Fracture Performance of Synthetic Fibre-Reinforced Asphalt Mortar

Apostolidis, Panos; Daniel, Gerald C.; Liu, Xueyan; Erkens, S.; Scarpas, Athanasios

Publication date
2019

Document Version
Accepted author manuscript

Published in
Proceedings of 2019 TRB Annual Meeting

Citation (APA)
Apostolidis, P., Daniel, G. C., Liu, X., Erkens, S., & Scarpas, A. (2019). Fracture Performance of Synthetic Fibre-Reinforced Asphalt Mortar. In *Proceedings of 2019 TRB Annual Meeting: 13-17 Januari 2019, Washington, USA* Transportation Research Board (TRB).

Fracture Performance of Synthetic Fibre-Reinforced Asphalt Mortar

P. Apostolidis[1], C.G. Daniel[1], X. Liu[1], S. Erkens[1], A. Scarpas[1,2]

[1] Section of Pavement Engineering
Faculty of Civil Engineering and Geosciences
Delft University of Technology
Stevinweg 1, 2628 CN Delft, the Netherlands

[2] Department of Civil Infrastructure and Environmental Engineering
Khalifa University of Science and Technology
Abu Dhabi, United Arab Emirates

Corresponding author:
P. Apostolidis
E-mail: p.apostolidis@tudelft.nl

Submitted for presentation and publication for the 98th meeting of the Transportation Research Board.

INTRODUCTION

The utilization of synthetic fibers has been reported in the past (*1-8*) showing enhancement of fatigue and thermal cracking resistance in asphaltic materials. However, the limited evidences about the benefits of these fibres in asphaltic materials at low material scales have been noticed. Also, the exact reinforcing mechanism of binding system in the asphalt pavement mixes is still unclear. Therefore, this research examined experimentally the fracture performance of the synthetic reinforced asphalt mixes at the mortar level by using specially designed tools. Samples of three different fibre contents and two fibre lengths were evaluated. Pull-out tests, whose objective was to explore the potential interaction of fibre-matrix, demonstrated a matrix-type of fracture. Moreover, direct tension tests were carried out with both monotonic and cyclic loading to assess the effect of the synthetic fibres on tensile strength, fracture energy and ductility; and fatigue life of reinforced mixes. Improvements on mechanical characteristics of asphalt mortars have been observed when fibres were added. Also, the longer fibres of low dosages generated equivalent performance to the mix with the high dosages of shorter fibre. Hence, a potential initial cost reduction could be reached by means of utilizing the longer synthetic fibres. Overall, the current results elucidated that implementing dedicated studies at various material levels can assist on understanding the material performance and on tailoring systems beyond sometimes the supplier-recommended additive dosages.

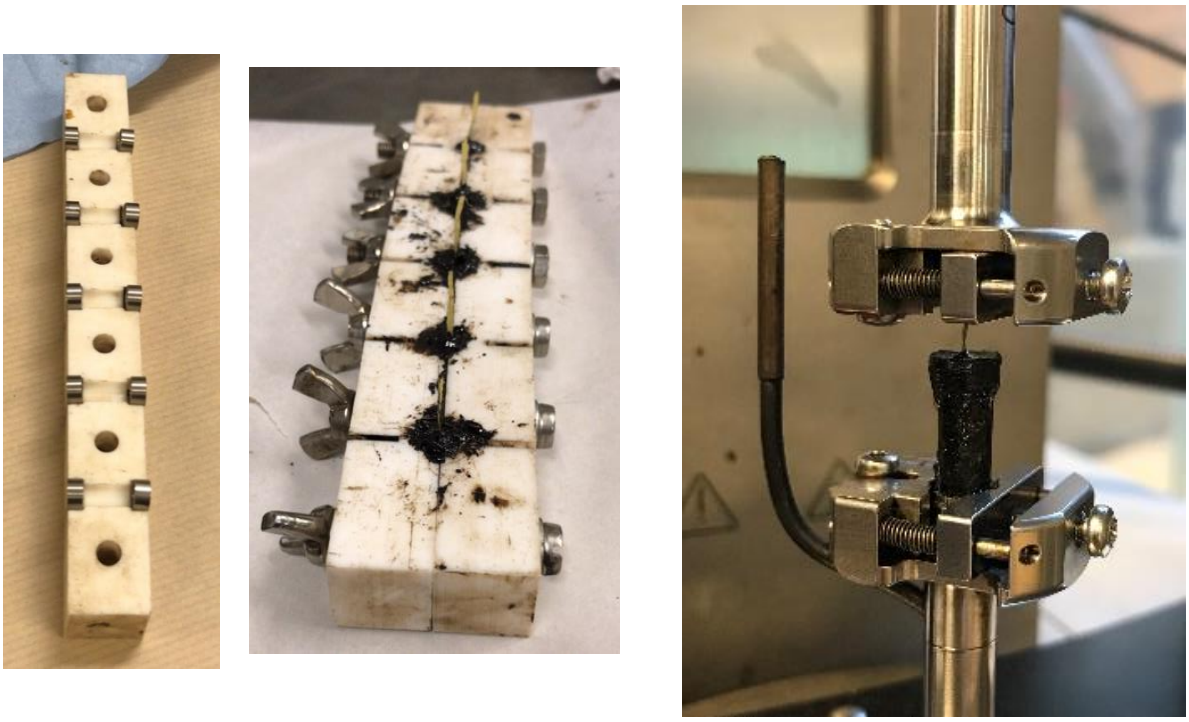
METHODOLOGY

Asphalt mortar samples with a fixed ratio by volume fraction of sand (0.47), filler (0.23) and bitumen of 50/70 pen-grad (0.30) were prepared in the laboratory. The ratio by weight of synthetic fibres between aramid (1.44 g/cm^3) and polyolefin (0.9 g/cm^3) fibres was 12.5:87.5, as supplied by the manufacturer.

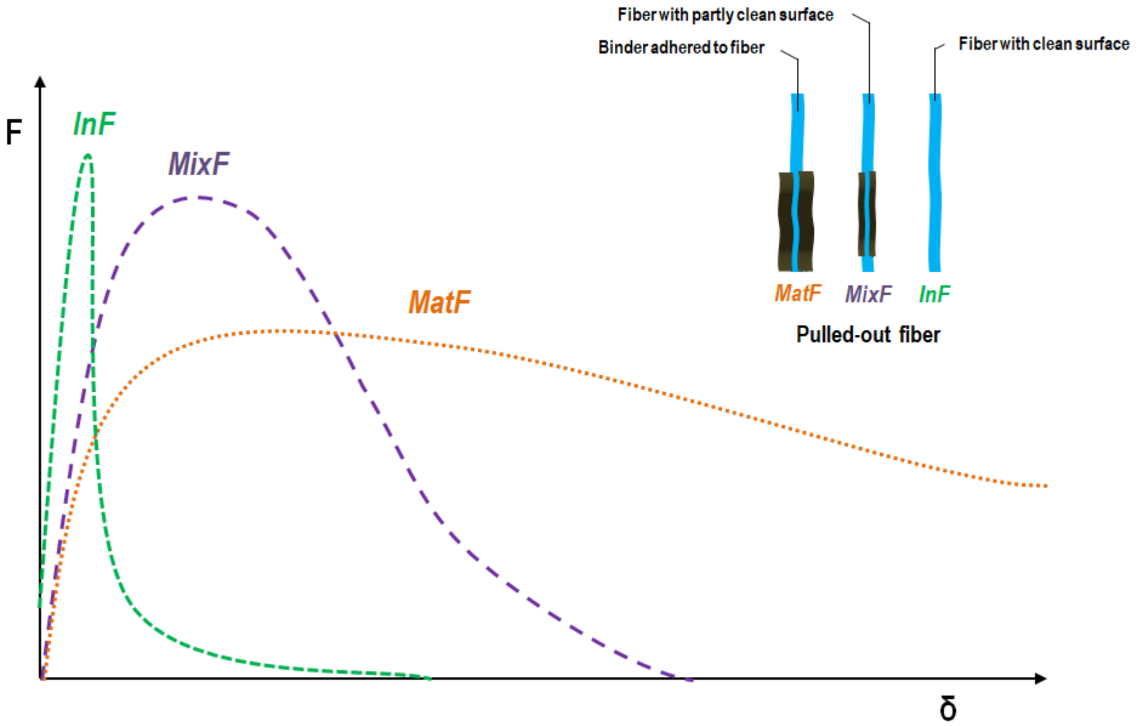
Pull-out Testing

The interface behaviour between metallic and synthetic fibres in asphalt mixes was investigated in the past, and it has been observed that aramid fibres had 5-7 times more pull-out strength than that of polyester fibres (*9, 10*). Nevertheless, the interaction between asphalt mortar and synthetic fibres was never examined and thus, in this research, a pull-out testing setup was developed, shown in **Figure 1-a&b**, to explore the bonding behaviour of synthetic fibre-asphalt mortar system. For the preparation of samples for pull-out testing, the synthetic fibre strands were formed by means of the weight after mixing the pre-heated at 130^{o}C mineral particles (i.e., sand and filler) and pre-heated at 130^{o}C bitumen including a warm additive (0.7% of binder weight). The pull-out tests were performed using a dynamic shear rheometer (DSR) and the generated results were in the form of force against time or displacement. The effect of different temperatures was not taken into account due to a limitation in the clamping force, and thus the influence of different loading speed was assessed at room temperature. The maximum load was obtained from the load-displacement curve at the peak point of the load, and the effect of various displacement rates on maximum load was evaluated.

The interpretation of interface failure mode was conducted considering three types of interfacial damage that can be generated with the pull-out testing (*9*) (**Figure 1-c**): (i) Matrix Failure (MatF), which resulted when the asphaltic matrix is pulled-out along with the fibre, mostly seen at high temperature and/or slow loading speed, (ii) Interface Failure (IntF); when caused when the fibre is pulled-out cleanly from the matrix (at low temperature and/or high loading speed), and (iii) Mix Failure (MixF) mode is the combination of the first and second mode which occurs most frequently. MatF is characterised by a slow and gradual increase in the force after the peak while IntF exhibits sudden drop after the peak.

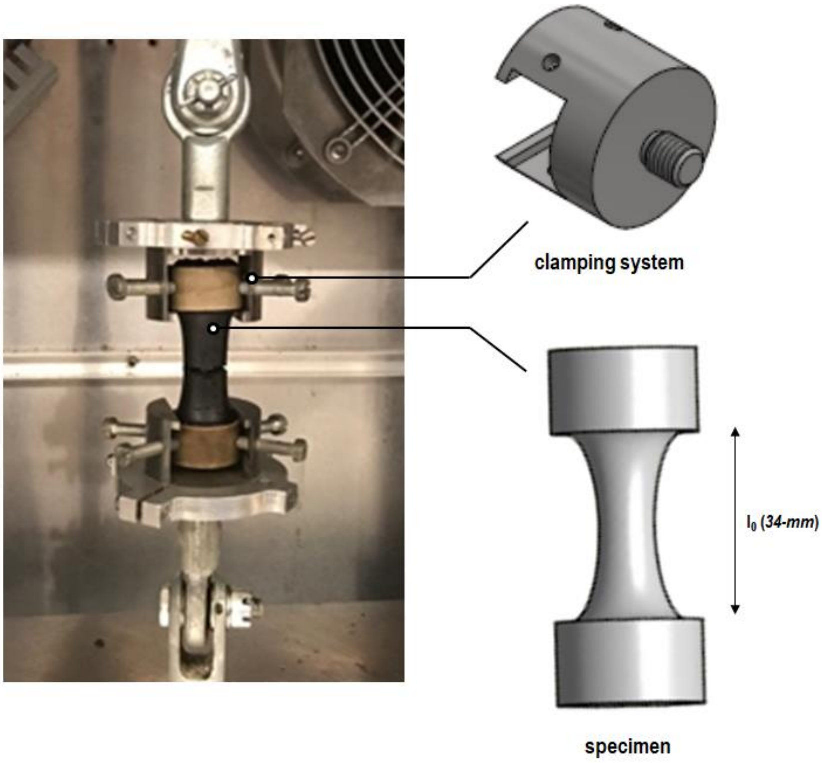


(a) (b)

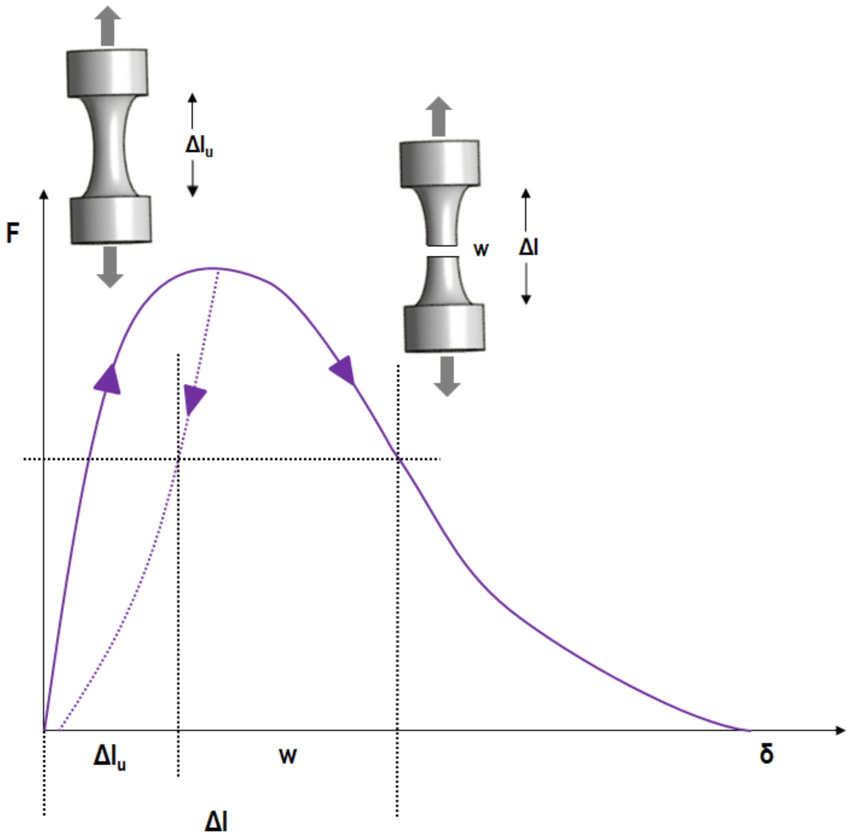


(c)

FIGURE 1 Pullout testing configurations: (a) split-up mould with steel ring (left) and the specimen in the mould, ready to be de-moulded (right), (b) pullout testing setup, and (c) typical force-displacement curve pullout testing of different failure modes



(a)



(b)

FIGURE 2 Direct tensile testing configuration: (a) specimen fixed in the clamping system after testing, and (b) schematic of uniaxial specimen response in tension

Direct Tensile Testing

The current standardised test on tension capacity of an asphalt mix is performed as an indirect tension test with a cylindrical shape sample (ASTM D6931). The compression load creates tension stress at the centre part of the specimen causing the fracture. Alternatively, the tensile capacity of asphalt mixes can be measured with uniaxial tension tests in a more accurate manner. A method was proposed initially to perform direct tension tests of a specimen of dog-bone geometry (*11*). The purpose of such geometry was to localise the failure to occur mainly in the centre part of the specimen. However, examinations in direct tensile test in asphalt concrete mixes did not show promising results, mainly due to the failure location occurred mainly near the top cap. Later on, a similar testing geometry of parabolic shape of different height was developed to examine the fatigue resistance of asphalt mortar (*12*). The primary goal was to achieve a better stress distribution around the height of sample and to avoid the failure near the end cap. Herein, the specimen was formed in the dog-bone shape using the same parabolic shape as (*12*) with a slight modification on the diameter of the centre to accompany the type of long fibres inside the mortar. The uniaxial tension tests of dog-bone like specimens, as shown in **Figure 2** were performed at three different temperatures and a displacement rate, taking into account three different fibre contents and two fibre lengths. For the cyclic loading tests, the goal was to observe the influence of the fibre on the fatigue life of asphaltic mortar, which was determined as the maximum number of cycles in which the sample failed.

FINDINGS AND CONCLUSIONS

The interface failure of fibre-asphaltic materials regularly occurred as the consequence of weak bonding between the host structure and the added phase, in this case, the synthetic fibres. Herein, the interaction of fibre-matrix was assessed by performing pull-out tests at test temperature showing a cohesive or a matrix-type of fracture (MatF). Also, testing under the uniaxial tension having dog-bone shape samples of fiber reinforced mixes, it is possible to localise the fracture at the middle of sample demonstrating clearly the effect of synthetic fibres on the fracture performance of mortar. The reinforcing effect of fibres of different characteristics was evident in the current research.

Under monotonic tension, the effect on tensile strength of fibre reinforced asphalt mortar was not significant at low temperature and still directly proportional to the fibre dosage within the matrix. The use of shorter fibre created the same trend generating a more dramatic improvement using a lower fibre dosage. However, any dosage of shorter fibre resulted in similar impact. Furthermore, the variation of total energy is mostly influenced by the applied load at low temperature. Meanwhile, the ductility plays a more dominant role at higher temperatures, in which the increase fibre dosage resulted in a decrease of ductility. In general, the result of the longer fibre is somewhat comparable to that of the shorter ones, a trend which can be explained as the presence of fibre inside the mix removed the other material while being stretched, causing the damage from inside. Finally, it was found that the dosage increase is able to extend fatigue life under cyclic uniaxial tension.

It is believed that the inclusion of polyolefin fibres in the strand of synthetic fibre helped on generating interfacial bonding between fibre and mortar increases and, hence, the de-bonding energy needed to result interfacial fracture. The incorporation of adhesion promoters to enhance the bonding characteristics is an option for future research work to optimise and tailor reinforced paving materials. Further, the fiber-binder interface should be studied in-depth since the latter affects the compatibility of the reinforced system in which the incorporation of synthetic fibers, as shown from the uniaxial tension tests, influence the stress distribution and the fracture propagation in reinforced asphaltic materials. Beyond the synthetic fibers, evolutionary developments in bio-inspired (e.g., bone and nacre) and nature oriented synthetic fibers (e.g., cellulose fibers) added of a small volume fraction could result in reinforced systems with remarkable structural properties.

Author Contribution Statement

The authors confirm contribution to the paper as follows: study conception and design: P. Apostolidis, X. Liu, A. Scarpas; data collection: C.G. Daniel; analysis and interpretation of results: C.G. Daniel, P. Apostolidis, X. Liu, S. Erkens, A. Scarpas; draft manuscript preparation: P. Apostolidis, C.G. Daniel. All authors reviewed the results and approved the final version of the manuscript.

REFERENCES

1. *NCHRP Synthesis 475. Fiber Additives in Asphalt Mixtures*. Transportation Research Board of the National Academies, Washington, D.C., 2015.
2. Kaloush, K. E., K. P. Biligiri, W. A. Zeiada, M. C. Rodezno, J. X. Reed. Evaluation of Fibre-Reinforced Asphalt Mixtures Using Advanced Material Characterization Tests. *Journal of Testing and Evaluation*, Vol. 38, No. 4, 2010, pp. 1–12.
3. Gibson, N., X. Li. Characterizing Cracking of Asphalt Mixtures with Fibre Reinforcement: Use of Cyclic Fatigue and Direct Tension Strength Tests. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2507, 2015, pp. 57–66.
4. Ho, C., J. Shan, F. Wang, Y. Chen, A. Almonnieay. Performance of Fibre-Reinforced Polymer Modified Asphalt: Two-Year Review in Northern Arizona. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2575*, Transportation Research Board, Washington, D.C., 2015, pp. 138-149.
5. Guistozzi, F., M. Crispino, E. Toraldo, E. Mariani. Mix Design of Polymer-Modified and Fibre-Reinforced Warm-Mix Asphalts with High Amount of Reclaimed Asphalt Pavement: Achieving Sustainable and High-Performing Pavements. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2523*, Transportation Research Board, Washington, D.C., 2015, pp. 3-10.
6. Gibson, N., X. Qi, A. Shenoy, G. Al-Khateeb, E. Kutay, A. Andriescu, K. Stuart, J. Youtcheff, T. Harman. *Performance Testing for Superpave and Structural Validation.* Report FHWA-HRT-11-045. FHWA, U.S. Department of Transportation, 2012.
7. Stempihar, J., M. Souliman, K. Kaloush. Fibre-Reinforced Asphalt Concrete as Sustainable Paving Material for Airfields. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2266*, Transportation Research Board, Washington, D.C., 2012, pp. 60-68.
8. Muftah, A., A. Bahadori, F. Bayomy, E. Kassem. Fibre-Reinforced Hot-Mix Asphalt: Idaho Case Study. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2633*, Transportation Research Board, Washington, D.C., 2017, pp. 98-107.
9. Park, P., S. El-Tawil, A. Naaman. Pull-out Behavior of Straight Steel Fibres from Asphalt Binder. *Construction and Building Materials* 144, 2017, pp. 125-137.
10. Qian, S. H. Ma, J. Feng. Fibre Reinforcing Effect on Asphalt Binder under Low Temperature. *Construction and Building Materials* 61, 2014, pp. 120-124.
11. Erkens, S. *Asphalt Concrete Response (ACRs): Determination, Modeling and Prediction*. PhD Thesis, Delft University of Technology, 2002.
12. Apostolidis, P., X. Liu, A. Scarpas, C. Kasbergen, M. van de Ven. Advanced Evaluation of Asphalt Mortar for Induction Healing Purposes. *Construction and Building Materials* 126, 2016, pp. 9-25.