ASGE Vol. 06 (01), pp. 122-132, 2022

Egyptian Knowledge Bank

International Journal of Advances in Structural and Geotechnical Engineering

https://asge.journals.ekb.eg/

Print ISSN 2785-9509 Online ISSN 2812-5142

Properties of Geopolymer concrete with recycled aggregate

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ABSTRACT

It is well known that Portland cement concrete isn't a friendly construction material. This due to cement manufacturing is an energy intensive process and it releases a large amount of greenhouse gas to the atmosphere. So, the effort of researchers is directed to use eco-friendly materials such as Geopolymer composites to achieve the green and sustainable construction industry. Moreover, recycling of the concrete waste from construction and demolition sites is considered another trend in saving the environment form pollution. In the light of this, the current research presents an experimental study to investigate the influence of using recycled aggregate in the properties of Geopolymer concrete. Geopolymer mixtures with different replacement percentages by volume of recycled coarse aggregate were used. Two types of recycled aggregates with maximum grain sizes namely 10 and 25 mm were investigated with 0, 20, 40, 60 and 100% as a replacement for the natural aggregate by volume. The used binder was a mixture of fly ash and alkaline solution, the used alkaline solution composed of sodium hydroxide with 12 mole concentration as well as sodium silicate. Both of fresh and hardened properties were investigated. The results show that the unit weight slightly reduced with the increase of the replacement ratio. Moreover, the consistency of the studied mixtures reduced with the increase of the replacement percentage. On the other hand, the mechanical properties indicated that the recycled aggregate may be used in producing structural Geopolymer concrete with comparable properties which can make construction industry more sustainable process.

***Keywords*:** Geopolymer concrete; recycled aggregate; fresh properties; hardened properties.

1. INTRODUCTION

Concrete is the major construction material of infrastructure. Repairing and upgrading the deteriorating of infrastructure systems will utilize large quantity of new concrete and in the meantime generate significant amount of waste concrete. Ordinary Portland cement (OPC) is commonly used as the binder in the manufacture of concrete. It is well known that the production of OPC not only consumes significant amounts of natural resources and energy but also releases substantial quantity of greenhouse gases. To produce 1 ton of OPC, about 1.5 tons of raw materials is needed and 1 ton of CO_2 is released to the atmosphere. Production of concrete also utilizes sand and aggregate. Quarrying operations for producing the sand and aggregate are energy intensive and can release high level of waste materials. [1]

The need to ensure sustainability of construction materials encourage the construction industry to look for alternative materials. On the other hand, it is a great challenge to handle the significant amount of waste concrete to be generated from repairing and upgrading the deteriorating infrastructure systems. Besides, finding areas suitable for landfilling is getting harder and disposing is getting more expensive. Therefore, recycling of waste concrete is encouraged by different agencies.

In 1978, Joseph Davidovits developed inorganic polymeric materials and coined the term geopolymer. Geopolymer concrete is concrete which does not utilize any Portland cement in its production; the binder of GPC is produced by the reaction of an alkaline liquid with a source material that is rich in silica and alumina such as fly ash. The most common activator is a mixture of water, sodium hydroxide and sodium silicate. Fly ash, the finely divided residue that results from the combustion of ground or powdered coal in thermal power station is available abundantly all over the world. Most of the fly ash is disposed as a waste material. Silicon and aluminum are the main constituents of fly ash. The use of fly ash as alternative of cement imparts environmental benefits, reduces landfill demands, reduces concrete costs, and improves concrete properties. [2]

On the other hand, the utilization of the recycled concrete aggregates in structural concrete is very limited. This can be referred to, when waste concrete is crushed, a certain amount of cement paste/mortar from the original concrete remains attached to stone particles in the concrete aggregate. The attached paste/mortar is porous and contains microcracks due to stresses endured during its operable life and crushing process [3], and this is the main reason for the lower quality of the concrete aggregate than the natural aggregate. Compared to natural aggregates, the concrete aggregate has increased water absorption, decreased bulk density, decreased specific gravity, increased abrasion loss, increased crushability, and increased quantity of dust particles. The low quality of the concrete aggregate generally leads to new OPC concrete with inferior strength, durability, and shrinkage properties. A limit of 30% of concrete aggregate is usually recommended. [1]

S. F. U. Ahmed [4] investigated the effect of used recycled coarse aggregate (RCA) as replacement (by weight) of natural coarse aggregate (NCA) with percentages 25,50,75 and 100%, In addition, used of 40% (by weight) class F fly ash as partial replacement of cement on the properties of recycled aggregate concrete. It was denoted that, hardened properties were better at 25% RCA replacement, but with higher replacement ratio hardened properties were decrease. However, in the case of recycled aggregate concretes containing 40% fly ash, the compressive strength at later ages was increased and the water absorption was decreased significantly.

M.KThangamanibindhu, et al. [5] presented the results of the studies carried out on the compressive strength of Geopolymer concrete partially replaced with recycle coarse aggregates.
different mixes were tested, having varying combinations of fly ash, GGBS and recycled coarse aggregates. The results were shown that the compressive strength and spilt tensile strength of different mixes were decreased with the increase in the percentage of recycled coarse aggregates.

P. Saravanakumar [6] studied the influence of recycled concrete coarse aggregate on engineering and durability characteristics of the geopolymer recycled aggregate concrete. The results were shown that the workability, the compressive and tensile strengths reduced with the increase in the RCA volume. Also, geopolymer recycled aggregate concrete showed better strength characteristics than ordinary recycled aggregate concrete. Furthermore, the sorptivity was directly proportional to replacement of natural aggregate with recycled aggregate. geopolymer recycled aggregate concrete showed better sorptivity than ordinary recycled aggregate concrete.

F.U.A. Shaikh [7] presented mechanical and durability properties of geopolymer concrete containing recycled coarse aggregate as a partial replacement of natural coarse aggregate. Results shown that the compressive strength, indirect tensile strength and elastic modulus of geopolymer concrete decrease with an increase in RCA contents. Also, the measured durability properties such as sorptivity, water absorption and volume of permeable voids of geopolymer concrete were also adversely affected by the incorporation of RCA.

In the light of this, the current research presents an experimental study to investigate the influence of using recycled aggregate in the properties of Geopolymer concrete.

2. Experimental Program

The main goal of this study is investigating the effect of increase the replacement percentages by volume of recycled coarse aggregate on geopolymer concrete performance. To achieve that five mixes with partial replacement (0,20,40,60,100%) by volume of recycled coarse aggregates for the natural aggregate in geopolymer concrete (GPC) were investigated also in ordinary Portland cement concrete (OPC) were prepared and tested for investigating both of fresh and hardened properties of GPC and comparing it with the OPC properties having the same replacement percentage.

2.1 Materials

2.1.1 Cement

The cement used was Portland cement (CEM1 42.5N) obtained by the Lafarge company and complies with Egyptian standard specification [ESS 4756- 1/2006]. The properties of the cement used are illustrated in Table (1).

Table 1. Physical properties of Portland Cement

property	value	ESS 4756- 1/2006
Specific gravity	3.15	-
Initial setting time (min)	100	>60 min
Final setting time (min)	350	<600 min

2.1.2 Fine Aggregate

The fine aggregate used in the experimental program was natural siliceous medium well graded sand. Its characteristics satisfy the requirements of [ECP 203/2007-part3]. It was clean and free from impurities, passing through sieve size 4.75 mm with a specific gravity of 2.65 and a fineness modulus of 2.29. The physical properties of the used sand are shown in Table (2). The Sieve analysis of the used sand as well as the limits of [ECP 203/2007] is given in Fig. (1).

Table 2: The physical properties of the sand

property	value
Specific gravity	2.65
Unite weight (t/m^3)	1.67
Void ratio %	36.98%
Fineness modules	2.29

2.1.3 Natural coarse aggregate (NCA)

The coarse aggregate used was crushed lime stone, which satisfies the requirements of [ECP203/2007]. The specific gravity was 2.7. Two sizes of NCA lime stone 1 (LS1) and lime stone 2 (LS2) were used with maximum grain sizes 10 and 20 mm, respectively. The physical and mechanical properties of the crushed lime stone are shown in the Tables (3 and 4). On the other hand, the sieve analysis as well as the limits of [ECP 203/2007] for the used coarse aggregate is presented in Fig. (2).

2.1.4 Recycled concrete aggregates (RCA)

Recycled aggregate was obtained from demolished building in Tanta. This was constructed 50 years ago. The samples of crushed concrete were taken from the reinforced concrete foundations, and then manually crushed into two sizes RCA10 and RCA25 with maximum grain sizes namely 10 and 25 mm, respectively. The used RCA were investigated with percentage of 0, 20, 40, 60 and 100% as a replacement for the natural aggregate by volume in five mixes of GPC also in another five mixes of OPC. The physical and mechanical properties of the two sizes are shown in Tables (3 and 4). The Sieve analysis of the investigated RCA10,25 as well as the limits of [ECP 203/2007] are given in figures (3 and 4).

From these data, it is evident that, RCA has a high value of absorption ratio and low abrasion resistance, this attributed to the weakness and higher porosity of the attached cement mortar.

Table 3: The physical properties of coarse aggregate

Aggregates	N.M.S. (mm)	Specific gravity	Dry-rodded density (kg/m^3)	Void ratio%	Absorption (%)	Fineness modulus
LS 1	10	2.7	1450	46%	1.6%	**6.29**
LS 2	20	2.7	1450	46%	1.3%	**7.0**
RCA 10	10	2.29	1104	51.8%	9.67%	**6.0**
RCA 25	25	2.38	1160	51.3%	5.64%	**7.29**

Table 4: The mechanical properties of coarse aggregate

Property	Values		Limits
	LS	RCA	
Crushing strength (%)	24	28.4	Max 30%
Los Angeles abrasion loss (%)	20	52.8	Max 30%

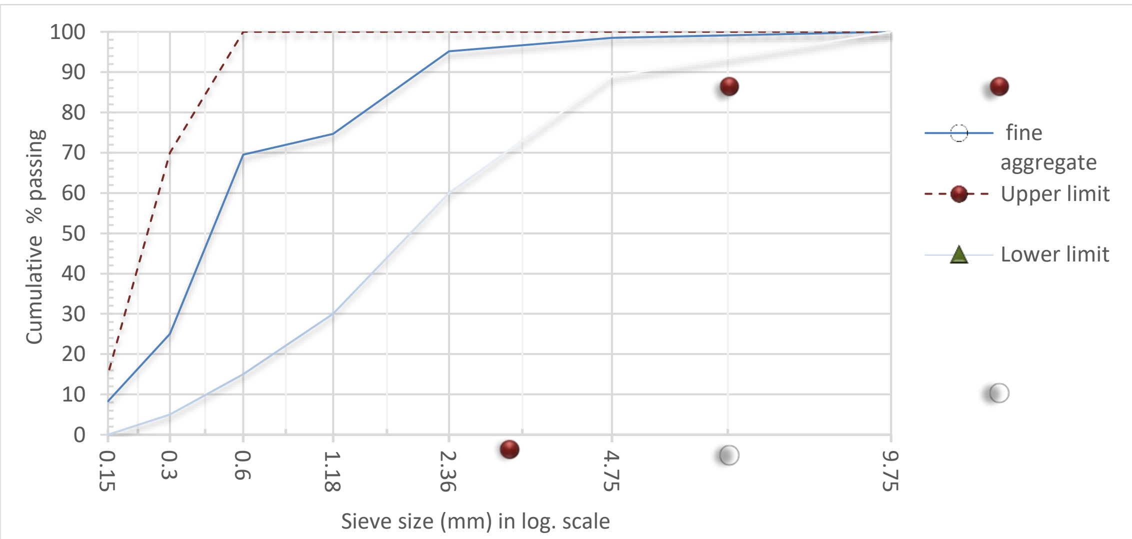

Figure 1. Sieve analysis of natural coarse aggregate.

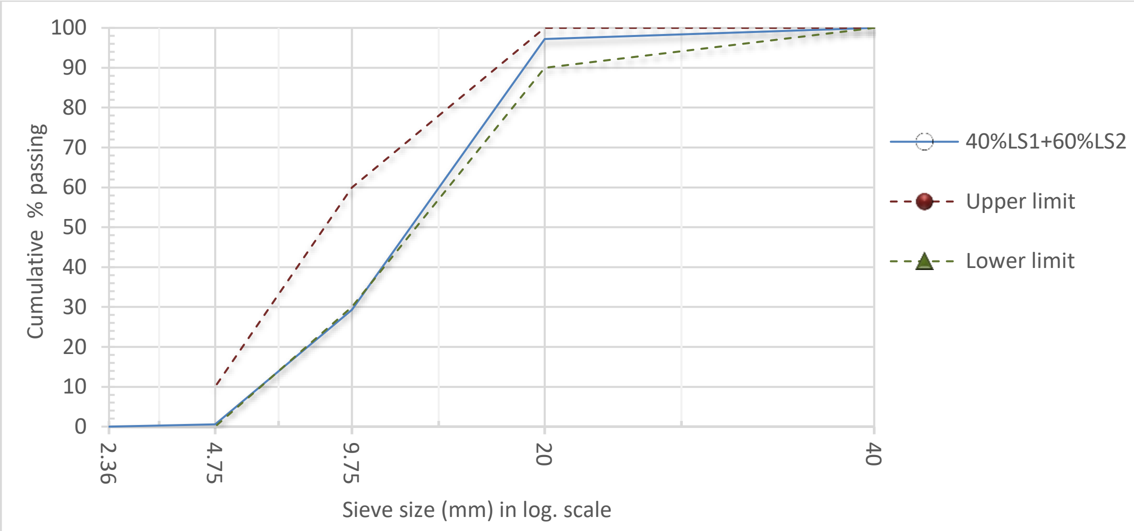

Figure 2. Sieve analysis of natural coarse aggregate.

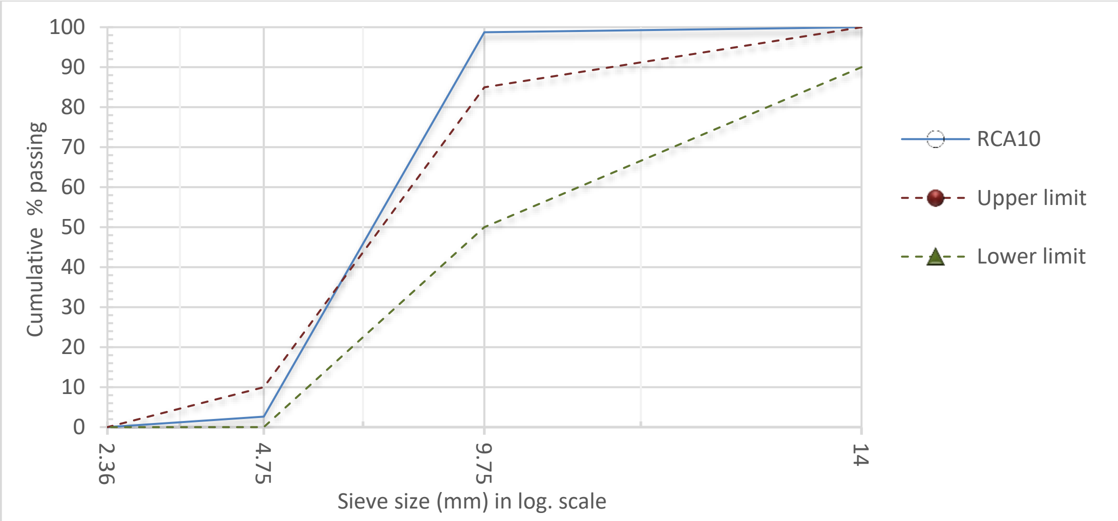

Figure 3. Sieve analysis of recycled coarse aggregate10 (RCA10).

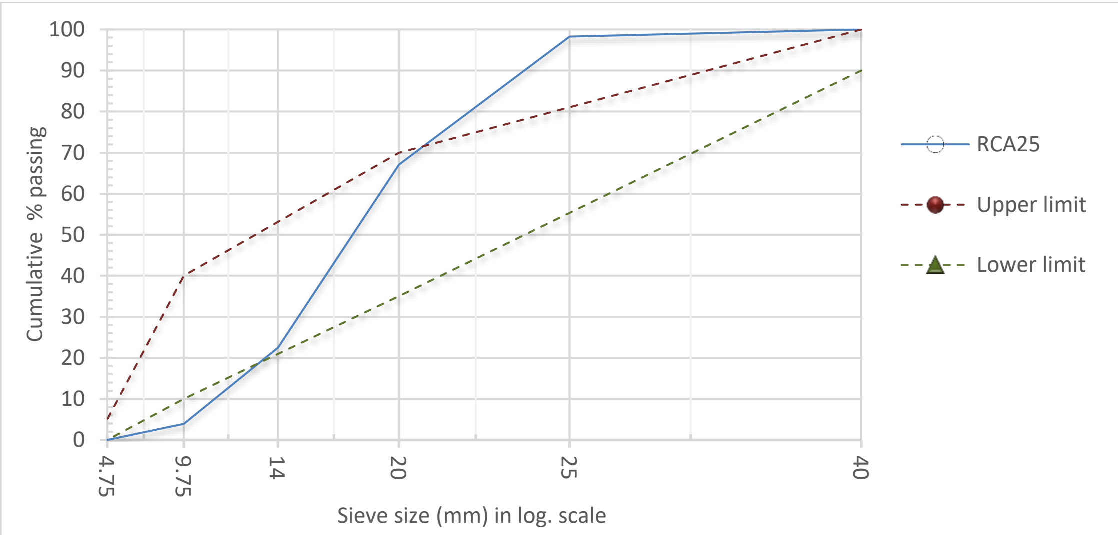

Figure 4. Sieve analysis of recycled coarse aggregate25 (RCA25).

2.1.5 Fly ash

Class (F) FA, produced in a coal-fired power plant was used in this study. It complies with the chemical of [ASTM C618] and relevant international quality standards for FA. The chemical composition and physical properties of (FA) according to the manufacturer are given in the Table (5).

Table 5: The chemical composition and physical properties of (FA)

Component	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	CaO	MgO	Na_2O	K_2O	So_3	Specific Surface Area (cm²/gm)	Specific gravity	Loss on Ignition
Result obtained %	49.62	20.79	1.32	12.71	8.3	3.02	1.82	1.66	0.72	5000	2.6	0.24

2.1.6 Alkaline activator

The alkaline activator liquid used was a combination of sodium silicate solution and sodium hydroxide with 12 mole concentration. An analytical grade sodium hydroxide in Flakes form (NaOH with 98% purity) was used. Water was used for preparing activating solutions. The activator solution was prepared at least one day prior to its use in specimen casting.

2.2 Details of experiments

2.2.1 Mixes proportions

For the present study, concentration of sodium hydroxide was taken as 12M, alkaline solution ratio (Sodium silicate /Sodium hydroxide) as 2.5, solution/fly ash ratio is kept constant at 0.45 in all GPC mixes and water/cement ratio is kept constant at 0.45 in all OPC mixes. The various mix proportions are given in Tables 6 and 7 for GPC and OPC.

Table 6: Mix proportions for the investigated OPC mixes (kg/m^3).

Series		**OPC 0%**	**OPC 20%**	**OPC 40%**	**OPC 60%**	**OPC 100%**
RCA replacement %		0%	20%	40%	60%	100%
RCA (kg/m^3)	**RCA 25**	_	126.76	253.51	380.27	633.78
	RCA 10	_	81.42	162.84	244.26	407.11
NCA (kg/m^3)	**LS 2**	719	575.2	431.4	287.6	_
	LS 1	480	384	288	192	_
Fine aggregate (kg/m^3)		590	590	590	590	590
Cement (kg/m^3)		408	408	408	408	408
Water(kg/m^3)		183.7	183.7	183.7	183.7	183.7

Notes:

- **sand: L.S = 1: 2 and L.S1: L. S2= 1: 1.5**
- **The RCA10,25 replacement is by volume of LS1,2, respectively.**
- **W/c ratio= 0.45**

Table 7: Mix proportions for investigated GPC mixes (kg/m³).

<table>
<tr><th colspan="2">Series</th><th>GPC 0%</th><th>GPC 20%</th><th>GPC 40%</th><th>GPC 60%</th><th>GPC 100%</th></tr>
<tr><td colspan="2">RCA replacement %</td><td>0%</td><td>20%</td><td>40%</td><td>60%</td><td>100%</td></tr>
<tr><td rowspan="2">RCA (kg/m³)</td><td>RCA 25</td><td>_</td><td>129.98</td><td>260</td><td>389.95</td><td>649.91</td></tr>
<tr><td>RCA 10</td><td>_</td><td>83.37</td><td>166.74</td><td>250.1</td><td>416.86</td></tr>
<tr><td rowspan="2">NCA (kg/m³)</td><td>LS 2</td><td>737.3</td><td>589.84</td><td>442.38</td><td>294.92</td><td>_</td></tr>
<tr><td>LS 1</td><td>491.5</td><td>393.2</td><td>294.9</td><td>196.6</td><td>_</td></tr>
<tr><td colspan="2">Fine aggregate (kg/m³)</td><td>604.6</td><td>604.6</td><td>604.6</td><td>604.6</td><td>604.6</td></tr>
<tr><td colspan="2">Fly ash (kg/m³)</td><td>408</td><td>408</td><td>408</td><td>408</td><td>408</td></tr>
<tr><td colspan="2">Sodium silicate solution (kg/m³)</td><td>131.2</td><td>131.2</td><td>131.2</td><td>131.2</td><td>131.2</td></tr>
<tr><td colspan="2">Sodium hydroxide (12 M) (kg/m³)</td><td>52.5</td><td>52.5</td><td>52.5</td><td>52.5</td><td>52.5</td></tr>
<tr><td colspan="7">Notes:
• Sodium silicate /Sodium hydroxide = 2.50
• alkali solution / Fly ash = 0.45
• sand: L.S = 1: 2 and L.S1: L.S2 = 1: 1.5
• The RCA10,25 replacement is by absolute volume of LS1,2, respectively.</td></tr>
</table>

2.2.2 Preparation, Casting and Curing

For geopolymer concrete, the activator solution was prepared at least one day prior to its use and both RCA and NCA are submerged in water for one day before casting, then drying their surface to reach to case saturated surface dry aggregate.

Fly ash and alkaline solution were mixed for 5 minutes and then coarse aggregate and fine aggregate in saturated surface dry condition were added and mixed for another 5 minutes.

For ordinary cement concrete, traditional method was adopted for mixing. Flow table test was done immediately after mixing the concrete to measure the workability of each mix. Then for each mix 6 cubes 10×10×10 cm^3 were cast for compression strength, 6 cylindrical samples with 100 mm diameter and 200 mm height were cast for splitting tensile strengths, and 6 prisms 10×10×50 cm^3 were cast to measure the flexural strength. Concrete was placed in the molds in three layers of equal thickness and each layer was vibrated until the concrete was thoroughly compacted using vibrating table. Specimens were demolded after 24hrs.

The OPC samples were water cured for a period of 7and 28 days, while GPC samples cured at 60 °C for 2 days. Then, they were demolded and kept in 23°C and 50% R.H. controlled room until the age of 7and 28 days.

3. Results and discussion

3.1 Workability

With the increase of the RCA volume the workability of concrete was reduced. Despite the use of saturated surface dry RCA tended to give a higher workability than that with lime stone. This may be due to the fact that, the RCA particles contain larger volume of pores and water at saturated surface dry condition than that of LS particles. The water inside RCA particles was available and improved the workability of the mixes which agree with previous study by (Poon et al., 2004) [8]. But, the rough surface of RCA has the greater effect on decreasing workability.

On the other hand, it was denoted that the GPC has lower workability than OPC and this attributed to a higher viscosity of GPC. The results of flow table test for both GPC and OPC are shown in Fig. (5)

3.2 Density

With the increase in the RCA volume, the density of concrete was reduced. This could be attributed to low value of Specific gravity of RCA which have amount of porous mortar attached to it. On the other hand, it was denoted that the GPC has higher density than OPC and this attributed to higher density of the alkaline activator liquid than water. the density of different mixes of GPC and OPC are shown in Fig. (6).

3.3 Compressive strength

For each mix, three cubes 10×10×10 cm^3 were tested at ages of 7 and 28 days to investigate the compressive strength. Fig. (7) shows the effect of RCA on the compressive strength of concrete containing different RCA contents. It can be seen that the replacement of 20% NCA by RCA slightly increased the compressive strength at all ages. Similar results were also observed by other researchers (Yong and Teo 2009; Tam et al. 2006) [9,10]. However, at higher replacement levels, such as at 40%, 60%, and 100%, the compressive strength decreased at all ages. On the other hand, it was observed that the GPC achieved the higher strength for all mixes compared to OPC.

3.4 Indirect tensile strength

For each mix three cylindrical samples with 100 mm diameter and 200 mm height were tested at ages of 7 and 28 days to investigate the Indirect tensile strength. Fig. (8) shows the effect of RCA on the Indirect tensile strength of concrete containing different RCA contents. It can be seen that with the increase of the replacement ratio, the Indirect tensile strength decreased at all ages. Moreover, it is clear that the splitting tensile strength for GPC is more sensitive for using RCA compared to OPC mixes.

3.5 flexural strength

For each mix, three prisms 10×10×50 cm^3 were tested at ages of 7 and 28 days to investigate the flexural strength. Fig. (9) shows the effect of RCA on the flexural strength of concrete containing different RCA contents. It can be seen that with increase the replacement ratio the flexural strength decreased at all ages except for 40% ratio it showed slightly increased in the flexural strength. Also, the results show that GPC achieve the higher strength for all mixes.

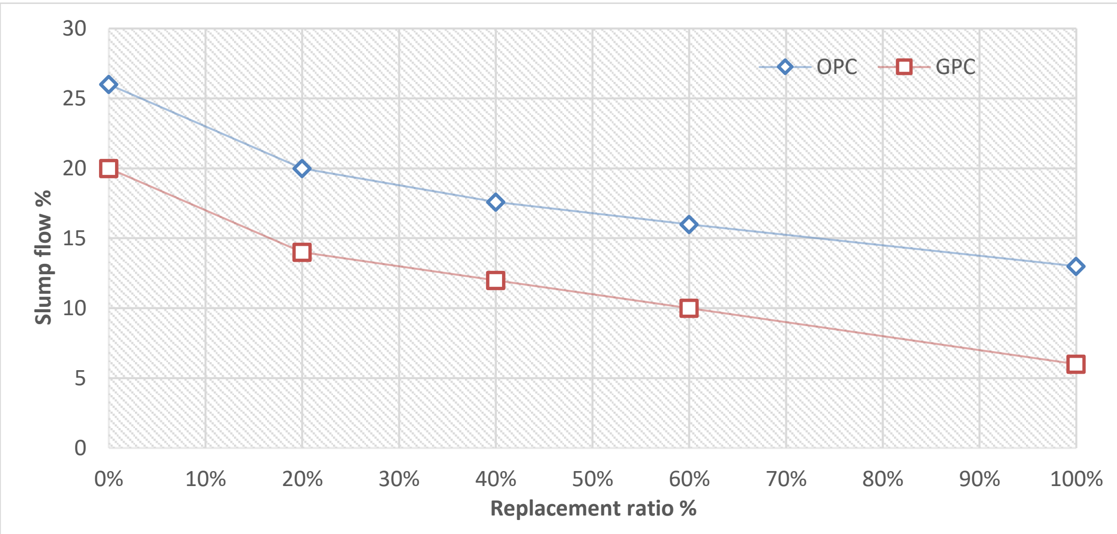

Figure 5. Slump flow% for GPC & OPC.

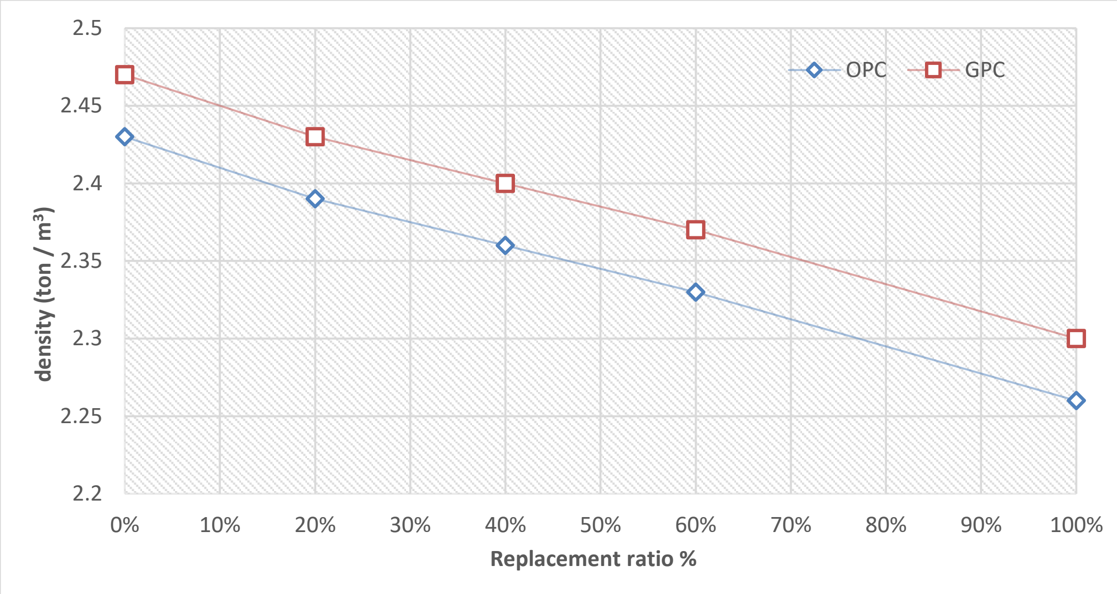

Figure 6. Density (ton/m^3) for GPC & OPC.

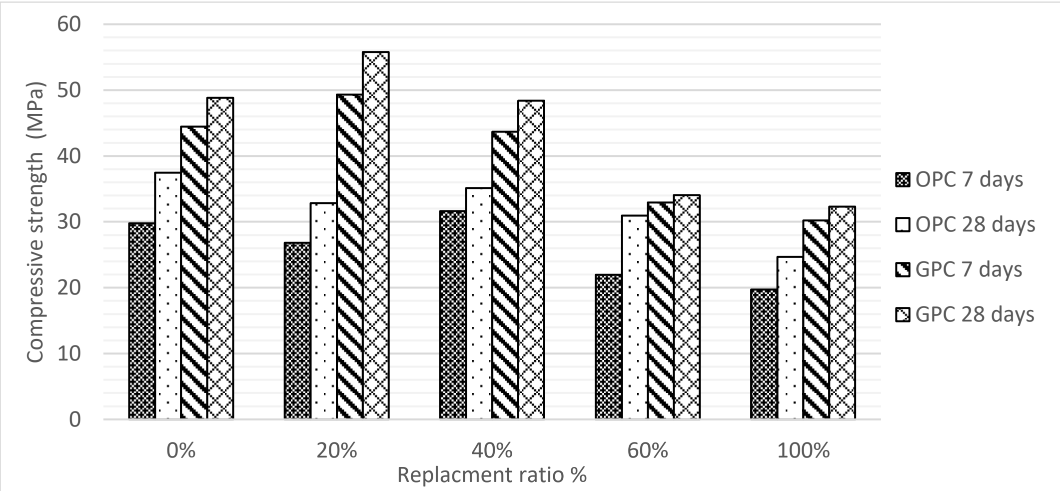

Figure 7. Compressive strength (MPa) for GPC & OPC.

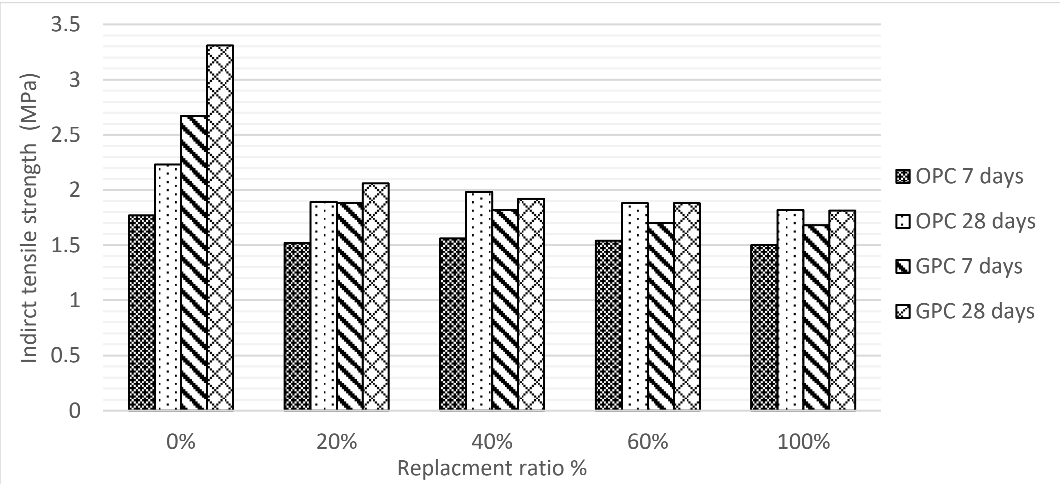

Figure 8. Indirect Tensile strength (MPa) for GPC & OPC.

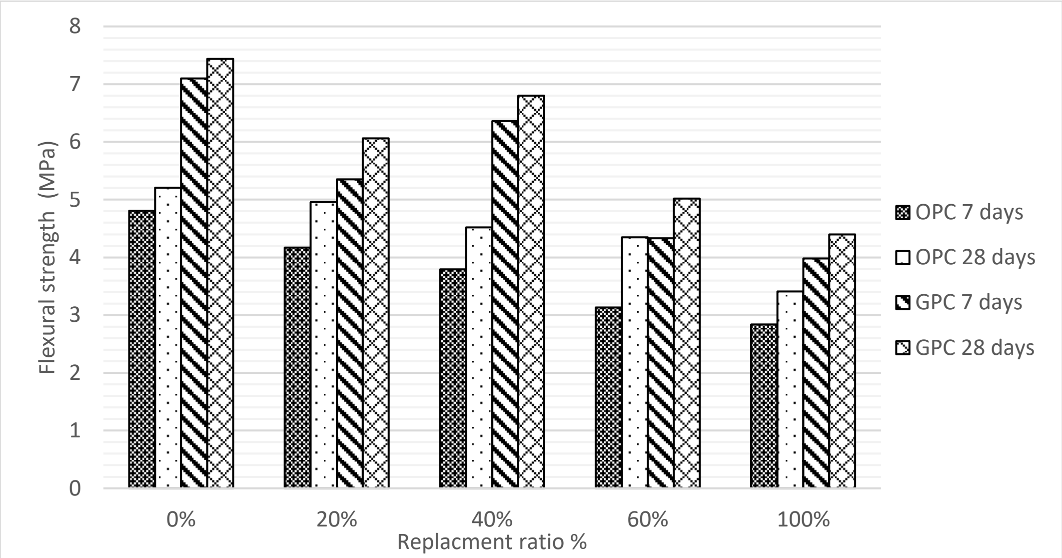

Figure 9. Flexural strength (MPa) for GPC & OPC.

4.Conclusions

This experimental work studied the influence of using recycled coarse aggregate obtained from the demolished concrete on fresh and hardened properties of the geopolymer recycled aggregate concrete and the following conclusions can be drawn;

1. The workability reduces remarkably with the increase of the percentage of RCA as a replacement for natural aggregate.

2. Replacing part of the natural aggregate with RCA reduces the compressive strength of GPC and OPC. The reduction increases with the increase of the replaced percentage. 65% and 66% of the compressive strength were achieved for OPC and GPC with 100% replacement, respectively.

3. Replacing part of the natural aggregate with RCA reduces the Indirect tensile strength of GPC and OPC. The reduction increases with the increase of the replaced percentage. 81% and 54% of the Indirect tensile strength were achieved for OPC and GPC with 100% replacement, respectively.

4. Replacing part of the natural aggregate with RCA reduces the flexural strength of GPC and OPC. The reduction increases with the increase of the replaced percentage. 65% and 59% of the flexural strength were achieved for OPC and GPC with 100% replacement, respectively.

5. Recycling of RCA in geopolymer comports shows more efficiency compared to those with Portland cement concrete.

The overall results indicate that it is feasible to use the Geopolymer concrete with a lower partial replacement of NCA with RCA, as a best alternative construction material for ordinary Portland concrete.

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