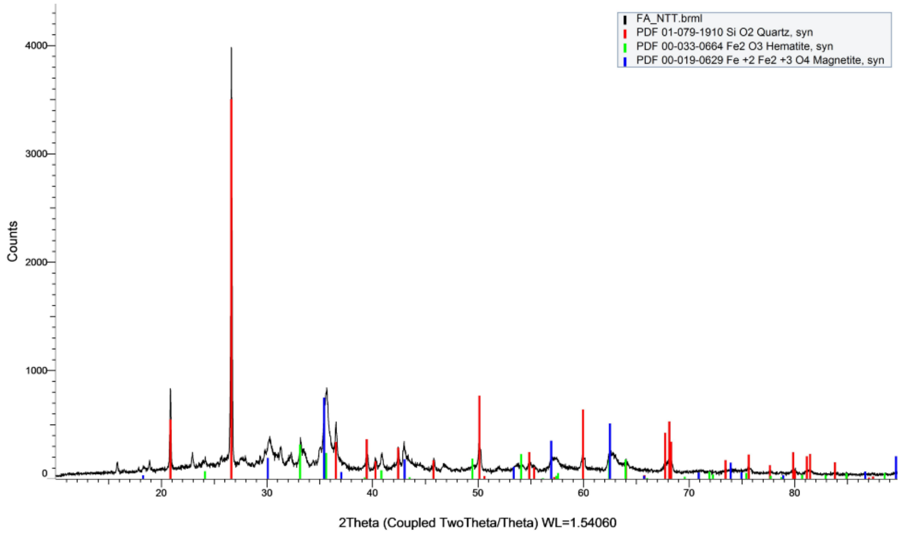

Fig. 1. X-Ray Diffraction pattern of fly ash.

surface of the drum, putting the zinc sheets into the drum and then tying it with metal glue, painting the outside of the drum with black paint to absorb the sun's heat, making the iron grill and placing the grill over the oven inside, putting the thermometer inside as a temperature controller, covering the top of the oven using a glass plate, and testing the oven on a sunny day. Manufacture and use of the oven are presented in Fig. 2.

Fig. 2. (a) Manufacture of the oven, (b) Use of the oven.

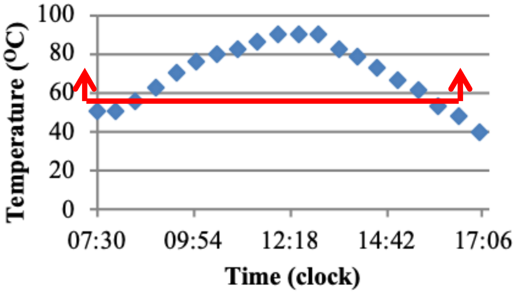

Fig. 3. Average temperature inside the oven.

The capacity of the oven was determined by comparing the temperature which occurred inside and outside of the oven. The temperature measurement in the oven was done for two consecutive days and started from 07.30-17.00. Each of the oven temperature observations was conducted for 30 minutes. The result of the average temperature measurement inside the oven can be seen in Fig. 3.

It appears that the oven temperature was larger than 60°C from at 09.00 am to 3.00 pm. So, dry curing to make a ferro-geopolymer element was for 6 hours, from 09.00 am to 3.00 pm. The oven has succeeded in increasing the inside temperature of about 1.62-2.37 times against the outside temperature. The maximum temperature outside of the oven was 38°C.

2.3 Manufacture of ferro-geopolymer element

The ferro-geopolymer element used was a beam with 600x100x100mm. Ferro-geopolymer elements were cured using 2 (two) dry curing methods, namely 1) inside the oven for 6 hours, and 2) outside the oven, which was directly under the sun for 6 hours. Six ferro-geopolymer elements were prepared for each method. The codes of the elements are given in Table 2.

Table 2. Code of element.

Code of Element	Number of wire mesh layers	Dry curing	Number of specimen
I-5	5	Inside oven	6
II-5	5	Outside oven	6

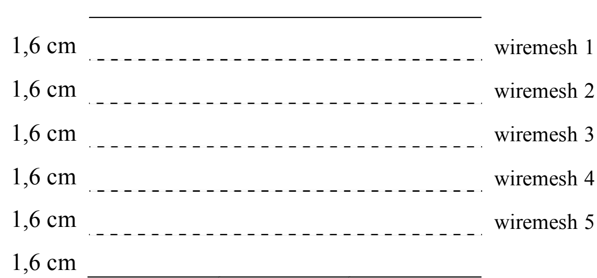

Fig. 4. Layout of wire mesh layers.

Fig. 5. Manufacture of ferro-geopolymer element.

The steps of making ferro-geopolymer element were as follows (1) preparing a mortar geopolymer with composition described in the previous section, (2) putting the mortar geopolymer evenly divided by the number of layers of wire mesh, (3) putting wire mesh sheet, (4) vibrating slightly to make a solid and flat surface of mortar for each layer, (5) putting mortar over the wire mesh layer and (6) doing steps 2-5 again until finished. A layout of the wire mesh layers of ferro-geopolymer elements, as seen in Fig. 4. Meanwhile, the manufacture of ferro-geopolymer elements is shown in Fig. 5.

2.4 Flexure strength testing

Flexure strength testing conducted is shown in Fig. 6. One centre point loading was used to comply to Indonesia Standard SNI 03-4154-1996 or ASTM C 293-02 [6].

Fig. 6. Flexure strength testing of ferro-geopolymer elements.

The flexure strength testing was conducted using Universal Testing Machine Galdabini with 100 KN capacity. Flexure strengths of ferro-geopolymer elements can be calculated:

$$\sigma_{fl} = (1.5 \text{ x } P \text{ x } L)/(B \text{ x } H^2) \quad (1)$$

where: σ_{fl} = flexure strength (MPa), P = maximum load (N), L = length of element (mm), B = width of cross section (mm), H = height of cross section (mm).

3 Results and discussion

3.1 Flexure strength of ferro-geopolymer element

The developments of load (P) versus displacement (Δ) the elements either cured inside or outside of the oven are given in Fig. 7 below. Graphs with a continuous line are for a ferro-geopolymer element cured inside of the oven. Meanwhile, graphs with a dotted line are for ferro-geopolymer elements cured outside of the oven. Based on these graphs, it is shown that there are significant increases in flexure strength, but there are not significant increases in displacement. The stiffness of the elements in the early stages looks almost the same.

The recapitulation of flexure strength and displacement is given in Table 3. The flexure strength of the ferro-geopolymer element was cured inside the oven at 5.39 MPa ± 0.58 MPa. Meanwhile, flexure strength of the Ferro-geopolymer element was cured outside the oven at 4.30 MPa ± 0.30 MPa. It means that there was a significant increase in flexure strength of about 25.34%. Meanwhile, there was not a significant increase in displacement with the displacement for ferro-geopolymer elements cured inside the oven of about 16.87

mm ± 1.78 mm and 16.31 mm ± 1.80 mm for ferro-geopolymer elements cured outside of the oven.

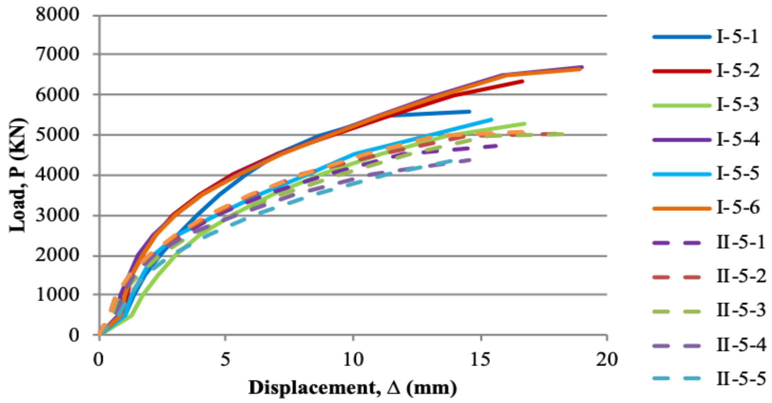

Fig. 7. Development of load (P) versus displacement (Δ) of ferro-geopolymer elements.

Table 3. The recapitulation of flexure strength and displacement of ferro-geopolymer elements.

Sample	Inside oven			Outside oven		
	P (N)	**σ_{fl} (Mpa)**	**Δ (mm)**	**P (N)**	**σ_{fl} (Mpa)**	**Δ (mm)**
Sample 1	5600	5.04	14.57	4735	4.26	15.60
Sample 2	6360	5.72	16.60	5025	4.52	18.00
Sample 3	5300	4.77	16.75	5050	4.55	18.72
Sample 4	6690	6.02	18.95	4350	3.92	14.55
Sample 5	5375	4.84	15.45	4400	3.96	14.35
Sample 6	6640	5.98	18.90	5100	4.59	16.64
Mean	5994.17	5.39	16.87	4776.67	4.30	16.31
SD	641.21	0.58	1.78	336.63	0.30	1.80

3.2 Crack pattern of ferro-geopolymer element

(a) (b)

Fig. 8. Flexure rupture of element: (a) I-5 (inside oven) and (b) II-5 (outside oven).

The rupture patterns of elements are given in Fig 8. It is shown that all elements undergone display the same failure patterns, which are also a common flexure rupture in cement-based mortar.

4 Conclusions

The utilization of solar energy to make ferro-geopolymer elements with dry curing is very likely to be developed. A low-cost solar energy collector as an oven was feasible to be used. The low-cost oven, as described in this paper, can increase the temperature about 1.62-2.37 times against outside temperature. The flexure strength of the ferro-geopolymer element cured inside the oven can be increased by 25.34% against the flexure strength of the element cured outside of the oven. However, there is no significant increase in displacement. Likewise, with the rupture pattern, there is no difference in its rupture for all elements.

This research was funded by Ministry of Research, Technology and Higher Education of Indonesia through PTUPT Grant 2018 with contract no 112/UN15.19/LT/2018. Thanks to Politeknik Negeri Kupang for conducting the flexure strength testing and Institut Teknologi Bandung for conducting XRD and XRF testing.

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