# Impact of synthetic fibres on asphalt concrete mix

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

**DOI**
10.1201/9781351063265-96

**Publication date**
2019

**Document Version**
Accepted author manuscript

**Published in**
Bituminous Mixtures and Pavements VII- Proceedings of the 7th International Conference on Bituminous Mixtures and Pavements, ICONFBMP 2019

**Citation (APA)**
Daniel, C., Liu, X., Apostolidis, P., Erkens, S., & Scarpas, A. (2019). Impact of synthetic fibres on asphalt concrete mix. In A. F. Nikolaides, & E. Manthos (Eds.), *Bituminous Mixtures and Pavements VII- Proceedings of the 7th International Conference on Bituminous Mixtures and Pavements, ICONFBMP 2019: 2019, Washington D.C.* (pp. 709-711) https://doi.org/10.1201/9781351063265-96

# Impact of synthetic fibres on asphalt concrete mix

C.G. Daniel, X. Liu, P. Apostolidis, S. Erkens & A. Scarpas*
*Section of Pavement Engineering, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, the Netherlands.*

** Department of Civil Infrastructure and Environmental Engineering, Khalifa University of Science and Technology, Abu Dhabi, United Arab Emirates.*

ABSTRACT: The use of synthetic fibres has been reported to enhance the performance of asphalt pavement materials in terms of permanent deformation, fatigue and thermal cracking. However, limited results about the benefits of synthetic fibres in the reinforced warm-mix asphaltic materials, and the exact mechanism of reinforcing the binding part in pavement structures is still unclear. In this contribution, a semi-circular bending test was performed by using various fibre amounts as well as fibre length inside the bituminous mix. The results indicate that the inclusion of fibre can improves the warm-mix performance. Tensile strength as the first criterion is enhanced proportionally by increasing fibre dosage. The reinforcing effect brought by 38-mm fibre is higher than the one with 19-mm.

## 1. INTRODUCTION

One of the major distresses in pavement structures is cracking due to thermal and mechanical loading. A thorough examination is therefore necessary to recognise the cracking mechanism, which is strongly related to the tensile strength of asphalt concrete mixes (Huang et al. 2005). One of the most widely used methods to evaluate cracking in asphalt mixes is the Indirect Tension Test (ITT). However, this test shows several flaws regarding the risk of initiating permanent deformation below the loading strip as well as the stress distribution at the centre of the specimen. A combination of tension-compression stress can occur simultaneously, and if the former is less than three times than the latter, such a compressive failure will arise (van de Ven et al. 1997). This test also encounters a problem in describing the fracture mechanics of a material that is vital in terms of addressing crack initiation and propagation (Li & Marasteanu 2009). A semi-circular bending (SCB) test has then become a promising method to characterize the tensile strength and fracture energy of asphalt concrete.

SCB test has been applied in pavement engineering field by several researches using different framework. Van de Ven et al. 1997 applied SCB test with aim to define the tensile strength of asphalt mixtures, followed by others (Krans et al. 1996; Molenaar et al. 2002). Molenaar et al. 2003 performed finite element analysis to simulate the crack propagation. In this work, the crack severity due to tension and compression were compared observing that the crack propagation at the specimen subjected under tensile forces was the most severe. Li & Marasteanu 2009 suggested the possibility to define the tensile strength and fracture resistance of specimen by means of SCB test, using different temperatures, loading rates and specimens of different geometric characteristics (i.e., thickness, notch depth). Evidently, higher notch depth decreases both tensile strength and fracture resistance, while the influence of specimen thickness is inversely proportional to both criteria. Moreover, the effect of testing temperature is directly proportional to fracture energy and inversed to the peak strength. A higher loading rate is shown to increase the peak force and decrease fracture energy; however, it has only a small impact on the fracture energy at lower temperatures. It can be explained as the material becomes stiffer at the lower temperature and hence is less loading rate-dependant. The application of this test is then accompanied by a European standard (NEN-EN 12697-44) as well as American standard (AASHTO TP 105-13). Therefore, this research adapts the European standard to examine the effect of the synthetic fibres to the tensile fracture resistance of a dense asphalt concrete mix.

## 2. METHODS AND PREPARATION

The type of asphalt concrete selected to be studied herein is as standard DAC-16 mix. The impact of two different fibre contents (0.05% and 0.5% of total specimen weight) and two different fibre lengths (19-mm and 38-mm) have been explored. To study the effect of fibre length on the mix performance, several specimens with the inclusion of 38-mm fibre with the proportion of 0.1% were investigated as well. Moreover, the specific gravity of the aggregates was examined and the results are shown in Table 1. The calculated maximum density of specimens was 2484.4 kg/m3 with air void ratio of 7%.

The preparation of the specimens was made by using a gyratory compactor (NEN-EN 12697-31). Firstly, the mould for compacting the gyratory sample had to be prepared for at least 2 hours prior to its use at testing temperature. The already mixed material was poured into the mould afterwards by using a funnel. The mould was brought out of the compactor and cooling down for around 10 minutes, and then the specimen was de-moulded. Four SCB samples were cut from one gyratory sample. The geometry of the cylindrical gyratory sample was 150-mm by height and 150-mm by diameter (D). The height (W) of an SCB-sample cuted from the gyrator sample was 50-mm. A notch was created at the centre with a depth of (12.5+3.5)-mm and width of (3.0+0.1)-mm. The width of the notch was approximately ten times larger than the norm. This dimension was based on the capacity of the production system provided in TU Delft, and the same approach was used in the research conducted in (Elseifi et al. 2012) with the result of the crack propagating exactly at the centre.

Table 1. Density of each aggregate fraction.

| Weight (gr) | Agg 11-16 | Agg 8-11 | Agg 5-8 | Agg 2-5 |
|---|---|---|---|---|
| Dry | 993.6 | 997 | 997.3 | 998 |
| SSD in air | 996.7 | 1001.7 | 1003.5 | 1002.5 |
| SSD under $H_20$ | 628 | 631.45 | 631.02 | 631.46 |
| Appar. spec. grv | 2.718 | 2.727 | 2.723 | 2.723 |

A compression load was transferred from the load cell to a loading metal strip placed on top of specimen, with the purpose to evenly distribute the force over the total thickness. The external force from top exert two reaction forces from the support at the bottom part, within the distance of 0.8 times the length of the specimen. A simply supported beam with a point load is best at resembling the testing condition, meaning that the highest bending stress occurs in the middle of the span, with the highest tensile stress occurs mainly at the bottom fibre of the middle span. As the result, crack will initiate from notch position.

The tested specimen was pre-conditioned in the test chamber at (0+1)℃ for at least 4 hours, while the others had to be kept on a flat surface in a climate chamber. The tests were carried out at a displacement rate of 5 mm/min. The test result can be considered as valid if only the crack ends in the zone of +15-mm from the centre of the loading strip.

The tensile strength of material is computed using the following expression

$$\sigma_{max,i} = \frac{4.263 \cdot F_{max,i}}{D_i \cdot t_i} \qquad (1)$$

where $F_{max,i}$ is the maximum force of specimen number $i$ (N), $D_i$ and $ti$ is the diameter and the thickness of specimen number $i$ (mm), respectively.

The fracture toughness of the material, which describes the ability of a material to resist fracture, can be calculated by the following equation

$$K_{Ic,i} = \sigma_{max,i} \cdot f\left(\frac{a_i}{W_i}\right) \qquad (2)$$

where $Wi$ is the height of specimen $i$ (mm), $ai$ is the depth of the notch of specimen i (mm), $\sigma_{max,i}$ is the stress at failure of specimen $i$ (N/mm2), and $f(a_i/W_i)$ is the geometry factor of specimen i which is dimensionless and should be rounded to three digits. The geometry factor is determined as ; for 9-mm < $\alpha i$ < 11-mm and 70-mm < $Wi$ < 75-mm, then $f(a_i/W_i)$ = 5.956, otherwise

$$f\left(\frac{a_i}{W_i}\right) = -4.9965 + 155.58\left(\frac{a_i}{W_i}\right) - 799.94\left(\frac{a_i}{W_i}\right)^2 + 2141.9\left(\frac{a_i}{W_i}\right)^3 - 2709.1\left(\frac{a_i}{W_i}\right)^4 + 1398.6\left(\frac{a_i}{W_i}\right)^5 \qquad (3)$$

The strain is obtained here as the strain at the maximum force:

$$\varepsilon_{max,i} = \frac{\Delta W_i}{W_i} \cdot 100\% \qquad (4)$$

where $\Delta W_i$ is the vertical displacement of sample i (mm), and $W_i$ is the height of specimen i (mm).

The fracture energy is calculated by the division of the fracture work and ligament area

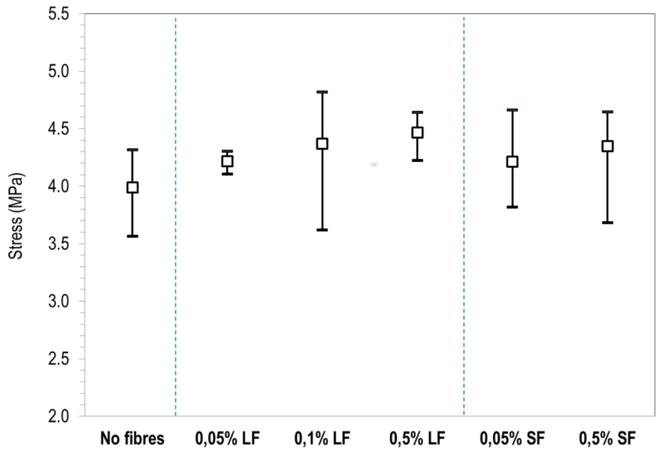
$$G_f = \frac{W_f}{A_{lig}} \qquad (5)$$

where $W_f$ (fracture work) is defined as the area of a force-displacement curve and $A_{lig}$ is the ligament area, calculated as (radius of specimen - notch length) * specimen thickness.

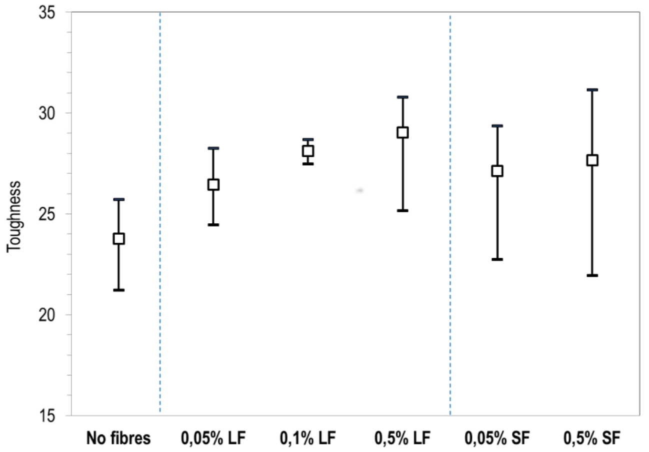
## 3. RESULTS

Figure 1(a) demonstrates that the addition of synthetic fibres provides a reinforcing effect to asphalt mix at low temperature. It can also be seen that the addition of 0.1% by weight of longer fibres could generate an equivalent performance to the 0.5% of shorter one. The strength of fibre-reinforced asphalt concrete with long fibres is higher than of mixes with short ones. Moreover, the term toughness refers to the ability of a subject to carry loading until its breaking point. While toughness is typically associated to the total amount of energy needed to fracture a material, the toughness is related to the strength and the shape factor (i.e., notch depth) herein. As depicted from Figure 1(b), the toughness is enhanced proportionally to the dosage of fibres, with a more significant impact brought by the longer fibres due to the same explanation as of the strength.

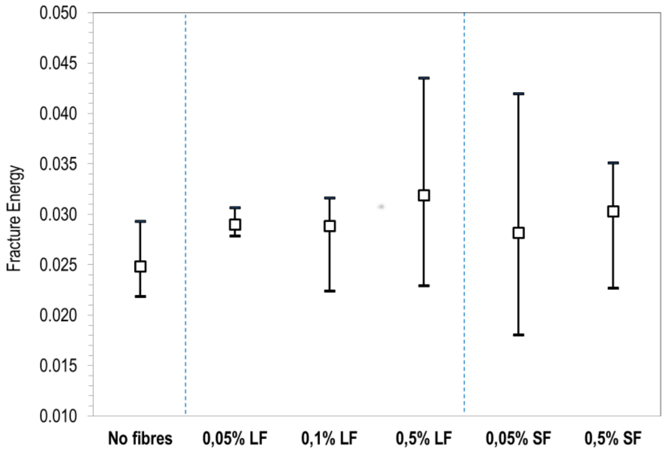
Additionally, the total fracture energy (Figure 1(c)), which is the area under a stress-strain curve, illustrates the total amount of work needed to bring a material to its failure state.




(a)




(b)




(c)

Figure 1. (a) Peak stress, (b) toughness and (c) total fracture energy at 0oC (LF: 38-mm fibres and SF: 19-mm fibres)

By performing a SCB test and since failure is imposed to locate precisely at the mid-span, thanks to the notch, the results describe mainly the contribution of the fibre at the mid-span. It is then believed that the total impact is not given by fibre network, since the fibre should be widespread through the whole body of specimen. Thus, the results may vary due to the fibres distribution in the specimen. Another testing method which is able to activate the role of fibre inside the whole specimen, such as a four-point bending test, is suggested for asphalt concrete mixes. Furthermore, the impact of the fibre on fatigue life of asphalt should also be examined, since the presence of synthetic fibre is proven to be able to increase the fatigue life of asphaltic materials (Apostolidis et al. 2019).

## 4. CONCLUSIONS

A semi-circular bending test is meant to examine the behaviour of a dense asphalt concrete more comprehensively. In this case, the contribution of the synthetic fibre to tension performance of studied mix is demonstrated. The results indicate that the inclusion of fibre improves the mix performance. Tensile strength as the first criterion is enhanced proportionally by increasing fibre dosage. However, the difference is not distinctive, especially between 0.1% and 0.5% dosage of 38-mm fibre. It is also found out that the reinforcing effect brought by 38-mm fibre is higher than the 19-mm one. Secondly, toughness also shows a prominent trend. Finally, fracture energy gives the similar tendency as the overall results. A conclusion can be drawn based on the mentioned criteria that the overall mechanical response of 0.1% w/w of 38-mm fibre is comparable to that with 0.5% w/w of 19-mm fibre.

## 5. REFERENCES

Apostolidis, P., Liu, X., Daniels, G.C., Erkens, S. & Scarpas, A. 2019. Effect of Synthetic Fibres on Fracture Performance of Asphalt Mortar. *Road Materials and Pavement Design*.

Elseifi, M., Mohammad, L., Ying, H. & Cooper III, S. 2012. Modeling and Evaluation of the Cracking Resistance of Asphalt Mixtures using the Semi-circular Bending Test at Intermediate Temperatures. *Road Materials and Pavement Design* 13, pp. 124-139.

Huang, B., Shu, X. & Tang, Y. 2005. Comparison of Semi-circular Bending and Indirect Tensile Strength Tests for HMA Mixtures. *Advances in Pavement Engineering* 22(8).

Krans, R., Tolman, F. & van de Ven, M.F.C. 1996. Semi-circular Bending Test: A Practical Crack Growth Test Using Asphalt Concrete Cores. In *3rd International RILEM Conference on Reflective Cracking in Pavements*, Maastricht, pp 123-132.

Li, X.-J. & Marasteanu, M. 2009. Using Semi Circular Bending Test to Evaluate Low Temperature Fracture Resistance for Asphalt Concrete. *Experimental Mechanics* 50(7), pp. 867-876.

Molenaar, A., Scarpas, A., Liu, X. & Erkens, S. 2002. Semi-circular Bending Test: Simple But Useful? In *Association of Asphalt Paving Technologists-Proceedings of the Technical Sessions*, pp. 794-815.

Molenaar, J., Liu, X. & Molenaar, A. 2003. Resistance to Crack Growth and Fracture of Asphalt Mixture. In *6th RILEM Symposium PTEBM'03*, Zurich, pp. 618-625.

van de Ven, M.F.C., Smit, A.D.F. & Krans, R.L. 1997. Possibilities of a Semi-circular Bending Test. In *8th International Conference on Asphalt Pavements*, pp. 939-950.