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BEARING LOAD CAPACITY of GEOPOLYMER CONCRETE THIN WALL PANELS UNDER ECCENTRIC COMPRESSION

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Abstract: Due to the current diffusion of reinforced concrete (RC) walls structures and the introduction of new concrete cords, RC walls are an important structural element such as beams, plates and columns. The experimental program included casting and testing of eight two-way thin geopolymer concrete wall panels by using local Iraqi material such as metakaolin and recycled concrete aggregate. The specimen divided in to two groups, group (A) consists of four geopolymer concrete wall panels including recycled concrete aggregate and group (B) consists of four geopolymer concrete walls including ordinary aggregate. In both groups the iron filings percentage volume is varying from 0 to 0.5, 0.75% and 1%. The result showed that the load capacity of the geopolymer concrete wall panel is increased by 17% for geopolymer concrete with recycled concrete aggregate (GCRA) and 4% for geopolymer concrete with natural aggregate (GCNA) by increasing the iron filling ratio to 1%. Also the lateral deflections decrease to 15% for geopolymer concrete with recycled concrete aggregate (GCRA) and 18% for geopolymer concrete with natural aggregate (GCNA) by increasing the iron filings ratio to 1%.

Keywords:*geopolymerconcrete recycled concrete aggregate, iron filings, metakaolin, Concrete Wall, Eccentric Load, and Two-way Action.*

سعة التحمل للألواح الجدارية النحيفة المصنعة من الخرسانة الجيوبوليمرية تحت ضغط غير مركز

الخلاصة:بسبب الانتشارالحالي لهياكل الجدران ا لخرسانية المسلحة (RC) وإدخال الخرسانية الجديدة، تعد جدرانRC عنصرًاهيكليًا مهمًا مثلا لعوارض والألواح والأعمدة. تضمن البحث اختبار ثمانية جدران خرسانية نحيفة ذات اسناد من الاتجاهين من خلال استخدام موادعراقية محلية مثلا لميتاكولين والخرسانة المعاد تدويرها. تنقسم العينة إلىمجموعتين، المجموعة (A) تتكون من أربع جدران خرسانيةجيوبوليمرية وركام من الخرسانة المدورة ومجموعة (B) تتكون من أربعةجدران خرسانيةجيوبوليمرية وركام عادي . في كلاالمجموعتين يختلف حجم النسبة المئوية لبرادةالحديد من0،الى0.5%،0.75%و1%.النتائج بينت وجود زيادة فيسعةالحمولة للجدرانالخرسانية جيوبوليمرية بنسبة 17% للخرسانة الجيوبوليمرية مع ركاما لخرسانة المعاد تدويرها (GCRA) و4% للخرسانة الجيوبوليمرية مع الركام الطبيعي (GCNA) عن طريق زيادة نسبة برادة الحديد إلى 1%, كما أن الانحرافات الجانبية تنخفض إلى 15%للخرسانة الجيوبوليمرية ذات الركام الخرساني المعاد تدويره (GCRA) و18%للخرسانة الجيوبوليمرية ذات الركام الطبيعي (GCNA) عن طريق زيادة نسبة برادة الحديد إلى1% .

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1. Introduction

Every country has problems with waste and management accumulation and in Iraq a large amount of construction waste, it is increasing every year and most of these are left untreated;by using construction waste more sustainably, environmental side effects can be reduced [1].As the total output of the building increases, the increase in landfill costs makes the replacement of recycled aggregates (RA) by natural aggregates a more interesting issue.In fact, it is only used as a base filler for road construction, recycled aggregates used in the production of concrete have become one of the most important areas for recycling these wastes in construction.The performance characteristics of concrete using recycled aggregate needs to re-evaluated for ordinary aggregate concrete[2].Every constituent material of concrete has some negative effects on the environment,Portland cement is an important building material for all development activities around the world [3]. Geopolymer concrete (GPC) proposed by Devidovits (1988 and 1994) [4,5] is currently considered to be an innovative technology in the cement-based construction industry, which has great potential in the manufacture of sustainable concrete.

In 2011, Mazen et al Studied the use of construction waste in concrete mixtures. The results show that the concrete prepared from this recycled aggregate has acceptable compressive strength and absorbability and is good compared with concrete. The local strength of the natural strength of the flexural strength and low dry density[6]. In 2017, Sarath et al proposed that the geopolymer concrete was tested for durability of ground granulated blast furnace slag (GGBS) and metakaolin. GGBS and metakaolin were considered to be based on concrete geopolymers, building materials without environmental pollution[7]. In 2001, Sabir et al studied the application of metakaolin as pozzolanic material for mortar and concrete, and mentioned the widespread application of metakaolin in the construction industry. They reported that the addition of metakaolin as volcanic ash will contribute to the early development of strength and some improvement in long-term strength[8].

2. Experimental Work

The experimental program included casting and testing eight geopolymer concrete wall panels;The dimensions of the wall are illustrated in Figure (1). All tested walls are fixed supported in two dimensions and subjected to uniform axial loads with eccentricity t/6 from thickness, The slenderness ratio (height/thickness) for all specimens is (15), aspect ratio (height/length)for all specimens is (1.5) and the thickness for all panels is 40 mm. These panels are divided into two groups, first group (A) consists of four panels geopolymer with recycled concrete aggregate, while the second group (B) consist of four panels geopolymer with natural aggregate;Both groups have the same percentages of iron filings content (0, 0.5%, 0.75% and 1%).

Table (1) Panels Designations and Dimensions for Groups (A) and (B)

Wall Panels (A)	Aggregate Type	Iron Filings %	Wall Panels (B)	Aggregate Type	Iron Filings %
WGR1	RCA*	0	WGN5	NA**	0
WGR2	RCA	0.5	WGN6	NA	0.5
WGR3	RCA	0.75	WGN7	NA	0.75
WGR4	RCA	1	WGN8	NA	1

*Recycled concrete aggregate
**Natural aggregate

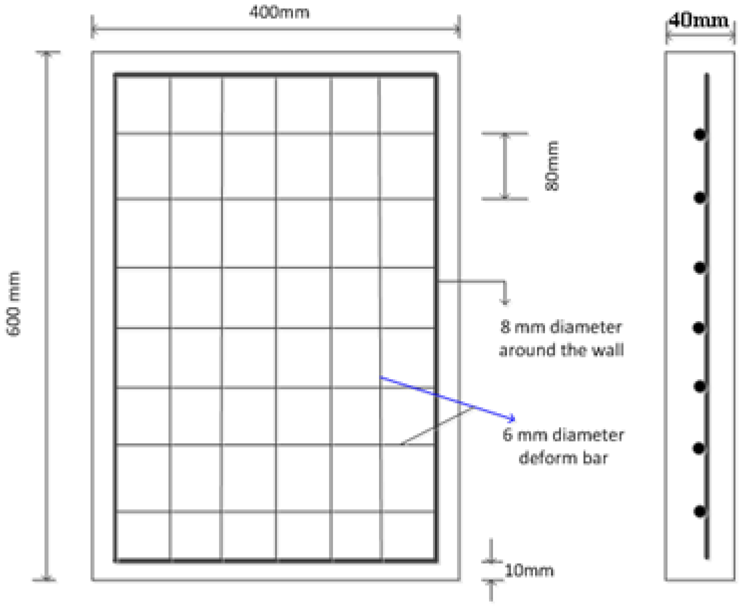

Figure (1) Dimension and Arrangement of Reinforcement in Tested Panel.

3. Concrete Mix

Initially, numerous geopolymerconcrete test mixtures are manufactured. Test mixtures are prepared to obtain a good consistency and survivability mixture and to understand the basic nature of the mixture.Mix Proportions for GPCbased on Basil S. et al (2015)[9]mix with some improvement involved as shown in Table 2.

Table (2) Mix Properties of Geopolymer Concrete

Metakaolin (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Alkaline* Solution (lit/m^3)	Water* (kg/m^3)	Iron Filings* %	Sp** %
400	720	1100	180	40	0,0.5,0.75,1	3

*Percent of mix volume.
**Percent of metakaolin volume.

4. Materials

4.1 Metakaolin

Metakaolin is the dehydroxylated form of kaolinite clay minerals. Rocks rich in kaolinite are called china clay or kaolin and are traditionally used in the manufacture of porcelain. Metakaolin has a smaller particle size than cement particles, but is not as fine as cerium oxide. The quality and reactivity of metakaolin depends to a large extent on the nature of the raw materials used. Metakaolin can be produced from a variety of primary and secondary sources containing kaolinite;Metakaolin is a calcined kaolin refined under strictly controlled conditions to produce an amorphous yttrium aluminate that is reactive in concrete [10], Table 3 shows the chemical analysis of metakaolin.

Table (3) Chemical Analysis of Metakaolin*

Oxide	Content, percent %
SiO_2	54.2
Al_2O_3	39.00
Fe_2O_3	0.92
CaO	1.37
MgO	0.15
SO_3	0.45
Na_2O	0.22
K_2O	0.27
L.O.I	0.71
TIO_2	0.8

*Chemical tests were conducted by Iraq geological survey, central laboratories department.

4.2 Alkaline Solution

A clear gel of Na_2SiO_3 and NaOH in the form of flakes are used as an alkaline activator. In this study, 14 moles of NaOH solution, Na_2SiO_3 and NaOH 3.5 activator ratios are used. A NaOH solution are prepared by dissolving the NaOH flakes in distilled water for one day before the using[9].

4.3 Iron Filings

Iron filings are steel product, which is produced in large quantities in factories and steel plants. As a result, the product has had an adverse impact on the environment. So far, most surveys have pointed to steel slag, but several iron slags have described the properties of iron. The using of iron filings will safe the environment and product of new concrete with low cost and consider as sustainable concrete. Table 4 shows thegrading of iron filings. Four percentage volumetric ratio of iron filings are used (0, 0.5, 0.75, 1) %.

Table (4) Grading of Iron Filings

Sieve size, mm	% passing
4.75	100
2.36	99.32
1.18	87.18
0.6	34.26
0.3	10.3
0.15	3.25

4.4 Natural Aggregate (NA)

4.4.1 Coarse Aggregate

Natural gravel is used as a coarse aggregate in mixes of group (B), and the specific gravity sulfate and absorption were equal to 2.6, 0.09 and 0.62%, respectively. The results indicate that the coarse aggregate conforms to the Iraqi Standard IQS 45-1984 [10].

4.4.2 Fine Aggregate

Natural fine aggregateis used in mixes of group (B), and should be cleaned before use; specific gravity, sulfate content and absorption are equal to 2.53, 0.4% and 0.71, respectively. The results show that the fine aggregate conforms to the Iraqi Standard IQS 45-1984 [10].

4.5 Recycled Concrete Aggregates (RCA)

The recycled concrete was used as the coarse and fine aggregates in the concrete mixes of group (A), to reduce the environment of rubble and produce cheap coast local concrete. A locally available crushed concrete maximum size of 12.5 mm is used as coarse aggregate, and a maximum size of 4.75 mm is used as fine aggregate. The recycled aggregates obtained from the demolished construction, in this investigation beams, cubes, cylinders and prisms are used to produce the aggregate, first, the crushed by crusher machine at material laboratory in College of Engineering at Mustansiriyah University. The grading of coarse and fine aggregate which conforms to the Iraqi Standard IQS(No. 45-1984)[11] as shown in Tables (5) and (6). The specific gravity and absorption is 1.25, 0.92% respectively for coarse aggregate and 1.39, 1.1% respectively for fine aggregate.

Table (5) Grading of Recycled Coarse Aggregate

Sieve Size, mm	Cumulative Percentage Passing	Limits of Iraqi Standard IQS 45-1984
14	100	100
10	94.47	85-100
5	1.66	0-25
2.36	0.0	0-5

*Grading tests were made in the material laboratory, College of Engineering, Mustansiriyah University**.**

Table (6) Grading of Recycled Fine Aggregate

Size of Sieve, mm	Cumulative Percentage Passing	Limits of Iraqi Standard IQS 45-1984, zone 2
10	100	100
4.75	99.65	90-100
2.36	92.32	75-100
1.18	64.15	55-90
0.6	45.19	35-59
0.3	26.78	8-30
0.15	3.11	0-10

4.6 High Range Water Reducing Admixture

A third generation geopolymer-based super plasticizer type (F) according to ASTM C494-04[12], designed for the production of UHPC is used (Glenium 51), Table (7) shows the physical properties of Glenium 51.

Table (7) Physical Properties of Glenium 51

Physical properties	Test result
Relative density	1.1 @ 20 °C
Form	Viscous Liquid
Color	Light Brown
PH	6.6
Dosage	(0.5-1.6) L/100 kg of Cement

4.7 Extra Water

Extra water used in the mix design of concrete is potable water from the water supply network system.

4.8 Distilled Water

This type of water is used to dissolve sodium hydroxide to prepareNaOH solution.

4.9 Sikadur-330 (Epoxy Used)

Sikadur-330 (Epoxy Used) In order to avoid any gap between tested specimen and the steel frame, an epoxy (Sikadur-330) resin is filled inside this gab around the specimen and left for (7) days curing of epoxy to brace (control) the fixity of the wall at supports.

4.10 Steel Reinforcement

The reinforcing mesh consists of 6 mm diameter deformed steel bars placed in a single layer at the intermediate thickness of the wallboard. Rebar spacing (80 mm) c / c spacing in both directions, clear side cover of 10 mm. In addition, place a (8 mm) rebar around the wall to reinforce or protect the edges of the wall. For 6 diameter bars and 8 mm diameter bars, the bar yield strength is 721 MPaand 505 MPa respectively,the adopted bars (6 and 8)mm are in accordance with Standard Specification for steel reinforcement ASTM A82-05[13] and ASTM A615-86[14].

5. Mechanical Properties of Hardened Concrete

The mechanical properties of geopolymer concrete mixes used are listed in Tables (8) and (9), the compressive strength test is carried out on three cubes of (100x100x100mm) in accordance with B.S. 1881, part 116 [15]. Flexural strength (modulus of rupture) test is carried out on prism of (100x100x500mm) in accordance with ASTM C 78-02[16]. Indirect tensile strength (splitting tensile strength) test is carried out on cylinder of (100x200mm) in accordance with ASTM C496-04[17].While themodulus of elacitisitytest is carried out on cylinder of (150x300mm) in accordance with ASTM C496-02[18].

Table (8) Properties of Hardened GPC with recycled concrete aggregate

Details	Iron filings %	f_{cu} MPa	Increasing %	f_{sp} MPa	Increasing %	f_r MPa	Increasing %	Ec GPa	Increasing %
GPC with recycled concrete aggregate	0	25.9	--	2.65	--	2.54	--	18.8	--
	0.5	26.5	2	3.18	20	3.2	26	19.2	2
	0.75	27.3	5	3.3	25	3.35	32	20.5	9
	1.0	28.5	10	3.51	32	3.6	42	20.8	11

Table (9) Properties of Hardened GPC withnatural aggregate

Details	Iron filings %	f_{cu} MPa	Increasing %	f_{sp} MPa	Increasing %	f_r MPa	Increasing %	Ec GPa	Increasing %
GPC with natural aggregate	0	30.8	--	3.0	--	3.8	--	20.4	--
	0.5	31.5	2	3.78	26	4.3	13	21.5	5
	0.75	32.5	6	4.2	40	4.79	26	22.1	8
	1.0	33.6	9	4.57	52	4.962	31	24.2	17

6. Mixing Procedure

The aggregates are prepared on a saturated surface in the dry state, SSD. The recycled concrete aggregate (fine and coarse aggregate) is first mixed in dry form in a bucket mixer for three minutes and then metakaolin is added and mixed for two minutes. The alkaline liquid was added to the geopolymer concrete mix and 65% of superplasticizer is mixed with additional water for not less than two minutes and gradually added to the dry materials in the mixing tray for five minutes. After that, the iron filings were added and 35% super plasticizer was added and mixed for two minutes. Then, the concrete was compacted with a vibrating table.

7. Curing of Samples

This method of curing means placing the specimen under direct sunlight outside the laboratory after demolding. Models were poured during temperatures 27° to 30°, placed models are under the ambient temperature based on previous researches.

8. Wall Panels Testing Procedure

Before test, the wall panels are cleaned and painted white to ensure that the crack pattern can be easily observed on the wall surfaces and to obtain a clear visibility of the cracks during the test. After the test equipment has been repaired, the panel is fixed to the top and bottom brackets, the wall panels are labeled and placed precisely along the edges of the brackets. Leveling the panel to ensure perpendicularity of the panels. The distributed axial load is applied to the eccentricity= t/6 from the center of the samples and the dial gage was placed in the middle center of the wall panels. During the application of loads, the corresponding side deflections of the middle section are recorded using a precision dial of 0.01 mm and a capacity of 25 mm located on the face of the wall panelsas shown in fig.2.

At the beginning of each test, approximately (1 kN) is applied to seat the supports and the loading system, then the load is released after applying the seat load. The compression axial load is applied progressively in increments of 10 kN. This amount of gradual loading allowed a sufficient number of loads and the resultant deflections during the test, which gives a realistic idea of the structural behavior of the wall panels. The cracking loads, the maximum axial load with its corresponding deflections at midheightof the wall and the reading of the maximum crack width are observed and recorded.

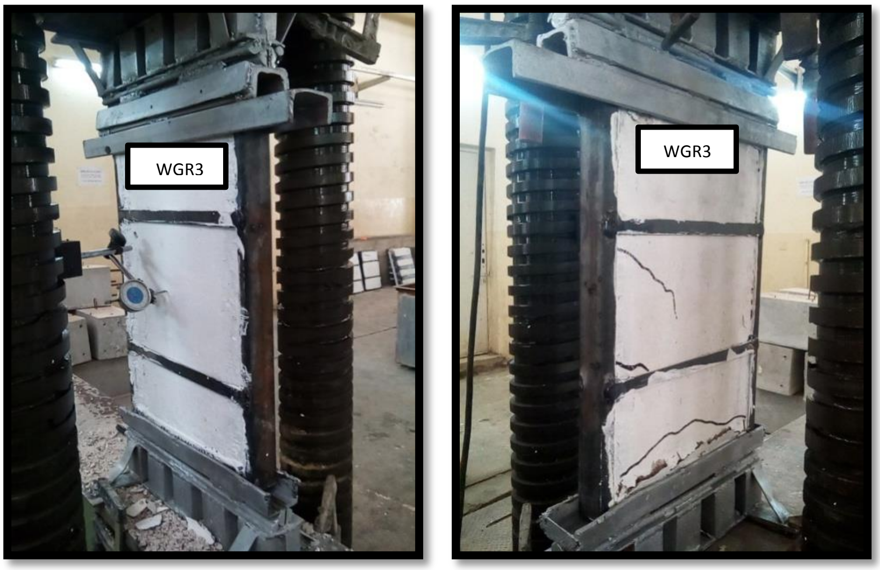

Figure (2) Panels Before and After the Test.

9. First crack load and Ultimate load

Tables(10)and (11) Show the first crack load and ultimate load values for the specimens under in-plane loading. First crack load was taken as the load corresponding to the point at which the load deflection curve becomes nonlinear.

Table (10) First Crack Load and Ultimate Load for Group (A)

Group (A)	GPC with recycled concrete aggregate							
Wall Number	V_i %	P_{cr} (kN)	Increasing %	P_u (kN)	Increasing %	(P_{cr}/p_u) %	Max Δ (mm)	Decreasing %
WGR1	0	38	--	250	--	15	9.92	--
WGR2	0.5	40	5	260	4	15	9.75	2
WGR3	0.75	42.5	12	285	14	15	8.52	14
WGR4	1.0	43.5	14	292.5	17	16	8.42	15

Table (11) First Crack Load and Ultimate Load for Group (B)

Group (B)	GPC with natural aggregate							
Wall Number	V_i %	P_{cr} (kN)	Increasing %	P_u (kN)	Increasing %	(P_{cr}/p_u) %	Max Δ (mm)	Decreasing %
WGN5	0	41	--	309	--	13	9.8	--
WGN6	0.5	43.5	6	314.5	2	14	9.5	3
WGN7	0.75	44.5	8	318	3	14	8.4	14
WGN8	1.0	46	12	322	4	14	8	18

For group (A) the ultimate strength of wall panel increases with increasingiron filings ratio. Table (6) shows that increasing of iron filings ratio from 0 to 0.5%, 0.75%

and 1%, resulted increasing percentage of ultimate bearing capacity with 4%, 14% and 17%respectively, also the same increasing in iron filings caused an increasing in cracking bearing load by 5%, 12% and 14%respectively, and an decrease in lateral deflection by 2%, 14% and 15% respectively.

For group (B) the ultimate strength of wall panel increases with increasingiron filings ratio. Table (7) shows that increasing of iron filings ratio from 0 to 0.5%, 0.75% and 1%, resulted increasing percentage of ultimate bearing capacity with 2%, 3% and 4%respectively, also the same increasing in iron filings caused an increasing in cracking bearing load by 6%, 8% and 12%respectively, and an decrease in lateral deflection decreasing by 3%, 14% and 18% respectively.

10. Load - Deflection Behavior

Based on the observations, the load-deflection graphs are plotted for the specimens and are shown in Fig.3, and Fig.4.

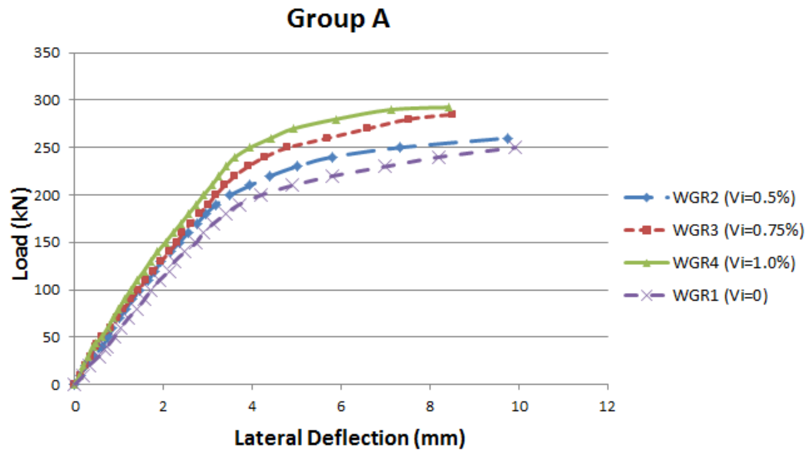

Figure (3) Effect of Iron Filings Ratio on Load-deflection Behavior for Group A

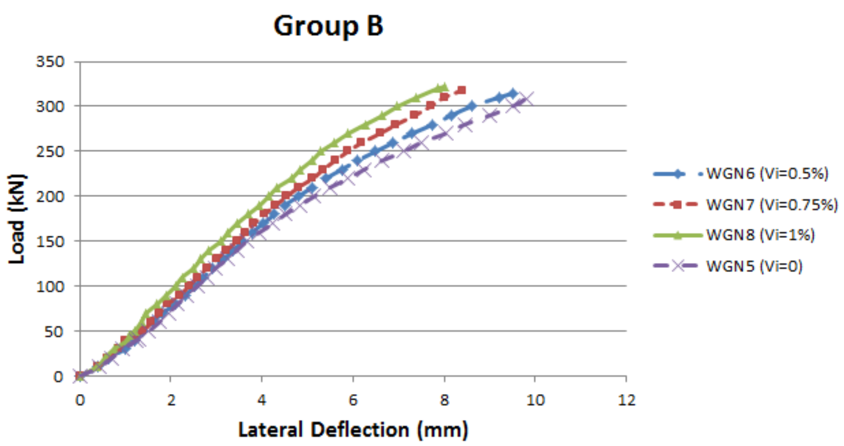

Figure (4) Effect of Iron Filings Ratio on Load-deflection Behavior for Group B

Fig. (3) Showsthat the lateral deflection decreases with increasingiron filings fewer than two ways in plane loading. A maximum deflection of 9.92mm is obtained for the ultimate load of 250kN in the case of the panels WGR1. The maximum deflection for the panels WGR2, WGR3 and WGR4 are 9.75mm, 8.52mm and 8.42mm respectively .

Fig. (4) Shows that the lateral deflection decreases with increasing iron filings under two ways in plane loading. A maximum deflection of 9.8mm is obtained for the ultimate load of 309 kN in the case of the panel WGN5. The maximum deflection for the panel WGN6, WGN7 and WGN8 are 9.5mm, 8.4mm and 8mm respectively.

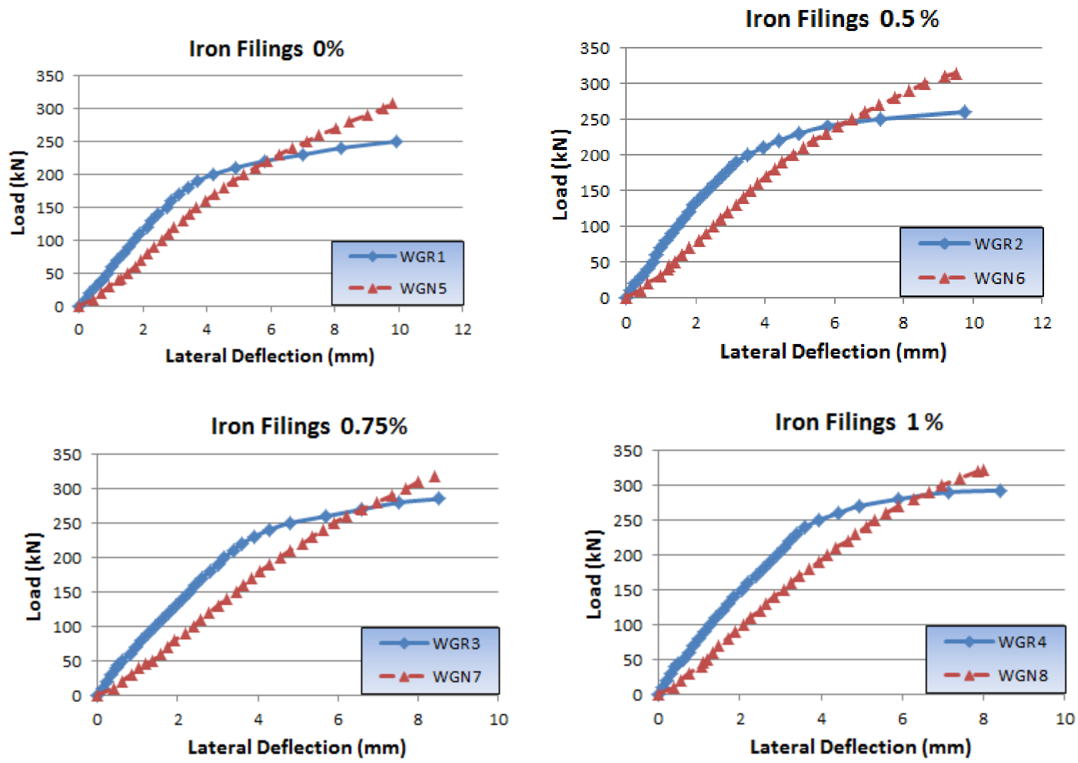

Figure (5) Effect of Types of Aggregate on Load-deflection Behavior for Groups A and B.

Tables (10) and (11) show that when replacing the recycled concrete aggregate by natural aggregate resulted in increasing percentage of ultimate bearing capacity and cracking bearing load by 24% and 8% respectively for iron filings 0% , 21% and 9%respectively for iron filings 0.5 %, 12% and 5% respectively for iron filings 0.75%, 10% and 6%respectively for iron filings 1 %.

Fig. (5) shows that when replacing the recycled concrete aggregate by natural aggregate resulted in decreasing percentage of lateral deflection at ultimate load by 1% for iron filings 0% , 3% for iron filings 0.5 %, 2% for iron filings 0.75%, 5% for iron filings 1 %.

11. Crack Pattern

The crack patterns for eight panels are shown in Figure (6).

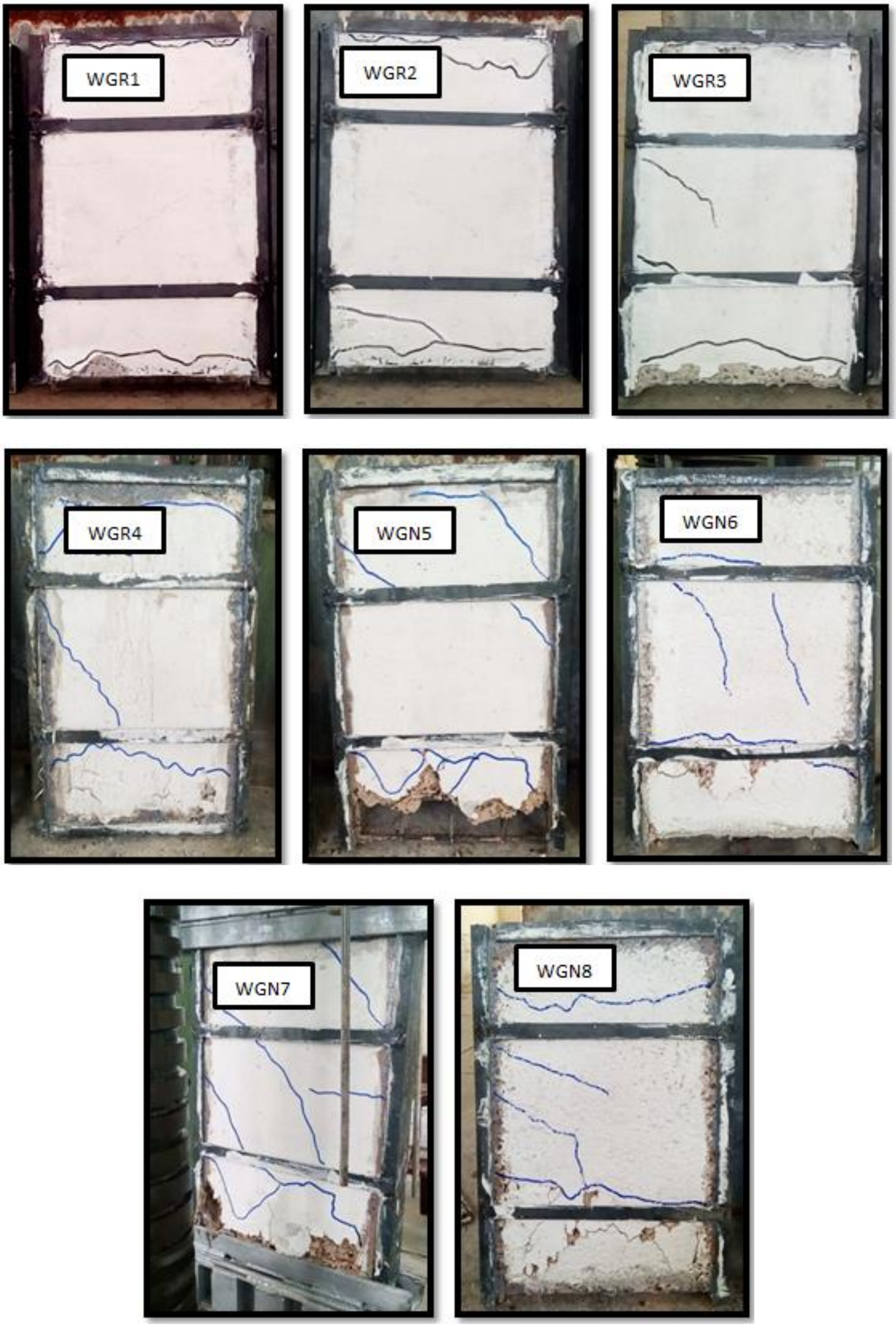

Figure (6) Crack Pattern forEight Wall Panels.

1. For panels WGR1, WGR2 and WGR3 Crush at top and bottom of the wall
2. For panels WGR4, WGN5, WGN6, WGN7 and WGN8 crushing occur at bottom of the wall.
3. Horizontal cracks at top and bottom of panels WGR2, WGR4, WGN5, WGN6 and WGN8 are propagated at failure.
4. Diagonal crack at top of panels WGR4, WGN5 and WGN7are propagated.
5. Diagonal crack at middle of panels WGR3, WGR4, WGN5, WGN6, WGN7 and WGN8are propagated.

12. Conclusions

From the experimental result conducted, it can be observed that:

1. The ultimate strength of wall panels increases with increasing iron filings under in plane loading. The increase in ultimate load is about 17% for geopolymer with recycled concrete aggregate (GCRA) and 4% for geopolymer concrete with natural aggregate (GCNA) by increase the iron filings to 1%.
2. The lateral deflection decreases to 15% forgeopolymer concrete with recycled concrete aggregate (GCRA) and 18% for geopolymer concrete with natural aggregate by increasing the iron filings to 1%.
3. Use of recycled concrete aggregates is roughly similar to the natural aggregates in the geopolymer concrete walls. Therefore, the use of recycled concrete aggregates in the geopolymer is better because of the low cost and its role in reducing the weste concrete.
4. 1% of volumetric ratio of iron filings (V_i)gives the rough increasein strength of geopolymer concrete walls.This ratio can be increased to 2%, to give clear increasing.
5. The effect of iron filings is obvious on the first crack as it works on a delayed its cracking loads, but it is unable to transfer loads from the affected areas to the new areas due to the relatively few aspect ratio.

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