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Effect of polypropylene fibres on bituminous concrete with brick as aggregate

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HIGHLIGHTS

- We present the results of a laboratory study of polypropylene modified bitumen mix.
- First class brick and over burnt brick were utilized as aggregate.
- Pavement design along with basic laboratory tests were carried out.
- Brick aggregates can be suitably used in pavement construction with polypropylene modified bitumen mix.

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ABSTRACT

The need for alternate materials in road construction is increasing due to non-availability of good aggregate in many places. In search of an alternate material in pavement construction, laboratory investigations were done to evaluate the effect of fibre reinforcement on bituminous concrete using brick as aggregates. Properties of the bituminous mix using brick aggregate, both first class brick and over burnt bricks were explored in this study. Resilient modulus, indirect tensile strength tests, and creep tests were carried out on test samples using polypropylene modified bitumen. When 2% fibre was added, the resilient modulus increased by 162% in case of first class brick aggregate and for overburnt brick aggregate resilient modulus increased to 157% when 4% fibre was added. Effect of temperature variations on the resilient modulus, moisture susceptibility, fatigue and rutting tests were also performed to analyze the feasibility of using brick aggregate as a pavement material. This study indicates that the use of polypropylene fibre has improved the properties of brick aggregate bituminous mix thus leading to an efficient pavement alternative.

1. Introduction

In the northeastern part of India, particularly in the state of Tripura, stone aggregates are not easily available, and the required natural stone aggregate is imported from other states to cater the demand of the state, thereby increasing the cost of construction. This extreme shortage of natural stones and the excessive cost of the imported natural stones have accelerated the necessity of finding out locally available materials. The road developers are therefore looking forward to an alternative material which is environment-friendly, energy efficient and cost effective for the construction and maintenance of roads. Brick aggregates, therefore, may be the best alternative here as it is easier and economical to produce by burning earth to the desired forms. Thus, brick aggregate plays a great role in pavement construction in this state due to the scarcity and high price of stone aggregate.

Intending to minimize the dependence on the supply of stone aggregate, it has become essential to inspect the possible applications of alternative materials for the construction of roads as a substitute of stone aggregate. This study focuses on the feasibility of using brick aggregate, both normal and over burnt with fibre strengthening in pavement designing. Polypropylene fibres are widely used in concrete as a reinforcing agent [1–5]. These studies proposed that the polypropylene fibres will make concrete more durable and tough by imparting three-dimensional reinforcements [6,7].

Laboratory studies have proved the efficiency of using fibres for modifying bitumen binders to reduce cracks in the pavement and providing adequate strength [8]. The principal functions of fibres as reinforcing materials are to provide additional tensile strength in the resulting composite and to increase strain energy absorption

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of the bituminous mixtures [9]. It changes the viscoelasticity of the modified bitumen [10], increases dynamic modulus [11], moisture susceptibility [12], and freeze–thaw resistance [13], while reducing the reflective cracking of bituminous mixtures and pavements [8,13,14]. Fibres also tend to bulk the bitumen, so that it will not run off from the aggregates during construction. Thus, adding fibres to bitumen is very similar to the addition of very fine aggregates to it. Thus, fibre can stabilize bitumen to prevent leakage [15]. Many other researchers also proved the advantages of using fibres for reinforcing bituminous mixes [16–21].

Polypropylene fibres provided excellent results for adequate bonding and strengthening of bitumen. Studies showed that the unit weight of the fibre-reinforced specimens is lower than that of plain specimens and the volume of air voids increased with increase in the content of polypropylene fibres along with significant improvement in stability and flow values [22]. Life of the fibre modified asphalt specimens under repeated creep loading at different loading patterns increased by 5–12 times versus the control samples [14]. Another study showed that the polypropylene additive has managed to counteract the effect caused by long-term aging of hot mix asphalt (HMA) [23]. Abtahi et al. (2011) analyzed the dry mixing of fibres with aggregate to bitumen with fibres using Marshall as well as Super-pave method. They blended fibres with aggregates at the optimized dosage of bitumen rather than conventional procedures. The experimental results show that adding polypropylene fibre increases the Marshall stability by 26% and the air voids by 67% while reducing the flow properties by 38% [24]. Reduction in rut depth and an increase in resilient modulus was also observed by the inclusion of fibres at high temperature [25]. Recycled polypropylene was induced into bituminous mixes in Malaysia and the modified mixes showed better stability and workability as compared to the control samples without fibre addition. A reduction in pavement deformations was noted in the study [26]. Adding polypropylene will result in low penetration, widens the plasticity range and improves the binder's load resistance [27]. Another study states that polypropylene modifier produces significant improvement in stiffness of binder which is shown by penetration and softening point tests. Besides, the binders having polypropylene modifier is more viscous than that of the base bitumen which also signifies the stiffening effect of bitumen [28]. The polypropylene fibres were found to increase the Marshall Stability by almost 25%. The fibres were also determined to be effective against rutting at elevated temperatures while the modification was found to increase the Indirect Tensile strength by stiffening the mix at high temperature but however at low temperature, the modification failed to perform effectively [29]. Yeole et al. studied the use of industrial polypropylene waste as a binder additive. Here the authors used wet mixing techniques and dry mixing techniques of mixing polypropylene fibres with bitumen. Results proved that polypropylene reinforcing enhances properties of conventional bituminous mix. According to them, it also reduces the processing cost in the manufacturing of mix design for the wearing course of flexible pavements by improving strength and durability [30]. Many more types of research were also done in this area of asphalt modification with polypropylene fibre and the results proved that polypropylene fibre could be used as an active binder modifier [31–34].

Non availability of good quality of stone aggregate in some of the places is one of the major problems faced by the engineers in the pavement construction. A viable alternative is in high demand in those areas where stone aggregate is less or not available. Many researchers reported that brick aggregate bituminous concrete mixes are suitable for use in the surface courses of bituminous concrete pavements from the standpoints of stability, stiffness and deformation characteristics [35–39]. It was also reported that the bituminous macadam base course with brick aggregate can give satisfactory results when they are constructed using dense grading and proper compaction along with low soaking period [40]. Studies also proved that the over burnt aggregates provide suitable replacement for the stone aggregates as it has comparable strength parameters with the stone aggregates [41].

The objective of the present study is to obtain a suitable bituminous mix with polypropylene fibre using brick as aggregate. Organization of the remainder of this paper is as follows. The following section discusses the experimental program. Section 3 discusses about results and discussions. Section 4 presents the pavement design section from the obtained results. Section 5 concludes the paper by summarizing the main findings of the study.

2. Experimental program

Marshall specimens were prepared in the laboratory according to ASTM standards [42]. Samples of 101.6 mm diameter and 63.5 mm height were prepared using moulds of 101.6 mm diameter and 76.2 mm height. For compaction of the samples, a compaction hammer of weight 4.53 kg and a free fall height of 457 mm were used. 75 compaction blows were given in both the sides of the cylindrical sample. Preliminary studies indicated that, for mixtures incorporating polypropylene fibres, the mixing temperature was less than 140 °C. Tests such as Marshall stability and flow tests, indirect tensile test, resilient modulus of bituminous mix and moisture susceptibility tests were carried out to determine the strength parameters of asphalt specimens. Further fatigue tests were performed to determine the performance life of the studied mixes. Beams of length 15 in. with a 3-inch square cross section were used for this analysis. Density corresponding to Marshall mix design is attained for the beam using a rectangular compactor. Permanent deformation criteria and creep nature of the mix was also taken into consideration to study the performance of the mix in the laboratory.

2.1. Materials used

Physical properties of the polypropylene fibres used, obtained from the manufacturer are summarized in Table 1.

First class brick and over burned bricks were used for the study. The properties of brick aggregates are detailed in Table 2.

The properties showing considerable strength parameters for the brick aggregate. These results prove the comparable nature of brick aggregates with normal stone aggregate. It is also seen that, the overburnt bricks have a clear advantage over normal first class brick in viewpoints of strength and stability. A standard specification for the use of brick aggregate in pavement construction is highly needed. VG 40 is the bitumen grade utilized in the study. Its physical properties are provided in Table 3.

The gradation of the aggregate (Table 4) was chosen as per MORTH specification [43].

Tube test for assessing the storage stability of modified bitumen was conducted according to the Standard EN 13399. Modified bitumen samples were stored in an oven at 180 °C for 3 days and then the differences of softening point between the modified bitumen in the top part and in the bottom part of the tube were measured. Modified bitumen samples are considered to be stable if the softening point differences are less than 5 °C [44].

2.2. Experimental setup and tests performed

2.2.1. Optimum fibre and bitumen contents using Marshall test

The properties of bitumen gets modified when fibres were added to it, has been evaluated by different experimental tests. The fibres in various proportions were added to bitumen, and the results were compared. The tests for determining properties of bitumen were carried out with polypropylene fibre for fibre dosages of 0.3%, 0.6%, 1%, 2%, 4% and 6% by weight of bitumen. The optimum bitumen content for first class brick and over burnt bricks was found to be 10.53% and 8.6%

Table 1
Physical properties of polypropylene fibre.

Particulars	Average value
Specific Gravity	0.91
Tensile Strength	330–414 MPa
Modulus of Elasticity	3.7–5.5 GPa
Length	12 mm
Melting Point	160 °C
Fire Point	590 °C
Water Absorption	0.65%