Workability and Material Testing of SBR and Polypropylene Rope Reinforced Concrete with Mixed Aggregates

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Abstract

This study investigates the workability characteristics of polymer fiber-reinforced M20-grade concrete and the material properties of its key constituents, including cement, sand, brick aggregate, natural aggregate, styrene-butadiene rubber (SBR), polypropylene rope fiber, and water. Standardized material tests were conducted to assess the quality and suitability of each component. Cement was tested for fineness, consistency, initial and final setting time, and specific gravity. Fine and coarse aggregates, including both natural and brick aggregates, were evaluated for gradation, water absorption, bulk density, and specific gravity. The influence of SBR polymer and polypropylene rope fiber on concrete workability was studied using the slump test, considering their effects on cohesion and flow ability. Results indicated that increasing fiber content reduced workability due to higher cohesion, while the inclusion of SBR improved mix stability. Brick aggregates exhibited higher water absorption, influencing the water-cement ratio and overall mix behavior. This study provides insights into optimizing mix proportions for improved workability in polymer fiber-reinforced concrete with hybrid aggregates.

Keywords: Cement, Sand, Brick Aggregate, Natural Aggregate, Styrene Butadiene Rubber, Polypropylene Rope Fiber, Workability, Slump Test, Water Absorption, Specific Gravity.

1. Introduction

Concrete is a widely used construction material due to its strength, durability, and versatility. However, optimizing workability while maintaining desirable mechanical and durability properties remains a challenge, especially when incorporating alternative aggregates and additives [1], [2]. The inclusion of polymer and fiber in concrete has gained significant attention for enhancing its performance characteristics. Styrene-butadiene rubber (SBR) polymer is known to improve adhesion, flexibility, and resistance to water penetration, while polypropylene rope fiber enhances toughness and crack resistance [3],[4].This study investigates the workability of M20-grade polymer fiber-reinforced concrete using both natural and brick aggregates. Due to its high water absorption capacity, brick aggregate affects the water-cement ratio, influencing the overall mix behavior [5,6]. Standardized material tests were conducted to assess the key constituents, including cement, fine and coarse aggregates, SBR polymer, polypropylene rope fiber, and water. Workability was evaluated using the slump test, which measures the effects of polymer and fiber on cohesion and flow ability [7], [8].The results indicate that increasing fiber content reduces workability due to enhanced cohesion, while the addition of SBR polymer improves mix stability. Understanding the interaction between these components provides valuable insights into optimizing mix proportions, ensuring a balance between workability and mechanical performance [9], [10]. This research contributes to the development of polymer fiber-reinforced concrete with hybrid aggregates, offering potential benefits for sustainable and high-performance construction applications.

2. Materials and Methodology

2.1 Materials

The materials utilized in this study include **Ordinary Portland Cement (OPC) 43 grade**, **fine aggregate**, **coarse aggregate**, **coarse brick aggregate**, **Styrene-Butadiene Rubber (SBR)**, and **Polypropylene Rope Fiber**, all conforming to ASTM standards.

2.2 Mix Design Proportion

Styrene Butadiene Rubber (SBR) polymer (10%) and **Polypropylene (PP) rope fiber (0–1%)** are incorporated into M20 grade concrete. The mix variations focus on different aggregate compositions while following ASTM standard guidelines as shown in Table 1.The **control mix** consists of **100% natural aggregates** with a proportion of **1:1.65:3.08 (Cement: Fine Aggregate: Coarse Aggregate)** and a **water-cement ratio of 0.50**, making it suitable for conventional construction. The second variation introduces **10% SBR polymer and 0–1% PP rope fiber**. To evaluate the effect of **brick aggregates**, the third mix replaces **50% of the natural aggregate with brick aggregate**, while cement and fine aggregate proportions remain unchanged. Due to the **higher absorption capacity of brick aggregate**, the **water-cement ratio is increased to 0.56** to ensure proper hydration and strength development. The final mix completely replaces **natural aggregate with 100% brick aggregate**, requiring an **even higher water-cement ratio of 0.60** to maintain hydration and strength.

Table.1 Mix Design Proportion for Different Compositions

Mix Type	Cement	Fine Aggregate	Coarse Aggregate	Water	Polymer (SBR)	Fiber (PP Rope)
100% Natural Aggregate	1	1.65	3.08	0.50	0%	0%
100% Natural Aggregate (With Polymer & Fiber)	1	1.65	3.08	0.50	10%	0–1%
50% Natural + 50% Brick Aggregate (With Polymer & Fiber)	1	1.65	3.08	0.56	10%	0–1%
100% Brick Aggregate (With Polymer & Fiber)	1	1.63	3.08	0.60	10%	0–1%

2.3 Workability Analysis (Slump Test)

Workability refers to the ease with which concrete can be mixed, placed, compacted, and finished without segregation or excessive bleeding. The workability of the different mix types in this study is influenced by the composition of natural and brick aggregates, the presence of styrene-butadiene rubber (SBR) polymer, and the percentage of polypropylene (PP) rope fiber.

3. Results and Discussion

3.1 CEMENT

OPC 43 grade cement was used, with a specific gravity of **3.12** (ASTM C188), ensuring appropriate density. The fineness was **5%** (ASTM C430), indicating adequate particle size distribution. Standard consistency was **27%** (ASTM C187), ensuring optimal water demand. Initial and final setting times were **128 minutes** and **317 minutes**, respectively, meeting ASTM C191 requirements.

Table.2 Cement Test Results for OPC 43 Grade Standard (ASTM C150)

Test Parameter	Test Standard (ASTM)	Obtained Value	Typical Range
Specific Gravity	ASTM C188	3.12	3.10 - 3.15
Fineness %	ASTM C430	5%	≤ 10%
Standard Consistency	ASTM C187	27%	26 - 33%
Initial Setting Time	ASTM C191	128 minutes	≥ 45 minutes
Final Setting Time	ASTM C191	317 minutes	≤ 375 minutes

3.2 COARSE AGGREGATE (Natural)

The specific gravity of coarse aggregate was 2.66 (ASTM C127), with a water absorption rate of 1.02% (ASTM C127), indicating low porosity. The flakiness and elongation indices were 16% and 26%, respectively (ASTM D4791), confirming good particle shape. The impact, crushing, and abrasion values were 9.1%, 19.50%, and 21.26% (ASTM D5874, ASTM C131), ensuring adequate toughness and strength.

Table.3 Coarse Natural Aggregate Test Results Standard (ASTM C33)

Test Parameter	Test Standard (ASTM)	Obtained Value	Typical Range
Specific Gravity	ASTM C127	2.66	2.6 - 2.9
Water Absorption (%)	ASTM C127	1.02%	≤ 2%
Flakiness Index (%)	ASTM D4791	16%	≤ 25%
Elongation Index (%)	ASTM D4791	26%	≤ 35%
Aggregate Impact Value (%)	ASTM D5874	9.1%	≤ 20%
Aggregate Crushing Value (%)	ASTM C131	19.50%	≤ 25%
Aggregate Abrasion Value (%)	ASTM C131	21.26%	≤ 30%

3.3 FINE AGGREGATE (Sand)

Fine aggregate exhibited a specific gravity of **2.66** (ASTM C128) and a fineness modulus of **2.74** (ASTM C136), confirming well-graded particle distribution. Water absorption was measured at **1.4%** (ASTM C128), ensuring minimal porosity and better durability.

Table.4 Fine Aggregate Test Results Standard (ASTM C33)

Test Parameter	Test Standard (ASTM)	Obtained Value	Typical Range
Specific Gravity	ASTM C128	2.66	2.6 - 2.9
Fineness Modulus (FM)	ASTM C136	2.74	2.0 - 3.0
Water Absorption (%)	ASTM C128	1.4%	≤ 3%

3.4 COARSE AGGREGATE (Brick)

Brick aggregate had a specific gravity of **2.25** (ASTM C127) and a water absorption rate of **9.5%**, indicating higher porosity. Flakiness and elongation indices were **20%** and **18%** (ASTM D4791), while impact, crushing, and abrasion values were **6.8%**, **23.5%**, and **33.3%** (ASTM D5874, ASTM C131), demonstrating satisfactory strength characteristics.

Table.5 Coarse Brick Aggregate Test Results Standard (ASTM C33)

Test Parameter	Test Standard (ASTM)	Obtained Value	Typical Range
Specific Gravity	ASTM C127	2.25	2.2 - 2.5
Water Absorption (%)	ASTM C127	9.5%	≤ 20%
Flakiness Index (%)	ASTM D4791	20%	≤ 25%
Elongation Index (%)	ASTM D4791	18%	≤ 35%
Aggregate Impact Value (%)	ASTM D5874	6.8%	≤ 30%
Aggregate Crushing Value (%)	ASTM C131	23.5%	≤ 30%
Aggregate Abrasion Value (%)	ASTM C131	33.3%	≤ 35%

3.5 STYRENE BUTADIENE RUBBER (SBR)

SBR polymer was used as an additive, with a solid content of **46%** (ASTM D1417) and a density of **1.01 g/cm³** (ASTM D1475). The pH level was **9.5** (ASTM E70), viscosity **250 cP** (ASTM D2196), and bond strength **3.8 MPa** (ASTM C882), indicating good adhesion properties.

Table.6 Physical and Chemical Properties of SBR Polymer Standard (ASTM C1059)

Test Parameter	Test Standard (ASTM)	Obtained Value	Typical Range
Appearance	Visual Inspection	Milky white liquid	Milky white to light yellow
Solid Content (%) by Gravimetric Method	ASTM D1417	46%	45 - 55%
pH Level	ASTM E70	9.5	7 - 11
Density (g/cm^3)	ASTM D1475	1.01	1.00 - 1.02
Viscosity (cP at 25°C)	ASTM D2196	250 cP	200 - 300 cP
Bond Strength (MPa)	ASTM C882	3.8 MPa	≥ 3 MPa

3.6 POLYPROPYLENE FIBER (Ropes)

Polypropylene rope fiber exhibited a tensile strength of **440 MPa** (ASTM D2256) and a density of **0.90 g/cm³** (ASTM D792). Water absorption was negligible (**0.01%**, ASTM D570). The fiber length and diameter were **38.1 mm** and **0.5 mm**, respectively, ensuring effective reinforcement in concrete.

Table.7 Physical and Mechanical Properties of Polypropylene Rope Fiber Standard (ASTM C1116)

Test Parameter	Test Standard (ASTM)	Obtained Value	Typical Range
Tensile Strength (MPa)	ASTM D2256	440MPa	350 – 800 MPa
Density (g/cm^3)	ASTM D792	0.90 g/cm3	0.89 –0.93 g/cm3
Water Absorption (% by weight)	ASTM D570	0.01%	≤ 0.1%
Fiber Length (mm)	No Specific ASTM	38.1mm	30 – 40 mm
Fiber Diameter (mm)	No Specific ASTM	0.5mm	0.4 – 0.6 mm

3.7 WATER

Water quality plays a crucial role in determining the **workability, strength, and durability** of concrete. ASTM C1602 sets specific limits to ensure that mixing water does not adversely affect concrete performance. The pH level of **7.1** falls within the recommended range of **6.0 - 8.5**, allowing for proper cement hydration. The total dissolved solids (TDS) content is **1240 mg/L**, which is well below the **2000 mg/L** limit, indicating minimal impurities. Additionally, the chloride concentration of **460 mg/L** remains within the **500 mg/L** threshold for reinforced concrete, reducing the risk of corrosion. Based on these parameters, the water available in **Rahim Yar Khan meets ASTM C1602 standards**, making it **suitable for concrete mixing** while ensuring long-term structural durability.

Table.8 Water Test Results Standard (ASTM C1602)

Test Parameter	Obtained Value	Typical Range
Chloride Content mg/L	460	<500
Total Dissolved Solids (TDS) mg/L	1240	≤ 2000
pH Level	7.1	6.0- 8.5

Figure 1. Material Tests

3.8 Workability Results (Slump Test – ASTM C143)

Table.9 Slump for M20 Grade Concrete (Without Fibers & SBR) Using 100% Natural Aggregate

Mix Type	Slump Value (mm)	Workability Classification	Slump Range (mm)
M20 (Without Fibers & SBR)	81 mm	Medium Workability	50-100 mm

The slump test measures the workability and consistency of fresh concrete. For M20 grade concrete without fibers and SBR polymer, using 100% natural aggregate, the slump value was recorded as 81 mm. According to workability classifications, a slump value between 50 mm and 100 mm falls under the category of medium workability. This indicates that the concrete has a balanced consistency, making it suitable for manual placement, moderate reinforcement, and general construction applications. The mix retains good cohesion without excessive water content, ensuring adequate strength development and durability.

Table.10 Slump for M20 Grade Concrete (With Fibers & SBR) Using 100% Natural Aggregate

Mix Type (with additives)	Slump Value (mm)	Workability Classification	Slump Range (mm)
M20 with 10% SBR & 0.25% Polypropylene Fiber (100% NA)	85 mm	Medium to High	80 – 90 mm
M20 with 10% SBR & 0.75% Polypropylene Fiber (100% NA)	79 mm	Medium	70 – 85 mm
M20 with 10% SBR & 1.0% Polypropylene Fiber (100% NA)	73 mm	Medium	65 – 80 mm

The slump test for M20 grade concrete with SBR and polypropylene fibers demonstrates how the addition of these materials affects workability. When 10% SBR and 0.25% polypropylene fiber were added, the concrete exhibited a slump of 85 mm, indicating medium to high workability, which ensures ease of placement and compaction. As the fiber content increased to 0.75%, the slump value decreased to 79 mm, still within the medium workability range, as the fibers slightly restricted the flow of the mix. Further increasing the fiber content to 1.0% resulted in a slump of 73 mm, maintaining medium workability, but with reduced fluidity due to fiber interlocking. While SBR enhances workability, the gradual slump reduction with increasing fiber content highlights the balancing effect between improved cohesion and slight stiffening of the mix.

Table.11 Slump for M20 Grade Concrete (With Fibers & SBR) Using 50%Natural and 50% Brick Aggregate

Mix Type (with additives)	Slump Value (mm)	Workability Classification	Slump Range (mm)
M20 with 10% SBR & 0.25% Polypropylene Fiber (50% Brick + 50% Natural Aggregates)	86 mm	Medium	85 – 95 mm
M20 with 10% SBR & 0.75% Polypropylene Fiber (50% Brick + 50% Natural Aggregates)	82 mm	Medium	80 – 90 mm
M20 with 10% SBR & 1.0% Polypropylene Fiber (50% Brick + 50% Natural Aggregates)	76 mm	Medium	75 – 85 mm

The slump test for M20 grade concrete with 50% brick and 50% natural aggregates, incorporating 10% SBR and varying polypropylene fiber content, indicates a gradual reduction in workability as fiber content increases. With 0.25% fiber, the slump measured 86 mm, placing it in the medium workability range (85–95 mm), and ensuring ease of placement. As fiber content increased to 0.75%, the slump decreased to 82 mm, still within the medium range (80–90 mm), showing a slight reduction in fluidity due to fiber interlocking. At 1.0% fiber content, the slump further dropped to 76 mm, remaining in the medium category (75–85 mm), but with increased stiffness. The results highlight that while SBR improves workability, the higher water absorption of brick aggregates and increased fiber content contribute to a reduction in slump, affecting the overall consistency of the mix.

Table.12 Slump for M20 Grade Concrete (With Fibers & SBR) Using 100% Brick Aggregate

Mix Type (with additives)	Slump Value (mm)	Workability Classification	Slump Range (mm)
M20 with 10% SBR & 0.25% Polypropylene Fiber (100% Brick Aggregate)	89 mm	Medium–High	85–95 mm
M20 with 10% SBR & 0.75% Polypropylene Fiber (100% Brick Aggregate)	84 mm	Medium	80–90 mm
M20 with 10% SBR & 1.0% Polypropylene Fiber (100% Brick Aggregate)	78 mm	Medium	75–85 mm

The slump test for M20 grade concrete with 100% brick aggregate, incorporating 10% SBR and varying polypropylene fiber content, shows a progressive decrease in workability as fiber content increases. With 0.25% fiber, the slump was 89 mm, placing it in the medium–high workability range (85–95 mm), ensuring good flow and ease of placement. At 0.75% fiber content, the slump decreased to 84 mm, moving to the medium workability range (80–90 mm), indicating a slight reduction in fluidity due to fiber dispersion. With 1.0% fiber, the slump further dropped to 78 mm, still classified as medium workability (75–85 mm), but with increased stiffness and reduced flow. These results suggest that SBR enhances workability, but the higher water absorption of brick aggregates and fiber interlocking effects contribute to a decrease in slump, making the mix stiffer as fiber content increases.

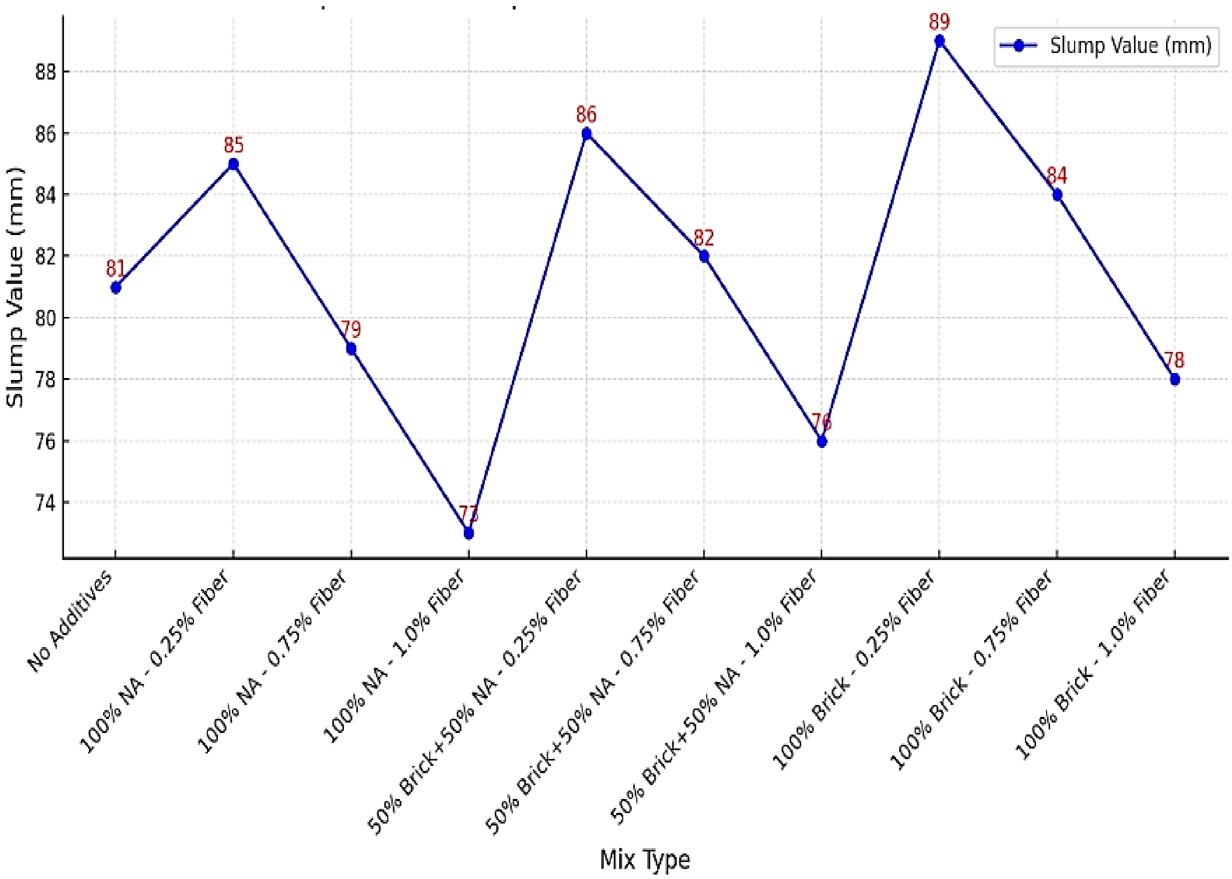

Figure.2 Comparison of Slump Values for Different M20 Concrete Mixes

Figure.3 Slump Test

4. Conclusion

This research investigated the workability of M20 grade concrete with various aggregate compositions, incorporating SBR polymer and polypropylene fibers to enhance properties. The study focused on six different mix variations, with natural aggregate (NA) and brick aggregate (BA) used in different proportions while maintaining a fixed 10% SBR polymer and varying polypropylene fiber percentages (0% to 1%). The results provide insights into the effectiveness of alternative aggregates in improving concrete properties.

4.1 Workability Analysis (Slump Test)

The control mix (100% NA, without polymer and fiber) exhibited a slump of 81 mm, classifying it as medium workability (50-100 mm range).Incorporating SBR polymer and fibers generally improved workability compared to the control mix due to SBR's plasticizing effect, but higher fiber content slightly reduced workability. Mixes containing brick aggregates showed higher slump values initially due to their porous nature, but water absorption led to slightly reduced workability at higher fiber contents. The 100% BA mix with SBR and fibers exhibited the highest slump (89 mm with 0.25% fiber), making it more workable compared to other modified mixes.

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