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Experimental Study on Engineering Properties of Cement Concrete Reinforced with Nylon and Jute Fibers

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Abstract: The use of synthetic fiber and natural fiber for concrete production has been continuously investigated. Most of the materials have become popular for their higher flexibility, durability, and strength. However, the current study explores the engineering properties of cement concrete reinforced with nylon and jute fibers together. Varying proportions and lengths of nylon and jute fibers were utilized in the concrete mixture. Hence, the combined effects of nylon and jute fibers on workability, density, water absorption, compressive, tensile, flexural strength, and drying shrinkage of concrete were investigated. Results showed that concrete with 1% of nylon and jute fibers together by the volume fraction showed a maximum enhancement of the compressive strength, split tensile strength, and flexural strength by 11.71%, 14.10%, and 11.04%, respectively, compared to the control mix of concrete at 90 days. However, the water absorption of concrete increased with increasing nylon and jute fiber contents. The drying shrinkage of concrete decreased with the addition of nylon and jute fibers together after 90 days. Thus, the sparing application of both nylon and jute fiber as discussed in this study can be adopted for concrete production.

Keywords: nylon fiber; jute fiber; reinforcement material; concrete; fresh and hardened properties

1. Introduction

Concrete has been a broadly utilized construction material for the development of infrastructures for a long time. It is composed of binder and aggregates with a suitable quantity of water [1,2]. The use of concrete is measured as the 2nd most consumed component after water, and today, construction of any structure is deemed impossible without the use of concrete [3–10]. Such a wide acceptance of concrete as a construction material is due to its durability, availability, and strength properties [1,11]. Moreover, nowadays, researchers are using different waste materials in concrete, which contributes a lot to a sustainable environment [12–14]. Except for these beneficial peculiarities, concrete also has undesired attributes such as low tensile strength, quasi-brittle failures, low resistance to wind and earthquake loads, and increased self-weight and/or density. These deficiencies demand optimal solutions, and hence, concrete is blended with supplementary cementitious resources and is conventionally reinforced with steel rebars and fibers, etc., to supplement the strength deficiencies [15–17]. Although the utility of fibers is not new, the research concerning the use of fibers has been rising since the early 1900s to supplement the strength deficiencies of concrete [18]. The introduction of fibers in the concrete matrix not only increases the toughness of the concrete body but also delays crack development [19]. The effect of fibers has been investigated in various studies. In addition, the fibers in the mixture of concrete also improve the shear and punching resistance of concrete and aid in recovering post-cracking strength losses [20–22]. Apart from these merits, the only risk associated with fiber reinforcement in the concrete matrix is the decline in workability of concrete which can be conventionally complemented with the use of admixtures [17].

In conclusion, the utility of fibers for supplementing concrete deficiencies up to a substantial extent is well-established [23]. The properties of fiber-reinforced concrete are highly influenced by the physical parameters of fibers, i.e., diameter, aspect ratio, length, etc. Unlike fibers with larger diameters, fibers with small diameters have been reported to be difficult for dispersion in fresh concrete [13,24,25]. Although the best-suited modifications in deficiencies of concrete can be achieved by the unidirectional orientation of fibers with fibers being parallel to the applied forces, it is still impractical because of the short lengths of fibers [26,27]. Numerous fibers such as sisal, steel, plastic, hemp, carbon, hybrid, glass, human scalp hair, etc., are used for reinforcement of concrete, depending upon their availability, characteristics, and feasibility [13,17,25,28,29].

The current study focused on using natural fiber, i.e., jute, and synthetic fiber, i.e., nylon, as reinforcing materials for concrete. Nylon fiber is a textile fiber invented in 1938 by Wallace Carothers to compete with the strength of silk fiber [30]. The tensile strength of nylon fiber was claimed to be 750–1000 MPa by [31], which became the reason for a 30% increment in the tensile strength of concrete in a recent study conducted in 2020 by [32]. Nylon fibers are also tough in their textures, and hence, 49% improvement was also observed in the toughness of concrete when reinforced with nylon fibers [32]. Similarly, Nitin and S. Verma [33] concluded that adding nylon fiber by 1% of volume increases the crushing strength of concrete by 10% and tensile strength of concrete by 25%. An increase of up to 17% in crushing strength and up to 21% in tensile strength was witnessed with the water–binder ratio of 0.63 and nylon fibers in 0.5%, 1.5%, and 2.5% by weight fraction of cement mortars [34]. Moreover, the nylon fibers are also observed to be effective in enhancing the mechanical, microstructural, and durability properties of concretes prepared with recycled aggregates [35]. The nylon fibers have also been studied for their usefulness in concrete composites along with fly ash for prominent growth in strength values [36].

Meanwhile, the jute fiber is a natural fiber with tensile strength ranging from 400 to 800 MPa [26]. M. Zakaria et al. [37] stated the use of yarn and jute fibers in concrete and concluded that there is a tremendous scope of using jute fibers in concrete. Similarly, Gupta et al. [38] recently conducted a study on the use of jute fibers of 15 mm and 25 mm long in 0.1–0.4% of the volume of concrete. The outcome was detected that the inclusion of 15 mm fibers increases the crushing strength up to 12.4%, and the introduction of 25 mm fibers in concrete increases its compressive strength up to 8% at 0.3% fiber inclusion level. Similarly, an incredible increase in tensile strength was observed, i.e., 58% with 15 mm fibers and 42% with 25 mm fibers with a reinforcement level of 0.3% by the total volume of concrete. In addition, the jute fiber also attenuated the brittleness and shrinkage of concretes [38]. These results were also in agreement with the study of [39]. Moreover, 0.4–0.5% jute fiber content was found to be optimum for concrete compressive and tensile strength [40–42]. The jute fibers have also found their effectiveness in strengthening the concrete beams as it improves strength values, ductility, stiffness, and toughness of concrete beams [43]. In addition, the jute fiber can also be utilized in high-strength concrete as a spalling prevention agent [44]. The reinforcement of concrete with jute fibers not only impedes the crack instigation but also helps in post-cracking propagation [45].

This review led to an observation that literature is scarce on studies focusing on a combination of synthetic nylon fiber and natural jute fiber. The present study intends to fill this gap and to investigate the influence of nylon and jute fibers combined reinforcement on various engineering properties of concrete, i.e., workability, water absorption, density, compressive strength, flexural and split tensile strength, elastic modulus, and drying shrinkage of concrete.

2. Materials

The materials utilized in this study were nylon fiber, jute fiber, and basic constituents of concrete, i.e., water, cement, fine aggregate, and coarse aggregate. The properties of materials are detailed as follows:

2.1. Cement

The Portland cement in concrete works as a binder to bind the materials together. In this research, the Grade 43 cement meeting the standards set in ASTM C150/C150M-19 [46] was employed. The chemical composition of cement is detailed in Table 1, while other physical and mechanical characteristics are listed in Table 2.

Table 1. Chemical composition of cement.

Oxide	SiO_2	CaO	MgO	Na_2O	Al_2O_3	Fe_2O_3	SO_3	K_2O
OPC	18.11%	60.22%	3.66%	0.18%	4.31%	2.38%	2.87%	0.67%

Table 2. Physical and mechanical properties of ordinary Portland cement.

Property	**Value**	**Standard [46]**
Normal Consistency	32%	-
Initial Setting Time	55 min	≥45 min
Final Setting Time	225 min	≤375 min
Compressive Strength		
2 days	27.63 MPa	-
7 days	40.27 MPa	-
28 days	48.94 MPa	≥19 MPa

2.2. Fine and Coarse Aggregates

The fine and coarse aggregates, conforming to specifications set in ASTM C33/C33M-18 [47], were acquired from the local market. The maximum size of fine aggregates was 4.75 mm and that for coarse aggregates was 19 mm. Further properties of fine and coarse aggregates are detailed in Table 3, and sieve analysis curves for coarse and fine aggregates were done by using ASTM C136 [48], respectively, displayed in Figures 1 and 2.

Table 3. Properties of fine and coarse aggregates.

Property	**Fine Aggregate**	**Coarse Aggregate**
Fineness Modulus	2.34	-
Water Absorption	1.67%	1.23
Specific Gravity	2.63	2.71
Density	2640 kg/m^3	2718 kg/m^3

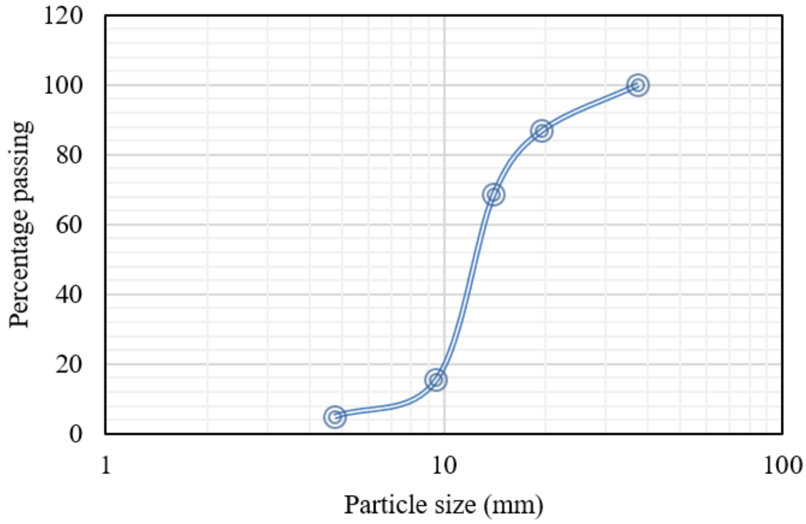

Figure 1. Grading curve of coarse aggregate (CA).

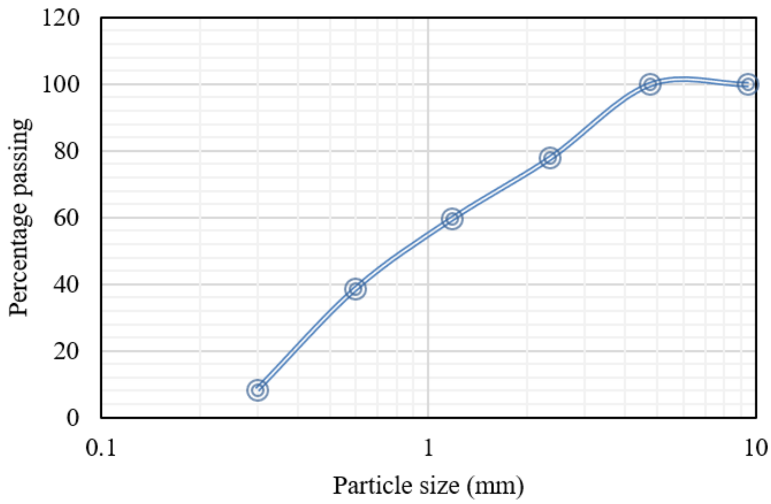

Figure 2. Grading curve of fine aggregate (FA).

2.3. Water

For this study, potable water, free from all impurities and meeting the standards set in [49], was used.

2.4. Nylon Fiber

Nylon fibers (NF) were purchased from the local market with various lengths and then cut into two different lengths of 10 and 20 mm. After cutting into the required length, the nylon fibers were used by the volume fraction of concrete in the mixture. It possessed 0.10 mm in diameter. Moreover, the properties of nylon fiber, such as density, tensile strength, and modulus of elasticity, are measured by 1120 kg/m^3, 36.80 MPa, and 3.88 GPa, respectively.

2.5. Jute Fiber

Jute fibers were used of 10 mm and 20 mm in length for this research work and collected from the local market. This fiber is a long, soft, and shiny vegetable fiber possessing an off-white to brown color. However, the collected jute fiber possessed various lengths, and then was cut into two different lengths, namely 10 and 20 mm. After that, it was ready to be used in concrete by the volume fraction. Properties such as tensile strength, density, diameter, and modulus of elasticity are noted as 488 MPa, 1440 kg/m^3, 0.10 mm, and 28.50 GPa, respectively. Therefore, the use of jute fiber in concrete might provide better results as compared to nylon fiber as jute fiber has superior material properties compared to nylon fiber.

3. Mix Design and Specimen Preparation

In this experimental program, five mixtures were made with concrete ingredients, nylon, and jute fibers. The fibers were used in concrete as reinforcement at 0%, 0.5%, 1%, 1.5%, and 2% levels where the content of nylon and jute fibers kept the same level based on a preliminary evaluation of the raw materials, and it was discovered that an equal fiber constituent would be utilized to balance the volumetric fraction of fibers in each of the mixtures. However, a combination of different contents of jute and nylon fiber could be considered in a future study. The NFJF0 mix was a control or conventional mix, only constituting the basic ingredients of concrete, while other mixes such as NFJF0.5, NFJF1, NFJF1.5, and NFJF2 represented the fiber introduction levels of 0.5%, 1%, 1.5%, and 2%, respectively. For example, NFJF1 means the mix employed nylon and jute fibers at a 1% reinforcement level. The mix proportions are detailed in Table 4. A total of 135 specimens were equipped. The preparation of specimens was completed in line with standards set in [50].

Table 4. Mix proportions (kg/m^3).

Mixture ID	PC	Nylon and Jute Fibers Content (%)	Nylon Fiber (%)	Jute Fiber (%)	Water	Fine Aggregate	Coarse Aggregate
NFJF0	375	0	0	0	188	562	1125
NFJF0.5	375	0.50	0.25	0.25	188	562	1125
NFJF1	375	1.0	0.5	0.5	188	562	1125
NFJF1.5	375	1.50	0.75	0.75	188	562	1125
NFJF2	375	2	1	1	188	562	1125

3.1. Procedures for Testing

3.1.1. Slump Test

The slump test was performed on the freshly made concrete, including several percentages of nylon and jute fibers by the volume fraction combined in the concrete by conforming BS EN 12350-2 [51] code.

3.1.2. Hardened Concrete

The water absorption and density of hardened concrete were performed on concrete, including various percentages of nylon and jute fibers combined in concrete by following BS 1881 [52] and BS EN 12390-7 [53] procedures at 28 days, respectively. However, the cubical samples (100 mm × 100 mm × 100 mm) were prepared for testing the compressive strength, and cylinders (200 mm × 100 mm) were made for exploring the splitting tensile strength concrete mix with the accumulation of nylon and jute as fibers by the mass of PC together in concrete by following the BS EN 12390-3 [54] and BS EN 12390-6 [55] code practice correspondingly. Similarly, flexural strength was achieved on prism (500 mm × 100 mm × 100 mm) samples of concrete prepared with nylon and jute fibers combined in a mixture by obeying BS EN 12390-5 [56] code practice. Moreover, the modulus of elasticity of concrete was determined with the accumulation of various percentages of nylon and jute fibers combined in concrete by following the BS EN 12390-13 [57] code procedure. These all-concrete samples were cured and tested at 28 and 90 days. Furthermore, drying shrinkage of concrete was performed on the cylindrical samples made of concrete with the addition of several percentages of nylon and jute fibers by the mass of PC in concrete by confirming the BS ISO 1920-8 [58] code procedure at 5, 10, 15, 20, 30, 60, and 90 days, respectively. The experimental setup of concrete testing is shown in Figure 3.

(**a**) Slump Test (**b**) Water Absorption Test (**c**) Water Curing Tank (**d**) Compressive Strength Test (**e**) Flexural Strength Test (**f**) Split Tensile Strength Test

Figure 3. Experimental details of concrete testing.

4. Results and Discussions

4.1. Slump Test

The slump test is used for measuring the workability of a freshly mixed concrete mixture. In simple terms, workability refers to the ease with which it can be placed and compacted, while workable concrete refers to concrete that can be placed and compacted without segregation. Figure 4 displays the slump test of concrete reinforced with several percentages of nylon and jute fibers. The maximum outcome of slump values was estimated by 60 mm at 0% of nylon and jute fibers together. The minimum value was calculated by 28 mm at 2% of nylon and jute fibers together by the volume fraction. However, the outcome was detected that the slump of freshly made concrete is declined with the incline in the amount of nylon and jute fibers in concrete. This decrease in workability could be linked to an increase in the constituent's specific surface area, increasing the cement mortar required to cover their area. Hence, the necessary quantity of water for the workability of reinforced concrete with nylon and jute fibers was lowered. According to Onuaguluchi and Banthia [59], increasing the amount of fiber in concrete reduces its workability. Similarly, Bayasi and Soroushian [60] found that when the amount of jute fiber in concrete increases, the workability decreases. According to Bheel et al. [61], when the amount of jute fiber in concrete increases, the workability of the concrete decreases. Gao and Wang [62] reported that the slump of steel fiber reinforced recycled fine aggregate concrete (SFRFAC) is reduced by improving the content of steel fiber in the mixture.

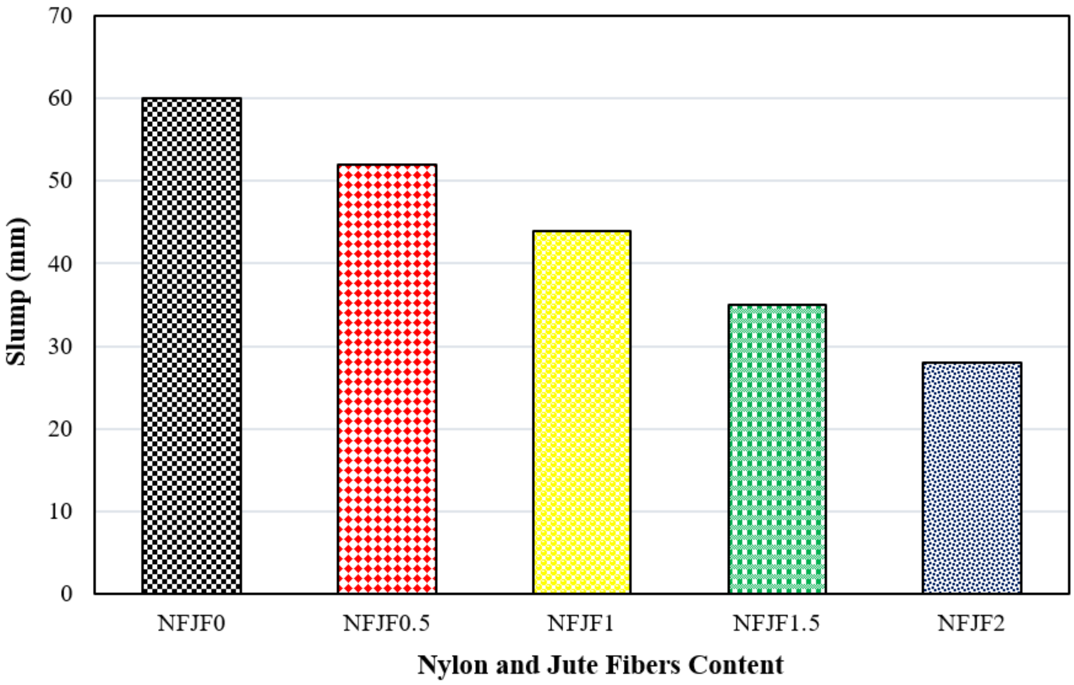

Figure 4. Slump test.

4.2. Density of Concrete

Figure 5 shows the bulk density of concrete reinforced with several percentages of nylon and jute fibers. The highest density was estimated by 2388 kg/m^3 at 0% of nylon and jute fibers, and the least density was recorded by 2300 kg/m^3 while using 2% of nylon and jute fibers in concrete at 28 days, respectively. It was deemed that the density of concrete is declined with reinforcement of nylon and jute fibers. This reduction in density may be attributed to growing porosity and air void, which brought about inadequate compaction of the high nylon and jute fiber content in the mixture. Moreover, the density was decreased as the density of nylon and jute fibers is lesser than other components of concrete, and nylon and jute fibers entrapped more air in concrete than that in the control mixture. This opinion is associated with Ismail et al. [63], where it was deemed that the density of concrete reinforced with jute fiber is reduced as compared to concrete without reinforced fiber. Similarly, Bheel et al. [64] itemized the density of concrete and found that it declined with growing in the amount of human hair fiber at 28 days.

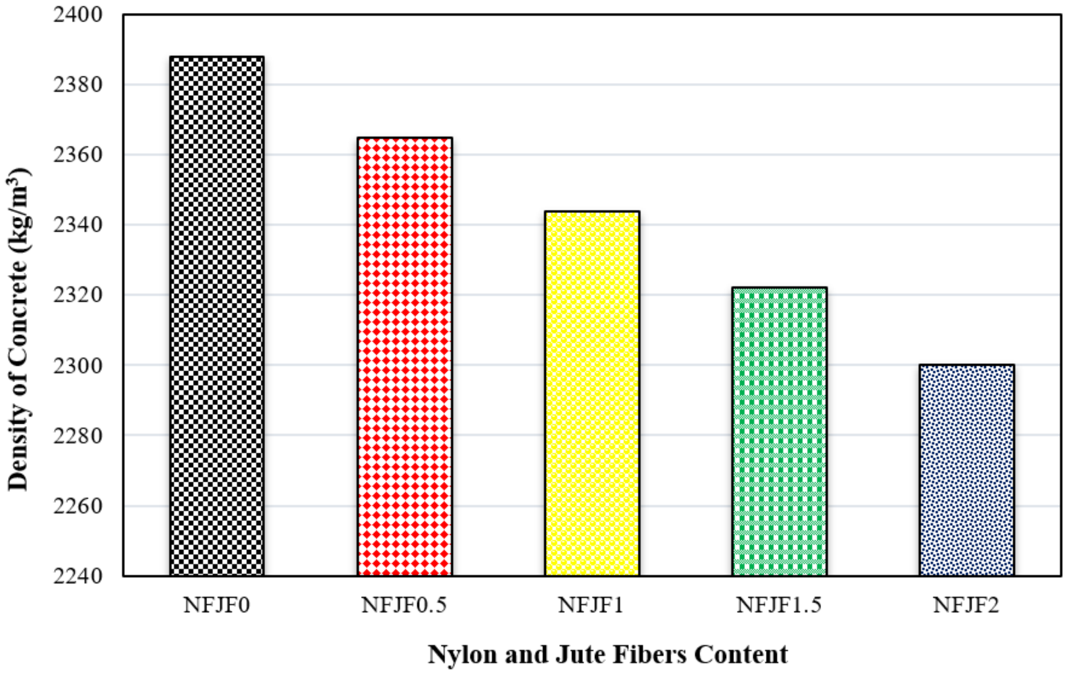

Figure 5. Density of concrete.

4.3. Water Absorption of Concrete

Figure 6 displays the water absorption of concrete reinforced with nylon and jute fibers together after 28 days. The maximum outcome of water absorption was estimated by 3.07% at 2% of nylon and jute fibers together, and the smallest value was considered by 2.40%, whereas applying 0% of nylon and jute fibers together by the volume fraction after 28 days, respectively. However, it was believed that the water absorption is increased with the inclusion of nylon and jute fibers together by the volume fraction. This improvement in the water absorption of concrete may be due to more water being absorbed by nylon and jute fibers in concrete than that of concrete without reinforced nylon and jute fibers by volume fraction, as well as the higher entrapped air in concrete by nylon and jute fibers than that in the control mixture. This opinion is in agreement with Bheel et al.'s study [64], where it was found that the water absorption of concrete is improved by the accumulation of human hair fiber in concrete.

4.4. Compressive Strength of Concrete

The cubical samples were tested for investigating the compressive strength of the concrete reinforced with various proportions of nylon and jute fibers at 28 and 90 days, correspondingly. The optimum outcomes of strength were estimated by 30.15 MPa and 31.28 MPa at 1% combined use of nylon and jute fibers, and the lowest strength was calculated by 25.48 MPa and 26.8 MPa while using 2% of nylon and jute fibers together after 28 and 90 days, respectively. Hence, the concrete with 1% of nylon and jute fibers together by the volume fraction showed the highest increase in compressive strength of 11.71% at 90 days. However, it was predicted that the compressive strength of mixtures was augmented with increases in the content of nylon and jute fibers together up to 1% by the volume fraction and rose with the curing age, as shown in Figure 7. The increase in strength of concrete when reinforced with fibers may be due to the quantity of fibers increasing up to a certain limit, which helps in controlling the formation, widening, and propagation of cracks more effectively. On the other hand, it has been discovered that the fiber-connecting effect prevents transverse deformation, resulting in increased concrete compressive strength [65]. Besides, the smaller volume of nylon and jute fibers binds the composite ingredients tightly and proceeds to an intact bound [66].

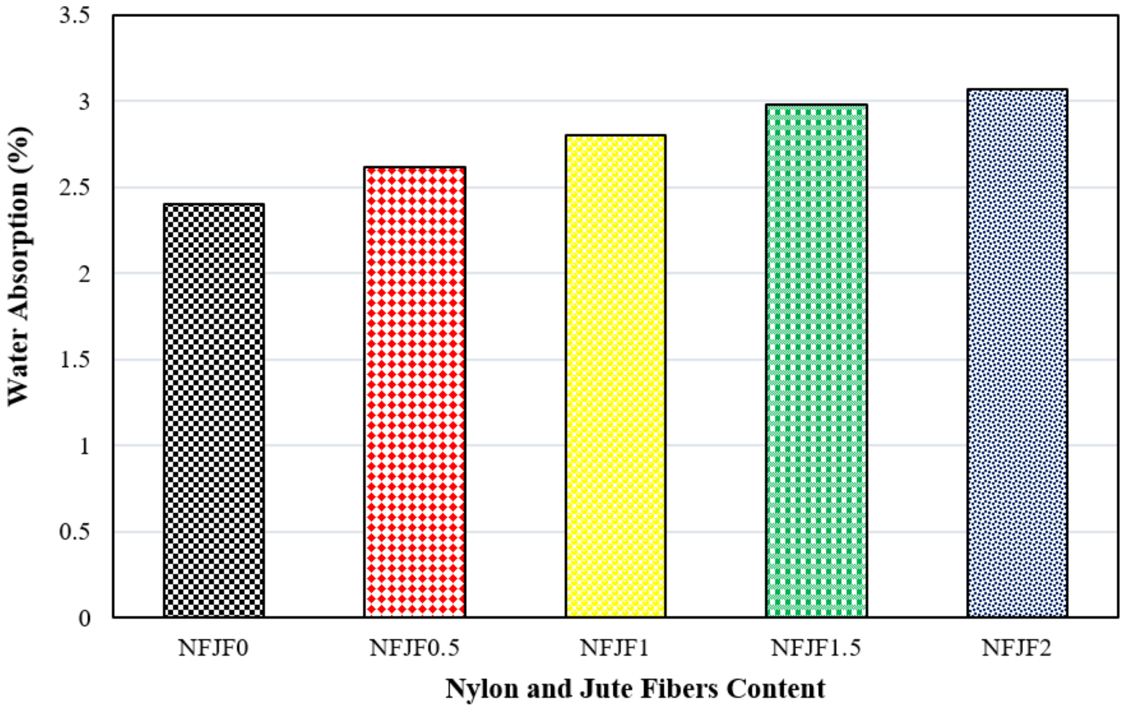

Figure 6. Water absorption of concrete.

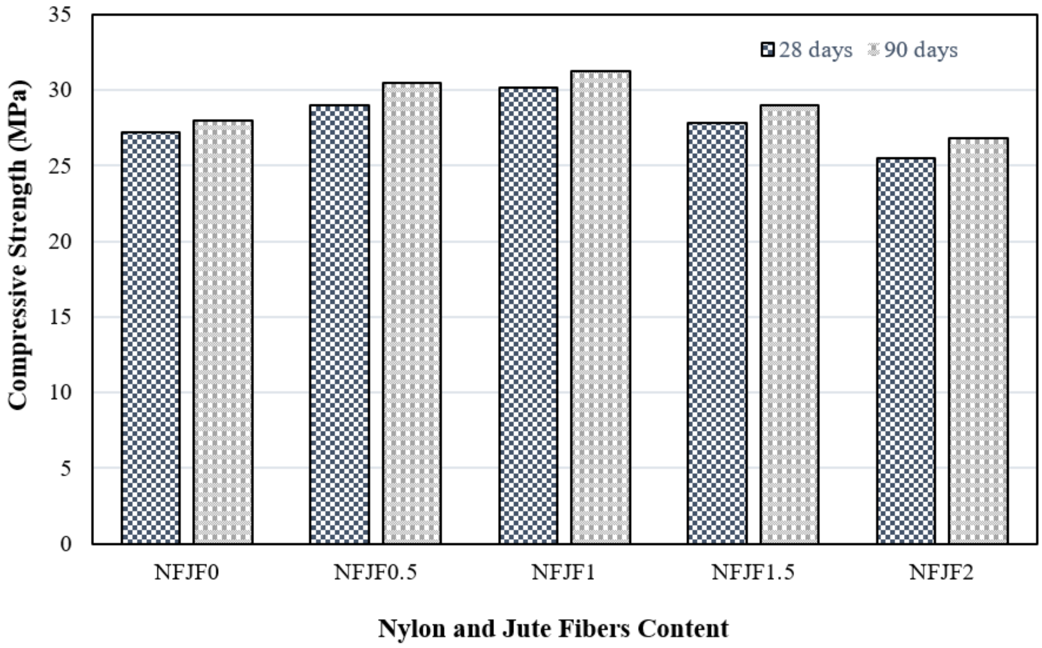

Figure 7. Compressive strength of concrete.

Furthermore, once the percentage of nylon and jute fibers in the concrete mixture exceeds 1%, the strength begins to decline owing to enhanced air spaces and porosity, resulting from poor compaction of a large number of nylon and jute fibers in the concrete mixture. Similarly, nylon and jute fibers have a ball-up tendency with an aspect ratio larger than 120, resulting in inadequate spreading in concrete mixes and reduced compressive strength [66]. The study of a similar trend was related to Zakaria et al. [67], where it was revealed that the compressive strength of concrete was boosted while using 0.5% of jute fiber. According to Bheel et al. [64], the compressive strength was increased by up to 1% when the amount of human hair was increased, and then it began to decrease.

Lehner et al. [68] described that the self-compacting concrete blended with steel fiber up to 1% provides the best compressive strength. Zhong et al. [69] testified that the compressive strength of fiber-reinforced concrete is improved while using the steel fiber up 1.5% by the volume fraction at 28 days.

4.5. Splitting Tensile Strength of Concrete

Figure 8 indicates the splitting tensile strength of concrete reinforced with different percentages of nylon and jute fibers after 28 and 90 days. The optimum outcome of split tensile strength reinforced with 1% of nylon and jute fibers together was recorded by 3.35 MPa and 3.65 MPa, and the minimum strength was calculated by 2.68 MPa and 2.98 MPa at 2% of nylon and jute fibers by the volume fraction after 28 and 90 days, correspondingly. Hence, the highest increment of split tensile strength of 14.10% was achieved by the concrete with 1% of nylon and jute fibers together by the volume fraction at 90 days. Moreover, it was deemed that the split tensile strength was boosted with the inclusion of nylon and jute fibers together up to 1.5% and enhanced with time. This increase in split tensile strength could be related to the strength of nylon and jute fibers, as well as the suitable physical/chemical connection between the nylon and jute fibers and the concrete matrix. Fibers can thereby prevent the spread of microcracks and, as a result, increase the split tensile strength of concrete. Due to the balling effect and improper bonding with concrete, the split tensile strength begins to decline after adding 1.5 percent nylon and jute fibers to concrete. Besides, this decrement in split tensile strength during the cracking may be owing to the smaller density of concrete at a greater percentage of fiber reinforcement in concrete. This finding is consistent with Bheel et al. [64], who found that the split tensile strength decreased as the extent of human hair increased up to 2%, then decreased after 90 days. A similar kind of study was explored by Bheel et al. [61]. Lehner et al. [68] described that the split tensile strength of self-compacting concrete is enhanced while reinforced with steel fiber up to 2% in the mixture.

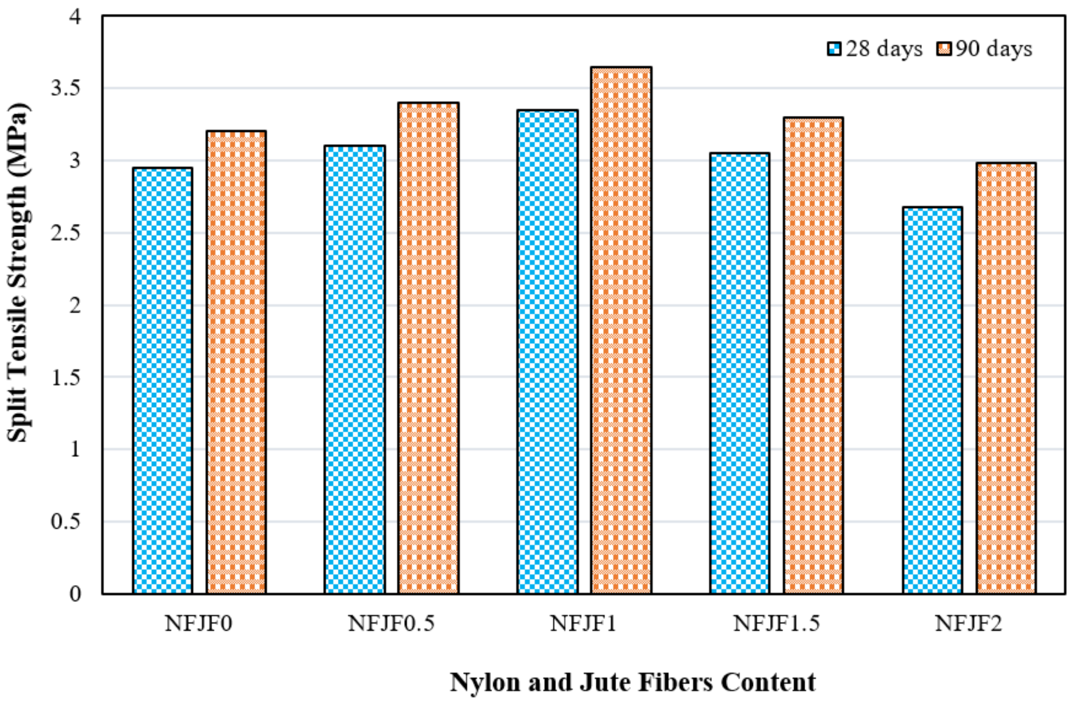

Figure 8. Splitting tensile strength of concrete.

4.6. Flexural Strength of Concrete

Figure 9 represents the flexural strength of concrete reinforced with various percentages of nylon and jute fibers together after 28 and 90 days. The highest flexural strength was predicted by 5.38 MPa and 5.85 MPa at 1% of nylon and jute fibers together, and the lowest flexural strength was noted by 4.45 MPa and 4.97 MPa while combined utilization of 2% nylon and jute fibers by the volume fraction of concrete after 28 and 90 days, respectively. Hence, the concrete with 1% of nylon and jute fibers together by the volume fraction showed the highest increase of flexural strength of 11.04% at 90 days. It was thought that the flexural strength was enhanced with growing in the content of nylon and jute fibers together up to 1.5% by the volume fraction. The growth in flexural strength of concrete blended with fibers may be due to the quantity of fibers increasing up to a certain limit (1.5%) which helps in controlling the formation, widening, and propagation of cracks more effectively. On the other hand, the ductile behavior of prism made of concrete is observed owing to the bridging effects of fibers across the cracks and enhances the ductility of the concrete prism, which increases the flexural strength of concrete.

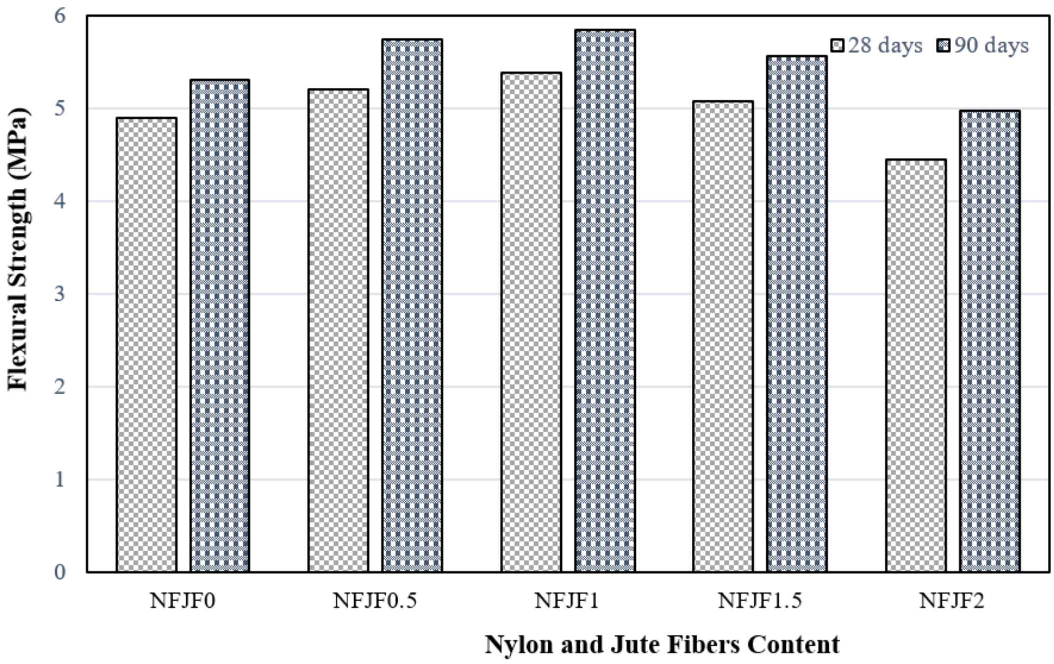

Figure 9. Flexural strength of concrete.

Similarly, beyond the 1.5% utilization of nylon and jute fibers together, the flexural strength starts dropping due to the balling effect and improper bonding of fibers with concrete, and it may reduce due to high porosity and irregular dispersal of reinforcing fibers in concrete. A comparable trend of findings was correlated to Meddaha and Bencheikh [70], where the flexural strength was reduced by using above 1% of fiber reinforcement in concrete after every curing period. Similarly, Bheel et al. [64] stated that the flexural strength was improved as the dosages of human hair fiber increased up to 2%. Zhong et al. [69] found that the flexural strength of fiber-reinforced concrete under four-point loading was enhanced up to the applied content of the steel fiber, which was 1.5% by the volume fraction at 28 days.

4.7. Modulus of Elasticity (MOE)

The deformation properties of the concrete reinforced with nylon and jute fibers together were estimated with the help of the elasticity modulus test. However, modulus of elasticity describes stiffness; greater MOE of a substance thus denotes a stiffer one. The optimum outcomes of modulus of elasticity were measured by 29.55 MPa and 31 MPa at 2% of nylon and jute fibers, and the minimum value was calculated by 26.5 MPa and 27.2 MPa at 0% of nylon and jute fibers together by the volume fraction after 28 and 90 days, respectively. From Figure 10, it was shown that the MOE was amplified with growth in the content of nylon and jute fibers together by the volume fraction. A higher amount of nylon and jute fibers together used in concrete creates a stiffer concrete. Moreover, the MOE of concrete blended with nylon and jute fibers together generally depends on the kind of fiber, its volume, and direction. Besides, the addition of nylon and jute fibers in concrete would control the proliferation of the crack and its propagation. Additionally, concrete reinforced without nylon and jute fibers indicated brittle failure, while concrete reinforced with nylon and jute fibers displayed less brittle failure compared to unreinforced concrete. This finding agrees with Bheel et al. [64], where the MOE of concrete was improved as the content of human hair fiber rose in concrete at 90 days.

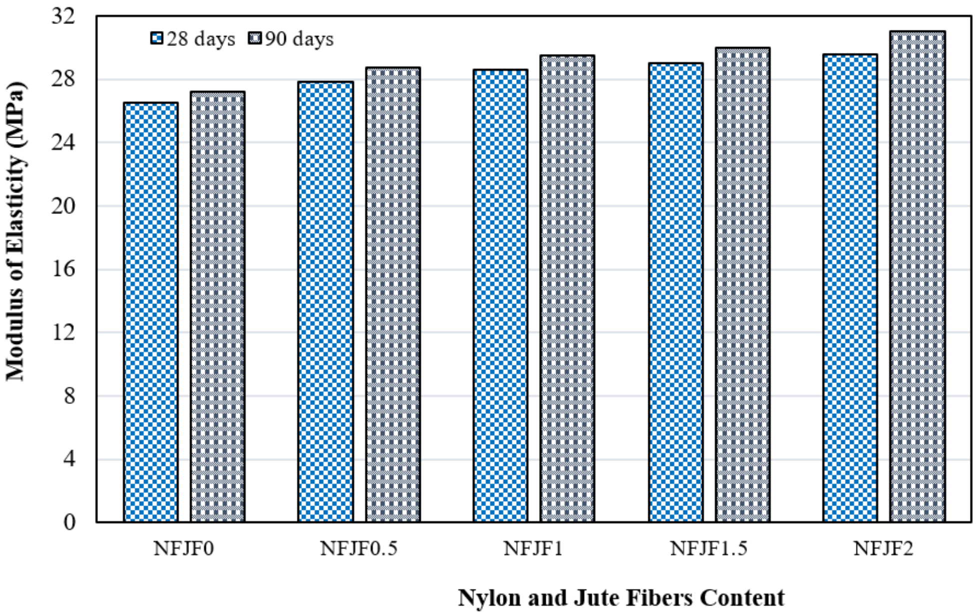

Figure 10. Modulus of elasticity of concrete.

4.8. Drying Shrinkage of Concrete

The drying shrinkage was performed on the concrete specimens reinforced with nylon and jute fibers together by the volume fraction as shown in Figure 11. It was noted that the drying shrinkage of concrete decreases with the inclusion of nylon and jute fibers together after every curing period. These outcomes show a dramatic lessening in the drying shrinkage of concrete reinforced with nylon and jute fibers together by the volume of fraction, and this decline is progressive with a rise in the content of nylon and jute fibers. This opinion is correlated with that of Bheel et al. [64], where it was deemed that the drying shrinkage is reduced with an increase in the amount of human hair fiber. According to Afroughsabet and Teng [71], the drying shrinkage deformations of hybrid fiber-reinforced concrete were smaller than the basic concrete without fibers. Fibers can help to reduce concrete drying shrinkage by strengthening the bond strength between the fibers and the concrete matrix, which assists to constrain shrinking [72,73] physically, or by preventing cracks, which is the most important effect of fibers in concrete shrinkage [74]. These findings are consistent with those of other researchers who discovered that including fibers in a composite can prevent cracking caused by drying shrinkage [75,76]. Passuelo et al. [77] stated that the PVA fibers could lessen free shrinkage in concrete by varying the internal water circulation within the concrete. Alrshoudi et al. [78] reported that the drying shrinkage values of all prepacked aggregates of fiber-reinforced concrete samples with blended polypropylene fibers were relatively lesser as compared to plain prepacked aggregate concrete specimens up to 180 days.

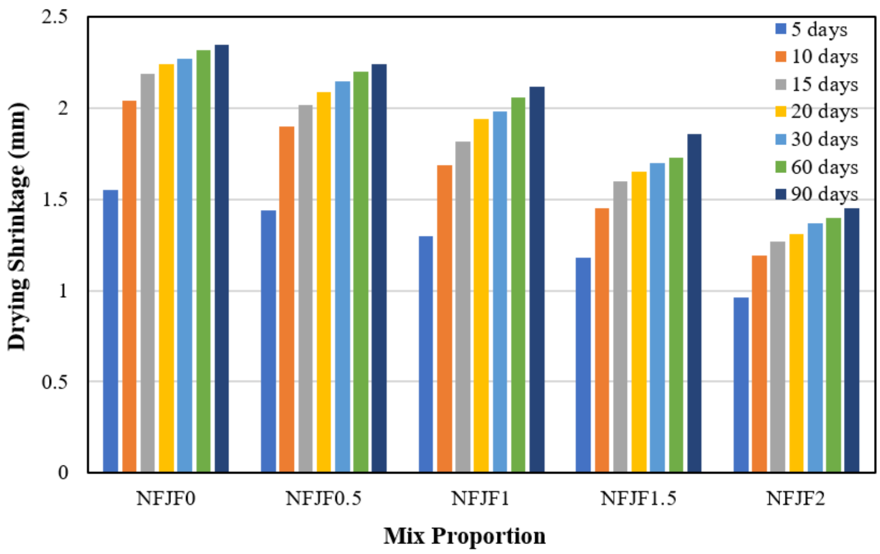

Figure 11. Drying shrinkage of concrete.

5. Conclusions

This paper investigates the effects of nylon and jute fibers on the engineering properties of cement concrete. Slump, water absorption, mechanical, and shrinkage tests were conducted on the concrete specimens with different contents of nylon and jute fibers. The following conclusions can be drawn from the present research:

- The slump test findings demonstrate that adding nylon and jute fibers combined by volume fraction reduces the workability of concrete. This decrease in workability could be linked to an increase in the constituent's specific surface area and high content of nylon and jute fibers in concrete, causing more cement mortar requirement to cover their area. Hence, the quantity of water necessary for the workability of concrete reinforced by nylon and jute fibers was lowered.
- The highest density was estimated by 2388 kg/m^3 at 0% of nylon and jute fibers, and the smallest density was recorded by 2300 kg/m^3 while using 2% of nylon and jute fibers in concrete after 28 days, respectively. This decrease in density is due to the lower density of nylon and jute fibers compared to other components of concrete and higher entrapped air in concrete by nylon and jute fibers than that in the control mixture.
- The maximum outcome of water absorption was estimated by 3.07% at 2% of nylon and jute fibers together, and the lowest value was considered by 2.40% while applying 0% of nylon and jute fibers together by the volume fraction at 28 days individually.
- The concrete with 1% of nylon and jute fibers together by the volume fraction showed the maximum enhancement of the compressive strength, split tensile strength, and flexural strength by 11.71%, 14.10%, and 11.04%, respectively, compared to the plain concrete (concrete with 0% of nylon and jute fibers) at 90 days. Those different strengths of concrete were increased with the increasing of the nylon and jute fibers content together up to 1% by the volume fraction. The increase in strength of concrete may be due to the quantity of fibers increasing up to a certain limit which helps in controlling the formation, widening, and propagation of cracks more effectively. Moreover, the fiber bonding effect prevents transverse deformation, resulting in an increase in concrete strength.
- The compressive, split tensile and flexural strengths of the nylon and jute fibers reinforced concrete begin to decline once the percentage of nylon and jute fibers content in the concrete mixture exceed 1% due to enhanced air spaces and porosity, resulting from poor compaction of a large number of nylon and jute fibers in the concrete mixture, as well as the ball-up tendency of nylon and jute fibers.

- The MOE of concrete is enhanced while the percentages of nylon and jute fibers increase in concrete at 28 and 90 days consistently. The more nylon and jute fibers are used in concrete, the stiffer the concrete becomes.
- The drying shrinkage of concrete is reduced as the content of nylon and jute fibers rises in concrete, as fibers enhance the bond strength between the fibers and the concrete matrix and assist to physically constrain shrinking.

In view of the above findings, it is suggested to adopt 1% of nylon and jute fibers by the volume fraction for cement concrete because it can achieve the maximum strength and also take into account other engineering properties.

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References

1. Bheel, N.; Memon, F.A.; Meghwar, S.L. Study of Fresh and Hardened Properties of Concrete Using Cement with Modified Blend of Millet Husk Ash as Secondary Cementitious Material. *Silicon* **2020**, 1–12. [CrossRef]
2. Keerio, M.A.; Abbasi, S.A.; Kumar, A.; Bheel, N.; Rehaman, K.U.; Tashfeen, M. Effect of Silica Fume as Cementitious Material and Waste Glass as Fine Aggregate Replacement Constituent on Selected Properties of Concrete. *Silicon* **2020**, 1–12. [CrossRef]
3. Chalangaran, N.; Farzampour, A.; Paslar, N. Nano Silica and Metakaolin Effects on the Behavior of Concrete Containing Rubber Crumbs. *Civ. Eng.* **2020**, *1*, 264–274. [CrossRef]
4. Farzampour, A. Temperature and humidity effects on behavior of grouts. *Adv. Concr. Constr.* **2017**, *5*, 659.
5. Farzampour, A. Compressive Behavior of Concrete under Environmental Effects. In *Compressive Strength of Concrete*; IntechOpen: London, UK, 2019; pp. 92–104. [CrossRef]
6. Chalangaran, N.; Farzampour, A.; Paslar, N.; Fatemi, H. Experimental investigation of sound transmission loss in concrete containing recycled rubber crumbs. *Adv. Concr. Constr.* **2021**, *11*, 447–454.
7. Bheel, N.; Keerio, M.A.; Kumar, A.; Shahzaib, J.; Ali, Z.; Ali, M.; Sohu, S. An Investigation on Fresh and Hardened Properties of Concrete Blended with Rice Husk Ash as Cementitious Ingredient and Coal Bottom Ash as Sand Replacement Material. *Silicon* **2021**, 1–12. [CrossRef]
8. Kumar, A.; Bheel, N.; Ahmed, I.; Rizvi, S.H.; Kumar, R.; Jhatial, A.A. Effect of silica fume and fly ash as cementitious material on hardened properties and embodied carbon of roller compacted concrete. *Environ. Sci. Pollut. Res.* **2021**, 1–13. [CrossRef]
9. Keerio, M.A.; Saand, A.; Chaudhry, R.; Bheel, N.; Bhatti, N.U.K.; Soohu, S. The Effect of Local Metakaolin Developed from Natural Material Soorh on Selected Properties of Concrete/Mortar. *Silicon* **2021**, 1–10. [CrossRef]
10. Bheel, N.; Ali, M.O.A.; Tafsirojjaman; Khahro, S.H.; Keerio, M.A. Experimental study on fresh, mechanical properties and embodied carbon of concrete blended with sugarcane bagasse ash, metakaolin, and millet husk ash as ternary cementitious material. *Environ. Sci. Pollut. Res.* **2021**, 1–16. [CrossRef]
11. Hrabová, K.; Lehner, P.; Ghosh, P.; Konečný, P.; Teplý, B. Sustainability Levels in Comparison with Mechanical Properties and Durability of Pumice High-Performance Concrete. *Appl. Sci.* **2021**, *11*, 4964. [CrossRef]
12. Afroughsabet, V.; Biolzi, L.; Monteiro, P.J.; Gastaldi, M.M. Investigation of the mechanical and durability properties of sustainable high performance concrete based on calcium sulfoaluminate cement. *J. Build. Eng.* **2021**, *43*, 102656. [CrossRef]
13. Zahmak, A.; Abdallah, M.; Jarah, B.; Arab, M.G. Environmental performance of alkali-activated binders for ground improvement. *Transp. Geotech.* **2021**, *31*, 100631. [CrossRef]

14. Bheel, N.; Ali, M.O.A.; Liu, Y.; Tafsirojjaman, T.; Awoyera, P.; Sor, N.H.; Romero, L.M.B. Utilization of Corn Cob Ash as Fine Aggregate and Ground Granulated Blast Furnace Slag as Cementitious Material in Concrete. *Buildings* **2021**, *11*, 422. [CrossRef]
15. Bheel, N.; Awoyera, P.O.; Olalusi, O.B. Engineering Properties of Concrete with a Ternary Blend of Fly Ash, Wheat Straw Ash, and Maize Cob Ash. *Int. J. Eng. Res. Afr.* **2021**, *54*, 43–55. [CrossRef]
16. Ranyal, A.; Kamboj, J. Effect of addition of different type of Steel fibers on the mechanical aspects of concrete—A review. *Int. J. Civ. Eng. Technol.* **2016**, *7*, 33–42.
17. Okeola, A.A.; Abuodha, S.O.; Mwero, J. Experimental Investigation of the Physical and Mechanical Properties of Sisal Fiber-Reinforced Concrete. *Fibers* **2018**, *6*, 53. [CrossRef]
18. Banthia, N.; Gupta, R. Influence of polypropylene fiber geometry on plastic shrinkage cracking in concrete. *Cem. Concr. Res.* **2006**, *36*, 1263–1267. [CrossRef]
19. Neville, A.M.; Brooks, J.J. *Properties of Concrete*; Longman: London, UK, 1995; Volume 4.
20. Mansouri, I.; Shahheidari, F.S.; Hashemi, S.M.A.; Farzampour, A. Investigation of steel fiber effects on concrete abrasion resistance. *Adv. Concr. Constr.* **2020**, *9*, 367–374.
21. Düğenci, O.; Haktanir, T.; Altun, F. Experimental research for the effect of high temperature on the mechanical properties of steel fiber-reinforced concrete. *Constr. Build. Mater.* **2015**, *75*, 82–88. [CrossRef]
22. Balendran, R.V.; Zhou, F.P.; Nadeem, A.; Leung, A.Y.T. Influence of steel fibers on strength and ductility of normal and light-weight high strength concrete. *Build. Environ.* **2002**, *37*, 1361–1367. [CrossRef]
23. Ali, M.; Liu, A.; Sou, H.; Chouw, N. Mechanical and dynamic properties of coconut fibre reinforced concrete. *Constr. Build. Mater.* **2012**, *30*, 814–825. [CrossRef]
24. Chung, D.D. Dispersion of Short Fibers in Cement. *J. Mater. Civ. Eng.* **2005**, *17*, 379–383. [CrossRef]
25. Bheel, N. Basalt fibre-reinforced concrete: Review of fresh and mechanical properties. *J. Build. Pathol. Rehabil.* **2021**, *6*, 1–9. [CrossRef]
26. Stähli, P.; Custer, R.; Van Mier, J.G.M. On flow properties, fibre distribution, fibre orientation and flexural behaviour of FRC. *Mater. Struct.* **2008**, *41*, 189–196. [CrossRef]
27. Gettu, R. Study of the distribution and orientation of fibers in SFRC specimens. *Mater. Struct.* **2005**, *38*, 31–37. [CrossRef]
28. Kandasamy, R.; Murugesan, R. Fiber Reinforced Self Compacting Concrete Using Domestic Waste Plastics as Fibres. *J. Eng. Appl. Sci.* **2011**, *7*, 75–82. [CrossRef]
29. Paris, J.M.; Roessler, J.G.; Ferraro, C.C.; DeFord, H.; Townsend, T.G. A review of waste products utilized as supplements to Portland cement in concrete. *J. Clean. Prod.* **2016**, *121*, 1–79. [CrossRef]
30. Rajab, P.M. Study on Structural Behavior of Nylon Fiber in Concrete. *J. Eng. Appl. Sci.* **2018**, *13*, 5455–5457.
31. Wu, H.; Lin, X.; Zhou, A. A review of mechanical properties of fibre reinforced concrete at elevated temperatures. *Cem. Concr. Res.* **2020**, *135*, 106117. [CrossRef]
32. Nguyen, T.N.; Moon, J.; Kim, J.J. Microstructure and mechanical properties of hardened cement paste including Nylon 66 nanofibers. *Constr. Build. Mater.* **2020**, *232*, 117134. [CrossRef]
33. Nitin, S.K.; Verma, P. Effect on Mechanical Properties of Concrete Using Nylon Fibers. *Int. Res. J. Eng. Technol.* **2016**, *3*, 1751–1755.
34. Hanif, I.M.; Syuhaili, M.R.N.; Hasmori, M.F.; Shahmi, S.M. Effect of nylon fiber on mechanical properties of cement based mortar. *IOP Conf. Ser. Mater. Sci. Eng.* **2017**, *271*, 12080. [CrossRef]
35. Lee, S. Effect of Nylon Fiber Addition on the Performance of Recycled Aggregate Concrete. *Appl. Sci.* **2019**, *9*, 767. [CrossRef]
36. Saxena, J.; Saxena, A.K.; Arora, T.R. Enhancement of the Strength of Conventional Concrete by using Fly Ash and Nylon Fiber. *Int. J. Sci. Eng. Res.* **2015**, *6*, 1557–1561.
37. Zakaria, M.; Ahmed, M.; Hoque, M.; Shaid, A. A Comparative Study of the Mechanical Properties of Jute Fiber and Yarn Reinforced Concrete Composites. *J. Nat. Fibers* **2020**, *17*, 676–687. [CrossRef]
38. Das Gupta, S.; Aftab, S.; Zakaria, H.M.; Karmakar, C. Scope of improving mechanical characteristics of concrete using natural fiber as a reinforcing material. *Malays. J. Civ. Eng.* **2020**, *32*, 49–57. [CrossRef]
39. Raval, G.; Patel, U. Impacts of adding Jute fibers to concrete. *Int. J. Adv. Eng. Res. Dev.* **2015**, *5*, 1–8.
40. Sal Aziz, M.A.; Mutsuddy, R. Effect of Jute Fiber on the Mechanical Properties of Concrete. *J. Built Environ. Technol. Eng.* **2018**, *5*, 48–59.
41. Dayananda, N.; Gowda, B.S.K.; Prasad, G.L.E. A Study on Compressive Strength Attributes of Jute Fiber Reinforced Cement Concrete Composites. *IOP Conf. Ser. Mater. Sci. Eng.* **2018**, *376*, 012069. [CrossRef]
42. Zakaria, M.; Ahmed, M.; Hoque, M.M.; Hannan, A. Effect of jute yarn on the mechanical behavior of concrete composites. *SpringerPlus* **2015**, *4*, 1–8. [CrossRef]
43. Salih, Y.A.; Sabeeh, N.N.; Yass, M.F.; Ahmed, A.S.; Khudhurr, E.S. Concrete Beams Strengthened with Jute Fibers. *Civ. Eng. J.* **2019**, *5*, 767–776. [CrossRef]
44. Ozawa, M.; Kim, G.; Choe, G.-C.; Yoon, M.-H.; Sato, R.; Rokugo, K. Thermal properties of jute fiber concrete at high temperature. *J. Struct. Fire Eng.* **2016**, *7*, 182–192. [CrossRef]
45. Zhang, T.; Yin, Y.; Gong, Y.; Wang, L. Mechanical properties of jute fiber-reinforced high-strength concrete. *Struct. Concr.* **2020**, *21*, 703–712. [CrossRef]
46. Standard ASTM. *C150/C150M-19a. Specification for Portland Cement*; ASTM International: West Conshohocken, PA, USA, 2019; pp. 1–10. [CrossRef]

47. Standard ASTM. *C33/C33M-18. Specification for Concrete Aggregates*; American Society for Testing and Materials: Philadelphia, PA, USA, 2018. [CrossRef]
48. Standard ASTM. *C136. Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates*; American Society for Testing and Materials: Philadelphia, PA, USA, 2005.
49. Standard ASTM. *C1602/C1602M-18. Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete*; Standard ASTM: West Conshohocken, PA, USA, 2018; Available online: https://www.astm.org/Standards/C1602.htm (accessed on 23 March 2020).
50. Standard ASTM. C192/C192M-19. Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory. Available online: https://www.astm.org/Standards/C192 (accessed on 24 March 2020).
51. BS EN 12350-2. *Testing Fresh Concrete, Part 2: Slump-Test*; British Standards Institution (BSI): Cambridge, UK, 2009.
52. BS 1881. *Part 122. Method for Determination of Water Absorption*; British Standards Institution: London, UK, 1983.
53. BS EN 12390–7:2000. *Part 7: Density of Hardened Concrete*; British Standards Institution: Cambridge, UK, 2000; p. 389.
54. BS EN 12390-3. *Testing Harden Concrete. Compressive Strength of Test Specimens*; British Standards Institution: Cambridge, UK, 2009.
55. BS EN 12390-6. *Testing Hardened Concrete. Tensile Splitting Strength of Test Specimens*; British Standards Institution: Cambridge, UK, 2009.
56. BS EN 12390-5. *Testing Hardened Concrete. Flexural Strength of Test Specimens*; British Standards Institution: Cambridge, UK, 2009.
57. BS EN 12390-13. *Testing Hardened Concrete. Determination of Secant Modulus of Elasticity in Compression*; British Standards Institution: Cambridge, UK, 2013.
58. BS ISO 1920-8. *Determination of Drying Shrinkage of Concrete for Samples Prepared in the Field or in the Laboratory*; British Standard Institution: London, UK, 2009.
59. Onuaguluchi, O.; Banthia, N. Plant-based natural fibre reinforced cement composites: A review. *Cem. Concr. Compos.* **2016**, *68*, 96–108. [CrossRef]
60. Bayasi, M.Z.; Soroushian, P. Effect of steel fiber reinforcement on fresh mix properties of concrete. *Mater. J.* **1992**, *89*, 369–374.
61. Bheel, N.; Sohu, S.; Awoyera, P.; Kumar, A.; Abbasi, S.A.; Olalusi, O.B. Effect of Wheat Straw Ash on Fresh and Hardened Concrete Reinforced with Jute Fiber. *Adv. Civ. Eng.* **2021**, *2021*, 6659125. [CrossRef]
62. Gao, D.; Wang, F. Effects of recycled fine aggregate and steel fiber on compressive and splitting tensile properties of concrete. *J. Build. Eng.* **2021**, *44*, 102631. [CrossRef]
63. Islam, M.S.; Ahmed, S.J. Influence of jute fiber on concrete properties. *Constr. Build. Mater.* **2018**, *189*, 768–776. [CrossRef]
64. Bheel, N.; Awoyera, P.; Aluko, O.; Mahro, S.; Viloria, A.; Sierra, C.A.S. Sustainable composite development: Novel use of human hair as fiber in concrete. *Case Stud. Constr. Mater.* **2020**, *13*, e00412. [CrossRef]
65. Yan, L.; Chouw, N. Natural FRP tube confined fibre reinforced concrete under pure axial compression: A comparison with glass/carbon FRP. *Thin Walled Struct.* **2014**, *82*, 159–169. [CrossRef]
66. Aziz, M.A.; Paramasivam, P.; Lee, S.L. Prospects for natural fiber reinforced concretes in construction. *Int. J. Cem. Compos. Lightweight Concr.* **1981**, *3*, 123–132. [CrossRef]
67. Zakaria, M.; Ahmed, M.; Hoque, M.; Islam, S. Scope of using jute fiber for the reinforcement of concrete material. *Text. Cloth. Sustain.* **2017**, *2*, 123. [CrossRef]
68. Lehner, P.; Konečný, P.; Ponikiewski, T. Comparison of material properties of SCC concrete with steel fibers related to ingress of chlorides. *Crystals* **2020**, *10*, 220. [CrossRef]
69. Zhong, A.; Sofi, M.; Lumantarna, E.; Zhou, Z.; Mendis, P. Flexural Capacity Prediction Model For Steel Fiber-Reinforced Concrete Beams. *Int. J. Concr. Struct. Mater.* **2021**, *15*, 1–12. [CrossRef]
70. Meddah, M.S.; Bencheikh, M. Properties of concrete reinforced with different kinds of industrial waste fibre materials. *Constr. Build. Mater.* **2009**, *23*, 3196–3205. [CrossRef]
71. Afroughsabet, V.; Teng, S. Experiments on drying shrinkage and creep of high performance hybrid-fiber-reinforced concrete. *Cem. Concr. Compos.* **2020**, *106*, 103481. [CrossRef]
72. Li, Z.; Lara, M.A.P.; Bolander, J. Restraining effects of fibers during non-uniform drying of cement composites. *Cem. Concr. Res.* **2006**, *36*, 1643–1652. [CrossRef]
73. Zhang, J.; Li, V. Influences of Fibers on Drying Shrinkage of Fiber-Reinforced Cementitious Composite. *J. Eng. Mech.* **2001**, *127*, 37–44. [CrossRef]
74. Barr, B.; Hoseinian, S.; Beygi, M. Shrinkage of concrete stored in natural environments. *Cem. Concr. Compos.* **2003**, *25*, 19–29. [CrossRef]
75. Kaïkea, A.; Achoura, D.; Duplan, F.; Rizzuti, L. Effect of mineral admixtures and steel fiber volume contents on the behavior of high performance fiber reinforced concrete. *Mater. Des.* **2014**, *63*, 493–499. [CrossRef]
76. Choi, S.; Park, J.; Jung, W. A Study on the Shrinkage Control of Fiber Reinforced Concrete Pavement. *Procedia Eng.* **2011**, *14*, 2815–2822. [CrossRef]
77. Passuello, A.; Moriconi, G.; Shah, S.P. Cracking behavior of concrete with shrinkage reducing admixtures and PVA fibers. *Cem. Concr. Compos.* **2009**, *31*, 699–704. [CrossRef]
78. Alrshoudi, F.; Mohammadhosseini, H.; Tahir, M.M.; Alyousef, R.; Alghamdi, H.; Alharbi, Y.; Alsaif, A. Drying shrinkage and creep properties of prepacked aggregate concrete reinforced with waste polypropylene fibers. *J. Build. Eng.* **2020**, *32*, 101522. [CrossRef]