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# Performance of Rice Straw Fibers on Hardened Concrete Properties under Effect of Impact Load and Gamma Radiation

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**Abstract:** Concrete is an essential artificial building material in modern society. However, because concrete structures have brittle characteristics, they have a limited service life when subjected to dynamic loads. Nuclear emissions and explosions threaten human lives and structures' safety due to harmful radiation and dynamic effects. Since agriculture has revealed a large amount of by-products that require disposal, the use of such by-products in many sectors is a challenge for contemporary studies. One of the most important areas for the disposal of such waste is construction, and concrete in particular. The utilization of the agricultural by-product rice straw fiber was chosen in this study to replace the usage of artificial fibers in concrete production and present an eco-friendly prospective contender with enhanced static/dynamic performance and gamma shielding characteristics. Different concrete mixtures were proposed in this study to evaluate the aforementioned characteristics. The designed concrete mixtures were conventional concrete with variations in the volume fraction of rice straw fibers (RSF) of 0%, 0.25%, 0.5%, and 0.75%. The desired static properties were compressive strength, splitting tensile strength, and flexural strength. Additionally, the drop weight impact test was used in this study to investigate the impact resistance of RSF-reinforced concrete. Finally, the radiation-shielding characteristic of the produced concrete was tested using the linear attenuation test. The results show that adding agricultural by-products of RSF in concrete production slightly enhanced the compressive strength by up to 7.0%, while it significantly improved the tensile and flexural properties by up to 17.1% and 25.8%, respectively. Additionally, a superior impact resistance of concrete was achieved by up to 48.6% owing to RSF addition. Furthermore, it enhanced the gamma shielding capability of concrete by up to 7.9%. The achievements in this study pave the way for utilizing RSF-reinforced concrete in various non-traditional applications.

**Keywords:** rice straw fiber; gamma radiation; impact resistance

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## 1. Introduction

Concrete is the main building material used in modern society. It is a mixture of water, aggregates, cement, and other additives that affect different concrete characteristics. The chemical reaction between water and cement produces heat and forms a great binding force that increases over time [1]. Utilizing industrial and agricultural by-products is one way to lessen concrete's environmental impact [2]. Concrete structures are brittle in nature, limiting their service lives in dynamic loadings. The brittle behavior is due to the concrete's weakness in tension cracking [2]. Concrete containing fiber is named fiber-reinforced concrete [3]. The fibers aid in transferring load at locations of micro-cracks; moreover, they help improve concrete's crack resistance and durability. There are various types of fibers depending on their chemical and physical compositions, including: (1) glass, (2) plastic wastes, (3) carbon, (4) metallic, and (5) polypropylene fibers [4]. Fiber was introduced to concrete to create an obstacle against crack development in concrete, increasing the concrete's toughness, tensile strength, fatigue and shrinkage characteristics, impact strength, erosion resistance, and serviceability. Most pertinent recent research work has focused on the impact behavior of cement-based materials reinforced by mono-fibers [5–7] and/or hybrid fibers with two or more different types of fibers [8–10].

In the past few decades, a great deal of effort has been focused on using different natural fibers due to their abundance and low cost. Agriculture reveals a large amount of by-products that require disposal, such as rice straw. The use of such by-products in many sectors, such as concrete production, has recently arisen. Natural fiber usage is compared to artificial fiber-reinforced concrete in numerous civil engineering applications [1]. On the other hand, natural fibers (agricultural by-products) are low-cost materials that offer an alternative to conventional fibers, such as polypropylene fibers. Natural fibers also have the advantage of having low emissions in processing and production. One of the most sustainable and abundant resources is rice straw, which could be used as a fiber in concrete. As a by-product of harvesting rice, rice straw is created [11]. Rice straw has several other utilizations, but the most commonly used disposal method for rice straw is burning the rice straw, which causes several environmental hazards.

Burning rice straw releases an immense amount of carbon monoxide, which affects humans negatively. Rice straw fibers can be used as an alternative replacement for artificial fibers, providing an economical and environmental impact on the community [12]. Researchers and engineers are innovating in the reuse of rice straw as a commodity to offer a sustainable solution for people [13]. Rice has many different usages, one of which is being used as a fiber in concrete for its high silica content, making it an appropriate candidate for such a function [14].

Vast research work has been conducted to evaluate the characteristics of fiber-reinforced concrete produced with such natural materials. For instance, Ramakrishna and Sundararajan (2005) [15] studied the impact resistance of cement mortar slabs reinforced with four natural fibers: coir, sisal, jute, and hibiscus cannabinus, in which they were subjected to impact loading using a simple projectile test. The results show that the addition of the above natural fibers raised the impact resistance of the mortar slab by 3:18 times that of the control concrete slab. Based on the set of specified indicators, coir-fiber-reinforced mortar slab specimens exhibited the best performance of the four fibers.

Additionally, Ilham et al. (2019) [16] investigated the mechanical qualities of concrete bricks with rice straw. It was concluded that the straw concrete bricks with a volume variation of 0.000625 $m^3$ achieved the highest compressive strength of 3.0852 Mpa relative to all other tested specimens, which exceeds the minimum standards' requirements in terms of the compressive strength of conventional concrete bricks. Likewise, Allam et al. (2011) [17] conducted a study to give an overview of how chopped rice straw can be recycled to make lightweight cement bricks that can be used as infills in skeleton constructions. Three rice-straw bricks were made and compared to a regular commercial pure cement brick. It was revealed that increasing the amount of chopped rice straw in each brick to 40 kg/1000 brick resulted in a maximum compressive stress of 115 $kg/cm^2$, which is considered suitable for construction. A cost–benefit analysis of the available cement bricks on the local market revealed that employing chopped rice straw could save up to 25% of the cost.

Furthermore, Marwa et al. (2019) [18] carried out a study to create ecologically friendly concrete with optimal qualities using recycled rice straw and rice husk, which were utilized as partial cement substitutes in concrete mixes. This study indicated that the compressive strength was increased by adding 1%RS to the concrete mix and slightly decreased by increasing RS content to 3% and 5%, respectively. The compressive behavior of the RS concrete was enhanced by heating to 700 °C for 1 h and 2 h compared to the 0% RS concrete. In addition, Chin et al. (2019) [19] carried out a study to evaluate the mechanical performance of concrete utilizing wheat straw fibers. It was concluded that improvements in compressive and flexural strength for wheat straw fibers were obtained when a 0.25% volume fraction was used. Wheat increased the overall performance in the 0.5 and 1 percent volume fractions compared to normal concrete.

Additionally, Ataie (2018) [20] studied the impact of adding fine/coarse rice straw fibers to concrete on compressive and flexural strength. It was deduced that samples that were made by using fine rice straw fibers had a better compressive strength than that of coarse rice straw fibers, while the flexural strength of fine straw fiber concrete showed a decrease in flexural strength compared to coarse straw fiber concrete. Nguyen et al. (2020) [21] studied the features of producing rice-straw-reinforced alkali-activated cementitious composites. The untreated and NaOH-treated rice straw were added to the mixtures in proportions of 1%, 2%, and 3% by weight of cement, respectively. In general, it was observed that adding 1% and 2% of both URS and TRS fibers to AACCs improved their wet/dry cycle durability by increasing the retained flexural strength ratios (between 0.62 and 0.69) compared with the control (0.55).

On the other hand, severe loading conditions, such as explosions, fatigue, earthquakes, nuclear bombs, and impact loads, pave the way for modern researchers to present special concretes with the ability to withstand such loading regimes. Special nuclear concrete shields are designed against synergy of impact loads, gamma radiation, and neutron emissions. The primary neutron emission source is the actinides and the transuranic isotopes of californium and cerium that undergo spontaneous fission [22]. For gamma radiation shielding, a massive shield structure is required [23]. The majority of research work in this field was applied experimentally [24–28], while other outcomes were measured numerically [29,30]. It is also crucial to research the phenomenon of nuclear barriers that withstand dynamic loads [17–30].

Vast research has been undertaken to evaluate the effect of using different materials and techniques on the gamma-radiation-shielding characteristics of concrete [31–35]. However, there is a lack of information on investigating the behavior of concrete shields incorporating rice straw fibers under synergy of impact load, gamma, and neutron radiations. Thus, this study was conducted to evaluate the behavior of various eco-friendly concrete mixtures produced with rice straw fiber under the effect of static; compressive strength, splitting tensile strength, and flexural strength. Additionally, its performance under drop weight impact load and gamma/neutron radiations was investigated.

In order to evaluate the aforementioned characteristics, different non-traditional concrete constituents were incorporated in this study. First, rice straw fibers (RSF) were used in this research as a replacement for polypropylene fibers as a sustainable candidate for natural fibers. RSF were implemented in concrete production with 0%, 0.25%, 0.50%, and 0.75% by volume fraction to evaluate the optimum RSF fiber content in concrete shields. Thereafter, a comparative study was applied on polypropylene (PP) fiber-reinforced concrete specimens produced with fiber content similar to that which achieved superior behavior under different loading conditions with RSF to investigate the applicability of utilizing such natural by-products in construction applications. Finally, silica fume was utilized in specimen preparation with different proportions, 5%, 10%, and 15%, as a percent replacement of cement in concrete manufacturing to present eco-friendly concrete contenders and optimize the concrete performance under different loading regimes.

## 2. Materials and Methods

### 2.1. Materials

In this research work, the grade of designed concrete mixes was intended to be M30. The volumetric approach was used to determine the mixing proportions and define the concrete's composition. The constituents in the mix design were the main requisites for conventional concrete. Ordinary Portland cement type I following the ASTM C150 [36] and silica fume, complying with ASTM C 1240 [37], was utilized as a binder material. Furthermore, dolomite aggregate and natural silica sand free from silt and clay impurities were used to create the concrete mixture as per ASTM C33 [38]. The major physical characteristics of the dolomite and silica sand are listed below in Table 1. In addition, natural water, along with a high-range water reducer admixture (HRWRA), were used in the construction of specimens to adjust the flow ability of concrete mixes in accordance with ASTM C 494 [39]. Additionally, polypropylene and rice straw fibers made up of short, distinct fibers that were uniformly scattered and oriented in a random pattern were used in concrete specimen production. The chemical composition of rice straw fiber is presented in Table 2. Also, the properties of polypropylene and rice straw fibers are shown in Table 3.

**Table 1.** Physical properties of aggregates.

| Characteristic | Dolomite | Silica Sand |
|---|---|---|
| Bulk-Specific Gravity (SSD) | 2.64 | 2.63 |
| Apparent Specific Gravity | 2.69 | 2.67 |
| Water Absorption | 0.66% | 0.91% |

**Table 2.** Chemical composition of rice straw fiber.

| Compounds | Percentage |
|---|---|
| $SiO_2$ | 75% |
| $K_2O$ | 10% |
| $P_2O_5$ | 3% |
| $F_2O_3$ | 3% |
| CaO | 1.3% |
| Mg and Na | Minimal percentage |

**Table 3.** Polypropylene and rice straw fiber properties.

| Characteristic | Polypropylene Fibers | Rice Straw Fibers |
|---|---|---|
| Length | 8 mm | 8 mm |
| Diameter | 20 μm | 16 μm |
| Tensile strength (MPa) | 520 | 450 |
| Specific gravity | 0.9 | 1.1 |
| Color | White | Greenish Yellow |
| Constituent | Pure Homopolymer Polypropylene | Cellulose, lignin, hemicellulose |
| Moisture content | - | 12–17% |

The experimental work includes eight different mixtures, as shown in Table 4. The abbreviations refer to the produced concrete with specific constituents. For example, RS0.5/10 belongs to an ordinary concrete produced with 0.5% by volume fraction of rice straw fiber and 10% of silica fume as a replacement for cement.

**Table 4.** Mix proportions of different concrete mixtures.

<table>
<tr><th>Mixture ID</th><th>Silica Sand (kg)</th><th>Coarse Aggregate (kg)</th><th>Cement (kg)</th><th>Water (kg)</th><th>Silica Fume (kg)</th><th>PP (%Vf)</th><th>Rice Straw Fiber (%Vf)</th><th>HRWRA (kg)</th></tr>
<tr><td>CC</td><td rowspan="5">760.75</td><td rowspan="5">1145.471</td><td rowspan="5">350</td><td rowspan="8">140</td><td rowspan="5">-</td><td rowspan="4">-</td><td>-</td><td rowspan="8">7.0</td></tr>
<tr><td>RS0.25</td><td>0.25%</td></tr>
<tr><td>RS0.5</td><td>0.5%</td></tr>
<tr><td>RS0.75</td><td>0.75%</td></tr>
<tr><td>PP0.5</td><td>0.5</td><td>-</td></tr>
<tr><td>RS0.5/5</td><td>766.6</td><td>1154.28</td><td>332.5</td><td>17.5</td><td rowspan="3">-</td><td rowspan="3">0.5%</td></tr>
<tr><td>RS0.5/10</td><td>772.44</td><td>1163.07</td><td>315</td><td>35</td></tr>
<tr><td>RS0.5/15</td><td>778.29</td><td>1171.87</td><td>297.5</td><td>52.5</td></tr>
</table>

### *2.2. Test Procedures*

#### 2.2.1. Unit Weight Measurement

Cubic specimens were created with dimensions 150 × 150 × 150 mm and weighed according to ASTM C138 guidelines [40] to evaluate the unit weight of the different concrete samples.

### 2.2.2. Compressive Strength Test

The compressive strength test was carried out on cubic concrete specimens of 150 × 150 × 150 mm according to ASTM C39 [41]. The concrete was poured and tempered adequately to avoid the presence of any voids in the concrete medium. After 24 h, the mold was detached, and the specimen was cured in water for 3, 7, and 28 days. Three cubes per each testing age of various concrete mixtures were tested to obtain an average of the compressive strength at all testing ages.

### 2.2.3. Splitting Tensile Strength Test

According to ASTM C 496, cylindrical specimens of 15 cm in diameter and 30 cm in height were tested for the different concrete mixtures at testing ages of 3, 7 and 28 days to evaluate the splitting tensile strength properties of different concretes.

### 2.2.4. Flexural Strength Test

Following the ASTM C 78 [42], three prisms of 100 × 100 × 500 mm from each specimen were tested under a four-point bending test at testing ages of 3, 7, and 28 days to evaluate the flexural strength of the various produced concrete mixtures. Equation (1) was used for determining the flexural strength as follows:

$$R = \frac{P \times l}{B \times d^2} \tag{1}$$

where R is the modulus of rupture in MPa, P is the maximum applied load indicated by the testing machine in kN, l is the length of prism in mm, d is the average depth of prism at fracture in mm, and b is the average width of prism at fracture in mm.

### 2.2.5. Impact Resistance Test

The drop weight impact test was carried out in this study to give an overview of concrete's endurance. The drop weight test depends on the number of hits a specimen requires to cause fracture. The measurement of the number of hits serves as a method to expect the energy absorbed by a specimen at failure. Usually, this test is carried by a concrete specimen containing fiber, and an ordinary control concrete is accompanied. Drop weight impact equipment is shown in Figure 1.

Concrete slabs of 500 × 500 × 50 mm were prepared and cured for the test according to ASTM C 31. The specimens were removed from the mold after 24 h of casting and then left to cure for 3, 7, and 28 days. The number of blows needed to create the first visible crack and the ultimate failure were recorded. The height of the hammer and the impactor weight are two elements that influence the impact test's energy capacity. On all tested specimens, the energy of 66.19 J for each strike was induced by a 45N steel weight falling from a height of 150 mm. The number of hits required to propagate a visible crack ($N_1$) and the number of hits required to cause fracture ($N_2$) were recorded. According to ASTM D5628-07 [43], the sustained impact energy was computed as presented below in Equation (2);

$$I = N_i \times h \times w \times f \tag{2}$$

where $N_i$ is the number of hits, h is the falling height in mm, w is the steel hammer mass in kg, and f is a constant of ($9.88 \times 10^{-3}$).

**Figure 1.** Drop weight impact test equipment.

#### 2.2.6. Linear Attenuation Test

One of the major contributions in this study is the production of concrete mixtures with ingredients which likely contribute to a strong gamma radiation shielding. The linear attenuation test provides an overview of the radioactive absorption of the material prepared for shielding. Specimens were created with different thicknesses. The thicknesses that were tested were 2 cm, 4 cm, 6 cm, 8 cm, and 10 cm, with a diameter of 15 cm. Two different sources were applied to the specimens for this test. The first radioactive source used was the Co-60 (+60 Cobalt), as shown in Figure 2, while a gamma radiation source of 2 energy levels, 1.17 MeV and 1.33 MeV, was applied. The other source was Americium–Beryllium, which emitted neutron radiation with an energy level of 7 MeV as shown in Figure 3. Both instruments were used to determine whether neutron and gamma radiation shielding were effective for the different proposed concrete mixtures. Each specimen was left in front of the source and an intensity reading was taken. After raising the thickness by a 2 cm increment, the operation was repeated.

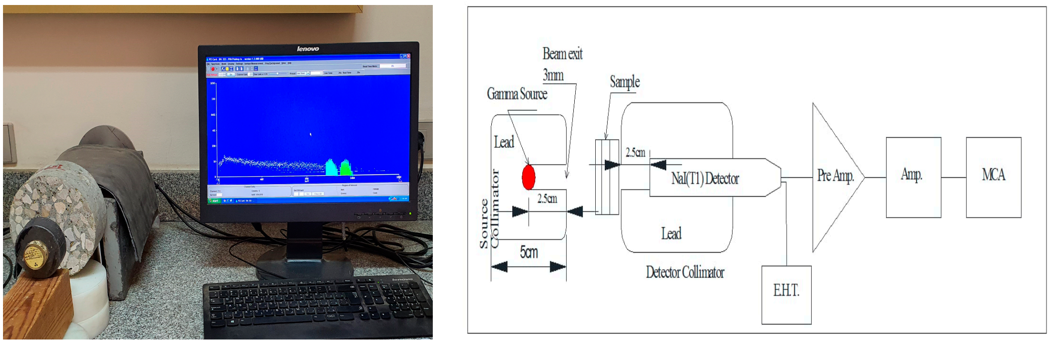


**Figure 2.** Test setup and schematic diagram of specimen under gamma radiation source (Co-60).

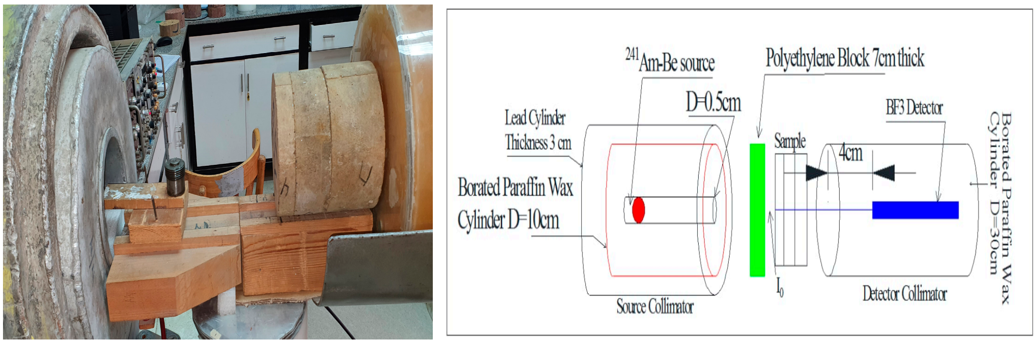


**Figure 3.** Test setup and schematic diagram of specimen under neutron radiation source (Americium–Beryllium).

The attenuation coefficient was evaluated following Equation (3):

$$\mu = \frac{1}{x} \ln \frac{I_0}{I} \tag{3}$$

where $I_0$ is the intensity when there was no sample between the source and the detector, I is the intensity when a sample was presented, and x is the thickness of the tested specimen.

## 3. Results and Discussion

### *3.1. Unit Weight Measurement*

Figure 4 presents the unit weight of concrete specimens. As shown in the figure, the unit weight of concrete decreased by about 1.8% when rice straw fibers were utilized by 0.25% volume fraction. As the volume fraction of the natural fiber increased by 0.5% and 0.75%, the unit weight decreased by approximately 0.2%. This is attributed to replacing heavyweight concrete constituents with lightweight rice straw fibers. A slight to non-existent increase in the unit weight of the samples was observed upon replacing rice straw with PP fibers. On the other hand, the partial replacement of cement by silica fume slightly increased the unit weight of concrete samples. This is due to decreasing the void content in concrete owing to the micro-filling capability of micro silica. The unit weight of rice-straw-reinforced concrete mixtures containing 5% silica fume increased by about 0.45% compared to those containing rice straw without silica fume.

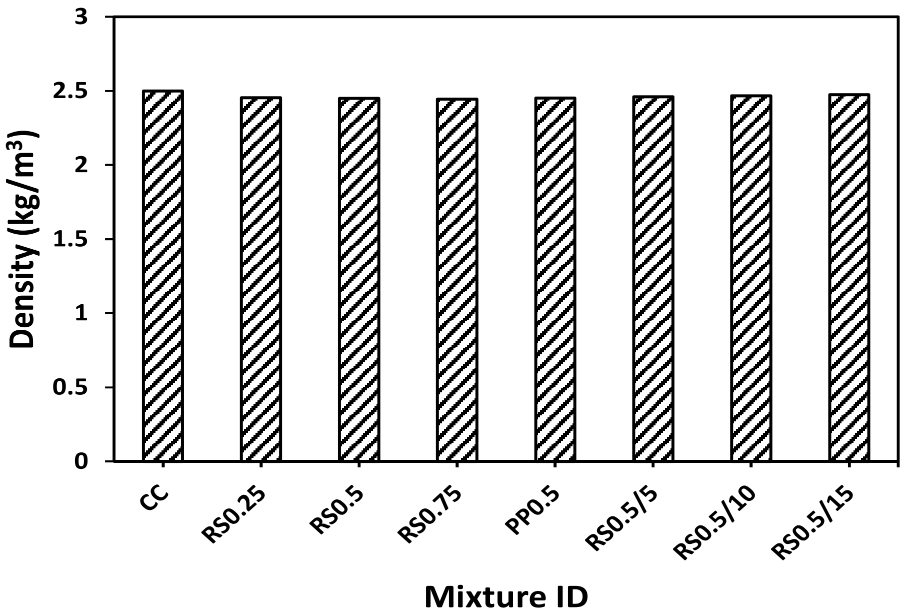


**Figure 4.** Unit weight of different concrete mixtures.

Furthermore, increasing silica fume content to 10% increased the concrete unit weight further by 0.76% compared to those containing 0.5% rice straw fiber. The percentage of increase deviated further to 0.98% when the silica content was increased to 15%.

### 3.2. Compressive Strength

Generally, as indicated in Figure 5, all tested specimens achieved the desired compressive strength of 30 MPa at maturity age of 28 days. Mixtures (RS0.25), (RS0.5), and (RS0.75) resemble the mixtures containing the rice straw fiber per volume fraction of 0.25%, 0.5%, and 0.75%, respectively. Mixture RS0.25 showed a slight to non-existent increase in the compressive strength at all curing periods. Furthermore, increasing the volume fraction of rice straw fibers to 0.5% demonstrated a 4, 7.5, and 1.9 percent improvement in compressive strength at testing ages of 3, 7, and 28 days, respectively. Further increase in the rice straw fiber content to 0.75% conversely decreased the compressive strength by 4.2, 1.5, and 1.9 percent at testing ages of 3, 7, and 28 days, respectively. The reduction in mechanical properties of the RS0.75 specimen, incorporating more than 0.5% rice straw fiber, is most probably due to increased porosity along with fiber clustering caused by increasing fiber dosage.

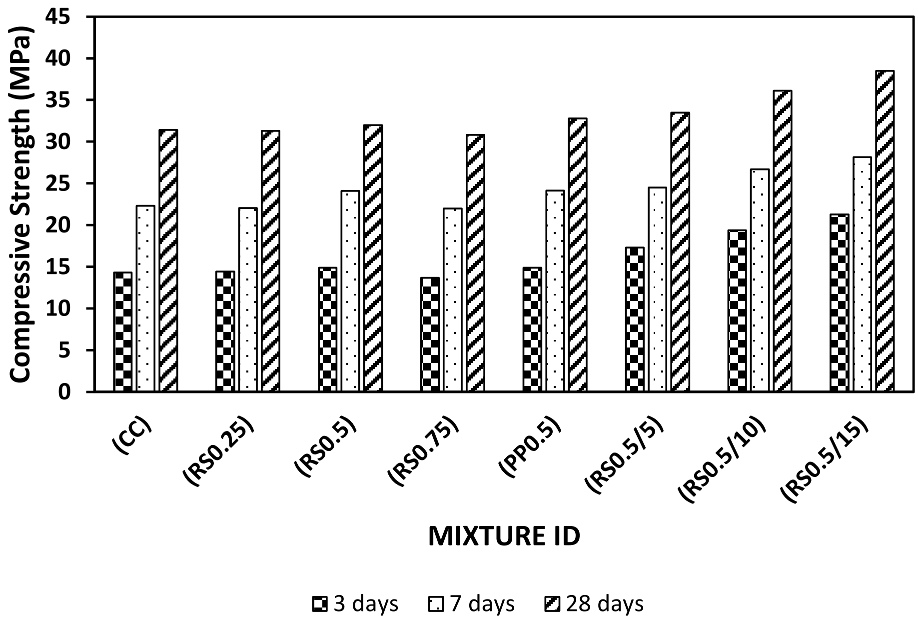


**Figure 5.** Compressive properties of various concrete mixtures at 3, 7, and 28 days.

Based on the aforementioned observations, mixture RS0.5 acquired the highest compressive strength compared to its counterparts. Thus, a comparison between incorporating 0.5% volume fraction of polypropylene relative to rice straw fibers was drawn. The comparison shows that the mixture containing volume fraction of 0.5% rice straw fiber acquired a higher compressive strength than that of the polypropylene (PP0.5) fiber, with a slight difference of 2.5% at 28 days, which reflects the applicability of utilizing such natural waste material as a contender to PP fibers in concrete production. The incorporation of silica fume in rice-straw-fiber-reinforced concrete production was also investigated. On the other hand, mixtures (RS0.5/5), (RS0.5/10), and (RS0.5/15) had specific percentages of silica fume addition of 5%, 10%, and 15%, respectively. A rise in the compressive strength of the (RS0.5/5) specimen compared to mixture (RS0.5) by about 17.3%, 8.9%, and 6.3% at testing ages of 3, 7, 28 days, respectively, was obtained, as indicated in the figure.

Likewise, the 10% silica replacement showed an increase in the compressive strength with increments of 23.2, 9.7, and 13.3 percent relative to mixture RS0.5 at all testing periods. Additionally, the results showed that the increase of silica fume addition to 15% increased the compressive strength by about 30%, 14.4%, and 16.9% at testing ages of 3, 7, and 28 days, respectively, relative to the RS0.5 specimen. The enhancement in the compressive characteristics of concrete specimens that incorporated silica fume is attributed to the pozzolanic activity of silica which enhances the mechanical behavior of concrete.

### *3.3. Splitting Tensile Strength*

All mixtures were tested using the splitting tensile test at curing periods of 3, 7, and 28 days. The results of the tensile strength are shown in Figure 6. As indicated in the figure, mixture RS0.25 showed a slight increase in the splitting tensile strength by up to 5% at all curing periods compared to the CC specimen. Likewise, increasing the volume fraction of rice straw fibers to 0.5% revealed a 9.1%, 9.8%, and 17.1% improvement in tensile properties of concrete at testing ages of 3, 7, and 28 days, respectively, compared to control specimen. Further increase in the rice straw fiber content to 0.75% increased the uniaxial tensile strength by about 4.2%, 5.9%, and 9.7% relative to the CC specimen at testing ages of 3, 7, and 28 days, respectively. The enhancement in tensile properties of rice straw concrete specimens is attributed to the fiber–matrix interfacial bond, which improved the load transfer across cracks, thus enhancing the overall tensile load carrying capacity of rice straw concrete.

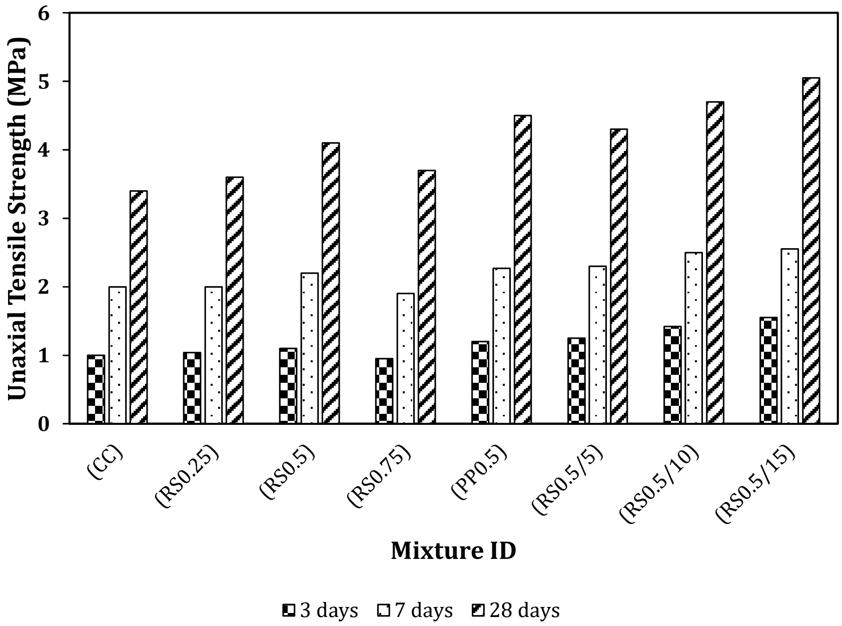


**Figure 6.** Splitting tensile properties of various concrete mixtures at 3, 7, and 28 days.

Following the aforementioned observations, a comparison between incorporating 0.5% volume fraction of polypropylene relative to rice straw fibers was evaluated. It was observed that the incorporation of 0.5% PP fiber acquired a higher tensile strength than that of the rice straw fiber with a slight difference of 8% at all testing ages, which also reflects the applicability of utilizing such natural waste material as a contender with PP fiber in concrete production. On the other hand, the addition of silica fume in rice straw concrete production showed a slight to non-existent increase in the tensile properties of rice straw concrete at early ages, while the tensile performance of RS specimens was improved at the testing age of 28 days. For instance, the splitting tensile strength of mixtures (RS0.5/5), (RS0.5/10), and (RS0.5/15) was increased by about 20.9%, 27.7%, and 12.8% compared to the RS0.5 specimen at the testing age of 28 days, respectively.

Following the aforementioned observations, a comparison between incorporating 0.5% volume fraction of polypropylene relative to rice straw fibers was evaluated. It was observed that the incorporation of 0.5% PP fiber acquired a higher tensile strength than that of the rice straw fiber with a slight difference of 8% at all testing ages, which reflects also the applicability of utilizing such natural waste material as a contender to PP fiber in concrete production. On the other hand, the addition of silica fume in rice straw concrete production shows a slight to no increase in the tensile properties of rice straw concrete at early ages, while the tensile performance of RS specimens was improved at testing age of 28 days. For instance, the splitting tensile strength of mixtures (RS0.5/5), (RS0.5/10), and (RS0.5/15) was increased by about 20.9%, 27.7%, and 12.8% compared to RS0.5 specimen at testing age of 28 days, respectively.

### *3.4. Flexural Strength*

The flexural strength of all mixtures were evaluated using the four-point bending test at curing ages of 3, 7, and 28 days. The test results are presented in Figure 7. As shown in the figure, a slight increase in the flexural strength of concrete specimens by up to 9.1% was observed at early ages, owing to rice straw fiber addition. However, superior flexural strength was achieved at the maturity age of 28 days for all rice straw concrete specimens. For instance, the flexural performance of RS0.25, RS0.5, and RS0.75 was improved by up to 17.1%, 25.6%, and 18.7% relative to CC specimen, respectively. The improvement in the rupture properties of rice straw concrete specimens is ascribed to the enhanced crack control capability owing to the rice straw fiber–matrix interfacial bond.

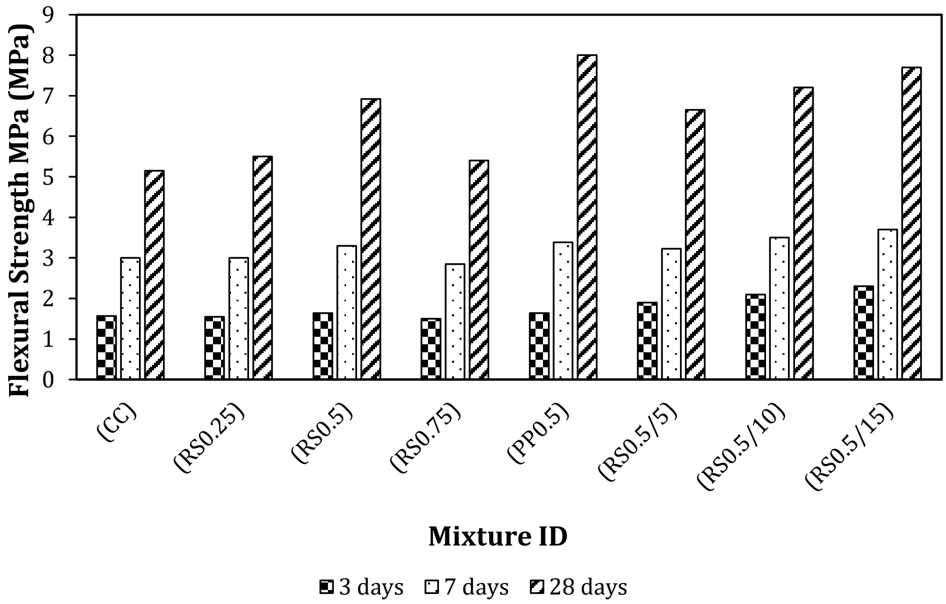


**Figure 7.** Flexural behavior of various concrete mixtures at 3, 7, and 28 days.

Based on that, a comparison was applied in order to evaluate the effect of replacement of rice straw by PP fiber with 0.5% volume fraction. It was revealed that implementing 0.5% PP fiber by volume fraction in concrete production achieved higher flexural strength than that of the rice straw fiber with a slight difference of 13.5% at the maturity age of 28 days. This reveals the applicability of utilizing such natural waste material as a contender with PP fiber in concrete production. Furthermore, the effect of pozzolanic activity on concrete specimens by addition of silica fume was investigated by incorporating 5%, 10%, and 15% by weight of cement. It was observed that the flexural properties of rice straw concrete were slightly affected at early ages by silica fume addition, while the flexural performance of rice straw concrete specimens was enhanced at the testing age of 28 days. For example, the modulus of rupture of RS0.5/5, RS0.5/10, and RS0.5/15 specimens was increased by about 22.6%, 33.1%, and 28.5% relative to the RS0.5 specimen at the testing age of 28 days, respectively.

### *3.5. Impact Resistance Test*

Figures 8 and 9 present the sustained impact energy of concrete specimens up to first crack and failure, respectively. As per the aforementioned observations, the rice straw fiber addition generally enhanced the impact energy of tested specimens relative to the conventional concrete specimen. For example, incorporating rice straw fiber by 0.25% and 0.75% volume fractions led to enhanced impact energy up to first crack by about 57.1% and 50.2%, respectively, while it improved the impact energy up to failure by about 37.9% and 29.8%, respectively. A superior performance under impact load was achieved by incorporating a 0.5% by-volume fraction of rice straw fiber in concrete production. For instance, the RS0.5 specimen sustained impact energy up to first crack and failure higher than CC specimen by about 62.5% and 48.6%, respectively. The enhanced impact energy accomplished by rice straw concrete specimens is attributed to the fiber–matrix interfacial bond, which improved the load transfer across cracks, thus enhancing the overall impact load carrying capacity of rice straw concrete.

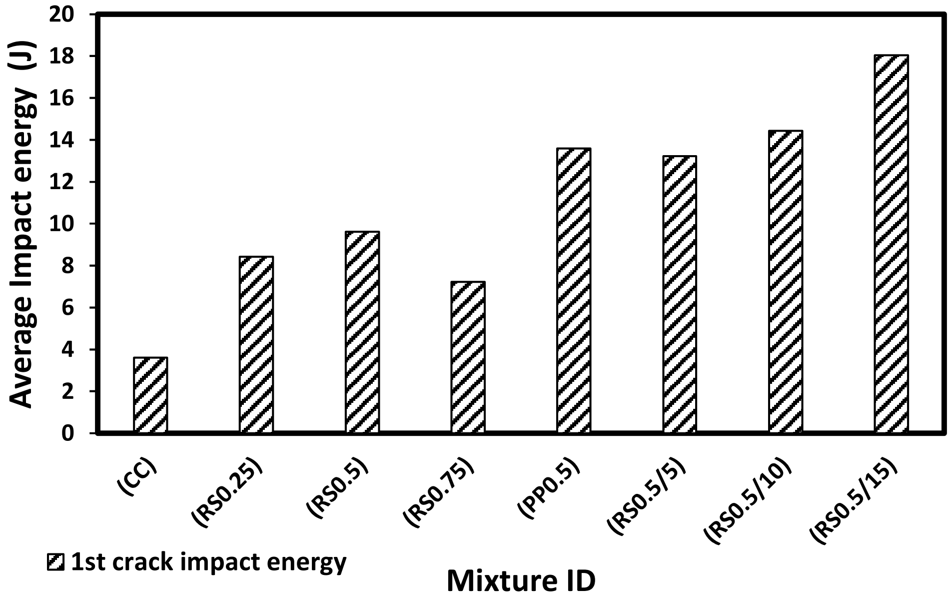


**Figure 8.** Sustained impact energy up to first crack.

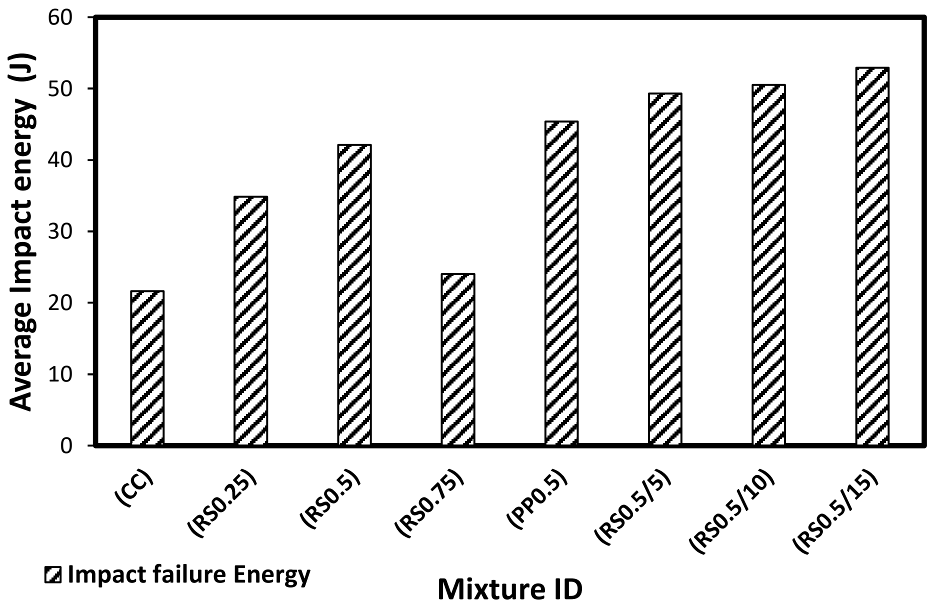


**Figure 9.** Sustained impact energy up to fracture.

On the other hand, the silica fume addition led to a general enhanced performance of concrete specimens under impact load. As illustrated in Figure 8, the sustained impact energy up to first crack with 5%, 10%, and 15% silica fume addition was increased by about 72.7%, 75.3%, and 73.8%, respectively, compared to control specimen. Similarly, as demonstrated in Figure 9, the sustained impact energy up to failure by 5%, 10%, and 15% silica fume addition was enhanced by about 56.1%, 57.2%, and 56.8% relative to control specimen, respectively.

The enhanced impact energy of the silica-fume-tested specimens can be attributed to the pozzolanic activity of silica fume material, which enhances the concrete performance under different loading regimes.

### *3.6. Linear Attenuation Test*

#### 3.6.1. Gamma Ray Results Analysis

The results for the gamma ray attenuation test at 28 days duration are shown in Figures 10 and 11. Each mixture generally had a different thickness of 2, 4, 6, 8, and 10 cm. The attenuation capability of all specimens was evaluated at 1332.51 KeV and 1173 KeV energy. It was observed that the effect of increasing rice straw fiber content in concrete specimens created a slight to non-existent increase in attenuation efficiency from 4 cm to 10 cm thickness, while a noticeable effect was achieved at smaller thickness.

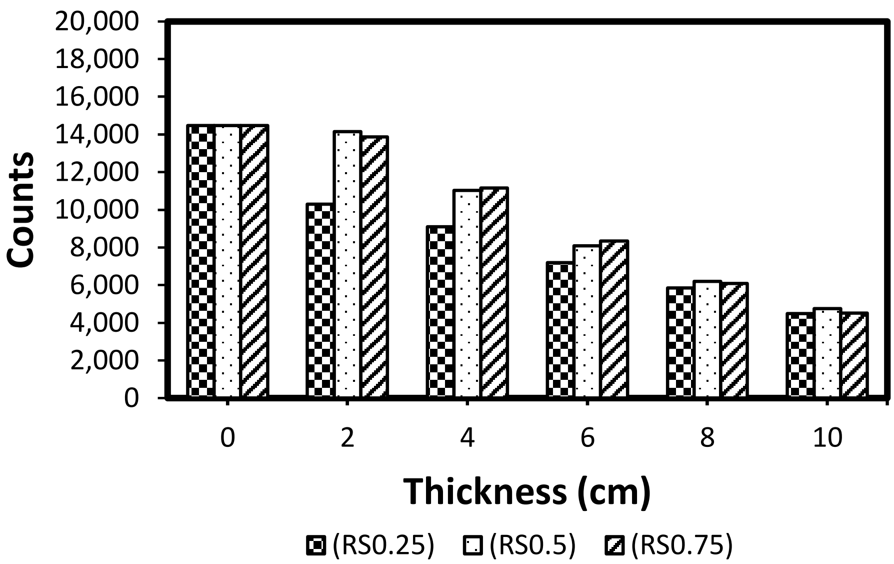


**Figure 10.** Net counts for gamma radiation energy of 1332 KeV.

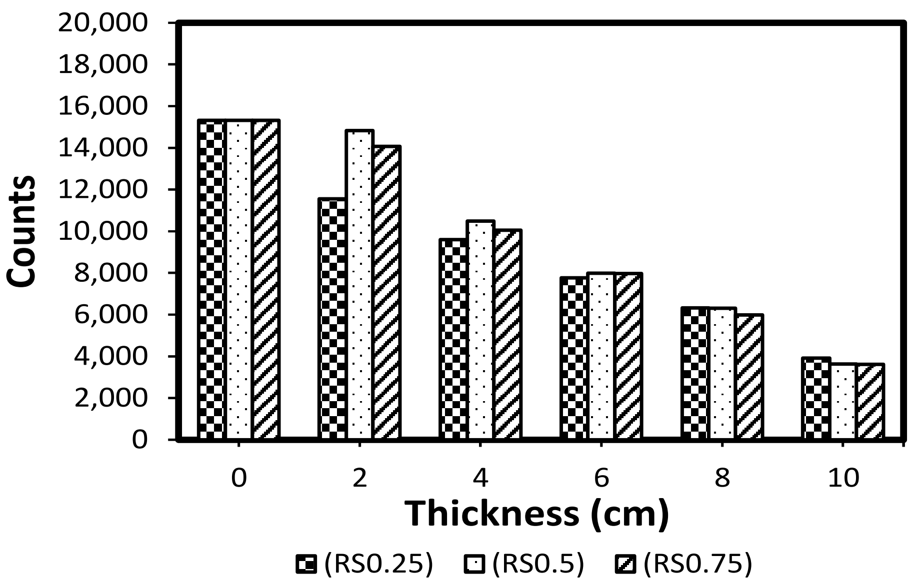


**Figure 11.** Net counts for gamma radiation energy of 1173 KeV.

For instance, regarding the energy of 1332 KeV, as shown in Figure 10, the mixtures containing rice straw with volume fraction of 0.25% recorded the range of 11,547.75 net counts at 2 cm to 3923 net counts at 10 cm thickness. Likewise, the mixture containing rice straw fiber by 0.5% volume fraction showed a slight increase in attenuation efficiency from about 2.2% at 2 cm thickness up to 7% at 10 cm thickness at a 28-day curing period. Furthermore, increasing the volume fraction of rice straw fibers to 0.75% (RS0.75) showed an increase in the attenuation efficiency from about 7.9% at 2 cm thickness to 8% at 10 cm thickness.

Similarly, regarding the energy of 1173 KeV, the mixtures containing rice straw fiber by volume fraction of 0.25% recorded the range of 10,295 net counts at 2 cm to 4482 net counts at 10 cm thickness as shown in Figure 11, while the mixture containing 0.5% volume fraction showed an increase in attenuation efficiency from about 5.2% at 2 cm to 7.6% at 10 cm thickness at 28 days maturity age. Furthermore, increasing the volume fraction of rice straw fibers to 0.75% (RS0.75) showed a slight increase in the attenuation efficiency from about 5.7% at 2 cm to 0.7% at 10 cm thickness during the same curing period. The aforementioned results reflect the efficiency of utilizing rice straw fiber in plaster applications (up to 2 cm thickness) rather than in structural concrete production, as illustrated in Figures 10 and 11.

### 3.6.2. Neutron Radiation Results Analysis

As shown in Figure 12, the mixtures containing rice straw fiber by volume fraction of 0.25% recorded the range of 1136.667 net counts at 2 cm to 841 net counts at 10 cm thickness, while the mixture containing 0.5% volume fraction showed a reduction in neutron attenuation efficiency from about 7.7% at 2 cm to 1.83% at 10 cm thickness over the 28-day curing period. Similarly, increasing the volume fraction of rice straw fibers to 0.75% showed a further decrease in neutron attenuation efficiency from about 10.6% at 2 cm to 1.14% at 10 cm thickness at the maturity age of 28 days. The neutron attenuation capability showed more efficiency at large thicknesses (10 cm) rather than at smaller thicknesses, as illustrated in Figure 12.

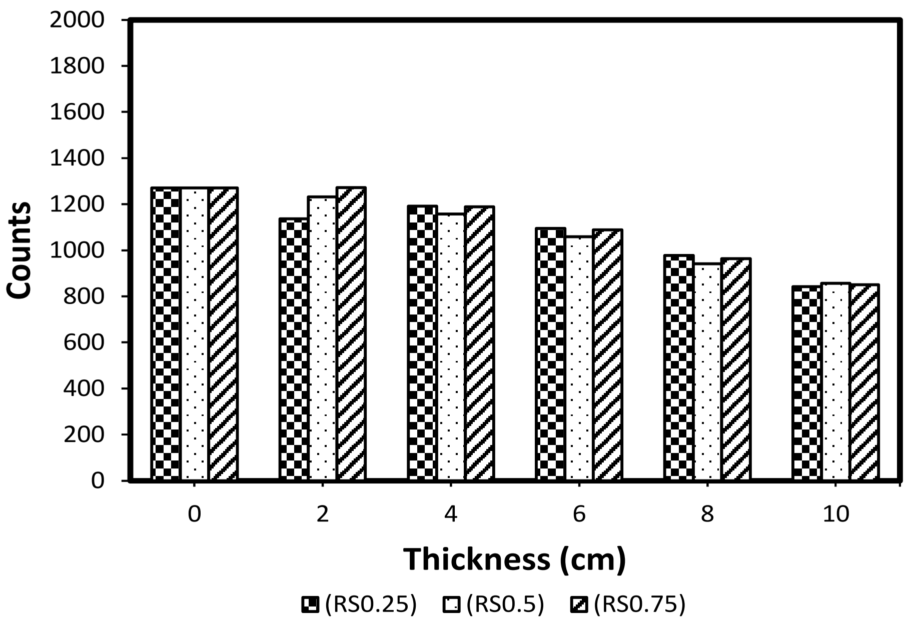


**Figure 12.** Net counts for neutral radiation.

## 4. Conclusions

Based on the current research, a summary of outcomes is drawn as follows:

- Replacing heavyweight concrete constituents with lightweight rice straw fibers led to a slight reduction in the unit weight of tested specimens of up to 1.8%, while incorporating silica fume in concrete manufacturing generally increased the concrete's unit weight by up to 0.98% compared to normal concrete.
- A slight to non-existent increase of up to 7% in compressive strength was observed due to rice straw and PP fiber addition; however, silica fume addition led to enhanced compressive properties of up to 30% at the rate of 15% addition by cement weight.

- Enhanced tensile and flexural properties of up to 17.1% and 25.8% were achieved, respectively, owing to rice straw fiber addition, which was attributed to the crack control capability of the utilized fiber.
- A superior dynamic performance was achieved by incorporating rice straw fiber in concrete production. The sustained impact energy up to first crack and failure were enhanced by about 62.5% and 48.6%, respectively, relative to conventional concrete due to the fiber–matrix interfacial bond, which improved the load transfer across cracks, thus enhancing the overall impact load-carrying capacity of rice straw concrete.
- Although the usage of polypropylene fiber improved the performance of concrete statically and dynamically compared to rice straw fiber, the latter generally achieved superior performance compared to normal concrete, which reflects the applicability of utilizing such natural waste materials as a contender with PP fiber in concrete manufacturing.
- The attenuation test demonstrated the effectiveness of using rice straw fiber concrete as radiation shields against gamma rays. The gamma ray attenuation capability was enhanced by about 7.9% owing to rice straw fiber incorporation compared to normal concrete shields at different energy levels.
- Generally, the rice straw fiber addition in concrete did not show a significant effect on the neutron attenuation capability of such shields.
- Among all tested specimens, the concrete shield which incorporated rice straw fiber of 0.5% by volume fraction and 10% silica fume by cement weight acquired the best performance under different loading regimes.

The outcomes of the current study pave the way for future applications utilizing such natural by-product fibers in reinforced concrete, such as concrete shelters, nuclear reactors, hospitals, radiation device storage, and radiation shielding facilities.

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