Compressive behavior of rice straw-reinforced concrete for rigid pavements

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Abstract. Micro-shrinkage cracking in concrete is normally observed at early stages. The cracking increases with the passage of time and affects the serviceability. The micro-shrinkage cracking can be avoided if its initiation is controlled by use of fibers. The utilization of natural fibers gains popularity in developing countries, including Pakistan, where vast resources of natural fibers are available as by-products with a low economic use. This paper primarily focuses on the utilization of locally available rice straw in concrete for rigid pavement application. The compressive behavior of rice straw-reinforced concrete (RSRC) is explored as per ASTM standard. The mix proportion of 1:2:4:0.6 (cement, sand, aggregate, and water, respectively by their weight) is considered for plain cement concrete (PCC) which is taken as reference. For RSRC, the length and content of rice straw are 25 mm and 1% (by wet volume weight), respectively. In addition to compressive strength, elastic modulus, absorbed energy, and toughness index of PCC and RSRC are experimentally determined and compared. The modulus of rupture is determined through empirical relation. Rigid pavements for PCC and RSRC are designed and compared using these parameters. The proposed rigid pavement design is discussed in detail.

1. Introduction
In the last few decades, fiber-reinforced concrete is studied by many researchers. As early as 1900, the asbestos fiber was firstly used in concrete [1]. Nowadays, the used fibers are either in chopped or long form in structural members of concrete such as slabs, beams, canal lining and pavements. The use of fibers in concrete increases the flexural strength, abrasion resistance, fatigue resistance and reduce the thermal cracking with drying shrinkage [2]. Rigid pavements are normally recommended because of their relatively longer service life as compared to flexible pavements and provides high-performance when subjected to traffic loading. Problems like uneconomical rigid pavement projects due to expensive constituents of concrete and similarly, deviation between experimental works including casting procedures in design laboratories leads to pre-mature distresses causing early age micro-cracking [3]. At early stages of concrete maturity, the micro shrinkage cracking is observed. The cracking increases with the passage of time and affects the serviceability of pavement, which can be reduced by use of natural fibers. Fibers amend the properties of composites and provide bridging behavior across the crack resulting the post-cracking toughness and residual strength to composites [4].

Fibers are frequently used in the concrete to resist the cracking due to the early age shrinkage and drying shrinkage [5]. Micro cracking creates before the structure is subjected to loading after drying shrinkage and different reasons for change of volume [6]. The fiber content used in the range of 0-1%
shows better results including flexural and abrasion value [7]. There is need to discover flaws of the rigid pavements, including poor construction practice and many more are evaluated in developing countries and to minimize them by using sustainable material and techniques. The fiber addition in concrete is to improve the capability of energy absorption and to resist the crack of the concrete [8]. The foremost role of fibers in composites is to make a bridge action, which controls the crack initial propagation and which leads to support more post-cracking resistance. From the last few decades production and availability of natural fibers showing physical properties are determined by various researchers in their study of work which shows the potential of the fibers to be used as construction material. The natural fibers that are used in applications of civil engineering include coir, sisal, sugarcane, bamboo, jute, palm, hemp, pineapple leaf, hair, wheat straw [5, 8-14]. The utilization of natural fibers can lead towards the sustainable development [15, 16]. In agrarian countries natural fibers are cheap and locally available which has very less economic use. Hence, its use as a construction material costs a very little, in fact almost nothing when compared with the total cost of composite. In this way, huge savings can be made by using natural fibers. Fibers are frequently used in the concrete to resist the cracking due to the early age shrinkage and drying shrinkage [5]. The joint spacing can also be increased by the use of fiber reinforced concrete [2].

To the best of author’s knowledge, rice straw is not used for pavement applications. The natural fibers examined in pavement application are hair fiber, wheat straw and sugarcane bagasse by Patel, an Farooqi and others [13, 17, 18]. Compressive and flexural stresses are produced in rigid pavements. The modulus of rupture and elasticity are the two leading factors which affect the rigid pavement thickness design [19]. The main objective of the research is to utilize available local natural fibers and to design rigid pavements for more economic and durable construction practices. Rigid pavement thickness can be decreased by increasing flexural strength and that of modulus of elasticity in equation available in AASHTO guide (1993) [20] while keeping remaining parameters constant. The ACI relationship to calculate the modulus of elasticity using compressive strength is recommended by AASHTO guide. Pavement thickness is not affected by the elastic modulus. Hence, the latter is calculated by using compressive strength as recommended by ACI.

2. Experimental

2.1. Raw materials
Rice straws are taken out from agricultural remains which are usually burnt after extraction of rice and rice husk. Raw fiber of rice straw is taken from the nearby source. The materials that are used in study are ordinary Portland cement with locally available aggregates, sand, and rice straws were used. Potable water is used for boiling water treatment to remove impurities.

2.2. Preparation of rice straw
The fiber with variable diameter is observed with split into smaller fibers at one end. These fibers are not taken in study while the selection of fiber is done by naked eye and the fibers are cut into an approximate length of 25mm (1-inch). Different researchers have adopted several approaches to increase the bond strength by improving the fiber surfaces. This pre-treatment requires physical and chemical modifications. Therefore a simple pre-treatment was used for coconut fiber in the study of Ali and Chouw [21]. The rice straw is dipped in boiling water for 15 –20 min interval and water is changed three times until the color of the water is clear and fibers are clean from impurities. These fibers are named as treated fibers and are shown in figure 1.
2.3. Mixing and casting procedure

For production of PCC and RSRC the locally available natural fiber, coarse and fine aggregates, Portland cement including water are used. Aggregate having maximum size of 20mm is used after sieve analysis. The mix design ratio of the plain cement concrete is 1:2:4:0.60 for cement, sand, aggregates and water by their weight. Water ratio in mix design is kept high. The reason for higher water ratio is to make the concrete workable because natural fibers absorb water and will cause reduction in water content. The fibers added in related mix design using fiber length of approximately 25 mm while fiber content of 1% by wet volume weight of concrete is used to prepare RSRC. For preparation of concrete all the constituents are added in concrete drum mixer for mixing. Water is than added in concrete drum mixer and revolved for about four to five minutes. After the proper mixing process, specimens are casted. The slump cone test is executed rapidly as per ASTM regulations C143 and C143M-15a before filling molds. The constituents are added in one-third layer of mix design of RSRC. Initially coarse aggregates, sand, rice straw and cement are added in concrete mixer, in form of layers by one-third of their volume. The same methodology is opted for additionally adding coarse aggregates, sand, rice straw and cement into the concrete mixer. The concrete mixer is revolved for about three to four minutes after the addition of two-third of the water in concrete mixer. The remaining water is poured into the concrete drum mixer and revolved again for about three additional minutes. The adding of more water present in composite might increase bleeding of RSRC mix. For the preparation of RSRC composite sample is cast in three layers and the 25 blows are required for compaction. For the removal of voids and for self-densification of RSRC mixture, the height of samples in the mold is increased up to 15-20cm, until its collapse. The specimens of RSRC is demolded and immersed into water for curing for almost 4 weeks (28 days).

The value for slump and compaction factor of concrete mix with water to cement ratio of 0.60 is decreased but, as predicted, slump and compaction factor of the FRCs is less than the concrete mix because of fiber presence. The slump value was noted to be 1-inch and 0.25-inch for PCC and RSRC, respectively. The compaction factor was computed as 0.88 and 0.82 for PCC and RSRC, which shows less workability of rice straw-reinforced concrete.

2.4. Specimens

All cylinders are casted having the specimens of 100 mm diameter, 200 mm height used for the preparation of samples for splitting tensile and compressive strength cylinders are formed. A total of three cylinders are cast for each PCC and RSRC.

2.5. Testing of composites

Compressive strength test is conducted on PCC and RSRC in compression testing machine composite as per C39 and C39M-15a of ASTM. Compressive strength and compressive energy gained before the failure and the toughness is determined. For uniform transfer of load the capping of every composite is done by the application of plaster before the test is performed. As per the report of Washington State Department of Transportation [21], the cap thickness and its maximum limit should be 3 and 8mm in any case. The mean capping thickness of composites is approx. 4mm.
3. Results and Analysis

3.1. Density
After testing, a decrease in density of RSRC was observed, as compared to density of PCC. The density of PCC and RSRC were 2318.67 and 2095.25 kg/m³, respectively. The same behavior was observed by the other researchers [22-25]. The decrease in density is primarily due to presence of less density rice straw fibers. The low density of composites results in excessive air voids.

3.2. Compressive behavior
The compressive strength is determined using stress-strain curve. For compressive strength calculation it is taken as the maximum value against the stress-strain curve. Under the own peak load of PCC and RSRC specimens, the first crack was appeared at 82 and 58%, respectively. The compressive strength test is conducted on specimen of PCC and RSRC after 28 days of curing. The stress-strain curve is shown in figure 2a.

![Stress-Strain Curve](image)

**Figure 2.** Mechanical behavior of RSRC: a) stress-strain; b) crack propagation under compressive load.
In the specimen of PCC, the first crack length and width were larger than those of RSRC. The initial crack lengths in PCC and RSRC were 0.5 and 0.3 cm, respectively.

3.3. Compressive parameters
The total absorbed energy is calculated using the area under stress-strain curve. It is taken as the sum of the maximum energy absorbed up to maximum stress and energy absorbed after maximum stress. The results are shown in Table 1. Compressive toughness of composite can be calculated using the stress strain curve of the compressive strength. The ratio between the total compressive energy absorbed up to the peak stress energy absorbed (i.e., total compressive energy absorbed / compressive absorbed energy before max. stress) is taken as toughness of compression. The results are shown in Table 1.

The RSRC showed the better inter locked behaviour while, the pieces of PCC specimen were broken during testing. This shows the ductile behaviour of rice straw reinforced concrete.

| Specimen | Compressive Strength (MPa) | Corresponding Strain (ϵ) | Energy up to max stress (MJ/m³) | Energy after max stress (MJ/m³) | Total absorbed energy (MJ/m³) | Compressive Toughness (Ϭ/ϵ) |
|----------|---------------------------|--------------------------|-------------------------------|-------------------------------|-----------------------------|---------------------------|
| PCC      | 16.78                     | 0.024                    | 0.13                          | 0.01                          | 0.14                        | 1.07                      |
| RSRC     | 11.69                     | 0.018                    | 0.19                          | 0.07                          | 0.26                        | 1.36                      |

4. Discussion
Two important factors namely modulus of rupture and elasticity plays important role in thickness design of concrete pavement and these are also utilized by the AASHTO guide [19]. The concrete elastic modulus can be determined via the correlation recommended by the American Concrete Institute (ACI) in AASHTO Guide [19]. Since pavement thickness is not affected by the elastic modulus, the latter can be derived via compressive strength as follows:

\[ E_c = 57,000 (fc')^{0.5} \]

where \( E_c \) represents concrete elastic modulus in psi, while \( fc' \) represents the compressive strength of concrete in psi. Modulus of rupture can be calculated by the empirical relation for conventional concrete given in Table 2, while Table 3 shows the thickness design comparison of PCC and RSRC. The relation used in this study is from ACI (1997), i.e. \( fr = 0.94fc^{0.5} \).

Table 2. Empirical relations between compressive and flexural strength values.

| Reference                     | Equation       |
|-------------------------------|----------------|
| Ahmed et al. (2008)           | \( f_{min} = 0.68fc^{0.5} \) |
| Selim (2008)                  | \( fr = 0.034 fc^{1.286} \) |
| Legeron and Paultre (2000)    | \( f_{avg} = 0.94fc^{0.5} \) |
| ACI Committee 363 (1997)      | \( fr = 0.94fc^{0.5} \) |

Rigid pavement thickness can be decreased by increase of modulus of rupture and modulus of elasticity in equation available in AASHTO guide (1993) [20], while keeping remaining parameters constant. The ACI relationship to calculate the elastic modulus using compressive strength is recommended by AASHTO guide (1997) [20].
Table 3. Thickness design of composite road via the AASHTO equation*.

| Specimen | Modulus of rupture (Sc’) (MPa) | Compressive strength (MPa) | Elastic modulus (Ec’) (GPa) | Thickness (mm) |
|----------|-------------------------------|---------------------------|-----------------------------|---------------|
| PCC      | 3.849                         | 16.77                     | 19.38                       | 263.398       |
| RSRC     | 3.214                         | 11.69                     | 16.18                       | 287.274       |

*In the AASHTO equation, k = 72 psi/in, R = 95, ZR = 1.64, Po = 4.2, Pt = 2.5, So = 0.30, J = 3.2, ΔPSI = 1.7, Cd = 1, and W18 = 5100,000.

5. Conclusion

The compressive behavior of plain cement concrete (PCC) and treated rice straw-reinforced concrete (RSRC) in rigid pavements are explored for possible applications especially for developing countries. On the basis of conducted study, the following conclusions are made:

- Compressive strength of RSRC is decreased by 30.3%, as compared to PCC.
- The elastic modulus of RSRC is decreased by 16.5%, as compared to that of PCC.
- There is an increase of 46.1% in total energy absorption by RSRC, as compared to that of PCC.
- The compressive toughness index is increased for RSRC by 21.33%, whereas RSRC and PCC showed a bridged and brittle behavior, respectively.
- The density of RSRC is decreased by 14.26 pcf, as compared to that of PCC.
- The pavement thickness is increased by 8.3% using rice straw by empirical relation. The actual modulus of rupture needs to be determined, which may result in variation with empirical relation because of post-cracking behavior.

Based on above results, it is concluded that rice straw reinforced concrete for applications of rigid pavement due to its post cracking behavior has the potential to be used as construction material. The results discussed here are based on limited scope using empirical relation. More detailed investigations need to be performed specially for modulus of rupture, which plays a vital role in the pavement design. The outcome of the study seems favorable due to post-cracking behavior, which demands a detailed investigation for economical design with a better performance.

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