http://dx.doi.org/10.21172/ijiet.101.07

Behavior of reinforced Concrete Beams with Steel slag Reinforced by Fiber Reinforced Polymers Bars

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Abstract-This paper presents experimental andnumericalstudy of the flexural behavior of concrete beams with steel slag as a coarse aggregate partiallyreplacement, and reinforcedby glass fiber reinforced polymers (GFRP) barsby pultrusion process as a solution to overcome the corrosion problem. A series of 10 experimental beams are cast and tested up to failure undertwo-pointload with 600 mm apart, where all beams had the same dimensions with width, depth, total length and clear span between two supports are 100mm, 200mm, 2000mm and 1800mm, respectively. Afinite element analysis program (ANSYS) is used to develop a calibration models for simulation of the behavior of experimentalbeams to give confidence in the use of ANSYS. Then a series of 16 beams models with different parameters (flexure and compression reinforcement ratio and type and shear reinforcement) are used to study how different parameters affect on the behavior of a concrete beam with steel slag and investigate how GFRP should be applied in order to get maximum increase of load capacity. Experimental tests and numerical analysis results show that adding the steel slag to the concrete mixes as a coarse aggregate replacement,using GFRP bars and increasing of GFRP bottom main reinforcement ratio have a significant effect on the flexure behavior of concrete beams with steel slag reinforced by GFRP bars.
Keywords-Flexure, Behavior, Steel slag, Beams and GFRP bars.

I. INTRODUCTION

The Egyptian construction sector is one of the most promisingsectors which are intended to achieve great gain to national gross domestic product. Reinforced concrete buildingmaterials were implemented a large scale development in recent years.Many of materials industries have evolved with the development of construction industry such as steel slag and fiber reinforced polymers.Steel slag is a by-product obtained either from conversion of iron to steel in basic oxygen furnace (BOF), or by the melting of steel scrap to make steel in the electrical arc furnace (EAF) [3]. The industrial wastes have been encouraged in construction industries because it contributes to reduce the usage of natural resources [2]. For many years, by products such as fly ash, silica fumes and steel slag were considered as waste materials. They have been successfully used in the construction industries, for the partial or full replacement of both fine and coarse aggregates,it is recommended that up to SSA 60% can be used as replacement of coarse aggregate [4,6]. The concrete casted with steel aggregate concrete was more durable than that prepared with natural basalt aggregate in terms of the chloride penetration resistance [5].

Recycling steel slagto use it in the concrete as natural aggregate replacement might prove aneconomical andenvironmentally friendly solution also this will encourage other investigations to find another filed of using the slag.As a replacement to steel reinforcement, Fiber Reinforced Polymers (FRP) bars have gained popularity due to their noncorrosive and non-metallic properties. FRP are light weight and have high strength-to-weight ratios 1.5 to 2 times the tensile strength of steel[1].Glass fiber reinforced polymer GFRP has a very important role to play as reinforcement in concrete structures that will be exposed to harsh environmental conditions where traditional steel reinforcement could corrode [7]. FRP is the most corrosion resistance replacement of steel reinforcement in concrete,the corrosion reduces the life time of structures, causes high repair costs. With this combination between a by-product aggregate and non corrosionreinforcement we can offer a cost effective reinforced concrete section that can achieve very high compression, flexure strength and very high durability against corrosion if we compare with normal concrete section reinforced with steel bars.

The aim of this study is to investigate the behavior of concrete beams with steel slag as a coarse aggregate partially replacement reinforced by GFRP bars. Experimental tests were performed to investigate the behavior of beams. The ANSYS program is used to develop finite element calibration models to simulate of the behavior of experimental results. The load-deflection response of the experimental beam will be compared to Finite elements model result to calibrate the FE model for further use [8,9]. Then series of beam models were then used to study how different parameters affect on beam behavior to get maximum increase of load capacity.

II. EXPERIMENTAL PROGRAM

Tested beams are cast and tested up to failure under two point load with 600 mm apart as shown in figure2,where all beams had the same dimensions with width, depth, total length and clear span between two supports are 100mm, 200mm, 2000mm and 1800mm, respectively,beams are divided into four groups as shown in table 1to study the effect of some parameters on the behavior and predicting deflections of the concrete beams with steel slag as a coarse aggregate replacement reinforced by FRP bars [10] with stress strain curve as shown in figure 1 as follow:

1. The tensile reinforcement ratio(0.8 and 1.60 % are used).
2. The compression reinforcement ratio(0.8 and 1.60 % are used).
3. Shear span to depth ratio (a/d= 2, 3 and 4 are used).
4. The characteristic strength of concrete (fcu= 30 and 40 N/mm²)

The specimens were loaded with two-point load 600 mm apart in the middle third of specimens for group 1, 2 and 4, the specimens were loaded with two-point load 800 mm from the support for group 3 to study the flexure behavior of concrete beams with steel slag as a coarse aggregate replacement reinforced by FRP bars when exposed to pure bending moment.

Table 1. Tested beam groups

group	parameters	beam	concrete	Fcu [N/mm²]	R.F.T.	Bottom RFT	Top RFT	stiruups	shear span [mm]
1	bottom R.F.T. ratio	B1	ordinary	30	steel	2Ø10	2Ø8	Φ8at150mm	600
		B2		30	FRP	2Ø10	2Ø8		
		B3	33% steel slag	30		2Ø10	2Ø8		
		B4		30		4Ø10	2Ø8		
2	Top R.F.T.	B5		30		2Ø10	2Ø8		
		B6		30		2Ø10	4Ø8		
3	shear span to depth	B7		30		2Ø10	2Ø8		400
		B8		30		2Ø10	2Ø8		800
4	Fcu	B9		30		2Ø10	2Ø8		600
		B10		40		2Ø10	2Ø8		

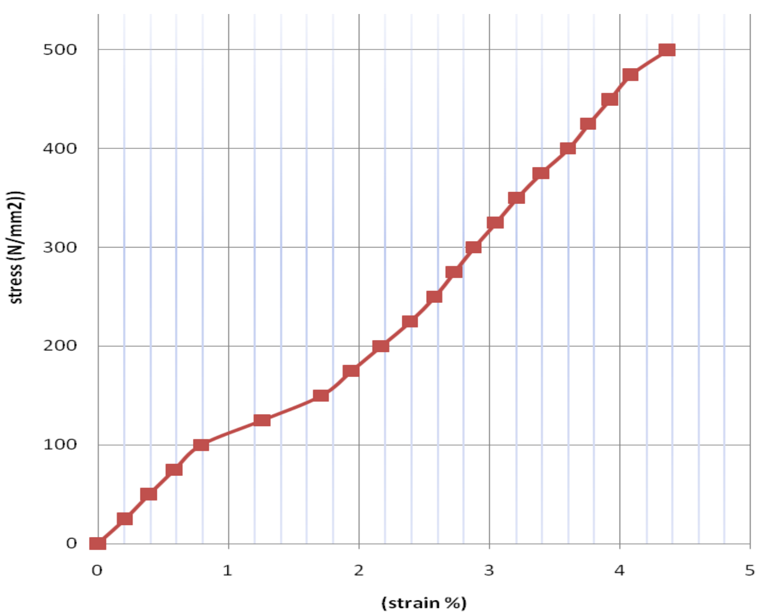

Figure 1. Stress-strain curve of used GFRP bar

Figure 2. Flexure testsof concrete beams

2.1 Results of Experimental Program

Table 2 shows the resultsof the tested beams in the experimental work in this study, the table includes the values of the first cracking and the fracture loads and its corresponding mid-span deflection.

Table 2.The Results of the Tested Beams of Groups 1, 2, 3&4

group	**beam**	**concrete**	**Reinf.**	**First crack load [KN]**	**fracture load [KN]**	**deflection at First crack [mm]**	**deflection at fracture load [mm]**
1	B1	Control	steel	12.00	40.41	1.268	22.804
	B2	N.A.	FRP	10.00	41.00	3.552	42.226
	B3	S.S.		10.15	42.50	3.442	40.638
	B4			12.02	50.04	5.174	38.992
2	B5			10.15	42.50	3.442	40.638
	B6			9.01	41.84	3.558	36.026
3	B7			11.03	42.46	8.318	39.172
	B8			11.01	42.46	8.31	39.164
4	B9			10.15	42.50	3.442	40.638
	B10			7.02	38.22	4.826	41.356

Where: N.A. = Concrete with normal dolomite aggregate
S.S. =Concrete with 33% steel slag as a coarse aggregate replacement

III. NUMERICAL ANALYSIS

3.1 Calibration Model

The use of finite element to create the calibration model using experimental load-deformation behavior of a concrete beam B3 from experimental program, ANSYS was used as the FE modeling package [8]. The width,depth, total length and clear span between two supports of the beam tested were 100mm, 200mm, 2000mm and 1800mm, respectively. Tested beam had tensile reinforcement 2#10 mm FRP bars and ø8mm@15cm stirrups.The element types for concrete, steel plates and reinforcement bars were solid 65, solid 45 and link 180, respectively as shown in figures 3, 4, 5

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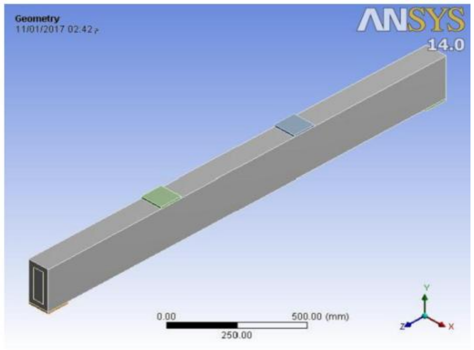


Fig.3.Volumes Created of specimens

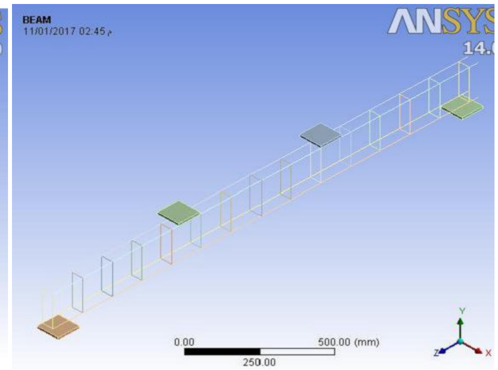


Fig.4Reinforcement modeling

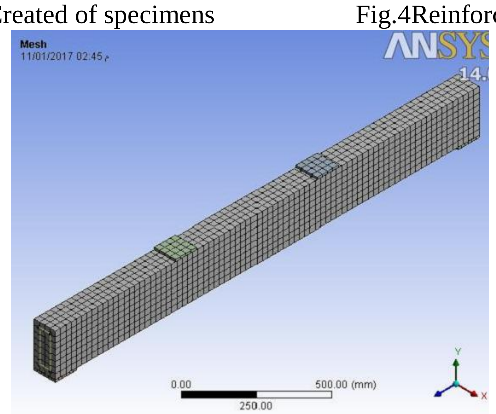


Figure5. Mesh of the Concrete

3.2 Calibration Model Results

To simulate the experimental test, A Static analysis type is utilized. The finite element model for this analysis is a concrete beam reinforced by FRP bars under two verticalloads. The load–deflection curve is considered the key aspect in studying the beam behavior as it involves response parameters including beam ultimate loads, and maximum deflection. Therefore, correlating the load–deflection relationships of the finite element results with that of the experimental ones is considered an effective mean to verify the model.

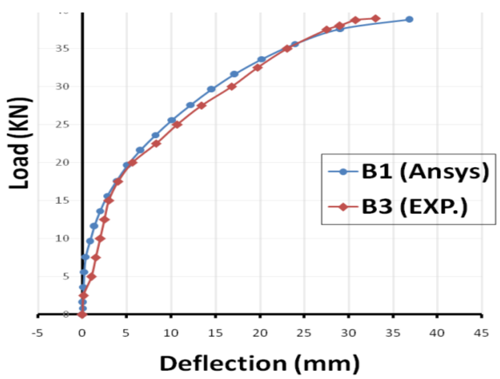


Figure 7.Load – Deflection Chart Comparison

The entire load-deformation response of the model produced compares well with the response from experimental work as shown in figure 7. This gave confidence in the use of ANSYS. The approach was then utilized to analyze a series of concrete beams with steel slag as a coarse aggregatepartially replacement reinforced by FRP bars.

3.3 Finite Element Beams Models:

Analysis were carried out on 16 beam models,divided into four groups, where all groupshave the same width, depth, total length and clear span between two supports of 100, 200, 2000, 1800 mm respectively to study the effects of some parameters on the behavior of the reinforced concrete beams with steel slag as a coarse aggregate reinforced

with GFRB bars using ANSYS software and compare it with the reinforced concrete beam models reinforced by steel bars with the same parameters, as shown in table 3.
The studied parameters include:

1. The tensile reinforcement ratios are (0.8, 1.20, 1.60 and 2.10 % are used).
2. The tensile reinforcement types (GFRP, and Steel).
3. The compression reinforcement ratios are 0.8, 1.20, 1.60 and 2.10 % are used).
4. Shear reinforcement ratios(0.2, 0.33 and 0.4% are used).

Table 3. Details and reinforcement of Beam models for Groups 1, 2, 3&4

No	Beam	Var.	Group	Bottom reinforcement		Top reinforcement		Stirrups
1	B1	Bottom reinforcement ratio	1	2#10mm (0.8%)	FRP Bars	2Ø8mm (0.8%)	Steel Bars	Ø8@150mm
2	B2			3#10mm (1.2%)		2Ø8mm (0.8%)		Ø8@150mm
3	B3			4#10mm (1.6%)		2Ø8mm (0.8%)		Ø8@150mm
4	B4			5#10mm (2.1%)		2Ø8mm (0.8%)		Ø8@150mm
5	B5	Bottom reinforcement ratio	2	2#10mm (0.8%)	Steel Bars	2Ø8mm (0.8%)	Steel Bars	Ø8@150mm
6	B6			3#10mm (1.2%)		2Ø8mm (0.8%)		Ø8@150mm
7	B7			4#10mm (1.6%)		2Ø8mm (0.8%)		Ø8@150mm
8	B8			5#10mm (2.1%)		2Ø8mm (0.8%)		Ø8@150mm
9	B9	Top reinforcement ratio	3	2#10mm (0.8%)	FRP Bars	2Ø8mm (0.8%)	Steel Bars	Ø8@150mm
10	B10			2#10mm (0.8%)		3Ø8mm (0.8%)		Ø8@150mm
11	B11			2#10mm (0.8%)		4Ø8mm (0.8%)		Ø8@150mm
12	B12			2#10mm (0.8%)		5Ø8mm (0.8%)		Ø8@150mm
13	B13	Shear rienfocement	4	2#10mm (0.8%)	FRP Bars	2Ø8mm (0.8%)	Steel Bars	Ø6@150mm
14	B14			2#10mm (0.8%)		2Ø8mm (0.8%)		Ø8@150mm
15	B15			2#10mm (0.8%)		2Ø8mm (0.8%)		#10@150mm
16	B16			2#10mm (0.8%)		2Ø8mm (0.8%)		#12@150mm

3.4 Results of Numerical Analysis

Table 4 shows the results of the numerical analysis models, the table includes the values of the max loads (P_{max}) and deflections at max loads.

Table 4. The Results of the Tested Beams of Groups 1, 2, 3&4

No	Beam	Parameters	Group	Intial crack load [Kn]	Max load [Kn]	Max deflection [mm]
1	B1	FRP Flexure reinforcement ratio	1	12.11	42.712	25.790
2	B2			13.21	43.99	31.200
3	B3			14.54	50.432	32.327
4	B4			19.88	54.314	26.253
5	B5	Steel flexure reinforcement ratio	2	9.9	29.988	35.900
6	B6			11.85	39.99	37.010
7	B7			12.65	42.23	38.317
8	B8			17.51	48.492	31.074
9	B9	Steel compression reinforcement ratio	3	10.52	36.746	21.974
10	B10			10.61	37.502	25.8
11	B11			10.66	39.036	25.387
12	B12			11.12	39.854	24.327
13	B13	Shear rienfocement	4	10.52	32.886	21.01
14	B14			10.54	37.484	22.907
15	B15			10.63	40.094	29.4
16	B16			10.66	41.892	29.1

IV. ANALYSIS AND DISCUSSION

4.1The tensile reinforcement type and ratios:

4.1.1 Crack patterns

The first crack appeared in the tension zone at the middle of the beam of B3 and B4, the number of cracks increased as the load increased and the cracks propagated upwards towards the compression zone until failure, as shown in figures8 and 9.

Figure 8.Crack Pattern of Beams B3

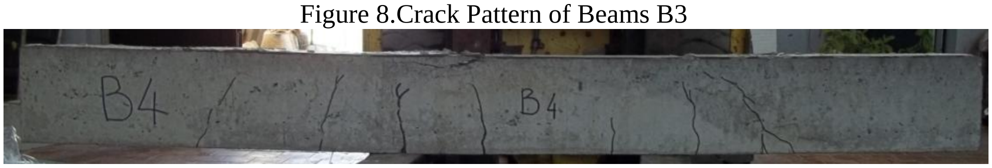


Figure 9.Crack Pattern of Beams B4

4.1.2 Load-Deflection Relationships

The descending branch of the load-deflection curve is not investigated in these tests because the testing machine is load controlled as shown in figure 10.

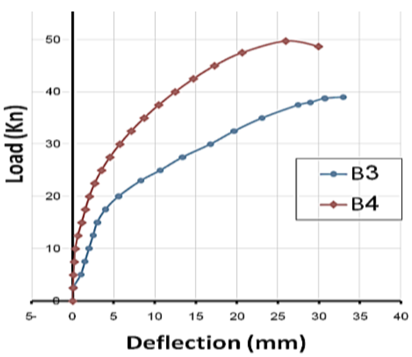


Figure 10. Load-deflection chart for B3 and B4 (Experimental work)

Load-Deflection Charts from the finite element modelwas determined, for the beams in Group2, the steel reinforced concrete beams B5, B6, B7 and B8 tend to exhibit greater midspandeflections than beams in Group1 as shown in figure 11, 12, 13 and 14. This indicates that, for the same area of reinforcement, GFRP bars tend to reveal different behavior than steel bars. For GFRP reinforced concrete beams, the midspan deflection tends to decreased as the reinforcement ratio achieve 1.6% as shown in figure 16.

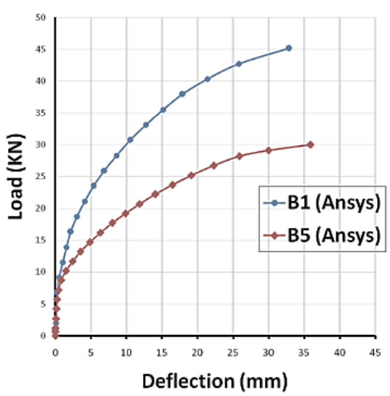


Figure 11.Load-deflection Chart for B1 and B5

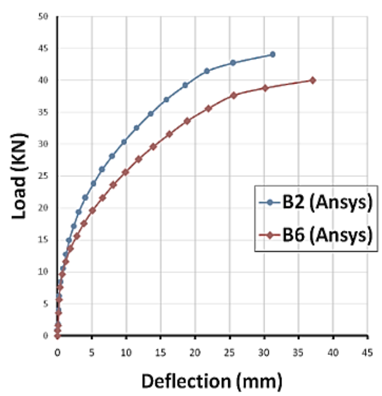


Figure 12.Load-deflection chart for B2 and B6

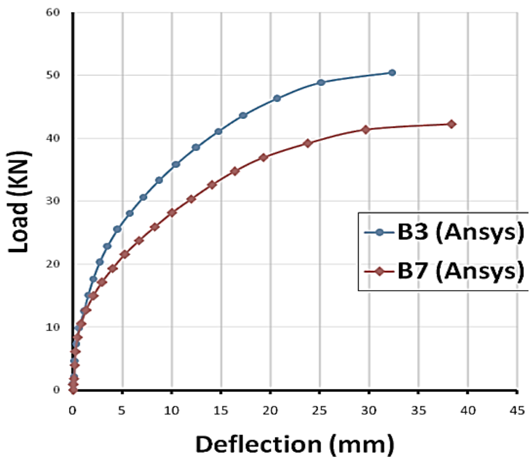


Figure 13.Load-deflection Chart for B3 and B7

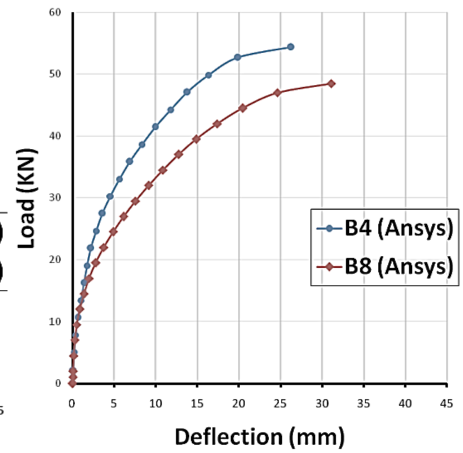
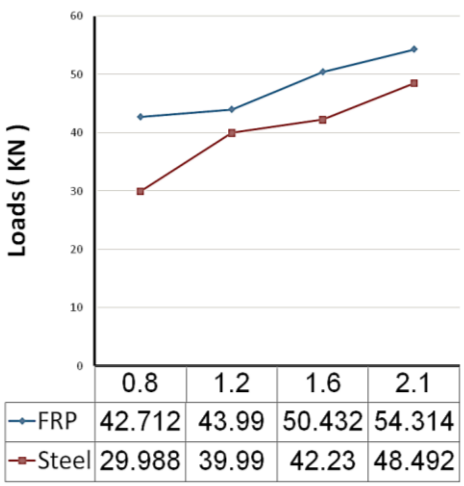
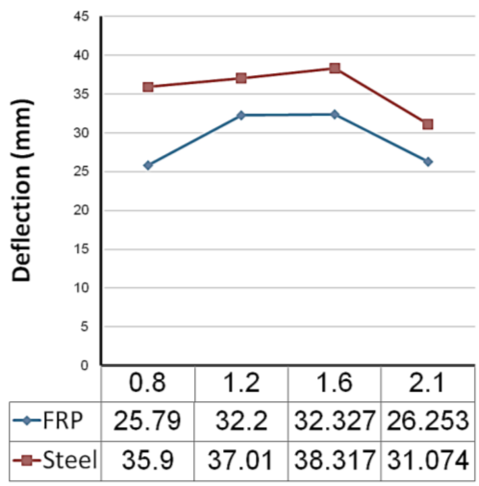


Figure 14.Load-deflection chart for B4 and B8



	0.8	1.2	1.6	2.1
FRP	42.712	43.99	50.432	54.314
Steel	29.988	39.99	42.23	48.492

Figure 15.Load-flexure A_s% for FRP and steel reinforcement



	0.8	1.2	1.6	2.1
FRP	25.79	32.2	32.327	26.253
Steel	35.9	37.01	38.317	31.074

Figure 16. Deflection- flexure A_s for FRP and steel reinforcement

4.2 The compression reinforcement ratios:

4.2.1 Crack patterns

The first crack appeared in the tension zone at the middle of the beam, the number of cracks increased as the load increased and the cracks propagated upwards towards the compression zone until failure, as shown in figure 17.

Figure 17. Crack Pattern of Beams B6

4.2.2 Load-Deflection Charts

forexperimental and Finite element model was determined at the mid span of the beams in Group 3 as shown in figure 18 and 19 as follow:

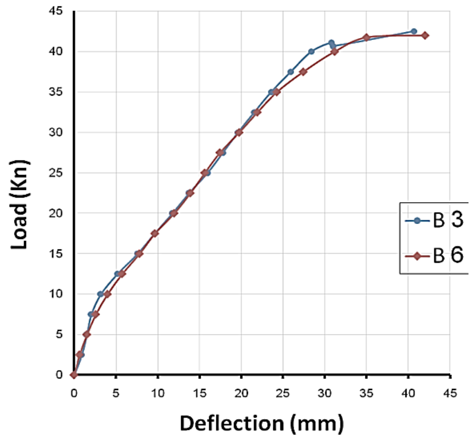


Figure 18. Load-deflection chart For B3 and B6(Experimental)

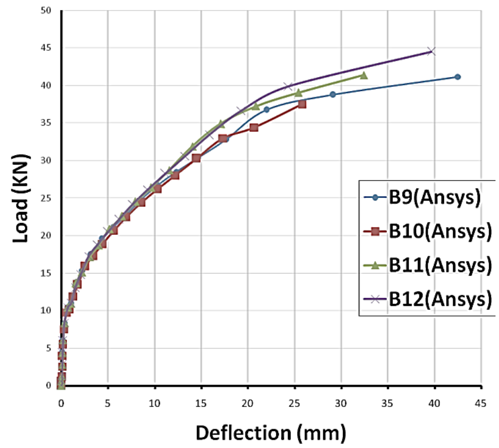


Figure 19. Load-deflection chart for Group 3 (Ansys)

From load – deflection curves shown in Figure 18 and 19, it was noticed that, the maximum load of (B10) is about 102% of (B9). The maximum deflection of (B10) is about 100.67 % of (B9), the maximum load of (B11) is about 104% of (B10). The maximum deflection of (B11) is about 98.4 % of (B10) and the maximum load of (B12) is about 102% of (B11). The maximum deflection of (B12) is about 85.8 % of (B11). It could be concluded that the increasing of compression reinforcement ratios has aninsignificant effect on maximum load of tested beams.

4.3 Shear reinforcement ratios

4.3.1 Crack patterns

The increasing of transverse reinforcement ratio increases the ductility of tested beams, hence, reduces the number of cracks and their widths as shown in figures 20.

Figure 20. Crack Pattern of Beams B8

4.3.2 Load-Deflection Charts

From the finite element model was determined at the mid span of the beams as follow:
The increasing of transverse reinforcement ratios increases the ductility of tested beams, hence, increases the maximum loads with a small amount as shown in figures 21 and 22.

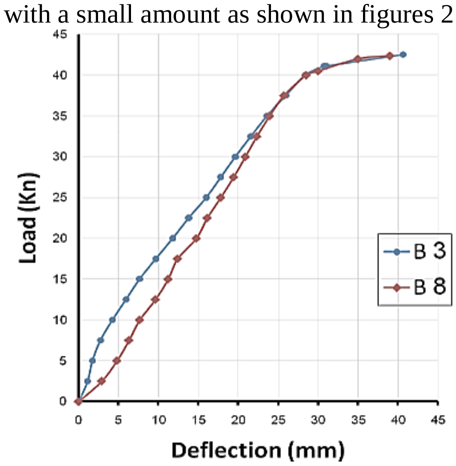


Figure 21. Load-deflection chart for B3 and B8for

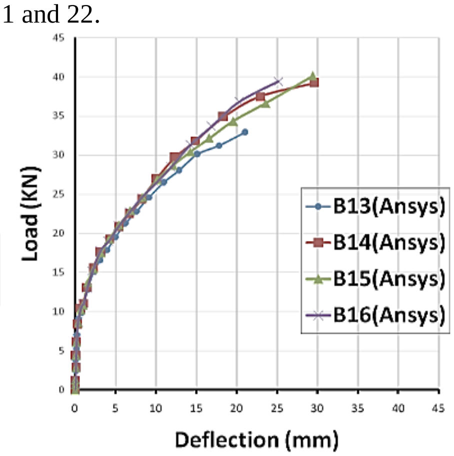


Figure 22. Load-deflection chart Group 4 (Ansys)

http://dx.doi.org/10.21172/ijiet.101.07

From load – deflection curves shown in Figure 22, it was noticed that, the maximum load of (B14) is about 113% of (B13). The maximum deflection of (B14) is about 109 % of (B13); the maximum load of (B15) is about 107% of (B14). The maximum deflection of (B15) is about 128 % of (B14); the maximum load of (B16) is about 104% of (B15). The maximum deflection of (B16) is about 99 % of (B15). It could be concluded that the increasing of shear reinforcement ratios has an insignificant effect on maximum load of tested beams.

V. CONCLUSIONS

This study investigated the flexural behavior of concrete beams with steel slag as a coarse aggregate replacement reinforced by locally produced glass fiber reinforced polymer (GFRP) bars. Within the scope of the experimental program considering the materials used, comparison of the experimental results with the values calculated using the calibration model and other numerical models resulted in the following conclusions:

1. Using of GFRP bars has advantages compared to steel bars reinforcement in the concrete beam contained EAFSS coarse aggregate.
2. The increasing of flexure reinforcement ratios from 0.8% to 2.1% has a significant effect on maximum load and deflection of tested beams.
3. Ultimate load is greater in case of EAFSS coarse aggregate concrete beam reinforced by GFRB bars than the Ultimate load of dolomite aggregate concrete reinforced with steel bars in all tested beams.
4. The increasing of compression reinforcement ratios has an insignificant effect on maximum load and deflection of tested beams.
5. The maximum deflection of tested beams is increasing when increase compression reinforcement from 0.8% to 1.6% then decreasing at 1.8 %.
6. The increasing of shear reinforcement ratios has a non significant effect on maximum load of tested beams, the maximum deflection of tested beams is increasing when increase shear reinforcement ratio from 0.2% to 0.33 then decreasing at 0.4%

1. Recommendations for Future Work

1. Long term deflection of EAFSS coarse aggregate concrete beam reinforced by GFRB bars should be studied.
2. High density concrete contained EAFSS coarse aggregate andreinforced by GFRB bars prevention and absorption of the nuclear rays must be investigate for shielding purpose.

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