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Effectiveness of hair and wave polypropylene fibers for concrete roads

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HIGHLIGHTS

- Hair and wave polypropylene fiber reinforced concrete (FRC) are evaluated.
- Properties of FRC are compared with that of plain control mix.
- HFRC and WPFRC properties are improved up to 19.1% and 21.5%, respectively.
- Application of FRC in concrete road is considered.
- Cost saving (per lane per km) up to 3% can be made along with better performance.

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ABSTRACT

Human hair fibers are abundantly available as waste and wave polypropylene fibers are commercially available. These fibers are studied with limited scope from only material point of view. In this study, the mechanical properties of hair fiber reinforced concrete (HFRC) and wave polypropylene fiber reinforced concrete (WPFRC) are explored for its possible applications in concrete roads. The properties are experimentally evaluated as per ASTM standards and the effectiveness of fibers in concrete are checked by comparing with that of control mix. In addition, by using the relevant properties, concrete road design is also compared. It is found that the compressive, flexural and splitting-tensile strengths of HFRC are improved by 12.4%, 16.2% and 19.1%, respectively, and that of WPFRC are increased by 11.7%, 21.5% and 17.5%, respectively. With these improvements, the thickness of concrete road for a particular studied loading condition can be reduced by 12.5 mm. This can result in cost saving (per lane per km) of 3% and 1.7% by use of HFRC and WPFRC, respectively. The performance of concrete road is also expected to be better because of improved toughness of HFRC and WPFRC.

1. Introduction

A concrete road provides high-performance, comfortable, cost effective and an efficient design choice [1]. In the last few decades, many researches have investigated the mechanical performance of fiber reinforced concrete (FRC) for pavements [1–5]. The fibers can significantly improve toughness of the cement matrix, tensile strength, durability, and impact resistance [4]. The main role of fibers in composites is bridging action which controls propagation of cracks and leading to more post-cracking resistance [5]. Besides an interesting construction material, FRC appears to be a very attractive concrete road matrix [1]. Concrete roads pavements are less susceptible to surface distress, for example raveling and potholes as compared to those of flexible pavements. Thus it can be considered in streets with continuous use by vehicles, including open transport, trades, side avenues with frequent stacking/emptying exercises in mechanical zones and auto parks. Concrete roads pavements are more durable than flexible pavements and require minimum maintenance requirements. Modulus of elasticity and shear modulus of concrete are much greater as compared to bituminous materials. Due to braking forces and heavy vehicular loading, flexible pavements are defenseless against numerous deformities, i.e. pushing, rutting, folding and slipping breaks. As compared to flexible pavements, concrete roads pavements are stronger over overwhelming braking zones, similar to carriageways at street junctions and at sharp bends. Both compressive and flexural stresses are produced in concrete pavements under vehicular loadings. As compared to flexural strength, compressive stresses are too small and hence have less influence on slab thickness design. Ratios of flexural stress to flexural strength are much higher, often exceed value of 0.5. Therefore, flexural stresses and

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List of notations

ACPA	American Concrete Pavement Association
C: S: A	cement: sand: aggregate
C-E	compressive absorbed energy up to the peak load
CEA	compressive energy absorbed after crack
CEB	compressive energy absorbed before crack
C-LTC	compressive load-time curve
C-S	compressive strength
T_C	compressive toughness
CM	control mix
FAA	Federal Aviation Administration
FRC	fiber reinforced concrete
F-E	flexural absorbed energy up to the peak load
FEA	flexural energy absorbed after crack
FEB	flexural energy absorbed before crack
F-LTC	flexural load-time curve
T_f	flexural toughness
HFRC	hair fiber reinforced concrete
HF	hair fibers
ITZ	interfacial transition zone
MoE	modulus of elasticity
MoR	modulus of rupture
PP	Polypropylene
S-E	splitting-tensile absorbed energy up to the peak load
SEA	splitting-tensile energy absorbed after crack
SEB	splitting-tensile energy absorbed before crack
S-LTC	splitting-tensile load-time curve
S-S	splitting-tensile strength
T_S	splitting-tensile toughness
WPFRC	wave polypropylene fiber reinforced concrete
WPF	wave polypropylene fibers

flexural strength are considered in slab thickness design. Merritt et al. [6] reported that the modulus of rupture and modulus of elasticity are the two main parameters which affect the concrete pavement thickness design. According to basic design equation of slab thickness of concrete pavement by AASHTO [7], the thickness is inversely proportional to modulus of rupture (MoR) and elastic modulus (E_c) of concrete as shown in AASHTO Equation. By improving the mechanical properties of concrete, the slab thickness can be reduced. StreetPave is a mechanistic-empirical procedure based on computed stresses, strains, deflections and empirical performance observations [8]. The design methodology used in StreetPave was taken from the American Portland Cement Association [9,10]. The Portland Cement Association procedure was originally published in 1933 and was updated in 1951, 1966, and 1984. The procedure incorporates mechanistic components (load/stress/deflection) with empirical observations, including results from the AASHTO Road Test, to establish a thickness design. The StreetPave 12 software is provided by American Concrete Pavement Association (ACPA). StreetPave has many inputs required for a thickness design of pavements which include many factors. These are Average 28-day flexural strength, concrete modulus of elasticity, ACI 330 Traffic Spectrums (Category A, Category B, Category C, Category D), Modulus of subgrade reaction, Traffic growth, Average Daily Traffic (ADT) with % trucks or Average Daily Truck Traffic (ADTT), Design life, Design lanes and directional distribution, Traffic category (user-defined, major arterial, minor arterial, collector and residential) and Reliability. The terminal Serviceability input used to calculate the number of ESALs for the asphalt pavement design and is not necessary for concrete pavement design [8]. This software can be used for thickness design calculation of parking lots, sidewalks and bicycle lanes. However, the AASHTO procedure can also be used for thickness design of concrete pavement used for light vehicle load. A reduction in slab thickness results in material savings.

The use of fiber reinforced concretes in concrete roads seeks proper attention. Now a days various fibers are being specified in bridge decks, ultra-thin pavements, thin un-bonded overlays, and concrete bus pads. Such types of concrete pavement are being increasingly used because their performance is excellent. The fiber reinforced concrete (FRC) is composition of small discrete fibers, cement, sand and coarse aggregate [11]. The dynamic and static properties of concrete can be improved by addition of fibers which acts as crack arrestor [12]. If the fiber volume of FRC is low then the mixing practice requires less or no modification compared to that of control mix [13]. Roesler et al. [14] and Altoubat et al. [15] reported that fibers had been used in the construction of concrete pavements and slabs on ground for almost 40 years. Due to addition of fibers, the structural capacity of concrete pavements got increased which helped to reduce the slab thickness [14]. As the performance of FRC in concrete pavements is excellent, so it can also be considered in concrete roads for reduction in thickness. Altoubat et al. [15] reported the simplified method with discrete structural fibers for concrete pavement design. The concrete pavement thickness design method of Federal Aviation Administration (FAA) was used to design slab with reduced thickness by utilizing fibers. An equivalent flexural strength ratio of 30 percent was achieved by choosing the 0.4 percent of synthetic structural fibers by volume of concrete. The result showed that the thickness requirements using structural fibers had been reduced by 17 percent as compared to that of control mix (CM). The effective strength approach for an equivalent flexural strength ratio of 30 percent was successfully run for several other concrete pavement design procedures such as the Portland Cement Association method for airports and AASHTO method which reduced thickness by approximately 15 percent as compared with that of CM thickness requirement.

Human hair can be used as fiber reinforcement because it is strong in tension as reported by Jain and Kothari [16], Ganiron [17], Khansaheb [18], Nila et al. [19] and Kumar et al. [20]. The human hair is dumped as waste in most places, certain kinds of high quality human hair and its products are also traded internationally at large scales. In 2010, India alone exported $\sim$ 1 million kg of human hair and its products worth US $238 million, and total global imports were valued at US $1.24 billion [21]. Therefore, a huge quantity of hair fiber waste is available which can be used in concrete. As an innovation to the field of fiber reinforced concrete, use of human hair as fiber reinforcement has gained its importance. By chemical composition, around 80% of human hair is framed by a protein known as keratin, with high sulphur, which is the characteristic to recognize it from different proteins [22]. Ganiron [17] reported that hair can be utilized as fiber strengthening material in concrete for the various reasons. Hair fiber has a high elasticity which is equivalent to that of a copper wire. Hair is a non-degradable waste, which has the landfill issue, so its utilization as fiber reinforcement in composites can minimize the issue. Addition of hair fiber strengthens the matrix and thus prevent spalling. Kumar et al. [20] performed an experimental study on use of human hair fibers in concrete having a content of 1.0%,