Effect of Fibre Content on Compressive Strength of Wheat Straw Reinforced Concrete for Pavement Applications

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Abstract. Many studies have been carried out on natural fiber reinforced concrete for the different civil engineering applications. Wheat Straw Reinforced Concrete (WSRC) is recently studied for pavement applications which resulted in improved toughness. This will ultimately help in reducing the micro-shrinkage and fatigue cracking in rigid pavements. The overall aim of the research program is to improve the rigid pavement construction techniques by using locally available natural fibres. In this work, compressive strength of WSRC is investigated experimentally by varying fiber contents i.e. 1%, 2% and 3%, by mass of wet concrete. The properties of WSRC are compared with that of Plain Concrete (PC). The compressive behavior, strength, energies absorbed and toughness indices of PC and WSRC are determined and discussed. It is observed that, under the compressive loading, the fragments of PC specimen are chipped off while in WSRC specimen only cracks are formed. It is concluded that compressive toughness index of WSRC is 71% more than that of PC. Based on the conclusions made, WSRC shows favorable results, therefore, future recommendations are to focus on optimization and durability of WSRC.

1. Introduction
Concrete pavements have longer structural life and superior durability as compared to asphalt pavements due to which their use in developing countries has been grown over the past decade [1]. However, its more extensive use is still prevented due to its higher initial cost, mainly due to cost of cement and reinforcement. Moreover, plain concrete (PC) is inherently a brittle natured material having low strain capacity and tensile strength. Therefore, the fatigue failure can potentially be exhibited at more locations in concrete pavements due to the combination of built-in temperature curl, moisture gradients, temperature gradients, and drying shrinkage, as pavements are directly exposed to environmental conditions [2]. It has been long recognized that energy absorption capacity of PC can be enhanced by the addition of fibres [3, 4]. Fibres have been used to strengthen the brittle matrices since Biblical times; for example, horsehair and straw was mixed with clay to form bricks and floors. For the first time in modern technology, Romualdi [5] proposed the steel fibres as dispersed reinforcement for concrete. Effect of artificial fibres in concrete, for rigid pavements, has been investigated by many researchers [6] which resulted in improved properties of concrete. Considerable efforts have been made for using different natural fibres in last few decades. As natural/vegetable fibres are cheap and available in abundance in tropical and sub-tropical regions.
Hence, it costs a very little as compared to the artificial/steel fibres. Natural Fibre Reinforced Concrete is comparable with Artificial Fibre Reinforced Concrete (AFRC) and Steel Fibre Reinforced Concrete (SFRC) for various civil engineering applications [7]. Natural fibres have already been investigated for concrete pavement applications with the limited scope [8, 9]. Results showed that natural fibres have the potential to be used as reinforcement in rigid pavements. However, the durability of natural fibres is still questionable till today. So, the application of natural fibres in the construction industry is still quite limited [10]. The overall aim of the research program is the development of economic and durable design and/or construction techniques for new rigid pavements by using locally available natural fibres in concrete. Wheat straw has been selected to start with. As a part of ongoing research project, the effect of fibre content on compressive strength of WSRC is intended for the pavement applications.

2. Experimental Methodology

2.1 Raw materials
Ordinary Portland cement of a local company, fine and coarse aggregates from the Margalla crushes in Pakistan, and portable water were used for preparing PC. Wheat straw were extracted from the agricultural residues of wheat crop in the surrounding region during the time of wheat cultivation. The locally available wheat straw were prepared after dipping in water for 15–20 minutes. These prepared straw were named as natural wheat straw.

2.2 Mix proportion and casting methodology
The mix proportion of PC and WSRC was 1:2:4 (cement: sand: aggregate) with a water – cement ratio of 0.55 and 0.60, respectively. Straw having varying lengths of approximately one inch and contents of 1%, 2% and 3%, by mass of wet concrete, were considered to make Wheat Straw Reinforced Concrete (WSRC). For preparing PC, all materials were put in the drum mixer along with water. The mixer was rotated for a period of five minutes. At that stage, the homogenous and workable PC mix was formed. All PC mix was taken out of the mixer. Whereas, for WSRC, half of PC mix was taken and weighed and then, put it again in the mixer. Straw (as per considered content) were added in the mixer and the mixer was again rotated for one-minute period. The mix was not seemed to be homogenous and workable at that stage. A small increment of 0.05% in the water-cement ratio (i.e. 0.55% initially) was made. Then, the mixer was started again to rotate for a period of three minutes to have the better mix. The mixing time was increased because at that stage, the further addition of water could have been resulted in bleeding of WSRC. Therefore, the increased water – cement ratio by only 0.05% and increased mixing time of 4 minutes came out to be a successful approach for a workable WSRC. It may be noted that it was relatively easy to fill moulds with WSRC having 1% content compared to WSRC having 2% and 3% contents. However, moulds were filled with WSRC having 2% and 3% contents with little difficulty i.e. lifting and dropping were made relatively more.

The mix was poured into the moulds in three successive layers for preparing WSRC specimen. After having compaction of each layer by 25 blows of tamping rod, the mould was lifted up to approximately 100-150 mm and dropped freely on the floor for removing air voids from WSRC mix and for self-compaction. All specimen were de-moulded after 24 hours and were kept for curing of 28 days in water tank before testing.

2.3 Specimen
PC and WSRC cylinders having dimensions of 100 mm diameter and 200 mm height were prepared for compressive strength tests. Labels PCC, A1, A2 and A3 were used for PC, WSRC with 1% content, WSRC with 2% content and WSRC with 3% content, respectively. Alphabets along with labels show the number of sample for each specimen. A total of 8 cylinders were cast. Average of two readings was taken for every property.
2.4 Testing methods
ASTM C39 standard was used to perform the compressive strength test on PC and WSRC specimen. Cylinder test specimen were tested after 28 days of curing to determine the compressive behavior, compressive energies absorbed, compressive energies absorbed up to the maximum load, compressive energies absorbed post the maximum load and compressive toughness indices of PC and WSRC.

3. Results and Analysis

3.1 Compressive behavior
Figure. 1 shows the load-time curves for PC, WSRC-1%, WSRC-2% and WSRC-3%. The noticeable thing is that the ascending side of WSRC-1% curve is comparatively less steep than that of PC. However, the WSRC cylinders bear the load over more time period. In spite of the fact that the curves for WSRC-2% and WSRC-3% are more flattened and bear less load, but even then, these are showing the tough behavior due to the presence of straw. The tested cylinder specimen of PC, WSRC-1%, WSRC-2% and WSRC-3% are shown in Figure 2. The fragments of PC specimen are broken, whereas, only cracks are observed in WSRC specimen. This shows the sewing effect and tough nature of WSRC due to the presence of straw.

![Figure 1. Compressive load – time curves for (a) PC, (b) WSRC-1%, (c) WSRC-2%, and (d) WSRC-3%](image)

![Figure 2. Tested specimen of (a) PC, (b) WSRC-1%, (c) WSRC-2%, and (d) WSRC-3% under compressive loading](image)

3.2 Compressive strength, compressive energies absorbed and compressive toughness index
Compressive strength (Ϭ) is taken from the maximum load of load – time curve of Figure 1. The area under load – time curve up to the maximum load is taken as the compressive energy absorbed up to the maximum load (CEM). The area under load – time curve from the maximum load up to the failure is taken as the compressive energy absorbed post the maximum load (CEP). The total area under load – time curve is calculated for measuring the compressive energy absorption (CE). The compressive toughness index (CTI) is ratio of compressive energy (CE) to the compressive energy absorption up to the maximum load (i.e., CE/CEM). Ϭ, CEM, CEP, CE, and CTI of PC, WSRC-1%, WSRC-2% and WSRC-3% are shown in Table 1. The Ϭ of WSRC-1%, WSRC-2% and WSRC-3% are decreased by 14%, 27% and 37%, respectively, when compared to the Ϭ of PC. Although, the Ϭ of WSRC specimen is decreased, but the CE of WSRC-1%, WSRC-2% and WSRC-3% are increased by 136%, 103%, and 64%, respectively, which shows the tough behavior due to the presence of dispersed straw. Here, it can be observed that almost 63% of total energy is absorbed by WSRC-1% after the maximum load, whereas, in case of PC, only 38% of the total energy is absorbed after the maximum load. Furthermore,
due to this sewing effect, an increase of 71%, 7% and 9% in CTI of WSRC-1%, WSRC-2%, and WSRC-3% is observed as compared to that of PC.

Table 1. Compressive strength, compressive energies absorbed and compressive toughness index of PC, WSRC-1%, WSRC-2%, and WSRC-3%

| Specimen   | $\sigma$ [MPa] | CEM [kN.s] | CEP [kN.s] | CE [kN.s] | CTI          |
|------------|----------------|------------|------------|-----------|--------------|
| PC         | 2.06           | 937        | 575        | 1512      | 1.61         |
| WSRC-1%    | 1.77           | 1296       | 2272       | 3568      | 2.75         |
| WSRC-2%    | 1.50           | 1771       | 1293       | 3064      | 1.73         |
| WSRC-3%    | 1.30           | 1408       | 1070       | 2478      | 1.76         |

The comparison of $\sigma$, CEM, CE, and CTI of PC, WSRC-1%, WSRC-2% and WSRC-3% are shown in Figure 3. In spite of the fact that the $\sigma$ of WSRC-1% is decreased up to some extent but as a whole, WSRC-1% behaves well as compared to all tested matrices.

4. Discussions

The cracks are usually observed in pavements at very early stage. These cracks are more likely to propagate as pavements endure dynamic loading. Previous studies show that, with addition of fibres, the energy absorption capacity of concrete can be enhanced [4]. Hence, the straw’s sewing effect in the concrete can resist the crack propagation, ultimately increasing its energy absorption capacity. The tested matrices with 2% and 3% straw content show a slight improved behavior in energies absorption and toughness indices when compared to PC but at the same time, a significant decrease in compressive strength is observed. This might be due to the less compaction or improper mixing of the matrices due to the more content. Among tested matrices, WSRC-1% behaves well in terms of improved CEM, CE, and CTI in spite of comparable $\sigma$ (even on lower side) in comparison with that of PC. So, it is likely that rigid pavements with WSRC-1% would behave better than pavements with PC.

5. Conclusions

The compressive behaviors of plain concrete, wheat straw reinforced concrete with 1% content, wheat straw reinforced concrete with 2% content, and wheat straw reinforced concrete with 3% content are investigated for possible applications in rigid pavements. Following conclusions are made on the basis of conducted study:

- Compressive strengths of WSRC-1%, WSRC-2% and WSRC-3% are decreased by 14%, 27% and 37%, respectively, when compared to the compressive strength of PC.
- An increase of 136%, 103%, and 64% is observed in the total energies absorbed by WSRC-1%, WSRC-2% and WSRC-3%, respectively, when compared to the energy absorbed by PC.
- CTI of WSRC-1%, WSRC-2% and WSRC-3% is increased by 71%, 7% and 9%, when compared to the CTI of PC. WSRC-1% shows the bridged behavior, whereas, PC shows brittle behavior.

So, it can be claimed that wheat straw reinforced concrete has the potential to be used for pavement applications due to its better post-cracking behavior. WSRC-1% behaves very well among all other tested matrices. Being an initiative study, the results discussed here are based on limited testing and analysis, the outcome seems favorable which demands for a detailed investigation focusing on optimization of materials and durability.

6. Acknowledgment
The authors would like to acknowledge all the organizations and persons who helped them during the research, particularly Mr. Muhammad Khalid and Mr. Muhammad Junaid for their kind help during lab work. The authors would also like to gratefully acknowledge the anonymous reviewers for the careful review and constructive suggestions.

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