EFFECT OF STEEL SLAG ON CONCRETE HAVING VARYING AMOUNT OF CEMENT

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Abstract- Concrete with cement as main ingredient has a high demand in construction industry. Due to its increasing demand, new materials in combination with cement are used for improving its properties. A concrete needs higher paste volume when using cement alone, which may lead to greater heat of hydration with excessive shrinkage and increased cost. It is reported that cement is one of the largest source of CO_2 emission on the planet. Now-a-days serious efforts are being made for finding a suitable substitution of cement. In this research, cement was partially replaced by steel slag (steel slag). Preliminary tests like strength activity index and XRF indicated its chances to use as a partial substitute of OPC. Control specimens with varying cementitious contents of 220kg, 310kg and 400kg were prepared. In modified specimens, cement was replaced by steel slag (30% by mass of cement). The mechanical strengths (compressive, tensile and bending) were examined at 7 and 28 days. The outputs show an increase in strength with steel slag. It is also observed that the strength increment is more pronounced at higher binder content.

Keywords- Concrete, steel furnace slag, cement, sustainability, mechanical strength.

1 Introduction

In the construction industry concrete is being used plenteously. The demand of concrete is increasing with every passing day and so are the expectations from the concrete vis-a-vis its performance. New techniques and materials are being furnished to produce concrete having enhanced properties. In its composition, concrete chiefly consists of cement (binder), sand and coarse aggregate. Despite being the most important material in any concrete mix, the production of cement comes at a very high economic and environmental cost, depleting natural resources on the one hand and polluting the environment on the other. From the extraction and transportation of raw material from quarry site to the factories of cement, all this process involves the release of hazardous gases which are serious threat to our environment [1], [2]. The raw materials used for the cement production are limited. In addition to these, manufacturing cement requires a great amount of energy and labor that is also a serious health hazard. These factors call for finding a binder material that is both economic and eco-friendly, yet does not compromise on the properties that cement brings to the concrete. In this regard, the utilization of steel slag has emerged as a viable replacement for the cement because it reduces the demand of cement and make the otherwise appropriate disposal of this waste much easier without any compromise on the properties of concrete. Different researchers have explored the useful effects of steel slag using different cementitious materials.

Samad et al. investigated the effect of partial substitution of cement by steel slag. They used replacement levels as 30%, 40% and 50%. They have concluded that concrete having 50% substitution of cement with a water to binder ratio of 0.35 gains more strength than ordinary Portland cement [3]. Gholampour et al. utilized high early strength cement in combination with steel slag. They substituted cement in different percentages and found steel slag effective for imparting better workability and absorption. They indicated optimum percentage of steel slag as 50% by mass of cement [4]. El-

Gamal et al. used slag for producing geo-polymer concrete in the presence of alkali activators. They also examined the impact of substituting slag with 5 and 10 percent of waste from clay-bricks. They concluded that 5and 10% brick waste substitution efficiently improves compressive strength, enhances microstructural properties and creates dense geo-polymer structures [5]. Vinai et al. used pulverized fuel ash and steel slag for producing a cement free concrete. They used Na_2SO_3 and NaOH solutions as activator. They investigated the compressive strengths at different ages and found that for the given composition, a water to binder ratio of more than 0.41 results in considerable strength reduction [6]. Nazari et al. focused on the use of steel slag as a partial replacement of cement in concrete. The substitution proportions were kept as 0%. 15%, 30% and 45%. Various hardened properties were evaluated. They found that concrete with slag up to 45% had enhanced properties of absorption and split tensile strength [7]. Dai et al. used et-grinding steel slag as partial replacement of cement in cement pastes. They have highlighted that 10% partial replacement results in the highest compressive strength under constraint conditions [8]. Lai et al. used steel slag aggregates as partial as well as full replacement of natural aggregates in concrete. They found that the slump of the mix decreases due to porous nature of the steel aggregates, however the compressive strength was enhanced. The slag also promoted denser packing, which reduced the chloride permeability in the concrete [9]. Low heat cement is highly desirable in mass concrete. Zhang et al. developed a novel low heat cement by using a combination of steel slag and nano silica. The results revealed that the novel mix met the standard requirements for low-heat cement and there was increase in the early strength as compared to the control specimens [10].

Pakistan has a vast steel industry, producing thousands of tons of waste, which is dumped in land spaces. There is need to convert this waste to wealth in accordance with the Sustainable Development Goals (SDGs). In this Research the main objective was to study the likelihood/feasibility of making good quality concrete by partially replacing varying amounts of cement with local steel slag, which is otherwise an important environmental burden. The control specimens with different cementitious contents of 220kg, 310kg and 400kg were prepared along with the specimens with 30% replacement of cement by steel slag. Different mechanical parameters evaluation techniques were performed and the results of control and modified specimen were compared.

2 Materials and Methods

The cylindrical samples were prepared for evaluation of compressive and split tensile strength, whereas, beams were prepared for flexural strength test. Specimens were casted by replacing cement with 30% of steel slag and then results were compared with the set of controlled specimens. The cement content taken in this study relates to the minimum required cement content for conventional concrete mixes of 1:1.5:3, 1:2:4, 1:4:8 [11]. The research methodology is described in the flow chart given in Figure 1.

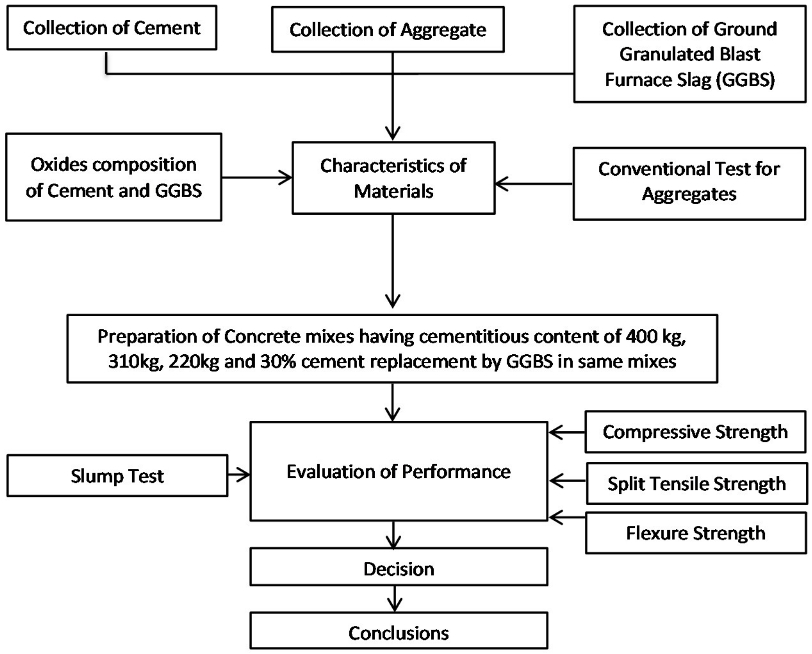


Figure 1. Research methodology

2.1 Raw materials.

The Ordinary Portland Cement (53 Grade) Type-I conforming ASTM C-150 is used in this research program [12]. Table 1 presents the oxides composition of the cement. Table 2 shows the physical characteristics of the cement. Lawrencepur sand and Margalla crush were applied as fine and coarse aggregates fractions. Their physical and mechanical properties are well-documented [1].

Table 1 Chemical composition of cement and steel slag (%)

Sr. No.	Oxides	Cement	steel slag
1.	CaO	64.19	40.04
2.	SiO_2	21.45	34.88
3.	Al_2O_3	5.20	12.04
4.	Fe_2O_3	3.25	1.16
5.	SO_3	2.70	0.59
6.	MgO	1.90	7.14
7.	K_2O	1.0	0.544
8.	L.O.I	1.88	0.53
9.	Na_2O	0.25	0.121

Table 2 Physical and mechanical properties of cement and steel slag

Sr. No.	Tests	Cement	steel slag
1	Compressive Strength (28 days)	63.84 MPa	-
2	Initial Setting Time	90 min	-

	Final Setting Time	247 min	-
3	Specific Surface Area	322 m^2/kg	587 m^2/kg
4	Specific Gravity	3.15	2.89
5	Soundness	1.00 mm	-
6	Passing	>90% (sieve #200)	>85% (sieve #325)

The pozzolanic activity of the steel slag was confirmed through strength activity index in accordance with the ASTM C618 [13]. The strength activity indices are mentioned in Table 3.

Table 3 Strength activity index

Sr No.	Tests	Result	Recommended
1	7 Days (Percentage of Control)	102.6 %	95%
2	28 Days (Percentage of Control)	118.3 %	115%

The chemical admixture (water reducer and super plasticizer) used was based on polycarboxylate ether at 1.2% by mass of cement in each mix designs [14]. It has a specific gravity of 1.180.

2.2 *Casting of specimens.*

The concrete mix design is shown in Table 4. For each test, a set of three samples was casted. Four sets of cylinders of control specimens for each mix design, while other four sets comprise of samples with 30% cement by mass replaced by steel slag. For performing flexural test, a set of three beams were casted. Two sets of beams for control and modified samples were prepared. Overall 72 cylindrical specimens and 36 beams were casted for this research. The casting and curing procedure was in accordance to ASTM C31 [15].

Table 4 Mix designs

	Quantity per m^3						
Designation	**Cement (Kg)**	**STEEL SLAG (Kg)**	**Sand (Kg)**	**Course Aggregate (Kg)**	**Water (l)**	**w/c**	**Superplasticizer (l)**
A1	400	0	732	1083	169	0.42	4.80
A2	280	120	724	1083	169	0.42	4.80
A3	310	0	811	1083	169	0.54	3.72
A4	217	93	803	1083	169	0.54	3.72
A5	220	0	889	1083	169	0.77	2.64
A6	154	66	883	1083	169	0.77	2.64

2.3 *Methods.*

The samples were tested against slump, compressive strength, split tensile strength and flexural strength tests; The tests were performed in accordance with ASTM C143/143M [16], ASTM C-39/C39M [17], ASTM C-496/C-496M [18] and ASTM C-78 [19] standard methods respectively.

3 Results and discussion

3.1 Workability.

The workability was determined by slump test and the test setup is shown in Figure 2. The results are shown in Table 5.

Figure 2 Slump setup

Table 5 Effect of steel slag on slump

S. No.	Mix Designation	Slump (mm)
1	A1	134
2	A2	142
3	A3	109
4	A4	115
5	A5	80
6	A6	83

The results given in Table 5 highlight that the workability increases if cement is replaced by steel slag (30% by mass of cement). The factors affecting the workability are water content, cement content, the properties of fine and coarse aggregate particles such as size, shape, grading, mix design and the admixture [20]. In all the samples, admixture was added @ 1.2 % by mass of binder. As such, the only difference was the cement replacement by steel slag. The steel slag particles have higher specific area than that of the cement; as such the concrete having steel slag should have lower workability values. Contrarily, there is increase in workability. There are two possible reasons. Firstly, the steel slag has lower bulk specific gravity. The specific gravity values depend upon the voids inside the material. More voids lead to higher workability and vice versa [21]. Secondly, steel slag has lesser lime content (40%) than cement (60%), and as such its primary hydration is lower than that of the cement during the very early age of the cementitious mix. Therefore, more water is available in fresh state for a material having steel slag as compared to the control specimen having 100% cement. This unreacted water in fresh state increases the workability of the concrete [22].

3.2 Compressive strength.

The cylinders having dimension of 150mm x 300mm were casted. The samples were test at loading rate of 4400N/s in the direction of depth of cylinder, as shown in Figure 3. The compressive strength results are the average of three tested specimens and are presented in Figure 4. While the 7 and 28 days' strength of the specimens are compared in Figure 5.

Figure 3 Compressive strength setup

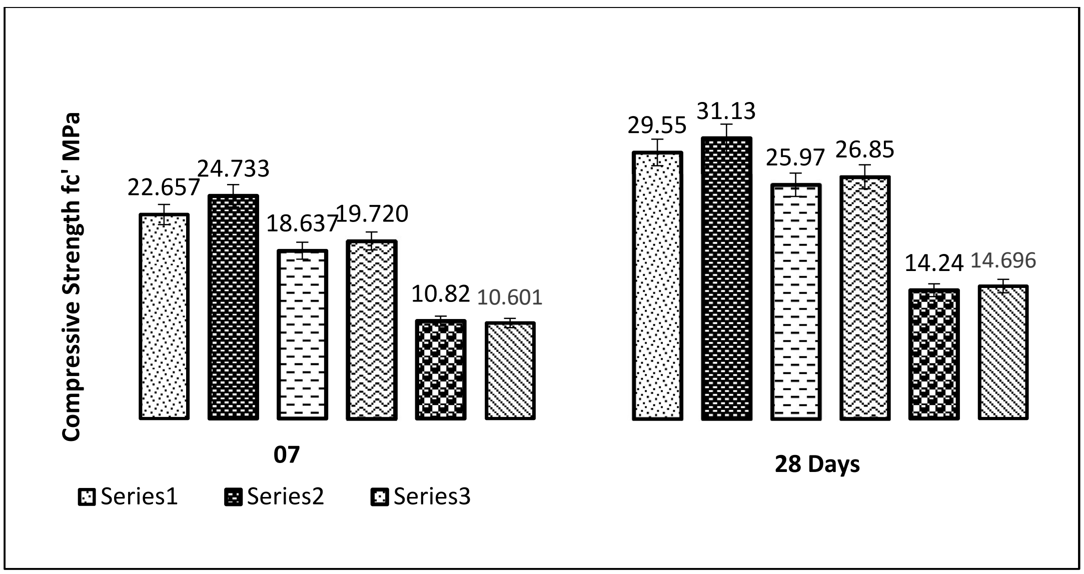
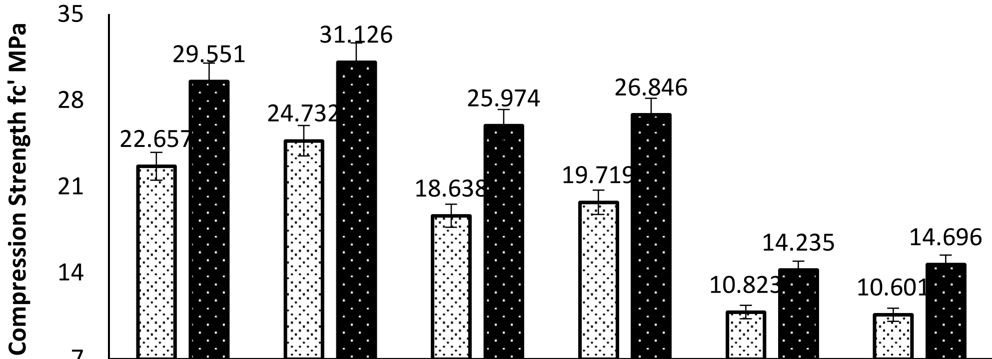


Figure 4 Effect of steel slag replacement on compressive strength



	A1	A2	A3	A4	A5	A6
7 Days	22.657	24.732	18.638	19.719	10.823	10.601
28 Days	29.551	31.126	25.974	26.846	14.235	14.696

Figure 5 Comparison of 7 and 28 days compressive strength of all specimens

Figure 4 shows that the compressive strength of concrete increases with replacement of cement by steel slag. The steel slag has much finer particles than those of cement. The pozzolanic activity strongly depends on the fineness of the particles. The presence of SiO_2, Al_2O_3, Fe_2O_3 along with CaO imparts significant cementing and pozzolanic characteristics to the slag particles, that combined with a fine size ultimately enhances the compressive strength. When slag is added to the cementitious composites, it chemically reacts with portlandite (CH phase) and form additional Calcium Silicate Hydrate gel: This in turn provides additional density and the strength is enhanced [23]. The higher cement content samples exhibit greater compressive strength development as compared to their control ones. For sample A2, compressive strength increases by 5.33% of control sample A1, at 28 days. The strength increase for specimen A4 is 3.36% as compared to its control A3 on 28th day. While for sample A6, compressive strength increases by 3.24% of its control counterpart. Normally, higher compressive strength is associated with a lower workability. Here, in this case, higher strength is accompanied with higher workability. Workability is associated with fresh state, whereas, strength is associated with hardened state. The unreacted water content is utilized while performing the pozzolanic activity, which ultimately enhances the strength.

3.3 Split tensile strength.

The split tensile strength was measured using the test setup presented in Figure 6. The test results (average of three) are shown in Figure 7. While the 7 and 28 days' strength of the specimens are compared in Figure 8.

Figure 6 Split tensile strength test setup

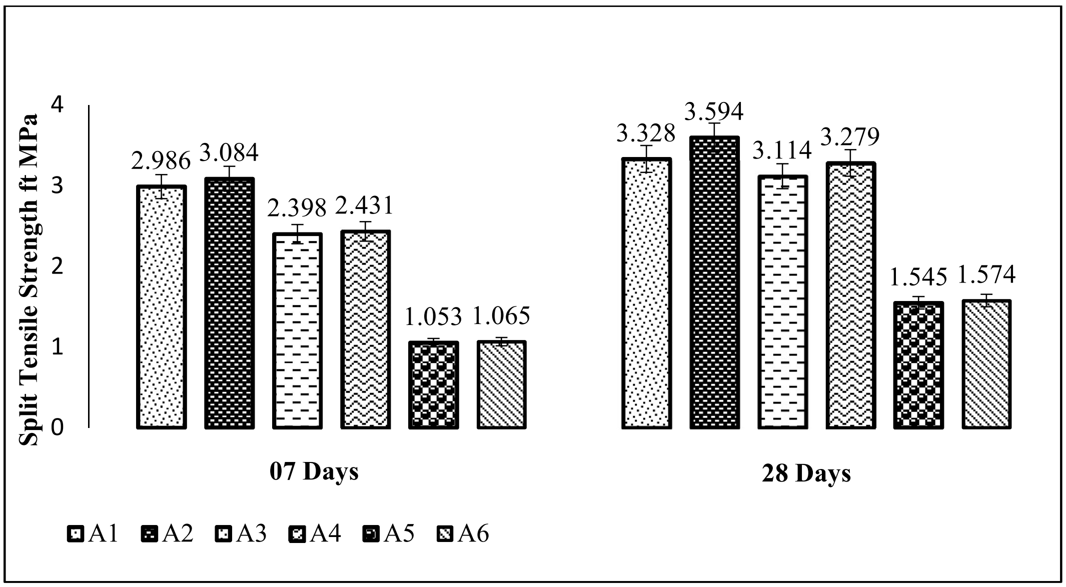
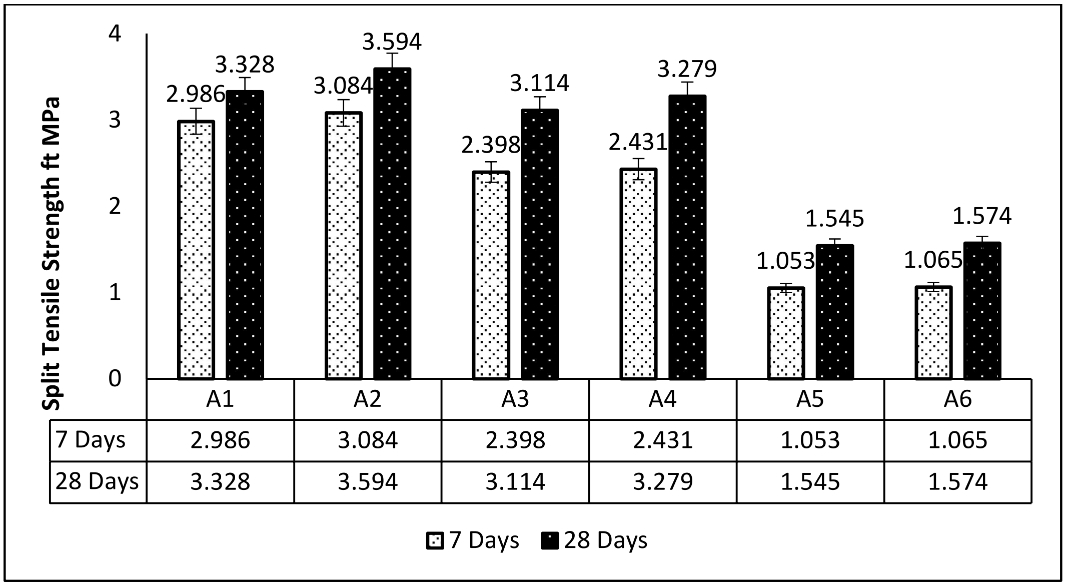


Figure 7 Effect of steel slag replacement on split tensile strength



	A1	A2	A3	A4	A5	A6
7 Days	2.986	3.084	2.398	2.431	1.053	1.065
28 Days	3.328	3.594	3.114	3.279	1.545	1.574

Figure 8 Comparison of 7 and 28 days split tensile strength of all specimens

Figure 7 and Figure 8 depict that split tensile strength of concrete increases with replacement of cement by steel slag. For higher binder content of 400 kg, specimen exhibit greater split tensile strength development as compared to their control specimen while for lower binder content of 220kg, sample exhibit lower increase in split tensile strength. For sample A2, split tensile strength increases by 7.99% of control sample A1 at 28 days. The strength for specimen A4 increases by 5.30% as compared to its control specimen A3. While for sample A6, split tensile strength increases by 1.87% of its control sample. Increase in strength with steel slag confirms its pozzolanic and cementitious characteristics and the fine size of the steel slag adds to the strength of the material.

3.4 Flexural strength.

The flexural strength test was performed using the setup shown in Figure 9. The results (average of three) are presented in Figure 10. While the 7 and 28 days' strength of the specimens are compared in Figure 11.

Figure 9 Flexural strength test setup

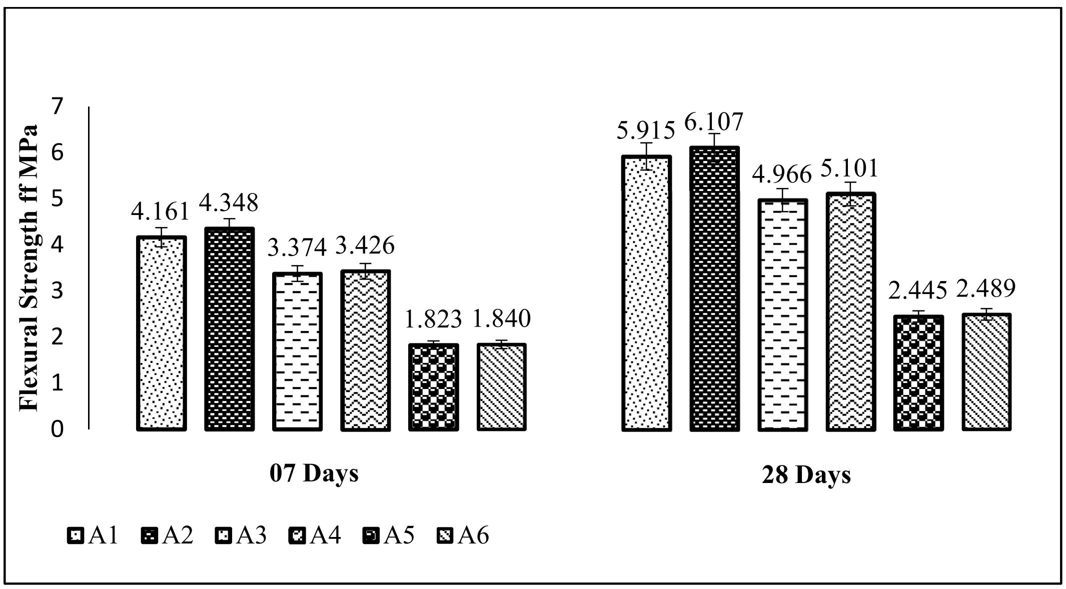


Figure 10 Effect of steel slag replacement on flexural strength

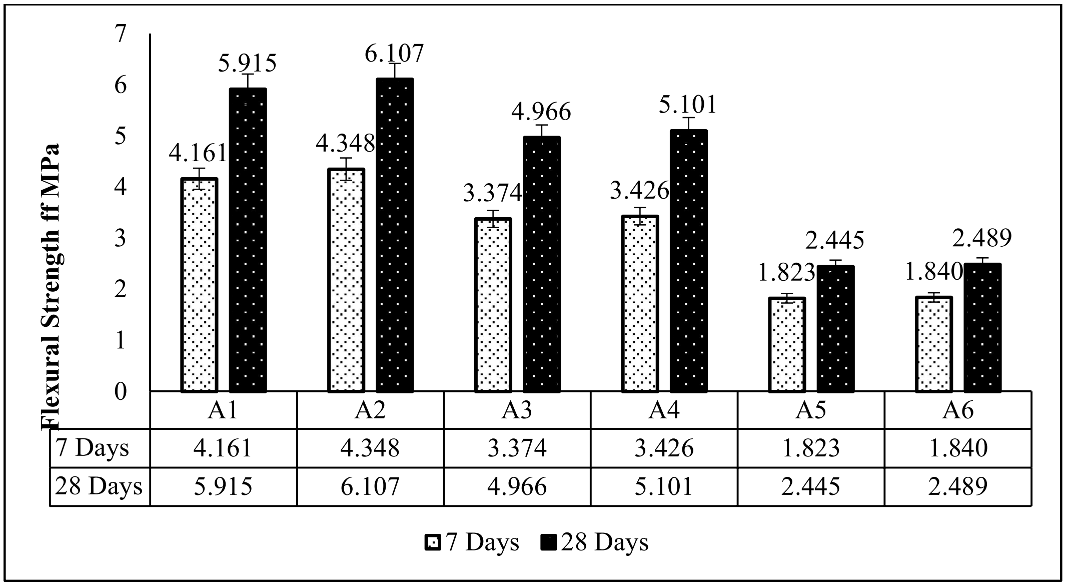


Figure 11 Comparison of 7 and 28 days flexural strength of all specimens

Figure 10 and Figure 11 highlight that the flexural strength of concrete increases with replacement of cement by steel slag. For sample A2, flexural strength increases by 3.25% to that of control sample A1, at 28 days. The flexural strength increases by 2.71% for specimen A4 as compared to its control A3. While for specimen A6, the strength increases by 1.80% of its control counterpart. This happens because there is more volume occupation by steel slag in comparison to that of the OPC. So the paste volume also increases along with an increase in binding properties towards aggregates. According to Dai et al., the ultrafine slag particles, which initially do not participate in hydration reaction because of its pozolannic property spread evenly in the pores and improve the pore structure and compactness of the samples [24].

3.5 Relationship between different strength results.

The relationship between different strength results of concrete is shown in Table 6.

Table 6 Ratio of split tensile and flexural strengths to compressive strength

	7 Days		**28 Days**	
	σ_t/σ_C	σ_f/σ_C	σ_t/σ_C	σ_f/σ_C
A1	0.131791	0.183651	0.112619	0.200162
A2	0.124697	0.175804	0.115466	0.196203
A3	0.128662	0.181028	0.119889	0.191191
A4	0.123282	0.173741	0.122141	0.19001
A5	0.097293	0.168437	0.108535	0.17176
A6	0.100462	0.173568	0.107104	0.169366

Table 6 demonstrates that the ratio of split tensile to compressive strength and that of flexural to compressive strength does not change appreciably if cement is partially replaced by 30% steel slag. Fapohunda et al. experimentally investigated the ratios of split tensile and flexural strength of the concrete containing different grades of cement [25]. As per their findings, the ratio of σ_t/σ_c at a water to cement ratio of 0.5 decreases from 0.126 at 7 days to 0.09 at 28 days. It has been reported that the split tensile strength is approximately 8-12% of the compressive strength for conventional concrete [26]. According to Lee et al., the ratio σ_f/σ_c varies from 10% to 20% for normal concrete [27]. Hence, the given results are in agreement with those of normal concrete.

The local steel slag used in this experiment is a pozzolanic material. Its pozzolanic activity enhances with increase in cement content. The use of steel slag offers many environmental and cost-effective benefits; It saves energy as regard lesser use of cement and, more performing products, being a partial cement replacement. Therefore, its substitution in concrete helps in sustainable development.

4 Conclusion

. Following conclusions can be drawn from the conducted study:

1 The workability of concrete increases as much water is available in fresh state for a material having steel slag as compared to the control specimen. This unreacted water in fresh state increases the workability of the concrete.
2 The 28 days' compressive strength increases from 3.24% to 5.79% of the control specimen for 220 kg to 400kg binder content with 30% replacement.
3 The 28 day split tensile strength of concrete increases for all mixes. This increase in strength is as much as 7.99% for higher binder content (400kg/m^3) to that of its control specimen while 1.87% for lower binder content (220kg/m^3) specimen.
4 The Flexural strength also increases for every concrete mix.
5 It is concluded that the steel slag can be utilized as a partial replacement material of cement, and 30% replacement of cement with steel slag gives better result in compression, tensile and flexural strength as compared to the normal concrete.

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