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Research Article

Effect of Wheat Straw Ash on Fresh and Hardened Concrete Reinforced with Jute Fiber

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In the present era, a number of researchers are using either industrial or agricultural priceless products as a basic source of raw materials for the construction industry. These waste products are economical and helpful in producing a sustainable environment and reducing environmental pollution, which is called handling waste products. However, this research work was conducted on concrete containing 0.25%, 0.50%, 0.75%, and 1% of jute fiber as reinforcement material and 10%, 20%, 30%, and 40% of wheat straw ash (WSA) as replacement for fine aggregates. Moreover, the separate and combined effect of jute fiber and WSA as a replacement for sand ingredient in concrete is to determine the fresh and hardened properties of concrete. In this research, a number of concrete samples were prepared with 1 : 1.5 : 3 mix proportion at 0.54 water-cement ratio and cured at 28 days. The experimental outcomes displayed that the compressive, splitting tensile, and flexural strengths improved by 32.88 MPa, 3.80 MPa, and 5.30 MPa at 0.50% of jute fiber along with 30% of WSA at 28 days consistently. Similarly, the modulus of elasticity was developed while the dosages of jute fiber and WSA increased together in concrete. Moreover, the permeability and workability of concrete were reduced while utilized jute fiber and WSA increased together in concrete.

1. Introduction

Concrete is the main building material substantially used all over the world. Since its creation in the Roman era, its use in various industries has grown. This phenomenon is primarily explained by its superiority over other types of building materials in terms of compressive strength, durability, and efficiency [1]. However, some deficiencies occur in concrete due to weak in tensile strength, poor resistance to cracking, and low tendency to deformation and fracture in concrete. [2]. To recompense for the brittleness of conventional concrete, fiber-reinforced concrete is usually utilized as an alternative [2, 3]. Moreover, the fiber is used in concrete as a reinforcement material from the Biblical era [4], and fibers are categorized into steel, glass, synthetic, carbon, and natural fibers, which have been incorporated into concrete to increase the tensile strength of concrete [5]. Among them, steel fiber is most extensively utilized in concrete [4, 6, 7]. However, steel fibers are susceptible to corrosion, which limits their use. To solve this problem, it is generally concluded that synthetic fibers are the alternative. However, the production of synthetic fibers is very expensive and energy consuming [8]. Under these conditions, natural fibers are generally considered a potential fiber replacement for the production of fiber-reinforced concrete. Natural fiber-reinforced concrete is a cement-based concrete matrix in which natural fibers of discontinuous length are randomly distributed throughout the concrete matrix. Natural fiber has advantages in terms of the environment, economy, and energy and resource conservation [9]. In addition, it can reduce the use of concrete components (e.g., aggregates and cement) and, therefore, can contribute to sustainability.

According to the source of natural fibers, they are usually produced from three main sources such as plants, animals, and minerals [10]. Among them, plant fibers are preferred. Meanwhile, the animal fibers possess mainly protein and mineral fibers that are related to health problems, but cellulose is an essential element in plant fibers which makes it the most preferred one. With the exception of Pickering et al.'s study [10], these plant fibers have been shown to have higher strength and stiffness than animal fibers. Onuaguluchi and Banthia [9] also described the potential of plant fibers in concrete and reported that the performance of cementitious materials can be significantly improved by using natural plant fibers to improve the properties of cementitious materials. In addition, cellulose-based plant fibers can provide convenient reinforcement of cement-based concrete composites due to their low density [11], high tensile properties, and special microstructure.

The possibility of mixing different fibers such as jute, kenaf, hemp, coconut [12], and sisal in concrete has been studied to improve the characteristic strength of concrete. It was found that the addition of natural fibers in concrete can improve compressive strength, tensile strength, impact strength, cracking and impact resistance of concrete, fatigue strength, and impact resistance, as well as the strain capacity of concrete [12–15].

Another significant benefit of natural fiber is that it requires little energy to be produced [16]. Due to the good properties of synthetic fiber, using it in concrete improves the tensile properties of concrete. However, conventional synthetic fibers (such as steel and acrylic) are expensive and can increase the cost of the project. On the other hand, natural fibers represent a cheaper, environmental friendly, and sustainable solution to improve the tensile properties of concrete [12]. Hence, for this experimental study, jute fiber is used as the reinforcement ingredient in concrete. However, jute is one of the cheapest and strongest natural fibers widely used in Bangladesh [17]. Jute is the second largest textile fiber in the world, after cotton. Jute produced in Bangladesh accounts for 33% of its world production, and Bangladesh is the second-largest jute producer in the world [17]. Jute fiber is mainly composed of cellulose and plant lignin. As a natural fiber, jute has many inherent convenience properties such as high tensile strength, moderate fire resistance, biodegradability, renewability, recyclability, and environmental protection, making it more beneficial than other types of fibers [17, 18]. In addition, natural sand is another main constituent of concrete used as fine aggregate that influences the natural resources. The maximum usage of river sand as fine aggregates which is derived from the river bed results in deterioration of the river bed, lower water table levels, erosion of the river bed, and destruction of the bridge structure, which causes unsustainable development of the country. Thus, finding possible alternatives to natural aggregates has become very essential and even more important. Besides, the continuous growth of agricultural and industrial waste is a major cause of a number of environmental problems, and this burden can be reduced by using wheat straw ash in concrete structures [19]. However, the use of agricultural ash such as WSA in concrete mixes is limited. In areas of mass production of WSA, the ability to use WSA as a specific component can provide a solution for managing this agricultural waste. Wheat provides the world's highest grain yield. Pakistan produces 27 million tons per year, making it the eighth largest wheat producer in the world. Pakistan produces large amounts of wheat straw as waste every year due to the high wheat harvest. For every kilogram of wheat grain produced, about 1.5 kg of wheat straw is obtained [20]. The high yield of wheat straw indicates that Pakistan produces about 16 million tons of wheat straw as waste annually. Traditionally, most of the straw produced in Pakistan has been disposed in open areas or burned outdoors. Thus, the improper handling of this waste leads to safety, health, and aesthetic problems. Therefore, the wheat straw ash is utilized as a replacement for sand ingredient in concrete. Although numerous experimental works were conducted on WSA as a replacement for cement in concrete [21–23], there is no research work performed on concrete with the inclusion of WSA as a replacement for sand ingredient. Besides, limited studies were conducted on jute fiber as reinforcement material in concrete. Furthermore, there is no any experimental work performed on concrete blended with the combined use of WSA as a replacement for sand ingredient and jute fiber as reinforcement constituents. Therefore, this research study is to determine the fresh (slump test) and hardened properties (i.e., compressive strength, tensile strength, flexural strength, modulus of elasticity, and water penetration depth) of concrete blended with the separate and combined usage of WSA as the replacement for sand ingredient and jute fiber as the volume fraction of concrete.

2. Materials and Methods

2.1. Materials. Wheat straw was collected from the Tando Jam region, Sindh, Pakistan. After collecting wheat straw, it was burnt under control temperature ranging from 500°C to 750°C for five hours to form ash. This ash was passed through a sieve of 4.75 mm in size, and then, it was utilized as a replacement for sand ingredient in concrete which possesses pozzolanic property. However, the sum of SiO_2, Al_2O_3, and Fe_2O_3 is greater than 50% in any material which categorizes that the material has pozzolanic nature according to ASTM C618 [24] as shown in Table 1. Jute fiber is a natural fiber which is found abundantly in tropical regions. Jute fiber lengths vary from 10 mm to 20 mm, and the diameter is 0.10 mm. It is easily available and has high tensile strength. Moreover, the Portland cement (PC) was used for this research study as a binding component. The PC was obtained locally from Hyderabad, Pakistan. The chemical composition of PC and WSA is revealed in Table 1. In addition, river sand

Table 1: Chemical composition of PC and WSA.

Binder	Compound (%)								
	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	SO_3	MgO	K_2O	P_2O_5
PC	20.78	5.11	3.17	60.22	0.18	2.86	3.00	0.39	0.26
WSA	67.83	6.44	4.36	10.60	0.47	1.85	1.78	5.43	1.24

was applied as fine aggregates (FA) that passed from the #4 sieve, and crushed stone was employed as coarse aggregates (CA) that were 20 mm in size. These materials were obtained locally from the region of Hyderabad, Sindh, Pakistan. The physical properties of the aggregates are mentioned in Table 2. The sieve analysis of coarse and fine aggregates was performed by using ASTM C136 [25] as shown in Figure 1, and the bulk density of aggregates was calculated by observing ASTM C29-97 [26]. Besides, the specific gravity and water absorption for fine and coarse aggregates were calculated under ASTM C128-93 [27] and ASTM C127-93 [28] correspondingly. Furthermore, drinking water was used for mixing and curing in the research study.

2.2. Mixture Design. The investigational procedure was implemented on the mixtures reinforced with 0.25%, 0.50%, 0.75%, and 1% of jute fiber as the volume fraction of concrete and 10%, 20%, 30%, and 40% of WSA as the mass of fine aggregates individually and together in concrete to obtain the fresh and hardened properties of concrete. However, twenty-five concrete mixes were prepared with 1 : 1.5 : 3 mix proportion at 0.54 water-cement ratio, in which one concrete mixture was made of PC only; four mixtures were equipped with the accumulation of 10%, 20%, 30%, and 40% WSA as a replacement for sand ingredient, four concrete mixtures were made with the reinforcement of 0.25%, 0.50%, 0.75%, and 1% jute fiber as the volume fraction, and remaining sixteen concrete mixtures were prepared with the addition of 0.25%, 0.50%, 0.75%, and 1% jute fiber along with 10%, 20%, 30%, and 40% of WSA as a replacement for sand ingredient in concrete as indicated in Table 3.

2.3. Testing Methods

2.3.1. Slump Test. The slump test was performed on all concrete mixes with accumulation of various proportions of jute fiber, different percentages of WSA as a replacement for sand ingredient individually, and combined use in concrete under the ASTM C143-90 [29].

2.3.2. Hardened Properties of Concrete. Hardened properties of concrete such as compressive strength, splitting tensile strength, flexural strength, modulus of elasticity, and water penetration depth were obtained. However, cube samples (100 mm × 100 mm × 100 mm) were utilized for estimating the compressive strength of mixture reinforced with various percentages of jute fiber as the volume fraction and blended with different percentages of WSA as a replacement for sand ingredient separately and together in concrete by observing the ASTM C39/C39M [30], and cylinders (200 mm × 100 mm) were utilized for splitting tensile strength of mixture reinforced with 0.25%, 0.50%, 0.75%, and 1% of jute fiber as the volume fraction of concrete and blended with 10%, 20%, 30%, and 40% of WSA as the mass of fine aggregates individually and together in concrete by following the ASTM C 496-90 [31]. Similarly, the beam samples (500 mm × 100 mm × 100 mm) were cast for determining the flexural strength of mixture inclusion with various percentages of jute fiber as reinforcement material and addition of different percentages of WSA by the weight of fine aggregates separately and together in concrete under the ASTM C293/293M [32]. Moreover, the modulus of elasticity and permeability of mixture reinforced with various proportions of JF and several ratios of WSA as a replacement for sand ingredient separately and together in concrete were calculated by following ASTM C 469 [33] and BS EN 12390-8 [34], respectively. These tests were conducted at 28 days during curing.

3. Results and Discussion

Table 4 indicates the descriptive statistical data on experimental results in order to determine the range, mean, standard deviation, and coefficient of variation.

3.1. Slump Test. Figure 2 indicates the workability of concrete with the accumulation of 0.25% to 1% jute fiber as the volume fraction of concrete. The workability of green concrete was recorded as 46 mm, 37 mm, 29 mm, and 20 mm at 0.25%, 0.50%, 0.75%, and 1% of jute fiber which is less when compared to concrete without jute fiber. It was found that that the workability was reduced while the content of jute fiber increased in concrete. Such a phenomenon might be prompted by the large specific surface and the smaller diameter of the jute fiber when compared to other ingredients of concrete. On the other hand, the use of jute fiber is increased in concrete which absorbs more amount of water as compared to control mixture that results in reducing workability of concrete [9]. This remark is associated with Islam and Ahmed [18], where the workability of green concrete is minimized while the content of jute fiber improves. A similar trend was observed by Bheel et al. [35]. However, the workability of concrete intermingled with 10% to 40% of WSA as a replacement for sand in concrete as demonstrated in Figure 2. The slump was noted to be 20.68%, 36.21%, 50%, and 65.52% at 10%, 20%, 30%, and 40% of WSA which is smaller than that noted in plain concrete. It was observed that the slump of concrete is plummeted while the extent of WSA increases. Such a phenomenon of reduction in the slump is due to the large

Table 2: Physical properties of materials.

Materials	Physical properties of materials			
	Fineness modulus	Specific gravity	Bulk density (compacted)	Water absorption
Fine aggregates	2.15	2.61	1845 kg/m^3	1.3%
Coarse aggregates	6.75	2.65	1630 kg/m^3	0.75%
Wheat straw ash	7.80	2.21	-----	------
Cement	5.60	3.15	-----	------

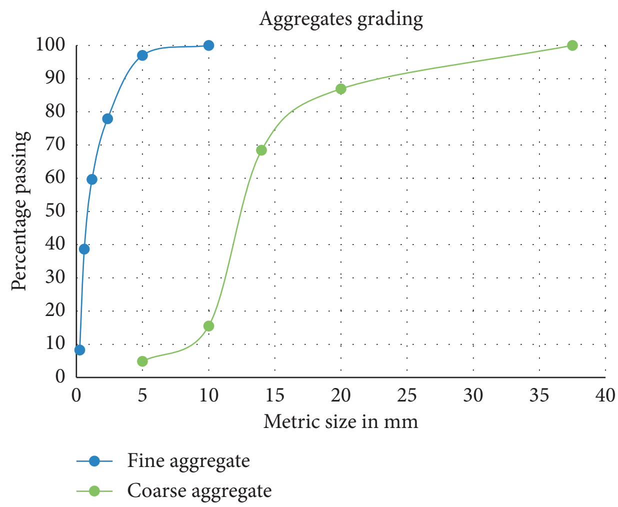

Figure 1: Sieve analysis for aggregates.

Table 3: Mix proportion for concrete.

Mix proportion	Mix ratio of concrete	Cement (%)	Wheat straw ash (%)	Fine aggregates (%)	Jute fiber (%)	Coarse aggregates (%)	Water/binder ratio
C	1 : 1.5 : 3	100	0	100	0	100	0.54
JF0.25	1 : 1.5 : 3	100	0	100	0.25	100	0.54
JF0.50	1 : 1.5 : 3	100	0	100	0.50	100	0.54
JF0.75	1 : 1.5 : 3	100	0	100	0.75	100	0.54
JF1	1 : 1.5 : 3	100	0	100	1	100	0.54
WSA10	1 : 1.5 : 3	100	10	90	0	100	0.54
WSA20	1 : 1.5 : 3	100	20	80	0	100	0.54
WSA30	1 : 1.5 : 3	100	30	70	0	100	0.54
WSA40	1 : 1.5 : 3	100	40	60	0	100	0.54
JF0.25WSA10	1 : 1.5 : 3	100	10	90	0.25	100	0.54
JF0.25WSA20	1 : 1.5 : 3	100	20	80	0.25	100	0.54
JF0.25WSA30	1 : 1.5 : 3	100	30	70	0.25	100	0.54
JF0.25WSA40	1 : 1.5 : 3	100	40	60	0.25	100	0.54
JF0.5WSA10	1 : 1.5 : 3	100	10	90	0.50	100	0.54
JF0.50WSA20	1 : 1.5 : 3	100	20	80	0.50	100	0.54
JF0.50WSA30	1 : 1.5 : 3	100	30	70	0.50	100	0.54
JF0.50WSA40	1 : 1.5 : 3	100	40	60	0.50	100	0.54
JF0.75WSA10	1 : 1.5 : 3	100	10	90	0.75	100	0.54
JF0.75WSA20	1 : 1.5 : 3	100	20	80	0.75	100	0.54
JF0.75WSA30	1 : 1.5 : 3	100	30	70	0.75	100	0.54
JF0.75WSA40	1 : 1.5 : 3	100	40	60	0.75	100	0.54
JF1WSA10	1 : 1.5 : 3	100	10	90	1	100	0.54
JF1WSA20	1 : 1.5 : 3	100	20	80	1	100	0.54
JF1WSA30	1 : 1.5 : 3	100	30	70	1	100	0.54
JF1WSA40	1 : 1.5 : 3	100	40	60	1	100	0.54

Table 4: Descriptive statistical data on experimental results.

	Slump (mm)	Compressive strength (MPa)	Tensile strength (MPa)	Flexural strength (MPa)	Modulus of elasticity (GPa)	Permeability (mm)
Number of values	25	25	25	25	25	25
Minimum	12.00	28.00	3.100	4.300	26.50	7.000
Maximum	58.00	32.88	3.800	5.300	31.45	22.00
Range	46.00	4.880	0.7000	1.000	4.950	15.00
Mean	31.52	30.70	3.473	4.844	29.30	14.32
Std. deviation	11.74	1.261	0.1564	0.2299	1.377	3.637
Std. error of mean	2.348	0.2522	0.03128	0.04597	0.2754	0.7274
Coefficient of variation	37.25%	4.108%	4.503%	4.746%	4.699%	25.40%

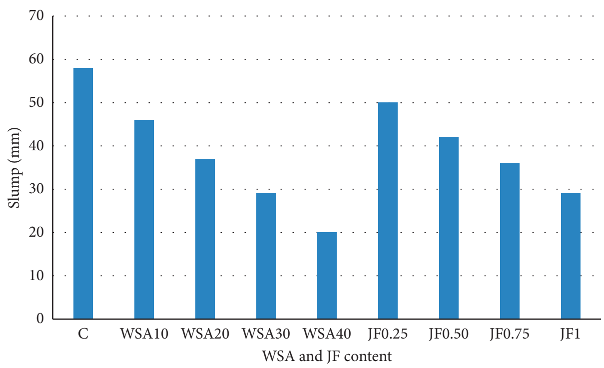

Figure 2: Workability of mixtures containing WSA and jute fiber.

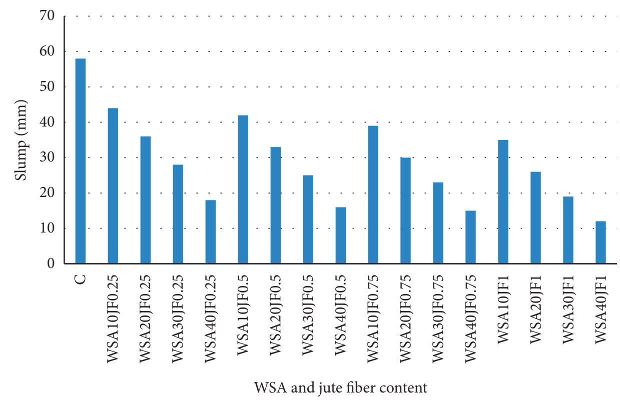

Figure 3: Workability of mixtures containing WSA and jute fiber.

specific surface area of WSA as constrained to cement which absorbs a high amount of water than PC. This opinion was in agreement with that of Bheel et al. [36] that the workability of fresh concrete is reduced as the extent of WSA as cementitious component increases. A similar trend was detected by Bheel et al. [37] and Dayo et al. [38]. Moreover, it was indicated in Figure 3 where the slump of concrete reinforced with 0.25% to 1% of jute fiber as volume fraction along with 10% to 40% of WSA as fine aggregate replacement. The optimum slump was noted as 58 mm at 0% of jute fiber and 0% of WSA, and the lowest slump was measured as 12 mm at 1% of jute fiber and 40% of WSA as fine aggregate replacement. It was noted that the slump drops as the dosages of jute fiber and WSA increase in concrete. This phenomenon of workability is reduced owing to large specific surface area of WSA and jute fiber which absorb some amount of water. This opinion was in agreement with Keerio et al. [39] that the workability decreases while the extent of glass powder as the replacement for sand along with silica fume as the replacement for cement component improve in concrete.

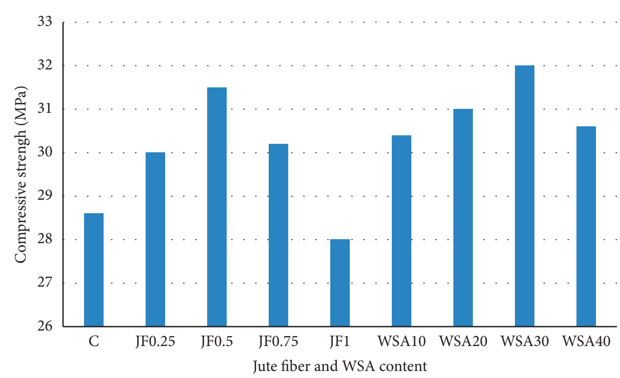

Figure 4: Compressive strength of mixture containing jute fiber and WSA.

3.2. Compressive Strength. Figure 4 displays the compressive strength of the mixture containing 0.25% to 1% of jute fiber as the reinforcement ingredient at 28 days. It was improved by 31.5 MPa which is 10.14% greater than that in plain concrete at 0.50% of jute fiber and the lowest strength was estimated as 28 MPa that is 2.1% lower than the control mix at 1% of jute fiber as the reinforcement ingredient in concrete at 28 days correspondingly. The outcome suggested that the strength was enhanced while utilizing jute fiber up to 0.50% as reinforcement components and with further addition of jute fiber in concrete; the strength reduces due to the maximum number of voids generated by jute fiber addition which is greater than the optimum level of voids produced in concrete. This trend was observed by Zarakia et al. [40]. Islam and Ahmed [18] stated that the compressive strength was reduced while utilizing jute fiber beyond 0.50% as the reinforcement ingredient in concrete. However, the compressive strength of mixture with the introduction of 10% to 40% of WSA as the replacement of sand in concrete is recorded at 28 days as shown in Figure 4. The optimum strength is recorded as 32 MPa at 30% of WSA, and the minimum strength is calculated as 30.60 MPa while utilizing 40% of WSA as the replacement for sand ingredient in concrete at 28 days correspondingly. It was noteworthy that the inclusion of WSA in concrete up to 30% that results in improving the strength can be indorsed to its voids-filling influence coupled with the potential pozzolanic reaction of the WSA, and then, the further addition of WSA causes reduction in compressive strength due to the dilution effect of the WSA that results in lower calcium hydroxide existing for product development [36]. This statement is similar to that by Kanaka and Thiyagarajan [41] and Bajad, Modhera, and Desai [42]. Keerio et al. [39] indicated that the strength is enhanced with increasing extent of glass powder equal to 30% as the sand substitute at 28 days. Figure 5 shows the compressive strength of the mixture with the introduction of 0.25% to 1% jute fiber and 10% to 40% of WSA as the replacement for sand ingredient at 28 days. The maximum compressive strength was calculated as 32.88 MPa at 0.50% of jute fiber along with 30% of WSA, and the lowest strength was estimated as 28 MPa while utilizing 1% of jute fiber along with 40% of WSA as the replacement for sand ingredient at 28 days correspondingly. It was observed that the strength was enhanced while utilizing jute fiber equal to 0.50% and WSA equal to 30% together because the fiber-associated influence stops transverse distortion resulting in increase in compressive strength [43]. Furthermore, accumulation of fiber at a greater rate causes more voids in concrete that results in reduction of compressive strength [44].

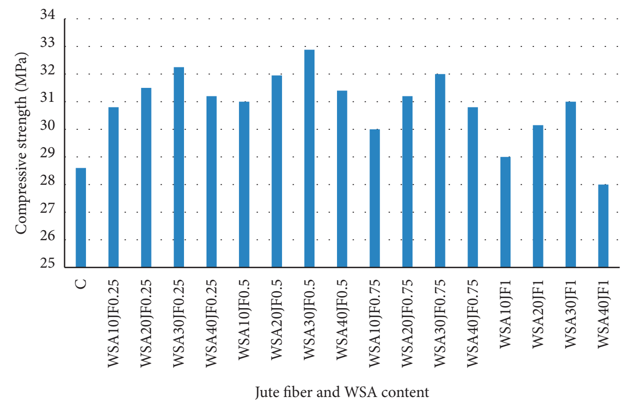

Figure 5: Compressive strength of mxture containing jute fiber and WSA.

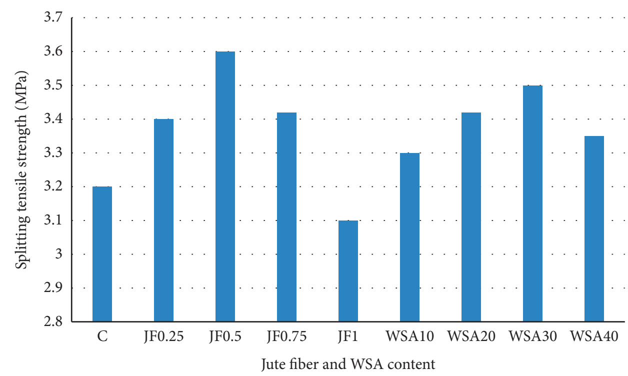

Figure 6: Splitting tensile strength of mixture containing jute fiber and WSA.

3.3. Splitting Tensile Strength of Concrete. Figure 6 indicates the splitting tensile strength of mixture containing 0.25% to 1% of jute fiber as the reinforcement ingredient at 28 days. It is improved by 3.60 MPa at 0.50% of jute fiber which is 12.50% greater than that in plain concrete, and the lowest strength is estimated as 3.10 MPa at 1% of jute fiber as the reinforcement ingredient in concrete that is 3.1% lower than in control mix at 28 days correspondingly. The outcome showed that the splitting tensile strength was enhanced while utilizing jute fiber equal to 0.50% as the reinforcement component and with further addition, it reduces due to increase in the amount of jute fiber which produces the voids in concrete. Besides, jute fibers can stop the spread of microcracks and finally improve the splitting tensile strength of the mixture. This trend was observed by Islam and Ahmed [18], where the indirect tensile strength was reduced while utilizing jute fiber beyond 0.50% as the reinforcement ingredient in concrete. The indirect tensile strength of concrete mix with the introduction of 10% to 40% of WSA as the replacement of sand in concrete obtained at 28 days is shown in Figure 6. The optimum strength was recorded as 3.50 MPa at 30% of WSA, and the minimum strength was calculated by 3.35 MPa while utilizing 40% of WSA as the replacement for sand ingredient in concrete at 28 days correspondingly. It was noteworthy that the inclusion of up to 30% WSA in concrete that results in increase in the strength may be because specific surface area of WSA is higher than that of other components of concrete and further addition of WSA can cause reduction in splitting tensile strength. This statement is similar to that of Bheel et al. [36] that the strength was enhanced with increase in the extent of WSA equal to 10% as the cement substitute at 28 days. A similar trend is observed by Keerio et al. [39]. Also, Figure 7 shows the splitting tensile strength of concrete with the introduction of 0.25% to 1% jute fiber and 10% to 40% of WSA as the replacement for sand ingredient at 28 days. The maximum splitting tensile strength was measured as 3.80 MPa at 0.50% of jute fiber along with 30% of WSA, and the lowest strength was estimated as 3.36 MPa while utilizing 1% of jute fiber along with 40% of WSA as the replacement for sand ingredient at 28 days correspondingly. It was observed that the strength was enhanced while utilizing jute fiber up to 0.50% and WSA equal to 30% together in concrete. This opinion was in agreement with that of Bheel et al. [36] that the tensile strength was enhanced as the increase in the extent of WSA equal to 10% as the cementitious constituent in concrete. This similar trend was observed by Bheel et al. [45, 46].

3.4. Flexural Strength. Figure 8 shows the flexural strength of mixture containing 0.25% to 1% of jute fiber as the reinforcement ingredient at 28 days. The flexural strength was

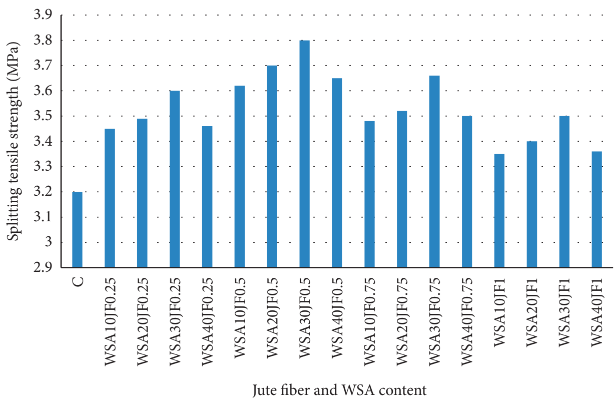

Figure 7: Splitting tensile strength of mixture containing jute fiber and WSA.

Figure 8: Flexural strength of mixture containing jute fiber and WSA.

improved by 5.0 MPa which is 11.11% greater than that in plain concrete at 0.50% of jute fiber, and the lowest strength was estimated as 4.30 MPa that is 4.44% lower than in the control mix at 1% of jute fiber as the reinforcement ingredient in concrete at 28 days correspondingly. The outcome of this study indicated that the flexural strength is enhanced while utilizing jute fiber up to 0.50% as the reinforcement component and with further addition of jute fiber, the flexural strength is reduced due to the increase in the amount of jute fiber which produces more voids in concrete. This trend was observed by Islam and Ahmed [18] that the flexural strength was reduced while utilizing jute fiber beyond 0.50% as the reinforcement ingredient in concrete. The flexural strength of the mixture with the introduction of 10% to 40% of WSA as the replacement of sand in concrete at 28 days is shown in Figure 8. The optimum flexural strength was recorded as 4.92 MPa at 30% of WSA, and the minimum flexural strength was calculated as 4.70 MPa while utilizing 40% of WSA as the replacement for sand ingredient in concrete at 28 days correspondingly. It was noteworthy that the inclusion of WSA in concrete up to 30% that results in increase in the flexural strength may be associated to the high dosage of silica, aluminum oxide, and iron oxide in WSA and further addition of WSA can cause reduction in the flexural strength owing to its slow pozzolanic reaction. This statement is in agreement with that of Bheel et al. [36] that the strength was enhanced with an incline in the extent of wheat straw ash equal to 10% as the sand substitute at 28 days. A similar trend was observed by Dayo et al. [47] and Bheel et al. [48]. Figure 9 shows the flexural strength of concrete with the introduction of 0.25% to 1% jute fiber and 10% to 40% of WSA as the replacement for sand ingredient at 28 days. The maximum flexural strength was measured as 5.30 MPa at 0.50% of jute fiber along with 30% of WSA, and the lowest strength was estimated as 4.40 MPa while utilizing 1% of jute fiber along with 40% of WSA as the replacement for sand ingredient at 28 days correspondingly. It was observed that the flexural strength was enhanced while utilizing jute fiber up to 0.50% and WSA equal to 30% together in concrete. This opinion was in agreement with that of Bheel et al. [45] that the flexural strength was enhanced as the extent of metakaolin and GGBFS equal to 10% as the binary cementitious component in concrete improved.

3.5. Modulus of Elasticity. Figure 10 shows the modulus of elasticity of concrete containing 0.25% to 1% of jute fiber as the reinforcement ingredient at 28 days. The modulus of elasticity of concrete is measured as 27.15 GPa, 28.50 GPa, 29.25 GPa, and 30.45 GPa at 0.25%, 0.5%, 0.75%, and 1% of jute fiber which is higher than that of plain concrete at 28 days, respectively. The outcome shows that the modulus of elasticity of concrete is enhanced while utilizing jute fiber as the reinforcement component in concrete to form harder one as compared to plain concrete. A similar investigational study was performed by Bheel et al. [35] that the modulus of elasticity is increased with the growth in the extent of human hair fiber at 90 days. The modulus of elasticity of mixture is determined with addition of 10% to 40% of WSA as the replacement of sand in concrete at 28 days as shown in Figure 10. The modulus of elasticity of concrete is recorded as 27.10 GPa, 28.30 GPa, 29.40 GPa, and 30.35 GPa at 10%, 20%, 30%, and 40% of WSA as the replacement for sand ingredient which is higher than that in plain concrete at 28 days correspondingly. It is noted that the inclusion of the WSA content in concrete results in increase in the modulus of elasticity. This aspect is observed by Foong et al. [49] that the modulus of elasticity of concrete is enhanced while utilizing rice husk ash equal to 15% as the cementitious material at 28 days. Figure 11 shows that the modulus of elasticity of concrete is calculated with inclusion of 0.25% to 1% jute fiber and 10% to 40% of WSA as the replacement for sand ingredient at 28 days. The maximum modulus of elasticity is measured as 31.45 GPa mm at 1% of jute fiber along with 40% of WSA, and the lowest modulus of elasticity is estimated at 26.50 GPa while utilizing 0% of jute fiber along with 0% of WSA as the replacement for the sand ingredient at 28 days, respectively. It is noted that the modulus of elasticity is increasing with increase in jute fiber and WSA content together in concrete. This opinion was in agreement with that of Bheel et al. [36] that the modulus of elasticity was inclined as the extent of wheat straw ash as the

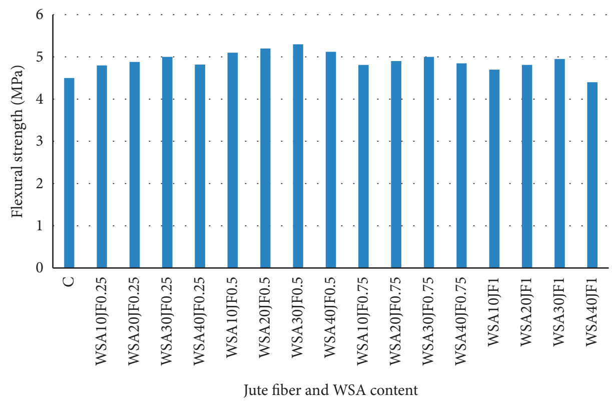

Figure 9: Flexural strength of mixture containing WSA and jute fiber.

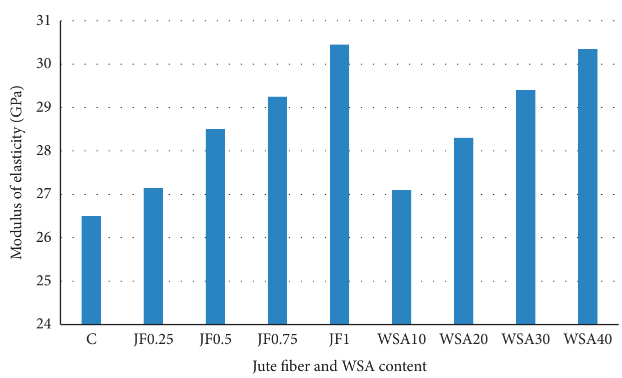

Figure 10: Modulus of elasticity of mixture containing jute fiber and WSA.

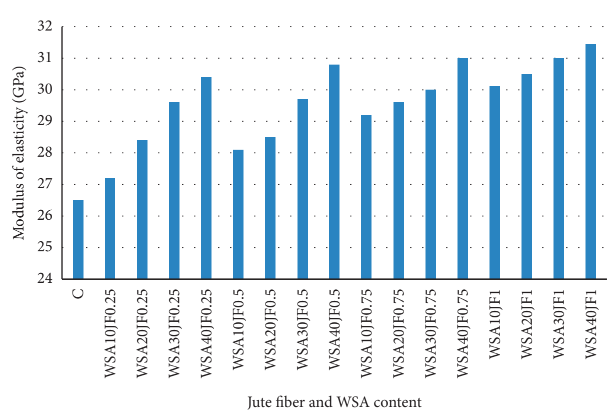

Figure 11: Modulus of elasticity of mixture containing jute fiber and WSA.

cementitious component in concrete increases. The same observation was observed by Bheel et al. [50].

3.6. Water Penetration Depth. Figure 12 shows the water penetration depth of concrete containing 0.25% to 1% of jute fiber as the reinforcement ingredient at 28 days. The permeability of concrete was estimated as 20 mm, 18 mm, 15 mm, and 14 mm at 0.25%, 0.5%, 0.75%, and 1% of jute fiber which is less than that in plain concrete at 28 days, respectively. The outcome suggested that the permeability of concrete is reduced with increase in jute fiber utilized as the reinforcement component. The permeability of mixture with the introduction of 10% to 40% of WSA as the replacement of sand in concrete at 28 days is shown in Figure 12. The water penetration depth of concrete was recorded as 13.64%, 22.73%, 36.36%, and 45.55% at 10%, 20%, 30%, and 40% of WSA as the replacement for sand ingredient which is less when compared to plain concrete at 28 days, respectively. It was recorded that the inclusion of WSA in concrete results in reduction in permeability. This aspect was in agreement with that of Guneyisi et al. [51] that the permeability of concrete is reduced by 29% while utilizing MK equal to 15% as the cementitious material at 28 days. Figure 13 shows that the permeability of concrete with the introduction of 0.25% to 1% jute fiber and 10% to 40% of WSA as the replacement for sand ingredient at 28 days. The maximum water penetration depth was measured as 22 mm at 0% of jute fiber along with 0% of WSA, and the lowest water penetration depth was estimated as 7 mm while utilizing 1% of jute fiber along with 40% of WSA as the replacement for sand ingredient at 28 days, respectively. It was observed that the permeability of concrete was reduced while jute fiber and WSA utilized increase together in concrete. This opinion conforms with that of Bheel et al. [45] that the permeability of concrete was reduced as the extent of metakaolin and GGBFS as the binary cementitious component in concrete increases.

Figure 12: Permeability of mixture containing jute fiber and WSA.

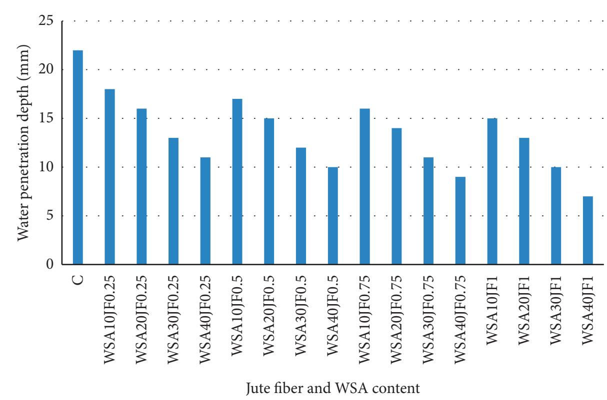

Figure 13: Permeability of mixture containing jute fiber and WSA.

4. Conclusions

In this experimental work, the separate and combined effect of jute fiber as the reinforcement ingredient and WSA as the replacement of sand in concrete was determined to obtain the fresh and hardened properties of concrete. Based on the experimental outcomes, the following key points are drawn:

(i) The slump is recorded as 13.80%, 27.58%, 37.93%, and 50% at 0.25%, 0.50%, 0.75%, and 1% of jute fiber which is less when compared to concrete without jute fiber. However, the slump is noted as 20.68%, 36.21%, 50%, and 65.52% at 10%, 20%, 30%, and 40% of WSA which is lower than that in plain concrete. Moreover, the optimum slump was noted as 58 mm at 0% of jute fiber and 0% of WSA, and the lowest slump is measured as 12 mm at 1% of jute fiber and 40% of WSA as fine aggregate replacement. This result shows that the slump is reduced while the extent of jute fiber and WSA increases in concrete.

(ii) The compressive strength, splitting tensile strength, and flexural strength are improved by 31.5 MPa, 3.60 MPa, and 5 MPa, which is 10.14%, 12.50%, and 11.11% at 0.50% of jute fiber, higher that that in plain concrete, and the lowest compressive, splitting tensile, and flexural strengths are estimated as 28 MPa, 3.10 MPa, and 4.30 MPa, that is, 2.1%, 3.1%, and 4.44%, at 1% of jute fiber as the reinforcement ingredient, lower than in control mix at 28 days, respectively.

(iii) The optimum compressive, splitting tensile, and flexural strengths are recorded as 32 MPa, 3.50 MPa, and 4.92 MPa at 30% of WSA, and the minimum strength was calculated as 30.60 MPa, 3.35 MPa, and 4.70 MPa while utilizing 40% of WSA as the replacement for sand ingredient in concrete at 28 days correspondingly.

(iv) The optimum compressive, splitting tensile, and flexural strengths are measured as 32.88 MPa, 3.80 MPa, and 5.30 MPa at 0.50% of jute fiber along with 30% of WSA, and the lowest compressive, splitting tensile, and flexural strengths are estimated as 28 MPa, 3.36 MPa, and 4.40 MPa while utilizing 1% of jute fiber along with 40% of WSA as the replacement for sand ingredient at 28 days correspondingly. It was observed that the compressive, splitting tensile, and flexural strengths are enhanced while utilizing jute fiber up to 0.50% and WSA equal to 30% together and with further addition, they are reduced.

(v) The modulus of elasticity of concrete was measured as 2.45%, 7.55%, 10.38%, and 14.91% at 0.25%, 0.5%, 0.75%, and 1% of jute fiber which is higher than that in plain concrete at 28 days, respectively. Also, the modulus of elasticity of concrete was recorded as 2.26%, 6.79%, 10.94%, and 14.53% at 10%, 20%, 30%, and 40% of WSA as the replacement for sand ingredient which is greater than in plain concrete at 28 days correspondingly.

(vi) Additionally, the maximum modulus of elasticity was measured as 31.45 GPa mm at 1% of jute fiber along with 40% of WSA, and the lowest water penetration depth was estimated to be 26.50 GPa while utilizing 0% of jute fiber along with 0% of WSA as the replacement for sand ingredient at 28 days, respectively. It was observed that the modulus of elasticity increased while jute fiber and WSA utilized increase together in concrete.

(vii) The permeability of concrete was measured as 9%, 18.18%, 31.82%, and 36.40% at 0.25%, 0.5%, 0.75%, and 1% of jute fiber which is less than in plain concrete at 28 days, respectively. However, the water penetration depth of concrete was recorded as 13.64%, 22.73%, 36.36%, and 45.55% at 10%, 20%, 30%, and 40% of WSA as the replacement for sand ingredient which is less when compared to plain concrete at 28 days, respectively.

(viiii) The maximum water penetration depth was measured as 22 mm at 0% of jute fiber along with 0% of WSA, and the lowest water penetration depth was estimated as 7 mm while utilizing 1% of jute fiber along with 40% of WSA as the replacement for sand ingredient at 28 days, respectively. It was observed that the permeability of concrete was reduced while jute fiber and WSA utilized increase together in concrete.

(ix) On the basis of experimental study, the use of jute fiber up to 0.50% along with 30% of WSA as the replacement of sand in concrete is suggested for structural applications.

Data Availability

The datasets generated during the current study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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