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Enhancing The Structural Behavior Of Beam-Column Joints Using Basalt Fiber Reinforced Self-Compacting Rubberized Concrete: An Experimental Investigation

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Abstract: This study investigates how Basalt Fiber Reinforced Self-Compacting Concrete (BFRSCC) performs in exterior beam-column joints subjected to positive quasi-static loading. The research focuses on understanding the behavior of basalt fibers when combined with M30 grade Self-Compacting Rubberized Concrete (SCRC) and 12mm chopped Basalt fiber. The aim is to provide valuable insights for the design and construction industry on the use of BFRSCC in reinforced concrete structures, following the principles of strong column weak beam theory for ensuring structural integrity. Experimental findings consistently show that the initial crack occurs near the bottom of the beam close to the joint and progresses upward during loading cycles, resulting in flexural cracks and beam hinging at the joint interface. Shear failure is identified as the primary mechanism leading to failure. By incorporating smaller proportions of crumb rubber and basalt fiber, the ductility of the specimens is improved in terms of displacement and stiffness. Crumb rubber inclusion enhances crack load and ultimate deflection, while basalt fiber reinforcement enhances crack load, ultimate load, and ultimate deflection. However, careful selection of the fiber content is crucial to balance the load-carrying capacity and stiffness. Challenges in meeting flowability requirements limit the exploration of higher fiber percentages, calling for further research. The study evaluates ductility and reveals significant enhancements with crumb rubber and basalt fiber. The findings contribute to construction practices and provide guidance for engineers, researchers, and practitioners involved in the construction of resilient and durable moment-resisting frame structures. Future research can explore alternative mix designs and examine the behavior of BFRSCC under different loading conditions to expand its practical applications.

***Index Terms* - Basalt Fiber Reinforced Self-Compacting Concrete; Beam-Column Joints; Positive Quasi-Static Loading; Ductility; Crumb Rubber; Structural performance**

I. INTRODUCTION

Beam-Column Joints (BCJs) play a critical role in ensuring the overall performance and safety of Moment Resisting Frame structures. These joints experience significant shear forces, making them vital for maintaining the structural integrity of the system (Li et al., 2020; Parvez & Maniyar, 2021). Traditional approaches to BCJ design involve the use of closely spaced stirrups and adequate development length for longitudinal bars to ensure ductile failure under reverse cyclic loading conditions (Wang et al., 2019). However, this conventional method often leads to congested areas within the joint, which can hinder concrete flowability, compaction, and result in weaker joints. To overcome these challenges, researchers have proposed the use of innovative materials and techniques. Self-Compacting Concrete (SCC) has emerged as a promising solution for enhancing the performance of BCJs (Othman et al., 2018). SCC possesses the ability to flow under its own weight, allowing it to navigate through congested areas without the need for mechanical vibration (Ismail et al., 2020). This unique characteristic improves flowability, reduces the risk of segregation, and ensures better compaction within the joints. In recent years, Basalt Fiber Reinforced Concrete (BFRC) has been explored as a reinforcement option to enhance the mechanical properties and sustainability of BCJs (Naderpour et al., 2018). Basalt fiber, derived from volcanic rocks, offers excellent tensile strength, corrosion resistance, and an environmentally friendly manufacturing process (Feng et al., 2020). Incorporating basalt fibers into the concrete matrix enhances crack resistance and overall durability (Eid et al., 2019). This has generated interest in investigating the potential of Basalt Fiber Reinforced Self-Compacting Rubberized Concrete (BFRSCRC) in BCJs. Additionally, the utilization of crumb rubber derived from end-of-life tires has gained attention for improving the strain capacity and impact resistance of concrete (Liu et al., 2021). Crumb Rubberized Concrete (CRC) involves replacing natural fine aggregates with shredded or ground rubber particles, resulting in improved ductility, dynamic properties, and resistance to cracking, wear, and frost (Hernandez-Olivares et al., 2021). Despite the extensive research on Fiber Reinforced Concrete beam-column joints, there is a lack of studies investigating the behavior of Basalt Fiber Reinforced Self-Compacting Rubberized Concrete in exterior BCJs (Rohm et al., 2012). This research gap emphasizes the need to explore the structural behavior of these innovative composite materials in BCJs to further enhance their performance and durability.

The objective of this study is to conduct experimental investigations to evaluate the structural behavior of BFRSCRC in external beam-column joints. The study aims to analyze the load-deflection behavior, hysteresis behavior, and displacement ductility of BFRSCRC specimens (Chandran & Ganesan, 2020). Furthermore, the study aims to compare the structural performance of BFRSCRC BCJs with normal Self-Compacting Concrete (SCC) external BCJs (Wang et al., 2021). A comprehensive numerical model will also be developed to predict the structural performance of Fiber Reinforced Concrete beam-column joints (Rahman et al., 2021). This study contributes to the existing knowledge on the behavior of Basalt Fiber Reinforced Self-Compacting Rubberized Concrete in BCJs, providing valuable insights for the design and construction of more durable and resilient Moment Resisting Frame structures.

II. METHODOLOGY

The methodology employed in this study follows a comprehensive approach to investigate the behavior of Basalt Fiber Reinforced Self-Compacting Rubberized Concrete (BFRSCRC) in exterior beam-column joints. Initially, the mechanical properties of the constituent materials, such as basalt fiber, crumb rubber, and other additives, are rigorously assessed through laboratory testing. Various tests, including compressive strength, tensile strength, and flexural strength tests, are conducted to evaluate the performance and characteristics of these materials. Subsequently, the mix proportioning of Self-Compacting Concrete (SCC) is meticulously performed in accordance with the guidelines specified in IS 10262:2019. The mix design process aims to achieve the desired concrete properties while considering factors like workability, strength, and durability. Special attention is given to the selection and incorporation of mineral admixtures, such as fly ash, to enhance the pore microstructure and interfacial bond within the concrete matrix. The design of the exterior beam-column joint is carried out using ETABS software, adhering to the design codes outlined in IS 456-2000 and IS 13920-2016. This includes a thorough structural analysis that takes into account the induced earthquake loads, axial forces, shear forces, and bending moments acting on the joint. The design ensures the joint's capacity to withstand these forces and maintain stability and integrity. Detailed reinforcement detailing of the exterior beam-column joint is conducted based on the specifications provided in IS 456-2000 and SP34. This involves determining the appropriate reinforcement requirements, such as rebar size, spacing, and arrangement, as well as ensuring adequate anchorage lengths to prevent anchorage failure. This meticulous detailing process is essential to ensure the joint's ability to carry loads and exhibit ductile behavior. To validate the numerical model and investigate the actual behavior of the BFRSCRC exterior beam-column joint, physical specimens are cast in the structural laboratory. The specimens are carefully prepared, considering the mix design proportions and reinforcement detailing, and undergo a curing period of 28 days to allow for proper hydration and concrete strength development. Cyclic loading testing is then conducted on the specimens using a specialized loading frame with a capacity of 500kN. The specimens are subjected to incremental cyclic loads that simulate real-world dynamic loading conditions. The behavior of the specimens, including load-deflection, hysteresis, and displacement ductility, is measured and analyzed to evaluate their performance under cyclic loading. The experimental results obtained from the testing are compared with the numerical modeling results obtained from the ANSYS software. This comparative analysis serves to validate and verify the accuracy and reliability of the numerical model in predicting the behavior of the BFRSCRC joint. Through this comprehensive methodology, the study aims to provide detailed insights into the structural behavior of BFRSCRC in exterior beam-column joints. The findings obtained from this research contribute to the advancement of construction practices by facilitating the design and construction of more resilient and durable moment-resisting frame structures.

Properties Of Materials And Mix Proportioning Of SCC

Cement

Cement plays a vital role as a binding material in concrete, especially in engineering works that require high strength and durability. For this study, Sankar brand 53 Grade OPC cement was used. The properties of the cement were thoroughly examined, and the results are presented in Table 1. It is worth mentioning that the tested properties of the cement comply with the standards specified by IS (Indian Standards).

Table 1 Properties of cement

Sl.No.	Particulars	Observed value
1	Specific gravity	3.15
2	Standard consistency	33%
3	Compressive strength (7 day)	40.2N/mm2
4	Compressive strength (28day)	57.5N/mm2
5	Initial setting time	63 min.
6	Final setting time	3hr 14 min.

Flyash

Flyash is used as mineral admixture. Flyash used belongs to class F . The property is shown in Table 2

Table 2 Properties of Flyash

Sl.No	Particulars	Observed value
1.	Specific Gravity	2.2

Fine aggregate

Aggregates are another important constituent in concrete. Aggregates strongly influence concrete’s fresh and hardened properties, mix proportions and economy. Aggregate passing through 4.75mm IS sieve was used as fine aggregate. For current study, manufactured sand obtained from nearby quarry was used for casting the specimens. The tests were conducted as perIS standards. The properties obtained from the test were as shown in Table 3. The fine aggregate grading curve was as shown in Fig.1.

Table 3 Properties of fine aggregate

Sl.No	Particulars	Observed value
1	Bulk Density	1.7g/cc
2	Specific Gravity	2.6
3	Particle Size Distribution	Zone II
4	Fineness Modulus	2.63

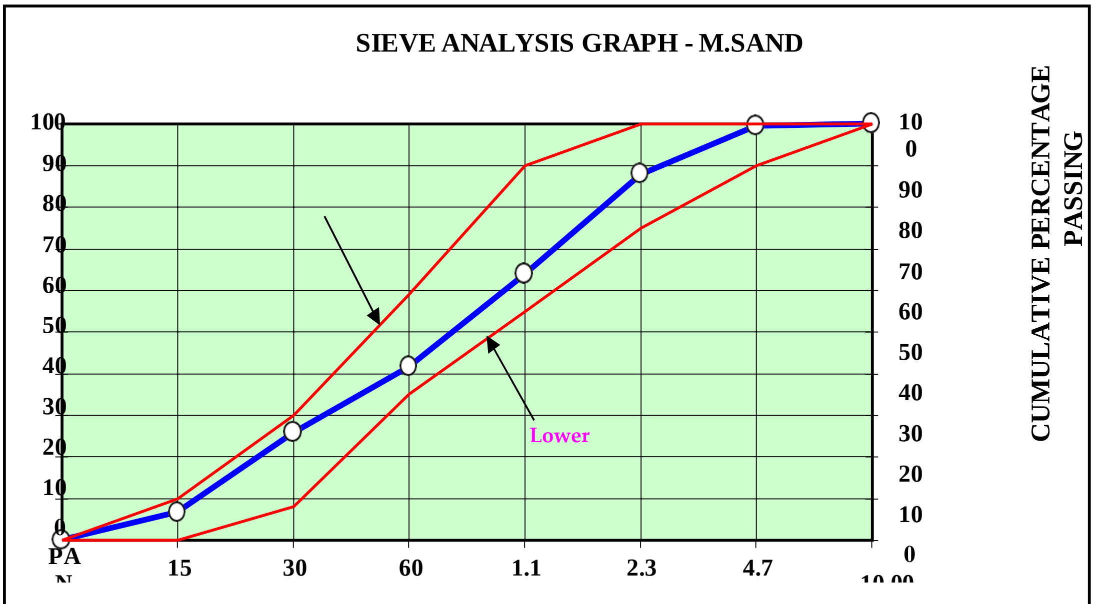

Fig.1 Grading curve for fine aggregate

Coarse aggregate

Coarse aggregate makes solid and hard mass of concrete with cement and sand. It increases the crushing strength of concrete. For current study crushed stones of 12.5 mm was used as coarse aggregate. The properties of coarse aggregate tested were as shown in Table 4. 12.5mm coarse aggregate was taken for obtaining the grading curve of coarse aggregate conform to IS 383-1970.This coarse aggregate grading curve was as shown in Fig.2.

Table 4 Properties of coarse aggregate

Sl.No	Particulars	
		12.5mm
1	Bulk Density	1.52g/cc
2	Specific Gravity	2.68
3	Fineness Modulus	7.29

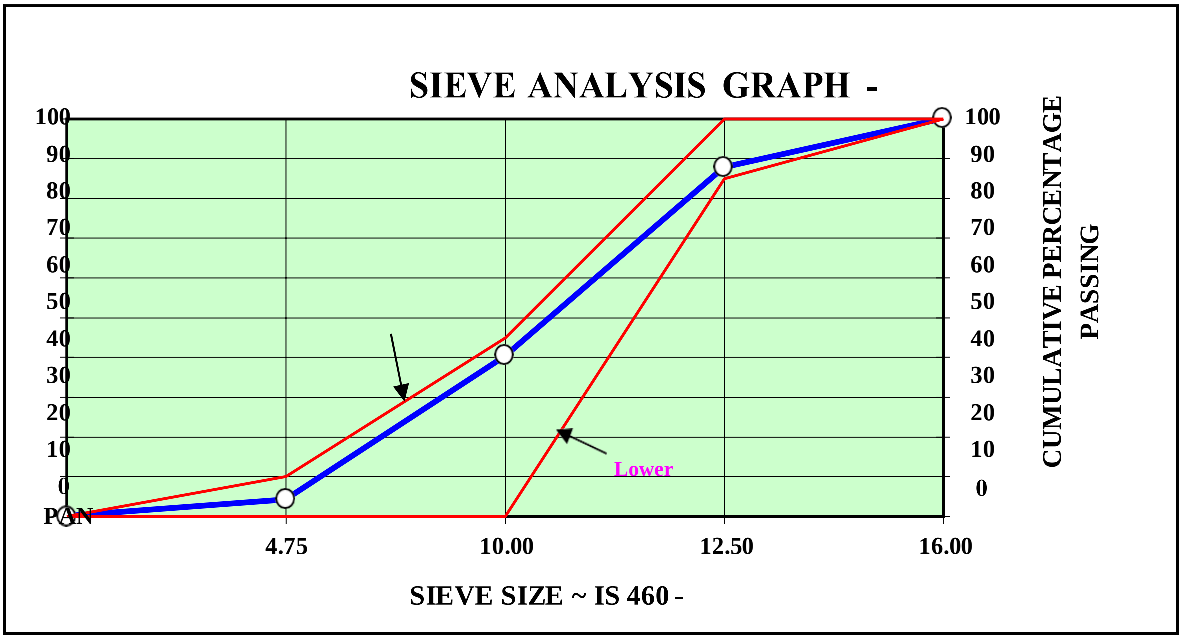

Fig.2 Grading curve for coarse aggregate

Crumb Rubber

Crumb Rubber obtained from crushing of end-of-life tyres is used for the experiment. Crumbrubber in the size range of sand is used. Grading of crumb rubber is shown in figure.3

Fig.3 Crumb Rubber

Steel reinforcement

Two different diameters of reinforcements were used for the construction of beam-column joints i.e., main reinforcement and stirrups, 8mm and 6mm. Three samples were tested from each size ofreinforcement. The results of the tension tests for rebars are given in Table 3.5.

Table 5 Material properties of steel reinforcement

Sl.No.	Material	Yield strength (MPa)	% elongation	Ultimate strength (MPa)
1	Bar 8mm Ø	572.66	23.33	659.06
2	Bar 6mm Ø	522.91	16	555

Experimental Programme

An experimental investigation has been carried out to understand the cyclic behavior of exterior beam-column joint. A beam-column joint was cast, cured for 28 days and tested under loading frame. The flexural load and deflection values and failure pattern for the specimen was observed.

Specimen Details

The exterior beam-column joint was scaled down to one-third size. The dimensions and reinforcement details of the test assemblages are shown in figure 4 below:

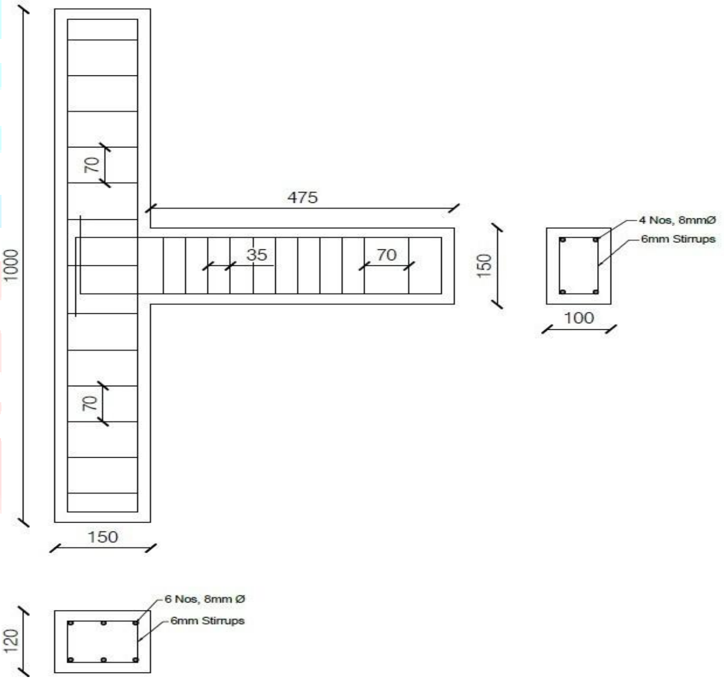

Fig. 4 Details of beam-column joint specimen

Specimens were cast with reinforcement detailed as per IS 456: 2000and SP34. Column size withcross section 150X120mm & beam with cross section 150mmX100mm is prepared. The column & beam length was selected upto point of contraflexure. The point of contraflexure of column is assumed at mid height of the column. Four specimens were prepared. First specimen with normalSCC and the other three specimens with varying percentage of basalt fiber as 0%,0.15% and 0.3%of volume of concrete with 5% crumb rubber as sand replacement. Since it is a combination of two materials and to be mixed with Self Compacting Concrete, proportions of crumb rubber and basalt fiber is started from the minimum, referring previous journals and also to get the required workability. The quantity of super plasticiser was adjusted to get the required workability. Detailsof mix proportions are shown in Table 6

Table 5 Mix proportions

Designation of specimen	Specimen no	Cement (kg/m3)	Fly ash (kg/m3)	Coarse aggregate (kg/m3)	Fine aggregate (kg/m3)	CR (kg/m3)	Super plasticiser (kg/m3)	Basalt fiber (kg/m3)
SCC	S1	350	150	796	949	0	3.25	0
SCC-CR5	S2	350	150	796	901	15.51	3.50	0
SCC-CR5-BF0.15	S3	350	150	796	901	15.51	3.65	3.98
SCC-CR5-BF0.3	S4	350	150	796	901	15.51	3.90	7.96

Test Setup

The specimens were tested in a loading frame of 500kN capacity. The top support of the column was hinged support and bottom of the column was firmly resting on top of the I-beam fixed to thetest floor. Hydraulic jack of 250kN is used to apply cyclic load at the end of the beam. The schematic illustration of the test arrangement is shown in figure 6. All the specimens were subjected to constant axial load of about 3% of column axial load capacity.16kN is applied in the column. The cyclic loading was applied through S gauge by hydraulic jackat 50mm from the free end of the beam portion of the assemblage. The test was load-controlled and the specimen was subjected to an increasing cyclic load up to its failure.

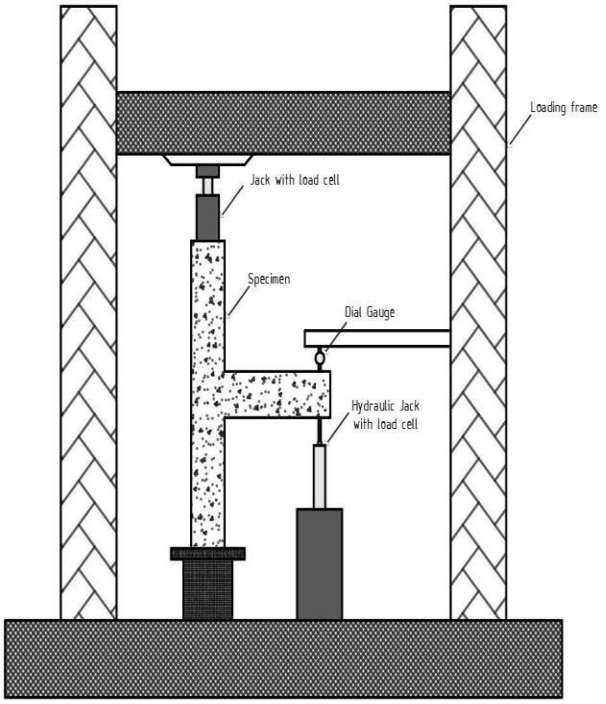

Fig. 5 schematic illustration of the test arrangement

III. RESULT AND DISCUSSION

The design of the beam-column joints in this study adhered to the principles of strong column weak beam theory, ensuring the structural integrity and strength of the joints. Experimental findings demonstrated that in all four specimens, the first crack initiated at the bottom of the beam near the beam-column joint. As loading cycles progressed, the crack propagated towards the top of the beam. Notably, flexural cracks were observed in the beam component, ultimately resulting in the failure of all specimens as anticipated, due to beam hinging at the beam-column joint interface.

To analyze the behavior of the beam-column joints, load-displacement hysteresis curves were plotted, and an envelope curve was constructed by connecting the peak load values corresponding to each displacement amplitude from the hysteresis curve. The deviation from linearity in the envelope curve marked the point of first crack load.

For the control specimen (S1), it was observed that the first crack appeared during the third cycle at a load of 6kN. The deflection at yield was measured as 0.94mm, and the failure load occurred at 34kN with a deflection of 13.94mm. The load-deflection plot for the control specimen exhibited the characteristic crack initiation at the bottom of the beam near the beam-column joint, followed by crack propagation towards the top and into the joint region. Additionally, severe concrete crushing was observed at the top of the beam near the joint after failure. Shear failure at the joint was identified as the failure mechanism in this case.

Fig.6 Load-Deflection curve of control specimen S1

In the case of specimen S2, the third cycle revealed the occurrence of the first crack at a load of 8kN, accompanied by a deflection at yield measuring 0.75mm. The failure load was recorded at 34kN, resulting in a deflection of 23.84mm. Incorporating crumb rubber into the mixture led to an improvement in both the first crack load and the ultimate deflection compared to the control specimen. Similarly, in specimen S3, the first crack emerged during the third cycle at a load of 8kN, with a deflection at yield of 0.68mm. The failure load was observed at 36kN, accompanied by a deflection at failure of 24.07mm. Specimen S3 demonstrated enhanced first crack load, ultimate load, and ultimate deflection compared to the control specimen. On the other hand, specimen 4 displayed a first crack load similar to the control specimen, occurring at a load of 6kN during the third cycle. The deflection at yield was measured as 0.84mm, and the failure load occurred at 30kN with a deflection of 19.00mm. However, the ultimate load of specimen S4 was found to be lower than that of the control specimen. This decrease in peak load was attributed to the debonding of basalt fibers from the concrete matrix at high strain rates, which created unfavorable conditions for the behavior of the Basalt Fiber Reinforced Concrete (BFRC) specimens under cyclic loading.

Additionally, the ductility of the specimens was evaluated to assess their ability to undergo deformation beyond the yield point while maintaining their load-carrying capacity. The displacement ductility, which quantifies the ductility of a structure, was determined by calculating the ratio of deflections at the end of the elastic range to the deflection at the yield level. Among all the specimens, the control specimen exhibited the lowest ductility factor. However, the inclusion of crumb rubber resulted in a significant enhancement of ductility, increasing it by a factor of 1.9 compared to the control specimen. Furthermore, incorporating basalt fiber at percentages of 0.15% and 0.3% in conjunction with crumb rubber further increased the ductility of the specimens by factors of 2.29 and 1.42, respectively. The presence of fibers constrained the yield load at lower displacement levels while simultaneously improving the post-peak load-carrying capacity at higher displacements, thereby augmenting the overall ductility of the specimens containing fiber-reinforced concrete (FRC).

IV. **CONCLUSIONS**

V. In summary, this research conducted a thorough investigation into the performance of Basalt Fiber Reinforced Self-Compacting Concrete (BFRSCC) in exterior beam-column joints under positive quasi-static loading. The primary focus was on the behavior of basalt fibers in conjunction with M30 grade Self-Compacting Rubberized Concrete (SCRC) and 12mm chopped Basalt fiber. The outcomes of this study significantly contribute to the knowledge and understanding of reinforced concrete structures, offering valuable insights for the design and construction industry. The inclusion of crumb rubber and basalt fiber in smaller proportions yielded notable improvements in the ductility of the beam-column joints. These structures exhibited enhanced displacement ductility and stiffness degradation characteristics. However, it was observed that an increase in the basalt fiber fraction resulted in a reduction in peak load and initial stiffness. This highlights the critical importance of carefully selecting the fiber content to ensure the desired load-carrying capacity and stiffness of the joint. The decline in peak load with higher basalt fiber content can be attributed to the altered behavior of the BFRSCC joint. The interaction between the basalt fibers and the concrete matrix influences the overall mechanical response of the joint, underscoring the need for optimizing fiber content to achieve the desired structural performance. While the present study utilized a total cementitious material of 500kg/m3, trials with higher basalt fiber or crumb rubber percentages were limited due to challenges in meeting the flowability requirements of Self-Compacting Concrete. This indicates the necessity for further research and development in mix designs that can accommodate increased fiber content without compromising the workability of the concrete. The insights derived from this study have significant implications for advancing construction practices, providing valuable information for the design and construction of resilient and durable moment-resisting frame structures. Future research endeavors should explore alternative mix designs and investigate the behavior of BFRSCC joints under various loading conditions, including dynamic and seismic loading. Such investigations will further enhance our understanding of the structural behavior and performance of BFRSCC in practical applications. Overall, the comprehensive analysis and findings presented in this study lay a strong foundation for future studies and advancements in the field of Basalt Fiber Reinforced Self-Compacting Concrete. The acquired knowledge will empower engineers, researchers, and practitioners to make informed decisions regarding the use of BFRSCC in exterior beam-column joints, ultimately contributing to the development of safer and more resilient infrastructure.

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