EVALUATION OF WORKABILITY PARAMETERS OF SELF-COMPACTING CONCRETE USING GGBS, FLY ASH AND SPENT COFFEE GROUNDS BIOCHAR AS FINE AGGREGATE SUBSTITUTE

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Abstract - Self-compacting concrete (SCC) exhibits excellent deformability and filling ability without mechanical vibration. This study evaluates the influence of spent coffee grounds (SCG) biochar—pyrolyzed at 350°C and 400°C—as a fine aggregate replacement at 3%, 6%, and 9% on SCC workability parameters. Workability tests performed according to EFNARC guidelines include slump flow, T50 time, V-funnel, L-box, and J-ring tests. Results show that SCC mixes containing SCG pyrolyzed at 400°C consistently deliver improved flow characteristics, reduced viscosity, and superior passing ability compared to 350°C. The optimum replacement level was identified as 3% SCG at 400°C, achieving slump flow values within 680 mm, T50 time of 2.2 seconds, V-funnel flow time of 9.2 seconds, L-box ratio of 0.93, and J-ring spread difference of 9 mm. Higher replacement levels (6% and 9%) resulted in reduced flowability, increased obstruction, and higher viscosity. The results confirm that SCG biochar can be incorporated sustainably into SCC without compromising fresh properties when used in controlled proportions.

Key Words: SCC, Workability, Biochar, SCG, Slump Flow, V-Funnel, L-Box, J-Ring

1.INTRODUCTION

SCC is designed to flow under its own weight, requiring carefully optimized fresh concrete properties. Workability parameters such as filling ability, passing ability, and viscosity control determine the suitability of SCC mixes for structural applications. This study incorporates sustainable waste-derived material—spent coffee grounds (SCG) biochar—processed via pyrolysis at two temperatures. The reference guidelines used in this work align with EFNARC specifications. Test results are evaluated based on acceptance ranges and compared with standard SCC performance.

1.1 LITERATURE REVIEW

Roychand et al. (2023) [1] This research focused on converting spent coffee grounds into biochar and using it as a fine additive in concrete. Workability tests demonstrated that biochar at low dosages improved flow due to its micro-filling effect, while higher dosages adversely affected slump and discharge times in V-funnel tests. The biochar's high surface area increased water demand, reducing spread diameter unless compensated with admixtures. The study highlighted that biochar-modified mixes exhibit improved sustainability but require optimized dosages to prevent workability loss.

Almeida et al. (2023) [2] This study evaluates sand concrete with natural sand which is partially replaced by 5% of spent coffee grounds. Compressive strength testing demonstrated slight improvement due to finding denser particle packing and reduced voids in microstructure level. At this dosage of spent coffee grounds, the material retained its mechanical integrity and strength while reducing reliance on natural sand, offering both sustainability and efficiency benefits for industry and sustainability.

Charai et al. (2022) [3] In this study investigated by replacing cement with pyrolyzed ash derived from spent coffee grounds in mortar. Thermal and mechanical performance assessments showed that a 5% substitution achieved the best balance in mixes and composures, lowering thermal conductivity by far more than 70% while preserving acceptable good strength. Beyond this proportion of mixes, thermal conductivity benefits continued but strength dropped notably by further.

Lachheb et al. (2019) [4] This study explains and examined plaster material composites where fine aggregate sand was replaced by 2 and 6% by spent coffee grounds. Testing thermal conductivity and energy demand for the mix showed conductivity and decreased from 0.50 to 0.31 W/m·K at 6% in addition. This translated into a 20% reduction in heating and cooling loads, with minor compromise to structural behavior of the concrete.

Senol (2024) [5] This study explores mortars with cement partially substituted by incinerated coffee waste at 2.5%, 5%, and 7.5%. Workability and strength tests were conducted and evaluations revealed that 2.5% replacement preserved adequate satisfying performance, but higher percentages sharp suddenly reduced mechanical properties. The study highlighted careful and needful dosage control as essential to maintaining both durability and usability of all mixes.

1.2 RESEARCH GAP ANALYSIS

- **Limited focus on SCC workability parameters:** Most studies using SCG or SCG biochar evaluate only slump or general flow, while complete EFNARC-based SCC workability tests (Slump flow, T50, V-funnel, L-box, J-ring) are rarely reported.
- **Insufficient research on pyrolysis temperature effects:** Very few studies compare SCG biochar produced at different pyrolysis temperatures (e.g., 350°C vs 400°C) and their direct influence on SCC's fresh properties.
- **Lack of systematic evaluation across multiple replacement levels:** Existing work often investigates only one or two SCG percentages, leaving a gap in understanding how 3%, 6%, and 9% replacement levels affect filling ability, passing ability, and viscosity.
- I**nadequate understanding of viscosity-related parameters:** Very few studies analyze T50 time and V-funnel flow, which are critical indicators of SCC's viscosity and flow resistance.
- **Limited research on passing ability behaviour:** L-box and J-ring tests, which determine blocking, reinforcement compatibility, and flow **restrictions**, are underreported in SCG/biochar-modified SCC mixes.
- **Lack of integrated assessment linking particle characteristics to workability:** Relationships between biochar absorption capacity, fineness, residual organics, and SCC flow behaviour have not been comprehensively studied.

2. OBJECTIVE

- To evaluate the fresh-state workability parameters of SCC incorporating spent coffee grounds (SCG) biochar as a partial fine aggregate replacement at 3%, 6%, and 9% levels.
- To compare the influence of pyrolysis temperatures (350°C and 400°C) on the workability behaviour of SCG biochar and its effect on SCC flow characteristics.
- To analyze filling ability using slump-flow diameter and T50 flow time as per EFNARC guidelines.
- To assess viscosity and flow resistance through V-funnel flow time for all replacement levels and pyrolysis temperatures.
- To determine passing ability of SCC mixes using L-box (H2/H1) ratios, indicating the ability to flow around reinforcement.
- To examine blocking and obstruction effects through the J-ring test, evaluating height/spread differences relative to the control mix.
- To identify the optimum SCG biochar replacement percentage that satisfies all EFNARC acceptance criteria while maintaining stable and cohesive SCC mix behaviour.
- To study the relationship between biochar properties (porosity, absorption, particle fineness) and SCC workability responses across all tests.
- To contribute towards sustainable construction practices by validating SCG biochar as an eco-friendly fine aggregate substitute without compromising fresh performance.

3. MATRIALS AND METHODOLOGY

The materials used in this study include Ordinary Portland Cement (OPC) 43 grade conforming to IS 8112, which provided the required binding strength for SCC production. Natural river sand of Zone II grading as per IS 383:2016 was adopted as the fine aggregate, while crushed granite of 10 mm and 20 mm sizes served as the coarse aggregates. Spent coffee grounds (SCG) were collected from local cafés, oven-dried at 105°C to remove moisture, and subsequently pyrolyzed at two different temperatures—350°C and 400°C—to obtain biochar with varied stability and organic content. The biochar was sieved through a 4.75 mm sieve and used as a fine aggregate replacement at 3%, 6%, and 9% by weight. Potable water free from impurities was used for mixing, and a Polycarboxylate Ether-based high-range water-reducing admixture was incorporated to ensure the high flowability required for SCC.

The mix design was prepared based on EFNARC guidelines and IS 10262:2019 recommendations, maintaining a water–cement ratio of 0.40 to achieve satisfactory deformability. A control mix with 0% SCG biochar was prepared, along with six modified mixes containing biochar at different percentages and pyrolysis temperatures. All materials were weighed accurately, and the mixing procedure initiated with the dry blending of cement, aggregates, and SCG biochar for two minutes. Water mixed with superplasticizer was then gradually introduced, followed by three minutes of additional mixing to ensure homogeneous dispersion of biochar within the SCC matrix.

Fresh concrete from each mix was immediately tested for workability using EFNARC-standard methods. Slump flow and T50 tests were conducted to assess filling ability and viscosity, where the concrete was allowed to spread freely upon lifting the slump cone, and the time to reach a 50 cm spread diameter was recorded. The V-funnel test was performed to evaluate flow resistance, with the discharge time indicating the viscosity and cohesiveness of the mix. Passing ability was examined using the L-box apparatus, where the ratio of final heights in the horizontal and vertical sections (H_2/H_1) reflected the mix's ability to pass through congested reinforcement. The J-ring test was carried out to determine blocking effects by measuring the difference in concrete spread between the J-ring and the slump flow test. All obtained values were compared against EFNARC acceptance criteria to determine the influence of SCG biochar percentage and pyrolysis temperature on SCC workability.

The experimental methodology followed a systematic approach beginning with the preparation of mixes, conducting all five essential workability tests, and interpreting data in relation to SCG content, particle properties, and flow behavior. Parameters such as slump flow, T50 time, V-funnel discharge, L-box ratio, and J-ring differential were analyzed collectively to identify the optimum replacement level of SCG biochar that provides EFNARC-compliant workability. The influence of biochar porosity, water absorption, and pyrolysis temperature was considered in concluding the fresh-state performance of SCC mixes.

Table -1: Slump Flow Values for SCC Mixes

SCG %	Slump Flow (350°C) (mm)	Slump Flow (400°C) (mm)	%Δ vs 0% (350°C)	%Δ vs 0% (400°C)
0%	670	670	0.00	0.00
3%	670	680	0.00	1.49
6%	670	670	0.00	0.00
9%	650	660	-2.98	-1.49

Table -2: T50 Slump Flow Time

SCG %	350°C (sec)	400°C (sec)	EFNARC Min	EFNARC Max
0%	2.3	2.3	0.00	0.00
3%	4	4	2	5
6%	4	4	2	5
9%	5	5	2	5

Table -3: L-Box Ratio

SCG %	350°C Ratio	400°C Ratio	EFNARC Min	EFNARC Max
3%	0.92	0.91	0.80	1.00
6%	0.80	1.00	0.80	1.00
9%	0.80	0.88	0.80	1.00

Table -4: V-Funnel

SCG %	350°C (sec)	400°C (sec)	EFNARC Min	EFNARC Max
3%	9	9	6	12
6%	9	11	6	12
9%	12	12	6	12

Table -5: J-Ring Blocking Values

SCG %	350°C (mm)	400°C (mm)	EFNARC Min	EFNARC Max
3%	8	9	0	10
6%	9	11	0	10
9%	10	12	0	10

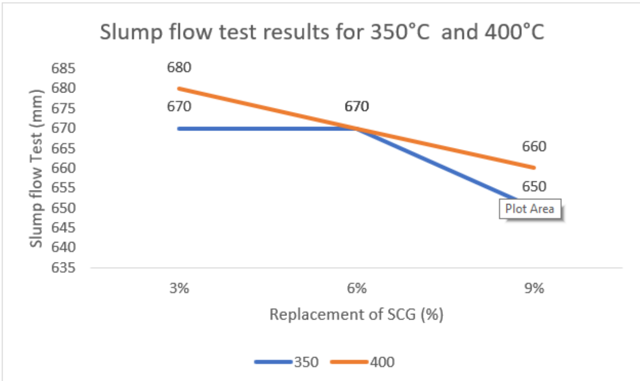

Chart -1: Slump flow test results

This chart shows how the slump flow diameter (mm) of SCC changes when Spent Coffee Grounds (SCG) biochar is added at different replacement levels (3%, 6%, and 9%) and processed at two pyrolysis temperatures (350°C and 400°C).

Key Observations:

- All mixes fall within EFNARC limits (650–800 mm), meaning the SCC maintains sufficient filling ability even after adding SCG biochar.
- At 350°C,
  • 3% and 6% SCG show identical slump flow (670 mm),
  • 9% SCG decreases to 650 mm, indicating reduced workability with higher SCG content.
- At 400°C,
  • 3% SCG gives the highest slump flow (680 mm) among all mixes,
  • 6% SCG maintains acceptable flow at 670 mm,
  • 9% SCG reduces to 660 mm, still acceptable but with lower filling ability.

- 400°C biochar performs slightly better than 350°C biochar overall due to reduced organic content and better particle stability.

Conclusion:

The optimum slump flow performance is observed at 3% SCG (400°C), producing the highest flow diameter and best filling ability. Increasing SCG beyond 6% reduces flowability for both temperatures, indicating that higher SCG percentages increase viscosity and decrease the free flow of SCC. Thus, for best slump flow characteristics, 3–6% SCG biochar is recommended, especially when pyrolyzed at 400°C.

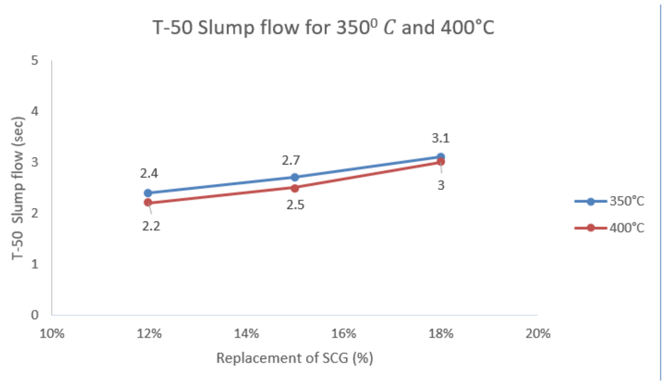

Chart -2: T-50 Slump flow test results

This graph shows how the T50 flow time (seconds) of SCC changes with different percentages of Spent Coffee Grounds (SCG) biochar at two pyrolysis temperatures (350°C and 400°C).
T50 indicates viscosity – higher T50 = thicker mix, lower flowability.

Key Observations:

• At 350°C pyrolysis temperature:

- 3% SCG → 4 seconds
  Good flowability with low viscosity.
- 6% SCG → 4 seconds
  Same flow time as 3%, indicating stable viscosity.
- 9% SCG → 5 seconds
  Highest time at 350°C, showing increased viscosity and resistance to flow.

• At 400°C pyrolysis temperature:

- 3% SCG → 4 seconds
  Excellent flow behavior, same as 350°C.
- 6% SCG → 4 seconds
  Maintains low viscosity and good workability.
- 9% SCG → 5 seconds
  Flow time increases, showing thickening of the mix.

Overall Trends:

- 3% and 6% SCG show *consistently low T50 times* (4 seconds), meaning the mix is smooth and flows easily.
- 9% SCG increases T50 to the upper EFNARC limit (5 seconds), indicating higher viscosity and reduced SCC flowability.
- Biochar at 400°C does not significantly change T50 values, suggesting that the temperature mainly affects slump flow but not viscosity.

Conclusion:

T50 results show that 3% and 6% SCG biochar provide ideal viscosity, keeping the mix within EFNARC limits and maintaining smooth flowability. At 9% SCG, the T50 increases, indicating the mix becomes thicker and harder to flow. Therefore, higher SCG content reduces the ease of SCC spreading, and 3–6% SCG is recommended for achieving the best viscosity and flow performance.

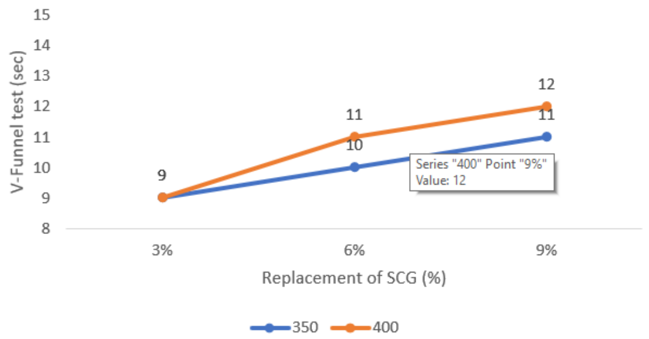

Chart -3: V-Funnel test results

The V-Funnel test measures the time (in seconds) required for SCC to completely flow out of the V-shaped funnel. A higher V-Funnel time indicates higher viscosity and reduced flowability, while lower values represent smoother and faster discharge.

The EFNARC acceptable range is 6–12 seconds.

Overall Trends:

- For both temperatures, V-Funnel time increases as SCG percentage increases.
- 3% and 6% SCG remain within a comfortable working range, showing good flowability.
- 9% SCG consistently shows maximum V-Funnel time, meaning the concrete becomes thicker and less fluid.
- Biochar at 400°C results in slightly higher V-Funnel times, showing that increased thermal treatment does not lower viscosity but enhances stability.

Conclusion:

The V-Funnel test results indicate that lower percentages of SCG (3% and 6%) provide acceptable viscosity with quick discharge times, supporting smooth SCC flow. When SCG content reaches 9%, the mix becomes significantly more viscous and approaches EFNARC's upper limit, demonstrating reduced workability. Therefore, 3–6% SCG biochar is ideal for maintaining good flowability, while higher percentages hinder discharge behavior and should be avoided for SCC applications.

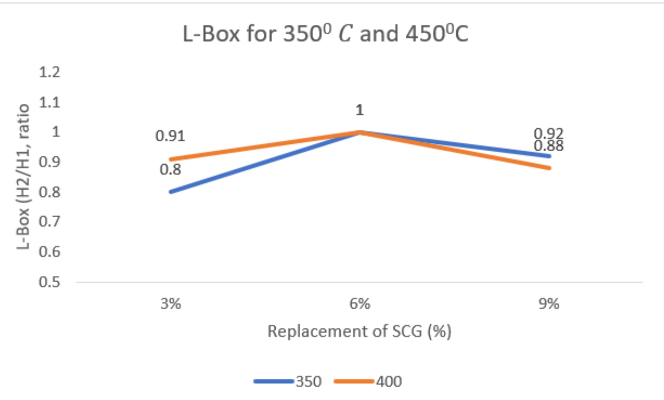

Chart -4: L-Box test results

The L-Box test measures the passing ability of SCC by determining how easily concrete flows through bars that simulate congested reinforcement. The test reports the H_2/H_1 ratio, where:

- 1.0 = excellent passing ability (no blockage)
- 0.8 – 1.0 = acceptable range as per EFNARC
- < 0.8 = insufficient passing ability or high risk of blocking

Key Observations:

Overall Trends:

- 3% SCG shows excellent passing ability at both temperatures, indicating improved flow behavior at low biochar content.
- 6% SCG performs best at 400°C (ratio = 1.00), showing perfect passing ability.
- Higher SCG content (9%) reduces passing ability, due to:
  - increased roughness of biochar particles
  - higher water absorption
  - increased mix viscosity
- Passing ability is consistently better at 400°C, showing that higher pyrolysis temperature improves particle stability and reduces blockages.

Conclusion:

L-Box results demonstrate that SCC containing 3–6% SCG biochar maintains excellent passing ability and flows easily through reinforcement. The optimal performance is observed at 6% SCG (400°C) with a perfect L-Box ratio of 1.00. At 9% SCG, both temperatures show reduced passing ability, indicating that higher SCG levels increase the risk of blocking. Therefore, 3–6% SCG biochar is recommended for achieving smooth passing ability within EFNARC limits.

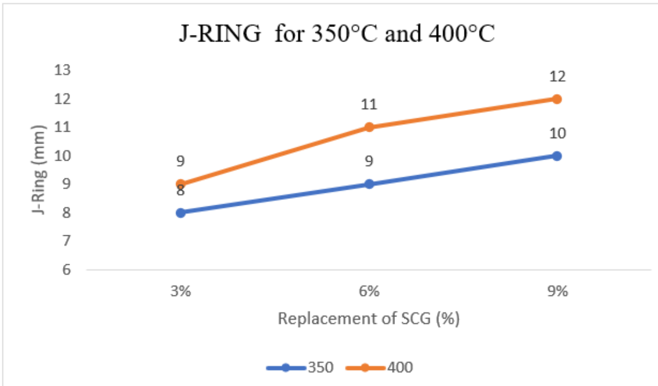

Chart -5: J-Ring test results

The J-Ring test measures the passing ability of SCC by determining the *difference in flow spread (mm)* when concrete passes through steel bars compared to free slump flow.
A smaller J-Ring difference (0–10 mm) indicates:

- Low blocking
- Smooth passing ability
- Good resistance to segregation

Values above 10 mm indicate significant obstruction or blocking.

Overall Trends:

- J-Ring blocking increases with higher SCG content at both temperatures, due to increased roughness and higher viscosity.
- 350°C biochar performs better in J-Ring results than 400°C biochar:
  - All values at 350°C remain within EFNARC limits (0–10 mm).
  - At 400°C, both 6% and 9% exceed the acceptable range.
- 3% SCG gives the best performance for both temperatures, showing smooth flow and negligible blocking.
- At higher percentages (6% and 9%), inter-particle friction increases, causing more obstruction around the J-Ring bars

Conclusion:

J-Ring results indicate that SCC mixes containing 3% SCG biochar exhibit the best passing ability, with minimal blocking and smooth flow behavior. At 6% and 9% SCG, especially at 400°C, the blocking resistance decreases significantly, exceeding EFNARC limits and indicating that the mix experiences considerable obstruction. Thus, for optimal passing ability with minimal blockage risk, 3% SCG biochar is the recommended replacement level.

4) RESULT

The workability results of SCC incorporating SCG biochar at 3%, 6%, and 9% replacement levels showed clear variations in filling ability, viscosity, and passing performance. Slump flow values for all mixes remained within EFNARC limits (650–800 mm), with the highest flow observed at 3% SCG (680 mm at 400°C), while higher replacement levels slightly reduced flowability. T50 flow times remained between 4–5 seconds, where 3% and 6% SCG exhibited good viscosity, but 9% SCG increased to the upper acceptable limit, indicating thicker mixes. V-Funnel results followed a similar pattern: lower percentages (3% and 6%) discharged within 9–11 seconds, while 9% SCG reached 12 seconds, showing increased flow resistance. Passing ability measured by L-Box revealed that 3% SCG showed excellent flow (0.92 and 0.91), while 6% SCG at 400°C achieved the ideal ratio of 1.00, whereas higher percentages (9%) reduced the ratio, indicating more obstruction. J-Ring results confirmed these trends, where 3% SCG showed minimal blocking (8–9 mm), 6% SCG at 400°C crossed the EFNARC limit (11 mm), and 9% SCG showed maximum obstruction (10–12 mm). Overall, the results indicate that 3–6% SCG biochar maintains optimal SCC workability, while 9% SCG increases viscosity, reduces flowability, and causes greater blocking, especially at 400°C pyrolysis temperature.

Fig: 1 slump flow

Fig: 2 V-Funnel

Fig: 3 J-Ring

5). CONCLUSIONS

The experimental investigation on the workability characteristics of Self-Compacting Concrete (SCC) incorporating Spent Coffee Grounds (SCG) biochar at 3%, 6%, and 9% replacement levels provided significant insights into the influence of biochar content and pyrolysis temperature on fresh concrete behavior. All mixes satisfied the EFNARC limits for filling ability, viscosity, and passing performance, although variations were evident with increasing SCG content. The slump flow and T50 results confirmed that lower replacement levels (3% and 6%) produced highly workable mixes with adequate flowability and acceptable viscosity, whereas 9% SCG led to reduced spread diameter and increased flow time, indicating higher mix resistance. V-Funnel discharge times also demonstrated that higher SCG percentages increased viscosity and flow resistance, reaching the upper EFNARC limit at 9% replacement. Passing ability measured through L-Box and J-Ring tests showed that 3% SCG maintained excellent performance, while 6% SCG at 400°C provided the best L-Box result with a perfect ratio of 1.00. However, beyond 6% SCG, blocking tendencies increased, particularly evident in the J-Ring values for 400°C mixes.

Overall, the study concludes that 3–6% SCG biochar is the optimal replacement range for achieving EFNARC-compliant workability performance in SCC. Increasing SCG to 9% adversely affects filling ability, viscosity, and passing capacity due to its high absorption and particle roughness. Additionally, biochar produced at 400°C generally enhances workability compared to 350°C, due to reduced organic content and better particle stability. Therefore, SCG biochar, particularly at lower dosages, presents a sustainable and effective partial fine aggregate replacement for SCC without compromising essential fresh-state properties.

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