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Performance of Reinforced Concrete Beams with Ground Blast Furnace Steel Slag

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Abstract:
The current paper presents an experimental investigation to study the performance of simply supported reinforced concrete beams with ground blast furnace steel slag (GBFS) as coarse and fine aggregates. Two different concrete mixes were prepared to evaluate the mechanical characteristics of the modified concrete. One mix was contained GBFS as fine and coarse aggregate instead of natural aggregate, the other mix was contained natural aggregate by using crushed stone for coarse aggregate and sand for fine aggregate. The results showed that the compressive strength , splitting tensile strength and flexural strength were enhanced by 119.20%, 120.0% and 123.70% respectively in the case of using GBFS in the concrete mix. Nine beams were cast and tested to study the performance of the reinforced concrete beams with GBFS. The beams were divided into two groups, the first group consists of six solid beams to study the effect of using concrete mix with and without GBFS as a part of concrete cross section with percentage (0% (as reference beam), 100%, 50%, 66% and 33%). The experimental results of the test specimens showed that the ultimate load capacity increases from 146.5 % to 122.4% for beams with different ratios of concrete slag with comparing to reference beam. While the second group consists of three infected beams (without concrete cover) to study the strengthening of reinforced concrete beam with concrete slag layer instead of the traditional method of strengthening. The results showed that the ultimate load capacity increases by 110.2% and 140.8 % for beams strengthed by traditional methods and by slag layer respectively with comparing to reference beam.

Keywords: *Reinforced concrete beams, Ground Blast furnace steel slag , Strengthening, flexural behavior and Cement,*

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I. Introduction

Devi et al. [1] and R Karolina et al.[2] studied the workability of concrete, including slag as coarse or fine aggregate the results showed that the workability of concrete decreases as the increase of the percentage of replacement slag instead of natural aggregate. As compared to natural rocks, slag has a high impact and crushing strength. It has increased skid resistance, excellent affinity to bitumen, and good resistance to polishing. Slag has a high bulk density and is suitable for hydraulic engineering purposes [3], a good aggregate for unbound and bituminous bound mixtures[4,5,6,7]. Due to its high frictional and abrasion resistance, steel slag is used widely in industrial roads, intersections, and parking areas where high wear resistance is a must. When compared to crushed limestone aggregates the physical properties of slag aggregates were found to be superior [8]. The partial replacement of fine aggregate by steel slag improves the compressive, tensile, and flexural strength of concrete. Improvement in strength property was slightly lower for coarse aggregate (CA) replacement when compared with fine aggregate (FA) replacement [1]. K. A. Olonade et al. [9] used crushed and sieved slag as a partial replacement material for sand in structural concrete. Compressive strength increased on the large number when both CA and FA were replaced by steel slag. But the flexural strength has slightly decreased for combined replacement. The optimum replacement ratio for fine aggregate is 40% and for coarse aggregate is 30%, beyond which the compressive strength decreases as a replacement. Several researchers [10-13] evaluated the mechanical properties of concrete inclusion granulated blast furnace slag as fine aggregate with different replacement ratios. It was observed that the partial replacement of sand by slag aggregate exhibits better results than conventional concrete

II. Experimental program

i- Materials

Cement

The cement used is Ordinary Portland cement (CEM 42.5 N). Tests are conducted on cement to ensure quality specifications according to ASTM C150 [14]. The physical properties of the cement as tested are shown in Table 1.

Table 1: Physical properties of cement

Property		Result
Specific gravity		3.17
Fineness		2000 cm^2/gm
Initial setting time		85 minutes
Final setting time		180 minutes
Compressive strength	3 days	205 Kg/cm^2
	7 days	300 Kg/cm^2
	28 days	435 Kg/cm^2
Soundness		1mm

Blast furnace steel slag as coarse and fine aggregates

Blast furnace steel slag is solid waste industrial material. Slag is the glass-like by-product left over after a desired metal has been separated from its raw ore. A slag aggregate sample was collected from the crushing plant of steel slag of a local steel manufacturing company. It was found that some slag aggregates were light in weight with a lot of voids and some were heavier with little or no voids. Therefore, the slag aggregates were separated into three types, such as lightweight slag aggregate (SL), heavyweight slag aggregate (SH), and mixed slag aggregate (SM). Different types of slag aggregates are shown in Fig. 1. At the laboratory, large-sized slag aggregates were broken into smaller sizes manually in coarse and fine form. Slag is usually a mixture of metal oxides and silicon dioxide. The primary components of Blast furnace steel slag are limestone (CaO) and silica (SiO2). Other components of blast furnace slag include alumina (Al2O3) and magnesium oxide (MgO), as well as a small amount of sulfur (S). Steelmaking slag contains iron oxide (FeO) and magnesium oxide (MgO). This means that the slag contains metal elements (such as iron) in oxide form, the chemical composition is provided in Table 2.

. The shape and physical characteristics of iron and Blast furnace steel slag are similar to ordinary crushed stone and sand, however, it is possible to provide different types of slag with a wide variety of unique properties due to differences such as the chemical components and cooling processes. Many applications that utilize the physical and chemical characteristics of slag have been developed and are being put to use in a broad range of fields [15]. The slag aggregate was tested for grading, unit weight, abrasion, specific gravity, and absorption capacity and abrasion as per ASTM standards [14].

Table 2: Chemical composition of Blast furnace steel slag

Component	CaO	SiO_2	T-Fe	MgO	Al_2O_3	S	P_2O_5	MnO
Value (%)	41.7	33.8	0.4	7.4	13.4	0.8	<0.1	0.3

a) Raw slag aggregate b) Coarse slag aggregate c) Fine slag aggregate

Fig.1 Blast furnace steel slag

Water

Water was used for mixing cement mortar samples and for curing samples. The chemical analysis of the water used is given in Table 3.

Table 3: Chemical analysis of the water

Property	Value
Density	1.025 gm/cm3
Soluble salts	35.438 gm/L
Ions	171
Carbonates	0.030 gm/L
Bicarbonate	0.305 gm/L
Sulfate	9.712 gm/L
Chlorides	12.985 gm/L
Calcium	0.500 gm/L
Magnesium	1.325 gm/L
Sodium	10.109 gm/L
Other	0.472gm/L

Steel reinforcement

Two types of steel reinforcement were used. The first type with a grade (28/45) was used with Ø 6 mm diameter as stirrups, where the second one was high-yield strength deformed bars with a grade (40/60) used with Φ10 mm as top and Φ12 mm bottom reinforcement.

ii- Mix portions of concrete

Two different concrete mixes were prepared to study the compressive strength, splitting tensile strength and flexural strength of the modified concrete. One mix was contained Blast furnace steel slag as fine and coarse aggregate instead of natural aggregate, the other mix was contained natural aggregate by using crushed stone for coarse aggregate and sand for fine aggregate. The water to cement (W/C) ratio is 0.5 for both two mixes. Table 4 shows the Mix composition of the concrete.

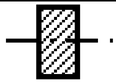
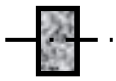
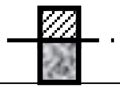
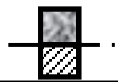
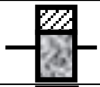
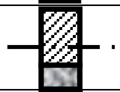
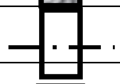
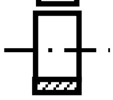
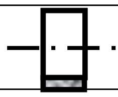
Table 4: Mix composition for concrete (kg/m^3)

Mix type	Cement	Water	Coarse aggregate	Fine aggregate
Slag mix (SC mix)	400	200	1132	629
Ordinary mix (OC mix)	400	200	1014	670

iii- Description of test specimens

The experimental program was conducted on nine beams to study the effect of using slag in concrete mix as coarse and fine aggregates. Dimensions of all beams were 1400 mm length with 1200 mm effective length, 120 mm width, and 300 mm height. The reinforcement was two longitudinal bars with 12 mm diameter on the tension side and two longitudinal bars with 10 mm on the compression side, and the stirrups were 8 mm diameter spaced at 150 mm center to center. The tested beams were divided into two groups, first group contains six beams to study the effect of using slag concrete as a part of the cross-section of the beam, either in compression or in tension zones of the beams with percentage (0%, 100%, 50%, 66% and 33%). The second group contains three infected beams (without concrete cover) to compare between using an ordinary concrete layer with epoxy resin and using a slag concrete layer with epoxy resin, as a strengthening layer. Table 5 shows the description of the tested beams, while fig. 2 shows sketches of the tested beam showing their dimensions and reinforcement.

Table 5: Description of testing beams

group no.	Model	Beam Sec.(mm)	TYPE	Test type	Cross section shape
Group 1	B1	120*300	PURE ORDINARY CONCRETE(OC)		
	B2	120*300	PURE SLAG CONCRTE(SC)		
	B3	120*150 120*150	½ OC and ½ SC	SC layer in tension zone	
	B4	120*150 120*150	½ OC and ½ SC	SC layer in compression zone	
	B5	120*100 120*200	1/3 OC and 2/3 SC	SC in tension zone	
	B6	120*200 120*100	2/3 OC and 1/3 SC	SC in tension zone	
Group 2	B7	120*270	Reference beam without concrete cover		
	B8	120*270	Repair with OC(30mm)with epoxy resin	Repair layer in tension zone	
	B9	120*270	Repair With SG(30mm) with epoxy resin	Repair layer in tension zone	

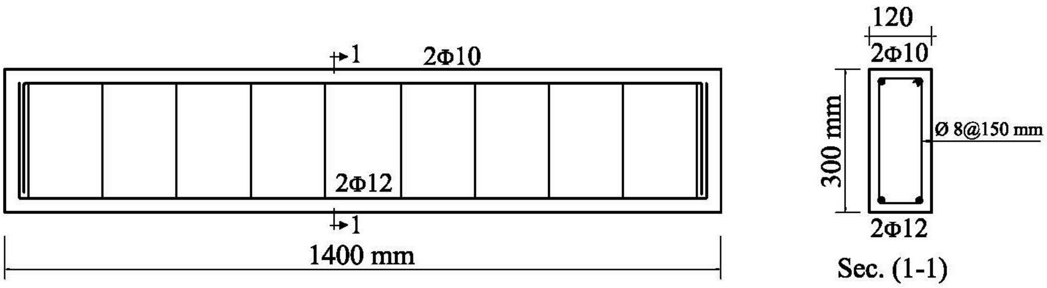


Fig. 2 Dimension and reinforcement details of the test specimens.

iv- Test Setup

All the specimens were simply supported with an effective span of 1200 mm and tested under the effect of asymmetric two point loads applied at the third points of the beam span. One LVDT with 100 mm was used and located on the bottom face of the specimen at the midpoint of the beam span. Fig.3 shows the experimental test setup. All specimens were tested at the material lab of the Arab Academy for Science, Technology and Maritime Transport, AAST, Smart Village.

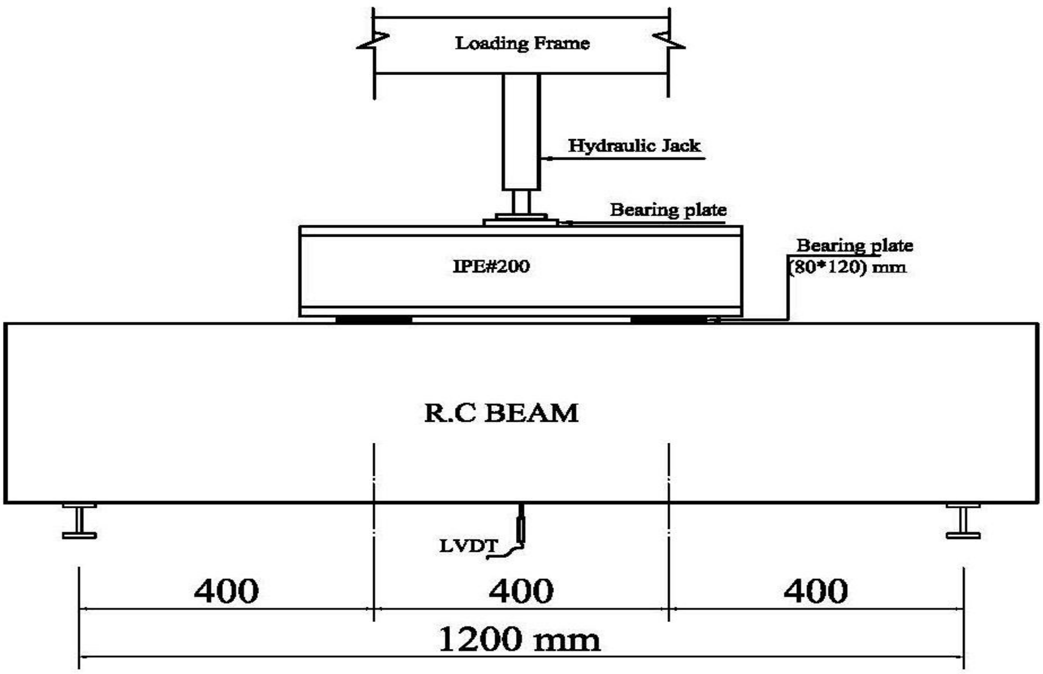


Fig. 3 Experimental Test Setup

III- Results And Discussion

1. Mechanical properties of plain concrete

Table 6 shows the average compressive strength, tensile strength, and flexural strength of concrete mixtures at 28 days. It was observed that the partial replacement of natural aggregate by slag led to a significant improvement in the mechanical properties of concrete. an increase in compressive, tensile, and flexural strengths was observed up to 19.2%, 20.0%, and 23.7% respectively.

Table 6: Mechanical properties of of concrete mixs (MPa)

Mix	compressive Strength	Splitting tensile strength	flexure strength
SC Mix	31	3.0	4.7
OPC Mix	26	2.5	3.8

2. Group 1

This section discusses the experimental results of the test specimens (B1-B6) which study the effect of using slag concrete as a part of the cross-section of the beam. The load versus the deflection values, failure load, and crack pattern were observed and initial stiffness and toughness were calculated.

2.1 Load- Deflection Relationships

Fig. 4 shows comparison curves between the applied loads and the corresponding central deflection of the test specimens of beams B1 and B2. The fig. 5 shows the deflection and the load-carrying capacity indicated that using slag as a fine and coarse aggregate (B2) increase the ultimate load capacity from 58 KN for B1 to 85 KN for B2. Fig. 6 indicates that using slag in half of the cross-section volume increase ultimate capacity to 71 KN and 78 KN for beam B3 and B4 respectively, with comparing to beam B1, while the load capacity decreases from 85 KN for B2 to 71kN and 78 KN for beam B3 and B4 respectively. Fig. 6 shows by using slag in two-third of the cross-section for B5 or one-third of the cross-section for B6 increase ultimate capacity from 58 KN for B1 to 84 KN and 71 KN respectively, otherwise the ultimate capacity decreases to 84 KN for B5 and to 71 KN for B6 with comparing to an ultimate capacity of B2.

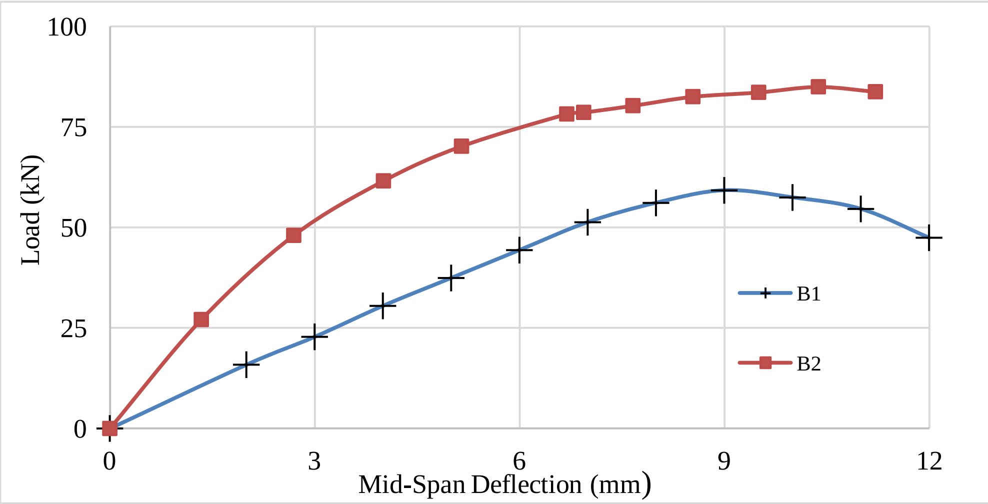


Fig. 4 load deflection curve for the two references beams

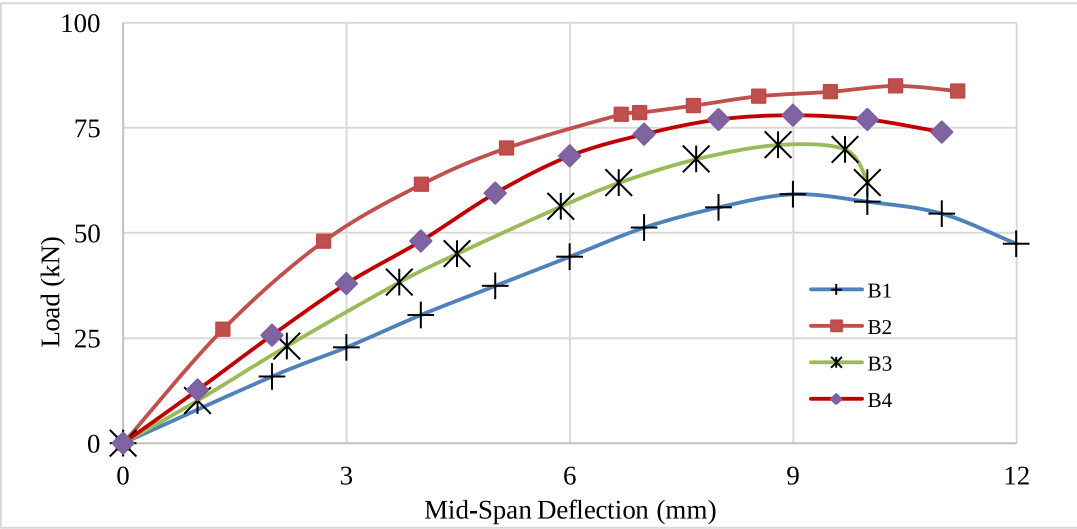


Fig. 5 load deflection curve for the using slag in full compression or tension zones

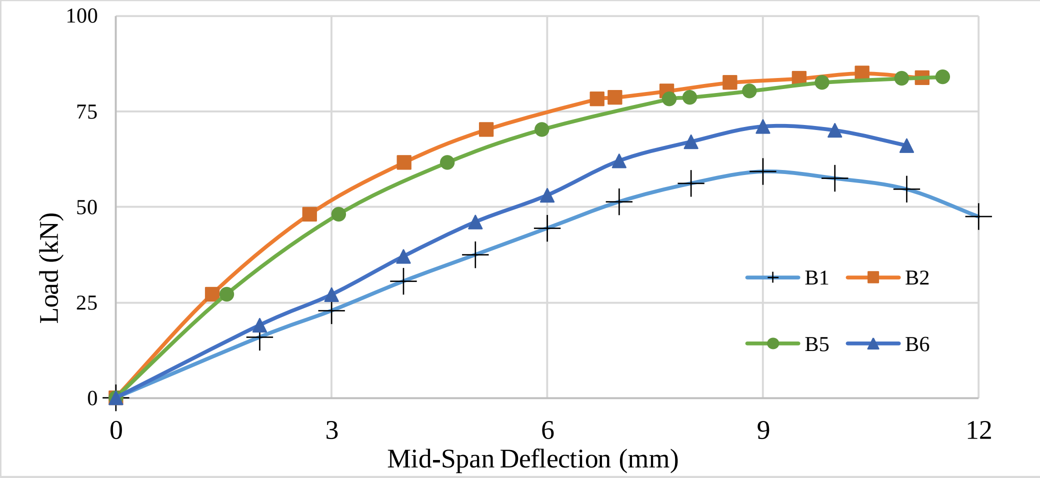


Fig. 6 load deflection curve for the using slag in third compression or tension zones

2.2 Ultimate Load, 1st cracking, ultimate deflection, and toughness.

The experimental results of the test specimens such that ultimate loads, 1st cracking loads, ultimate deflection, initial stiffness, and toughness are listed in Table 7. It's clear that the ultimate load capacity increases by 146.5 %, 125%, 134.5%, 144.8%, and 122.4% for beams B2, B3, B4, B5, and B6 respectively with comparing to reference beam B1. The results show there is no significant difference in the ultimate load values between the beam B2 and B5(1.1%), and between B3, B6 (0.0%). But there is a significant difference in the ultimate capacity between B1 and other beams, the maximum difference reaches 46.5% between B2 and B1. The results indicate that the 1st cracking load capacity increases by 156.1 %, 121.9%, 129.2%, 153.6%, and 126.8% for beams B2, B3, B4, B5, and B6 respectively with comparing to reference beam B1. The results show there is no significant difference in the 1st cracking load values between the beam B2 and B5(1.56%), and between B3, B6 (4.0%). But there is a significant difference in the 1st cracking load between B1 and other beams, the maximum difference reaches to 56.1% between B2 and B1. The results show that the values of the ultimate deflection of all beams nearest the same, in spite of the large difference in the ultimate loads for the same beams. Comparing flexural toughness or energy absorption values for a beam with slag (B2, B3, B4, B5, and B6) to reference beam B1 were 152.4%, 96.9%128.9%,149.7, and 107.2% respectively.

Table7 : Summary of test results of group 1.

Specimens	Ultimate Load Pu (kN)	1 st cracking Load (kN)	Ultimate Deflection δu (mm)	Initial stiffness (kN/mm)	toughness (kN.mm)
B1	58	41	10.00	6.93	461.24
B2	85	64	10.50	20.31	703.40
B3	71	50	9.00	10.22	447.39
B4	78	53	9.50	12.83	594.74
B5	84	63	11.00	13.45	690.82
B6	71	52	9.00	9.78	494.50

2.3 Cracking Pattern and Mode of Failure

Fig. 7 shows the cracking patterns of the test specimens after the completion of the test. It can be observed that all the test specimens failed in flexural failure mode. The first crack occurs in the constant flexure region. It, in general, occurs in the middle span of the beams and it is a flexure crack (vertical cracks). Cracking increases with increasing the loads and have appeared on the tension side of the beam, accompanied by vertical cracks in other regions of the beams. Spalling of concrete was seen on the surface of the beam and increased gradually until the load approached almost its ultimate value.

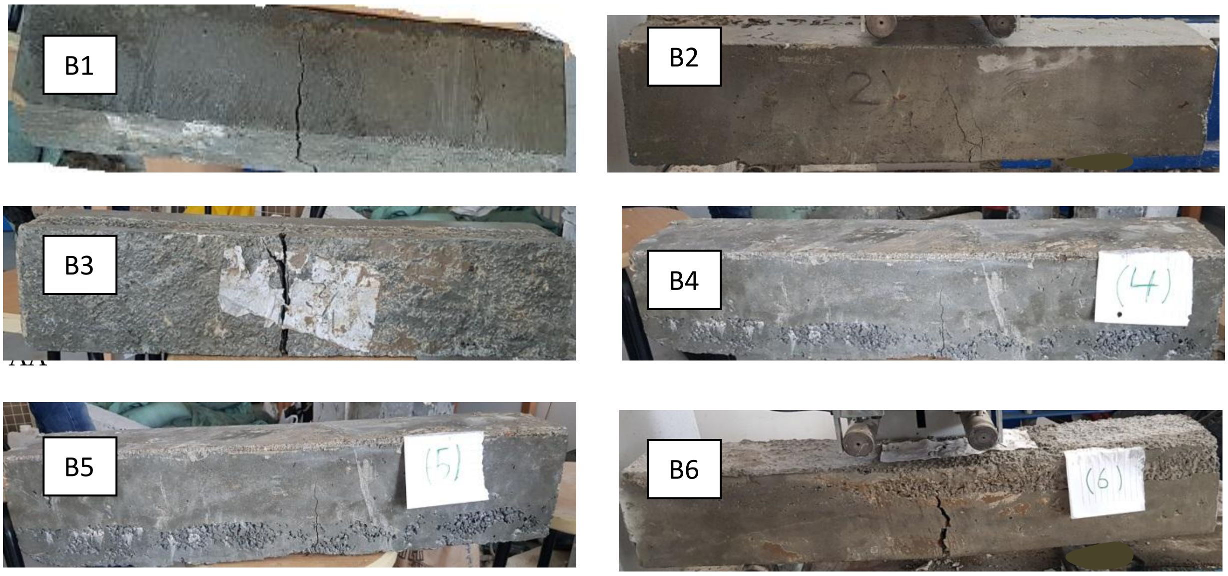


Fig. 7 Crack patterns of the tested beams

3. Group 2

This section discusses the experimental results of three infected beams (without concrete cover) to compare between using an ordinary concrete layer with epoxy resin and using a slag concrete layer with epoxy resin, as a strengthening layer. The load versus the deflection values, failure load, and crack pattern were observed and initial stiffness and toughness were calculated.

3.1 Load- Deflection Relationships

Fig. 8 shows a comparison curve between the applied loads and the corresponding central deflection of the test specimens of beams B1, B7, B8, and B9. The deflection and the load-carrying capacity indicated that the using slag concrete layer as a repairing technique increases the ultimate load capacity from 49 kN for B7 to 69 kN for beam B9. While using the ordinary concrete mix as a repairing layer increases the ultimate load capacity from 49 kN for B7 to 54 kN for Beam B8. The figure also shows that using a slag concrete layer as a repairing layer increases the ultimate load capacity from 58 kN for beam B1 to 69 kN for beam B9.

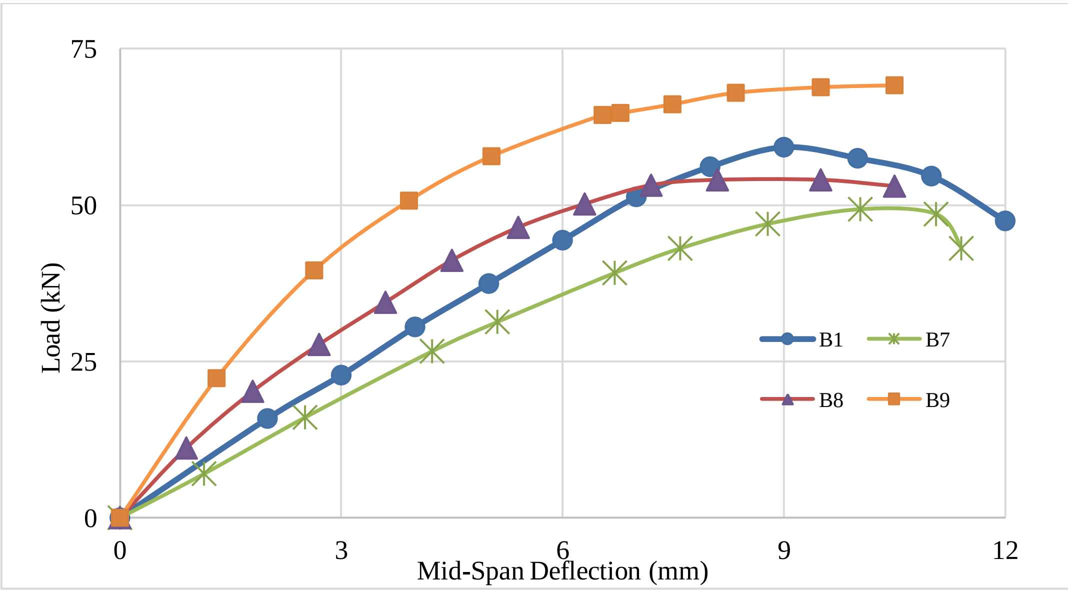


Fig. 8 load deflection curve for the using slag as repaired layer

3.2 Ultimate Load, 1st cracking, ultimate deflection, and toughness.

The experimental results of the test specimens such that ultimate loads, 1st cracking loads, ultimate deflection, initial stiffness, and toughness are listed in Table 8. It's clear that the ultimate load capacity increases by 110.2% and 140.8 % for beams B8, B9 respectively with comparing to reference beam B7. The results indicate that by comparing the reference beam (B1) to the method of repair by using slag layer (B9) or ordinary concrete layer (B8) there is increasing in the ultimate load capacity by 118.9% when using slag concrete, while there is decreasing in the ultimate load capacity by 6.9% when using ordinary concrete layer. The results indicate that the 1st cracking load capacity increases by 131.03%, 172.4% for beams B8, B9, respectively with comparing to reference beam B7. The results indicate that by comparing the reference beam (B1) to the methods of repair by using slag layer (B9) or ordinary concrete layer (B8) there is increasing in the 1st cracking load by 121.9% when using slag concrete, while there is decreasing in the ultimate load capacity by 7.3% when using ordinary concrete layer. The results show that the values of the ultimate deflection of all beams nearest the same, except in the case of using an ordinary concrete layer as a repair technique. Comparing flexural toughness or energy absorption values for a beam with different methods of repair (B8, B9) to reference beam (B7) was 150.4% and 123.9%respectively. Otherwise Comparing flexural toughness values for the beam with a different methods of repair (B8 and B9) to reference beam (B1) were 115.5% and 95.2%respectively.

Table 8 : Summary of test results of group 2.

Specimens	Ultimate Load Pu (kN)	1 st cracking Load (kN)	Ultimate Deflection δu (mm)	Initial stiffness (kN/mm)	toughness (kN.mm)
B1	58	41	10.00	6.93	461.24
B7	49	29	9.50	6.07	354.34
B8	54	38	8.00	11.22	439.29
B9	69	50	10.50	15.73	533.02

3.3 Cracking Pattern and Mode of Failure

Fig. 9 shows the cracking patterns of the test specimens after the completion of the test. It can be observed that all the test specimens failed in flexural failure mode. The first crack occurs in the constant flexure region. It, in general, occurs in the middle span of the beams and it is a flexure crack (vertical cracks). Cracking increases with increasing the loads and have appeared on the tension side of the beam, accompanied by vertical cracks in other regions of the beams. Spalling of concrete was seen on the surface of the beam and increased gradually until the load approached almost its ultimate value.

Fig. 9 Crack pattern for the tested beams

IV. Conclusions

This study investigated experimentally, first the concrete mechanical properties by using slag in the concrete mix as aggregates instead of natural aggregate. Second the behavior of simply supported beams by using slag concrete mix either as a part of cross-section or as strengthening layer in the tension zone. Based on the presented results, the following conclusions are obtained:

1. The replacement of natural aggregates by slag increased the compressive strength, tensile strength, and flexural strength.
2. Using slag concrete mix (SC mix) in casting a simply supported beam increase the ultimate capacity, 1st crack load, initial stiffness, and toughness with comparing to a reference beam with conventional concrete.
3. Using a SC mix in casting two-third or half or third of cross-section of simply supported beams decreases the ultimate capacity, 1st crack load, initial stiffness, and toughness with comparing to the beam which fully cast by SC mix. Otherwise the beams still more efficient than the reference beam
4. Strengthening simply supported beam by SC mix layer increase the ultimate loads, 1st cracking loads, ultimate deflection, initial stiffness, and toughness with comparing to reference infected beam (B7), as well as the reference beam B1 which cast with OC mix.
5. Strengthening by SC mix layer was more efficient than strengthening the beam by traditional method.

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