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Analysis of Geopolymer Concrete Columns at Normal and High Strength

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ABSTRACT: Geopolymer is an eco-friendly concrete replacement of Ordinary Portland concrete and possesses strength similar to or greater than the conventional concrete. Geopolymer concrete is a combination of fly ash or GGBS or both along with hydroxide and silicate solutions. In this paper, a combination of both fly ash and GGBS were used to make geopolymer concrete along with sodium hydroxide and sodium silicate solutions. This paper focuses on the study of reinforced geopolymer concrete columns. The objectives of this paper are to experimentally study the ultimate axial load and shorting of geopolymer columns with varying strengths under axial loading. The experimental study included testing of two geopolymer concrete short columns and two conventional concrete short columns. In addition, the behaviours of columns of geopolymer concrete were studied. The behaviours include toughness, stiffness and ductility. The effects of different variables were considered and experimentally investigated in the current study. The tested four columns reflect these variables which are the effect of the grade of parent concrete that the geopolymer materials were made of and the quality of the concrete of the parent concrete mix. Each column was loaded to failure and some topics were covered through the analysis of the test results. All columns that possessed slag with replacement ratio of fly ash showed upper ultimate carrying capacities, lower stiffness values, and lower toughness values when compared with the conventional columns. Increasing the grade of the parent concrete of the geopolymer concrete decreases each of the reduction of the stiffness and toughness of the tested columns.

KEYWORDS: Geopolymer Concrete, conventional concrete, Toughness, Stiffness and Ductility factor.

I. INTRODUCTION

In recent times, construction activities are rocketing throughout the world. This exponential trend of construction has made the requirement of cement shoot up. Subsequently, the upward demand for cement has led to the mushrooming of many cement industries all over the world. As predicted by Scientists, the worldwide requirement of cement, in recent years, would be around 2.2 billion tones, [1]. However, it is well known that the production of OPC not only consumes a significant amount of natural resources and energy but also releases a substantial quantity of carbon dioxide (CO₂) to the atmosphere. Currently, the cement industries produce 1.5 billion tons of OPC each year. This adds about 1.5 billion tons of CO₂ into the atmosphere,[2]. Recent research works have studied the properties of temperature cured fly ash-based geopolymer concrete. The results of these studies have shown the potential use of geopolymer concrete as a construction material,[3]. The studies have shown that geopolymer concrete has the properties of high compressive strength, very little drying shrinkage, low creep, good bond with reinforcing steel, and good resistance to acid, sulfate, and fire. It was also found from the experimental and analytical works that the performance of geopolymer concrete structural members such as beams and columns was similar to that of OPC concrete members. Other recent studies have also reported similar engineering properties of

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geopolymer concrete which are favorable for its use as a construction material. The effect of the exposure to direct fire on the behavior of high strength concrete columns,[4]. Each of them concluded that the exposure to either elevated temperature or fire causes severe reduction in the ultimate capacity of the tested columns. It reported that exposure to 550°C elevated temperatures adversely affected the structural behavior of the tested columns under uni-axial bending moment in terms of residual capacity, serviceability performance, stiffness and toughness, [5]. Sumajouw et al and Sujatha et al [6&7] conducted experiments on low calcium fly ash GPC slender circular columns and found that it possesses higher load carrying capacity and better ductility than conventional concrete columns (RCC). It proposed the stress-strain model for GPC and it was validated by using it for the analysis of the GPC column. Studies on the effect of temperatures on the strength and behavior of GPC columns under axial loading have not come across. Since GPC requires temperature curing it is more suitable for prefabricated construction. The prefabricated industry has evolved to a stage that even multi-storeyed buildings can be constructed using an assemblage of individual structural elements (beams, columns, slabs, wall panels). Once the behavior of GPC structural elements is understood, it can be used for various construction purposes,[8]. The carried out literature review indicated that the results of the previous researches gave irreconcilable behavior for the geopolymer concrete. Moreover, more advanced studies are still needed for understanding the structural behavior of the reinforced concrete elements made of geopolymer materials. These advanced studies can help in recognizing the effect of the type of the geopolymer concrete on their behavior and the optimum percentages of temperature which can be used. However, very little information are available about the behavior of reinforced concrete columns made of geopolymer concrete,[9&10]. Accordingly, the current research aims to investigate the structural behavior of axially loaded reinforced concrete square short columns made of geopolymer concrete. The effects of four main variables on the structural behavior of the columns are experimentally investigated. These variables are the temperature of 300 at 1hr., 300 at 2hr., 500 at 1hr. and 500 at 2hr.

II. DETAILS OF THE TESTED COLUMNS

All tested columns in this study (four columns) were of the same concrete dimensions; 200 * 200 mm² in cross-sectional area, 1500 mm in length. Figure (1) shows the geometrical and reinforcement details of the tested columns. Using steel jackets, special strengthened heads designed to avoid failure at stress concentration zones were used. The main reinforcing bars were 4 Φ 12 (high tensile steel 400/600) for all columns. Stirrups with diameter φ 8 mm (mild steel 280/420) and spacing 180 mm were detailed to keep the thickness of the concrete cover of the tested columns equals to 15 mm. Also, it can be noticed that additional stirrups were used for strengthening the column heads. The yield strengths of the used high grade and mild steel were 445 N/mm² and 343 N/mm² for diameters 12 and 8 mm, respectively. The mixes used in casting the columns consists of four concrete mixes with different intended compressive strengths ranged between (25 Mpa and 40 Mpa) were designed in the first stage of the experimental program in the first paper from this study. Table (1) shows the details of the studied mixes. Cement type CEM I – 42.5 with different contents was used for these mixes,[12]; from 300 kg/m³ in mix 1 to 420 kg/m³ in mix 2, to achieve the different intended grades which ranged from normal strengths to high strength. Natural dolomite coarse aggregate size 10 mm was used alone as coarse aggregates in mixes 1, 2, 3 and 4, respectively. On the other hand, natural sand was used as fine aggregates in the studied mixes. In this study, To obtain the same workability without increased water, super-plasticizer Sicament R2004 was used. Sicament R2004 is a plasticizer and flowing concrete Admixture (Complies with ASTM C- 494 Type G and BS 5075 part 3,[11]), with plasticizer dosage, 2% of water/binder content to achieve the required level of workability defined by a slump value of 10± 2cm, As illustrated in a table (1), water/binder ratios ranged from 0.5 in mix 1 and 3 to 0.4 in mix 2 and 4, respectively. These ratios were the minimum required water/binder ratios which gave a suitable and constant workability. All the designed mixes possessed the same workability and slump tests were carried out to judge the workability characteristics of the concrete mixes. The slump values remained between 80 mm to 110 mm for all mixes. Ground Granulated Blast Furnace Slag (GGBS)

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which is a byproduct of the steel industry in Egypt was used instead of cement for producing the GPC. Blast furnace slag is defined as “the non-metallic product consisting essentially of calcium silicates and other bases that is developed in a molten condition simultaneously with iron in a blast furnace. The percentage of GGBS passing through 45µm IS Sieve was found to be 97% and its specific gravity was 2.90, GGBS type f with different contents was used for these mixes; from 350 kg/m³ in mix 3 and 350 with replacement 10% fly ash kg/m³ in mix 4, see table (2). The used slag complied with the ESS. Fly ash concrete mixes are the alumina-silicate source material used with the GGBS in one of the geopolymer. The Fly ash was of low calcium Fly ash which confirms to class F of ASTM standards. The percentage of fly ash passing through 45µm IS Sieve was found to be 95% and its specific gravity was 2.20. Fly ash was replacement with ratio 10% of the GGBS content in the mix. 4. Sodium silicate gel (Na₂SiO₃) and sodium hydroxide (NaOH) pellets were used for activation, and The ratio of Sodium silicate to sodium hydroxide was about (1:2.5),[12&13]. The sodium hydroxide solution of 10 Molar was prepared by mixing the pellets with water. The mass of NaOH solids in the solution varied depending on the concentration of the solution expressed in terms of molar, M.in the current research , NaOH solution with a concentration of 10 M consisted of 10×40 =400 grams of NaOH solids (in pellet form) per liter of the solution, where 40 is the molecular weight of NaOH. The Sodium silicate and Sodium hydroxide solution were mixed 24 hrs. Before usage.

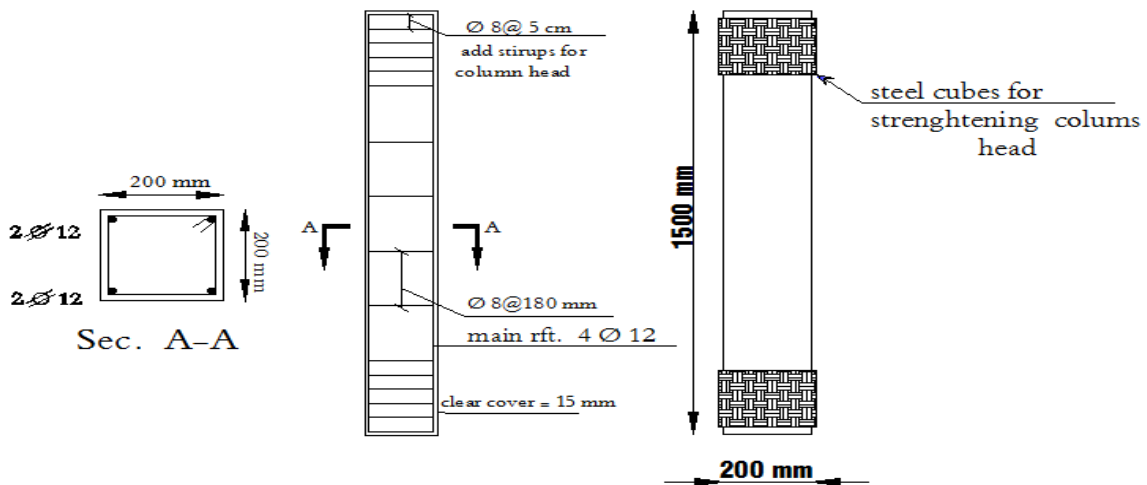


Fig. (1): Typical Concrete Dimensions and Reinforcement Details of the Test Columns

Table 1: Cement Concrete Mixes

Ingredients of concrete mixes kg/m ³						Compressive strength (MPa)
Group	Cement	Fine Agg.	Coarse Agg.	Water	Sp	
CC25	300	798	1196	150	6.0	27.3
CC40	420	693	1040	168	8.4	41.7

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Table 2 :Geopolymer concrete mixes

Ingredients of concrete mixes kg/m ³									Compressive strength (MPa)	
Group	Slag	Fly ash	Fine Agg.	Coarse Agg.	Water	NaOH	Na ₂ SiO ₃	Sp	Steam curing duration (day)	
									One	two
GC25	350	-	702	1053	127	35	87.5	7	26	-----
GC40	315	35	745	1117	87	35	87.5	7	-----	43

III. SPECIMENS CURING FOR OPC AND GPC CONCRETE

After 24 hours of casting, The curing process of the conventional concrete columns was carried out by kept the specimens in the ambient temperature, columns were kept at ambient temperature until the test date As shown in Figure (2-A). In the other hand ,Curing of geopolymer concrete Columns, After 24 hours of casting, The curing process was carried out by keeping the columns specimens after demoulding in steam temperature of 60⁰C for a period of 1 or 2 days for columns with concrete grade 25 and 40 Mpa, respectively. After steam curing, columns were kept at ambient temperature until the test date As shown in Figure (2-B).

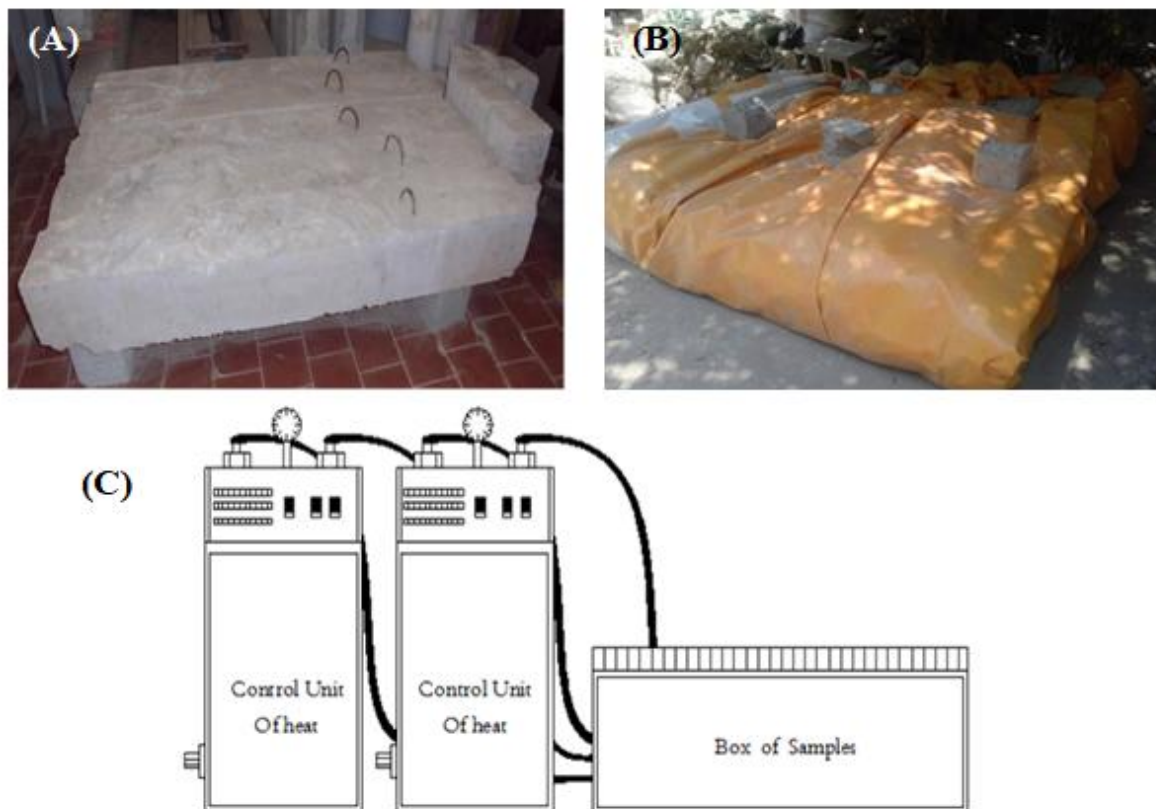


Fig. (2):(A), Curing for conventional concrete columns,(B) Steam curing for geopolymer concrete columns and (C) Scheme of steam treatment for strength acquisition for geopolymer concrete .

IV. INSTRUMENTATION AND TEST SETUP

Figures (3-A) and (3-B) illustrate schematics of the loading setup and instrumentation system of the tested columns. After about 28 days from the casting date of the test columns, all columns were tested under a 5000 KN hydraulic compressive machine. A load cell 2000 KN was used to measure the applied load and the readings were recorded automatically by means of a data acquisition system. The tested columns were mounted vertically and the C.G. was centered with the machine axis as much as possible. Strains were measured at two sides of each tested column by attaching linear variable displacement transducers (LVDTs) connected to the data acquisition system. The LVDT measurements were determined on pegs drilled in the column at 700 mm spacing. The pegs were drilled all through the concrete cover. Loads were incrementally increased until failure. The LVDT measurements were determined at each load increment up to the maximum load. Also, some readings were determined beyond the maximum load and during the load drop for evaluating the post peak behavior of the tested columns (if possible).

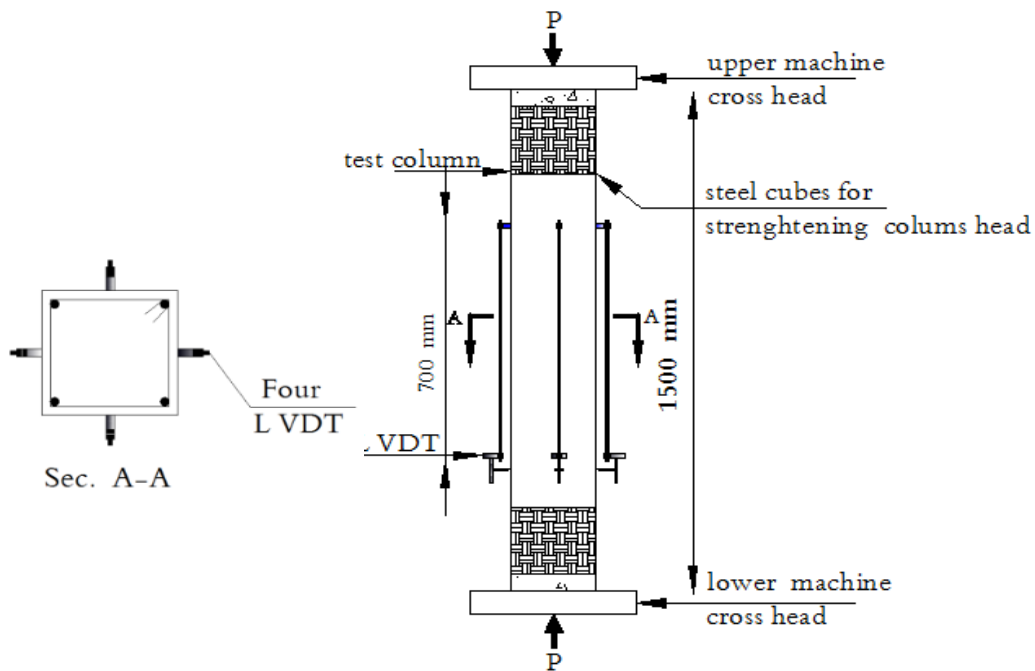


Fig. (3): Test setup and instrumentation of the tested columns

V. TEST RESULTS AND ANALYSIS

To achieve the aims of the current paper, This section presents and analyzes the test results and the observed behavior of the tested columns under the application of the vertical concentric loads. Modes of failure were determined for all tested columns. Records of load – axial strain relationships of all of the tested columns were also obtained. Also, stiffness and toughness values were determined for the tested columns. Evaluation of the effects of the considered key parameters (variables) which are the effect of the grade of parent concrete that the geopolymer materials were made of, the quality of the concrete of the parent concrete mix and the replacement percentage on the structural behavior and ultimate bearing carrying capacities of the tested columns will be analyzed and discussed in the following subsections.

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VI. CRACKING BEHAVIOUR AND MODE OF FAILURE

The appearance of all of the tested conventional and geopolymer columns in the current study after loading is presented in figure (4 - A,B, C and D) respectively. In general, the failure modes of the geopolymer and conventional concrete columns were approximately similar.

The compression failure modes of most of the tested columns started by crushing of the concrete cover of the four sides at a section between the two strengthened heads of the columns followed by large deformation occurred and large parts of concrete were demolished and fallen down from four sides accompanied with a very little increase in then the applied load, and the agreement of the results with references, [14,15&16].

Upon further loading, buckling of the longitudinal main reinforcing bars then the applied load decreased gradually. It was noticed that, premature crushing failure of the upper head of the column GC40 occurred at first during loading. This was due to tensile failure in one of the steel bolts used in assembling the attached steel jacket to the column's heads, i.e. The failure of this one test column occurred at the zones of stress concentration. Therefore, these test column failed at a value of ultimate load slightly less than the expected values. On the other hand, A small eccentricity occurred during loading test column CC40 which appeared from the mode of failure of the column. Two reinforcing longitudinal bars buckled only in one face after loading, see figure (4). This means that this column appeared an ultimate capacity lower than that expected, and the agreement of the results with references, [17,18&19].

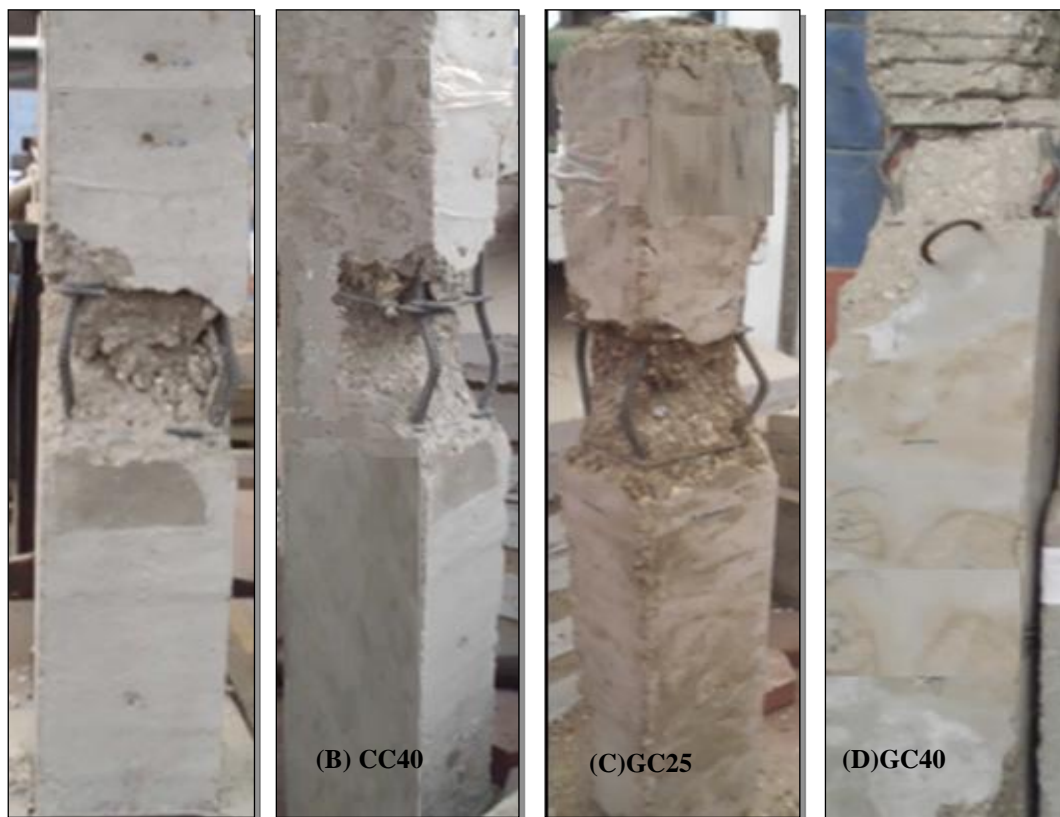


Figure (4): Appearance of all tested reinforced conventional and geopolymer concrete columns after loading

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VII. CRACKING LOADS, ULTIMATE LOADS, STIFFNESS , TOUGHNESS AND DUCTILITY OF THE TESTED COLUMNS

Shorting of all tested columns were measured directly under the applied load using linear variable displacement transducers (LVDTs). The load-shortening relationships exhibited almost linear behavior up to the occurrence of the first crack representing the behavior of the columns utilizing un-cracked concrete section. After formation of the first crack, the columns showed nonlinear curved path until the ultimate load. Table (3) list the determined main results of the tested unheated and heated columns, respectively. Stiffness, ductility and toughness of the tested columns were calculated from the load-strain relationships of the tested columns as shown in the following subsection. Ratios between the ultimate loads of the geopolymer columns to the ultimate loads of the control columns were also computed and listed in table (3) to obtain the occurred reductions in capacity due to the strength different for both of conventional concrete and geopolymer concrete columns. Figure (5) shows the ultimate load values of the tested columns. It can be observed that geopolymer concrete columns lost dramatic parts of their capacities when exposed axial load if compared to comparable conventional concrete columns, and the agreement of the results with references,[20].

Mix.	P_{cr} (KN)	P_{ult} (KN)	Stiffness (KN/mm) $\times 10^3$	Ductility Factor	Toughness (KN mm/mm)
CC25	1184	1259	1.286	1.16	0.685
CC40	1397	1651	1.571	1.30	0.946
GC 25	983	1101	1.060	1.10	0.631
GC 40	1633	1756	1.295	1.35	1.465

Table (3):Major test results of the tested columns

Where:

CC25,CC40,GC25 and GC40 are Conventional cement concrete of intended grade 25 Mpa , Conventional cement concrete of intended grade 40 Mpa, Geopolymer concrete of intended grade 25 Mpa. And Geopolymer concrete of intended grade 40 Mpa, respectively. p_{cr} and P_{ult} are Cracking load and Ultimate load , respectively.

VIII. EFFECT OF CONCRETE TYPE

Comparisons between the results of the columns CC25, CC40, GC25 and GC40 which contained conventional and geopolymer concrete of grade 25 Mpa and 40 Mpa , respectively were carried out. Such comparisons indicate the effect of the type of concrete on the behavior of the tested columns. Figure (5) shows the load -axial compressive strain relationships of the tested columns. and the agreement of the results with references ,[21&22].

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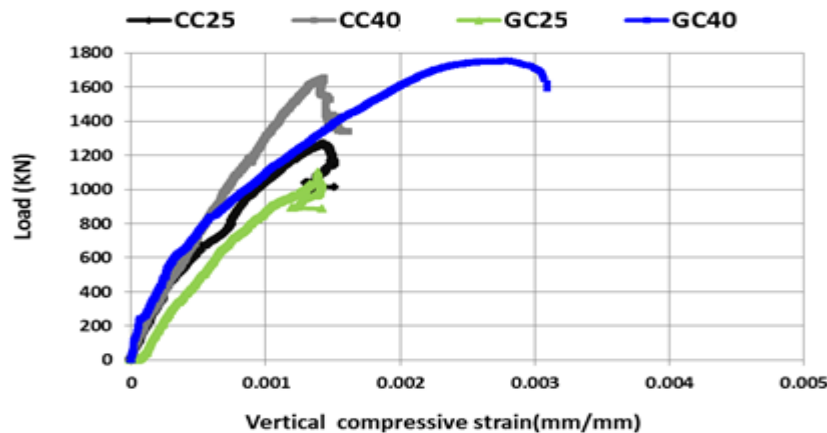


Figure (5): Load-vertical compressive strain relationships of the geopolymer and conventional concrete control columns (CC25, CC40, GC25 and GC40).

IX. SURVEY ON CONCRETE TYPE

- 1) It was noticed that, changing the concrete type changed the ultimate capacity, cracking load, ductility, stiffness and toughness of the tested concrete columns. In general, Cracking loads, ultimate loads, ductility factor and stiffness decreased in geopolymer concrete columns while the toughness values increased if compared to cement concrete columns.
- 2) All the Geopolymer concrete columns behave different to OPC columns regardless of the grade of concrete. Despite having the same steel reinforcement ratio for both reinforced Geopolymer Concrete and OPC concrete columns, the geopolymer Columns exhibited higher shorting at the same load stages.
- 3) All geopolymer concrete columns showed lower stiffness and higher toughness when compared to the comparable OPC columns, see table (3).

X. EFFECT OF COMPRESSIVE STRENGTH OF CONCRETE

Comparisons between the results of the control columns (CC25 and CC40), which contained conventional concrete of grade 25Mpa and 40 Mpa, respectively were carried out. Other comparisons were also carried out between the results of the control columns, (GC25), and GC40, which contained geopolymer concrete of grade 25Mpa and 40 Mpa, respectively. Such comparisons indicate the effect of the concrete compressive strength on the behavior of the tested columns, and the agreement of the results with references, [23].

XI. SURVEY ON COMPRESSIVE STRENGTH

1. As expected, increasing the concrete compressive strength increased the cracking load, ultimate capacity, toughness, ductility factor and stiffness of the tested conventional and geopolymer concrete columns, see table (3).
2. significant effect on both the initial stiffness and toughness took place for the tested columns when changing the quality of mortar of the parent concrete mix of the geopolymer concrete.
3. Increasing the quality of the mortar (the volume of mortar is constant) in the parent concrete mix of the used geopolymer concrete led to stronger particles of the conventional concrete. Hence, using these strong particles could increase the increase in the ultimate capacity of the tested columns made of geopolymer concrete.

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4. Increasing the grade of the parent concrete of the geopolymer increases the enhancement of the toughness of the tested columns.

XII. CONCLUSIONS

Based on the results of the presented experimental work in the current research, the following conclusions could be deduced:

- The load - vertical strain and load - deflection responses for geopolymer concrete columns showed higher values than the conventional concrete columns at the same levels of loading.
- All columns that possessed geopolymer concrete with different replacement percentages showed lower ultimate load carrying capacities than the control columns (group CC25 and group CC40).
- Geopolymer concrete columns showed almost similar failure of those counterpart columns of conventional concrete, sudden failure occurred immediately after formation of the Longitudinal crack for columns, however providing GGBS replacement enhanced the ductility for geopolymer concrete columns of about 103.22 % when Compared conventional concrete columns .
- Using geopolymer of the highest grade of parent concrete, showed a reasonable high ultimate load, where column GC40/S0 failed at load equal to 1755.7 KN with increase percentage equal to 6.36 % with respect to the control column, CC40/C0. While using geopolymer of the lowest grade of parent concrete, showed a low ultimate load, where column GC25/C0 failed at load equal to 1100.9 KN with decrease percentage equal to 12.54 % with respect to the control column, CC25/C0.

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