International Journal of Applied Engineering & Technology

INVESTIGATION INTO THE USE OF STEEL SLAG AND MANUFACTURED SAND IN ENHANCING SELF-COMPACTING CONCRETE PROPERTIES

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

ABSTRACT

Due to its unique and solidifying properties, self-compacting concrete (SCC) is considered an advanced construction material in the industry. As natural sand deposits deplete and environmental concerns rise, artificial sand is increasingly replacing natural sand in fine aggregate applications. This study investigates how different fineness modulus (FM) values of manufactured sand (2.4, 2.6, 2.8, 2.9, and 3.2) affect the initial properties of SCC while maintaining the required quality of fine aggregate. Four test methods—slump flow, T55cm, V-channel, and L-box—were employed to evaluate the performance.

Results indicate that SCC with an FM value of 2.8 exhibited superior characteristics compared to lower FM values. It was observed that as the FM value increased from 2.4 to 2.8, the fresh properties of SCC improved due to a decrease in the finer portion. Conversely, increasing the FM value from 2.8 to 3.2 decreased the fresh properties of SCC as the coarser portion increased. Therefore, achieving adequate fresh properties of SCC necessitates maintaining an appropriate balance between the finer and coarser components of manufactured sand.

Keywords: Self-compacting concrete, manufactured sand, fineness modulus, fresh properties, fine aggregate.

1. INTRODUCTION

Steel slag, a prominent by-product of the iron and steel manufacturing process, has emerged as a significant environmental and resource management concern due to its rapid accumulation. Globally, steel production generates 15% to 20% of crude steel output as steel slag, highlighting its substantial volume and environmental impact. For instance, in 2018, China alone produced 928 million tons of crude steel and 150 million tons of steel slag, underscoring the scale of this issue (China Economic Network, 2018).

Self-compacting concrete (SCC) represents a cutting-edge development in the construction industry, offering advantages such as rapid placement, enhanced efficiency, and reduced labor requirements. Initially conceived and researched at Tokyo University, Japan, by Okamura (1995), SCC eliminates the need for mechanical compaction by flowing under its weight to completely fill formwork. The design of SCC mixes, crucial for achieving desired performance, follows the "Japanese model method" or "step-by-step method," where initial mix proportions significantly influence SCC's final properties (Kanadasan et al., 2015).

Aggregate, comprising 70% of concrete volume, is crucial for concrete production. Traditional sand, a primary fine aggregate, faces scarcity and environmental concerns due to unsustainable extraction practices from rivers. This situation has led researchers, like Weiwu (2010), to explore alternatives, including industrial by-products such as steel slag (SS). Produced during steelmaking, SS can vary widely in composition depending on the steelmaking process, typically yielding 130 to 200 kg of slag per ton of steel produced (Furlani, 2010).

The incorporation of steel slag as a substitute aggregate in concrete has been studied extensively for its potential to improve concrete properties. Studies have shown that concrete containing slag exhibits refined pore structures compared to conventional Portland cement due to reduced drying shrinkage and improved durability (Bouikni, 2009). Moreover, the replacement of natural aggregates with slag aggregates reduces concrete density, offering advantages in applications requiring lighter weight (Rainova, 2012).

Research efforts have focused on evaluating the performance of SCC incorporating slag aggregates. For instance, Ríos et al. (2019) examined SCC's flow characteristics when incorporating air-cooled blast furnace slag, finding that substitution levels affect self-compacting properties. Similarly, Valizadeh et al. (2019) studied heavyweight SCC using magnetite aggregate, demonstrating that increasing aggregate replacement levels adversely affect fresh concrete properties.

Furthermore, studies like Khan et al. (2010) have explored enhancing SCC performance by incorporating additives like ethylene vinyl acetate (EVA) and furnace slag, evaluating properties through various tests such as slump flow, V-funnel, L-box, and J-ring tests. Their findings underscore the complex interaction between different additives and slag content on SCC performance.

In conclusion, while steel slag presents challenges as a waste product, its incorporation into concrete offers promising environmental and performance benefits. Ongoing research aims to optimize SCC formulations incorporating slag to enhance sustainability and construction efficiency.

Application of Steel Slag in normal and Self-Compacting Concrete

Steel slag, a by-product of steel production, has gained attention for its potential applications in both normal concrete (NC) and self-compacting concrete (SCC) due to its unique properties and environmental benefits. This discussion explores its application in these concrete types.

Steel Slag in Normal Concrete (NC)

1. **Substitute for Natural Aggregates:** Steel slag can replace traditional coarse and fine aggregates in NC. Studies (Furlani, 2010) have shown that it offers comparable or even superior mechanical properties to natural aggregates due to its angular shape and good bonding with cement paste.
2. **Enhanced Durability and Strength:** Concrete incorporating steel slag exhibits improved durability characteristics such as higher resistance to chemical attack and abrasion. This is attributed to its dense structure and the formation of a protective layer of hydration products over time (Bouikni, 2009).
3. **Reduction in Environmental Impact:** Utilizing steel slag in NC reduces the environmental footprint by minimizing the depletion of natural resources like river sand and gravel. It also reduces CO2 emissions associated with traditional aggregate production (Pellegrino, 2009).
4. **Challenges:** One of the challenges in using steel slag in NC is its variability in composition, which can affect concrete properties. Proper quality control and testing are essential to ensure consistent performance (Van Oss, 2021).

Steel Slag in Self-Compacting Concrete (SCC)

1. **Flowability and Workability:** SCC is designed to flow under its own weight, filling formwork without the need for vibration. Steel slag, when used as aggregate in SCC, enhances its flowability and workability due to its particle shape and surface texture (Khan et al., 2010).
2. **Improved Consolidation and Placement:** The use of steel slag in SCC results in better consolidation and improved placement efficiency. This is crucial for complex structures where access is limited, reducing labor costs and construction time (Ríos et al., 2019).
3. **Impact on Fresh and Hardened Properties:** Studies (Valizadeh et al., 2019) have indicated that SCC containing steel slag maintains its fresh properties while improving hardened properties such as compressive strength and durability. The slag's chemical composition influences these properties positively.
4. **Optimization and Research Needs:** Further research is needed to optimize the mix design of SCC incorporating steel slag. This includes understanding the effects of slag particle size distribution, chemical composition, and curing conditions on SCC performance (Rainova, 2012).

1.1. The Feasibility of SCC

Self-Compacting Concrete (SCC) has emerged as a revolutionary material in the construction industry due to its ability to flow and consolidate under its own weight without the need for mechanical vibration. This section explores the feasibility of SCC, discussing its advantages, challenges, and applications.

Advantages of SCC

1. **Enhanced Workability and Flowability:** SCC exhibits excellent workability, easily filling intricate and congested formwork without segregation. This property is particularly advantageous in complex concrete structures where traditional compaction methods are impractical (Okamura, 1995).
2. **Time and Labor Savings:** The self-consolidating nature of SCC reduces construction time by eliminating the need for vibration, leading to faster placement and improved productivity. This saves labor costs and accelerates project schedules (Kanadasan et al., 2015).
3. **Improved Quality and Surface Finish:** SCC produces high-quality concrete with superior surface finish and texture due to its ability to flow uniformly and fill mold contours effectively. This results in aesthetically pleasing concrete surfaces without defects (Kanadasan et al., 2015).
4. **Reduced Noise and Environmental Impact:** Compared to traditional concrete placement methods involving vibration, SCC operations generate less noise and vibration, minimizing disturbance to surrounding areas. This makes SCC suitable for urban environments and sensitive construction sites (Okamura, 1995).

Challenges and Considerations

1. **Mix Design and Optimization:** Designing an optimal SCC mix requires careful consideration of materials, proportions, and rheological properties to achieve desired flowability and performance. Variability in raw materials, such as aggregates and additives, can impact SCC consistency and workability (Okamura, 1995).
2. **Compatibility with Reinforcement:** SCC must ensure compatibility with reinforcement placement to prevent segregation or displacement of steel bars during casting. Proper mix design adjustments and testing are necessary to achieve adequate bond strength between concrete and reinforcement (Kanadasan et al., 2015).
3. **Cost Considerations:** Initial costs of SCC may be higher compared to conventional concrete due to specialized materials and testing requirements. However, potential savings in labor, equipment, and construction time often offset these initial costs over the lifecycle of the project (Okamura, 1995).

Applications of SCC

1. **Highly Reinforced Structures:** SCC is ideal for structures with dense reinforcement patterns, such as columns, walls, and bridge piers, where traditional compaction methods are challenging. It ensures uniform distribution of concrete around reinforcement without voids (Kanadasan et al., 2015).
2. **Architectural Concrete:** SCC is widely used in architectural applications where aesthetics and surface finish are critical. It enables the creation of complex shapes, textures, and exposed finishes without compromising structural integrity (Okamura, 1995).
3. **Precast Concrete Production:** SCC enhances the efficiency of precast concrete production by enabling rapid and reliable casting of intricate molds. This supports mass production of precast elements with consistent quality and dimensional accuracy (Kanadasan et al., 2015).

2. SCOPE OF THE STUDY

The conventional method of enhancing workability in concrete involves increasing water content in the mix. However, this study reveals that incorporating Ethylene Vinyl Acetate (EVA) into concrete enhances its workability without compromising compressive strength. While some researchers suggest that substituting steel-production slag for coarse aggregates could reduce mechanical properties by up to 50% (Gulderen, 2015), recent literature indicates that incorporating Ladle Furnace Slag (LFS) as a fine aggregate improves concrete's mechanical properties and increases compressive strength.

Concrete plays a pivotal role in construction due to its fundamental contribution to structural integrity. However, concrete production requires substantial energy input, leading to significant carbon dioxide emissions (M. S. Imbabi, 2012). The increased concrete demand to achieve enhanced characteristics in Self-Compacting Concrete (SCC) has the potential to escalate construction costs. Therefore, this research explores the feasibility of using EVA as a partial substitute for cement, aiming to simplify material handling, improve mechanical properties, and address these challenges within existing construction practices.

LITERATURE REVIEW

2.1. Application of Steel Slag in The Process of Preparing SCC

Sheen, Le, & Sun (2015) investigated self-compacting concrete (SCC) incorporating tempered steel oxidizing and reducing slags (SSRS) as partial replacements of concrete. Their findings indicated that SCC with tempered steel slag can accelerate the curing process, and SCC with full SSOS replacement shows comparable or slightly improved compressive strength compared to the control, despite potential volume instability.

A. Santamaría (2019) focused on mix design, fresh, and hardened properties of SCC by integrating electric arc furnace slag (EAFS) as aggregate. They concluded that SCC can be successfully produced by blending coarse and fine slag from an electric arc furnace in optimal proportions with appropriate chemical additives.

Hisham (2018) studied the impact of subnormal aggregate steel slag on SCC using various tests including slump flow, V-funnel, column segregation, sieve analysis, segregation test, and U-shaped box tests. The research indicated that while steel slag can be used in SCC, its workability deteriorates when replacing more than 50% of the aggregate.

Rehman, Iqbal, & Ali (2018) explored the combined effect of glass powder and granular steel slag on the fresh and mechanical properties of SCC. They found that the rough and porous surface of steel slag reduces the workability of SCC as its content increases.

Pan Z. (2019) investigated the influence of steel slag powder on SCC using recycled aggregates. They observed that steel slag powder improved the workability of the material but made it prone to segregation.

Sosa, Thomas, Polanco, Setién, & Tamayo (2020) studied the feasibility of high-performance SCC made with EAFS aggregate and vault slag powder. Their experiments demonstrated that a homogeneous, balanced mix can be achieved without segregation or concentration of coarse particles. EAFS significantly reduces SCC's flow slump and passing ability by 10% due to its high viscosity.

V. Subathra Devi (2014) examined steel slag concrete, evaluating the impact of replacing coarse and fine aggregates with steel slag (SS) on the strength and durability of M20 grade concrete. The study indicated that compressive strength decreases with more than 40% fine aggregate replacement and 30% coarse aggregate replacement. Increased substitution reduces concrete workability. Experimental tests included compressive strength, tensile strength, flexural strength, and acid resistance using HCL, H_2SO_4, and rapid chloride penetration. Results showed that steel slag enhances compressive, tensile, and flexural strength in conventional concrete. After acid immersion, samples lost minimal mass. RCC radiation emits to avoid additional loads. ASTM C 1202 sets limits for chloride ion susceptibility. SS concrete is feasible.

J. Guru Jawahar (2012) developed a simple tool for SCC mix design focusing on the initial concrete ingredients. SCC mix design considers the relative proportions of key components by volume rather than mass. The tool was tested with an SCC mix containing 28% coarse aggregate, 35% class F fly ash, 0.36 water/cementitious ratio (by weight), and a 388 liter/m3 paste volume. 60:40 by weight of total coarse aggregate is crushed into 20mm and 10mm stone. This study validates the tool's significance in designing SCC mixes and potentially other SCC materials.

Gaurav Singh (2015) analyzed the use of granulated blast furnace slag (GBFS) in concrete for sustainable infrastructure. Environmental constraints on riverbed sand mining have prompted the construction sector to seek alternatives, particularly in urban areas. This has stressed sand supplies, leading to the exploration of alternatives without compromising concrete strength. GBFS, an industrial waste, offers sustainable applications, reducing solid waste disposal and environmental issues. Tests analyzed using GBFS to substitute natural sand in concrete. The compressive strength of concrete with GBFS was studied. Besides cost analysis, the optimum GBFS usage varies by scenario. Normal conditions require 40% to 50% GBFS, while marine conditions require 50% to 60%. On land and at sea, BFS concrete has twice the strength areas of normal concrete for as long as possible

OBJECTIVE OF THE STUDY

Our study aimed to assess steel slag and manufactured sand's effects on SCC. In this work, we tested the effects of different fineness modulus values (2.4, 2.6, 2.8, 2.9, and 3.2) on fresh SCC characteristics. Slump flow, T_{55cm} slump flow, V-funnel, and L-box tests were undertaken.

3. EXPERIMENTAL SETUP

In this review, normal concrete 53 grade as per IS 12269:1987 and class F fly debris as per ASTM: C 618 were both used. Table 1 or figure 1 records the synthetic and actual qualities of concrete and fly debris.

Table 1: Cementitious material's chemical and physical characteristics

Items	Sand	Class F fly
Chemical Structure		
% Silica	18.23	65.6
% Alumina	6.26	28.0
% Iron Oxide	5.32	4.0
% Lime	62.36	2.0
% Magnesia	0.96	2.0
% Sulphur Trioxide	3.52	0.3
Physical Structure		
Specific Gravity	4.15	3.15
Fineness (m^2/Kg)	412.6.	420

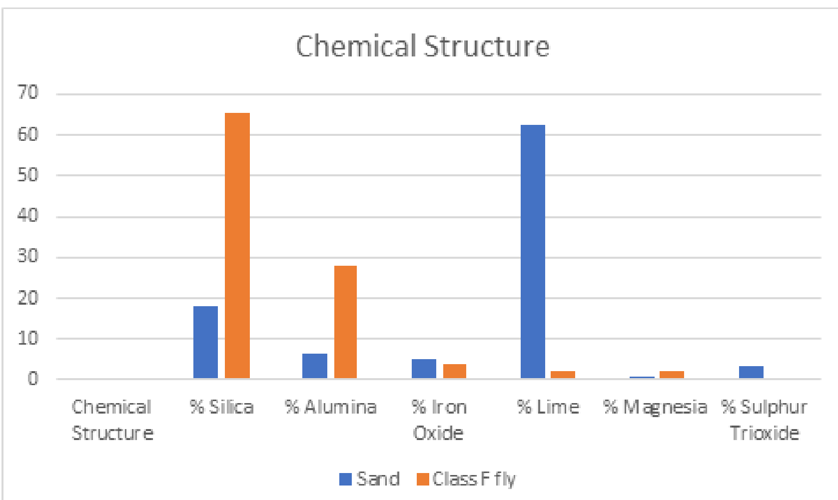

Figure 1: Graphical Representation Cementitious material's chemical and physical characteristics

As coarse total, 12.5 mm-sized squashed rock stones were utilized. The coarse total's mass explicit gravity at stove dry circumstances and water ingestion were 2.7 and 0.3%, separately. The fine total utilized was manufactured sand. The produced sand's mass explicit gravity at broiler dry circumstances and water retention were 2.7 and 2%, individually. As per IS 383:1970, the degree of coarse total and fine total was estimated by strainer examination, and the outcomes are displayed in Tables 2 and 3 or figure 2 and 3. SCC utilized a super plasticizer (SP) in view of polycarboxylate ether. SP had 40% dry material by volume.

Table 2: An aggregate sieve analysis

Sieve size		
Sieve size	**12.5 mm**	**IS 383-1970 limits**
12.5 mm	98.36	80-100
11 mm	42.36	0-50
5.25 mm	7.26	0-10
2.42 mm	1.3	N/A

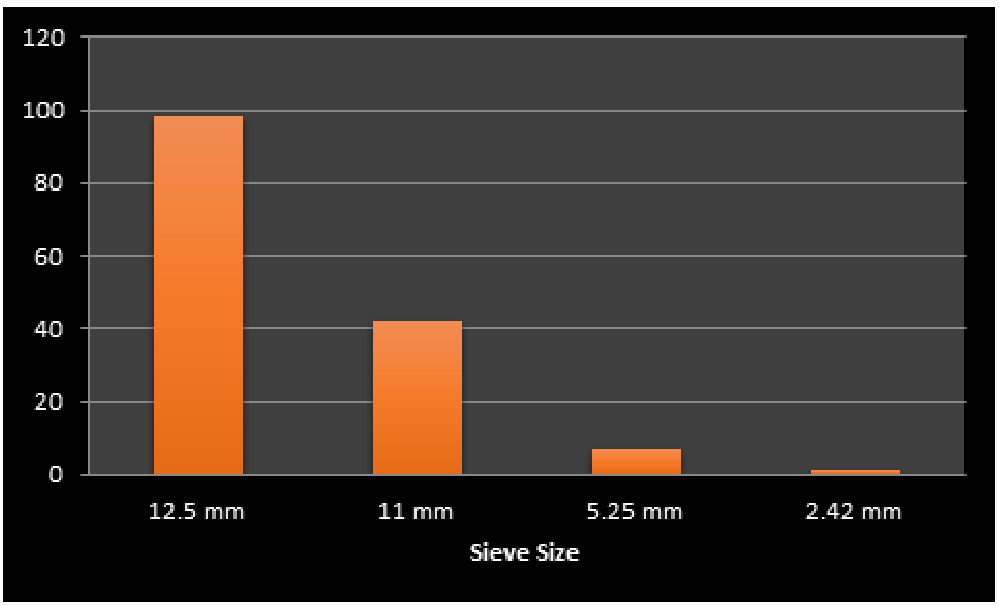

Figure 2: Graphical Representation of an aggregate sieve analysis

Table 3: Analysis by Sieve of Different fineness moduli of sand

Sieve size (mm)	Passing Cumulative %				
	F.M -2.4	**FM-2.6**	**FM -2.8**	**FM-2.9**	**FM-3.2**
4.85	98.00	97.00	93.23	92.36	92.36
2.42	92.36	88.00	85.36	83.26	79.23
1.19	84.00	77.00	80.23	65.36	59.00
0.8	77.00	57.00	50.36	45.23	39.00
0.5	17.23	29.00	25.36	21.36	21.36
0.20	14.00	15.00	11.00	8.23	7.00

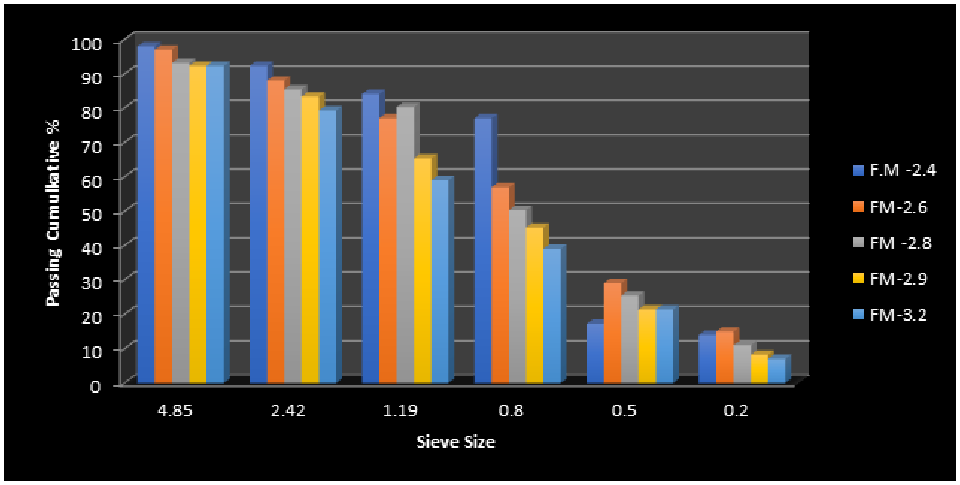

Figure 3: Analysis by Sieve of Different fineness moduli of sand

SCC blends were ready with manufactured sand having different fineness modules (2.4, 2.6, 2.8, 2.9, and 3.2) to assess the SCC new properties [opt]. According to EFNARC (2002), least coarse total substance of 28% was kept up with for every one of the blends. Keeping considering the investment funds in cost and land fill, ozone depleting substance outflows, new, mechanical and solidness properties of SCC, the substitution level of class F fly debris was kept at 45% according to IS 456:2000 for all blends. Keeping considering the moderate fines and all SCC properties, water - Cementitious proportion (w/cm) by weight was kept at 0.36 for all blends. SCC blends have been assigned as SCC_FM2.3, SCC_FM2.5, SCC_FM2.7, SCC_FM2.9 and SCC_FM3.1 separately for different FM upsides of 2.4, 2.6, 2.8, 2.9 and 3.2. Blend extents of all SCC blends are stay same and introduced in Table 4 or figure 4.

Table 4: Combination of Sand Proportion

Combination	**SCC**
w/cm	0.42
Binder, kg/m3	459
Cement	326
Fly ash	185
water	189
Manufactured Sand	875
SP	5.23

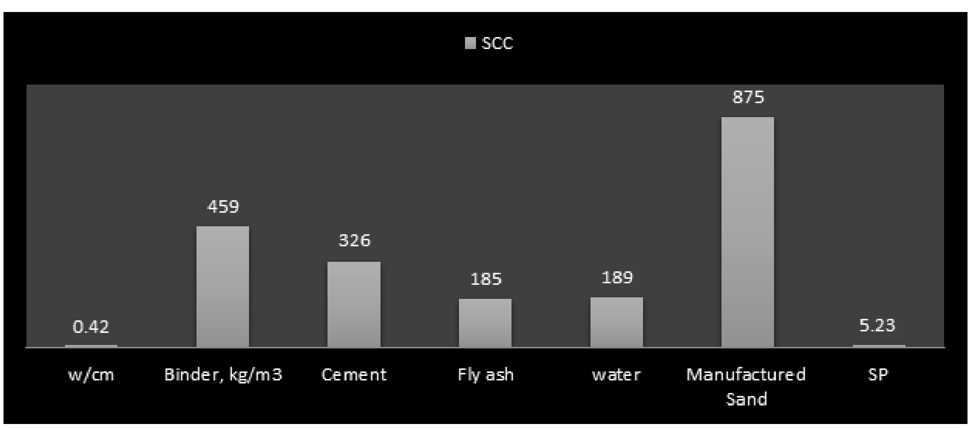

Figure 4: Graphical Representation of Combination of Sand Proportion

The new characteristics of SCGC were assessed by test strategies, for example, droop stream, T_{55cm} Slump flow, V-channel, and L-box, as per EFNARC. The spread of the SCC is surveyed utilizing a downturn stream test. The SCC's not entirely set in stone by estimating T50 cm. Estimations of the V-Funnel time and the L-Box test are utilized to decide the SCC's thickness and entry limit, separately.

4. RESULTS AND DISCUSSION

SCC new properties for every one of the blends, including Slump flow, $T_{55\ cm}$, V-Funnel time, and L-box proportion (h2/h1), are displayed in Table 5.

Table 5: Fresh SCC mix properties

Type of mixture	(mm) value of Slump Flow	T_{55cm}	(Sec) of V-funnel time	L-box Ratio
FM-2.4	590	6.23	16.23	Blocked
FM-2.6	660	5.26	7.23	0.92
FM-2.8	680	3.26	6.23	1.00
FM-2.9	670	4.96	7.96	0.95
FM-3.2	600	5.33	15.36	Blocked
Acceptance Criteria	600-850	4-6	7-14	0.85-0.100

Table 5 shows that the blend FM-2.4 failed the L-box test because of the slump flow spread, T55 cm, and V-channel time upsides of 590 mm, 6.23 sec, and 16.23 sec, separately. This combination can be viewed as a failed blend on the grounds that its new characteristics didn't fulfill SCC acknowledgment norms. It is generally brought about by a higher level of delivered sand that is better and has a lower fineness modulus (2.4). This fabricated sand's better piece has a greater explicit region, which requires more water and glue. The plastic consistency of better particles, which influences the usefulness of SCC, likewise builds because of their rakish shape. It has been concluded that the FM-2.6, FM-2.8, and FM-2.9 blends are sufficiently new to meet the SCC's necessities for acknowledgment. This implies that they are viewed as effective SCC blends.

Out of these three viable blends, FM-2.8's presentation was viewed as perceptibly better than that of FM-2.6 and FM-2.9. It ought to be noticed that the FM-3.2 blend bombed the L-box test and had droop stream spread, T55 cm, and V-channel time upsides of 600 mm, 5.33 sec, and 15.36 sec, individually. This blend likewise qualifies as a bombed combination on the grounds that its new qualities didn't satisfy SCC endorsement principles. It is essentially brought about by an expansion in fabricated sand's coarser division at higher FM levels (3.2). This coarser division has more rakish shapes and a better return pressure, the two of which make SCC harder to work with.

From the outcomes, it is obvious that as FM values expanded from 2.4 to 2.8, the SCC new properties likewise expanded because of a reduction in the better portion. It ought to be noticed that the expansion in FM esteem from 2.8 to 3.2 diminished the SCC's new properties in light of the fact that the coarser division expanded. To get sufficient SCC new properties, it is hence uncovered that legitimate degree of better and coarser parts of produced sand should be kept up with.

Figure 5: V funnel test

Figure 6: L-Box Ratio

Figure 7: Slump Flow Test

5. CONCLUSION

The following inferences can be made in light of the findings of this experimental investigation: Since the mix FM 2.4 comprises a finer component, which raises the plastic viscosity, it failed at a fineness modulus of 2.4. The mix FM 3.2 failed at 3.2 fineness modulus because it contains a higher proportion of coarse particles, which raises the yield stress. As a result of meeting SCC acceptance requirements, three mixes, FM-2.6, FM-2.8, and FM-2.9, are designated as successful SCC mixes. Of these three, FM2.7's presentation was viewed as fundamentally better than that of the other two effective blends, FM-2.6 and the outcomes show that the expansion in FM value from 2.4 to 2.6 supported the SCC new qualities because of a diminishing in the better division. It ought to be noticed that the expansion in FM esteem from 2.8 to 3.2 brought down the SCC's new qualities on the grounds that the coarser part expanded. To get SCC new qualities that are acceptable the right degree of better and coarser parts of made sand should be kept.

5.1. Future work Scope

In the future, research could focus on exploring the utilization of steel slag and manufactured sand as fine aggregates in the following areas:

- Investigating their use in specialized concretes and self-compacting concrete (SCC) under challenging environmental conditions.
- Studying their performance as fine aggregates in critical structural elements such as beams and column-to-beam joints, catering to the needs of the construction industry.

REFERENCES

1. A. Santamar´ıa, A. Orbe, M. M. Losañez, M. Skaf, V. Ortega Lopez, and J. J. Gonzalez, "Self-compacting concrete in- ´ corporating electric arc-furnace steelmaking slag as aggregate," Materials and Design, vol. 115, pp. 179–193, 2019.
2. Aneta RAINOVA, Karel SEPS, Vladimira VYTLACILOVA, Possible use of the slag aggregate in fibre reinforced concrete. METAL(2012) 23-25
3. Bouikni.A, Swamy.R.N, Bali.A, Durability properties of concrete containing 50% and 65% slag. Construction and Building materials 23(2009) 2836 – 2845.
4. Carlo Pellegrino, Vittorio Gaddo, Mechanical and durability characteristics of concrete containing EAF slag as aggregate, Cement & Concrete composites 31(2009) 663 – 671.
5. Davidovits J, Chemistry of geopolymeric systems, terminology, Proceeding of Geopolymer International Conference, Saint -Quentin, France, 1999.
6. Davidovits J. Geopolymers: Inorganic Polymeric New Materials, Journal of Thermal Analysis, 37 (1991) 1633 -1656.
7. F. Faleschini, K. Brunelli, M. A. Zanini, M. Dabala, and C. Pellegrino, "Electric arc furnace slag as coarse recycled aggregate for concrete production," Journal of Sustainable Metallurgy, vol. 2, no. 1, pp. 44–50, 2015
8. Furlani.E, Tonello.G, Maschio.S, Recycling of steel slag and glass cullet from energy saving lamps by fast firing production of ceramics. Waste management 30 (2010) 1714 – 1719.
9. G. I. Sezer and M. G¨ulderen, "Usage of steel slag in concrete as fine and/or coarse aggregate," Indian Journal of Engineering and Materials Sciences, vol. 22, pp. 339–344, 2015.
10. Gaurav Singh, Souvik Das, Abdulaziz Abdullahi Ahmed, Showmen Saha,Somnath Karmakar(2015), 'Study of Granulated Blast Furnace Slag as Fine Aggregates in Concrete for Sustainable Infrastructure', Procedia - Social and Behavioral Sciences 195,2272 – 2279
11. H. Qasrawi, "• e use of steel slag aggregate to enhance the mechanical properties of recycled aggregate concrete and retain the environment," Construction and Building Materials, vol. 54, pp. 298–304, 2014
12. H. Qasrawi, "Use of relatively high Fe2O3 steel slag as coarse aggregate in concrete," ACI Materials Journal, vol. 104, no. 4, pp. 471–478, 2012.

13. Hisham, Q. Towards Sustainable Self-Compacting Concrete: Effect of Recycled Slag Coarse Aggregate on the Fresh Properties of SCC. Adv. Civ. Eng. 2018, 2018, 1–90
14. J. Guru Jawahar, C. Sashidhar, I.V. Ramana Reddy and J. Annie Peter (May 2012) ‘A Simple Tool For Self Compacting Concrete Mix Design.’ International Journal of Advances in Engineering & Technology Vol. 3, Issue 2, pp. 550-558.
15. Kanadasan, J.; Fauzi, A.F.A.; Razak, H.A.; Selliah, P.; Subramaniam, V.; Yusoff, S. Feasibility studies of palm oil mill waste aggregates for the construction industry. Materials 2015, 8, 6508–6530
16. M R Suresh, Rajath U Pole, (July - 2014) ‘Development of Self Compacting Concrete by Replacing Foundry Sand and Granular Blast Furnace Slag for Sand’ International Journal of Engineering Research & Technology Vol. 3 Issue 7,1637-1642
17. M. Maslehuddin, A. M. Sharif, M. Shammem, M. Ibrahim, and M. Barry, “Comparison of properties of steel slag and crushed limestone aggregate concretes,” Construction and Building Materials, vol. 17, no. 2, pp. 105–112, 2003
18. M. Pasetto, A. Baliello, G. Giacomello, and E. Pasquini, “Sustainable solutions for road pavements: a multi-scale characterization of warm mix asphalts containing steel slags,” Journal of Cleaner Production, vol. 166, pp. 835–843, 2017
19. M. S. Imbabi, C. Carrigan, and S. Mckenna, “Trends and developments in green cement and concrete technology,” International Journal of Sustainable Built Environment, vol. 1, no. 2, pp. 194–216, 2012.
20. McCaffrey R. Climate Change and the Cement Industry , Global Cement and Lime Magazine (Environmental Special Issue), (2002) 15 -19.
21. Nagesh M K, Dr Y M Manjunath, (June 2015) ‘Study on Behaviour of Self Compacting Concrete by Replacing Sand with GBFS at Sustained Elevated Temperature.’ International Journal of Engineering Research & Technology (IJERT) Vol. 4 Issue 06, 978-983
22. Okamura, H. Mix design method for self-compacting concrete. Concr. Libr. Jpn. Soc. Civ. Eng. 1995, 25, 107–120
23. Palomo SA, Grutzeck MW, Blanco MT. Alkali - activated fly ashes – A cement for the future, Cement and Concrete Research, 29 (1999) 1323 -1329.
24. Pan, Z.; Zhou, J.; Jiang, X.; Xu, Y.; Jin, R.; Ma, J.; Zhuang, Y.; Diao, Z.; Zhang, S.; Si, Q.; et al. Investigating the effects of steel slag powder on the properties of self-compacting concrete with recycled aggregates. Constr. Build. Mater. 2019, 200, 570–577
25. 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. 2018, 178, 153–160
26. 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 2019, 11, 1702
27. S. Shrihari, Seshagiri Rao M.V,(Dec-2015) ‘Properties Of Self Compacting Concrete With Metakaolin Replacing Sand With GBFS.’ International Journal of Research in Engineering and Technology. Volume: 04 Special Issue: 13,368-372
28. Santamaría, A.; Ortega-López, V.; Skaf, M.; Chica, J.A.; Manso, J.M. The study of properties and behavior of self compacting concrete containing Electric Arc Furnace Slag (EAFS) as aggregate. Ain Shams Eng. J. 2019

29. Sheen, Y.; Le, D.; Sun, T. Innovative usages of stainless steel slags in developing self-compacting concrete. Constr. Build. Mater. 2015, 101, 268–276

30. 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

31. V. Subathra Devi, B. K. Gnanavel(2014) ‘Properties of concrete manufactured using steel slag’ 12th Global Congres On Manufacturing And Management , GCMM,95-104

32. Valizadeh, A.; Aslani, F.; Asif, Z.; Roso, M. Development of Heavyweight Self-Compacting Concrete and Ambient-Cured Heavyweight Geopolymer Concrete Using Magnetite Aggregates. Materials 2019, 12, 1035.

33. Weiwu, Weide Zhang, Guowei Ma, Optimum content of copper slag as a fine aggregate in high strength concrete. Materials and Design 31(2010) 2878 – 2883

34. Xu, H, Van Deventer JSJ. The geopolymerisation of aluminosilicate minerals, International Journal of Mineral Processing , 59 (2000) 247 -266.

35. Y. N. Sheen, D. H. Le, and T. H. Sun, “Greener self-compacting concrete using stainless steel reducing slag,” Construction and Building Materials, vol. 82, no. 1, pp. 341–350, 2015