SEYBOLD Report
ISSN: 1533 - 9211
https://seyboldreport.net/

EXPERIMENTAL ANALYSIS OF DURABILITY AND WORKABILITY OF SELF-COMPACTING CONCRETE USING MANUFACTURED SAND AND STEEL SLAG

Ashutosh Kumar [1] and Dr. Prashant S. Lanjewar[2]
Department of Civil Engineering, Engineering & Technology, Dr. A. P. J. Abdul Kalam University, Indore, MP, India
[1]ashutoshoney413@gmail.com, [2]pslanjewar@yahoo.com

Abstract
Self-compacting concrete (SCC) has gained prominence in construction due to its ability to flow and fill formwork without the need for vibration, ensuring uniform distribution and improved finish. This experimental study investigates the influence of incorporating manufactured sand (M-sand) and steel slag (SS) on the durability and workability characteristics of SCC. Various concrete mixes were prepared by replacing natural sand partially with M-sand and incorporating SS as a partial replacement of cementitious materials. The study evaluates the fresh properties including flowability and viscosity, as well as hardened properties such as compressive strength, durability against chloride penetration, and resistance to sulfate attack. The findings reveal that the inclusion of M-sand and SS enhances the workability and durability performance of SCC, offering potential environmental and economic benefits. Keywords: Self-compacting concrete, manufactured sand, steel slag, durability, workability

Keywords: Self-compacting concrete, manufactured sand, steel slag, durability, workability, compressive strength, chloride penetration resistance, sulfate attack resistance

1. Introduction

The Self-compacting concrete (SCC) represents a significant advancement in concrete technology, characterized by its ability to flow under its own weight into intricate formwork and around congested reinforcement without the need for mechanical vibration. This unique property of SCC not only enhances construction efficiency but also ensures high-quality surface finish and uniform concrete distribution, particularly in complex structural elements where traditional concrete placement techniques may be challenging.

The conventional ingredients of SCC typically include cement, water, aggregates, and chemical admixtures. Among these, aggregates play a crucial role in determining both the fresh and hardened properties of concrete. Natural river sand has conventionally been the primary choice as fine aggregate due to its excellent workability and compatibility with cementitious materials. However, concerns over environmental sustainability and the depletion of natural resources have prompted the exploration of alternative materials such as manufactured sand (M-sand) and industrial by-products like steel slag (SS).

Manufactured sand (M-sand) is produced by crushing rocks and is increasingly being used as a substitute for natural river sand in concrete production. M-sand offers advantages such as consistent quality, reduced environmental impact from quarrying, and improved particle shape, which can enhance the workability and cohesiveness of concrete mixes.

Steel slag (SS), a by-product of the steel manufacturing process, has emerged as a promising supplementary cementitious material due to its pozzolanic and latent hydraulic properties. Incorporating SS in concrete not only contributes to the sustainability by reducing waste but also improves durability properties such as resistance to chloride penetration and sulfate attack. The combination of M-sand and SS in SCC holds promise for achieving superior mechanical properties and enhanced durability compared to conventional concrete mixes. However, the effectiveness of these materials in SCC needs to be systematically evaluated through experimental investigations. This study aims to fill this gap by conducting a comprehensive experimental investigation into the effects of M-sand and SS on the durability and workability of SCC.

Significance of the Study:

The findings of this research are expected to provide valuable insights into optimizing SCC mixes using sustainable materials like M-sand and SS. By enhancing the understanding of how these materials influence the fresh and hardened properties of SCC, the study aims to contribute to the development of more durable and sustainable concrete structures. This is particularly relevant in the context of modern construction practices that emphasize environmental responsibility and resource efficiency.

In conclusion, this experimental study seeks to advance the knowledge base on SCC technology by exploring the potential of M-sand and SS as viable alternatives to conventional materials. By addressing both durability and workability aspects, the research aims to support the adoption of eco-friendly and high-performance concrete solutions in the construction industry

.Steel Slag

Steel slag (SS) is a by-product generated during the steelmaking process, typically from the conversion of iron to steel in a blast furnace. It consists primarily of calcium, magnesium, aluminum, silica, and iron oxides in varying proportions, depending on the specific steelmaking process and raw materials used. The composition of steel slag can vary widely, but a typical composition may include the following components:

a. **Calcium Oxide (CaO):** Essential for cementitious properties and contributes to the strength and durability of concrete.
b. **Magnesium Oxide (MgO):** A stabilizer in concrete, enhancing durability and resistance to chemical attack.
c. **Silica (SiO_2):** Contributes to the pozzolanic activity of steel slag, enhancing long-term strength and durability.
d. **Aluminum Oxide (Al_2O_3):** Affects the hydraulic properties and chemical stability of steel slag in concrete.
e. **Iron Oxides (FeO, Fe_2O_3):** Provide coloring and can affect the reactivity of steel slag in concrete applications.

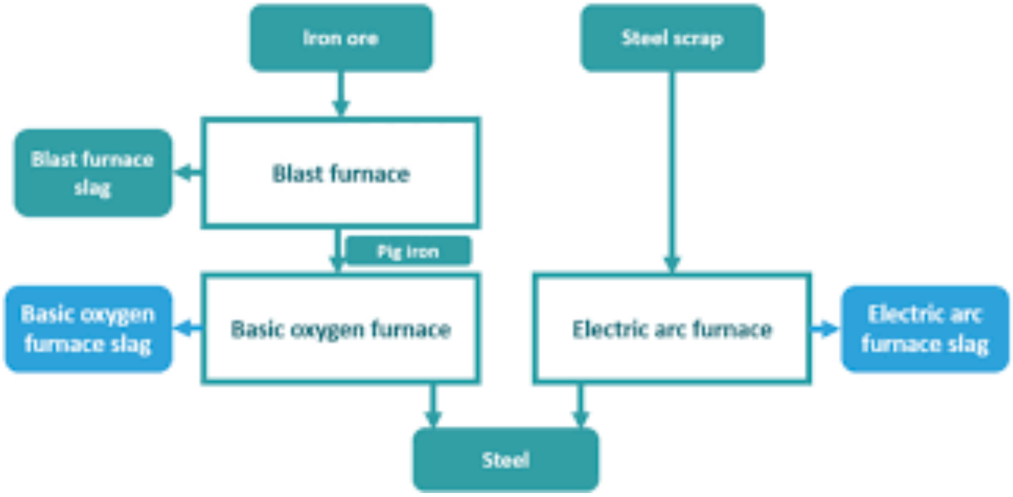
The chemical composition of steel slag makes it suitable for use as a supplementary cementitious material in concrete production. When finely ground, steel slag can exhibit pozzolanic properties, meaning it reacts with calcium hydroxide ($Ca(OH)_2$) in the presence of water to form additional calcium silicate hydrate (C-S-H) gel. This reaction contributes to the

densification of concrete microstructure, reducing permeability and improving resistance to chemical attacks such as chloride ingress and sulfate exposure.
The pozzolanic activity of steel slag can be quantified by measuring its calcium hydroxide consumption over time, often represented by the pozzolanic activity index (PAI). PAI is calculated based on the percentage of calcium hydroxide consumed by the pozzolanic material in a specified period, typically up to 28 days. Higher PAI values indicate greater pozzolanic activity, which correlates with improved concrete performance in terms of strength and durability.
In concrete mixtures, steel slag is typically used as a partial replacement for cement or as a fine aggregate, depending on its particle size distribution and desired engineering properties. The incorporation of steel slag in concrete not only enhances its mechanical properties but also contributes to sustainable construction practices by reducing greenhouse gas emissions associated with cement production and providing a beneficial use for industrial by-products. Therefore, steel slag represents a valuable resource for enhancing the sustainability and performance of concrete in construction applications. The main categories of slag created by the steel industries are listed below.
1. Basic-Oxygen-Furnace (BOF) slag
2. Electric-Arc-Furnace (EAF) slag and
3. Ladle slag.

1.1.1. Steel Slag Production

Millions of tonnes of steel slag are produced annually all over the world. The slag produced by steel mills covers a large area, and the wind carries the little slag particles. As a result, the steel slag causes land occupation issues for the affected industries as well as environmental problems for the general public. Steel slag can be utilised as an alternative material to natural granite metal in the production of concrete since it has strength and other qualities that are comparable to granite metal (Khan & Nasir, 2021). Steel slag can be utilised as an alternative material to natural granite metal in the production of concrete since it possesses strength and other qualities that are comparable to granite metal.

Figure: 1. Production process of steel slag



1.1.2. Properties of steel slag

The slag that is created is typically highly angular, porous, and has a rough surface roughness. Depending on the furnace, raw materials, and slag formers (fluxing agents) used to create the steel, the slag's chemical characteristics change. Steel slag has a rough, vesicular structure with plenty of unconnected cells, which results in a larger surface area than smoother aggregates of the same volume. This characteristic offers a strong connection with cement paste. High bulk specific gravity and average water absorption characterise steel slag. Although steel slag aggregate has a high density, most of its other physical characteristics are superior to those of hard conventional rock aggregates (Manuel G Beltran, 2020). Processed steel slag provides advantageous mechanical features for usage as an aggregate, such as strong bearing strength, good soundness characteristics, and good abrasion resistance. In conclusion, SSA is porous and angular, has a high specific gravity, is more resistant to abrasion and impact, is very stable due to high internal friction angles, has a high load carrying capacity as determined by the CBR, and has hardness that is similar to quartz. Calcium oxide (CaO), silicon oxide (SiO_2), iron oxide (Fe_2O_3), magnesium oxide (MgO), manganese oxide (MnO), and aluminium oxide make up the majority of the slag-derived aggregate (Al_2O_3). Steel slag aggregate are found to maintain heat far longer than traditional natural aggregates due to their high heat capacity. In cold weather, the steel slag aggregate's ability to retain heat is helpful for hot mix asphalt repair projects (Mathew, 2020).

2. Literature Review

Steel slag (SS) is increasingly recognized as a potential alternative material in concrete production due to its unique chemical composition and beneficial properties. This literature review synthesizes findings from various studies investigating the utilization of steel slag in concrete, focusing on its effects on durability and workability.

Table 1- Literature summary

S.no	Author(s)	Year	Major Key Finding	Research Gap

1	Hisham, Q.	2021	Recycled slag coarse aggregate enhances fresh properties of Self-Compacting Concrete (SCC).	Need for further studies on long-term durability of SCC with recycled slag.
2	Khan and Shinde	2020	Unprocessed steel slag improves shear strength of concrete when used as fine aggregate.	Lack of comprehensive studies on the effect of varying slag content on concrete properties.
3	Khan, K.A. et al.	2021	Incorporating steel-making slag in SCC with Ethylene Vinyl Acetate enhances both fresh and hardened properties.	Limited research on the combined effects of additives and slag in SCC formulations.
4	Mathew, P. et al.	2020	Steel slag improves the performance of concrete pavements.	Few studies on the specific mechanisms by which slag enhances pavement durability.
5	Rehman, S. et al.	2021	Glass powder and granular steel slag combination enhances fresh and mechanical properties of SCC.	Need for standardized methods to assess the combined effects of multiple additives in SCC.
6	San-Jose, J.T. et al.	2021	Performance of steel-making slag concretes in hardened state meets industry standards.	Further investigations into long-term durability and environmental impacts are needed.
7	Sosa, I. et al.	2020	High-performance SCC using electric arc furnace slag and cupola slag powder shows promising results.	Limited studies on the scalability of these high-performance SCC mixtures.
8	Tarawneh, S.A. et al.	2020	Steel slag aggregates enhance mechanical properties of concrete.	Need for studies on the effect of slag aggregate on long-term durability under harsh conditions.
9	Van Oss, H.G.	2021	Steel slag is a valuable resource due to its chemical composition and availability.	More research needed on optimizing slag processing and integration in concrete production.
10	Zheng Jian-Ian & Huang Li-pin	2020	Carbonation resistance of SCC containing steel slag is significantly improved.	Further studies required to understand the long-term carbonation behavior of slag concrete.

Hisham, Q. (2021)

Hisham conducted a study focusing on the use of recycled slag coarse aggregate in Self-Compacting Concrete (SCC). The research highlighted that incorporating slag enhances the fresh properties of SCC, making it easier to handle and ensuring better flowability during placement. However, the study identified a research gap in the need for further investigations into the long-term durability of SCC with recycled slag aggregates.

Khan and Shinde (2020)

Khan and Shinde explored the effect of unprocessed steel slag on the shear strength of concrete when used as fine aggregate. Their findings indicated that steel slag can significantly improve the shear strength properties of concrete. However, the literature review highlighted a lack of comprehensive studies examining the optimal slag content for achieving desired concrete properties.

Khan, K.A. et al. (2021)

In their research, Khan et al. investigated the incorporation of steel-making slag and Ethylene Vinyl Acetate (EVA) in SCC. The study demonstrated that combining steel slag with EVA enhances both the fresh and hardened properties of SCC. However, the review pointed out a research gap in the need for further studies focusing on the synergistic effects of additives and slag in SCC formulations.

Mathew, P. et al. (2020)

Mathew et al. studied the application of steel slag in concrete pavements. Their findings suggested that incorporating steel slag improves the performance and durability of concrete pavements. However, there is limited literature on the specific mechanisms through which steel slag enhances pavement durability, highlighting the need for further research in this area.

Rehman, S. et al. (2021)

Rehman et al. investigated the combined influence of glass powder and granular steel slag on the fresh and mechanical properties of SCC. The study concluded that the combination of glass powder and steel slag enhances the fresh workability and mechanical strength of SCC. Nevertheless, the literature review identified a gap in standardized methods for assessing the combined effects of multiple additives in SCC.

San-Jose, J.T. et al. (2021)

San-Jose and colleagues evaluated the performance of concrete made with steel-making slag in the hardened state. Their research indicated that steel slag concretes meet industry standards for performance in various applications. However, there is a need for further investigations into the long-term durability and environmental impacts associated with the use of steel slag in concrete.

Sosa, I. et al. (2020)

Sosa et al. studied the development of high-performance Self-Compacting Concrete (SCC) using electric arc furnace slag and cupola slag powder. Their findings suggested that SCC with slag aggregates exhibits promising mechanical properties. However, the review highlighted a gap in research focusing on the scalability of high-performance SCC mixtures containing slag.

Tarawneh, S.A. et al. (2020)

Tarawneh et al. investigated the effect of using steel slag aggregates on the mechanical properties of concrete. Their research indicated that incorporating steel slag aggregates enhances the compressive and flexural strength of concrete. However, there is a need for further studies to understand the long-term durability performance of concrete with slag aggregates under various environmental conditions.

Van Oss, H.G. (2021)

Van Oss reviewed the literature on the utilization of steel slag as a valuable resource in concrete production. The study highlighted the chemical composition and availability of steel slag as key advantages for its use in concrete. However, the review identified a gap in research focusing on optimizing slag processing techniques and integrating slag in concrete production for enhanced sustainability.

Zheng Jian-Ian & Huang Li-pin (2020)

Zheng and Huang conducted research on the carbonation resistance of SCC containing steel slag. Their findings indicated that steel slag significantly improves the carbonation resistance of concrete, thereby enhancing its durability. However, the literature review emphasized a need for further studies to investigate the long-term carbonation behavior and performance of slag concrete in various structural applications.

2.1. Research problem

Steel slag aggregates have been the subject of several researches, and the majority of the findings indicated that the durability and workability of the concrete may be enhanced. Although there is insufficient data to conclusively determine the ideal steel slag ageing duration and the impacts of various steel slag ageing periods on concrete qualities, it is evident from the literature that steel slag must be allowed to age before it is utilised as aggregate. Therefore, a thorough analysis of the impact of various steel slag and manufactured sand ageing durations on the workability and durability of self-compacting concrete has been conducted in this research (Ríos, Vahí, Leiva, Martínez-De la Concha, & Cifuentes, 2021). There are various types of slag produced by various steel-making processes, including basic oxygen slag, slag from electric arc furnaces, slag from electric induction furnaces, and slag from ladles, among others. Only the utilisation of locally accessible electric induction furnace slag in concrete is the subject of this investigation.

2.2. Objectives of the study

1. To investigate the fresh properties of SCC containing M-sand and SS, including flowability and viscosity.
2. To assess the compressive strength development of SCC with varying proportions of M-sand and SS.
3. To evaluate the durability performance of SCC in terms of resistance to chloride penetration and sulfate attack.
4. To compare the performance of SCC with M-sand and SS against conventional SCC mixes.

3. Materials and Method

There are numerous experimental tools and techniques available for measuring and assessing the viability of SCC. After careful examination, the slump flow test, J-ring test, sieve analysis, and visual stability index were chosen to assess the workability of SCC with various substitute rates of steel slag as fine aggregates. The three categories of these methods are fundamental workability, static stability, and dynamic stability. Table 1 displays the chosen test techniques and evaluation indices.

Table: 2. Test and evaluation method of workability for SCC

Method Types	Evaluating Method	Evaluating Indicator	Workability
Basic workability	Slump flow test	Slump flow diameter (SF)	Filling ability
	T500 test	Slump flow time (T500)	Filling ability
	J-ring test	J-ring spread diameter (SFJ)	Passing ability
		J-ring height difference (Δh)	
Dynamic stability	Visual stability	Visual stability index	Segregation

		(VSI)	resistance
Static stability	Sieve analysis	Segregation rate (SR)	Segregation resistance

3.1. Choice of Suitable Constituents of SCC

The selection of the necessary constituents when constructing the SCC's proportioning and the correct research have created a requirement for the evaluation of their material qualities in order to learn more about how different materials interact with one another and make the most use of them. The elements are utilised to proportion this SCC of M20, M30, and M40 grade concrete, with steel slag and M-Sand serving to partially replace the fine aggregate.

3.1.1. Material Constituents

The following things are shown below as the material constituents used in proportioning the SCC. Enhanced SCC is achieved through careful material selection, management, and proportioning of every component (San-Jose, 2021).

- **Cement**

In this experimental study, ordinary Portland cement (OPC) of grade 53 that complies with IS 12269-1987 is employed. According to IS 4031-1988 testing, the physical and mechanical characteristics of cement are listed in Table 2.

Table: 3. Physical and mechanical properties of cement

Specific gravity	Standard consistency	Initial setting time	Final setting time	Compressive strength (MPa)			Soundness (Lechatelier)
				3 Days	7 Days	28 Days	
4.08	34%	59 min	217 min	28.46	42.57	59.24	5 mm

- **Steel slag aggregate**

Raja Steels Private Ltd, Coimbatore, India, created the steel slag. Boulders made of steel slag were obtained. Table 3 lists the chemical make-up of steel slag that was collected from the producer. It should be mentioned that the Japanese code JISA5011, "Slag Aggregate for Concrete," specifies an acceptable limit of CaO as 45%.

Table: 4. Chemical composition of steel slag

Chemical compound	% by weight						
	Present study	Wang (2002)	FHWA (2008)	Moon (2012)	Fujii (2017)	Netinger (2020a)	Saaid (2021)
SiO_2	18.04	15.22	12-20	16.43	13.00	15.26	30.34
Al_2O_3	11.17	5.00	2-32	7.32	3.78	9.61	5.19

Fe_2O_3	27.72	27.24	12-44	16.99	19.46	27.69	28.20
MgO	6.18	10.21	7-13	9.68	8.52	9.44	8.45
CaO	40.52	40.32	42-54	37.34	47.83	33.55	34.22
Na_2O	0.18	0.15	-	-	-	0.15	0.11
K_2O	0.12	0.06	-	-	-	0.10	0.07
Insoluble residue	8.92	-	-	-	-	-	-
Loss of ignition	0.32	-	-	-	-	6.73	-

- **Fly ash**

High performance concrete is made using Class F Fly ash (FA) of Specific Gravity 2.15 that was obtained from the Mettur Thermal Power Station and confirms to IS 3812:2003. Fly ash obtained from the factory is listed with its physical characteristics and chemical make-up in Tables 5 and 6, respectively.

Table: 5. Physical properties of fly ash

Property	Value
Physical form	Powder form
Bulk density (kg/m^3)	754
Specific gravity	3.12
Specific surface area (m^2/kg)	358

Table: 6. Chemical composition fly ash

Chemical component	% by weight
SiO_2	59.58
Al_2O_3	34.42
Fe_2O_3	6.63
MgO	0.85
CaO	2.12
Na_2O	0.24
K_2O	0.96
Loss of ignition	3.41

- **Water**

Given that it actively participates in the chemical interactions with cement, water is a crucial component of concrete. The binding power of the hydrate cement gel is primarily responsible for the strength of cement concrete. For mixing concrete and curing the specimens, potable tap water with a pH range of 7.0 to 11 that complies with IS: 456-2000 criteria is made accessible in the lab (Sivakumar, 2021).

- **M-Sand**

M-sand, which is utilised as fine aggregate, is comparable to natural Zone II sand. Table 7 lists the physical characteristics of M-sand that confirm to IS 2386 (Part III) 1963.

Table: 7. Physical properties of manufactured sand

Properties	Results
Specific gravity	4.56
Fineness modulus	4.69
Bulk density (kg/m^3)	1872
Water absorption	2.6%

The materials analysis shows that while the workability of concrete is decreased by the fine aggregate gradation and characteristics of steel slag and m-sand, the durability of the concrete is increased.

4. Result and Discussion

The mix proportions for M20, M30, and M40 SCC were determined by substituting 100% steel slag for coarse material.

Figure: 2. Mix proportion for SCC – M20 grade with 100% steel slag as coarse aggregate

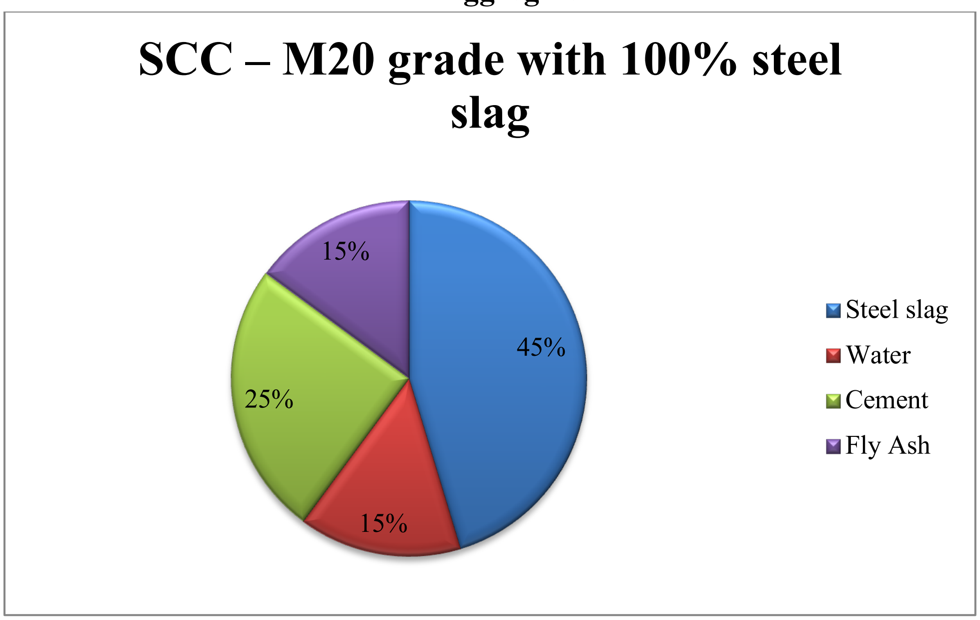


Figure: 3. Mix proportion for SCC – M30 grade with 100% steel slag as coarse aggregate

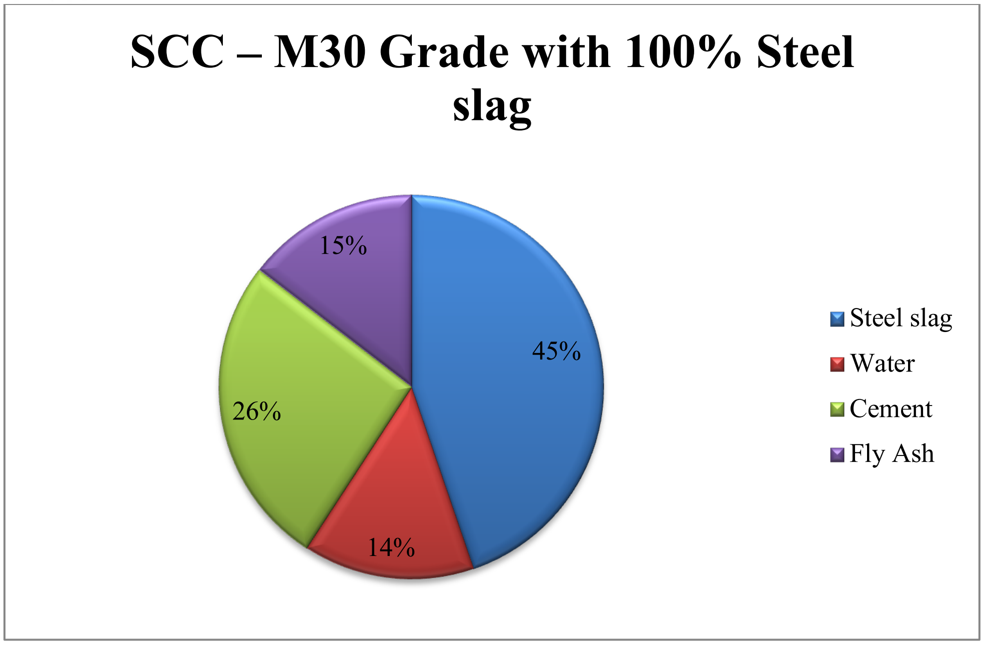
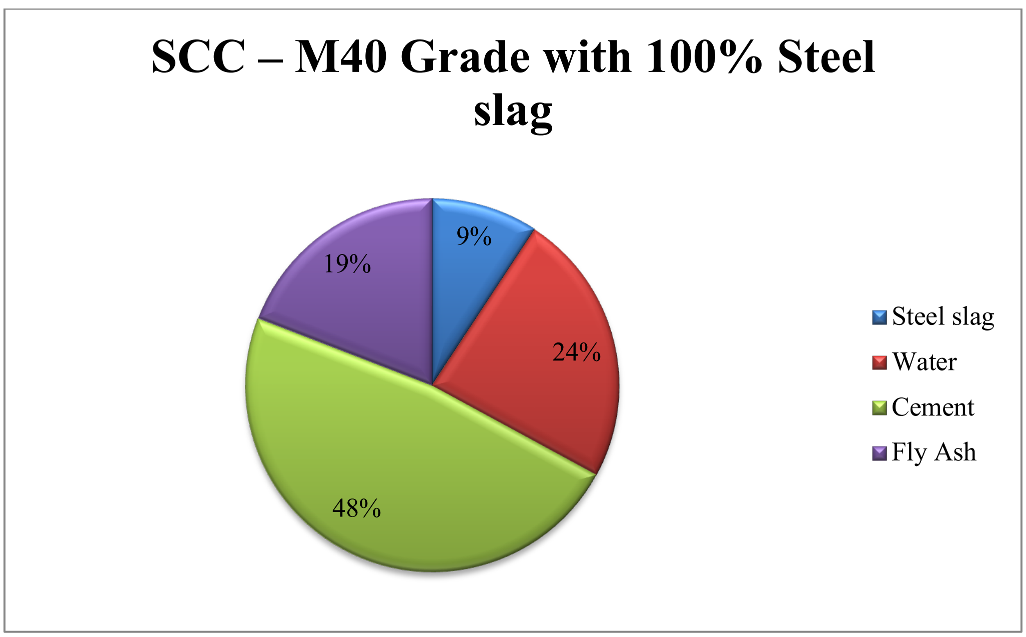


Figure: 4. Mix proportion for SCC – M40 grade with 100% steel slag as coarse aggregate



The analysis demonstrates that a high ground friction resistance between coarse aggregate and fine aggregate results in a large flow time and generally poor filling performance of SSCC when the replacement ratio of steel slag sand is high. The optimal replacement proportions of M20, M30, and M40 grade SCC with steel slag have been examined for their durability features. It has been found that SCC with M-sand and steel slag produces better results in the characteristics, increasing the structure's longevity (Sosa, Thomas, Polanco, Setién, & Tamayo, 2021).

5. Conclusion

The development of Self-Compacting Concrete (SCC) represents a novel approach aimed at effectively utilizing industrial waste. In response to the scarcity of river sand, a valuable natural resource, the incorporation of industrial by-products such as steel slag and M-sand offers a sustainable solution. Steel slag and M-sand serve as partial substitutes for fine aggregates, promoting environmental conservation and reducing reliance on natural resources. Blending M-sand with fine aggregate decreases microfines content, enhancing the workability, strength, durability, and structural integrity of SCC.

Steel slag is recognized in literature as a promising alternative to natural aggregates, albeit requiring an aging process before application as aggregate material. Various perspectives exist on the optimal aging period for steel slag, with limited research investigating its effects on SCC properties. Evaluation of steel slag's suitability as concrete aggregate hinges on tests assessing strength and durability properties, determining the ideal aging duration.

The aging process of steel slag aggregates and M-sand significantly enhances the properties of SCC. Studies indicate that extending the aging period of steel slag aggregates improves the workability and durability of SCC (Tarawneh, 2020). Steel slag aggregate can effectively substitute natural granite coarse aggregate in SCC, contributing to reduced environmental impact, resource depletion, and construction costs.

Overall, leveraging steel slag and M-sand in SCC production not only addresses environmental concerns but also enhances the performance and sustainability of concrete structures. Further research is essential to optimize aging protocols for steel slag and validate its long-term benefits in various concrete applications.

References

1. DzExperimental investigation of using slag as alternative to normal aggregates (coarse and fine) in concretedz. International Journal Of Civil and Structural Engineering. Vol. 3, pp 117-127, 2020.
2. Erdem & Kambiz Ramyar 2021, ‘Permeability properties of selfconsolidating concrete containing various supplementary cementitious materials’, Science Direct, pp.326-336.
3. Hisham, Q. Towards Sustainable Self-Compacting Concrete: Effect of Recycled Slag Coarse Aggregate on the Fresh Properties of SCC. Adv. Civ. Eng. 2021, 2021, 1–9.
4. Khan andShinde(2020) ‘Effect of Unprocessed Steel Slag on Shear Strength of Concrete when used as Fine Aggregate,’ International Journal of IT, Engineering and Applied Sciences Research (IJIEASR), vol.2,no.4.
5. Khan, K.A.; Nasir, H.; Alam, M.; Wali Khan, S.; Ahmad, I.; Rehman, Z.U. Investigation of Fresh and Hardened Characteristics of Self-Compacting Concrete with the Incorporation of Ethylene Vinyl Acetate and Steel-Making Slag. Adv. Civ. Eng. 2021, 2021, 1–11.

6. Manuel G Beltran, Auxi Barbudo & Francisco Agrela, Adela P Galvin, Jose Ramon Jimenez 2020, 'Effect of cement addition on the properties of recycled concretes to reach control concretes strengths', Science Direct, vol.79, pp.124-133.
7. Mathew, P, Stephen, L & George, J 2020, ‗Steel Slag Ingredient for Concrete Pavement,' International Journal of Innovative Research in Science, Engineering and Technology, vol. 2, no. 3, pp. 710-714.
8. Nadeem andPofale(2020) 'Experimental investigation of using slag as an alternative to normal aggregates (coarse and fine) in concrete', International Journal of Civil and Structural Engineering,vol.3,no 1.
9. Nili, M.; Sasanipour, H.; Aslani, F. The Effect of Fine and Coarse Recycled Aggregates on Fresh and Mechanical Properties of Self-Compacting Concrete. Materials 2021, 12, 1120.
10. P. Dinakar, M. Kartik Reddy, Mudit Sharma DzBehaviour of self compacting concrete using Portland Pozzolana cement with different levels of fly ashdz. Material and Design Journal of ELSEVIER Vol. 46, pp 609-616, 2020.
11. Papayianni, I, & Anastasiou, E 2020, ‗Concrete Incorporating HighCalcium Fly Ash and EAF Slag Aggregates,' Magazine of Concrete Research, vol. 63, no. 8, pp. 597-604.
12. Pellegrino, C, & Faleschini, F 2020, ‗Experimental Behavior of Reinforced Concrete Beams with Electric Arc Furnace Slag as Recycled Aggregate,' ACI Materials Journal, vol. 110, no. 2, pp. 197- 206.
13. Pengand Hwang (2020), 'Carbon steel slag as cementitious material for self-consolidating concrete', Journal of Zhejiang University- SCIENCE A (Applied Physics & Engineering) vol. 11, no.7, pp.488 494
14. Rehman, S.; Iqbal, S.; Ali, A. Combined influence of glass powder and granular steel slag on fresh and mechanical properties of self-compacting concrete. Constr. Build. Mater. 2021, 178, 153–160.
15. Ríos, J.D.; Vahí, A.; Leiva, C.; Martínez-De la Concha, A.; Cifuentes, H. Analysis of the Utilization of Air-Cooled Blast Furnace Slag as Industrial Waste Aggregates in Self-Compacting Concrete. Sustainability 2021, 11, 1702.
16. Sable andRathi (2020), 'Comparison of normal compacted concrete and Self compacted concrete in shear and torsion', International journal of computer technology and electronics Engineering (IJCTEE), vol.2, issue.4, pp.74-78.
17. San-Jose, JT, Vegas, I, Arribas & Marcos I 2021, ‗The Performance of Steel-Making Slag Concretes in the Hardened State,' Materials and Design, vol. 60, pp. 612-619.
18. Sivakumar, N, Muthukumar, S, Sivakumar, V, Gowtham, D & Muthuraj, V 2021, 'Experimental studies on high strength concrete by using recycled coarse aggregate', International Journal of Engineering and Science, vol.4, issue.1, pp.27-36.
19. Sosa, I.; Thomas, C.; Polanco, J.A.; Setién, J.; Tamayo, P. High Performance Self-Compacting Concrete with Electric Arc Furnace Slag Aggregate and Cupola Slag Powder. Appl. Sci. 2020, 10, 773.

20. Tarawneh, SA, Gharaibeh, ES & Saraireh FM 2020, ‗Effect of Using Steel Slag Aggregate on Mechanical Properties of Concrete,' American Journal of Applied Sciences, vol. 11, no. 5, pp. 700-706.
21. Thomas, C, Setien, J, Polanco, JA, Alaejos, P & Sanchez de Juan, M 2020, 'urability of recycled aggregate concrete', Science Direct, vol.40, pp.1054-1065.
22. Van Oss, H.G. 2021, ‗Iron and Steel Slag,' Mineral Commodity Summaries 2021, U.S. Geological Survey, Reston.
23. Venkataram Pai, BH, Maitreyee Nandy, Krishnamoorthy, A & Pradip Kumar Sarkar, 2020, 'Development of Self Compacting Concrete with various mineral admixtures', American Journal of Civil Engineering, issue.2, no.3, pp.96-101.
24. Zheng Jian-Ian & Huang Li-pin, 2020, 'Study on carbonation resistance of Self-Compacting Concrete containing massive mineral admixture', CNKI Journal.
25. ZHENG Jian-lan & HUANG Li-pin, 2021, 'Experimental study on carbonation of self-compacting concrete under tensile and compressive strength', CNKI.