Use of steel slag in concrete mixtures

Nasser Al-Nuaimi, Ramzi Taha, Abdulazeez Kilayil, and Abdelhamid Ben Salem
Qatar University, Department of Civil and Architectural Engineering, Doha, Qatar
E-mail: anasser@qu.edu.qa

Abstract. The recent unprecedented growth in the building industry in the State of Qatar has created a pressing demand for construction materials. Needs for concrete, being the major construction material has grown with the rapidly growing construction sector. Aggregate generally occupy about 70-80% of the volume of concrete used in buildings. The needs for alternative sources of aggregates are pressing. Steel slag, which is a by-product of steel manufacturing, could be an alternative solution.

This paper presents the results from experimental works completed at Qatar University to check the applicability of using steel slag aggregates in concrete mixes in Qatar. Five trial concrete mixes were prepared. One concrete mix composing of 100% gabbro coarse aggregates was designated as the control mix. Four other concrete mixes were prepared and they contained 100%, 75%, 50%, and 25% partial replacement of gabbro aggregates with slag aggregates, by weight. The concrete mix was proportioned to have a 28-day compressive strength of 35 MPa. The water-to-cement ratio was kept constant at 0.58 for all of the five mixes. All mixtures were cured for 7, 28, and 90 days. No admixtures or additives were used in these mixes. The data indicate that steel slag has a promising potential to be used as a partial replacement for conventional aggregates in concrete.

The emphasis of the work in the initial phase of this study was on the feasibility of utilizing steel slag aggregates in concrete, as a total or partial replacement of gabbro aggregate, used in construction in the State of Qatar by studying the properties of fresh and hardened concrete. Tests were conducted on concrete samples made of different aggregates to determine their acceptability for use in concrete. The different mixes were tested to determine compressive strength, splitting tensile strength, flexural strength, air content, and bulk density. Laboratory results, obtained in the six months research project, indicated that steel slag alone or in combination with other virgin raw materials such as gabbro, sand, and others could find uses in road construction applications in the State of Qatar.

1- Introduction:

Steel slag which is a by-product of steel manufacturing is generated in large quantities in Qatar. It is estimated that more than 400,000 tons of steel slag are generated annually in the country. There will be a great demand for aggregates and other construction materials over the next ten years as a result of infrastructural renewal in Qatar. Utilizing the steel slag in concrete mixes could find beneficial uses in Qatar construction sector.

Several research studies [1, 2, 3, 4] were conducted on the use of steel slag aggregates in concrete. Control mixtures were prepared using natural aggregates such as limestone and crushed gravel. Trial concrete mixes were also cast using different percentages of steel slag aggregates as substitutes for coarse natural aggregates. Fresh and hardened concrete were subjected to mechanical and durability tests. All laboratory results indicate that concrete prepared using steel slag aggregates produced equal or better performance than that of concrete cast using coarse natural aggregates. However, there were no serious attempts to investigate the performance of fresh steel slag aggregate against aged aggregates in concrete. Also, data regarding long-term concrete performance are limited and inconclusive, especially concerning the expansive characteristic of steel slag aggregate. Much research work remains to be done in this regard.

Mechanical properties for each mix such as: slump, unit weight and air content were determined for the fresh concrete. In addition, specimen of 150 mm x 300 mm cylinders and 200 mm x 800 mm beams were cast for later testing in accordance with ASTM C39, ASTM C496 and ASTM C78, respectively in order to determine the compressive strength, splitting tensile strength, and flexural strength of concrete at curing periods of 7, 28, and 90 days. Three specimens for each required test were cast and immersed after 24 hours in water, until the time of test inside the laboratory at room temperature.

2- Materials' Collection and Mix Proportioning

2.1- Cement

Cement used in this study was Ordinary Portland Cement (OPC) produced by Qatar National Cement Company (QNCC). To minimize the storage time and other problems of bagged cement storage at the distribution sale market point, the cement was directly purchased from the QNCC through a special request. This brand of cement is the most widely available and used by the construction industry in the State of Qatar, as QNCC is the largest cement producer in Qatar.

2.2- Sand

Fine sand used in the study was washed sand known in Qatar as government wash sand, which was brought from the government sand washing plant. This sand was used in all concrete mixes prepared in this study. The sand was tested in accordance with ASTM C33 to meet the specifications requirements of concrete mixtures. Sieve analysis results for the sand are shown in Figure 1 along with the upper and lower ASTM limits for each sieve size.

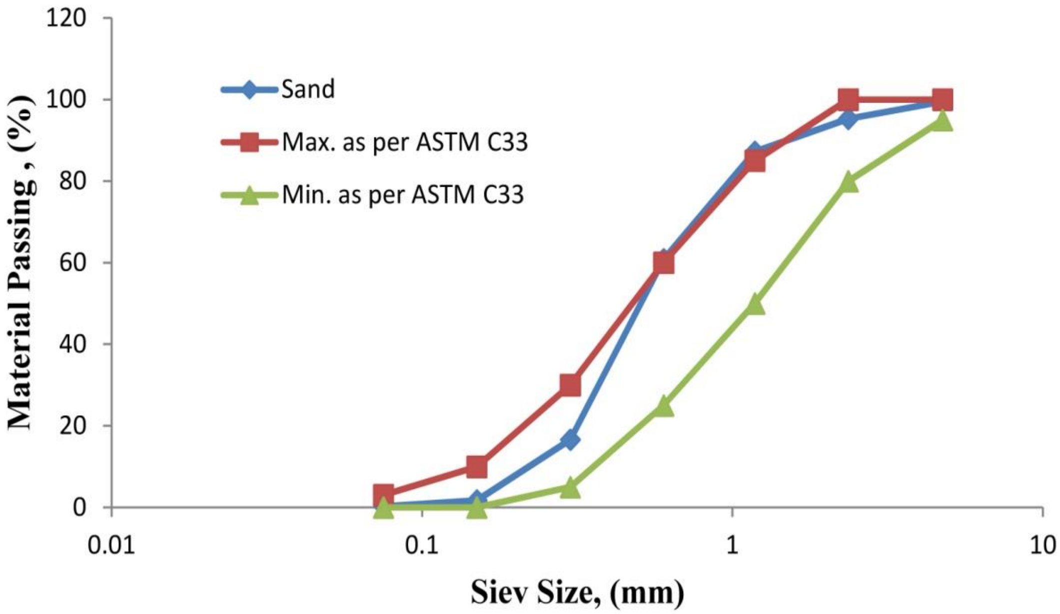

Figure 1 Sieve Analysis Envelope for Normal Concrete Sand.

2.3- Aggregates

The coarse aggregates used in this study were gabbro and steel slag were delivered in bags of approximately half cubic meter at different particle sizes. Five bags for each of the three materials, in five different particle size ranges of 0-2 mm, 2-5 mm, 5-10 mm, 10-15 mm, and 15-23 mm, were received at our laboratory.

2.4- Gabbro

Gabbro is an aggregate type used by the construction industry in Qatar to replace the local limestone aggregate. These crushed dark stone particles are not produced in Qatar and they are barged mainly from the United Arab Emirates and the Sultanate of Oman in the form of coarse aggregates. This resulted in a surge in the cost of concrete products.

2.5- Steel Slag

Steel slag aggregates are of an angular shape, with a rough surface and have a high bulk specific gravity in comparison with gabbro.

The five container bag aggregate received in five different particle sizes, ranging from 0-2 mm to 15-23 mm. In order to satisfy ASTM C33 standard, sampling of these materials was conducted to meet specification requirements. Sample blending was done for three different sample sizes of 10, 20 and 40 kg. The blended aggregates were then tested in accordance with ASTM C33 to meet the specifications requirements for a concrete mix. Sieve analysis results for these three blends are shown in Figure 2 along with the upper and lower ASTM limits for each sieve size. Note that the three lines are plotted on top of each another.

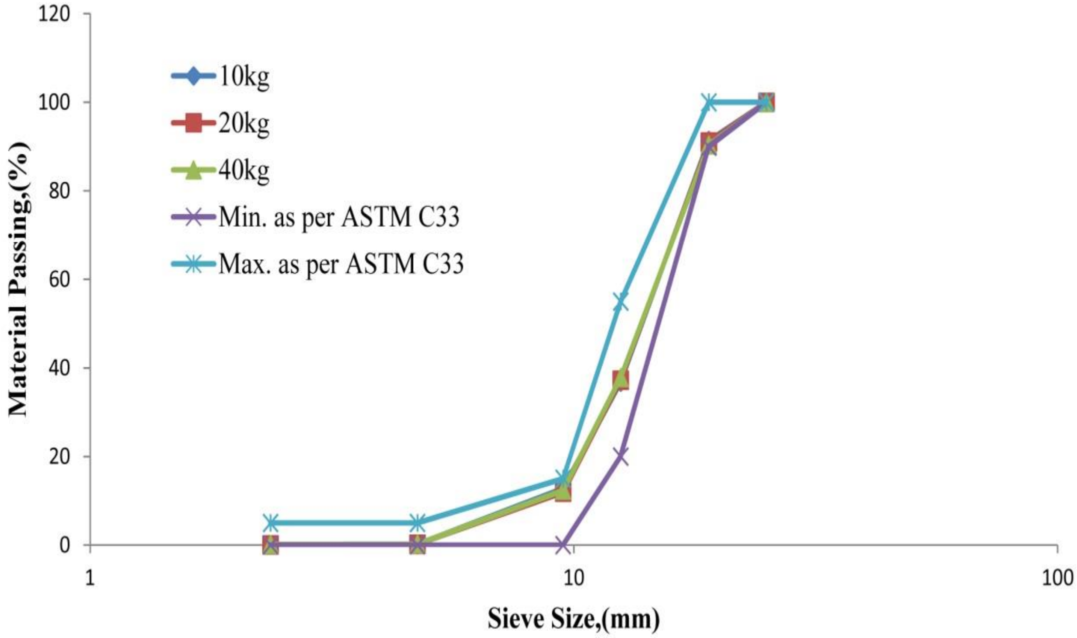

Figure 2 Sieve Analysis Envelope for Aggregate Size Blend.

3- Concrete Mixture Design

Five trial concrete mixes were prepared in the Civil Engineering Laboratories. One concrete mix that contained 100% gabbro coarse aggregate was kept as the control mix (G 20-100). Four concrete mixes containing 100%, 75%, 50%, and 25% as partial replacement of gabbro aggregate with slag aggregate, by weight were designated as S 20-100, S 20-75, S 20-50 and S 20-25, respectively.

The concrete mix design was proportioned to have a 28-day compressive strength of 35 MPa. The water-to-cement ratio (w/c of 0.58) was kept constant for all of the five mixes. No admixture or any additives were used in these mixes. Details of the concrete mixture proportions of all mixes are given in Table 1.

Table Error! No text of specified style in document.**1 Concrete Mixture and Test Data for Fresh Concrete with Steel Slag.**

	Concrete Mix				
	G20-100	S20-100	S20-75	S20-50	S20-25
Specified design strength(MPa)	35	35	35	35	35
Cement (kg)	347.77	347.77	347.77	347.77	347.77
Water (kg)	201	201	201	201	201
Sand (kg)	709	709	709	709	709
20mm Course aggregate(Gabbro)	1076	0	269	538	807
20mm Course aggregate(Slag)	0	1076	807	538	269
Slump (mm)	80	70	70	80	80
Air content (%)	0.90	1.20	1.40	1.20	1.30
Fresh concrete density (kg/m^3)	2508.75	2705.29	2600.23	2578.40	2519.72
Hardened concrete bulk density(kg/m^3)	2428.97	2600.15	2552.23	2512.60	2465.50

4- Concrete Samples' Preparation

At the start, trial mixes were prepared. The ingredients (coarse aggregates, sand, cement, and water) were blended using an electric tilting-drum-type mixer having a 0.2 m3 mixing capacity. For each mix, slump, unit weight and air content were determined for the fresh concrete; 150 mm x 300 mm cylinders and 200 mm x 800 mm beams were cast for later testing in accordance with ASTM C39, ASTM C496 and ASTM C78, respectively in order to determine the compressive strength, splitting tensile strength, and flexural strength of concrete at curing periods of 7, 28, and 90 days. Three specimens for each required test were cast and immersed after 24 hours in water, until the time of test inside the laboratory at room temperature.

Figure Error! No text of specified style in document.**3 Portion of Specimens during Mixing, Casting, and Curing Period.**

A total of 135 concrete specimens were cast for the trial mixes; 90 cylindrical specimens (150 mm x 300 mm) and 45 beams (200 mm x 800 mm) were cast for the five trial mixes and the designated tests. Figure 3 shows photos of the electric mixer used in preparation and proportioning of specimens during their casting and curing in the water tank.

5- Test Results

The fresh concrete data showed that the control mix which contained 100% gabbro aggregates (G 20-100) had a slump of 80 mm at the same water-to-cement ratio of 0.58. Slump for the steel slag concrete mix with 100% slag aggregate (S 20-100), was 70 mm. Concrete mixes showed an increase in slump with an increase in gabbro aggregate content used in the mixes, and slump eventually increased to the controlled mix slump value of 80 mm.

The unit weight of fresh concrete made of 100% steel slag aggregates (S 20-100) recorded the highest value of all mixes at a 2,705 kg/m3. The control mix which contained 100% gabbro aggregates (G 20-100) had a unit weight of 2,508 kg/m3. The unit weight decreases with an increase in the percentage of gabbro aggregate used in mixes containing steel slag aggregates.

Hardened concrete specimens were crushed in the laboratory at the designated curing periods depending on the mixing dates of the specimens. Results obtained from specific test are discussed in details later. After the completion of each test, samples were stored temporarily in the laboratory for later verification of failure mode and test reliability. Figure 4 shows photos of the crushed concrete samples.

Figure Error! No text of specified style in document.**4 Photos of Crushed Concrete Samples from Various Tests.**

5.1- Compressive strength

Compressive strength of different concrete mix after 7 and 28 days of curing are presented in Table 2 for steel slag concrete mixes, respectively. The test data indicate that all the five mixes had average 28-day compressive strengths greater than 35 MPa. The compressive strength was found to increase with age for all concrete mixes.

The compressive strength of concrete containing steel slag aggregates increased with an increase in percentage of slag aggregates in the mix. The compressive strength reached a maximum value of 43.88 MPa with 100% steel slag aggregate (S 20-100) and a minimum value of 38.62 MPa for the mix with 25% steel slag aggregate (S 20-25). This value of 43.88 MPa for the 100% steel slag aggregate mix indicates an increase of 11% gain in compressive strength compared to the compressive strength for the control mix (0% slag). The concrete mix with the minimum steel slag aggregate of 25% (S 20-25) gave an average compressive strength of 38.6 MPa, which is within the 1% of the control mix. Figure 5 shows the relationship in comparison with the control mix at 28-day curing. The data indicate that there is a clear indication of better performance of steel slag aggregate concrete mixes over the control mix in-terms of compressive strength.

Table 2 Compressive Strength Data for Concrete Made With Steel Slag.

Test age (days)	Compressive strength (150 mm x 300 mm cylinder)									
	G20-100		S20-100		S20-75		S20-50		S20-25	
	Actual (MPa)	Average (MPa)	Actual (MPa)	Average (MPa)	Actual (MPa)	Average (MPa)	Actual (MPa)	Average (MPa)	Actual (MPa)	Average (MPa)
7	24.2*		23.76*		35.15		31.39		30.32	
7	18.8*	**21.85**	22.83*	**22.47**	33.55	**34.56**	30.48	**31.07**	29.51	**30.05**
7	22.6*		20.83*		34.98		31.34		30.32	
28	36.95		44.23		43.19		41.14		38.62	
28	40.62	**39.19**	43.68	**43.88**	42.5742.	**42.86**	38.44	**39.25**	38.74	**38.62**
28	40.19		43.74		87		38.17		38.51	

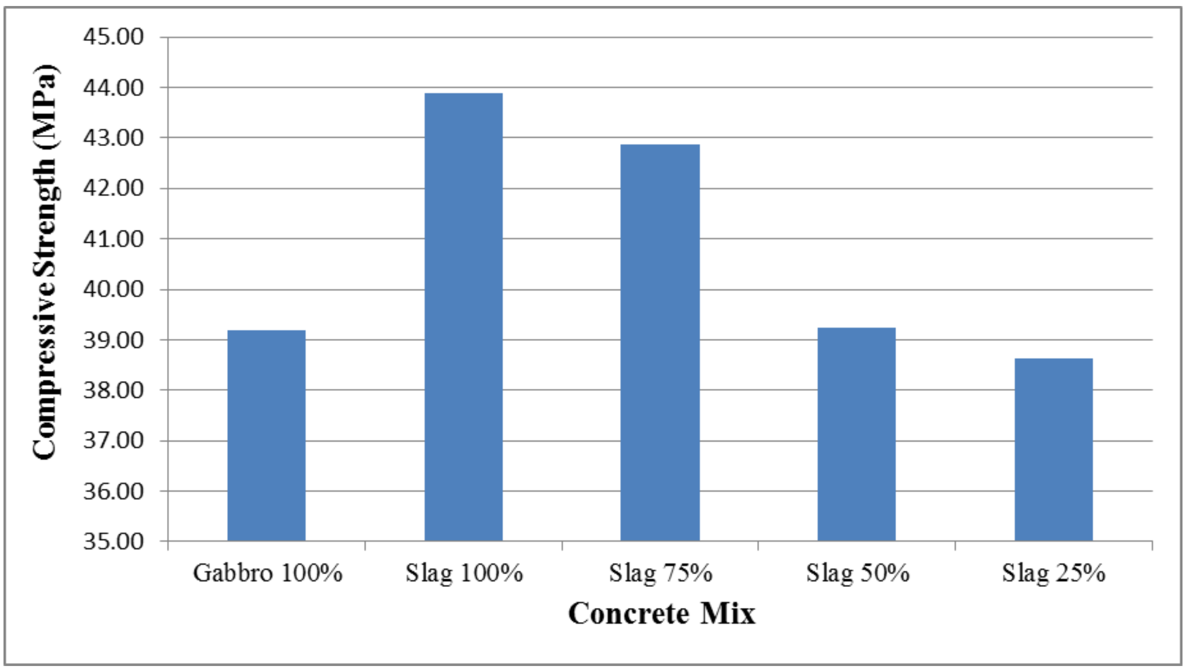

Figure 5 28–Day Compressive Strength for Different Slag-Concrete Mixes.

5.2- Splitting Tensile Strength

The splitting tensile strength for all mixes are shown in Table 3 for concrete made with steel slag. The 28-day splitting tensile strengths are depicted graphically in Figure 6 for steel slag. The data indicate an increase in the tensile strength with age for all mixes.

Concrete mixes with slag aggregates showed a range increase from 11% for 100% steel slag to a 1% for 25% slag in comparison with the control mix at the 28-day age. These percent increases in the tensile strength are in agreement with the results obtained from the compressive strength tests.

Table 3 Splitting Tensile Strength Data for Hardened Concrete Made With Slag.

Test age (days)	Splitting Tensile Strength (150mm x 300mm cylinder)									
	G20-100		S20-100		S20-75		S20-50		S20-25	
	Actual (MPa)	Average (MPa)	Actual (MPa)	Average (MPa)	Actual (MPa)	Average (MPa)	Actual (MPa)	Average (MPa)	Actual (MPa)	Average (MPa)
7 7 7	2.686 3.087 2.875	2.882	3.067 3.064 2.843	2.991	3.120 3.329 2.876	3.108	2.740 2.950 3.000	2.897	2.777 2.929 3.059	2.922
28 28 28	3.265 3.359 3.600	3.408	3.798 3.579 4.011	3.796	3.783 3.016 3.291	3.363	3.745 2.781* 3.625	3.625	3.182 3.404 3.786	3.457

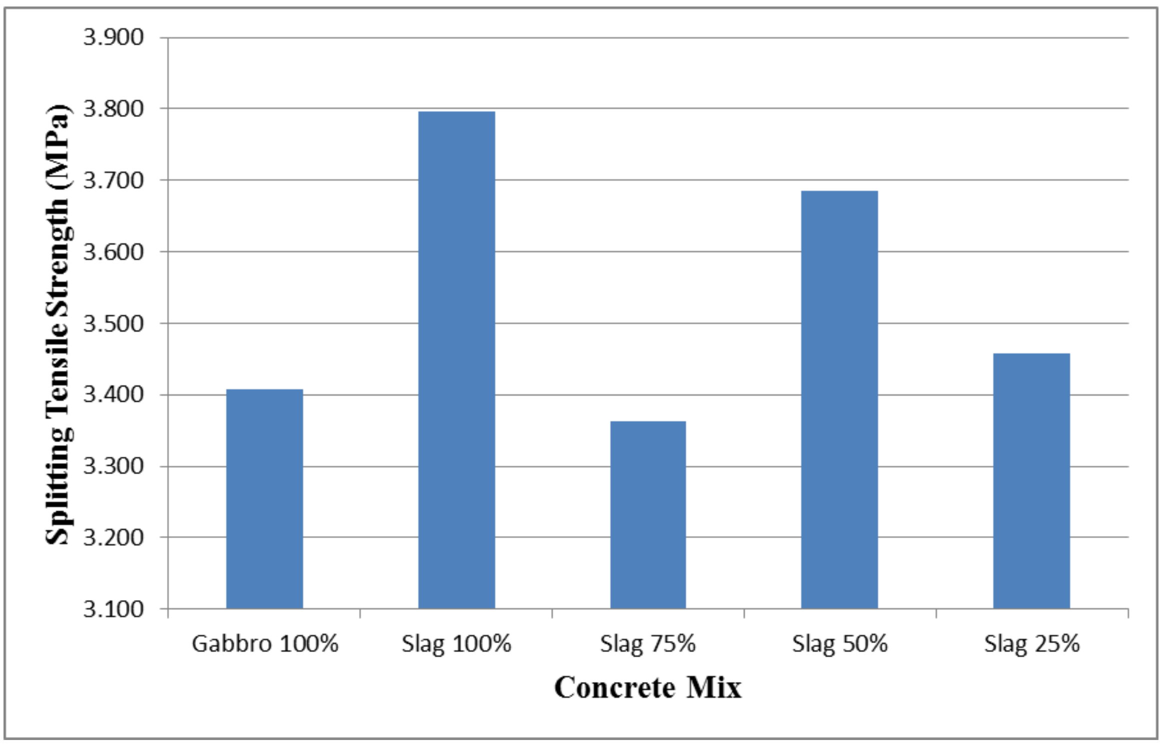

Figure Error! No text of specified style in document. **28–Day Splitting Tensile Strength for Different Slag-Concrete Mixes.**

5.3- Flexural Strength

The flexural strength test results are presented in Table 4. The data showed an increase in the flexural strength with age for all mixes. It was observed from the test results that the flexural strengths for the concrete mixes (S 20-100) surpass that of the control mix (G 20-100) at the 28-day curing period. The 28-day flexural strength results for slag concrete mixes are depicted in Figure 7.

Mixes containing steel slag aggregates showed respective increases of 12.8% and 12.6% in the flexural strengths for concrete containing 100% and 75% steel slag in comparison with the control mix. The other two mixes prepared using 50% and 25% steel slag came within the 1% range.

Table 4 Flexural Data for Hardened Concrete Made With Steel Slag.

Test age (days)	Flexural Strength									
	G20-100		S20-100		S20-75		S20-50		S20-25	
	Actual (MPa)	Average (Mpa)	Actual (MPa)	Average (Mpa)	Actual (MPa)	Average (Mpa)	Actual (MPa)	Average (Mpa)	Actual (MPa)	Average (Mpa)
7 7 7	3.357 3.935 5.108	4.133	4.411 4.698 4.530	4.546	4.487 4.415 4.005	4.302	3.875 4.149 4.191	4.072	3.631 3.657 3.755	3.681
28 28 28	4.560 4.387 4.808	4.585	5.300 4.969 5.257	5.175	4.685 5.769 5.036	5.163	4.903 4.330 4.317	4.517	4.650 3.518 5.313	4.494

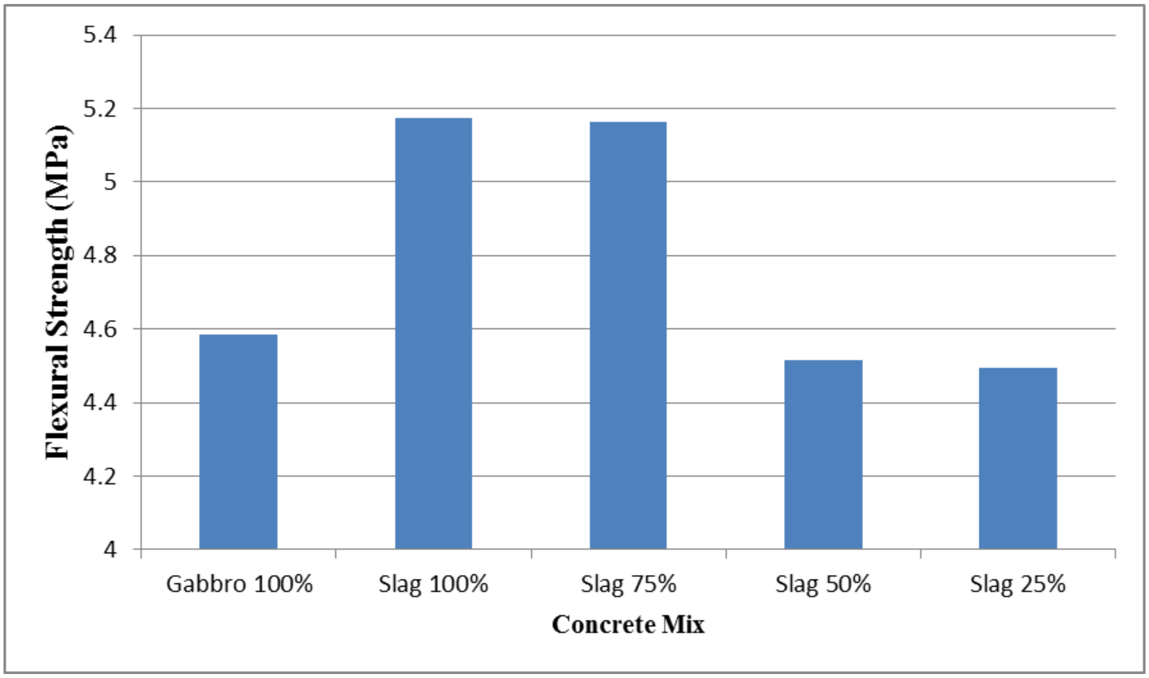

Figure 7 28-Day Flextural Strength for Different Slag-Concrete Mixes.

6- Conclusion

The 28-day compressive strength, splitting tensile strength and flexural strength data obtained for concrete prepared using 100% steel slag aggregates yielded better results than the control mixture (concrete made with 100% gabbro. All concrete mixtures prepared easily met the 28-day compressive strength design requirement of 35 MPa.

Based on the positive laboratory-based physical and mechanical test results, it is highly recommended to initiate pilot field studies on the use of steel slag for concrete applications, additional work is necessary to establish long-term performance, especially concerning what is reported in the literature about the expansive characteristics of steel slag aggregates when used in concrete.

References

1. Maselehuddin, M., and N.U. Khan (1999). "Performance of Steel Slag Aggregate Concrete." Exploiting Wastes in Concrete, Proceedings, International Seminar held at University of Dundee, Scotland, UK.

2. Maseluhddin, M., M. Al-Farabi, M. Sharif, M., Shameem, M., Ibrahim and M.S. Barry (2003). "Comparison of Properties of Steel Slag and Crushed Limestone Aggregates Concrete." Construction and Building Materials, 17(2), pp. 105-112.

3. Bosela, P., N. Delatte, R. Obrati and A. Patel (2008). "Fresh and G=Hardened Properties of Paving Concrete with Steel Slag Aggregates." Proceedings, 9th International Conference on Concrete Pavements, San Francisco, California.

4. Patel, J (2008). "Broader Use of Steel Slag Aggregates in Concrete." Master's Thesis, Civil Engineering, Cleveland State University.