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STUDYING THE BEHAVIOR OF COMPOSITE SLAG BEAM UNDER SHEAR STUD CONNECTOR IN TENSION AND COMPRESSION ZONES

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ABSTRACT

Every year, the quantity of slag produced in Jordan from steel making is approximately 500,000 ton. This huge amount of slag caused environmental and disposal problems. To solve these problems, research has been carried out to use part of the slag as base course in road making and as aggregate in concrete mixes.

The present work used composite beam with shear stud connector and replaced the conventional aggregate by slag at 100%, 75%, 50%, 25%, and 0% (limestone) proportions. The experimental results show increase in stress of about 36.7% when replacing all limestone aggregate with slag. This indicates that the slag aggregates enhanced the strength of the structural element in building and reduced the deflection. Similarly, the strain is reduced in the slag composite beam (as compared with that in limestone beams with zero slag). Consequently, improvement in the modulus of elasticity and stiffness of structural elements occurred. It can be concluded that including slag in beams improves their mechanical properties and may at least partly alleviate the environmental problems arising from production of steel. The presence of shear stud welded on the web prevent the slipping between concrete and steel as seen in the testing of specimens.

Keywords: shear stud; steel slag; durability; replacement, Jordan

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1. INTRODUCTION

Shear studs are usually connected to the top flange steel girder of bridges. In this research, a shear stud was attached to the web of composite slag beam and welded to the bottom (tension zone) and top (compression zone) of the web at 25 cm interval for both sides of the web. As noticed in the laboratory, the shear stud shows that there is no slipping between concrete and steel in the composite section when the load is increased on the composite beam.

The present work researches the effect of replacing limestone aggregate with slag on the strength and other properties of composite beams (with shear studs). The cross section of composite slag beam (3000 mm steel length) with 80 mm top and bottom flanges is 160 mm high, thickness of flanges is 7.4 mm, and web 5 mm, and length of the beam is 3000 mm steel.

The shear studs were welded every 25 cm in the bottom tension zone and at the top compression zone on both sides of the web as shown in Figure 1.

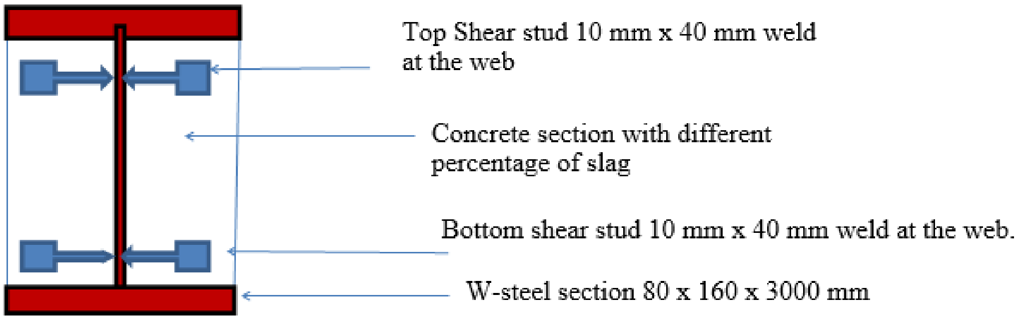

Figure 1 The cross section of the composite slag beam, (length of the beam 3000 mm)

During the testing of the composite beam, shear studs prevented slipping between the steel section and surrounded concrete and enhanced the load carrying capacity of the composite beam and reduced its deflection. Fifteen 150 mm cubes were tested: 3 cubes 0% slag (limestone to be as control mix), 3 cubes 25% slag, 50% slag, 75% slag, and 100% slag. The compressive strength shows significant increase as the percentage of slag increased to reach its maximum 100% slag. Table 1 and Figure 2 show 36.7% stress increase and 13% to 27% deflection decrease between limestone (0% slag) and 100% slag concrete.

Many researchers conducted experimental studies on the use of slag aggregate in road pavements and in concrete aggregate. Manso[1] at el (2006), conducted a comprehensive research on durability of concrete made with Electric arc furnace (EAF) slag as aggregate". EAF slag, a by-product of steel making recovered after the oxidizing process, is useful when employed as aggregate in hydraulic concrete and bituminous mixtures. Concrete made with EAF oxidizing slag as an aggregate shows good physical and mechanical properties and further study of its durability will ensure greater reliability in its usage**.** Tarawneh[2] et al (2014), conducted a study on the effect of using steel slag aggregate on mechanical properties of concrete. This study presents an evaluation of the physical and mechanical properties and characteristics of steel slag aggregate concrete in comparison with the typical crushed limestone aggregate concrete. Hiraskar[3] and Patil (2013), evaluated the use of blast furnace slag aggregate in concrete. Blast Furnace Slag from local industries has been utilized to find its suitability as a coarse aggregate in concrete making. Yildirim[4] and Prezzi (October 2009), investigated the use of steel slag in subgrade applications and found that out of the 10-15 million metric ton of steel slag generated in the U.S.A every year, 50-70% is used as aggregate for road and pavement construction.

2. METHODOLOGY

The author prepared 15 cubes, for investigation of the compressive strength of the composite section,0% (limestone), 25%, 50%,75%, and 100% slag. In addition to that, ten composite beams with cross section 80mm x 160mm x3000mm were tested. Two composite beam with 50% slag and 0% slag(limestone), in this case the stud attached at the bottom zone as shown in Table, Figure 3, Figure 3-a, and Figure 3-b. Two beams with the same dimension 50% slag, top and bottom stud were attached to the web as in Table 4, Figure 4. Another two beams 25% slag with top and bottom stud as in Table 5. Moreover two beams 75% and 100% slag with top and bottom stud as in Table 6. Finally, two beams 50% slag and 0% slag(limestone) with top and bottom stud as shown in Table 6.

2.1. Results

Table 1 Comparison between average strength (kN/cm2) verses Different percentage of Slag Aggregate.

Type of Aggregate	%of Aggregate in the Mix	Cube 1 Load kN	Cube 2	Cube 3	Average Strength kN/cm2	Stress MPa	Average Load kN
Slag	100	1002	990	1025	4.47	44.69	1005.7
Slag	75	890	910	905	4.01	40.1	901.7
Slag	50	877	860	840	3.82	38.2	859
Slag	25	790	788	799	3.52	35.2	792
Limestone	100 (0 slag)	740	752	721	3.27	32.7	737.7

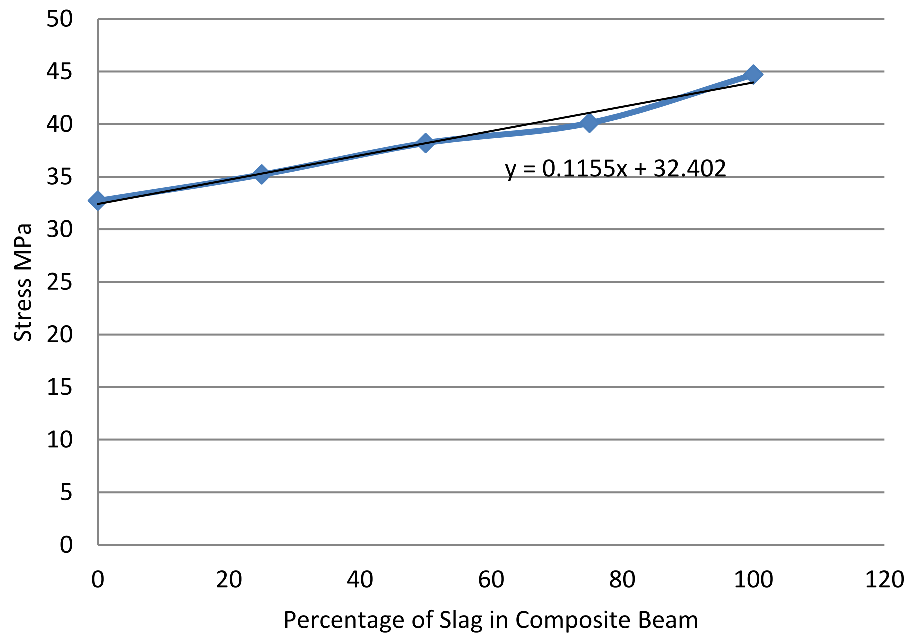

Figure 2 Average Compressive Strength Mpa Versus % of Slag (0% slag= Limestone)

As shown in Table 1 and Figure 2, the strength of slag cubes compares with limestone increase by 7.5%, 17%, 22%, and 36% as the percentage of slag increases from 25%, 50%, 75%, and 100%, respectively. This indicates that the slag contributes highly to the mix design and durability of concrete element, since the slag aggregate is much stronger than limestone.

Table 2 and Figure 3-a show less deflection in 50% slag beam compared to that of the limestone beam. This indicates that beams made using slag aggregate are stiffer than made using limestone aggregate.

Table 2 Tension, compression strains and deflection for 50% Slag versus limestone.

	Bottom shear stud for 50% Slag			Bottom shear stud for limestone			
Load kN	Tension Strain (bottom fiber)	Compression Strain (top fiber)	Deflection mm	Load kN	Tension Strain (bottom fiber)	Compression Strain (top fiber)	Deflection mm
0	0	0	0	0	0	0	0
10	0.0002	-0.00018	2.31	10	0.0002	-0.00103	4.56
25	0.0005	-0.00043	6.86	25	0.00052	-0.00132	9.32
50	0.001	-0.00093	12.44	50	0.00123	-0.00189	15.86
60	0.0013	-0.00128	14.91	60	0.00166	-0.00229	18.3
67.5	0.0021	-0.00204	22.76	66	0.00292	-0.00282	25.25
68.5	0.0025	-0.00344	30.31	67	0.0032	-0.00359	30.3
71.5	0.003	-0.004	43.38	68.5	0.00359	-0.00457	36.2

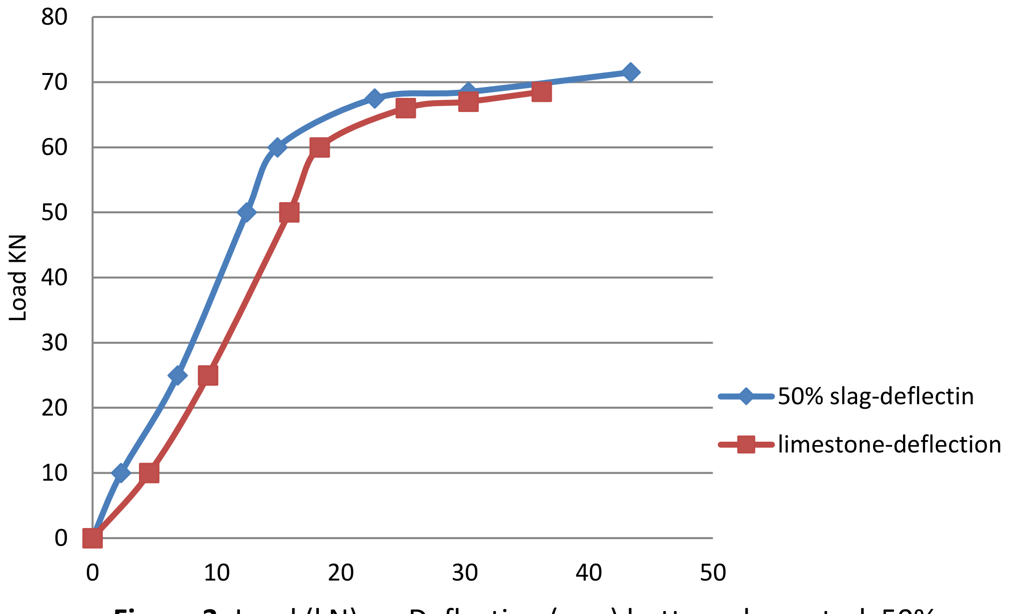

Figure 3: Load (kN) vs. Deflection (mm) bottom shear stud, 50% slag.

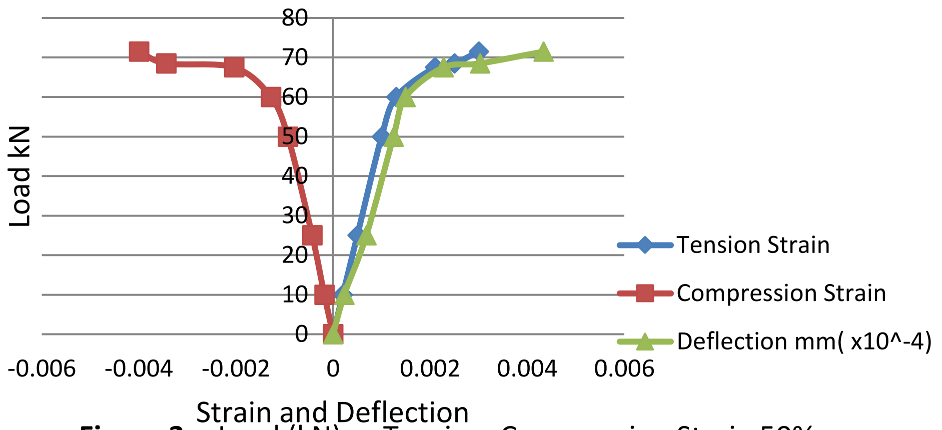

Figure 3-a Load (kN) vs Tension ,Compression Strain 50% Slag

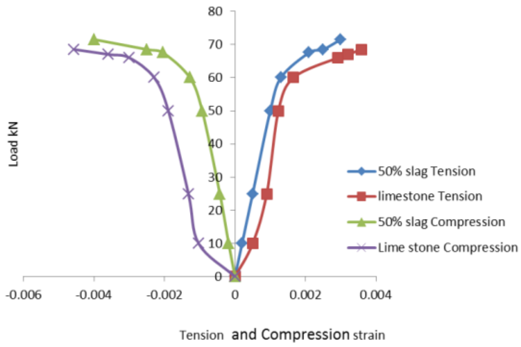

Figure 3-b:Tension, Compression Strain for 50% Slag and Limestone Vs. Load (kN).

Figure 2-b shows that increasing the load resulted in increasing the strain for both limestone and 50% slag increase. But, the increment in compression strain for 50% slag is approximately twice that of limestone. However, the tension strain for 50% slag is about 1.5 times that of limestone. This result reflects stiffness increase and finally enhancement of modulus of elasticity.

From Table 3 and Figure 4, when the shear stud at the top and bottom and the slag is 50%. The deflection was less when the stud at the bottom than that at the top of about 14%.The tension stress decrease by average of 30% if load increase from 10kN-70kN. For the compression strain, if the load increase from 10, 25,50,60,67, and 71kN. This result indicates that putting the stud at the bottom (of two faces) of the web is more effective than that at the top location.

Table 3 Top and bottom shear stud 50% slag.

Top Stud Connector 50% Slag				Bottom shear stud for 50% Slag			
Load	Tension	Compression	Deflection	Load kN	Tension Strain (bottom fiber)	Compression	Deflection
kN							mm
0	0	0	0	0	0	0	0
10	2.96	-1.92	2.4	10	2	-1.8	2.31
25	5.76	-6	6	25	5	-4.3	4.86
50	10.56	-9.84	12.25	50	10	-8.3	9.44

Top Stud Connector 50% Slag				Bottom shear stud for 50% Slag			
60	21.68	-17.36	16.45	60	13	-12.8	13.91
65	27.5	-33.84	21.75	67.5	21	-20.4	22.76
67.5	52.2	-43.2	26.15	68.5	25	-34.4	30.31
68.5	61.3	-52.4	33.5	71.5	30	-40	43.38
69.5	66.9	-60	35.9				
71.8	72.6	-68	39.6				

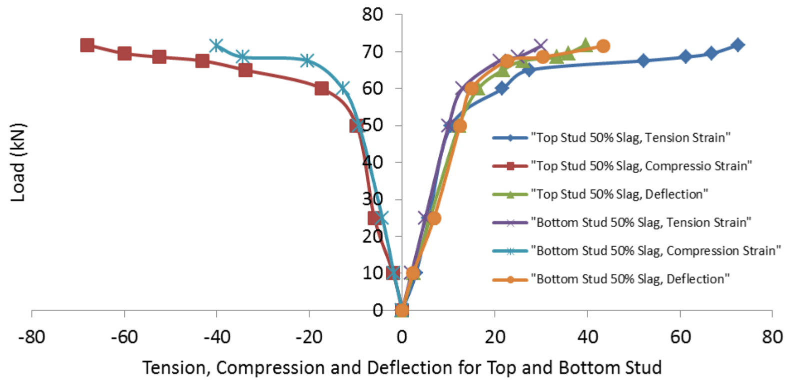

Figure 4: Top and Bottom Stud with Tension and Compression strain

When percentage of slag is 25%, and 50% as shown in Table 4 with shear stud at the top deflection, tension and compression strains were less for 50% slag than that of 25%.

Table 4 25% and 50% Slag versus tension and compression (strains) and deflection.

Top Stud Connector 25% Slag				Top Stud Connector 50% Slag			
Load kN	Tension Strain	Compression Strain	Deflection x0.01mm	Load kN	Tension	Compression	Deflection
0	0	0	0	0	0	0	0
10	0.0003	-0.00024	2.23	10	0.000296	-0.000192	2.4
25	0.0006	-0.00066	6.23	25	0.000576	-0.0006	6.0
50	0.00142	-0.00108	12.98	50	0.001056	-0.000984	12.25
60	0.00235	-0.00185	17.23	60	0.002168	-0.001736	16.45
66	0.00302	-0.00344	24.83	65	0.00275	-0.003384	21.75
67.5	0.0056	-0.00443	29.83	67.5	0.00522	-0.00432	26.15
69	0.007	-0.0051	46.31	68.5	0.00613	-0.00524	33.5
				69.5	0.00669	-0.0060	35.9
				71.8	0.00726	-0.0068	39.6

Table 5 shows that when the slag is at 75%, and 100% and the shear stud is at the top, the deflection decreases at 100% slag more than that at 75%slag, even though, the tension strain increases as the load increases. However, the strain in compression decreasing, while the load increasing. Table 5 shows that tensile strain increases as the load increases while the compression strain decreases as the load increase. It was noticed that the tension strain for 75% slag is less than that for 100% slag, but the compression strain for 75% slag is greater than that for 100% slag and decreased when increasing the load for 75%, but it decreased at 100% slag when increasing the load.

Table 5 75%, 100% Slag versus tension, compression strains and deflection.

Top Stud Connector 75% Slag				Top Stud Connector 100% Slag			
Load kN	Tension Strain	Compression Strain	Deflection X 0.01mm	Load kN	Tension Strain	Compression Strain	Deflection X 0.01mm
0	625	1140	1642	0	819	845	1546
10	657	1121	1752	10	840	778	1640
25	689	1080	2100	25	878	746	1965
50	741	1035	2747	50	952	680	2570
60	880	940	3140	62	1020	636	3057
65	951	769	3780	68	1115	554	3580
67.5	1250	653	4510	70	1210	460	4033
68.5	1370	545	5267	72	1300	365	
70.5	1430	431	6017	75.5	1470	241	
72.5	1509	391	6745				

As shown in Table 6, when the stud is at the top and bottom of the web 50% slag compares with limestone. The deflection decreases from 6%-20% compared to 50% slag with limestone at the same location of the stud at the top and bottom, while the compression and tension strains remain mostly close to each other.

Table 6 Bottom and top stud for 0% -50% slags.

Bottom and Top Studs 50% Slag				Bottom and Top Studs Limestone			
Load kN	Tension Strain gage (bottom fiber) $x0.8x10^{-5}$	Compression Strain (top fiber) $x0.8x10^{-5}$	Deflection x0.01mm	Load kN	Tension Strain (bottom fiber) $x0.8x10^{-5}$	Compression Strain (top fiber) $x0.8x10^{-5}$	Deflection x0.01mm
0	790	824	1294	0	807	830	1389
10	898	807	1525	10	844	810	1622
25	843	687	1871	25	875	778	2010
50	954	657	2419	50	949	726	2715
60	1182	647	2845	60	1003	706	3395
65	1218	621	4018	67	1270	640	3880
69	1248	591	4329	69	1420	588	4510
73	1285	552	5217	70	1612	522	4880

3. DISCUSSION OF THE RESULTS

The shear studs which were attached to the web of the composite slag beam show that there was no slipping occurred throughout the gradually loading between slag concrete and steel section. This new idea enhanced the load carrying capacity of the composite slag beam. The compressive strength increased by 36%, when the percentage of slag changed from 0% (limestone) to 100%. This significant result strongly indicates the need of using slag in the concrete mix. The average deflection decreased by 18% as the percentage of slag increased from 0% to 50% of the mix. For the same ratio of slag, the strain decreased by 23% in the tension zone and 60% in the compressive zone. The strain results show that the higher the percentage of slag in the composite beam the higher the stiffness of composite beam in tension and compression zones. However, the average deflection decreases by 12% at 50% slag content compared with 0% slag (limestone) when the shear stud is attached only to tension zone (the bottom part of the composite beam section). It will reduce the strain in tension and compression zones.

4. CONCLUSION

Regarding deflection and strain, the study shows a significance of using stud in tension zone rather than compression zone. The use of slag up to 50%, increase the strength of concrete, increase modulus of elasticity, and increases the stiffness of the composite slag beam and decreases the deflection and strain.

The author highly recommends further studies on composite column slag and location of stud.

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