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Laboratory performance evaluation of environmentally sustainable sisal fibre reinforced bituminous mixes

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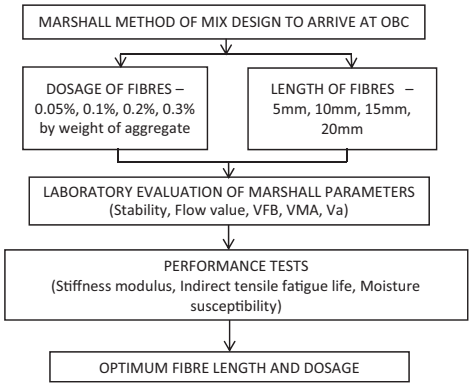
HIGHLIGHTS

- This study investigated the effect of sisal fibre on performance of bituminous mix.
- Laboratory tests were conducted on mixes with 4 different fibre lengths and dosages.
- Optimum results were obtained for 15 mm fibres at 0.05% dosage by weight of aggregate.

GRAPHICAL ABSTRACT



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ABSTRACT

Sisal fibre is a natural fibre, which runs along the length of sisal leaves, extraction of which yields fibre. These fibres, which are spared from decomposition, may find significant application in pavement engineering. In this study, an attempt has been made to evaluate the application of sisal fibres in improving the behaviour of bituminous mixes. The effects of addition of four different lengths (5, 10, 15 and 20 mm) with four different dosages (0.05, 0.1, 0.2 and 0.3% by weight of aggregate) on stability, flow and air voids in the bituminous concrete mixes were investigated. The optimum bitumen content was obtained for different combinations. To arrive at the optimal dosage of fibre and length, laboratory performance tests such as stiffness modulus, fatigue life and moisture sensitivity were carried out for all the combinations. The fibre length of 15 mm at 0.05% dosage by weight of aggregate with an optimum bitumen content of 5.4% by weight of mix was seen to provide better performance.

1. Introduction

The growth of the economy of a country depends largely upon its development in infrastructural facilities. Of all the infrastructures, development of the transport system is required for the effective transport of goods and passengers. The road transportation has become a wider choice among all the transport systems in India. Over the past four decades, the share of road transport has been continually increasing with a substantial shift from other modes to road. Hence, it is important to have a better road infrastructure with minimal possible hindrance to road user by providing regular periodic and routine maintenance. In India out of 48.85 lakh kilometers of road network [1], flexible pavements constitute over 90% of the share. With time and traffic, the condition of

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the road deteriorates. The bituminous wearing course continues to prematurely fail due to steep increase in vehicular traffic volume, channelized movement of heavy loads, excess rampant overloading and high occurrence of temperature variations which may results into various types of distresses such as rutting, fatigue, etc. According to various performance study reports, the useful life of bituminous layers has declined considerably in the recent years. This made the researchers to carry out studies to improve the performance of the pavement by modifying the bitumen properties by adding additives or fibres in the bitumen or the bituminous mix.

The use of modified bitumen with modifiers such as polymers (elastomers and plastomers), crumb rubber, natural rubber latex and chemical modifiers improves the performance of the pavement against rutting and moisture resistance damage [2]. Further, the use of modified bitumen extends the life of the pavements. Fatigue cracking may appear at a delayed stage.

The modern development of fibre reinforcement started in the early 1950s. Initially, studies were carried out using wire mesh as reinforcement for arresting reflective cracks in the bituminous overlay. Asbestos fibres were used until they were found hazardous to health. As a reinforcement material, the principal function of the fibre is to provide additional tensile strength in the resulting composite. This could increase the amount of strain energy that can be absorbed during the fatigue and fracture process of the mix.

In addition, attempts have been made by researchers to evaluate the effect of adding various types of fibres. The use of fibres to improve the behaviour of bituminous mixes is the recent trend in many countries. The uses of artificial/synthetic fibres such as polypropylene, polyester, cellulose, mineral fibres, etc., have been widely studied [3–5] and are practised presently throughout the world. The addition of fibres in small quantities in the bituminous mixes has improved the rutting potential, crack-resisting capacity, the life of the pavement and anti-slide performance [6].

A multitude of fibres and fibre materials such as polyester fibre, glass fibre, carbon fibre, asbestos fibre, cellulose fibre, polypropylene fibre, etc. [7] are being introduced in the market for new applications. The addition of carbon fibre showed better mechanical behaviour, a significant increase in stiffness, fatigue life and rutting resistance [8]. The addition of glass fibre [9] also improved the resistance to cracking and permanent deformation of bituminous mixes. The addition of steel fibres [10] and basalt fibres [11] had a positive impact on stability of the bituminous mixes. The tensile strength and related properties of a mixture containing fibres were found to be improving in many cases [12,13]. Study has been carried out to assess the use of algae fibre as additive in stone matrix asphalt mixtures [14]. Recently laboratory studies have been carried out to evaluate the warm mix asphalt added with synthetic [15] and natural fibres [16].

The use of naturally available plant fibre in bituminous mixes is not widely practised. Further, it is observed that the studies on the use of eco-friendly natural fibres in bituminous mixes are very limited and they are in nascent research stage only. Many natural fibres such as straw, coconut coir, palm leaf, cotton, sisal, sugarcane, bamboo, jute, etc., possess excellent strength and using them in bituminous mixes has not been explored much. The natural fibres are used as reinforcements due to their various advantages compared to conventional man-made fibres. The primary advantages of natural fibres are low density, low cost, biodegradability, acceptable specific properties, less wear during processing and low energy consumption during extracting. Among natural fibres, sisal is abundantly available in India. Sisal fibre possesses better tensile strength, temperature resistance [17] and its long life is compatible with the design period of flexible pavements. Further, it has other advantages like competitive cost, environmental compatibility and biodegradability. In fact, it is a hard and tough fibre which retains its properties even in wet condition.

Fig. 1a. Sisal plant.

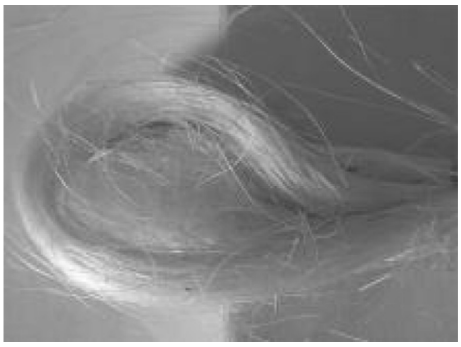

Fig. 1b. Sisal fibre.

Sisal is a widely cultivated and naturalized plant in many countries (Figs. 1(a) and 1(b)). Its fibre is extracted by a process known as decortication, removal of the cortex to extract the fibres that run along the length of the leaves. It is extracted either by retting process or mechanical method and the stiff fibre is used in making various products. It has superior engineering properties (better tensile strength, higher modulus and elongation) making an excellent material for manufacturing high strength textile and as reinforcement in composites for various applications. It is traditionally used for rope and twine and has many other uses, including paper, cloth, wall coverings, carpets and dartboards. It is also used for manufacturing products like geotextiles, buffing cloth, bonding, construction materials, handicrafts, furniture, padding and mattresses. In recent years, sisal has also been utilized as a strengthening agent to replace asbestos and fiberglass and is increasingly a component used in the automobile industry, where its strength, naturalness and environmentally friendly characteristics are greatly appreciated [18].

Laboratory investigations have been carried out using sisal fibre in Stone Matrix Asphalt [19]. However, extensive studies have not been conducted on sisal fibre in dense graded bituminous mixes [17]. Hence an attempt is made in this study to investigate the effect of sisal fibres in dense bituminous mixes.

2. Objective

The objective of this study is to investigate the effect of sisal fibre on the following engineering properties of bituminous concrete mixes and to identify the optimum length and dosage for better performance.