Experimental analysis of basic mechanical properties of concrete upon replacement with silica fume and steel slag.

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Abstract: The prime aim in this paper is to find out the effect of Silica Fume and Steel Slag replacements for cement and fine aggregate respectively in the concrete matrix. The research included replacement of constant percentage of silica fume i.e. 10% with cement and varying percentages of steel slag replacements viz. 40%, 45%, 50% and 55% with fine aggregates. It was found from the experimental investigations that optimum results for strength in compression, flexure and split case for concrete were established on 10% of silica fume replacement for steel slag and 50% replacement of steel slag with sand.

1. Introduction
Concrete in present period has turned into a significant development material because of industrialization and urbanization going at a fast speed worldwide. Major of the application regions displayed in can be found in day by day travel and give a short thought of amount of material being utilized around the environmental elements. Concrete being prior viewed as essentially a combination of cement, sand and aggregate has seen a great deal of improvement with the progression of time and fortunately to commitments of analysts, researchers, and industry specialists. As said in the previously mentioned articulations that concrete has turned into a significant development material internationally, its interest has additionally been on top in the current time which further prompts the inclusion of alternate constituent materials because of shortage in regular constituent materials. The shortage of constituent materials had enough of the weight-age to help the use of substitute materials in the concrete [1–3].

The undertaken article exhibits the research of two such material i.e. silica fume and steel slag being replaced with cement and fine aggregates respectively.

A brief literature on the topic is summarized below. There is improvement in the properties such as compressive strength by 45.32% & tensile strength by 8.62% is observed. Both compressive and tensile strength improve. Compressive strength due to use of S.S as coarse aggregate is improved by 53.64% &
tensile strength by 17.45% respectively. Inclusion of S.F increases strength of binder mixes, improves early strength gains of fly ash cement, the capillary action and porosity of binder mix is reduced [4], addition of S.S to concrete containing S.S aggregate in coarser form reduces strength at any stage. Concrete formed using fly ash S.F simultaneously results in cohesive and sticky concrete. Incorporation of S.F enhances the quality of various sorts of binder blend by increasing their density. Addition of S.F reduces capillary action. S.F can be utilized as substituent on cement without influencing the properties of the bond alongside upgrade in properties of cement. On 15% cement substitution by S.F and half of sand replacement by S.S. the concrete performance get enhanced furthermore it will decrease the development cost and the natural contamination brought on by chemical items. 15% substitution of micro silica against cement with a w/p ratio of about 0.8 gives good results for flow of slump [5]. 5% substitution of micro silica against cement with a w/p ratio of about 0.8. 15% substitution of micro silica against cement with a w/p ratio of about 0.8 enhances compressive strength at 7th day and 14th day but it fails in flow properties. Supplanting cement with 10% micro silica with a w/p ratio of about gave better fresh concrete performance and compressive strength at the age of 28 days. In addition the flow of fresh concrete in SCC by micro silica may be attained using combination type consisting viscosity changing Agent or chemical admixtures such as poly carboxylated ethers and sulphonates.S.F included blends indicates higher quality qualities contrasted with their high volume fly cinder partners at later stages (following 28 days). S.F gives most elevated value of flexural and compressive quality when contrasted with the rice husk ash and iron slag [6]. Concrete supplanting up to 7.5% with S.F and up to 2% with nano silica, prompts expanding compressive quality, split elasticity and flexural quality for both M40 and M50 grade. Past seven and a half percent of SF and two percent of NS there is diminishing in strength parameters of both M40 & M50 blends [7]. Most extreme substitution of S.F is 7.5 percent and nano silica is 2percent for both M40 and M50 concrete and the rate increment in compressive quality, split elasticity and flexural quality of cement with mix of SF at 7.5percent & NS at 2percent is (25.807percent, 25.766percent & 18.9percent).for M40 grade and (25.357percent, 25.035percent and 16.067percent) for M50 concrete which is More when contrasted with ordinary concrete of M40 & M50 standards. Optimum value of compressive strength can be achieved in 10percent replacement of S.F, the best percentage for S.F replacement ranges from 10 percent to 15 percent replacement, 10percent being best. Slump value of concrete mix reduces with reduction in S.F content [8]. S.S can be used as substitution of fine aggregates that is sand in bulk which leads to reduction environment pollution caused by deposition of steel slag in open areas as the waste product is directly introduced to concrete. Cement replacement with 15percent S.F introduction helps in bring increment to different strength parameters of hardened concrete. Substitution of S.S for upto 50% of aggregates reveals to be the best percentage out of all different percentages used and is termed as absolute optimum. Failure was observed on 100percent replacement of natural aggregate by S.S aggregate. Increase in percentage of S.S decreases workability of concrete [9]. This standard deviation of the analysis was within the permissible limits Aggregate produced from cooled S.S is good for the use in concrete mixes. The use of S.S aggregates increases compressive strength, slag aggregates have better abrasion factor, the compressive strength of concrete is also increased. Addition of S.F increases compressive strength (6 percent to 57percent) depending upon percentage of reinforcement. The tensile and flexural strength of S.F concrete is almost similar to referral concrete. The addition of S.F improves the bond strength of concrete but modulus of elasticity almost similar to the referral concrete. Crushed Stone dust is good replacement for fine aggregate with conventional river sand in concrete. PPC cement can be replaced with fly ash 30 percent [10]. Clubbing of S.F and fly ash makes the increases cohesiveness and density of concrete and there reducing the permeability of concrete making concrete
more durable. Economical footprint is reduced using flyash for cement. Introduction of S.S to concrete blended with GGBS and Ordinary Portland cement increases quality for low quality cement, for example, M25 when contrasted with concrete containing River sand [11]. Additionally the pickup in quality of cement containing S.S isn't as high when contrasted with traditional cement yet toward the finish of 28 days the objective quality was accomplished indicating dependability. During the investigations it was watched that the workability of cement containing S.S was less. Since there is no acknowledgment for S.S as a standard material in the Indian standard codes [12], not much of the awareness about materials is found. Therefore blend plans for S.S are not accessible and henceforth additionally studies ought to be conducted for the same. From the information charts for M25 and M50 it can be watched that for M25 concrete the slump value is less workability is observed to the flakiness of the S.S totals. When the measure of S.S is reduced for M50 there is a considerable rise in slump value when contrasted with that of M25 having greater quantity of fines. It can be likewise observed that the objective mean quality is acceptably accomplished suggesting that the S.S can be utilized as an environmental friendly constituent. aggregates cannot be replaced fully with 100 percentage weight age as results doesn’t hold good for compressive, flexural and split strengths. Use of S.S aggregates increased compressive strength by 6%, flexure strength by 28% and split strength by 34% [13].

2. EXPERIMENTAL PROGRAM

2.1 MATERIALS

Silica Fume (S.F.)
Silicon dioxide polymorph is termed as S.F. or micro silica. It is highly fine powder material and is obtained as a byproduct of silicon manufacturing. Silica fume is used as suited substitution for cement in concrete matrix in the under taken project [14].

Steel Slag (S.S.)
Steel slag a byproduct obtained during the production of steel is delivered while segregation of steel in molten state from impurities inside steel furnace. It has the advantage of being used as aggregate (coarse or fine) in concrete manufacturing process [15].

Cement
Grade 43, OPC cement conforming protocols of IS: 8112 – 1989 was used in the research.

Fine aggregates
The sand sized below 4.75mm were used in the experimental work. Properties were as follows. Specific Gravity: 2.58, water absorption: 1 percent, Free surface moisture: 0 percent, Color: Gray, Bulk Density: 166 kg/m³. The FM of sand was found to be 3.03 [16].

Coarse aggregates
The stones of size above 4.75 mm are specified as coarse aggregates. 20 mm coarse aggregates were used in the research. Coarse aggregates were angular in shape. The characteristics of used stones are inscribed as follows. Specific Gravity: 2.69, water absorption: 0.50 percent, free surface moisture: 2 percent, Color: Gray. The F. M of coarse aggregates was traced as 7.94. The aggregate impact value was traced a 13.02 percent. The crushing value of aggregates was traced to be 17.51 percent [17–19].
Water quality as mentioned in Indian Standard 456 was maintained. Sufficient care was taken to keep water safe from grease, oil, impurities. The water was transparent through visual appearance.

3. REPLACEMENT DETAILS
The detail of mix proportions are showcased in Table 1 as under:

| Sample Name             | Cement replaced by silica fume | Fine aggregates replaced by steel slag |
|------------------------|--------------------------------|---------------------------------------|
| SCC (Standard Concrete Composition) | 10 percent                      | 0 percent                             |
| CR40 (Content replacement 40)      | 10 percent                      | 40 percent                            |
| CR45 (Content replacement 45)      | 10 percent                      | 45 percent                            |
| CR50 (Content replacement 50)      | 10 percent                      | 50 percent                            |
| CR55 (Content replacement 55)      | 10 percent                      | 55 percent                            |

4. TEST METHODS
The various tests were done on concrete in order to check out if the research project is feasible or not.
The following tests were carried out on the concrete samples:

1. Test on concrete in its fresh state
   a) Slump Test
   b) Compaction factor test

2. Test on concrete in hardened state
   a) Compression test
   b) Flexural test
   c) Split tensile strength test

5. RESULTS

5.1 Slump Test results: See table 2.

| Mix Type | Cement replaced by silica fume | Fine aggregates replaced by steel slag | Slump observed (mm) |
|----------|-------------------------------|--------------------------------------|--------------------|
| SCC      | 10percent                      | 0percent                             | 68                 |
| CR40     | 10percent                      | 40percent                            | 6                  |
| CR45     | 10percent                      | 45percent                            | 64                 |
| CR50     | 10percent                      | 50percent                            | 62                 |
| CR55     | 10percent                      | 55percent                            | 59                 |

Workability of fresh concrete is seen to decrease with incremental replacement of steel slag in concrete matrix.

5.2 Compaction factor (CF) test: See Table 3.

| Mix Type | Cement replaced by silica fume | Fine aggregates replaced by steel slag | Compaction factor |
|----------|-------------------------------|--------------------------------------|-------------------|
| SCC      | 10percent                      | 0percent                             | 0.90              |
| CR40     | 10percent                      | 40percent                            | 0.85              |
| CR45     | 10percent                      | 45percent                            | 0.83              |
| CR50     | 10percent                      | 50percent                            | 0.83              |
| CR55     | 10percent                      | 55percent                            | 0.82              |

From test results it was evident that CF of fresh concrete declines with incremental replacement of steel slag in place of sand used in formation of concrete.

5.3 Compression Test: See Table 4.
Table 4: Average Compression Test Values for various mixes

| Mix Type | Average Compressive Strength on 7th day in N/mm² | Average Compressive Strength on 28th day in N/mm² |
|----------|--------------------------------------------------|--------------------------------------------------|
| (SCC)    | 17.377                                           | 32.31                                           |
| (CR40)   | 18.36                                            | 30.65                                           |
| (CR45)   | 19.64                                            | 32.72                                           |
| (CR50)   | 20.94                                            | 33.29                                           |
| (CR55)   | 12.32                                            | 24.36                                           |

The compression strength for 7 and 28 days is found passing the limits for sand replacement with steel slag in case of 40% to 50% and on further increment of 55% it decreases beyond permissible limit. 50% substitution of steel slag as fine aggregate gives best results [20–22].

5.4 Flexural strength test: See Table 5.

Table 5: Average Flexural Test Values for various mixes

| Type of mix | Average Flexural Strength on 7th day in N/mm² | Average Flexural Strength on 28th day in N/mm² |
|-------------|-----------------------------------------------|-----------------------------------------------|
| (SCC)       | 2.56                                          | 3.85                                          |
| (CR40)      | 3.07                                          | 3.91                                          |
| (CR45)      | 3.21                                          | 3.95                                          |
| (CR50)      | 3.59                                          | 4.31                                          |
| (CR55)      | 3.72                                          | 4.45                                          |

The flexural strength upraises with up shoot of steel slag %age in concrete. As compressive strength results are obtained best at 50%, the 50% replacement of steel slag is considered as optimum one for both compressive and flexural strengths collectively.

5.5 Split tensile strength test: See Table 6.

Table 6: Average Split tensile strength Test Values for various mixes

| Mix Type | Average Split tensile Strength on 7th day in N/mm² | Average Split tensile Strength on 28th day in N/mm² |
|----------|----------------------------------------------------|----------------------------------------------------|
| (SCC)    | 2.32                                               | 4.55                                               |
| (CR40)   | 2.12                                               | 4.32                                               |
| (CR45)   | 1.99                                               | 4.10                                               |
| (CR50)   | 1.81                                               | 3.90                                               |
6. Discussion
The undertaken experimental program gives us a thought regarding the revision in properties of cement on consideration of materials under investigation in the concrete matrix and what it means for its properties by utilizing varying rates of steel slag in place of sand. From the outcomes of compressive test it was observed the compression strength for 7 and 28 days holds good for sand replacement with steel slag in case of 40% to 50% and on further increment of 55% it decreases beyond permissible limit. The flexural strength upraises with upshoot of steel slag %age in concrete. As compressive strength results are obtained best at 50%, the 50% replacement of steel slag is considered as optimum one for both compressive and flexural strengths collectively. Split tensile strength was observed to be achieving within limits at 50% and beyond that it decreased. The outcomes show that the strength associated with compression, flexure and split parameters will be ideal on 10percent silica fume and 50% of steel slag supplantation with fine aggregate in respective order. Therefore 50percent substitution of steel slag for fine aggregates and 10percent substitution of silica fume for cement gives best result.

Conclusion
1. Cement can be substituted with silica fumes up to 10%.
2. Steel slag being used as supplement of sand gives increased strength in compression. The replacement can be done up to 50% for optimum results.
3. The flexural strength increases beyond 50% as well but to keep compression strength to limiting values replacement beyond 50% is not recommended.
4. Workability and compaction factor are achievable upon replacements as undertaken in the research.
5. The replacements of cement and sand with silica fume and concrete respectively will contract the cost footprint on the concrete material industry as both the materials are byproducts and also boost economical footprint as waste disposal in open areas will be minimized

7. Limitations and Scope for further research
The research gave positive result for concrete dimension. Further studies can be under taken to have more information on use of SCMs with steel slag. Some of them are listed below:
1. The current study is based over test results taken up-to 28 days but it does not gives information about the concrete in long run. Therefore arrangements need to be made to test concrete at later stages so as to get assurance of durability and functionality standards for long term use.
2. Microstructure structure studies can be done in order to find behaviors of microstructures of concrete blended with multiple industrial by-products.
3. Studies can be undertaken to find out comparative behavior of current study concrete with concretes blended with other SCMs.
4. Since steel slag is by product of steel production. Some traces of steel and iron may by discovered in the concrete specimens. This might lead to corrosive action and degradation of concrete. The study about same has not been concluded in the research and can be taken into future scope.

References
[1] Guleria A N and Salhotra S 2016 Effects of silica fume (micro silica or nano silica) on mechanical properties of concrete: A review Int. J. Civ. Eng. Technol. 7 345–57
[2] Sivakumar S, Rajesh Kumar K, Vinod Kumar M, Rasha, Gurumoorthy N, Vandhiyan R, Balaji Kumar G and Kameshwari B 2020 Effect of plastic powder, silica fume and steel slag in concrete-An Experimental and Analytical Approach ‐ IOP Conference Series: Materials Science and Engineering vol 981, ed M K Rajasri Reddy I. (IOP Publishing Ltd)

[3] Sivaprasad G and Netula O 2018 Effect of silica fume on steel slag concrete Int. J. Civ. Eng. Technol. 9 839–46

[4] Boquera L, Pons D, Fernández A I and Cabeza L F 2021 Characterization of supplementary cementitious materials and fibers to be implemented in high temperature concretes for thermal energy storage (TES) application Energies 14

[5] Guan J, Zhang Y, Yao X, Li L, Zhang L and Yi J 2021 Experimental study on the effect of compound activator on the mechanical properties of steel slag cement mortar Crystals 11

[6] Kansal C M, Singla S and Garg R 2020 Effect of Silica Fume & Steel Slag on Nano-silica based High-Performance Concrete IOP Conference Series: Materials Science and Engineering vol 961 (IOP Publishing Ltd)

[7] Zeng H, Liu Z and Wang F 2020 Effect of Accelerated Carbonation Curing on Mechanical Property and Microstructure of High Volume Steel Slag Mortar [碳化养护对大掺量钢渣砂浆的力学性能及显微结构的影响] Kuei Suan Jen Hsueh Pao/Journal Chinese Ceram. Soc. 48 1801–7

[8] Sebbar N, Lahmili A, Bahi L and Ouadif L 2020 Treatment of clay soils with steel slag, in road engineering E3S Web of Conferences vol 150, ed B L B F C E K M L A M M N A O L Akhssas A. Baba K. (EDP Sciences)

[9] Jena S, Panigrahi R and Sahu P 2019 Effect of silica fume on the properties of fly ash geopolymer concrete Lect. Notes Civ. Eng. 25 145–53

[10] Liu J and Wang D 2017 Influence of steel slag-silica fume composite mineral admixture on the properties of concrete Powder Technol. 320 230–8

[11] Sharma A and Singh J 2017 The study of strength characteristic of concrete by adding coir fibre and replacement of steel slag Int. J. Mech. Eng. Technol. 8 1814–22

[12] Heniegal A M, El Salam Maaty A A and Agwa I S 2015 Simulation of the behavior of pressurized underwater concrete Alexandria Eng. J. 54 183–95

[13] Jin H, Guohua J, Qiang W, Haibing Z and Aimin T 2014 Influence of early-age moist curing time on the Late-Age properties of concretes with different binders Indian J. Eng. Mater. Sci. 21 677–82

[14] Wang H L, Sun X Y, Peng Q W and Xue F 2013 Durability and mechanical behaviors of steel slag powder concrete Appl. Mech. Mater. 438–439 58–62

[15] Peng Y, Hu S and Ding Q 2009 Dense packing properties of mineral admixtures in cementitious material Particuology 7 399–402

[16] Matsunaga H, Kogiku F, Takagi M, Tanishiki K and Nakagawa M 2004 Environment-friendly block made from steel slag American Concrete Institute, ACI Special Publication vol SP-221, ed M V.M. (American Concrete Institute) pp 457–70

[17] Siddhu B S, Sharda R and Singh S 2021 Spatio-temporal assessment of groundwater depletion in Punjab, India Groundw. Sustain. Dev. 12

[18] Singh S, Kumar R and Chohan J S 2020 Comparative analysis for natural and zycobond modified soil for green development J. Green Eng. 10 8251–8

[19] Singla N, Singla S, Thind P S, Singh S, Chohan J S, Kumar R, Sharma S,
Chattopadhyaya S, Dwivedi S P, Saxena A, Issakhov A and Khalilpoor N 2021 Assessing the Applicability of Photocatalytic-Concrete Blocks in Reducing the Concentration of Ambient NO2 of Chandigarh, India, Using Box-Behnken Response Surface Design Technique: A Holistic Sustainable Development Approach J. Chem. 2021

[20] Kumar S, Kumar M and Handa A 2018 Combating hot corrosion of boiler tubes – A study Eng. Fail. Anal. 94 379–95

[21] Gairola P, Gairola S P, Kumar V, Singh K and Dhawan S K 2016 Barium ferrite and graphite integrated with polyaniline as effective shield against electromagnetic interference Synth. Met. 221 326–31

[22] Sarowa S, Singh H, Agrawal S and Sohi B S 2018 Design of a novel hybrid intercarrier interference mitigation technique through wavelet implication in an OFDM system Digit. Commun. Networks 4 258–63