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Geopolymer Concrete Cast Using Palm Fronds ash as a Recycled Material

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ABSTRACT

Geopolymer concrete is considered eco-friendly concrete. In this research, the replacement of cement in concrete using Palm fronds ash and red brick powder is studied. The Geopolymer concrete control specimens were tested in terms of compressive, splitting tensile, and flexural strengths at different ages. The main variables are the effect of the elevated temperatures (200, 400, and 600ºC for 2 hours) and cooling methods (air-water). The samples were heated then, the specimens were cooled by using two regimes, left in air for one day or by immerging in water for one day. Then the samples were tested to obtain compressive and splitting tensile strength. Test results indicated that for specimens cooled in the air, the samples exposed to 200 and 400ºC as elevated temperatures, the compressive strength values increased by about 7.30% and 10.15%, respectively, and the tensile strength values increased by about 6.7% and 8.68 %, respectively. As samples were exposed to 600°C, the compressive and splitting tensile strength decreased by about 43.7 % and 44.65 %, respectively. For specimens cooled in water and exposed to 200 and 400ºC, the compressive strength values increased by about 4.54% and 7.40%, respectively, and the tensile strength values increased by about 4.16% and 6.5 %, respectively. In the specimens exposed to 600°C, the compressive and splitting tensile strength decreased by about 46.2 % and 46.4 %, respectively.

Keywords: *Geopolymer Concrete, Palm fronds ash, red brick powder, Mechanical properties.*

1. Introductions:

According to reports, about 2.8 tons of raw materials, including fuel, are required to produce one ton of Portland cement [1]. Large amounts of (CO_2) will be released into the atmosphere where the cement industry contributes around 8% of the worldwide CO_2 emission yearly [2]. Hence the provision of alternative products to move towards sustainable development is essential. Therefore, the use of eco-friendly concrete enables the reduction of consumption of ordinary Portland cement (OPC) with activated pozzolanic binders as a replacement, [3]. CO_2 emissions can be minimized by using alternative cementitious material which has ceramic-like properties [4].

Geopolymer, which was created by Davidovits in 1978, is an inorganic material formed by alkaline activation of alumina and silica-containing materials through a poly-condensation process where the tetrahedral silica (SiO_2) and alumina (AlO_4) are linked with each other via sharing the oxygen atoms [5]. Materials containing mostly silica (SiO_2) and alumina (Al_2O_3) are possible sources for Geopolymer components. Geopolymer is produced by combining alumino-silicate source material or a pozzolanic, including palm ash, rice husk ash, fly ash, ground steel slag, natural pozzolan, and metakaolin with alkaline solutions [6, 7]. Recycled materials can be used to obtain Geopolymer concrete [8].

Palm frond ash is an alternative useful renewable source of silica (SiO_2), Which can be used to bond aggregate grains [9]. The red brick powder is considered to also be an alumino-silica material due to the presence of high contents of silica and alumina [10]. large amounts of Palm fronds are produced annually in Egypt which is considered agricultural waste and disposed of by the environment [11]. The annual production of Palm fronds ash is anticipated to increase with time due to the rapid increase in the number of date palm trees planted all over Egypt [12]. These agricultural wastes can be recycled and replaced with cement in concrete. This research aims to study the Geopolymer concrete (GPC) cast using palm fronds ash and red brick powder.

2. Research Significance

This research aims to produce eco-friendly concrete using waste materials that decrease the environmental impact. Geopolymer is a sustainable composition. The importance of this research is to address the behavior of GPC cast using palm fronds ash and red brick powder for the researchers and engineers to overcome the possible problems due to insufficient data addressing GPC.

3. Experimental Program

The experimental program was designed to study the properties of hardened Geopolymer concrete using recycled materials.

3.1. Materials

3.1.1. Fine Aggregate

Fine aggregate was clean desert sand. It has physical and mechanical properties that comply with Egyptian Standard Specifications (ECP.1109/2013).

3.1.2. Coarse Aggregate

The coarse aggregate is the size of crushed dolomite. Its physical and mechanical properties comply with Egyptian Standard Specifications (ECP.1109/2013) with a specific gravity of 2.75 and a crushing modulus of 18.5% absorption of 2.1%. The shape of these particles was irregular and angular with a relatively high percentage of elongated particles and a very low percentage of flat particles.

3.1.3. Alkaline liquids (AL)

A combination of sodium hydroxide (NaOH) solution and sodium silicate (Na_2SiO_3) solution was used as an alkaline activator for geopolymerization. It is recommended that the alkaline liquid (NaOH solution) should be prepared before casting. That was conducted by Mixing both solutions at least 24 hours before use and should be used before 36 hours of Mixing the pellets with water.

a. Sodium hydroxide (NaOH)

Sodium hydroxide is available commercially in flakes and pellets form. For this experimental program, NaOH flakes with 97-98% purity were dissolved in potable water to make a sodium hydroxide solution. The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molar (M). Prepare a solution with a concentration of 12M consisting of 12x40 = 480 grams of NaOH solids per liter of the solution (where 40 is the molecular weight of NaOH). The mass of NaOH solids is measured as 361 grams per 1 kg of NaOH solution. It is obtained from "Al-Radwan chemicals company in Tanta ".

Table 1**.** Components of One Kilogram sodium hydroxide solution According to Concentration

Concentration	NaOH	Water	NaOH solution
12 M	361 gm	639 gm	1 Kg

b. Sodium Silicate (Na_2SiO_3)

The sodium silicate is available commercially in solution form. The chemical composition of the Na_2SiO_4 solution supplied by the manufacturer is as follows: 14.7% Na_2O, 29.4% SiO_2, and 55.9% water by mass. It is obtained from "Al-Radwan Chemicals Company at Tanta".

3.1.4. Admixtures

a. Superplasticizer

A high-range water reducer was used under the commercial name of "Sikament®.R4QV". It is especially suitable for use in concrete Mixes containing micro silica and other pozzolanic materials like fly ash. This product is suitable for tropical and hot climatic conditions. It is obtained from "Sika Egypt for Construction Chemicals".

Table 2: The properties of the mix used.

Mix Code	Binder (Kg)		Alkaline activator (Kg)	Fine Aggregate (Kg)	Concrete aggregate (Kg)	Water (Kg)	Superplasticizer (Kg)	Temperature
	P.F.A	R. B						
Mix	1.00		0.45	1.5	3	0.25	0.00	Room condition
Proportions	408.16 Kg							
Mix 1	100%	0%	183.67	612.25	1224.48	102	0.00	25°C
Mix 2	90%	10%						
Mix 3	80%	20%						
Mix 4	70%	30%						
Mix 5	60%	40%						
Mix 6	50%	50%						
Mix 7	40%	60%						
Mix 8	30%	70%						
Mix 9	20%	80%						
Mix 10	10%	90%						
Mix 11	0%	100%						
Mix 1	100%	0%	183.67	612.25	1224.48	102	0.00	70°C
Mix 2	90%	10%						
Mix 3	80%	20%						
Mix 4	70%	30%						
Mix 5	60%	40%						
Mix 6	50%	50%						
Mix 7	40%	60%						
Mix 8	30%	70%						
Mix 9	20%	80%						
Mix 10	10%	90%						
Mix 11	0%	100%						
Mix 1	100%	0%	183.67	612.25	1224.48	61.20	10.20 (2.5%)	70°C
Mix 2	90%	10%						
Mix 3	80%	20%						
Mix 4	70%	30%						
Mix 5	60%	40%						
Mix 6	50%	50%						
Mix 7	40%	60%						
Mix 8	30%	70%						
Mix 9	20%	80%						
Mix 10	10%	90%						
Mix 11	0%	100%						

- The ratio of alkaline liquids, fine aggregate, coarse aggregate, water, and superplasticizer to fine waste were 0.45, 1.5, 3, 0.15, and 2.5%, respectively.

The Control Mix was 100% red brick and 0.00% palm ash cured at 70 °C without any addition.

c. Palm Fronds Ash

Palm fronds are burned to get ash in isolation from the air in a closed container in order to retain their pozzolanic properties. Palm fronds ash sieved passing through 90µm. The chemical components of PFA are shown in Table 3.

d. Red Brick Powder

Red brick waste was obtained from a demolition field. It is separated from concrete and other building materials. It was grinded and sieved on sieve No 90µm. The chemical components of RBP are shown in Table 3.

3.2. Mixing Procedures

The concrete mix proportion is shown in Table 2, The alkaline activator solutions were prepared 24 hours before the Mixing process. The alkaline activator was sodium hydroxide (NaOH) solution (12 molars) prepared 24 hours before use. The liquid sodium silicate was mixed. The sodium silicate solution (Na_2SiO_3) with sodium hydroxide (NaOH) ratio by mass of 2.5 is fixed to use. The dry material was weighed for each mix. First; all the dry components (dolomite, sand, palm fronds ash, and red brick) are mixed for one minute. Then the Mixing alkaline activator was added and Mixed for one minute, then the water and superplasticizer were gradually added and Mixed for another minute that resulted in a better homogenous Mixture.

4. Results and Discussion

4.1. X-ray fluorescence and X-ray diffraction analysis

The X-ray fluorescence and X-ray diffraction analysis were used to identify the chemical composition, quantity, and crystallographic structure of the compounds present in both RBP and PFA. X-ray fluorenes (WD-XRF) model Axios operating at 22°C is used, and the result is presented in Table 4. The chemical composition of RBP shows that SiO_2 has the highest composition at 68 wt.%, followed by Fe_2O_3, CaO, MgO Na_2O, TiO_2, K_2O, and traces of other oxides as shown in Table **3**. The good brick should contain about 50-60% of silica, which prevent cracking, shrinking, and wrapping of raw bricks, it also imparts a uniform shape to the bricks. Also, the chemical composition of PFA shows that SiO_2 has the highest composition at 44.1 wt%, followed by, CaO, Al_2O_3, Fe_2O_3, MgO, K_2O, and traces of other oxides as shown in Table 3.

Table 3: The chemical composition of red brick powder (RBP) and palm fronds ash (PFA)

Composition (%)	Red brick powder	Palm fronds ash
SiO_2	67.9	44.1
Fe_2O_3	6.93	2.91
Al_2O_3	-	3.51
CaO	2.33	9.97
MgO	1.52	2.14
Na_2O	1.31	0.43
TiO_2	1.35	0.22
K_2O	0.17	2.63
MnO	0.1	0.09
Cr_2O_7	0.02	0.02
SrO	0.02	0.03
ZnO	0.01	0.02
Cl	-	1.13
P_2O_5	-	2.21
SO_3	-	1.65

While the XRD analysis measurements in powder forms were conducted using a high-resolution GNR, APD 2000 Pro Step Scan Diffractometer Cu-Kα radiation, (Central Laboratory, Tanta University, Egypt), $\lambda = 1.540598$ Å in the range of diffraction angle ($2\theta^{o} = 10\text{-}90^{o}$). The applied voltage and the current flows are 40 kV and 30 mA, respectively as shown in Fig.1.

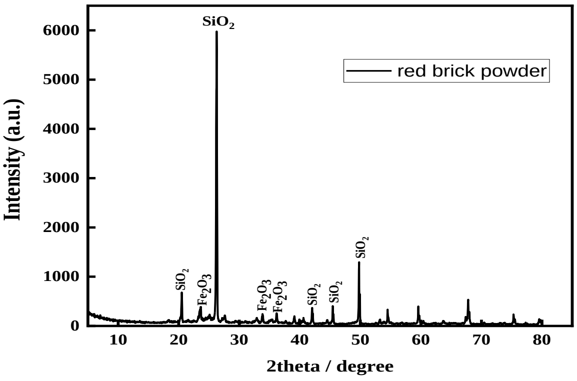

Fig. 1. XRD pattern for red brick powder (RBP).

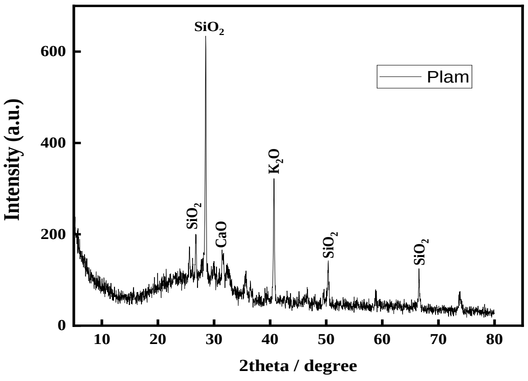

Fig.2. XRD pattern for palm fronds ash**.**

Compressive strength

Thirty-three Mixtures of Geopolymer concrete was made to select the optimum Mixture. Three cube samples (70x70x70 mm) at each age were cast and tested to obtain more reliable results based on the average of three results to determine the compressive strength. A compression test is carried out by using a hydraulic testing machine (2000 kN capacity) to study the development of compressive strength. The Geopolymer concrete showed high performance concerning strength. The specimens were tested at the ages of 7, 28, 90, and 120 days. From the results shown in Fig 3, it was observed a significant enhancement in compressive strength, the compressive strength of mix "4" is better. When the red brick was replaced with 70% of palm frond ash at curing heat of 70°C in the oven, the compressive strength at 7 days was found to increase by about 56 % on average. Using a superplasticizer and curing heat at 70°C in the oven, the compressive strength at 7 days is found to increase by about 65% over the average.

The water content before using the superplasticizer was 0.25 from fine waste. The compressive strength was found (31.02 MPa) but when a superplasticizer was used and the water content decreased, the compressive strength was found to be (34.69 MPa).

That is because increasing water causes a decrease in the concentration of the alkaline solution which led to a decrease in compressive strength.

Table 4: Compressive strength of specimens at 7 days age

Mix	Binder		Alkaline activator (Kg)	Fine Aggregate (Kg)	Coerce aggregate (Kg)	Comp. strength (N/mm^2)	Comp. strength (N/mm^2)	Comp. strength (N/mm^2)
	P.F. A	R. B						
Mix Prop	1		0.45	1.5	3	water 0.25 25°C	water 0.15 70°C	water 0.15 70°C SP. 2.5%
Mix 1	100%	0%	183.67	612.25	1224.48	5.92	8.37	9.8
Mix 2	90%	10%				9.59	14.69	16.94
Mix 3	80%	20%				17.14	28.37	31.84
Mix 4	70%	30%				19.8	31.02	34.69
Mix 5	60%	40%				17.76	28.78	32.65
Mix 6	50%	50%				16.94	27.55	30.82
Mix 7	40%	60%				14.08	24.08	27.14
Mix 8	30%	70%				11.63	15.92	23.47
Mix 9	20%	80%				9.18	15.92	18.57
Mix 10	10%	90%				5.31	7.14	8.78
Mix 11	0%	100%				3.67	5.1	6.33

Table 5: Geopolymer Concrete with curing heat (70°C) and using Superplasticizer at different ages

Mix	Compressive Strength, MPa			
	7 days	28 days	90 days	120 days
Control	5.1	5.75	6.24	7.1
Mix 4	35.31	37.96	39.39	41.02
Mix 5	32.04	34.69	36.12	38.16

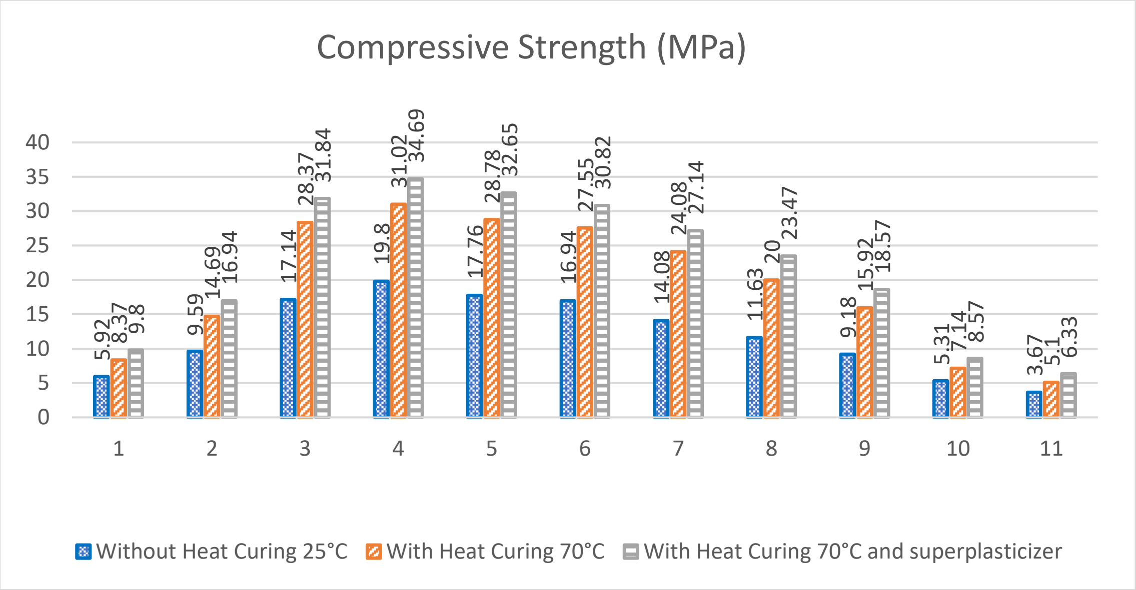

Fig.3. Compressive strength at different curing temperatures for Geopolymer concrete mixtures.

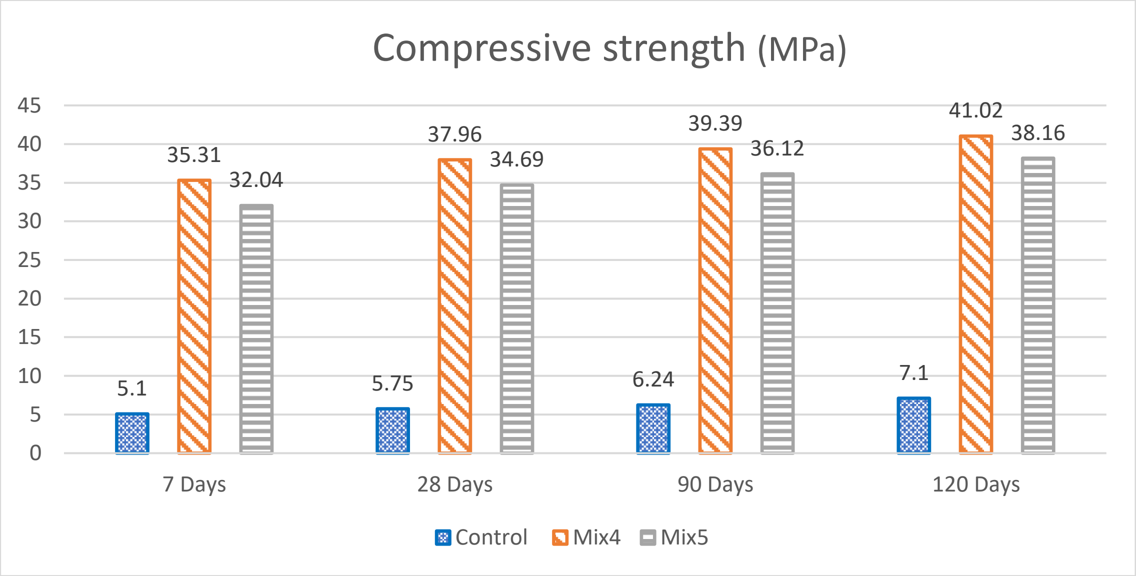

Fig. 4. Compressive strength at different ages for Geopolymer concrete mixtures.

From the results shown in Fig. 4., It was observed a significant enhancement in compressive strength, The compressive strength at 7, 28, 90, and 120 days age for Mix "4" was found 35.31, 37.96, 39.39, 41.02 µPa. It was found to increase by a range of 592.35%, 560%, 531.25%, and 477.7%, respectively.

For Mix "5", the compressive strength at 7, 28, 90, and 120 days of age was found 32.04, 34.69, 36.12, 38.16 µPa. It was found to increase by a range of 528.2%, 503.3%, 478.8%, and 437.5%, respectively.

This means that adding palm frond ash affects the compressive strength of the Geopolymer concrete. Using a superplasticizer reduces the water content so, the compressive strength increases, which may satisfy previous research [7, 9].

Tensile strength

The splitting tensile test was carried out on cylinders of size 50mm diameter and 100 mm height was conducted on the compressive test machine (2000KN). specimens to get a bit of information about the effect of palm fronds ash and red brick on the tensile strength of Geopolymer concrete to check whether it will improve its resistance to tension forces or not.

From the results shown in Fig.5, it was observed that when the red brick was replaced by 70% palm fronds ash, The tensile splitting strength at 7, 28, 90, and 120 days age for Mix "4" was found 3.29, 3.62, 3.9, 4.1 MPa, it was found to increase by a range of 585.4%, 538.5%, 482%, and 454% respectively compared to control Mix.

Table 6: Tensile strength of specimens

Mix No	7 Days	28 Days	90 Days	120 Days
Control	0.48	0.52	0.67	0.74
Mix 4	3.29	3.62	3.9	4.1
Mix 5	2.96	3.31	3.72	3.86

For Mix "5", the tensile splitting strength at 7, 28, 90, and 120 days of age was found 2.96, 3.31, 3.72, and 3.85 MPa. It was found to increase by a range of 516.7%, 536.5%, 455%, and 421.6%, respectively compared to the control mix. This means that adding palm frond ash affects the indirect tensile resistance of the Geopolymer concrete.

Flexural Strength

For the flexure test, the specimens used were prisms with dimensions of 40x40x160mm in accordance with the code specifications.

Table 7: Flexural strength of specimens

Mix No.	7 Day	28Day	90Day	120Day
Control	0.38	0.46	0.51	0.56
Mix 4	2.81	3.02	3.22	3.42
Mix 5	2.60	2.75	2.94	3.14

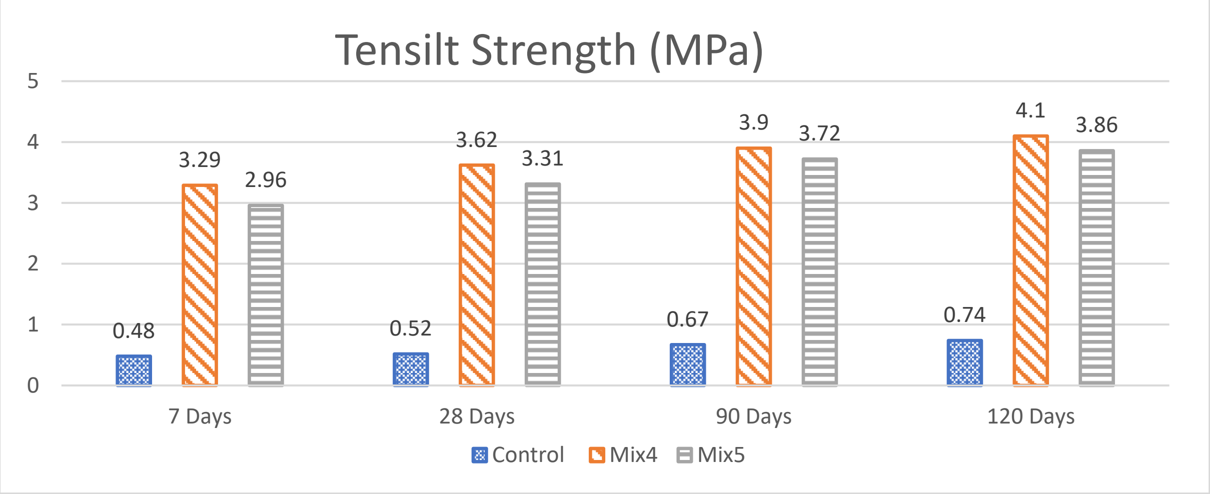

Fig. 5. Tensile strength of Geopolymer concrete mixtures.

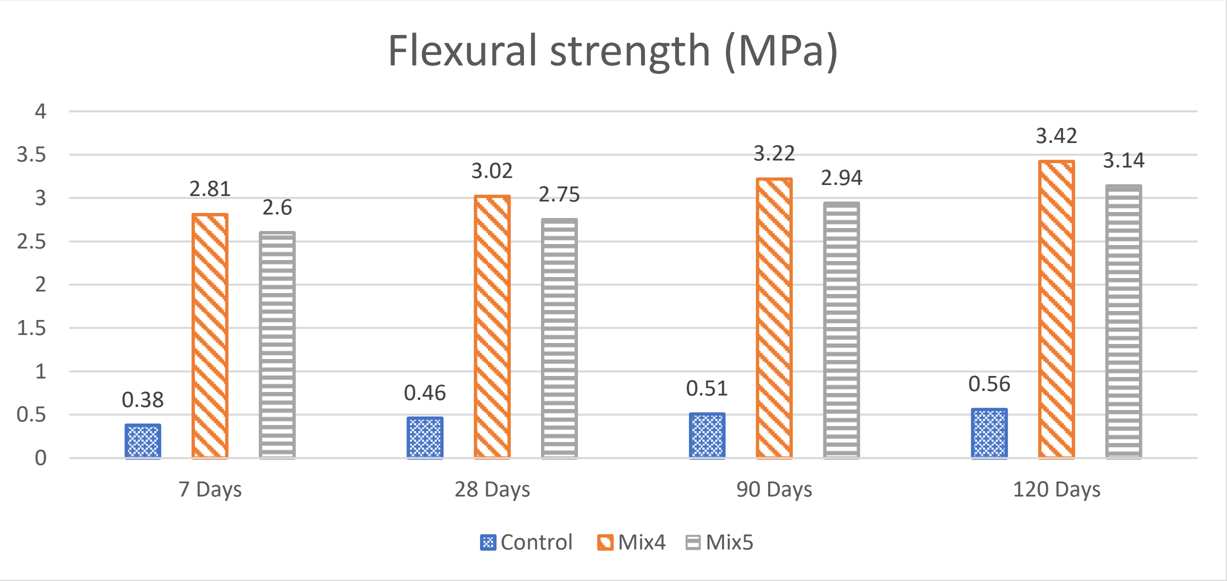

Fig. 6. Flexure strength of Geopolymer concrete mixtures.

From the results shown in Fig.6., it was observed that when the red brick was replaced by 70% palm fronds ash, The flexure strength at 7, 28, 90, and 120 days age for Mix "4" was found 2.81, 3.02, 3.22, and 3.42 MPa, it was found to increase by a range of 639.5%, 556.5%, 531.4%, and 510.7%, respectively compared to control mix. For Mix "5", the flexure strength at 7, 28, 90, and 120 days of age was found 2.6, 2.75, 2.94, 3.14 µPa, it was found to increase by a range of 584.2%, 497.8%, 476.5%, and 460.7%, respectively compared to control Mix. This means that adding palm frond ash affects the flexure resistance of the Geopolymer concrete. They can be used as a good alternative to conventional concrete.

4.2. Performance after being Exposed to Elevated Temperatures

The best sample (Mix "4") was taken and exposed to elevated temperatures in electric woven with 1100°C capacity with an internal dimension of 30 Cm x 30 Cm was used to affect samples with an elevated temperature of 200, 400, and 600°C for 2 hours, then cooled in water and air for 24 hours before tested. This test was carried out to determine the compressive strength of recycled Geopolymer concrete cubes after being exposed to different elevated temperatures then samples were left to be cooled in air and cooled by immersion water. Tests of compressive strength were performed after storage times of 1 day of exposure to elevated temperatures as a mean of 3 identical cubes for each test and results were compared. To compare the effect of elevated temperatures.

Table 8: Geopolymer concrete exposed to elevated temperatures after age 28 days

Mix . 4	Air Cooling			Water Cooling		
	200°C	400°C	600°C	200°C	400°C	600°C
37.9	40.7	41.8	21.4	39.7	40.8	20.4

a. Compressive Strength

From the results shown in Fig.7, The compressive of specimens cooled in the air were found 40.73, 41.8, and 21.37 MPa after being exposed to the elevated temperature of 200, 400, and 600°C, respectively. That indicates the compressive strength values of the specimens that were exposed to 200ºC and 400ºC, increased by about 7.30 % and 10.15 %, respectively, and the specimens that were exposed to 600°C decreased by about 43.7 % compared to Mix "4".

For the specimens cooled by using water cooling, it indicated that the compressive strength values of the specimens exposed to 200ºC, 400ºC, and 600°C were 39.68, 40.76, and 20.42 MPa, respectively. That is indicating the compressive strength values of the specimens exposed to 200ºC and 400ºC, increased by about 4.54 % and 7.40 %, respectively while the specimens exposed to 600°C decreased by about 46.2 % compared to Mix "4".

b. Tensile Strength

The results obtained from test results of samples cooled in the air indicated that the tensile strength values of the specimens exposed to 200ºC and 400ºC, increased by about 6.7% and 8.68 %, respectively while the tensile strength of specimens exposed to 600ºC decreased by about 44.65 %. For samples cooled using water cooling, the tensile strength values of specimens exposed to 200ºC and 400ºC increased by about 4.16 % and 6.5%, respectively while the tensile strength of specimens exposed to 600ºC decreased by about 46.4 %.

For the specimens cooled in the air, samples exposed to 200ºC and 400ºC tensile strength increased by 6.7% and 8.68 %, respectively. The tensile strength of specimens exposed to 600˚C decreased by about 44.65 % compared to Mix "4". Where the value of tensile strength of Geopolymer concrete cylinders was found 3.86, 3.92, and 2 MPa after being exposed to the elevated temperature of 200, 400, and 600°C, respectively. But for Mix "4", it was found 3.62 µPa at age of 28 days.

For the tensile strength values of the specimens cooled in water, samples exposed to 200ºC and 400ºC, increased by about 4.16 % and 6.5%, respectively while the specimens exposed to 600⁰C decreased by about 46.4% compared to Mix "4". The value of the tensile strength of Geopolymer concrete cylinders was found to be 3.77, 3.86, and 1.92 MPa after being exposed to the elevated temperature of 200, 400, and 600°C, respectively. For Mix "4" was found 3.62 MPa at age of 28 days.

Table 9: Tensile strength of specimens, age 28 days

Mix "4"	**Air Cooling**			**water Cooling**		
	200°C	**400°C**	**600°C**	**200°C**	**400°C**	**600°C**
3.62	3.86	3.93	2	3.77	3.86	1.92

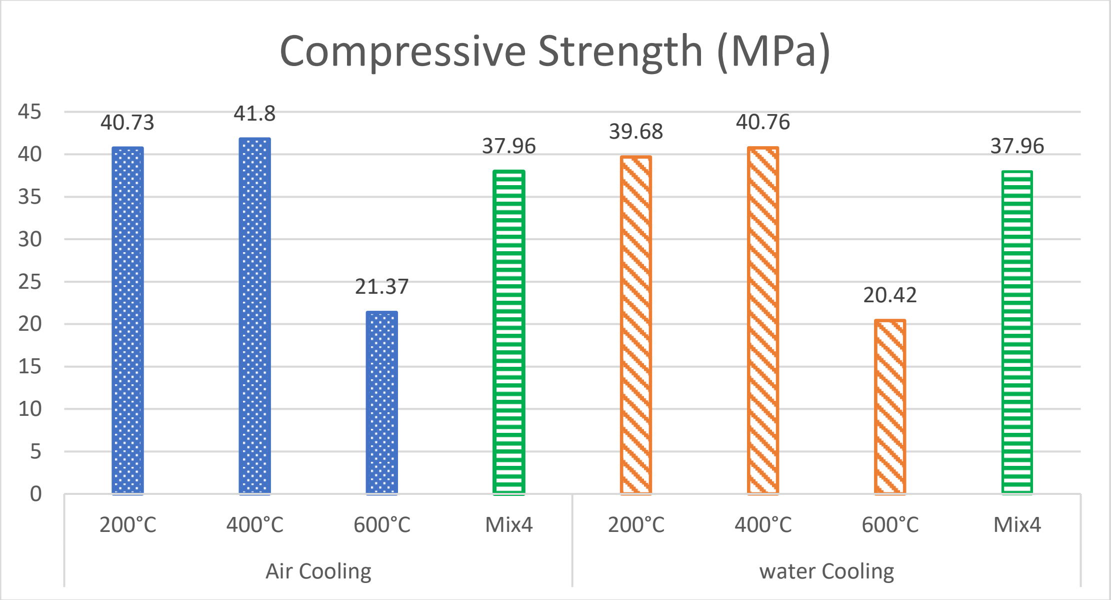

Fig. 7. Compressive strength of Geopolymer concrete mixture after exposure to elevated temperatures.

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Fig. 8. An electric woven with 1100ºC Capacity.

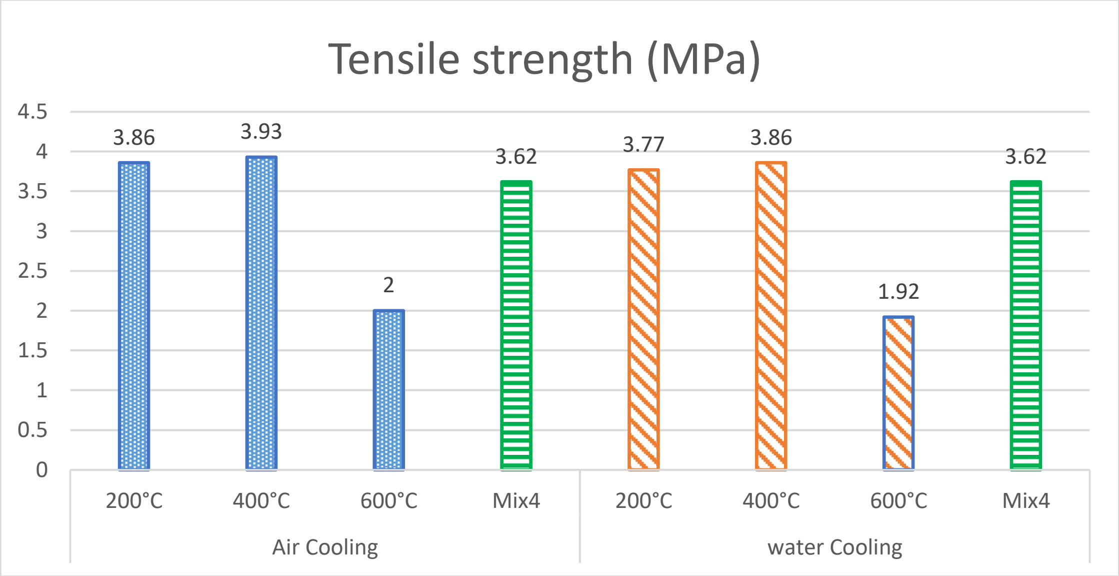

Fig.9. Tensile strength of Geopolymer concrete mixture after exposure to elevated temperatures.

5. Conclusions

Based on the test results obtained in this study, the following conclusion can be drawn as follow:

1. The feasibility of using RBP and PFA as raw materials for the production of Geopolymer concrete using the alkaline activation technique is effective.
2. The optimum mix proportions of fine aggregate, coarse aggregate, water, and superplasticizer to fine waste are 1.5, 3, 0.15, and 2.5%, respectively.
3. Using a superplasticizer reduces the water content so, the compressive strength increased.
4. The higher compressive, split tensile, and flexure strengths of Geopolymer concrete were obtained when curing at 70° C for 24 h.
5. When Geopolymer concrete was exposed to elevated temperatures of 200ºC and 400ºC, the compressive strength values increased.
6. When Geopolymer concrete was exposed to elevated temperatures over 400ºC, the compressive strength values decreased.

Generally, palm fronds ash and red brick powder to produce Geopolymer concrete are effective. The curing heat plays an important role in the rate of strength gain, especially at early ages.

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