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Strengthening of hot-mix asphalt mixtures reinforced by polypropylene-impregnated multifilament glass fibres and scraps

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HIGHLIGHTS

- The indirect strength of fibrous mix is about two times higher than the plain mix.
- The rut-depth of fibrous mixtures is about three times lower than the plain mix.
- The glass fibre is utilised as a strengthening material of asphalt concrete.

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ABSTRACT

This study presents an experimental overview of thermoplastic polymer-coated glass fibre and scrap-reinforced hot-mix asphalt (HMA) mixtures. The toughening effects of the reinforced HMA mixtures were characterised using indirect tensile and Hamburg wheel-tracking tests. The indirect tensile loading tests were used to calculate the relative indirect tensile strengths of samples and to compare their moisture susceptibilities.

The fibre's relative contributions to increasing the indirect tensile strength and the resistance to rutting are quantified by comparing the maximum indirect peak tensile stress and tensile strength ratio (TSR). The indirect tensile strength and TSR of the fibrous mixtures are nearly two times higher than those of the plain mixtures, demonstrating the lower moisture susceptibility and superior field performance of the fibrous asphalt mixture. Accelerated rutting tests using the Hamburg wheel test setup for the fibrous mixtures caused at least three times more loading passes to be required to reach the rut-depth criteria compared to the number of loading passes required for the plain mixtures.

1. Introduction

Recently, non-synthetic and synthetic fibres have been utilised to improve the performance of hot-mix asphalt (HMA) mixtures against permanent deformation and fatigue cracking. A few studies in the literature have reported on experiments using various fibres in asphalt concrete mixtures.

Kaloush et al. found that the use of polypropylene (PP) and aramid fibres mixed in an asphalt mixture improves the resistance of the asphalt mixture to shear deformation, as demonstrated by triaxial shear strength tests. The fibrous mixture increases the tensile strength by 25–50% [1].

Lee et al. demonstrated that the increase in fracture energy due to the addition of recycled nylon fibres from carpet represents a potential avenue for improving the fatigue life of asphalt mixtures. Their study also suggested that the fibre's balling during mixing should be overcome to ensure the reinforcing effect on the asphalt concrete mixture [2].

Mahrez and Karim reported that the addition of 20-mm-long glass fibres resulted in higher resistance to fatigue cracking and permanent deformation during repeated indirect load tensile tests. They concluded that chopped glass fibres distributed in random directions in a mixture resist shear displacement and effectively prevent the internal dislocation of aggregates [3].

HMA mixtures reinforced with various fibres, such as carbon fibres or polyethylene terephthalate fibres, have been reported to exhibit a superior mechanical behaviour compared to general HMA in terms of toughness, indirect tensile strength, shear strength, and fracture energy. The improved toughness and fracture energy, which can increase the fatigue life of HMA, were the most significant effects in the use of those fibres with HMA [4,5].

Li et al. emphasised that not all fibres mixed in a composite are equally effective in their toughening effects. The fibre's random distribution and orientation features require the use of assumptions regarding the probability density functions for calculating

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the effective composite stresses along the failure plane by accounting for the fibre's bridging forces. The randomness may be overcome by the acceptable dispersion of fibres without fibre balling by determining the effective dimension or the optimum content of fibres in the HMA. A promising cause of toughening may be that the fibres in an HMA can increase the shear strength at the interface between the HMA matrix and the fibres and that this increased shear strength can delay the initiation and propagation of damage [6].

Yoo and Kim proposed a reinforcing mechanism as well as a method of optimising the fibre content utilising a direct tensile loading test that they developed. However, the fibre's dimension and aggregate gradation in their study were set as constant values; therefore, the applicability of the study is limited [5].

Although the various effects of fibres in asphalt concrete can differ considerably depending on the dimensions and contents of the fibres, this study only utilises a constant fibre dimension and a fixed mixture design to verify the marginal strengthening effect of glass fibres in asphalt concrete. In addition to the fibrous mixture, fibres can also affect the ductility or stiffness of the bitumen. However, this study only addresses the experimental results obtained when including glass fibres in asphalt concrete mixtures.

The objective of this study was to evaluate the mechanical characteristics of glass fibre-reinforced asphalt concrete, which was coated in a PP resin, using indirect tensile loading and Hamburg wheel tests. The manufacturing process for the PP-coated glass fibre was proposed to obtain an effective fibre dispersion in HMA by increasing the specific gravity and dimension of the fibres.

2. Multifilament glass fibre-reinforced HMA

The "electrical" grade glass (E-glass) fibres used in this study were from a chopped rod containing 800 to 1000 monofilaments of glass fibre. The roved multifilament glass fibre was coated using the PP resin through an impregnation process. In addition to the physical characteristics, as shown in Table 1, the mechanical properties of the fibres, such as the tensile strength and Young's modulus, are referred from the study of Wallenberger et al. and are at least 100–1000 times higher than the typical values of an HMA at room temperature [7].

The specific gravity of the glass fibre is comparable to a general aggregate greater than 2.0, whereby the PP-coated multifilament fibre strand may behave as an aggregate without any noticeable balling of fibres during the mixing process. The effective dispersion without fibre balling may be expected due to the aggregate-like behaviour of the fibre.

Two different concentrations of PP-coated multifilament fibres, 1% and 2% of the weight of the mixture, were used to reinforce the asphalt concrete. Only one mixture contains the fibre scraps in the shape of aggregate; the fibre scraps were coated using the PP resin through an extrusion process, as shown in Fig. 1. The glass fibre scraps are a by-product obtained from producing a roving fibre. The nominal maximum sieve size of the scraps was 100 μm, which is one grade higher than a standard sieve size for mineral filler. The scraps passing the 75-μm sieve were utilised in making the aggregate-like scraps in this study, which are coated using the PP resin (PPGS) through the extrusion process, as shown in Fig. 1.

The application rate of PP for coating the scraps (PPGS) and roving fibres (PPGF) was controlled by the relative weight ratio between the weight of scraps or roving fibres and the weight of PP by 1:1.

The gradation of scraps was as shown in Table 2. Because of the difficulty in controlling the content of dust or mineral filler when performing a mixture design in an asphalt plant, this study utilised the PPGS to more easily perform the mixing with the aggregate compared to the powder type and to replace all mineral fillers and dust in the HMA concrete.

In addition to the PPGS, PP-coated multifilament glass fibres (PPGFs) were developed for use in HMA applications as reinforcing media, as shown in Fig. 2a and b. The extrusion process with an impregnation step for the PP coating shown in Fig. 2a can give the PPGFs an elliptical cross-section. The PPGFs were cut into 10-mm-long pieces that were 1 mm wide on the short side and 2 mm wide on the long side, as shown in Fig. 2b.

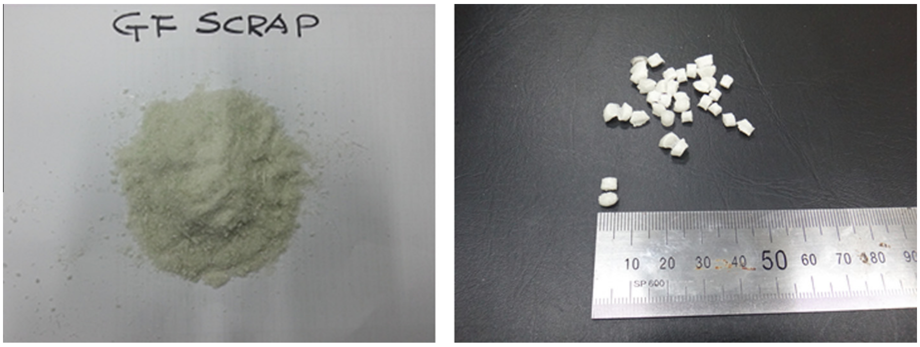
The circular PP particles in Fig. 2b were added to the HMA according to the equivalent weight ratio between the glass fibre before coating and the PP resin. The PP particles were completely melted during the wet-mixing process with a hot binder in a plant,

Table 1
Physical characteristics of E-glass fibres [7].

Physical properties	Characteristic value
Density (g/cm^3)	2.55
Tensile strength (MPa)	3400
Elongation (%)	4.5–5.0
Number of filaments	800–1000
Length (mm)	10–12

Table 2
Gradation of glass fibre scraps.

Sieve size (μm)	% Passing
100	100.0
75	83.0
45	47.0



(a) (b)

Fig. 1. (a) Glass fibre scraps and (b) aggregate-like PP-coated scrap (PPGS).