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Research Article

Nanosilica-Based Teff Straw as an Eco-Friendly Substitute for Special Concrete

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No construction activity can be conceived in the current context without concrete. A popular method is to manufacture concrete from a mixture of three ingredients: aggregates, cement, and water. Because of poor construction materials, many structures deflect prematurely and excessively. Another major worry in the building business is the cost of materials required to make concrete. As a result, adding other suitable components (known as additives) in a specific proportion to boost concrete strength is a regular requirement. Teff agriculture is more prevalent in the study region (Ambo Town), as Enjera is a common Ethiopian delicacy made from Teff. Nanofiber-based Teff Straw production from Teff agricultural fields is in excess, and it was not being used for anything other than feeding cattle, donkeys, and other animals. As a result, farmers use the unfavorable habit of burning surplus Nanofiber-based Teff Straw, resulting in environmental pollution issues such as carbon footprint. Furthermore, the natural Nanofiber-based Teff Straw is extremely strong, used to blend nanoparticles, and it may be useful in overcoming general structural problems while also being cost-effective for local building businesses. In light of this, the current research focuses on an experimental assessment of the applicability of Nanofiber-based Teff Straw as an extra concrete material in concrete mixes. The typical mix for C25 concrete has been designed to achieve a target average strength of 28 MPa with a liquid (water)-cement ratio (l-c ratio) of 0.50 and a slump range of 20-50 mm. All Nanofiber-based Teff Straw reinforced concrete beam samples failed due to pure flexural failure, whereas plane concrete beams failed due to beam crushing. With the addition of Nanofiber-based Teff Straw to concrete, the mean flexural strength increased by 19.38 percent, 4.19 percent, and 0.66 percent, respectively, with M1, M2, and M3 adding up this particular ingredient by the weight of concrete. As a result, adding Nanofiber-based Teff Straw to concrete increased its bending strength when compared to ordinary concrete. Slump reduction effects of 20.00 percent, 40.00 percent, and 50.00 percent were seen for mix designs M_1, M_2, and M_3 when Nanofiber-based Teff Straw was added to the concrete weight. Finally, due to volume addition of fresh concrete with Nanofiber-based Teff Straw, fresh concrete densities were reduced by 2.00 percent, 2.32 percent, and 2.84 percent, respectively.

1. Introduction

The need of concrete for civil infrastructure is in excessive demand in both structural and nonstructural elements. The most commonly used materials include reinforcing fibers like rubber tires, crushed glass pieces, broken plastics, and industrial wastes; the organic wastes such as bagasse, wheat husk, groundnut shell, sisal, Nanofiber-based Teff Straw; and inorganic elements like concrete aggregates and reinforcement elements [1]. The nanosilica-like organics are agro-waste used as a surrogate for fine aggregate and provides a supplementary pozzolanic property in the production of concrete [2, 3]. The organic and inorganic materials can be used in a various form in concrete as fractional

Figure 1: Teff production process and nanofiber-based straw release in ambo agricultural zone.

substitution of aggregates and cement or in terms of reinforcing steel along with fibers to boost the tensile strength of concrete [4]. The use of sustainable materials for construction could considerably reduce the amount constitutive elements of concrete. Concrete is the highly demanded construction material in the building industries through the application of locally available ingredients along with cement. The manufacturing cost of material, the ease of molding it in any shape required, its ability to resist fire, less corrosion attack, and other advantageous properties over other construction materials make it preferable [5]. Due to the fact that the effective applications of fine aggregate (sand) and coarse aggregates (natural gravel) help for bearing the compressive load, the conventional concrete is comparatively influential in compression [6]. The compressive strength in concrete is an important mechanical property and is directly related to the other optimistic behavior of concrete. High compressive strength in concrete shows a hard nature, moisture resistant tendency, and the resisting tendency to other external forces. The quality of concrete can be assured through the determination of compressive strength [7, 8]. The workability of fresh concrete gives an idea of the frictional behavior of the concrete from the time it is mixed to the time it is compacted. It has four major components like the ability of the concrete to be mixed, transported, molded, and compacted [9, 10].

Shrinkage in concrete and creep in concrete are the fundamental issues responsible for cracking. The shear strength of concrete members reduces considerably due to the formation of cracks and be detrimental to the appearance of the structure [11]. Additionally, the cracks may allow the reinforcing to be bare to the open atmosphere and thereby developing the possibility of corrosion [12]. Hence, the current case study introduces the addition of ordinary fibers to the actual concrete in order to investigate the potency property and to strengthen the engineering properties of concrete. Most of the pioneer researches were focused on the application of the natural fiber construction materials for concrete [13].

Teff is common flour used for making the traditional food in Ethiopia. The excess production of Teff in Ambo, Oromia region, Ethiopia, showed in Figure 1. It leads to the net outcome of Nanofiber-based Teff Straw recycling it as a reinforcing ingredient in the construction industry. Although Nanofiber-based Teff Straw is used for plastering, its usage is very rare and undergoing with unnecessary burning and, in turn, results in the emission problem. Hence, an experimental trail was made by using Nanofiber-based Teff Straw for concrete to pace towards the most sustainable way of adopting the system [14–16]. Measuring the strength of concrete to determine its engineering properties in service is challenging. Generally speaking, using Nanofiber-based Teff Straw as concrete as reinforcement ingredient can solve problems like reduction in the cost of concrete as it replaces rebar and reduction of environmental pollution as it is a by-product of Teff production.

2. Materials and Methods

The selection of economically low and eco-friendly fiber which fits for making concrete is utmost important and fascinating in the construction firms [17].

(1) Cement: different sources of cement may differ with cement properties which in turn will influence properties of concrete mix [18, 19]. Portland Pozzolana cement was designed for the general use of structural construction work at different places. From locally produced cement Dangote Portland Pozzolana, CEMI-32.5R grade cement has been used in this specific study. The physical characteristics of the fine aggregates, coarse aggregates, and ingredients have been done to ensure its quality

(2) Nanofiber-based Teff Straw: Nanofiber-based Teff Straw of length in the range of 40-60 mm and 0.8 to 1.2 mm diameter, to have the aspect ratio of 30-100 mm taken and used as additive material in this study, was collected from local community's farm shown in Figure 2. The specific size of Nanofiber-based Teff Straw is suitable for enhancing workability. Naturally, Nanofiber-based Teff Straw is having the "fiber tendency" and strong enough, it is applicable to increase the elastic property of this special concrete. Usually, reinforcing of concrete is not only by the bars. Hence, it is advisable to make use of the natural fibers like Teff straw to increase the elasticity property of concrete. As a part of initial treatment,

Figure 2: Teff-straw-collection techniques and specimen preparation process.

Table 1: Mixing code and design for 1 m^3 concrete.

Mix code	Teff Straw (%)	W/C ratio	For 1 m^3 of concrete				
			Cement (kg)	Water (kg)	Sand (kg)	Coarse agg. (kg)	Teff fiber (kg)
M0	0.00%	0.5	350	181	678	1133	0.00
M1	0.15%	0.5	350	181	678	1133	3.27
M2	0.25%	0.5	350	181	678	1133	5.45
M3	0.35%	0.5	350	181	678	1133	7.63

Nanofiber-based Teff Straw was immersed in Sodium Hydroxide solution for 1 hour. This treatment is known as alkali treatment for Teff straw before its application for making the special concrete, and it was further washed by water for 15 – 20 minutes. This helps to remove the dusts and other impurities from Nanofiber-based Teff Straws and makes fit for its application. After that, straws were air-dried until it dried well, considering the water observation capacity of Nanofiber-based Teff Straw and chopped to satisfy the required straw length as per aspect ratio designed to be added in concrete mix with sand, cement, and stone in dry state and well mixed until the Nanofiber-based Teff Straw gets distributed uniformly [20].

(3) Fine aggregate: river sand collected from the quarry was the alteration for fine aggregate used in the current research. The laboratory experiments were conducted to ascertain the quality of the sand before it was taken to mix proportioning as ASTM standard documents. For specific gravity and absorption capacity ASTM C128, for fineness modulus ASTM C136 and for silt content and moisture content, ASTM C566 specification and standards were considered

Table 2: Mixing code vs. slump value (mm) and fresh concrete density (kg/m^3).

Mix-code	Nanofiber based Teff Straw (%)	Slump (mm)	Fresh concrete density (kg/m^3)
M0	0.00%	50	2412.6
M1	0.15%	40	2364.3
M2	0.25	30	2356.7
M3	0.35	25	2344.2

(4) Coarse aggregate: in Ordinary Portland cement concrete, aggregates are made up with 60% to 75% of the volume and 79% to 80% of the weight. The aggregates are used to perform as a load-bearing material and fill the space to diminish the amount of cement paste required in the mix. For this study, crushed aggregate from the basaltic rock was used. ASTM C127 for specific gravity and absorption capacity,

Table 3: Test report on compressive strength and split tensile strength.

Mix-code	Sample no.	Load failure for 150 mm size cubes (KN)	Concrete compressive strength (for 150 mm size cubes) (MPa)	Cylinder no.	Load failure (KN)	Tensile strength (splitting condition) (MPa)
M0	1	557.38	24.77	1	147.98	2.54
	2	742.14	32.98	2	149.87	2.10
	3	629.17	27.96	3	149.11	2.31
	Mean	642.90	28.57	Mean	148.98	2.11
M1	1	736.79	32.75	1	156.49	2.21
	2	762.86	33.90	2	151.67	2.15
	3	752.68	33.45	3	162.59	2.30
	Mean	750.75	33.37	Mean	156.92	2.22
M2	1	587.23	26.10	1	135.46	1.92
	2	515.64	22.92	2	159.78	2.26
	3	603.39	26.82	3	148.69	2.10
	Mean	568.75	25.28	Mean	147.98	2.09
M3	1	572.14	25.43	1	162.12	2.29
	2	609.42	27.09	2	150.47	2.13
	3	594.76	26.43	3	135.94	1.92
	Mean	592.11	26.32	Mean	149.51	2.12

ASTM C566 for moisture content, and ASTM C136 for sieve analysis have been used

(5) Water: the impurities/contaminants in water could change its physical characteristics and, in turn, unfavorably influence the strength of concrete and lead to corrosion of the steel reinforcement. It should be free from venomous substances such as acid, oil, salt, alkali, silt, sugar, organic loads, and other elements responsible damaging the concrete. Thus, potable water helps to satisfy with the appropriate curing time and strength of the special concrete and to facilitate the chemical reaction of cement in the production of special concrete. Hence, potable/wholesome water was used for producing the concrete and for the curing process

2.1. Mix Design. The mixing process is carried out to enhance a thorough mix of Nanofiber-based Teff Straw with the other ingredients using a standard mixture with a stirring rate of 2000 revolutions per minute for about 15 minutes. This standard speed of stirring in a specific period helps to bring homogeneous and uniform mixture. To satisfy the performance need on concrete, the mix proportioning was carefully examined with the optimum combination of concrete ingredients under a specific condition. An appropriate ratio of cement, fine aggregate, and coarse aggregate was taken for the mix design of Teff fiber-reinforced concrete and proportioned for making C25 grade concrete. In view of DOE technique of mix design, the wet density was determined for 1 m^3 of concrete, and it is found to be 2400 kg/m^3 and, on the basis of weight, Teff fiber 0.0%, 0.15%, 0.25%, and 0.35%. The mix design and fresh property of concrete is shown in Tables 1 and 2.

The concrete cylinder specimen of size 150 mm diameter and 300 mm length, plain concrete beam of size 100 mm × 100 mm cross-section with 500 mm length, and special concrete cube of size 150 mm are used for various testing.

2.2. Result and Discussion Workability. The investigation over the slump test and density tests for fresh concrete were accomplished and the result is shown on Table 2. Among the fresh concretes, properties for each present Nanofiber-based Teff Straw addition of concrete mixture (0.00%, 0.15%, 0.25%, and 0.35%) are taken by the weight of concrete. The proportions for Nanofiber-based Teff Straw application was fixed appropriately based on the literature review [20]. For the mix M1 (mix with 0.15% Nanofiber-based Teff Straw), for mix M2 (mix with 0.25% Nanofiber-based Teff Straw), and for mix M3 (mix with 0.35% Nanofiber-based Teff Straw), the fresh concrete density has been reduced by 2.0%, 2.32%, and 2.84%, respectively. Patnaik et al. used 0.5% increment in adding the Nanofiber-based Teff Straw in their study, which shown the compressive strength of 5.5 MPa corresponding to 1.5% of Nanofiber-based Teff Straw @ 56 days [21].

2.3. Compressive and Split Tensile Strength. According to Chandrasekar et al., in their study, the result on the compressive strength and the flexural strength noted 2.6 MPa and 0.36 MPa, respectively, on brick specimen with the application of pumice aggregate (9%) and Nanofiber-based Teff Straw (0.4%) [22]. In the current study, laboratory experiment was conducted on three cubes of size 150 mm; for different percentages, the addition of Nanofiber-based Teff Straw and test on splitting tensile strength for the special type of hardened concrete (quality test) was carried out using the standard cylinders. For 150 mm cube and standard

Table 4: Results on flexural strength.

Mixing code	Sample no.	Load failure in KN	Flexural strength in MPa
M0	1	9.48	4.74
	2	8.66	4.33
	Mean	9.07	4.54
M1	1	9.20	4.60
	2	12.46	6.23
	Mean	10.83	5.42
M2	1	8.14	4.07
	2	10.79	5.40
	Mean	9.47	4.73
M3	1	9.40	4.70
	2	8.86	4.43
	Mean	9.13	4.57

cylinders, the typical failure loads and compressive and split tensile strength for the 28th day are shown in Table 3.

The target mean strength of TFRC (fm = fck + 1.65σ) with 0.15% addition of the special Nanofiber-based Teff Straw by the own weight of concrete has shown an augmentation of 17.08% as compared to the normal conventional concrete. The Teff fiber-reinforced concrete of 0.25% special Nanofiber-based Teff Straw has shown a compressive strength reduction of 11.51%. This type of special concrete with 0.35% Nanofiber-based Teff Straw has resulted in a compressive strength reduction of 7.87%. The mean failure loads with 0.15% increased by 16.78%, while 0.25% and 0.35% Nanofiber-based Teff Straws were also decreased by 11.53% and 7.89%, respectively. The applications of Nanofiber-based Teff Straw and Pumice with potable water have shown a considerable improvement for adobe brick, according to the pioneer research [22]. The Nanofiber-based Teff Straw has highly gained a specific attention upon the best improvement in a special concrete, and the statement is proven by Abilash et al. [23].

2.4. Flexural Strength. "Plain concrete beam" with a size of 100 mm × 100 mm × 500 mm without reinforcement bars is used for the flexural strength test. For TFRC samples, under third-point loading, the typical failure loads and its corresponding bending strength over 28 days are illustrated in Table 4.

The statement of Devnani and Sinka proves that Teff Straw fiber was used to connect the internal concrete materials and, in turn, increases the shear strength. Thus, Nanofiber-based Teff Straw fibers act as the reinforcement bars [24]. Moreover, the elastic property of Nanofiber-based Teff Straw fiber is highly suitable for developing durable special concrete with lightweight [25].

2.5. Strain and Stress Relationship. As most of the ingredients used for making this special concrete are manufactured/produced by the Ethiopian companies, the local code

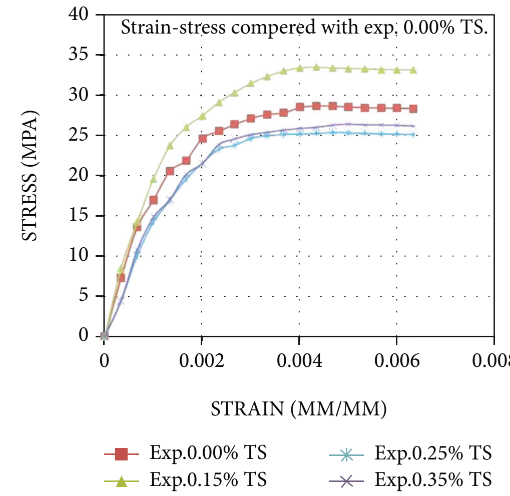

Figure 3: Strain-stress relationship of concrete produced with the addition of Nanofiber-based Teff Straw.

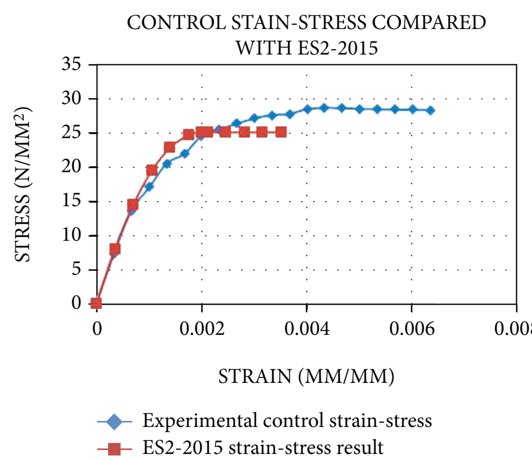

Figure 4: Control strain-stress compared with ES2-2015.

(Ethiopia code) of ES-2-2015 was preferred for comparison on stress and strain. Figure 3 shows the comparison of conventional cube (150 × 150 × 150) over strain-stress properties without the addition of Nanofiber-based Teff Straw, against ESC2-2015 standard. For the other Nanofiber-based Teff Straw additions, the strain-stress was compared with the control experimental test related with ES2-2015 as shown in Figure 4.

The stress-strain graph of cube control (M0) was related to the standard of ES2-2015. Compared to the other M1, M2, and M3 with the strain-stress graph of control mix, it showed the improvement for 0.15% addition of Nanofiber-based Teff Straw. The other graph for M_2 and M_3 graph is below the control strain-stress graph.

3. Conclusions

Improvement on the concrete's compressive strength showed 0.15% addition of Nanofiber-based Teff Straw showed the reduction by 17.08%, whereas 0.25% and

0.35% addition of Nanofiber-based Teff Straw showed the reduction by 11.51% and 7.87%, respectively. The adding up of very high percentage of Nanofiber-based Teff Straw has not shown any consistent improvement on the splitting tensile strength with 0.35% and in turn, which showed the declined tensile strength. Similarly, the experimental test for 28 days on Teff fiber-reinforced concrete corresponding to 0.15%, 0.25%, and 0.35% Nanofiber-based Teff Straw had clearly shown a stable increment on flexural strength. From the test result of experiment on three different proportions studied under investigation of Nanofiber-based Teff Straw additions to the total weight of concrete, 0.15% Nanofiber-based Teff Straw addition indicates a maximum strength increment in all strength test results.

Therefore, the addition of 0.15% Nanofiber-based Teff Straw is an optimum proportion for this specific research which results in 17.08%, 5.28%, and 19.38% over the 28th day, which shows a tremendous improvement on compressive strength, splitting tensile strength, and flexural strength of the special concrete held in the study as compared to the normal conventional concrete.

Data Availability

The data used to support the findings of this study are included within the article. Should further data or information be required, these are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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