A Study on the Compressive and Split Tensile Strength of Steel Slag Concrete Mixes for Rigid Pavement

Prof. M.H.Lunagaria[1] Gatesi Jean De Dieu[2]
[1]Professor [2]Student
[1,2]Department of Civil Engineering
[1]Govement Engineering College, Godhra [2]L.D College of Engineering, 3800-15, Ahmedabad

Abstract— The growing of infrastructures are the mostly compromised now day for making the mobility of people and goods. In this case the development of any country increases when there is sufficient infrastructures. The roads constructions is the mostly infrastructure promoting quickly development of any country. The pavement materials are required to construct the good roads which helping to connect the different locations. The natural aggregates are occupied the 75% of concrete volume, therefore it is very interested to find the alternative materials which can replace the natural aggregates in order to save environment as well as the economically. The steel slag is the co-product of mills steel industry in which the pig iron are molted in BOF and EAF for reproducing the waste steel materials that can be used as coarse aggregates in place of natural coarse aggregates. This material is strong enough because of its composition of steel for high percentage. The main objective of this research is to check the suitability of coarse steel slag aggregate in concrete mixture. The engineering properties were studied for materials as well as the fresh and hardened concrete.The slump, compacting factor and unity weight tests have been evaluated for fresh concrete and showed that as increment of steel slag % and also the properties improved. The compressive and spilt tensile strength was evaluated by using Indian standard method. The result sowed that as increment of steel slag% improve the hardened properties progressively up to 30% and start decrease up to 40% for compressive strength. The split tensile strength increases as steel slag % also increase up to 40%.The proportion of replacement natural coarse aggregates 0, 10, 20, 30, 40% by coarse steel slag. The concrete mix of M40 was selected for rigid pavement and water cement ration of 0.4.

Key words: Concrete mixture, rigid pavement, coarse steel slag, natural coarse aggregates, M40, compressive and split tensile strength

I. Introduction

A rigid pavement structure is composed of a hydraulic cement concrete surface course and underlying base and sub base courses (if used). Another term commonly used is Portland cement concrete (PCC) pavement, although with today's pozzolanic additives, cements may no longer be technically classified as "Portland." The surface course (concrete slab) is the stiffest layer and provides the majority of strength. The base or sub base layers are orders of magnitude less stiff than the PCC surface but still make important contributions to pavement drainage and frost protection and provide a working platform for construction equipment.

Concrete is prepared by mixing various constituents like cement, aggregates, water, etc. which are economically available. Concrete plays a critical role in the design and construction of the nation's infrastructure. Almost three quarters of the volume of concrete is composed of aggregates. The coarse aggregate fraction is that retained on 4.75 mm sieve and fine aggregates fraction is that passing 4.7mm sieve. To meet the global demand of concrete in the future, it is becoming a more challenging task to find suitable alternatives to natural aggregates for preparing concrete. Therefore the use of alternative sources for natural aggregates is becoming increasingly important. Steel slag is a co-product of the steel making process in which Steel cannot be prepared in the Basic Oxygen Furnace (BOF) or in an Electric Arc furnace (EAF) without making its co-product; steel slag. The use of steel slag aggregates in concrete by replacing natural aggregates is a most promising concept. Steel slag aggregates are already being used as aggregates in concrete paving road mixes due to their mechanical strength, stiffness, porosity, wear resistance and water absorption capacity. Studies and tests are being conducted on ways to use this steel slag as an aggregate in concrete by different researchers. However there were no serious attempts to investigate the performance of fresh steel slag aggregate against aged aggregate in concrete. Also the data regarding long term concrete performance are limited and inconclusive. Especially concerning the expansive characteristics of steel slag aggregates. Much research remains to be done in this regard.

II. Literature Review

According to **Dr.Kadyali and Dr.N.B.Lal**, authors described the concrete pavement as pavement in which derives its capacity to withstand loads from the flexural strength or beam strength (modulus of elasticity), permitting the slab to bridge over minor irregularities in the sub grade, sub base or base upon which it rests. This implies that the inherent strength of the slab its self is called upon to play a major role to resisting the wheel loads. Minor imperfections or localized weak spots in the materials below the slab can be taken care of by the slab itself. It is named because the pavement structure deflects very little under loading due to high modulus of elasticity of its surface course. A rigid pavement structure is typically composed of PPC (mostly) surface course built on top of either, the sub grade and underplaying base.

It is consisted the following parts:

A. Surface Course:

This is the top layer, which consists the Portland cement concrete slab.

B. Base Course:

This is the layer directly below the PCC layer and generally consists of aggregate or stabilized sub grade.

C. Sub Base:

This layer under the base layer but it is not always needed and therefore may often be omitted.

According to **P. Kumar Mehta, 1999**, in his research described the concrete as a composite material which is composed by the coarse and final aggregate, cement, water and admixtures if required, in additional the steel bars and so forth. Aggregates are usually obtained from natural rocks, either crushed stone or natural gravel. In general cement is used as binding together and makes cohesion of mixed materials. Aggregates are divided into two parts: fine aggregate which is considered as material passing in 4.75mm sieve size. The natural coarse aggregate are generally crushed stones or gravels which is retained in 4.75mm sieve size. Finally water is added to initiate the binding process. This makes mix stiffer and form one material called concrete which can be used in different construction structures.

According to **Tepordei, Valentin V. 2008,** they described the importance of natural aggregate in concrete. Aggregates are considered in one material which is playing the big role in making of concrete, in which occupy almost 75% of the concrete volume. They also influence the mechanical and physical properties of concrete. They should be hard, strong, free from undesirable impurities and chemically stable. They should be also free from the organic matter which may affect the hydration process of cement. The good characteristics of aggregates influence the strength, workability, durability of concrete. The size and grading of aggregate is also important parameters in design of a mix in a particular project**.** Certain properties of aggregates must be known before designing a particular mixture for any construction project. These include shape and gradation, moisture content, unit weight, specific gravity, void ratio and chemical properties. The different properties of aggregate will be discussed in the next chapter.

According to **National Slag Association, 2003,** they carried out the research for using the non natural aggregate in place of normal aggregate; they found that a wide range of material can be used as alternative to natural aggregate. Generally when new material used in concrete, there is different consideration to be based on such as economic, compatibility with other materials and concrete properties. The economical use of non natural aggregate in concrete depends on the different factors such as transportation, quantity available and mixing design requirements. The aggregate has a vital role in concrete as described earlier and the use of industrial byproduct in the concrete has received increasingly attention in the recent years. Blast furnace slag is used as an aggregate for asphalt concrete and also as a cementitous material in concrete. The steel slag which is also an industrial byproduct has potential to be utilized as an aggregate in concrete now.

According to **Iren Zeynep Yildirim,2011,** author described the formation of steel slag and its composition as defined, Steel slag is a byproduct obtained either from conversion of iron to steel in a Basic Oxygen Furnace (BOF), or by the melting of scrap to make steel in the Electric Arc Furnace (EAF). Slags are named based on the furnaces from which they are generated. Figure2.2 shows a flowchart for the iron and steel making processes and the types of slag generated from each process.

1) Electric-Arc-Furnace Process Of Steelmaking And Slag Generation:

Unlike (BOF) process, the electric arc furnace (EAF) does not use hot metal, but uses cold steel scraps. Charged material is heated to a liquid state by means of an electric current. The electricity has no electrochemical effect on the metal, making it perfectly suited for melting scrap. During the melting process, other metals are added to the steel to give the required chemical composition. Meanwhile oxygen is blown into the EAF to purify the steel. This slag which floats on the surface of molten steel is then poured off.

2) Ladle Furnace Refining And Slag Generation:

In order to adjust precisely the chemical composition of the steel to produce different grades of steel, the desired alloys are added to the molten steel through an alloy hopper that is connected to the ladle furnace. Ladle furnaces also function as a storage unit for the steel before the initiation of casting operations. Therefore, ladle furnaces reduce the cost of highgrade steel production and allow flexibility in the steelmaking operations.

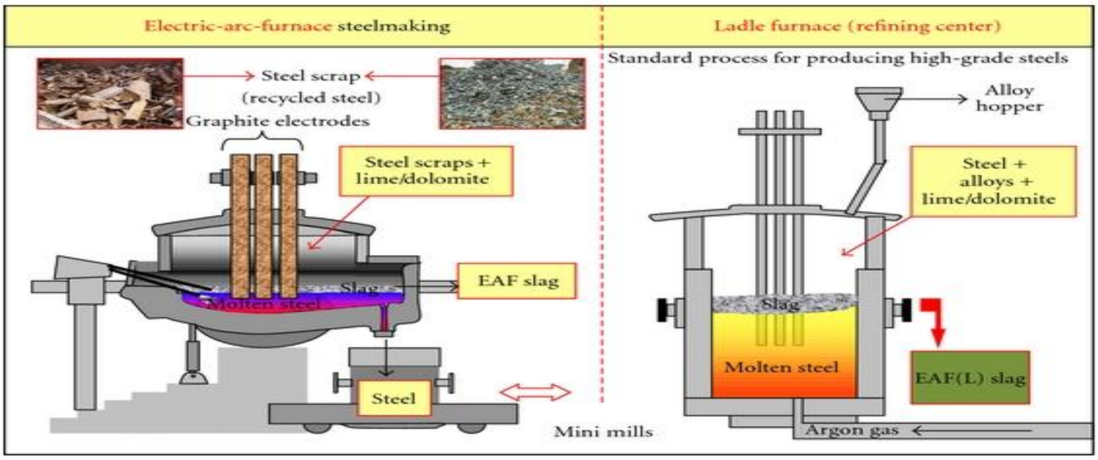


Fig. 2.4: Schematic representation of the electric-arc-furnace steelmaking and ladle refining process. (Source: Google image)

According to **Stein Inc 2008**, described how the steel slag can be stored in order to use it with the good quality without any problem of some contains compound which should be disappeared in determined period. Steel slag must be allowed to undergo weathering process before using as aggregate in construction because of it expensive nature.

This is done in order to reduce the quantity of free lime acceptable limits. The steel slag is allowed to stand in stockpile for a period at least 4 months and exposed to weather. During this weathering process the steel slag is required to be in contact with water so that the hydration process between lime and water take place. Hydration of free lime (CaO) or free magnesia (MgO) is responsible for expansive nature of steel slag.

According to **Anastasiou and Papayianni, 2006** had been studied the utilization of steel slag in construction works, as described earlier the steel slag is an industrial by product and instead of disposing it in the land fill, the use of such product in construction market would increase the efficiency and economic. The physical, mechanical and chemical characteristics have been extensively examined by the above researchers. Due to its potentially expansive properties, it requires the special carefully if it is applicable in construction works (eg concrete pavement). The possibility of using the steel slag as aggregate concrete without any problem was studied by the above researchers.

According to **Manso and Gonzalez, 2004,** they have been determined the durability of steel slag concrete and they found that the results are acceptable. They conducted also the test for mix design by using EAF slag and the result showed that the workability of fresh and the strength of hardened concrete were very good. After that the result showed that the behavior of mixed concrete against aggressive environment condition is acceptable.

After the tests result, they were concluded that:

- The compressive strength of steel slag concrete was similar to the traditional natural aggregate concrete.
- The durability of steel slag concrete is slightly lower than conventional concrete.
- The steel slag concrete has good physical and mechanical properties.
- The special attention may be done for gradation and crushing process.
- The porosity of EAF slag may affect the concrete resistance to freezing and thawing.
- To avoid that effect, the improvement is done on the field by using admixtures (eg air entraining).

According to **Manso, Polanco et al, 2006,** they conducted also the tests on the durability and mechanical properties of steel slag concrete and they concluded that: By proper mix proportion, both mechanical strength and durability of steel slag aggregate concrete can be improved.

According to **Wagam and Stanley, 2005**, they studies about the effect of slag on environment as a by-product from mild industries. This study showed that the slag has been used in treatment of acid mine drainage discharge in which rendering waste water more ecologically beneficial. In short notes about steel slag effect on environment, the utilization of the steel waste products from the manufacturing industries can help to save environment as well as the health of human being.

III. MATERIALS

The materials used in this research are locally available in ahmedabad city. The ordinary porltland cement of 53 grade were selected in the concrete mixture. The natural crushed coarse aggregates of 20 mm and 10 mm were tested according to Indian standard methods. The natural river sand passing through 4.75 mm sieve size have been used as fine aggregates. The pure tap water was used in mixture. No admixture used in this research.

The coarse steel slag aggregates were selected as research materials from NAROD, GIDC location, Ahmedabad. The steel slag of 20 mm and 10 mm were used in concrete mixes as replacement of natural coarse aggregate of 20 and 10 mm respectively.

Physical and mechanical properties of materials were evaluated according to Indian standards. The chemical composition of steel slag was also studied in this research. The following results as shown in below tables are concerned for concrete materials as well as steel slag.

1	Property	Testing apparatus	Experimental results	Testing methods
2	Fineness value	Blaine's air permeability	239.5	IS: 4031 (Part 1) – 1996
3	soundness	Le-chatelier	3.0	IS: 4031 (Part - 1) - 1988,
4	Initial setting time	Vicat apparatus	70	IS: 269-1976
	Final setting time	Vicat apparatus	300	
5	Compressive strength	Loading machine		IS:10080
		72 ± 1 h	28.5	
		168 ± 2h	39.3	
		672 ± 4h	53.0	
6	Specific gravity	Picynometer apparatus	3.15	IS:4031, part-11-1988

Table 1: Physical requirement for 53 grade OPC used in this research

Sr. no	Types of property	Testing method	Laboratory results	Max permissible limit
1	Specific gravity	IS:2386 -1963, Part III	2.63	≤ 3.0
2	Fineness modulus	IS:2386 -1963, Part III	2.4	≤ 3.0
3	Density/unit y weight	IS:2386 -1963, Part III	1692	≥1600
4	Water absorption	IS:2386 -1963, Part III	1.24%	≤ 2.0%

Table 2: Physical properties for concrete road construction/fine aggregate

1	Aggregate impact value	IS:2386 -1963,	11.02%	≤ 45%

		Part IV		
2	Aggregate abrasion value	IS:2386 -1963, Part IV	10.0%	≤ 50%
3	Aggregate crushing value	IS:2386 -1963, Part IV	15.0%	≤ 45%
4	Flakiness index	IS:2386 -1963, Part I	12.6%	≤ 25%
	Elongation index		17.3%	≤ 30%
5	Specific gravity 20 mm	IS:2386 -1963, Part III	2.73	≤ 3.0
	Specific gravity 10 mm		2.71	
7	Water absorption 20 mm	IS:2386 -1963, Part III	0.38%	≤ 2.0%
	Water absorption 10 mm		0.49%	

Table 3: Mechanical properties for concrete road construction/coarse aggregate

Sr. no	Compound name	Oxide compound	% containing
1	Iron oxide	FeO	29.5
2	Limestone	CaO	22.8
3	Silicate oxide	SiO_2	12.1
4	Magnesium oxide	MnO	7.9
5	Aluminate oxide	Al_2O_3	6.8
6	Manganese oxide	MgO	4.8
7	Phosphorous oxide	P_2O_3	0.3
8	Sulfur	S	0.2

Table 4: Chemical composition of steel slag

Sr. no	Properties	Testing methods	Experimental results	Allowable limit
1	Specific gravity	IS:2386-1963, Part III	3.20 for 20 mm	≥ 3.0
			3.0 for 10 mm	
2	Bulk density in kg/m³	IS:2386-1963, Part III	1756	≥ 1600 kg/m³
3	Water absorption	IS:2386-1963, Part III	0.23 for 20 mm	≤ 1%
			0.25 for 10 mm	
4	Fineness modulus	IS:2386-1963, Part III	8.34 for 20 mm	≥ 3.0
			6.16 for 10 mm	≥ 3.0

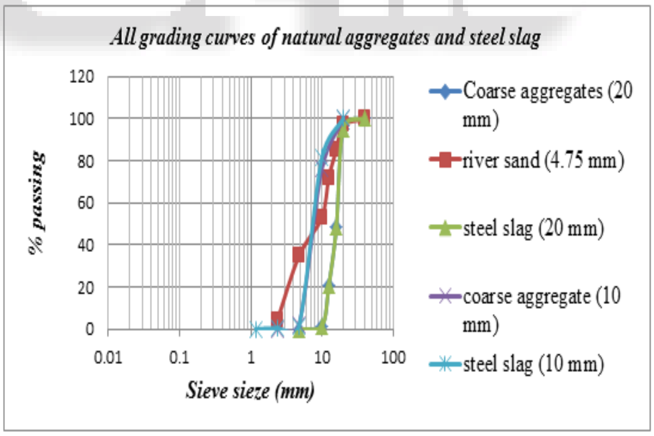
Table 5: Physical properties of steel slag aggregate

Sr. no	Properties	Testing methods	Experimental results	Wearing surface of concrete
1	Impact value	IS:2386-1963, Part IV	12.5%	≤ 30%
2	Abrasion value	IS:2386-1963, Part IV	11.7%	≤ 30%
3	Crushing value	IS:2386-1963, Part IV	16.13%	≤ 30%

Table 6: Mechanical properties of steel slag aggregate

IV. EXPERIMENTAL RESULTS

A. Gradation of Aggregates and Steel Slag:



B. Mixing Proportion:

<table>
<tr><td colspan="3">Description</td><td colspan="8">Mix proportion in Kg/m³</td></tr>
<tr><td colspan="3">Ingredients</td><td>Water</td><td>Cement</td><td>Sand</td><td colspan="4">Coarse aggregates</td><td rowspan="5">Number of specimens</td></tr>
<tr><td colspan="3">Weight (Kg)</td><td>192</td><td>480</td><td>657</td><td colspan="4">1111</td></tr>
<tr><td colspan="3">Per bag of cement</td><td>20</td><td>1</td><td>68.43</td><td colspan="4">115.73</td></tr>
<tr><td colspan="3">Per the w/c ratio</td><td>0.4</td><td>1</td><td>1.37</td><td colspan="4">2.32</td></tr>
<tr><td>SN</td><td>%Steel slag</td><td>W/C ratio</td><td>water</td><td>cement</td><td>sand</td><td>10mm</td><td>S.slag</td><td>20mm</td><td>S.slag</td></tr>
</table>

1	0	0.4	19.06	47.62	65.24	33.06	-	77.25	-	15
2	10	0.4	19.06	47.62	65.24	29.75	3.31	69.53	7.73	15
3	20	0.4	19.06	47.62	65.24	26.45	6.61	61.80	15.45	15
4	30	0.4	19.06	47.62	65.24	23.14	9.92	54.08	23.18	15
5	40	0.4	19.06	47.62	65.24	19.84	13.22	46.35	30.90	15
Total			95.30	238.10	326.20	132.24	33.06	309.01	77.30	75

C. Experimental Results:

The concrete mix proportion used in this research was 1:1.4:2.4 with the water cement ratio of 0.4, according to Indian standard referred for performing different laboratory experiment, the two types of concrete properties were evaluated.

1) Fresh Concrete:

Fresh concrete is the property of concrete which was evaluated in term of workability by slump and compaction factor test. The bulk density (unit weight) was also tested, the results obtained for the first trial of mix (conventional concrete) was summarized in the form of table:

Trial mix	**% replacement**	**Slump in mm**	**Comp actor factor %**	**Unity weight in kg/cc**	**w/c ratio**
M1	0%	55	0.84	2346.4	0.4
M2	10%	58	0.85	2350.5	0.4
M3	20%	60	0.86	2365.3	0.4
M4	30%	63	0.87	2370.1	0.4
M5	40%	65	0.88	2390.2	0.4

Fresh concrete/workability: Average value of below test results

2) Hardened Concrete:

The compressive strength of concrete was tested for 7 and 28 days. The specimens were casted and cured for the above period. The cubes having 15*15*15 cm have been used. The minimum 3 specimens were tested for each age. The 30 specimens were tested according to Indian standard (**IS: 516-1959**). The below results were averaged for 3 specimens for each age:

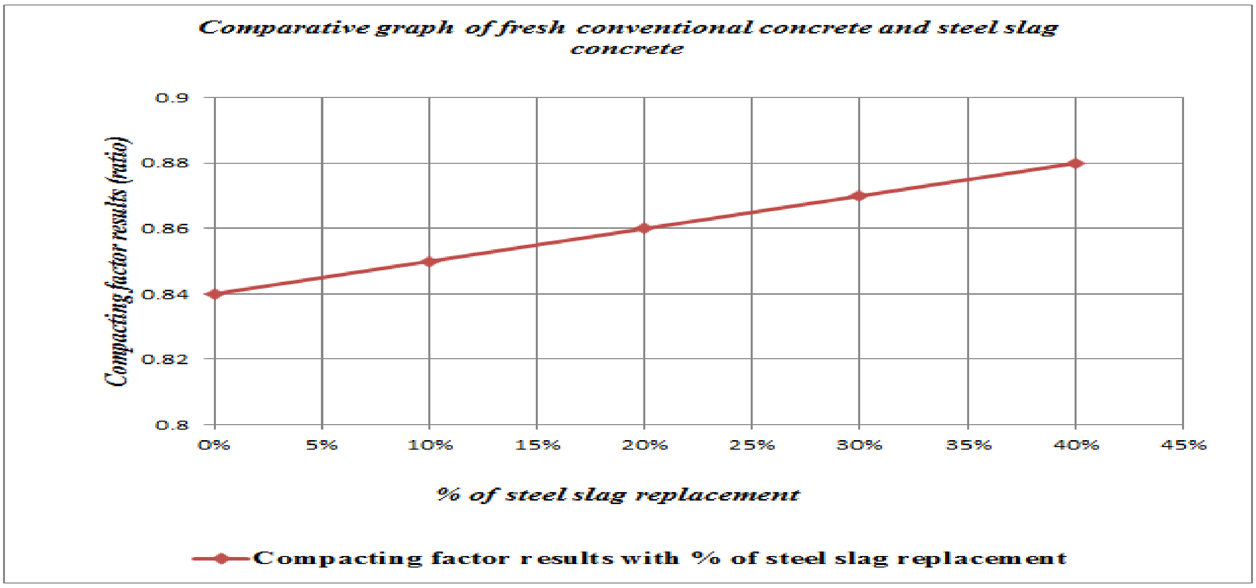
Type of test performed		**Compressive strength in Mpa**		
Period of curing		**7days**	**28 days**	**No of specimens**
Trial mix	**% of replacement**			
M1	0	32.40	51.0	6
M2	10	33.0	52.6	6
M3	20	33.03	53.18	6
M4	30	33.13	53.51	6
M5	40	33.04	53.02	6

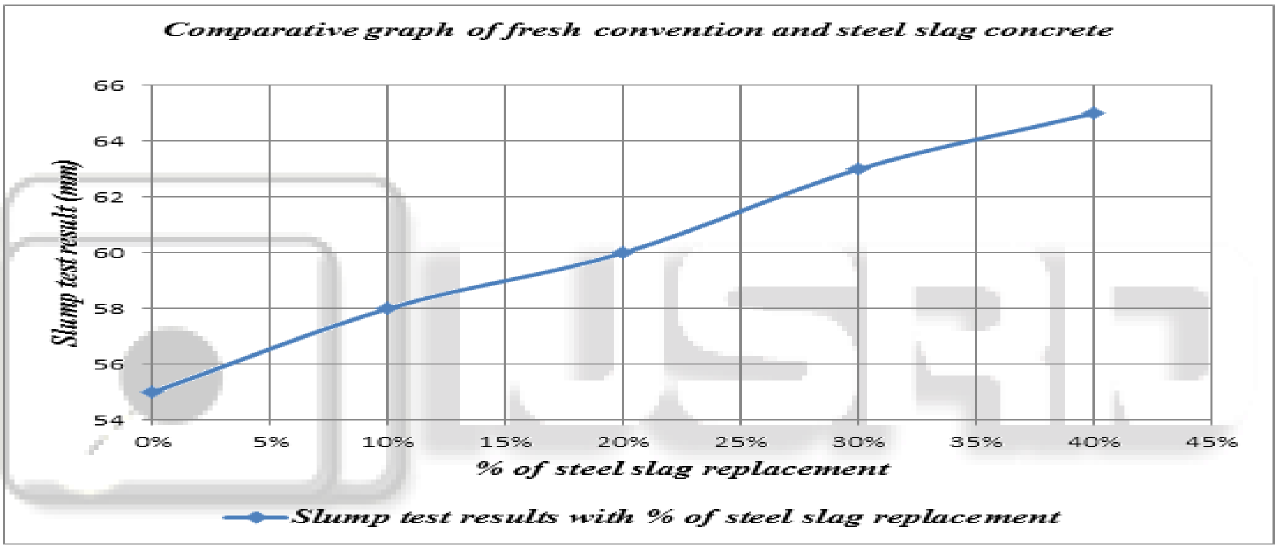
The tensile strength of concrete was also tested in 7 and 28 days. The specimens were casted and cured the above period. The cylinders having 15*30 cm have been used. The minimum 3 specimens were tested for each age. The 30 specimens were tested according to Indian standard (IS: 5816-1959). The application load was 250 KN for 7 days and 500KN for 28 days. The below results were averaged for 3 specimens:

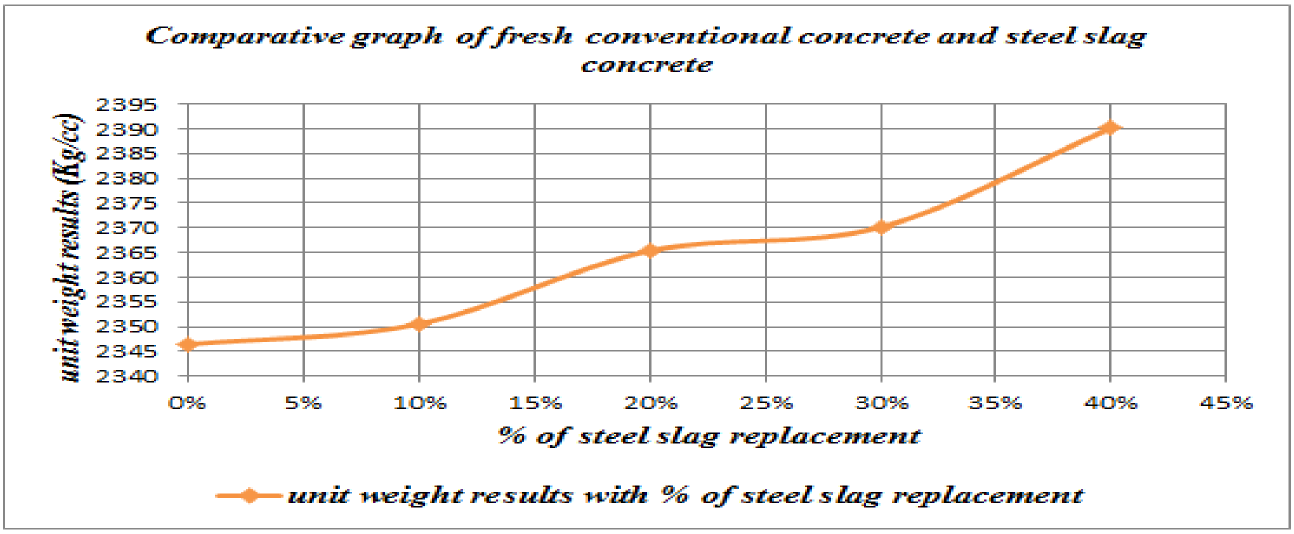
Type of test performed		**Split tensile strength in Mpa**		
Period of curing		**7days**	**28 days**	**No of specimens**
Trial mix	**% of replacement**			
M1	0	3.27	4.70	6
M2	10	3.33	4.79	6
M3	20	3.39	4.87	6
M4	30	3.51	5.04	6
M5	40	3.62	5.17	6

3) Comparison Of Conventional Concrete And Steel Slag Concrete By Graphically:

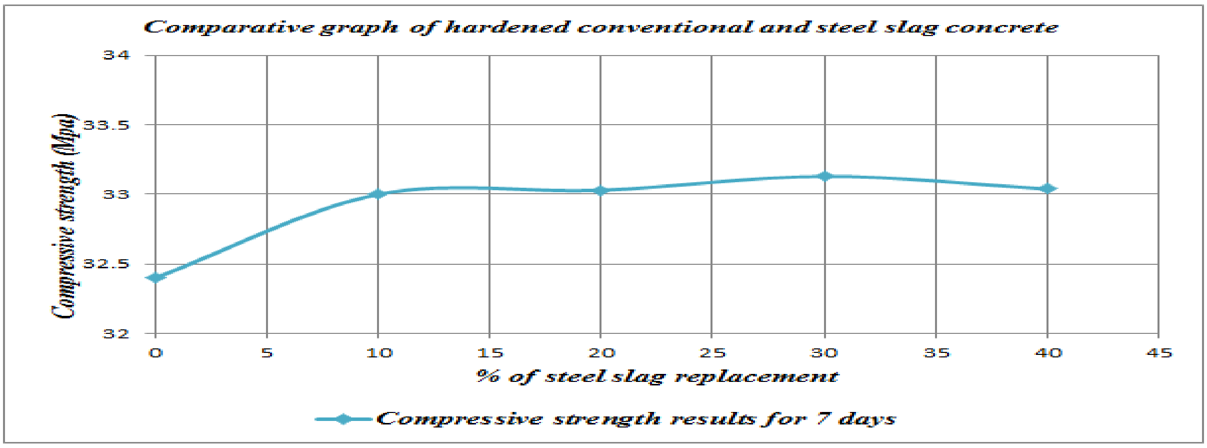
a) Fresh concrete graphs:

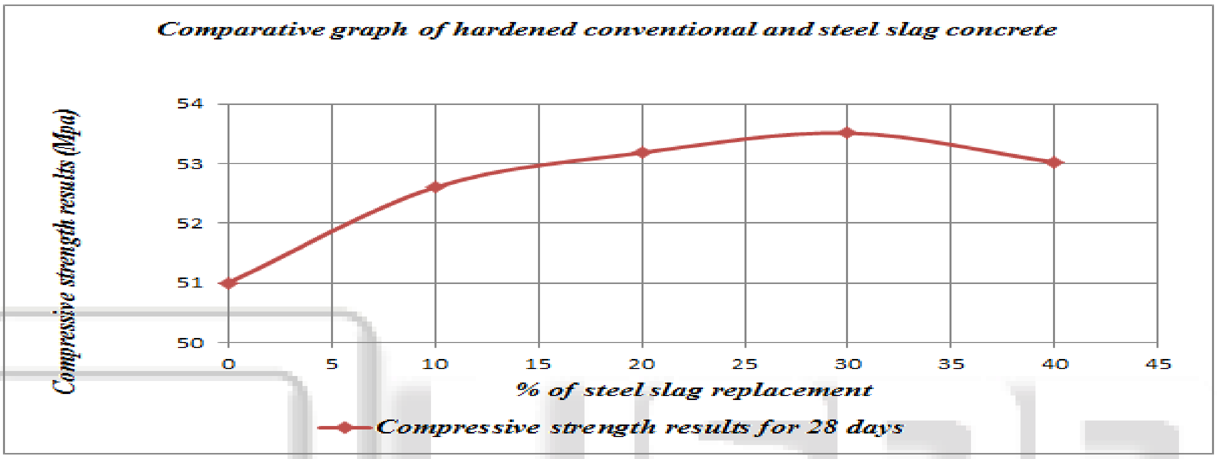


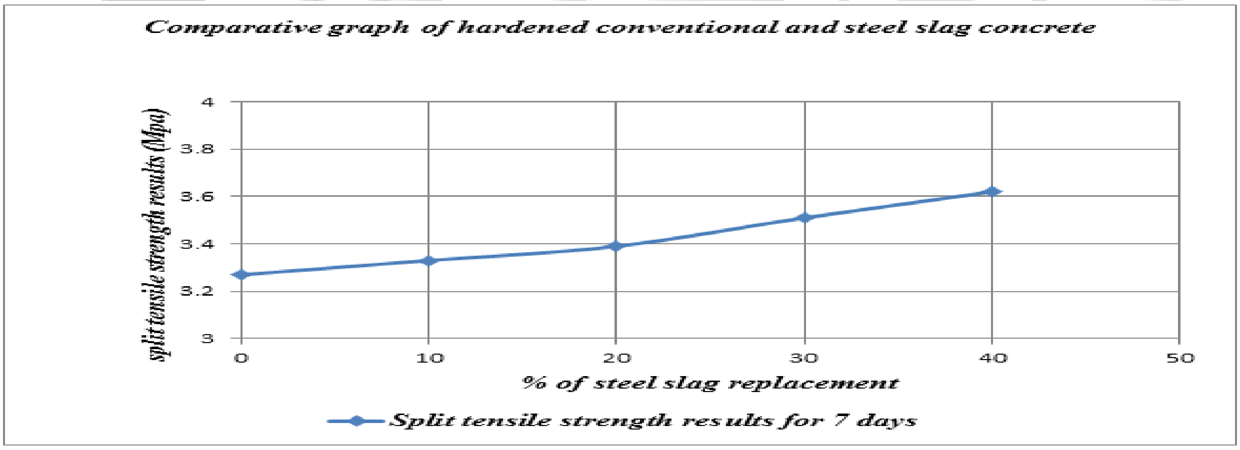


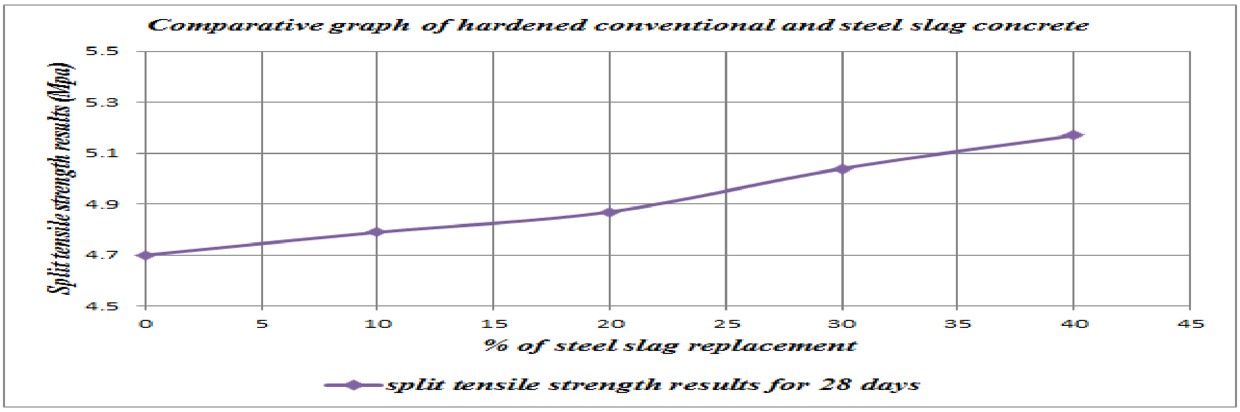


b) Hardened Concrete Graphs:


Comparative graph of hardened conventional and steel slag concrete
Compressive strength (Mpa)
34
33.5
33
32.5
32
0
5
10
15
20
25
30
35
40
45
% of steel slag replacement
Compressive strength results for 7 days


Comparative graph of hardened conventional and steel slag concrete
Compressive strength results (Mpa)
54
53
52
51
50
0
5
10
15
20
25
30
35
40
45
% of steel slag replacement
Compressive strength results for 28 days


Comparative graph of hardened conventional and steel slag concrete
split tensile strength results (Mpa)
4
3.8
3.6
3.4
3.2
3
0
10
20
30
40
50
% of steel slag replacement
Split tensile strength results for 7 days


Comparative graph of hardened conventional and steel slag concrete
Split tensile strength results (Mpa)
5.5
5.3
5.1
4.9
4.7
4.5
0
5
10
15
20
25
30
35
40
45
% of steel slag replacement
split tensile strength results for 28 days

V. OBSERVATION OF RESULTS

The study of compressive and split tensile strength of concrete for replacing the coarse natural aggregates by coarse steel slag in this research, have been observed that the different engineering properties can be improved as the % of steel slag increase.

The laboratory results showed that the crushed angular aggregates have god interlocking and cohesiveness with cement paste. But the steel slag as replacements has been showed that the cubical shape of steel slag and its roughness improve the strength of concrete as well as the workability of concrete.

(1) After studying the properties of conventional concrete and steel slag concrete, the following observations were made as under: The workability of conventional concrete is less than the steel slag concrete
(2) The increment of steel slag % could also increase the slump, compacting factor as well as the unit weight of concrete.
(3) The compressive strength of conventional concrete increase when the % of steel slag increases up to 30% and decrease when the % of steel slag greater than 40% for 7 days of curing.
(4) The compressive strength of concrete increase also up to 30% of steel slag replacement and decrease when the percentage goes behind 40% for 28 days of curing.
(5) The split tensile strength of concrete increase when the % of steel slag increases up to 40% for 7 days of curing.
(6) The split tensile strength of concrete increased when the ratio of steel slag as replacement increase up to 40% for 28 days of curing.

The comparative strength of conventional concrete and steel slag concrete showed that the increment of steel slag percentage made the improvement of hardened concrete.

VI. ACKNOWLEDGEMENT

The study of steel slag concrete as comparative to conventional concrete showed the good results as shown in the above discussion. This research work was acknowledged to **Prof. M.H.Lunagaria**, who guided me to achieve this work. My thanks also addressed to the Gujarat technological university staffs. Finally as almost firstly my greatest thanks is expressed to almighty **God**, gave me strength to complete this research paper.

REFERENCES

[1] Sultan A. Tarawneh, Emhaidy S. Gharaibeh and Falah M. Saraireh (2014).” Effect of using steel slag aggregate on mechanical properties of concrete”.
[2] E.Anastasiou and I. Papayianni, (2006 Springer)" Criteria for the Use of Steel Slag Aggregates in Concrete" Measuring, Monitoring and Modeling Concrete Properties.
[3] Patel, J (2008). “Broader Use of Steel Slag Aggregates in Concrete.” Master’s Thesis, Civil Engineering, Cleveland State University
[4] Juan M Manso, Javier J Gonzalez and Juan A Polanco, (2004)"-Electric Arc Furnace Slag in Concrete". Journal of Materials in Civil Engineering ASCE Nov 2004.
[5] GeoPave-Material Technology- (Nov-1993) "Steel Slag Aggregates"- Technical note 9 1993.
[6] P. E. Tsakiridis, G. D. Papadimitriou, S. Tsivilis, and C. Koroneos(2008).“Utilization of steel slag for Portland cement clinker production,”
[7] Irem ZeynepYildirim1and MonicaPrezzi, (2011).”Chemical, mineralogical and morphological properties of steel slag” Advances in civil engineering volume, ArticleID463638
[8] IS-10262:2009, “Indian standard for concrete mix proportioning guidelines” First revision, Bureau of Indian Standard, New Delhi.
[9] IS 9103:1999, “Specification for admixtures for concrete”, Bureau of Indian Standards, New Delhi, India.
[10] IS 383-1970, “Specification for coarse and fine aggregates from natural sources for concrete” Bureau of Indian Standards, New Delhi.
[11] IS: 383-1970, “Specification for coarse and fine aggregates from natural sources for concrete”, Bureau of Indian Standards, New Delhi.
[12] IS: 516-1959, “Method of test for strength of concrete”, Bureau of Indian Standards, New Delhi.
[13] IS: 5816-1959, “Splitting tensile strength of concrete - Method of test”, Bureau of Indian Standards, New Delhi

