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Investigation on Strength Properties of Concrete using Steel Slag as a Partial Replacement for Fine Aggregate

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Abstract. The economic and ecological performance of normal concrete can be increased by modulating fine aggregate content with a series of combinations of steel slag which possess different physical and chemical behaviour based on its cooling method, heating processes. Many research shows that magnetic separating of steel slag increases its efficiency towards integrating with clinker by 50% compared to integrating of clinker with non-magnetically separated steel slag. It has proved to be an impressive replacement material in concrete surfaces where high skid resistance is essential. Steel slag produced in various types of furnaces have different characteristic nature, blast furnace slag (BFS) has hydraulic and cement properties when used in water-bound macadam roads and also in flexible and rigid pavements. Issue in steel slag is energy consumed in its production and transportation where it is utilized, if energy consumed in slag grinding/magnetic separation is high when compared to cement calcining and grinding, then it would not be economical in replacement criteria. This study exhibit mechanical properties of concrete with partial replacement of fine aggregate with steel slag in distinct proportions. The optimum amount of replacement in fine aggregate is found to be 20% giving a strength increment of 8% in the compressive strength category. In split tensile and flexural strength criteria strength increment of 7.5% and 40.625% is observed. There are many practical implications of steel slag in the construction industry, road constructions, and clinker substitutes as granulated BF slag, water treatment plants, evidently many researches have proved slag as productive coarse aggregates replacement.

Introduction

A roundabout economy is a right now acknowledged fundamental, where the conventional direct economy is changed into a roundabout economy, where each movement is imagined as a cycle, where squander materials are considered as expected new assets, rather than side-effects to discard.[1]. Innumerable hills and valleys are carved to get the most utilised material in the construction field, the aggregate, 75% of concrete volume is constituted by aggregate or metal. There is a developing interest in involving waste materials as elective total materials and critical exploration is utilized a wide range of materials as total substitutes, for example, coal debris, impact heater slag and steel slag. [1]. More recently through awareness on sustainable development paved the way for extensive research and development to use waste by-products from diverse industries in construction. Slag, which is an expensive waste material, came to light in the last century by growing awareness on environmental issues in our society that had an impact on the effective utilisation of slag. To maintain the new aspiration of a circular economy, engineers and contractors pose a challenge to exploit waste by-products from the building industry to be integrated as raw material in the same building cycle. Utilisation of slag products started with the first ore smelting process in the 19th century and compensation in using by-products and also space to store these products were lacking. Lightweight cement is less ecologically strong than typical weight concrete on a cubic meter reason for two reasons, first and foremost, it is less compelling for warm mass purposes, and also, the typified natural effects will generally be higher due to the energy required in making the totals and the higher concretes substance utilized in the mixes. It is suggested that during the plan and obtainment of concrete, some thought be given to the related ecological effects. [7] This might well show that gross decreases in effects can be made without modification to the nature of the design delivered. It is additionally suggested that singular organizations develop information about the effects related with their strategies, for instance how much waste, to guarantee that the information utilized in any investigation are both explicit and current. This will work on the precision of the computations and the objectivity of the appraisal prompting better educated plan and obtainment choices. [7]

Slag

Slag is a by-product of the pig-iron and steel industries, made up of Calcium, Magnesium, and Aluminium Silicates in various combinations; different kinds of slag are created by changing the cooling process, but the fundamental compositions stay the same. Slag is produced in metallurgical and combustion processes when impurities in metals or ores are removed. During the smelting and refining process, slag floats to the surface, protecting it from oxidation and reduction and keeping it clean. The slag phase is used in the iron and steel industries to purify the liquid metal by eliminating impurities. Iron or ferrous slag is formed in the blast furnace process, non-ferrous slag is produced during the manufacture of non-ferrous metals (Pb,Cu,Ni), and steel slag is produced. The material that results in the solidification of molten BF slag under atmospheric conditions is air cooled slag, which is widely used as a base or sub-base in pavement construction, filler or concrete aggregate, and also in scour protection layers, depending on the cooling conditions in the blast furnace. The blistering and high porosity expanded slag produced by controlled quick cooling of molten slag in water or with a mix of steam and compressed air is utilised in light weight concrete. High pressure water jets are used to produce granulated slag with quenching which gives out glass like granules. Steel slag production process is shown below Fig.1.

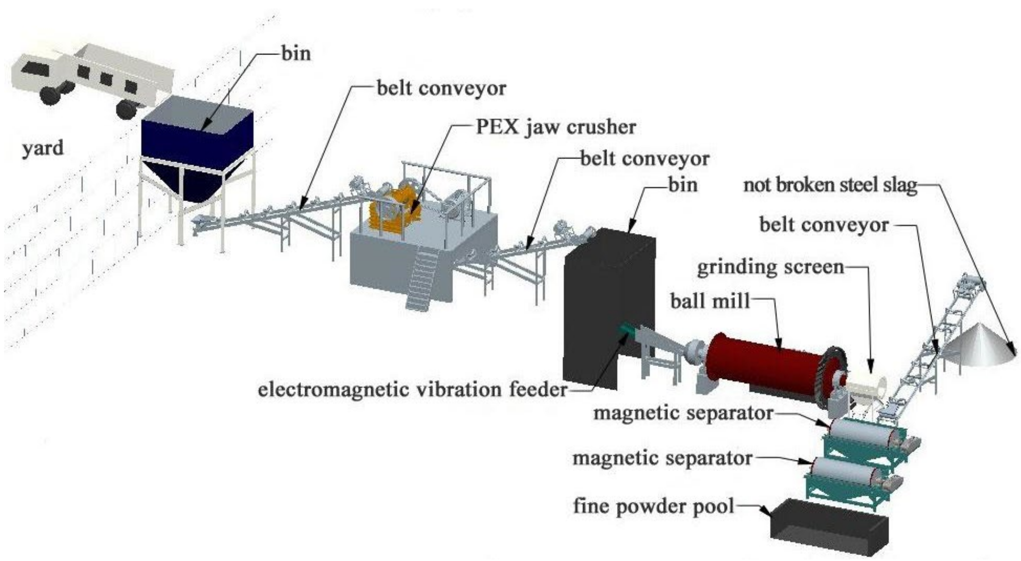

Fig.1: Steel slag production process.

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Water glass- activated slag concrete has a stronger mechanical strength and durability than traditional Portland cement concrete with the same dosage. Additionally, adding extra cementitious material to concrete mixes enhances mechanical characteristics and increases structural density, reducing susceptibility to aggressive agent penetration in both OPC and AAS concretes.[13] Granulated slag is then crushed, pulverised and screened to desired sizes, used in cement production to produce slag cement with enhanced heat of hydration, resistance to sulphate and chloride properties. Another well-known and cement-like material called GGBFS (ground granulated blast furnace slag) is produced which when integrated in concrete gives durable and high strength mixes in a longer time-scale. For a long time, several countries throughout the world, including Japan, Australia, Russia, and the European Union, have employed GBFS to produce artificial sand.[12] The GBFS sources in these nations are typically consistent in composition and engineering qualities, and the output slag quality is rigorously monitored. Despite the fact that a large volume of GBFS is generated in Vietnam each year, the countries focus on function is still lacking. As a result, their quality is unregulated, and their composition and qualities are insecure. [12] An alternative material for clinker production reducing energy consumption and overall reduction in carbon footprint of cement industry, after slag drying clinker with 40-50% slag in conveyed into ball mill with 6% gypsum resulting in Portland slag concrete which have low hotness of hydration and low salt total response properties. Portland slag concrete enjoys the benefit of better execution, toughness and ideal expenses likewise being eco-accommodating. Compound organizations of slag is given in Table.1.

Table 1: Steel slag composition.

CONSTITUENTS AS OXIDES	SYMBOL	BF SLAG [%]
Calcium oxide	CaO	41
Free lime	-	0
Silicon oxide	SiO_2	35
Iron oxide	Fe_2O_3	0.7
Magnesium oxide	MgO	6.5
Manganese oxide	MnO	0.45
Aluminum oxide	Al_2O_3	14
Titanium oxide	TiO_2	1
Potassium oxide	K_2O	0.3
Chromium oxide	Cr_2O_3	<0.005
Vanadium oxide	V_2O_5	<0.05
Sulphur	S	<0.6

Steel slag

Steel slag as a road building material might minimise the cost of obtaining and processing naturally existing aggregates from an economic standpoint. The steel industry may also be able to lower the cost of treating and disposing of massive stockpiles of steel slag. [16]. Oxidized elements which remain after removal of silicon and carbon as carbon-di-oxide in basic oxygen furnace (BOF) and electric arc furnace method (EAF) when combined with lime forms steel slag, hard, dense and similar to iron slag. The properties and composition of steel slag depends on type of steel production, Black slag is mostly produced in melting scrap metal in EAF method. Non-resting

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steel production gives out slag called white slag, which is also produced in small amounts in the secondary metallurgy process in vacuum oxygen decarburisation furnaces. These slags differ in chemical and mineral composition and possibilities of their use will also vary. Another type of slag is used in bituminous mixes in roads called non-ferrous steel slag produced in recovery of smelting process in Non-ferrous metals. It usually contains residual metal substitutes. Steel slag proved to be a barrier remedy in waste dumpsites where leaching of toxic heavy metals to nearby land bodies is evident. Steel slag presents permeable design and huge surface region; likewise, it is not difficult to isolate from water because of its high thickness. In this way, the use of steel slag in modern waste water therapy has gotten serious consideration as of late [5]. Development pace of SMA blend with steel slag is beneath 1% following 7 days, which guarantees the security of steel slag in SMA mixtures. In short, the fruitful use of steel slag as total in asphalt development can give a new and more financially savvy approach for total assets, and abatement the dangers of strong squanders to climate. In any case, more examinations ought to be completed on its reusing interaction and wide application in future [6].20% GGBFS replacement had a considerably positive effect on the cube and cylinder compressive strength but 40% and 60% GGBFS replacements reduced the strength at the age of 28 days. • The maximum loss of strength of 0%, 20%, 40%, and 60% GGBFS concrete is due to the effect of magnesium chloride followed by magnesium sulphate. [9]**.** the characteristics of water quenched slag are found to be quite similar to those required for use in the Portland slag cement making process. Air-cooled slag, on the other hand, is acceptable for use as an aggregate in the building sector. [14**].** Steel slag processing is critical for steel recovery because it produces an angular, typically well-graded material that is largely free of metallic contaminants, and the recovered steel (2 to 4% of raw steel production) is a valuable scrap. [15]. the asphalt concrete has a regular heating time and a prolonged cooling time once steel slag is replaced. Steel slag induction of healing asphalt concretes is given more time to mend. [17]

Literature review

Kunal K. Das and Eddie S. S. Lam (2020), "Partial replacement of cement by ground granulated blast furnace slag and silica fume in two-stage concrete (preplaced aggregate concrete)", to improve the qualities of two staged concrete or preplaced aggregate concrete, researchers tested partial substitution of cement with granulated blast furnace slag (GGBS) and silica fume (SF) (PAC).This concrete is produced by gravity method by placing aggregates in the formwork and injecting grout into it to fill voids between the aggregates. Optimum proportion of replacements is found to be GGBS of 30% and SF of 10% to give the suitable mix. Although adding these replacements increases the shrinkage potential, the amount of shrinkage is significantly lower than that of conventional concrete. [3]

M.Gouthampriya et al (2020), "Partial Replacement of Cement by Ground Granulated Blast-Furnace Slag in Concrete", inspection attempts to find the possibility of replacement of cement with granulated blast furnace slag (GGFS), varying proportions of percentage of binding material is replaced with GGFS and compressive, split tensile and flexural strength properties are observed and found that 20 % replacement of cement is enhanced in all mechanical criteria compared to control concrete. Compressive Strength results are presented below in Table 2.

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Table 2: Compressive strength results

S.No	Percentage of Replacement [%]	Compressive strength [N/mm^2]		
		7 Days	14 Days	28 Days
1	0%	18.43	22.61	25.82
2	10%	19.48	23.60	26.73
3	20%	21.33	24.93	28.12
4	30%	16.65	18.93	22.65

Split tensile strength for cylinders are as below in Table 3.

Table 3: Split tensile strength

S.No	Percentage of Replacement	Split Tensile Strength [N/mm2]
28 Days		
1	0%	2.86
2	10%	3.28
3	20%	4.34
4	30%	2.20

Flexural strength of beams are as below in Table 4.

Table 4: Flexural strength.

S.No	% of Replacement	Flexural Strength (N/mm2)
28 Days		
1	0%	6.28
2	10%	7.45
3	20%	8.36
4	30%	5.69

María Eugenia Parron-Rubio at al, “Slag Substitution as a Cementing Material in Concrete: Mechanical, Physical and Environmental Properties'', to achieve a circular economy by utilizing waste materials as raw materials in construction field, cement substitution by different types of slag from steel mills, behaviour of concrete with slag from blast furnace and ladle furnace in terms of physical and technical properties. For an environmental aspect, leachate test is conducted, it is found that blast slag has excellent substitute capability providing properties above reference concrete and ladle slag can be used for non-structural applications. For physical properties density and porosity are studied. The proportion of slag substitution studied are 30%, 40% and 50%. Totally 10 mixes are prepared with three types of slags of 3 proportions. Results shows for density property, ladle furnace slag 1(LFS 1) makes the mix aerated and porous more than mixes with other slags. Density of other slag compared to control mix is very identical and substitution doesn’t pose any threat to this property. GGBFS and LFS2 slags reduced the porosity to 25% and a 43% increase in performance compared to reference concrete which will have good performance in long run preventing the external agents that deteriorate the material’s microstructure, on other hand LFS1 give rise to high porosity and threat of propagation of crack and corrosion of steel frame. In the compressive strength category, GGBFS on the first day of hardening shows less compressive strength, but strength increases even after 30 days. Other slags lose strength giving up chances of structural material. Also this work proves if SiO_2 is high then higher pozzolanic activity, LFS1 attains less strength due to less SiO_2 and also of greater porosity. Optimum proportion in this study is found to be 25% of GGBS based on a previous study. A similar trend is observed for flexural strength where 50% substitution gives 4% increase in strength compared to no substitution mix. Other slag are worst performing, losing strength even after 90 days, owing to their chemical and physical properties.

Mani et al, "Replacement of Coarse Aggregate using Steel Slag in Concrete", this study focuses on mechanical property analysis of concrete where its aggregate part is replaced with steel slag in different proportions, it is found that more stable mix with high durable and resisting nature is formed and optimum quantity of slag replacement is 70 % of aggregates giving a 7-8% increase of strength when compared to control concrete.

Bilim et al.(2008) "Artificial neural networks and predicted the compressive strength of GGBFS concrete", The substantial blends were made with three diverse water-concrete proportions (0.3,0.4 and 0.5) three distinctive concrete measurements (350,400 and 450 kg/m3) and four fractional slag substitution proportion (20%,40%,60% and 80%). Compressive strength of soggy relieved examples were estimated at 3, 7, 28, 90 and 360 days. Results from the review are introduced beneath in Table 5.

Table 5: Results from above study for varying w/c ratios in consequent curing periods, Compressive strength is in [N/mm^2]

W/C Ratio	GGBFS (%)	Age [Days]				
		3	7	28	90	360
0.30	0	63.8	75.7	80.3	85.7	92.8
	20	58	72.1	81.8	90.1	95.9
	40	49.8	66.4	83.8	91.4	96.8
	60	36.8	63.2	80.6	92.5	101.3
	80	26.3	50.2	66.3	77.4	78.4
0.40	0	53	59.2	64.3	71	79.4
	20	45.8	60.3	73.5	82.3	86.6
	40	35.9	56.3	66.4	81	84.6
	60	26.9	38.6	61.8	73.4	80.6
	80	22.6	36.7	46.8	54.6	58.9
0.50	0	25.8	36.6	48.7	50.5	60.2
	20	21.3	33.2	50.4	56.2	66.7
	40	16.7	28.3	49.3	53.4	65.1
	60	13	20.8	39.5	49.1	57.4
	80	9	17.5	27.7	35	39.6

For all slag substitution proportion, strength commitment of slag to concrete is low upto 7 days old enough. Notwithstanding, compressive strength of cement containing slag concrete is higher than that of control ordinary Portland concrete cement for 20% and 40% substitution proportions at 28 days, 90 days and one year. Counterfeit neural organization (ANN) model is made with 45 substantial combinations. Information that is utilized in the model is organized in organization of six info boundaries that covers concrete, GGBFS, water, hyper plasticizer, total and time of tests and a result boundary which is compressive strength of cement. The outcomes showed that ANN can be an elective methodology for anticipating the compressive strength of GGBFS substantial involving fixings as information boundaries.

Pelligrino and gaddo (2009)"Natural aggregates of traditional concrete with black/ oxidizing electric Arc Furnace (EFA) slag", The substantial made with EFA slag as total showed great strength qualities in typical condition and strength properties of the combination containing EFA slag are absolutely tantamount than those noticed for conventional cement, the compressive strength of solid shapes examples with customary and EFA slag total later 7,28and 74 days displayed in table as beneath. It is important to see that compressive strength settles later the initial 28 days for customary combination though it keeps on improving for the EFA slag aggregate, maturing diminishes the strength of conventional cement wherein expanding for EFA aggregate. Aftereffects of compressive strength utilizing EFA slag are given underneath in Table 6.

Table 6: Results with EFA slag as aggregate.

Mix	7 days	28days	74days
Traditional	25.3	32.5	30.4
With EFA slag	37.2	42.3	44.4

Ismail and Hashmi (2008), "Report that the waste iron were reused to partially replaced sand at 10%, 15% and 20% in a concrete mixtures", droop, fresh thickness, dry thickness, compressive strength, and flexural strength tests were done to assess waste - iron significant quality. This technique is useful for restoring ages for the considerable mixes for 3,7,14, and 28 days. The results reveal that considerable mixes including waste iron have better compressive properties. For the 3, 7, and 28 days restoration periods, the compressive strength of the significant blends formed of 20% waste - iron total grew by 22.60 percent, 15.90 percent, and 17.40 percent, respectively. Aftereffects of solidarity increase rate is given in underneath Table 7[10].

Table 7: strength in percentage rise or fall.

% waste iron Aggregates	**Increasing (+) or decreasing (-) (%)**			
	3 days	**7 days**	**14 days**	**28 days**
0	0.00	0.00	0.00	0.00
10	8.20	11.43	-6.60	+1.80
15	15.20	14.90	2.97	1.2.95
20	22.60	15.90	+0.46	17.40

Madhavi et al, "Investigations on Sulphate Attack on Copper Slag Concrete", effect of sulphate on concrete can be as far as substance and actual qualities, whitish appearance in surface of cement is reaction of sulphate assault, sulphate changes hydrations items, for example, calcium hydroxide into calcium sulphate or gypsum and Tri-calcium aluminate hydrates are changed over to ettringite. These inside regulations cause turning and pushing, at last loss of joining between particles, vulnerability increments and water streams easily to the internal part. 2.2-2.3 huge loads of copper slag are delivered for each one ton of copper in the matte purifying cycle. Copper slag is fused at 20%, 40% and 60% in concrete, presented to magnesium sulphate answer for 30 days sway loss of solidarity. Substantial blend in with 40 % substitution of copper slag expands the strength from 60 MPa-64.65Mpa. Compressive Strength following 30 Days Curing of MgSo4 Exposure is displayed in underneath table: Results are displayed beneath in table 8 impact of sulphate on strength qualities. [4]

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Table 8: Strength reduction or increase after $MgSO_4$ exposure.

Proportion	Compressive load, kN	Compressive Strength, 30 days	Increase/ Decrease in Compressive Strength %
CS 0	950	42.22	-
CS 20	1000	44.44	21.97
CS 40	1350	60.00	64.65
CS 60	1250	55.56	52.46

Materials

As per codal requirements and standard procedures of experiments materials that are used should be tested for compliance and of shear quality for their correctness or credibility of results. In addition to steel slag, cement, fine aggregate, coarse aggregates were used in experiments. The purpose of these preliminary experiments are to enable an engineer to design a mix for desired strength. Descriptions of each materials is given below:

Portland cement

A scientifically controlled material whose compositions can be varied based on requirement of concrete mix, the function of cement is to fill the voids between sand and aggregates and also to bind them forming a interfacial layer to form a compact mass, although its constitutes less than 20% in whole concrete volume but it is an active binding medium with inevitable place in concrete. Change in proportion of cement increases the strength up to a level then strength remains the same. Portland cement is the most important and widely used type of cement, classified into three types based on grade which signifies the strength of cement. Higher grade cements are finer and costlier than lower grade cements. Lower grade cement gives many advantages such as faster rate of strength attainment, cost saving of 10-15%. In this study Shankar cement of grade 43 is used, it was cool, without lumps or adulteration, various tests conferring to IS 8112:1989 were conducted. It was safely stacked in moisture free condition to prevent hydration. Various tests done are initial and final setting time, specific gravity, fineness and consistency. Properties are presented in table 9 below. In comparison to PSC concrete, replacement of OPC with GGBFS in concrete resulted in comparatively low strength development for the majority of the cement content in the concrete. For most of the cement content, using PSC as cement directly in concrete mix resulted in considerable strength growth for a curing period of up to 28 days. [11] However, compared to OPC and GGBFS concrete, the rate of strength growth for PSC concrete cured at 3 days showed somewhat lower strength gain at low cement content (300 and 320 kg/m3). The compressive strength growth at all ages of curing shows considerable strength development over OPC plus GGBFS concrete at higher levels of cement concentration, between 340 and 380 kg/m3. This is due to a reduction in variation in cement quality and an optimised amount of gypsum in the resulting concrete for improved strength development. [11]

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Table 9: Cement properties after conducting respective tests.

SI.NO	CHARACTERISTICS	VALUES OBTAINED EXPERIMENTALLY.
1	Specific Gravity	3.12
2	Initial Setting Time	32 min
3	Final Setting Time	10.03 hours
4	Consistency	28%
5	Fineness	7.31%

Aggregates

Bulk of concrete is covered by aggregates, which is of nearly 75% of whole volume, fine aggregate is essential for giving required workability and binding cement paste and coarse aggregates, they should possess certain requirements so that concrete is workable, strong, durable and economical. They should be strong, clean, durable and well graded. Coarse aggregates are added in combination to get uniform distribution of particles.

Coarse aggregate

Metals held over 4.75 mm sifter are called coarse aggregates , they are delivered by squashing enormous stones or rock, one more way is uncrushed rock that are gotten by normal breaking down. In view of sort of cement and grade aggregates utilization shifts. The sizes shift from 10-20 mm and accessible as rocks up to 40mm. lower sizes of 8 and 6 mm are utilized in self compacting concrete. Locally accessible 20mm size total is utilized in this review. The totals are washed to eliminate residue, soil and a SSD condition is accomplished. The totals are tried as per IS383-1970. Properties of coarse totals are given beneath in Table 10.

Table 10: Properties of coarse aggregate.

SI.NO	CHARACTERISTICS	VALUES OBTAINED EXPERIMENTALLY
1	Maximum size	20 mm
2	Specific gravity	2.65
3	Water absorption ratio	0.51%
4	Shape test(Elongation Index)	11.38%
5	Shape test(Flakiness Index)	16.10%
6	Crushing value	21.33%
7	Impact value	10.94%

Sieve analysis results for coarse aggregates are given below in Table 1.

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Table 11: Sieve analysis report for coarse aggregate

Weight of sample taken =3000gm					
SI.NO	**IS Sieve (mm)**	**Wt. Retained (gm)**	**% Retained**	**% Passing**	**Cumulative % Retained**
1	80	0.00	0.00	100	0.00
2	40	0.00	0.00	100	0.00
3	20	68.5	2.28	97.72	2.28
4	10	2776.5	92.55	5.17	94.83
5	4.75	113.5	3.78	1.38	98.62
6	Pan	0.00	0.00	0.00	
	Total	**3000**		**sum**	**695.73**
				FM	**6.95**

Fine aggregate

Aggregates which pass over 4.75mm are fine aggregates. They are formed by natural disintegration of rocks and also by crushing stones or gravel. Based on size distribution fine aggregates are categorized into three types. Fine, medium and coarse are types, IS 383-1970 presents 4 grading zones (I to IV). The grading zones become progressively finer from grading zones I to IV. Properties and sieve analysis results are given in below table 12.

Table 12: Sieve analysis report for fine aggregate.

Weight of sample taken =1000gm					
SI.NO	**IS Sieve (mm)**	**Wt. Retained (gm)**	**% Retained**	**% Passing**	**Cumulative % Retained**
1	4.75	14.5	1.45	98.55	1.45
2	2.36	37	3.70	94.85	5.15
3	1.18	246.5	24.65	70.20	29.80
4	600μ	205.5	20.55	49.65	50.35
5	300μ	287.5	28.75	20.90	79.10
6	150μ	177	17.70	3.20	96.20
7	Pan	32	3.20		
	Total	**1000**		**sum**	**262.65**
				FM	**2.62**

Water

Consumable water is thought of as good for blending and relieving of cement. Water ought to be liberated from sewage and any unfavourable foreign substances. Water obtained from lakes and streams are not should have been tried or tested. However, water when suspected to have sewage or taken from modern plants or canneries, it shouldn't be utilized in concrete except if tests are done and palatable outcomes are noticed. Normally water obligated for drinking is took into account utilization in concrete. Water utilized for this review was liberated from any toxins and reasonable for utilization.

Steel slag

For this study steel slag was bought from “Agni steel plant” Ingur in Tamilnadu. Sieve analysis of steel slag is given below in Table 13. Image of steel slag used is given in Fig 2.

Table 13: Sieve analysis for steel slag.

Weight of sample taken =1000gm					
SI.NO	**IS Sieve (mm)**	**Wt. Retained (gm)**	**% Retained**	**% Passing**	**Cumulative % Retained**
1	4.75	14	1.4	98.6	1.4
2	2.36	28	2.8	95.8	4.2
3	1.18	94.5	9.45	86.34	13.65
4	600μ	189.5	18.95	67.8	32.2
5	300μ	329.5	32.95	34.95	65.05
6	150μ	291.5	29.15	5.8	94.2
7	Pan	58	5.8		
	Total	**1000**		**sum**	**210.6**
				FM	**2.10**

Fig.2: Steel slag used in this study.

Methodology

Mix design

To find the relative proportion of all materials in concrete is mix design. Among various methods to design the concrete mix, a method proposed in Indian standard code was selected and calculations were made. The design mix of grade M20 as designed is given below:

Design stipulation

Characteristic compressive strength

Strength that should be attained on 28 days : 20 N/mm^2
Maximum size of aggregate : 20mm (angular)
Degree of workability : 0.90compaction
Degree of quantity control : Good

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Exposure conditions : Mild

Test data for materials

Cement used : OPC
Specific gravity:
Cement : 3.12
Coarse aggregate : 2.69
Fine aggregate : 2.54
Water absorption:
Fine aggregate : 0.89%
Coarse aggregate : 0.43%
Free moisture:
Coarse aggregate : Nil
Fine aggregate : Nil
Sieve analysis in fine aggregate : conforming to grading

Mix proportion of various mixes that are designed based on steel slag percentage is given in table below Table 14:

Table 14:Mix proportions for various SS replacements.

Water(W) Kg/m^3	Cement (C) Kg/m^3	Fine Aggregate(FA) Kg/m^3	Coarse Aggregate(CA) Kg/m^3	Steel Slag (IS) Kg/m^3
180	360	573.86	1233.54	0
180	360	516.48	1233.54	57.38
180	360	459.088	1233.54	114.772
180	360	401.702	1233.54	172.158

Compressive strength testing

In most underlying components, concrete is fundamentally used to oppose compressive burdens. At the point when cement is exposed to pressure, disappointment happens in the upward plane of the part along its slanting, the break shows up because of parallel malleable strains. Miniature break shows up along the upward hub of the part in hub pressure because of horizontal elastic strains.

Test procedure

For compression testing, 150X150X150 mm test specimen cubes were casted. Concrete mixes containing varied percentages of steel slag (0, 10%, 20%, 30%) as a partial substitute for fine aggregate were cast into cylinders and cubes for further testing. To achieve a homogenous mixture, fine aggregate and steel slag were dry mixed first, followed by coarse aggregate and cement mixture. After achieving the desired colour, the needed amount of water is added, and concrete is formed. Before pouring concrete into the mould, the interior surfaces of the mould and the base plate were lubricated. The cubes were taken from the mould after 24 hours and put in clean fresh water at 27+2 degrees Celsius. The samples were evaluated after 7, 14, and 28 days of curing. No cushioning was provided while testing in a compressive testing machine. Load was applied axially till failure or crushing happens. Results of compressive strength varying in the curing period are presented in the next section.

Flexural strength testing
Flexural strength is one of the important parameters considered to design a member to take loads and also play a role in limiting the state of serviceability criterion. It comes into play when an inadequate subgrade support is subjected to wheel loads. IS 516-1959 gives procedure and apparatus required, standards for doing this test.

Test procedure
Specimens of size 15X15X75 mm are prepared since aggregate size is less than 40mm and greater than 19mm. steel rollers of 4 numbers are taken for loading and supporting. Length of rods are taken 10mm longer than specimen width and placed at 3d distance of outer rollers, distance between centres of inner rollers is d, such that all is systematic. The test specimen is tested immediately after storing it in water, whilst it is still wet, the example is set in the machine accurately focused with the longitudinal hub of the example at right points to the rollers. Load is applied at a pace of 400kg/min as the example is of width 15cm. Flexural strength of examples in various relieving periods is given in the following segment.

Split tensile strength testing
The split tensile strength is one of the important parameters that has its extent toward size of crack and cracking load. Usually concrete is not subjected to direct tension owing to its low tensile strength property, but these parameters help us to know where the concrete cracks. This method of test gives more uniform results than the ring tension test and double punch test. IS 5816-1999 presents a procedure for this test with tolerances and mould dimensions.

Test procedure
Each considerable mix is tested in a barrel-shaped form with a 150mm diameter and a 300mm length, in accordance with IS 10086-1982. Cement is laid down in 50mm layers throughout the projecting process. The test instances are stored in a vibration-free environment with a clammy character of about 90% relative dampness and at a temperature of 25 °C to 29 °C for 24 hours (12 hours from the hour of water expansion to the dry fixes). The samples are verified for layering correctness till the nearest 0.2m and then removed from the moulds and submerged in clear water until taken out before the test. Any sand particles on the testing machine's bearing surfaces are removed. Two headings pieces of ostensible (1/8 inch for example 3.175 mm) thick compressed wood liberated from blemishes around (25 mm) wide and of length equivalent to or somewhat longer than that of the example are set from every example, these two bearing strips are put among top and base bearing plates of machine. Polar lines are drawn at each finish of the example with a gadget so they are in a similar pivotal plane. One of the bearing strips is put along the focal point of the lower bearing square. Example is set in a strip and adjusted so the line drawn toward one side is vertical and loped over the compressed wood strip. Second bearing strip is put longwise along the chamber, loped over lines set apart on the finishes of the chamber. Load is applied at a uniform pace of 689-1380 kPa/min till disappointment. Separating two times of most extreme burden applied with result of breadth, phi (22/7) and length gives the split rigidity of an example. Aftereffects of examples are given in the following segment.

Results and discussion.
Consequences of tests led on concrete are examined here. As the target of this review is to observe the mechanical properties of cement with fractional substitution of steel slag as fine total, to accomplish that outcome a test review was intended to explore the impact of steel slag in compressive, split malleable and flexural strength of cement. This included, blend configuration,

projecting and relieving of solid shapes likewise with starter trial of material utilized for this review.

Slump test

To determine the consistency and amount of water-cement ratio needed, slump test is conducted for each mix proportions, this gives the workability of concrete and not suitable for very wet and dry mix.IS 456 gives workability values for different converting works in construction. It involves finding loss of height when a concrete filled frustum cone is lifted and behaviour of each mix shows the real picture of consistency. Results obtained from the slump test are given below in Table 15.

Table 15:Slump Test results.

SI.NO	% REPLACEMENT OF STEEL SLAG	W/C RATIO	SLUMP(mm)
1	0	0.50	30
2	10	0.55	30
3	20	0.60	27.5
4	30	0.65	24

Compressive strength

Below table shows mean compressive strength of specimens tested in 7, 14, and 28 days of curing from time it is mixed with water. Strength values are in MPa or N/mm^2 as given in below Table 16. Ultra fine slag replaces concrete with three distinct rates viz 5, 10, and 15% to concentrate on the compressive strength, porosity and sorptivity. Execution of monetarily accessible ultra-fine slag was viewed as substandard as ground one and cement with 10% ultra-fine slag was viewed as ideal. [8]

Table 16: Compressive test results of our study.

Tested day	0%	10%	20%	30%
7th day	16.25	17.55	18.60	17.20
14th day	18.56	19.20	20.50	19.26
28th day	20.98	21.56	22.66	21.10

The compressive strength increases as the percentage of steel slag is increasing, if 10% replaced in fine aggregate, on 7th day compressive strength is 8% more than control mix, correspondingly 14.46% more strength for 20% replacement and 5.8% increase for 30 % replacement. It also shows early strength development for all three replacement mixes compared to reference mixes. Optimum amount of replacement of steel slag is found to be 20 % giving more durability and strength with considerable cost benefits. 28th day strength for 20% replacement is 8% more than control concrete.

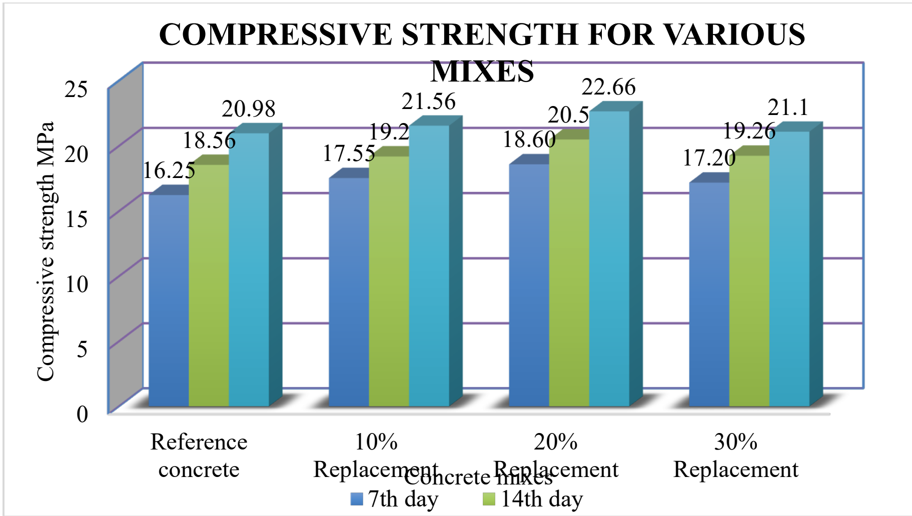

Fig 3: Graph comparing compressive strength for various design mix.

Flexural strength

Below Table 17 presents the flexural test observations for various mixes. From these values (in MPa) we infer that the same trend is continued as before, that increasing proportion ultimately improves flexural strength of the mix compared to CM. for 20 % replacement a 40.62% improvement of strength is observed.

Table 17: Flexural strength outcome after required test.

	0%	10%	20%	30%
7th day	1.24	1.56	1.80	1.62
14th day	1.96	2.24	2.68	2.10
28th day	2.56	3.34	3.60	3.10

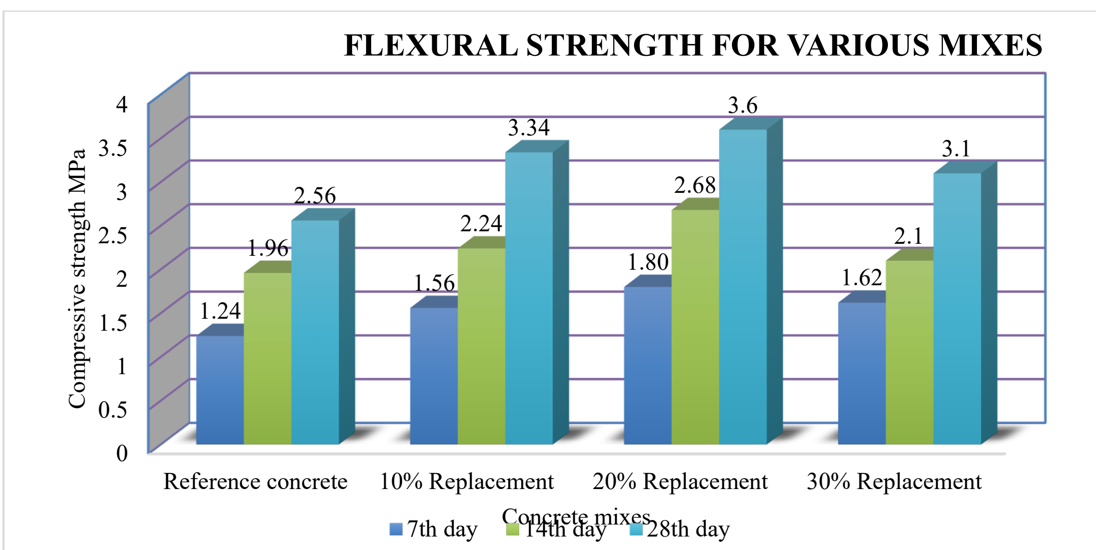

Fig 4: Flexural strength comparison for different mixes.

Split tensile strength

Below 18 tables exhibits strength improvement of 11.667% for 20 % replacement compared to reference concrete, more support for the limit state of cracking is given by this mix than nominal concrete which is more susceptible for cracking.

Table 18: Split tensile strength development in successive curing periods.

	0%	10%	20%	30%
7th day	1.36	1.50	1.62	1.78
14th day	1.80	1.96	2.10	1.98
28th day	2.40	2.46	2.68	2.10

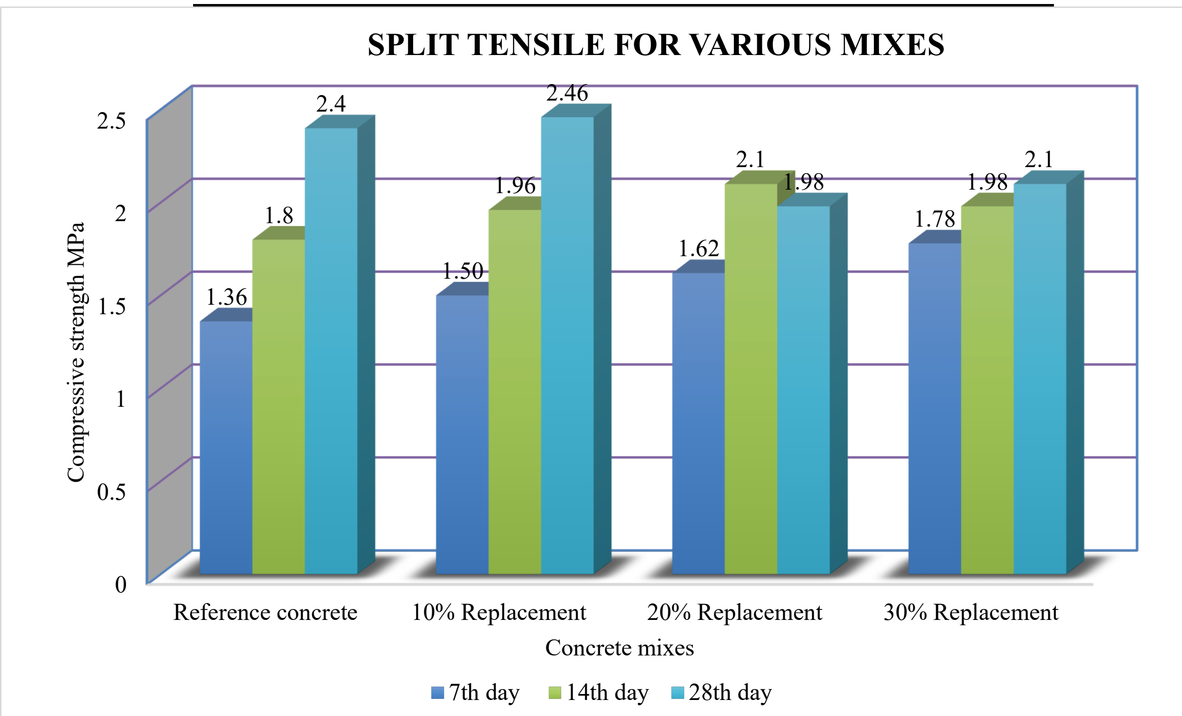

Fig 5: Split tensile strength comparison for different mixes.

Conclusion

The Primary objective of this study is to study the mechanical aspects and behaviour of various mixes replaced with steel slag in three proportions to get an economical, durable, and compact, eco-friendly concrete conglomerate. Infrastructure industry all over the world is going through a rapid phase, so exploiting the remaining resources would be catastrophic and a sustainable way of economic development. Need for aggregate related products is increasing, steel slag would be a suitable product to effectively incorporate in concrete, the most used element after aqua. Many research and development in this field is going on to tackle inadequacy of resources and the engineering field should have the obligation to safeguard a circular economy befriending ecologic wellbeing as a salient factor. A comprehensive study is carried out in reviewing other studies and experimental analysis is carried out. Further study can be made on different detrimental attacks on concrete such as chemical and environmental influence in long term behaviour of slag aggregate concrete.

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