ISSN 2229-5518

Effect of Adding Portland cement on the Characteristics of Geopolymer Concrete Containing Recycled Coarse Aggregate

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Abstract—This paper presents an experimental study to evaluate the influence of adding different selected ratios of Portland cement on the characteristics of geopolymer concrete containing recycled coarse aggregate (RCA). The RCA is collected from building demolition wastes. The RCA is used as a partial substitution of virgin coarse aggregate (dolomite) in geopolymer concrete at 25% and 50% by weight. Portland cement partially substituted fly ash of geopolymer paste at ratios of 5%, 10%, and 15% by weight of binder. Compressive strength, indirect tensile strength, modulus of elasticity, flexural strength, porosity and setting time were examined to investigate the purpose of this study. The outcomes showed that, the compressive strength values were noticed to be in the range of 36- 46MPa, indirect tensile strength values in the range of 4.1- 4.8 MPa, modulus of elasticity values in the range of 23-26 GPa, and flexural strength values were in the range of 10.5-11.5MPa. In addition, it was noticed that the highest increase in the obtained mechanical properties of recycled geopolymer concrete containing Portland cement compared to geopolymer concrete with 100 % virgin coarse aggregate, was achieved by using 25% of recycled coarse aggregate and 15% of Portland cement. The outcomes also showed that the use of Portland cement as an additive to substitute part of fly ash in recycled geopolymer concrete reduced the setting time and porosity, while the compressive strength, indirect tensile strength, flexural strength and modulus of elasticity imitate to increase.

Index Terms— Geopolymer concrete; Recycled aggregate; Portland cement; Mechanical properties; Porosity

1 INTRODUCTION

CONCRETE is one of the most important building materials in the world owing to its many advantages including the availability of materials, cheapness, durability and availability of skilled labors [1, 2]. Concrete manufacturing technology depends mainly on cement as a bond material for concrete components. However, the importance of cement as a major material in the concrete industry, the production process of ordinary Portland cement (OPC) causes serious damage and air pollution due to the emission of large amounts of $CO2$ during the manufacturing process [3]. Therefore, the effort focuses on how to replace OPC with by-products or natural materials [4]. Basil et al.[5] investigated the concrete manufacturing by using environmentally friendly materials such as fly ash to replace the cement. Fly ash, a by-product material from the coal production, which is vastly obtainable in the world, contains silicate and alumina [6]. Fly ash interacts with alkaline solution produces alumina silicate gel which binds aggregates to produce new and green concrete called geopolymer concrete [7, 8]. Recently, the interest in geopolymer concrete has increased due to its strength and durability in comparison with ordinary concrete, as well as helping to reduce environmental pollution [9-12].

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It has become clear that fly ash is convenient as a basic material for producing good geopolymer concrete [13-14]. Most of the researches concerned with geopolymer concrete have concluded that the amorphous structure of the components of these concrete helps to achieve the best mechanical properties required [16, 17]. Many researches have suggested the ability of using recycled aggregates as a replacement percentage of natural aggregates in concrete that will contribute to the provision of natural resources and reduce the cost of concrete production [18-20]. Antonio Caggiano et al. [21] investigated the mechanical action of recycled concrete aggregates (RCA) pediment from building destruction. The experimental results confirmed that the use of aggregates obtained from crushed concrete building in replacement of natural aggregates leads to concretes having lower strengths and higher permeability. Anuar Khairulniza et al. [22] studied the effect of concentration of sodium hydroxide (NaOH) solution on strength of Geopolymer concrete containing recycled aggregates. The results showed that the concentration (in term of molarity) of NaOH affected the strength feature of recycled geopolymer concrete. As concentration of sodium hydroxide (NaOH) solution increases, the compressive strength of recycled geopolymer concrete increased. Jonathan and Kenneth [23] studied the affect of heat emmission from OPC on mechanical properties of geopolymer concrete. Results showed that the process of manufacturing geopolymer concrete containing fly ash, heat is produced from the reaction between the concrete components used. This heat helps in the formation of polymer chains that work on the cohesion of concrete. However, the rate of emission of this heat is not large enough to give a concrete with greater resistance. So the importance of adding part of Portland cement in specific quantities is accelerating the interaction process, the geo-polymerization process and the setting time of concrete. Nazari and Safarnejad [24] used specific proportions of cement in their investigation as an additive for geopolymer concrete containing natural aggregate. The results showed an improvement in compressive strength due to the presence of cement in mixtures. However, many researches [20, 21] provided that the use of recycled aggregate as replacement percentages of natural aggregate in geopolymer concrete reduced the strength. Therefore, this study presents an experimental application to find out the effect of using selected ratios of OPC with recycled geopolymer concrete in order to improve its properties. In this study, the virgin coarse aggregate (dolomite) was replaced by 25% and 50% of recycled coarse aggregate and fly ash was replaced by selected ratios of OPC (5%, 10% and 15%) in geopolymer concrete. The effect of replacement levels of both coarse aggregate and fly ash on the main mechanical properties, porosity and setting time of recycled geopolymer concrete with different ratios of OPC as an additive was studied.

2 EXPERIMENTAL PROGRAMS

2.1 Materials Used

The materials used in this study were cement, fly ash, fine aggregate, virgin coarse aggregate, recycled coarse aggregates (RCA), super plasticizer and alkaline solution. Ordinary Portland cement (CEM I 42.5 N) with a specific gravity of 3.15 and fineness of 3650 g/cm2 and confirming to (ASTM C150-2015/Type V) was used [25]. Dolomite was used as a virgin coarse aggregate. Dolomite used in this study was a mix of 10 mm and 20 mm in size. The recycled aggregate was obtained from building demolition waste in Shebin Elkom, Egypt. The building demolition wastes were crushed separately using crusher machine at concrete lab. After the crushing treatment, the RCA was graded to the required particular size (fig.1). Then the RCA is sieved using standard sieves to split up the fine and coarse RCA. Table (1) presents the properties of the aggregates used in this study. Well graded sand having a fineness modulus of 2.73 and specific gravity of 2.82 was used. The virgin coarse aggregate and RCA used in this study were in saturated and a surface dry situation before being used in the blending. Fly ash is reflected as the main component of the binder materials in geopolymer concrete. Fly ash was gained from the GEOSS Company in Cairo. Specific gravity of fly ash was 2.6. The chemical properties of fly ash and OPC are given in table (2). High Range Water Reducing (HRWR) as a super plasticizer was used to enhance the workability of the geopolymer concrete in this study. Sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) with molarity 10M were used as alkaline solutions in this study. Sodium silicate has specific gravity of 1.6 and molar mass of 122.07 g/mol., and sodium hydroxide has density of 2.32 g/cc and molar mass of 40 g/mol.

Table 1: Properties of used Aggregates

Property	values	
	Virgin aggregate(Dolomite)	Recycled aggregate
Specific Gravity	2.66	2.58
Water Absorption (%)	1.6	5.5
Abrasion resistance (%)	32	48
Fineness modulus	6.4	7.2

Table 2: Chemical components of fly ash and OPC - % by mass

material	SiO_2	Al_2O_3	FeO_3	CaO	MgO	Na_2O	K_2O	LOI
Fly ash	36.2	17.7	12.48	3.3	2.45	1.96	2.3	0.58
OPC	22.8	5.6	4.3	65.5	1.5	0.21	0.35	0.85

a.Recycled coarse aggregate

b.Virgin aggregate (dolomite)

Fig.1. Aggregate used in geopolymer concrete

2.2 Mix Proportions

For mix design, the mass of coarse and fine aggregates constitutes 75% of the total mass of geopolymer concrete. Geopolymer pastes varies according to the present of cement substitution (5%, 10% and 15%) in each mixture by mass of binder.The ratio of alkaline solution was assumed as 0.45 to find out the quantity of fly ash and alkaline solution. From the previous studies [24,26], it noticed that the activation of sodium silicate (Na2SiO3) and sodium hydroxide (NaOH) solutions produced high quality geopolymer concrete. The alkaline solution has been prepared 24 hours before being used as an activator for the desired mixtures. The weight of Na2SiO3 used is 2.5 times that of the NaOH. Trial and error method was used for mix design of geopolymer concrete as there is no approved coded procedure [10]. To achieve the workablity of mixture, 2% of super plasticizer was added to all mixtures [9]. In this study, nine mixes are considered. Table (3) shows the detail of mix proportions of all mixtures. The first mixture is the control one where 100% virgin coarse aggregate (dolomite) is used in geopolymer concrete without any addition of OPC and is symbolized as GVC mixture. Two mixtures contain (25% and 50%) of RCA as a partial replacement of virgin coarse aggregates without any addition of OPC and symbolized as GR25 and GR50. The rest six mixtures are geopolymer concrete mixtures containing selected ratios of OPC (5%, 10% and 15%) and applied for each replacement percentage of the RCA aggregate (25% and 50% and symbolized as GR25opc5, GR25opc10, GR25opc15, GR50opc5, GR50opc10andGR50opc15. The alkali solution to binders' ratio of all geopolymer concrete is kept constant. The geopolymer concrete mixes were done using traditional method. First fly ash is mixed with the specified replacement ratio of Portland cement for the mixture required in pan mixer with fine aggregate and the regular coarse aggregate or recycled coarse aggregate in dry condition for three minutes. Alkali solutions and super plasticizer were then added into the mixer pan and mixed for further 4 min until homogenous mixing is visually noticed. The specimens are then cast and cured in the oven at a temperature of 80 ° C for three days and then took out and placed in the laboratory in room temperature (24 ° C) until the date of testing. Required mechanical properties were tested at 7 and 28 days.

Table 3: The Mixtures Proportions per cubic meter

Mix symbol	Fly ash (Kg)	OPC (Kg)	Sand (Kg)	Dolomite (Kg)	Recycled Coarse aggregate (Kg)	Sodium silicate (Kg)	Sodium hydroxide (Kg)
GVC	415	-		1324	-		
GR25	415	-		993	331		
GR50	415	-		662	662		
GR25opc5	394.25	20.75		993	331		
GR25opc10	373.5	41.5	610	993	331	115	46
GR25opc15	352.75	62.25		993	331		
GR50opc5	394.25	20.75		662	662		
GR50opc10	373.5	41.5		662	662		
GR50opc15	352.75	62.25		662	662		

2.3 Testing Mechanism

After mixing, workability of mixtures was estimated by using cone test to determine mixes slump according to ASTM C143/C143M [27]. Also setting time of geopolymer pastes was evaluated in accordance with ASTM C109 [28]. Cube specimens of size 100 mm*100mm*100mm were cast to determine compressive strength and beams of size 100 * 100 * 500 mm to examine flexural strength. Concrete cylinders having 100 mm in diameter and 200 mm in height were cast to measure indirect tensile strength, while 150 mm diameter by 300 mm height cylinders were cast to calculate the modulus of elasticity. The specimens were cast and after 24 hours were heat treated inside the oven at a temperature ranging from 60 ° C to 90 ° C for three days. After the heat curing, the samples were taken from the oven and placed at laboratory temperature (24 ° C) until the date of testing. The compressive strength, flexural strength, indirect tensile strength and modulus of elasticity were examined as per ASTM C496/C496 M [29]. Three cylinders with a diameter of 100 mm and a height of 20 mm have been used to set the porosity value for each of the nine mixtures used in the practical study and are detailed in Table (3). The porosity value is measured according to ASTM C642 [30]. Average value is taken for the results of the three cylinders for each mixture.

3 Results and Discussions

3.1 Setting Time

Fig. (2.a) presents the setting time values for both control mix and recycled geopolymer mixes with 25 % replacement ratio, compared with setting time values of mixes of recycled geopolymer containing different replacement ratios of OPC (5%,10% and 15%). The initial setting time values of mixtures (GVC, GR25, GR25opc5, GR25opc10 and GR25opc15) were 48, 43, 32, 26 and 20 min. respectively, and the final setting time of these mixtures were 91, 85, 69, 58 and 49 min, respectively. The results showed that the setting time decreased with the increasing of the ordinary Portland cement replacement rates. This result is due to the fastening hardening of the paste due to the availability of free Ca from OPC, which leads to accelerate interaction process of concrete that decreases setting time.[31,32,33].

Fig. (2.b) presents the setting time values for both control mix and recycled geopolymer mixes with 50 % replacement ratio comparing with setting time of mixes of recycled geopolymer containing different replacement ratios of OPC. The initial setting time values of mixtures (GVC, GR50, GR50opc5, GR50opc10 and GR50opc15) were 55, 47, 36, 29 and 23 min, and the final setting time of these mixtures were 95, 89, 71, 63, and 52 min, respectively. It was also noticed that the setting time of the geopolymer paste increases at a higher ratio of recycled aggregate replacement at the same ratio of OPC for both final and initial setting time.

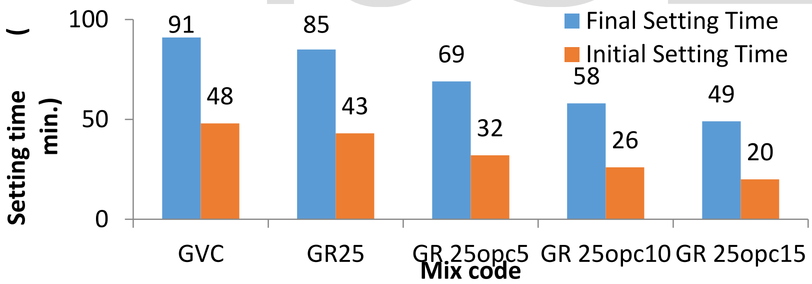

Fig. 2.a. Comparison between setting time of geopolymer pastes containing 25% of RCA with control mix and mixtures containing selected ratios of OPC

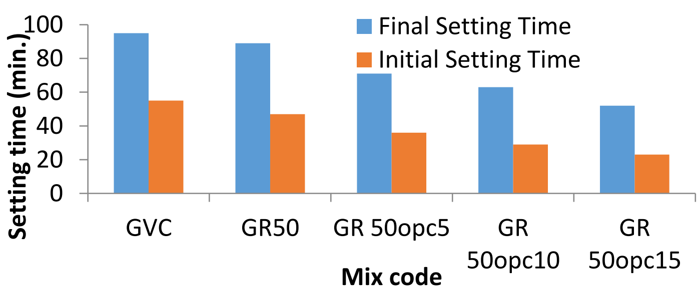

Fig. 2.b. Comparison between setting time of geopolymer pastes containing 50 % of RCA with control mix and mixtures containing selected ratios of OPC

3.2 Workability

The slump values of mixtures (GVC, GR25, GR25opc5, GR25opc10 and GR25opc15) were 75 mm, 85 mm, 82 mm, 80 mm and 77 mm respectively. As the percentage of OPC replacement increased, the slump values of recycled geopolymer concrete decreased. The slump values of mixtures (GVC, GR50, GR50opc5, GR50opc10 and GR50opc15) were 75 mm, 91 mm, 86 mm, 83 mm and 79 mm. As RCA amount increased in the mixture, the slump values increased. The results showed that mixtures containing RCA without OPC have less workability than those containing addition ratios of OPC. This is due to the percentage of voids decreases with the increasing of OPC content in the mixtures [34]. However, the slump values for mixtures containing OPC were lower than the slump values of the mixtures without cement, the mixtures with cement were the best workability in terms of mixing ease, good compaction and speed of setting time.

3.3 Mechanical properties

3.3.1 Compressive strength

The obtained compressive strength of recycled geopolymer concrete with and without Portland cement was examined at the ages of 7 and 28 days to study the effect of various levels replacement of Portland cement on recycled geopolymer concrete strength. From the experimental outcomes, which were presented in (fig.3.a, fig.3.b), it was clear that the compressive strength of the recycled geopolymer concrete increased with the increasing of replacement ratio of Portland cement. The rising in the strength of recycled Geopolymer concrete was due to the rising amount of Ca content in geopolymer concrete. Ca modifies the microstructure of geopolymer gels [36]; while compressive strength of geopolymer concrete without OPC decreased as percentage replacement of recycled aggregate increased. For control mixture, the compression strength of examined concrete was (40 and 44 MPa) at the age of 7 and 28 days respectively. The average decrement of compression strengths at 25% and 50% replacement of recycled coarse aggregate in geopolymer concrete were 18.1% and 22.7% respectively. These outcomes agreed with the previous researches e.g. [1, 35]. Outcomes showed also the microstructure of the concrete modified due to the increase of Ca amount .Ca interaction with SiO_2 and Al_2O_3 of binder to form $Ca (OH)_2$, addition C-S-H and addition C-A-S-H [31]. The interaction products act to enhance the internal cohesion of the microstructure of the concrete paste, thereby increase compressive strength and geo-polymerization reaction is improved [36]. An increase in compressive strength was achieved when using different substrates of cement until reaching the highest value (46Mpa) at replacement recycled aggregates of 25% from virgin aggregate and replacement level of Portland cement at 15% from fly ash amounts

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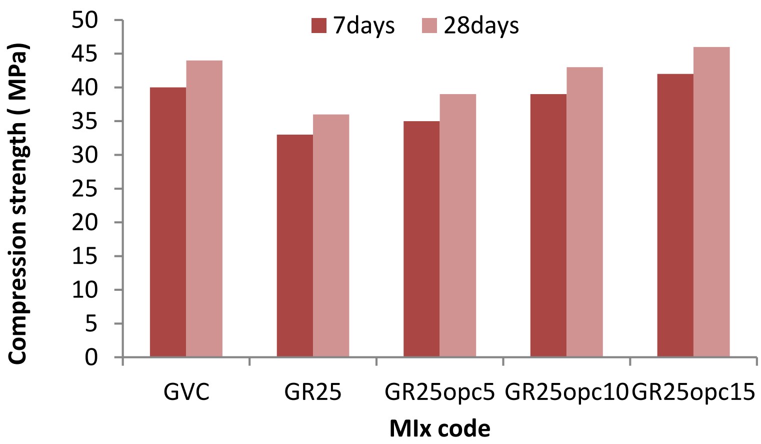

Fig.3.a. Comparison between compression strength of geopolymer concrete containing 25% of RCA at 7 and 28 days with control and mixtures containing selected ratios of OPC

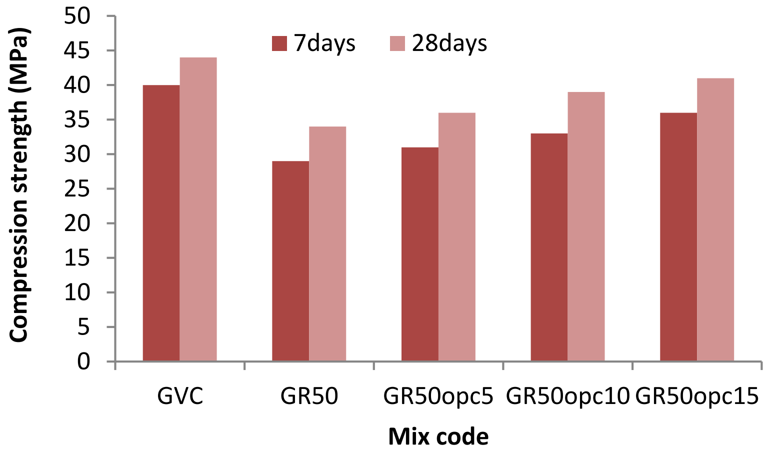

Fig.3.b Comparison between compression strength of geopolymer concrete containing 50% of RCA at 7 and 28 days with control and mixtures containing selected ratios of OPC

3.3.2 Indirect tensile strength

The obtained indirect tensile strength of recycled geopolymer concrete with and without Portland cement was collected from testing cylinder specimens at the ages of 7 and 28 days. Similar trend of indirect tensile strength was observed like compressive strength, where it increases with the increasing in OPC contents. For control specimen at the ages of 7 and 28 days, the indirect tensile strength of geopolymer concrete was (3.8 and 4.6 MPa) which were 5.2% and 4.2 % smaller than indirect tensile strength value of recycled geopolymer concrete with 15 % OPC. In the case of geopolymer concrete containing 25% and 50% RCA without OPC, it has been found out that the 7 and 28 days indirect tensile strength is dropped by about 27.05% and 18.5%, respectively compared to control specimen. The increment in indirect tensile strength of geopolymer concrete containing various ratios of OPC compared to its counterpart recycled geopolymer concrete without OPC could be as a result of the best bond of the geopolymer binder with the RCA.The clear difference could be due to discrepancy in binder types (OPC vs. fly ash) and the aggregate types (virgin vs. recycled) as shown in fig. (4.a, 4.b)

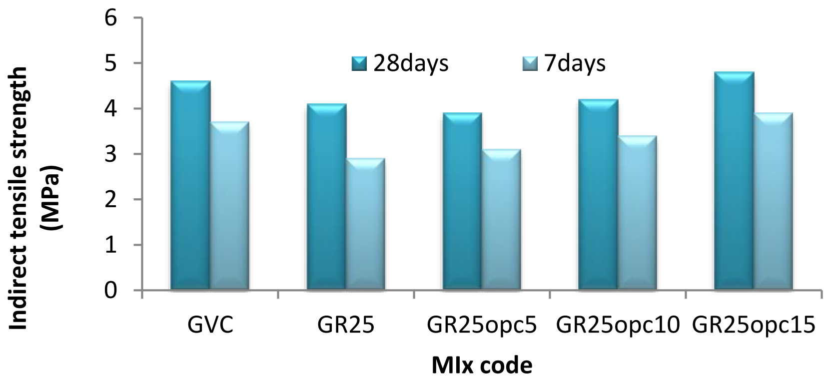

Fig.4.a. Comparison between indirect tensile strength of geopolymer concrete containing 25% of RCA at 7 and 28 days with control and mixtures containing selected ratios of OPC

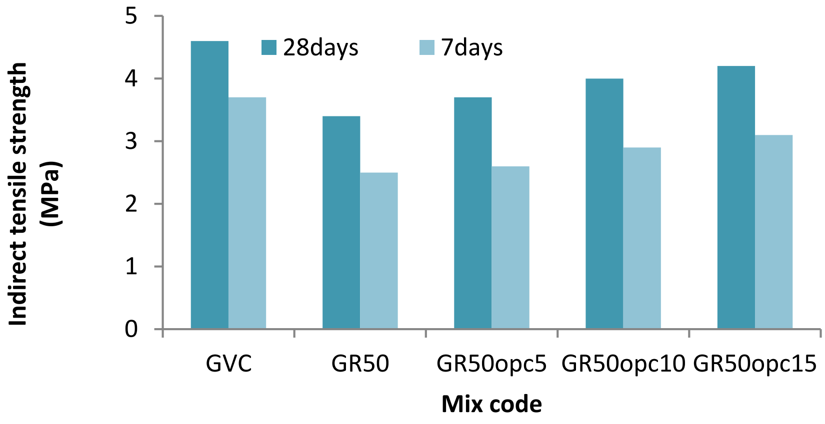

Fig.4.b. Comparison between indirect tensile strength of geopolymer concrete containing 50% of RCA at 7 and 28 days with control and mixtures containing selected ratios of OPC

3.3.3 Flexural strength

The test outcomes showed that using recycled aggregates reduced flexural strength. The flexural strengths for mixtures without selected ratios of OPC were within the range of 6.2 –7.1MPa for 7 days and 9.4 –10.5 MPa for 28-days. The flexural strength loss was around 11.95% compared to the reference specimen after 28 days; while the mixtures containing replacement ratios of OPC increased flexural strength more than their counterparts without OPC by percentages around 3 %. The mix had additional amount of silicate species in the combination, and therefore the geo-polymerization reaction was enhanced [35]. As Geo-polymerization process increased, flexural strength increased. Fig. (5.a, 5.b) showed a comparison between the average values of flexural strengths of specimens at 7 days and 28 days.

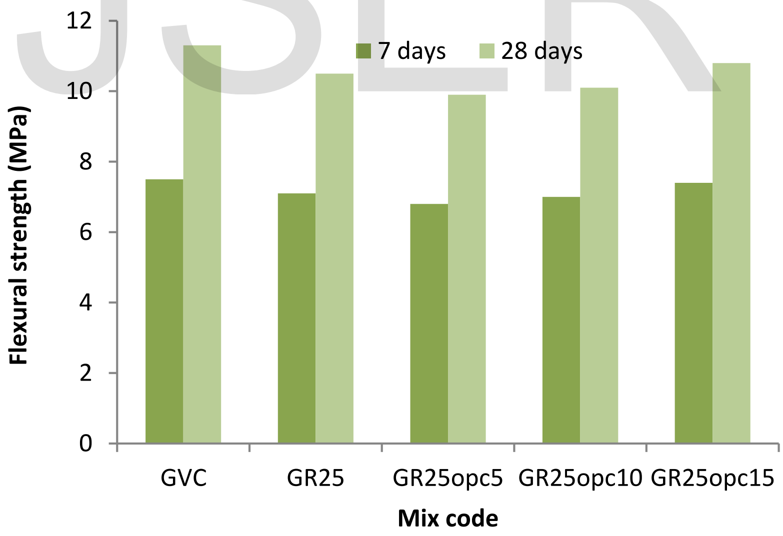

Fig.5.a. Comparison between flexural strength of geopolymer concrete containing 25% of RCA at 7 and 28 days with control and mixtures containing selected ratios of OPC

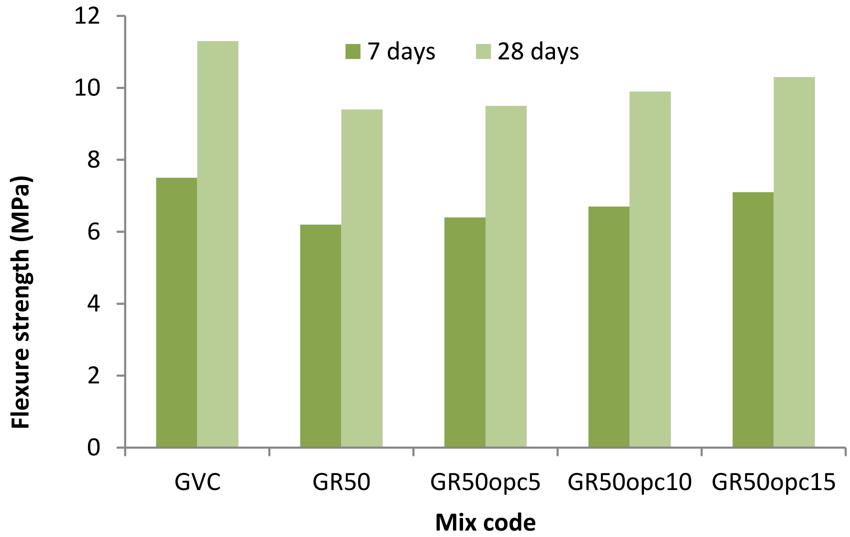

Fig.5.b. Comparison between flexure strength of geopolymer concrete containing 50% of RCA at 7 and 28 days with control and mixtures containing selected ratios of OPC

3.3.4 Modulus of elasticity

Recorded modulus of elasticity of mixtures containing OPC was calculated to be between 18 and 26 GPa, which was more than that of recycled geopolymer mixtures without OPC by average value 12% .The measured elastic modulus of recycled geopolymer concrete compared with geopolymer concrete containing natural aggregates is shown in (fig. 6.a,fig.6.b). The RCA is considered to be the cause for the major difference. The RCA is generally obtained from crushed concrete structures; therefore, old pastes always glue to the RCA. It is also known that in RCA the old stick pastes are more pored than regular coarse aggregates and during the treatment process of the RCA often includes micro-cracks. The elastic modulus values of normal strength Portland cement pastes were reported to be between 12.5 and 17.5 GPa [35], which were similar to that of geopolymer pastes without OPC. The addition of OPC produced additional C-S-H and CA-S-H within geo-polymeric binder and acted as a micro-aggregate, which enhanced the compressive strength and increased the elastic modulus of the pastes. Additional calcium silicate gel is created to fill the voids and make intensive and durable geopolymer pastes [36]. As the voids filled, the concrete become stronger and more durable.

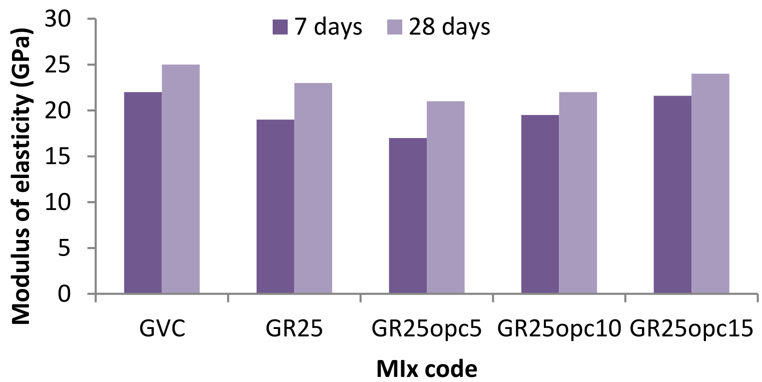

Fig.6.a. Relation between modulus of elasticity of geopolymer concrete containing 25% of RCA at 7 and 28 days with control and mixtures containing selected ratios of OPC

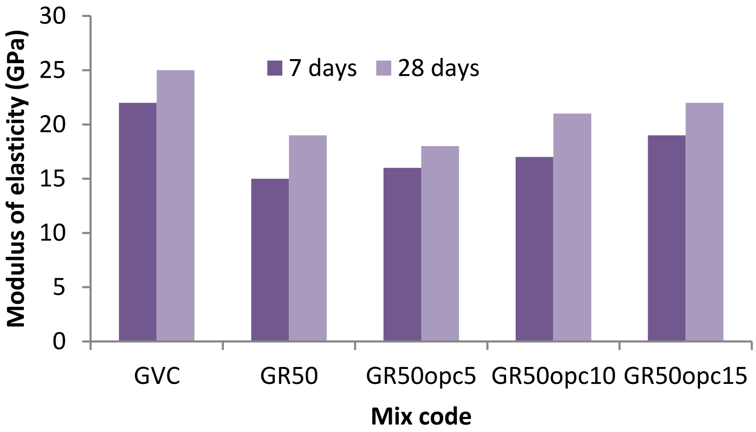

Fig.6.b. Relation between modulus of elasticity of geopolymer concrete containing 50% of RCA at 7 and 28 days with control and mixtures containing selected ratios of OPC

4 Porosity

The impact of OPC on the proportion of porosity of geopolymer concrete containing 25 % and 50% of RCA contents was reported in table 4. The results showed that the porosity value at the age of 28 days for control mixture (GVC) was 14.9 %, while the porosity at the same age for the mixture containing the addition of 15% of OPC was 11.8%.Thus, with the increase in cement content up to 15% of the weight of the binder, the porosity decreases by 20.8% at the age of 28 days. The presence of soft and micro-bead cement increases the density of the mixture and helps to reduce its porosity [24]. These results extend the work life of the concrete and help it resist the destructive factors that increase its strength.

Table 4: Porosity of geopolymer mixtures

Mix code	Porosity %	
	7 days	28 days
GVC	15.6	14.9
GR25	17.2	16.8
GR50	19.1	18.6
GR25opc5	14.8	14.3
GR25opc10	12.7	12.2
GR25opc15	12.2	11.8
GR50opc5	15.2	14.7
GR50opc10	13.4	12.8
GR50opc15	12.9	12.4

5 Conclusions

This study investigated the characteristics of geopolymer concrete containing recycled coarse aggregate and different selected ratios of OPC. The outcomes of this study can be drawn as follows:

1-The use of OPC as a replacement ratio of fly ash in geopolymer concrete containing recycled coarse aggregate, works to reduce the setting time of geopolymer concrete, as a result of increased calcium content in the mixture, which speeds up the setting and hardening of concrete .The initial and final setting times of geopolymer mixtures with OPC are between 20-32 min and49-69 min,respectively.

2-The addition of OPC increases the workability and mechanical properties of geopolymer mixes (compressive strength, indirect tensile strength and flexural strength) .The additional of Ca amounts in the mixtures enhanced the geopolymerization process.This is an advantage to increase the strength of recycled geopolymer concrete.

3- The use of OPC also raises the modulus of elasticity and minimizes porosity and the voides in geopolymer pastes, which leading to a high strength and durable recycled geopolymer concrete.

4- The best mechanical properties obtained were achieved when OPC is replaced fly ash by 15% by weight and using 25% of recycled aggregate as a substitute for virgin aggregate.

Further work is required to study the impact of the use of other types of cement, such as high-slag cement and sulfate-resistant cement on recycled geopolymer concrete properties.

ACKNOWLEDGMENT

The author is grateful to the members of "laboratory of testing of materials" at Faculty of Engineering, Menofia University, Egypt. This research did not receive any specific funding from the public, commercial, or not-for-profit sectors.

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