# *Sustainable use of COVID-19 discarded face masks to improve the performance of stone mastic asphalt*

This is the Published version of the following publication

Zhu, Jiasheng, Saberian, Mohammad, Li, Jie, Yaghoubi, Ehsan and Rahman, Md Tareq (2023) Sustainable use of COVID-19 discarded face masks to improve the performance of stone mastic asphalt. Construction and Building Materials, 398. ISSN 0950-0618

The publisher's official version can be found at
https://www.sciencedirect.com/science/article/pii/S0950061823022407?via%3Dihub
Note that access to this version may require subscription.

Downloaded from VU Research Repository https://vuir.vu.edu.au/47849/

Construction and Building Materials 398 (2023) 132524

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

# Sustainable use of COVID-19 discarded face masks to improve the performance of stone mastic asphalt

Jiasheng Zhu [a,1], Mohammad Saberian [a,1], Jie Li [a,*], Ehsan Yaghoubi [b], Md Tareq Rahman [c]

[a] School of Engineering, RMIT University, Melbourne, Victoria, Australia
[b] College of Sport, Health and Engineering, Victoria University, Melbourne, Australia
[c] Department of Transport and Planning, Victoria, Australia

ARTICLE INFO

*Keywords:*
COVID-19
Discarded face masks
Mask fibre
Stone mastic asphalt
Pavement

ABSTRACT

Since COVID-19 was declared a global pandemic, the production, consumption, and discard of personal protective equipment (PPE), such as face masks, have been rapidly increasing. The massive amount of face mask waste poses a severe threat to the ecology, environment, and public health. Alleviating the adverse effects of mask waste requires the cooperation of professionals from various fields. To reduce the epidemic-generated waste and improve the performance of stone mastic asphalt (SMA) mixes, in this study, comprehensive laboratory experiments, including volumetric assessment, Marshall stability and flow, resilient modulus, dynamic creep, moisture susceptibility, and binder drain-off test were carried out on SMA specimens prepared with 0.3%, 0.5%, 0.7%, and 1.0% of mask fibre (MF) by weight of asphalt mixture. The results were compared with the control SMA specimen (i.e., SMA mixed with 0.3% cellulose fibre (CF)) that complied with the road industry regulations and standards. The results of the study illustrated that the introduction of MF into the SMA mix improved the stability, resilient modulus, indirect tensile strength, resistance to permanent deformation, resistance to moisture damage and binder drain-off performance. Experimental results indicated that the inclusion of 0.3% and 1.0% MF in SMA complied with industry requirements and suggested that MF could be used instead of virgin CF as a fibre additive. Considering the available supply, performance and industry standards, SMA containing 0.3% MF demonstrates more potential for pavement applications.

## 1. Introduction

During the COVID-19 pandemic, WHO introduced guidelines on the utilisation of personal protective equipment (PPE) and requested that the production of PPE, including face masks, should be increased by 40% [1]. Most countries agreed to the recommendations of the WHO and implemented a policy of mandatory mask-wearing in public areas in response to this public health emergency of international concern [2–4]. The main part of the medical three-layer masks consists of a layer of melt-blown fabric and two layers of spun-bond fabric made of ultra-fine polypropylene (PP) nonwoven fibres [5]. It was estimated that more than 5.3 million used medical masks were generated every day in Victoria, Australia [6]. The WHO model predicted that 89 million disposable face masks were consumed by healthcare staff worldwide every month [7]. Treatment of used face masks has become an extreme challenge due to their persistent nature. Most countries collect and eventually treat medical waste, including face masks, through incineration and landfilling [8]; however, this is an unsustainable approach since incineration produces secondary pollutants such as dioxins, furans, and bottom ash and is costly to implement [9]. In addition, face masks can remain in landfills for extended periods because they are made of non-biodegradable thermoplastic polymers [10,11]. A report published by OceansAsia stated that approximately 1.56 billion discarded face masks leaked into the seas in 2020 [12]. These plastic-based face masks can gradually decompose and break into microplastic particles in the water column [13–17]. Consequently, marine organisms may absorb these microplastic particles, causing physical damage and posing a risk of contaminating the human food chain [5,8,13,17]. Although a vaccine against COVID-19 has been developed, the timeline for the complete conclusion of the pandemic remains uncertain [5]. The global supply of face masks has been estimated to increase at a compound annual growth

* Corresponding author.
*E-mail addresses:* s3557884@student.rmit.edu.au (J. Zhu), mohammad.boroujeni@rmit.edu.au (M. Saberian), jie.li@rmit.edu.au (J. Li), ehsan.yaghoubi@vu.edu.au (E. Yaghoubi), tareq.rahman@roads.vic.gov.au (M.T. Rahman).
[1] Jiasheng Zhu and Mohammad Saberian are joint first authors.

https://doi.org/10.1016/j.conbuildmat.2023.132524
Received 9 February 2023; Received in revised form 3 July 2023; Accepted 13 July 2023
Available online 18 July 2023
0950-0618/© 2023 The Author(s). Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

**Nomenclature**

| | |
|---|---|
| PPE | Personal protective equipment |
| SMA | Stone mastic asphalt |
| MF | Mask fibre |
| CF | Cellulose fibre |
| PP | Polypropylene |
| HMA | Hot mix asphalt |
| OBC | Optimum bitumen content |
| PMB | Polymer-modified bitumen |
| SMA10H | Heavy-duty SMA with 10 mm nominal maximum gradation |
| VMA | Voids in mineral aggregate |
| VFA | Voids filled with asphalt |
| $M_R$ | Resilient modulus |
| LVDTs | Linear variable differential transducers |
| P | Vertically applied load |
| N | Poisson ratio |
| H | Recovered horizontal deformation of the specimen after application of load |
| $h_c$ | the height of the SMA specimen |
| TSR | Tensile strength ratio |
| $S_1$ | the average tensile strength of the unconditioned (dry) SMA specimens |
| $S_2$ | the average tensile strength of the conditioned (wet) SMA specimens |

rate of 20% through 2025 [27]. Even if the COVID-19 situation ends, there will still be a significant demand for face masks in healthcare and other domains. Abovementioned studies and statistics show that discarded face masks can cause long-term, devastating, and irreversible impacts on ecology, economy, and human health.

As a means of alleviating such negative effects, researchers were working toward reusing discarded masks in civil construction projects such as concrete [11], pavement base/subbase layers [4], subgrade layer and soil stabilisation [18]. However, there is limited research on the use of waste masks in different types of asphalt mixtures. Currently, 95% of the highways around the globe are flexible, with the surface layer made up of asphalt concrete mixture [19]. The total length of paved roads in Australia has exceeded 310,000 km. The annual consumption of bitumen has exceeded 800,000 metric tonnes, and the annual production of asphalt concrete has reached around 10 million metric tonnes in Australia [20,21]. Therefore, introducing waste masks in the large-scale construction of flexible pavements can significantly reduce the volume of waste masks and assist in sustainable practices for future pavement projects.

Several investigators have studied the possibility of using various plastic-based fibres in asphalt concrete to solve problems associated with plastic wastes and improve the engineering properties of asphalt mixtures [22]. Putman and Amirkhanian (2004) compared the performance of stone mastic asphalt (SMA) reinforced with tyres, carpet, polyester, and cellulose fibres. The toughness of asphalt mixtures prepared with polyester, carpet, and tire fibres was higher than that of SMA samples prepared with cellulose fibres. The effect of tire and carpet fibres in improving permanent deformation and moisture susceptibility was comparable to that with cellulose or polyester fibres [23]. Tapkın (2008) investigated the effect of PP fibres on the performance of asphalts that were produced at optimum bitumen content. It was demonstrated that the addition of PP fibres to asphalt mixes could provide better rutting resistance, prolong fatigue life, and reduce reflective cracking [24]. Xu et al. (2010) conducted a comprehensive study to investigate the effect and mechanism of asphalt concrete reinforced with four different types of fibrous additives (i.e., polyester, polyacrylonitrile, lignin, and asbestos). It was reported that fibre-reinforced asphalt concrete mixtures exhibited better rutting resistance, fatigue life, and toughness. Compared to asbestos and lignin fibres, polymer fibres (polyester and polyacrylonitrile) showed more significant effects on fatigue performance because of their excellent networking effects [25]. Yin and Wu (2018) studied the performance of stone matrix asphalt containing different percentages of waste nylon fibres through comprehensive experiments, including three-point flexural, rutting test, Marshall stability test, and moisture susceptibility test. The experimental results indicated that the inclusion of nylon fibres enhanced the low-temperature crack resistance, high-temperature stability, and moisture sensitivity of the stone matrix asphalt mixtures. The strengthening mechanism was explained by the retarding effect of nylon fibres on the development of cracks [26].

Currently, researchers have made impressively promising development in their investigation of reusing masks in hot mix asphalt (HMA) [5,27]. Wang et al. (2022) investigated the rut depth of HMA mixed with various ratios of shredded face mask (i.e.,0%, 0.25%, 0.5%, 0.75%, 1%, 1.25%, and 1.5% by weight of the asphalt mixtures). The experimental results illustrated that the inclusion of 1.5% shredded mask resulted in a significant reduction of 69% in the rutting depth value in comparison with the control sample. The increased stiffness and rutting resistance of the asphalt mix were explained by the effect of the shredded face mask enhancing the adhesion between aggregate and bitumen materials [27]. In addition, a series of mechanical tests, including Marshall stability, resilient modulus, moisture damage, indirect tensile, fatigue, and rutting tests, were carried out by Goli and Sadeghi (2022) [5] to study the engineering properties of HMA prepared with different ratios of mask fibre (0%, 0.07%, 0.1%, 0.12%, and 0.15% by the weight of aggregates) with two different lengths (8 mm and 12 mm). Test results indicated that adding mask fibres could improve the indirect tensile strength, rutting performance, moisture damage resistance, durability, and longevity of pavements and decrease the permanent deformations of the HMA mixture. It was also revealed that the mask fibre could provide higher adhesion between bitumen and aggregates particles, withstand tensile force, and absorb energy when HMA samples were subjected to the traffic load [5]. Previous investigations have demonstrated the prospect of reusing and recycling waste masks in hot mix asphalt [5,27]. However, there is no study on applying mask fibres (MF) in SMA as an alternative to traditional cellulose fibres (CF). Compared to the standard HMA mixtures, SMA generally contains higher-quality mineral aggregates. The excellent mechanical and physical properties of high-quality aggregates are needed for the aggregate-to-aggregate contact structures. The high proportion of coarse aggregates in the SMA mix provides higher rutting resistance and durability compared to HMA [21,28]. Nevertheless, CFs are required to be added in SMA to prevent binder drain-off during the mixing process, placement, and transportation due to the higher bitumen content in SMA according to Pavement Technology Guidance recommended by Austroads [29].

## 2. Current research

The sustainable technology of reusing discarded masks in asphalt mixture can provide an alternative solution to mitigate the deleterious impacts of epidemic-related waste. However, there is a lack of knowledge about mask wastes in pavement asphalt layer applications. In addition, the application of masks as fibre additives in SMA has never been studied. This study focuses on applying MF as an alternative to CF to enhance the mechanical performance of stone mastic asphalt for heavy traffic design, thus developing a sustainable pathway to reduce stockpiles of mask waste. For the first time, a comprehensive experimental study was conducted to evaluate the volumetric and mechanical performance of the SMA mixes blended with 0.3% CF and different percentages of MF being, 0.3%, 0.5%, 0.7%, and 1.0% by the weight of asphalt mixture. Following VicRoads standard document Section 404 Stone Mastic Asphalt, the proportion of CF is suggested as 0.3% by the weight of the asphalt mixture [30]. The specific aims of the present research are described as follows.

Compare SMA made with MF and those with CF as the control.
Conduct experiments to determine the effect of blending different proportions of MF to SMA.
Evaluate the potential for MF to replace CF in the SMA mix.

## 3. Materials and methods

### 3.1. Research design

The research plan can be divided into two main stages, as shown in the research design diagram of Fig. 1. The first stage consists mainly of the preparation of MF and gradation setting, the determination of the optimum bitumen content (OBC), and the preparation and compaction of SMA samples mixed with MF and CF. The second stage includes a series of performance evaluations of the SMA samples. The volumetric assessment, Marshall stability and flow test, resilient modulus test, dynamic creep test, moisture susceptibility test, and binder drain-off test were conducted on the SMA samples in this stage. Finally, the mechanical properties of SMA specimens prepared with MF were compared with the control SMA specimens containing 0.3% CF to investigate the potential use of MF as a substitute for CF in SMA mixtures.

### 3.2. Materials

The aggregate and bitumen for this research were supplied by Boral Asphalt, Victoria. Class 1 granite crushed stone aggregates were adopted. The maximum allowable flakiness index of coarse aggregates is 35% for heavy traffic design [31]. The flakiness index of coarse aggregates in this study was determined to range from 30 to 35% following AS 1141.15 (1999) [32], complying with the requirements of the regulation. Polymer-modified bitumen (PMB) A10E was used as the binder in this research. PMB A10E is the bitumen generally selected for the production of SMA because it can improve the deformation resistance of SMA [28,29]. The softening point of the PMB A10E was 90.7℃, viscosity at 165℃ was 1.03 Pa.s., and the penetration value was 62.2 dmm.

The medical three-layers masks used in this study were collected by the authors during their daily lives. Isolation and dry heat disinfection processes were implemented to sanitise the used masks. The isolation and disinfection procedures were referenced from the research undertaken by Zhu et al. (2022). The researchers performed a similar process for disinfecting the used plastic-based nitrile gloves [33]. Firstly, the used masks were kept in a sealed container for at least four days for isolation treatment. According to the research on the aerosol and surface stability of the virus conducted by Doremalen et al. (2020), the novel coronavirus can survive on the surface of plastic materials for up to 72 h [34]. After isolation treatment, the used masks were placed in a 70-degree oven for one hour according to the dry heat disinfection procedure suggested by Xiang et al. (2020), who stated that used surgical masks could be disinfected by heating them at 70 °C for one hour [35]. The metal strips and earloops were removed from the sterilised masks, and next these disinfected masks were ground in a grinder and turned into MF, as shown in Fig. 2. To find out whether the masks fibre could remain as fibrous material in the SMA after mixing and compaction at high temperatures, randomly selected seven discarded masks and seven piles of MF were placed in an oven at 165 °C for 2, 6, 8 and 10 min and 1 h respectively. Fig. 3 (a) shows that the mask slightly shrank at a high temperature due to surface tension but maintained its initial shape for 2 to 10 min. Fig. 3 (b) shows that there was no significant change in the MFs at a heating time between 2 and 4 min. During the heating times of 6, 8 and 10 min, it was observed that most of the MFs were maintained; however, a small portion of the MF melted at 165 °C and bonded with other fibres. The melted portion solidified rapidly when the MFs were removed from the high-temperature environment.

### 3.3. Preparation of SMA

Heavy-duty SMA with 10 mm nominal maximum gradation (SMA10H) was selected for this research. According to VicRoads standard Section 404, the bitumen used in SMA10H should be PMB A10E [30]. Table 1 shows the grading distribution of aggregates followed in the preparation of SMA samples. Fig. 4 illustrates the particle distribution curve for the aggregates used in this study, as well as the upper and lower limits of aggregate passing the sieve according to VicRoads standard [30].

Following AS/NZS 2891.2.2 (2014), trial SMA mixtures were prepared by using a SERVOPAC Gyratory compactor to obtain the OBC [36]. According to VicRoads (2018), the proportions of bitumen should lie within the range of 6.0% – 7.0% for preparing SAM10H [30]. The A10E bitumen contents used during the tests were 6%, 6.3%, 6.5%, and 6.7% by the weight of the asphalt mixtures, respectively. VicRoads (2018) recommends that the air void of SMA10H should be in the range of 4.8% to 5.2% [30]. Therefore, the air void of the trial SMA samples was maintained at 5% in this study. The Marshally stability and flow test

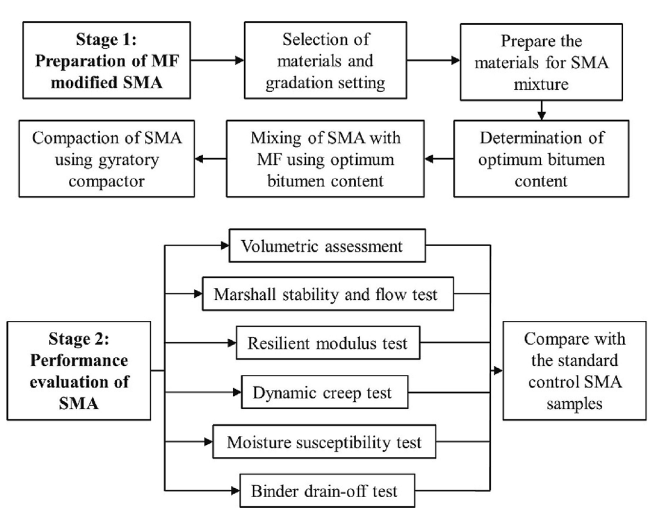
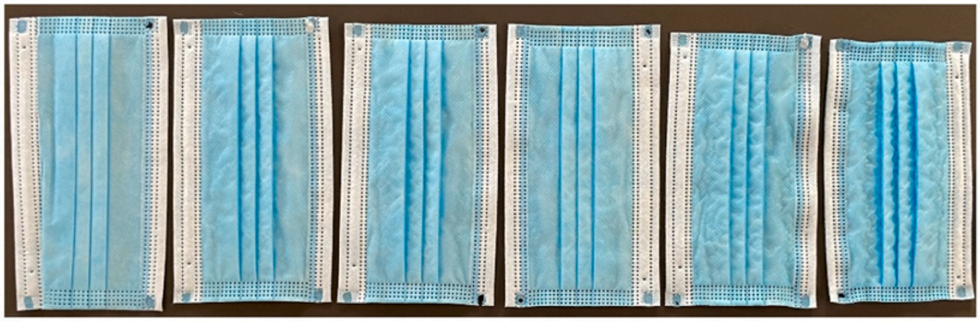



**Fig. 1.** The research plan designed for this study.

**Fig. 2.** An image of the mask fibre prepared for this study.



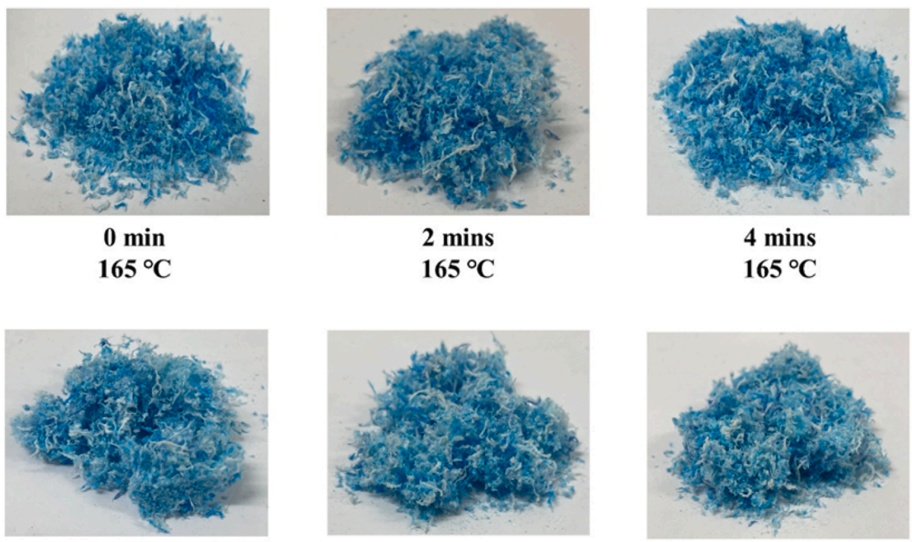




**Fig. 3.** Melting of the (a) discarded mask (b) mask fibre at a constant temperature of 165 °C at different durations.

**Table 1**
Grading distribution of aggregates followed in the preparation of SMA samples.

| Sieve size (mm) | Percentage cumulative retained on the sieve (%) | Percentage passing through the sieve (%) |
|---|---|---|
| 9.5 | 5.00 | 95.00 |
| 6.7 | 65.00 | 35.00 |
| 4.75 | 75.00 | 25.00 |
| 2.36 | 77.50 | 22.50 |
| 1.18 | 81.50 | 18.50 |
| 0.6 | 83.50 | 16.50 |
| 0.3 | 86.00 | 14.00 |
| 0.15 | 88.00 | 12.00 |
| 0.075 | 90.00 | 10.00 |

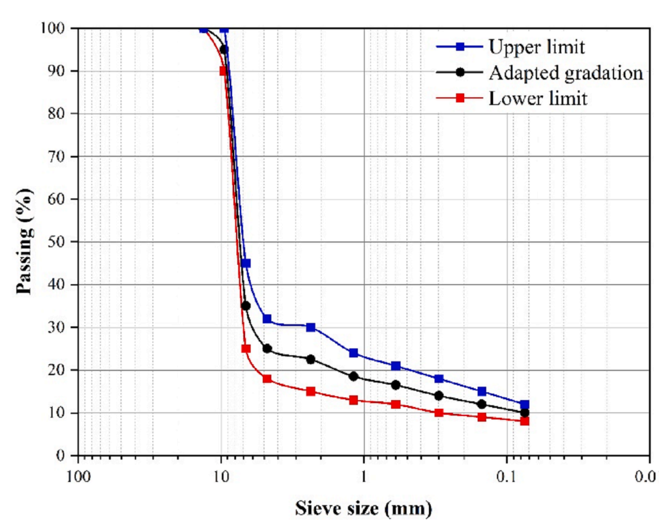



**Fig. 4.** The particle size distribution curve of SMA aggregates.

was performed in accordance with the AS 2891.5 (2004) to obtain the OBC among the trial mixes [37]. It was found that the SMA prepared with 6% PMB A10E exhibited the highest Marshall stability value, as shown in Fig. 5.

Evirgen et al. (2021) and Morova (2013) claimed that the inclusion of different percentages of fibrous additives with optimum bitumen content provided similar results [38,39]. The application of fibres is very

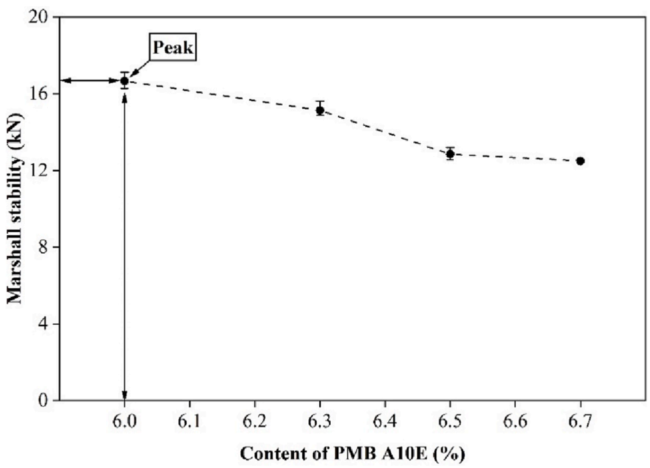


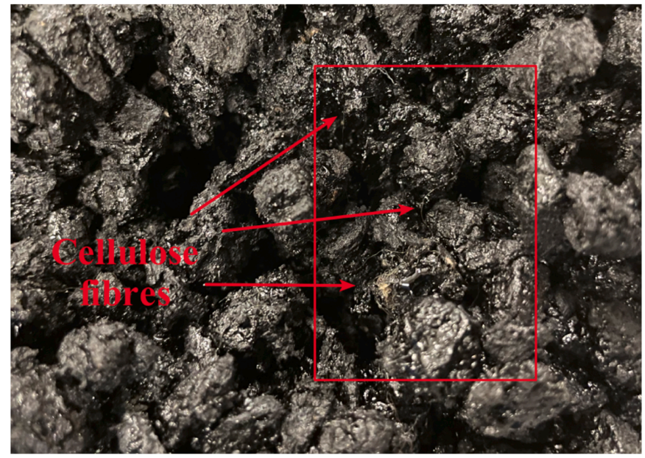

**Fig. 5.** Determination of optimum bitumen content.

small in quantity; hence the proportion of bitumen may have a very low impact on the strength. Therefore, 6% A10E by weight of asphalt mix was considered as the OBC for all SMA sample preparation. Five types of SMA specimens were prepared, including SMA prepared with 0.3% CF (control sample) and SMA prepared with 0.3%, 0.5%, 0.7%, and 1% MF by weight of asphalt mixture. This percentage range is consistent with the previous studies on using plastic-based fibre additives for asphalt applications [23–26]. The gradation of aggregate, as illustrated in Table 1, was maintained throughout the process. The aggregates were dried in the oven and mixed with bitumen and fibres at 165 °C using a PAVEMIX asphalt automatic laboratory mixer for 5 min. Following AS/NZS 2891.2.2 (2014), a SERVOPAC Gyratory compactor was used to compact and produce the cylindrical SMA specimens of 100 mm in diameter and 65 mm in height after mixing, as shown in Fig. 6 [36]. Air void of each SMA sample was maintained at 5% during the compaction process, following the guidelines recommended by the VicRoads standard [30]. An additional 1 kg of the loose mixture was prepared for the five SMA mixtures for conducting the binder drain-off test. Three replicate specimens were prepared and tested for each test, and the average results were reported. Fig. 7 shows the loose mixture with CF and MF. It was evident that although a small proportion of MF melted during the high-temperature mixing and compaction process, the majority of the mask was present in the SMA in the form of fibres.

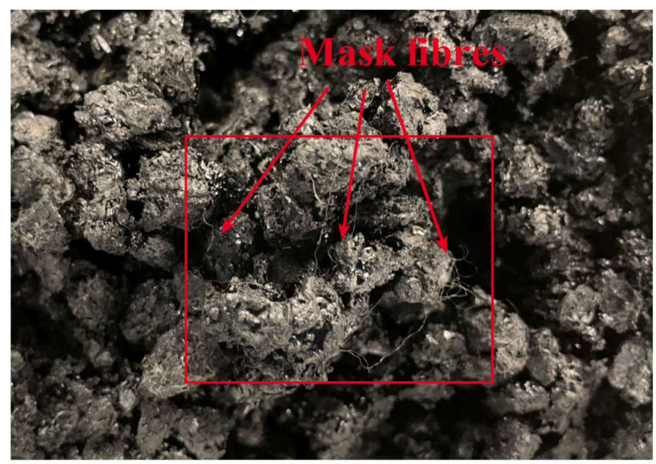
### 3.4. Experimental procedures

After the compaction process, the physical and volumetric assessments were conducted on the compacted SMA specimens. The Marshall stability and flow [37], density, voids in mineral aggregate (VMA), and voids filled with asphalt (VFA) [40] were investigated by following the guidelines recommended by relevant Australian standards. The Marshall stability and flow test is one kind of rupture test. After conditioning the SMA specimens in a MATEST water bath with a digital thermostat at 60 ± 1 °C for 2 h, the conditioned SMA specimens were positioned horizontally in the braking head. A diametric load was applied using the Shimadzu testing machine with a 50 mm/mins loading rate. The sustaining period of the SMA specimens was determined by observing the time to reach peak stability value [28].

The resilient modulus test was performed on the SMA specimens according to AS/NZS 2891.13.1 (2003) using the indirect tensile method to evaluate the stiffness of the asphalt samples [41]. Resilient modulus ($M_R$) is the essential parameter indicating the amount of energy that the SMA specimen can absorb without permanent deformation. In order to understand the effect of temperature variations on the stiffness of




(a)




(b)

**Fig. 7.** Loose mixtures with (a) cellulose fibre and (b) mask fibre.


**Fig. 6.** Five types of SMA prepared for the experimental studies.

asphalt mixtures, SMA specimens were tested at 10 °C, 25 °C, and 40 °C, respectively. Following AS/NZS 2891.13.1 (2003), the rise time of 40 ± 5 ms, pulse repetition period of 3000 ± 5 ms, and recovered horizontal stain of 50 ± 20 με were selected [41]. AsphaltQube, the modular electro-mechanically operated asphalt tester, was used to control the temperature variation and perform the test. The horizontal displacement of the specimens was measured by linear variable differential transducers (LVDTs). $M_R$ can be calculated by using Equation (1).

$$MR = P \times \frac{(v + 0.27)}{H \times h_c} \quad (1)$$

Where $M_R$ is resilient modulus; P is vertically applied load; $v$ is Poisson ratio; H is recovered horizontal deformation of the specimen after application of load; and $h_c$ is the height of the SMA specimen.

The dynamic creep test was performed to investigate the rutting characteristics of the SMA specimens according to AS 2891.12.1 (1995) [42]. Khodaii and Mehrara (2009) stated that the dynamic creep test correlated excellently with measured rutting depth, and the test was highly capable of detecting the rutting potential of asphalt pavement layers [43]. The dynamic creep test was chosen as an appropriate testing methodology for assessing the permanent deformation performance of asphalt mixtures [43,44]. The prepared SMA specimens were tested at two different applied stress levels of 200 kPa and 500 kPa at 50 °C. A rectangular pulse wave with a 0.5 s pulse wide and a 1.5 s rest period was chosen. Following the previous studies undertaken by Babalghaith et al. (2020), Lavasani et al. (2015), and Rahman and Mohajerani (2021), the termination condition in this study was considered as 2000 loading cycles [45–,47] or 30,000 με accumulated axial strain, based on AS 2891.12.1 (1995) [42]. AsphaltQube equipment was used to conduct the dynamic creep test. The axial deformation of the specimens was measured by LVDTs.

The loss of adhesion between aggregate particles and bitumen or the loss of cohesion within the bitumen is a consequence of moisture damage, which is mainly because of repeated traffic loading with the presence of water in the asphalt pavement [48,49]. The moisture susceptibility test was conducted on the SMA specimens using the indirect tensile method according to AASHTO T 283 (2017) [50]. The SMA specimens were divided randomly into two subsets, each consisting of three identical specimens. The dry subset was wrapped with plastic film and then placed in leak-proof plastic bags. The dry subsets were placed in a water bath at 25 °C for 2 h before testing. The wet subset was wrapped with plastic film and then placed in leak-proof plastic bags with water. The wet subset was conditioned in a freezer at a temperature of −18 ± 3 °C for 24 h, followed by soaking in a water bath at 60 °C for 24 h. The wet subset was moved to another water bath at 25 °C for 2 h before testing. A diametric load was applied to the specimens using the Shimadzu testing machine at a constant rate of 50 mm/mins. The tensile strength of both unconditioned (dry) and conditioned (wet) SMA specimens was investigated. The tensile strength ratio (TSR) was used to evaluate the moisture susceptibility of the SMA specimens following Equation (2).

$$\mathrm{TSR} = \frac{S_2}{S_1} \quad (2)$$

Where $S_1$ is the average tensile strength of the unconditioned (dry) SMA specimens and $S_2$ is the average tensile strength of the conditioned (wet) SMA specimens.

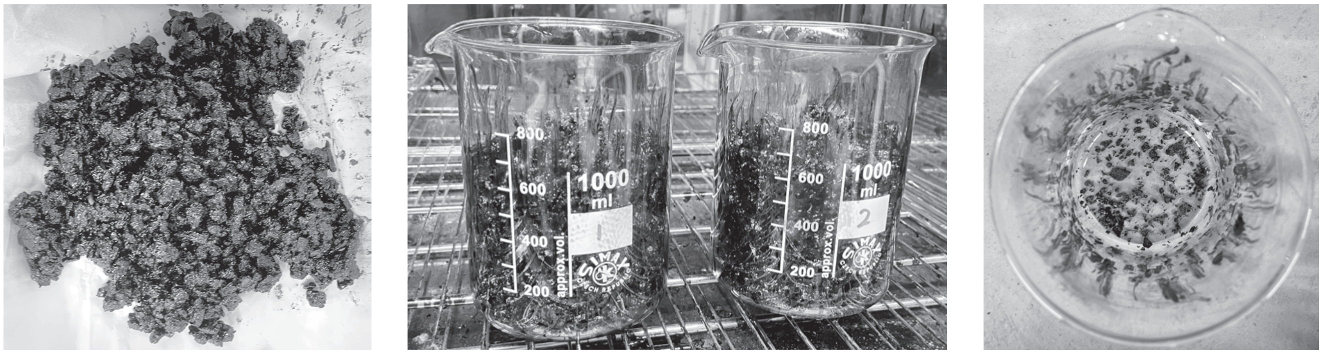
Binder drain-off test was carried out to investigate the amount of binder drain-off in SMA specimens at the maximum mixing temperature according to AG:PT/T235 (2006) [51]. The proportion of bitumen should be between 6% and 7% by weight of asphalt mixture to produce SMA10H, according to VicRoads (2018) [30]. Therefore, it was necessary to check for the binder drain-off due to the high content of bitumen in SMA. Binder drain-off can lead to the separation of bitumen and filler paste during the mixing and transportation to the site, causing some of the mix to become over-rich and fatty patches to appear on the surface of the new asphalt layer [51]. 1 kg of the SMA loose mix was placed in a preheated beaker, and its mass was measured. The loose mix and beaker were placed in an oven at 185 °C for 1 h. After 1 h, the beaker was removed from the oven, immediately turned over, and hung upside down on a metal tray for 10 ± 1 s to allow the bitumen to fall into the tray. The mass of the binder left in the beaker and the mass of the beaker were measured. Fig. 8 shows the steps of the binder drain-off process.

## 4. Result and discussion

### 4.1. The volumetric assessment and Marshall stability and flow test results

As a preliminary investigation, volumetric assessment and the Marshall stability and flow test were performed on five types of SMA specimens. The properties, including Marshall stability, flow, air void, density, VMA, and VFA were determined and shown in Table 2. The results indicate that increasing the MF content decreased the density of the SMA mixture, as the specific gravity of the fibres is much lower than that of the mineral aggregates [52]. The increase in VMA and VFA with increasing MF content in SMA can be explained by the replacement of mineral aggregates with higher content of MF in the asphalt mixture. Following the VicRoads standard, the standard range of air voids is between 4.8% and 5.2% [30]. In accordance with the Austroads standard, the general range of VFA is between 65% and 80%, and the typical range of VMA is between 13% and 20% [29]. According to industry requirements and standards, the VMA and VFA were found to be applicable to all SMA specimens.

Fig. 9 illustrates the results of the Marshall stability and flow test. It can be observed that the stability increased as the percentage of MF in the SMA increased. In comparison to the control sample (0.3% CF), the stability of SMA specimens prepared with 0.3% and 0.5% MF increased by 1.2% and 3.5%, respectively (Fig. 9 (a)). A similar result for SMA containing PP fibre and nylon fibre was presented by Asmael et al. (2010), Tapkın (2008) and Yin and Wu (2018) [24,26,53]. The joint between mineral aggregates and bitumen was strengthened by MFs, which helped to effectively limit the relative movement between the aggregates when subjected to loads and provided greater load-bearing capacity on the joint surface. A more robust filamentary network was generated by increasing the content of MF in the asphalt mixture, thus increasing the marshall stability [5]. However, the Marshall stability of the specimens decreased continuously when the MF addition exceeded 0.5%. The reduction in stability is due to the large amount of MF preventing the effective binding between bitumen and aggregates. In addition, the partial replacement of rigid aggregates by relatively soft MF reduced the stiffness of SMA specimens. In previous studies, researchers found that excessive amounts of nylon and PP fibre reduced the stability of asphalt mixtures [26,53]. It can be concluded that incorporating the appropriate content of MF can increase the stability of SMA. Fig. 9 (b) and 9 (c) illustrate the effect of MF content on the flow and sustaining period of SMA. The incorporation of 0.5% MF resulted in a reduction in flow from 9.46 mm to 5.92 mm and a decrease in the sustaining period from 11.67 s to 7.67 s compared to the control sample. However, when MF content increased to 1.0%, MF in SMA significantly increased the flow to 9.51 mm and extended the sustaining period of SMA to 12.17 s. It is notable that although the addition of 0.3%, 0.5%, and 0.7% MF enhanced the stability of the SMA compared to the control specimen, they reduced the flow and sustaining period, which means that the samples had less time to resist peak loads and less ability to deform vertically. A similar trend illustrating a notable decrease and then a gentle increase in the flow value of SMA blending with PP and carbon fibre was reported by Asmael et al. (2010) [53]. Tapkın (2008) also reported a reduction in the flow of SMA due to the addition of PP fibres [24]. The Marshall stability for highly trafficked and heavy-duty pavements is at least 8.0 kN [54]. Asphalt mixes with low flow values are more susceptible to fatigue cracking, while higher flow values can lead to rutting and bleeding. Thus, a flow with a targeted range of 8 mm



(a) (b) (c)

**Fig. 8.** Binder drain-off process: (a) loose mix, (b) loose mix in the beaker, and (c) drain-off binder with fine aggregates retained in the beaker.

**Table 2**
Results of volumetric assessment and Marshall stability and flow tests.

| SMA sample type | Marshall stability (kN) | Flow (mm) | Air void (%) | Density (t/m3) | VMA (%) | VFA (%) |
|---|---|---|---|---|---|---|
| 0.3% CF | 16.66 | 9.46 | 5 | 2.421 | 14.74 | 66.08 |
| 0.3% MF | 16.86 | 9.15 | 5 | 2.412 | 15.07 | 66.81 |
| 0.5% MF | 17.25 | 5.92 | 5 | 2.409 | 15.17 | 67.04 |
| 0.7% MF | 16.70 | 7.50 | 5 | 2.401 | 15.44 | 67.63 |
| 1.0% MF | 16.38 | 9.51 | 5 | 2.369 | 16.57 | 69.83 |

and 14 mm is also required [54]. The stability of all the SMA specimens tested was much higher than the minimum values recommended by the guideline (Fig. 9 (a)); however, the detected flow values of SMA specimens prepared with 0.5% and 0.7% MF were below the standard ranges (Fig. 9 (b)).

### 4.2. Resilient modulus test results

The results of the resilient modulus tests for all SMA specimens at 10 °C, 25 °C, and 40 °C, respectively, are presented in Fig. 10. It can be observed that the introduction of MF in SMA increased the resilient modulus of the specimens compared to the control specimen (i.e., 0.3 % CF) at all of the tested temperatures. For instance, at 25 °C, a remarkable increase in the resilient modulus value by 53% was observed in SMA mixed with 0.3% MF, and the specimen prepared with 0.5% MF showed a 77.9% increase in comparison to the results for the control specimen. This indicates that the MF in SMA improved the stiffness of the mixture. The inclusion of MF in SMA mixtures created a reinforcing filament network that stabilised the binder on the surface of aggregates and limited the movement of aggregates when the SMA specimens were subjected to loads [5]. In addition, high temperatures during the mixing and compaction process led to the surface melting of the MF. The partially melted mask strengthened the bond between aggregate particles [5]. A portion of melted MF combined with bitumen at high temperatures during the sample preparation process and solidified at low temperatures, which increased the viscosity of the bitumen binder resulting in an increased resilient modulus. However, the resilient modulus decreased as the MF content exceeded 0.5%. The addition of 0.7% MF and 1.0% MF resulted in a 14.0% and 20.3% decrease in resilient modulus compared to the specimen prepared with 0.5% MF, respectively. The excessive addition of MF replaced the aggregates, resulting in a softer SMA sample and reducing the strength of the asphalt mixture. Following the recommendations, at 25 °C, the minimum resilient modulus of SMA10H prepared with PMB A10E bitumen is 1500 MPa at the rise time of 40 ms [28,29]. Thus, according to the results, all SMA specimens met the requirement. It is worth pointing out that although the inclusion of 1% MF leads to a reduction in the resilient modulus, the resilient modulus of the specimen containing 1% MF is still higher than that of the control specimen at all target temperatures. It can be concluded that the inclusion of MF in the asphalt mixture significantly increased the resilient modulus and enhanced the resistance to permanent deformation of SMA.

Fig. 10 also shows that the resilient modulus values of the specimen at 10 °C are considerably higher than those measured at 25 °C. However, the resilient modulus results of specimens measured at 40 °C were less than those measured at 25 °C. Bitumen binder is highly susceptible to temperature. The viscosity of the bitumen increases rapidly with decreasing temperatures, leading to a significant improvement in strength and a requirement for more energy to split the binding.

### 4.3. Dynamic creep test results

In dynamic creep testing, the temperature condition of 50 °C and the applied stress level of 200 kPa are used to determine the permanent deformation under the standard condition following AS 2891.12.1 (1995) [42]. Nevertheless, in this study, increasing the stress level to 500 kPa was also intended to simulate the increasing load on tyres in heavy vehicles in modern times. Fig. 11 shows the results of the dynamic creep test under both 200 kPa and 500 kPa conditions. The results showed that the replacement of 0.3% CF with 0.3% MF significantly reduced the permanent strain level of SMA. However, the permanent strain level steadily increased when the inclusion of MF exceeded 0.3%. In addition, the increase in stress level from 200 kPa to 500 kPa led to an increase in the permanent strain level of the SMA. The permanent deformation of the SMA specimens under both conditions at 2,000 loading cycles is illustrated in Fig. 12. The lower depth of permanent deformation demonstrates higher resistance to rutting. It was observed that replacing 0.3% MF with 0.3% CF in SMA showed better performance in terms of rutting resistance. Compared to the control sample, the SMA mix containing 0.3% MF showed a 34.1% and 37.6 % improvement in resistance to permanent deformation at 200 kPa and 500 kPa, respectively. However, a steady increase in the depth of permanent deformation was observed as SMA was prepared with 0.5%, 0.7% and 1.0% MF. The enhancement in the deformation resistance of the SMA specimens can be explained by the strong filament network formed by the MF preventing the movement of the aggregates at the high temperatures of 50 °C and the tensile strength provided by the appropriate proportion of MF. In addition, the melting and hardening process of the MFs enhanced the adhesive strength between the mineral aggregates, thus resisting the flow of the asphalt under repeated stress. However, when the fibre content exceeded 0.5%, excessive fibres tended to entangle together and decreased the adherence capability between the aggregates and bitumen, thus reducing the strength. The reduced

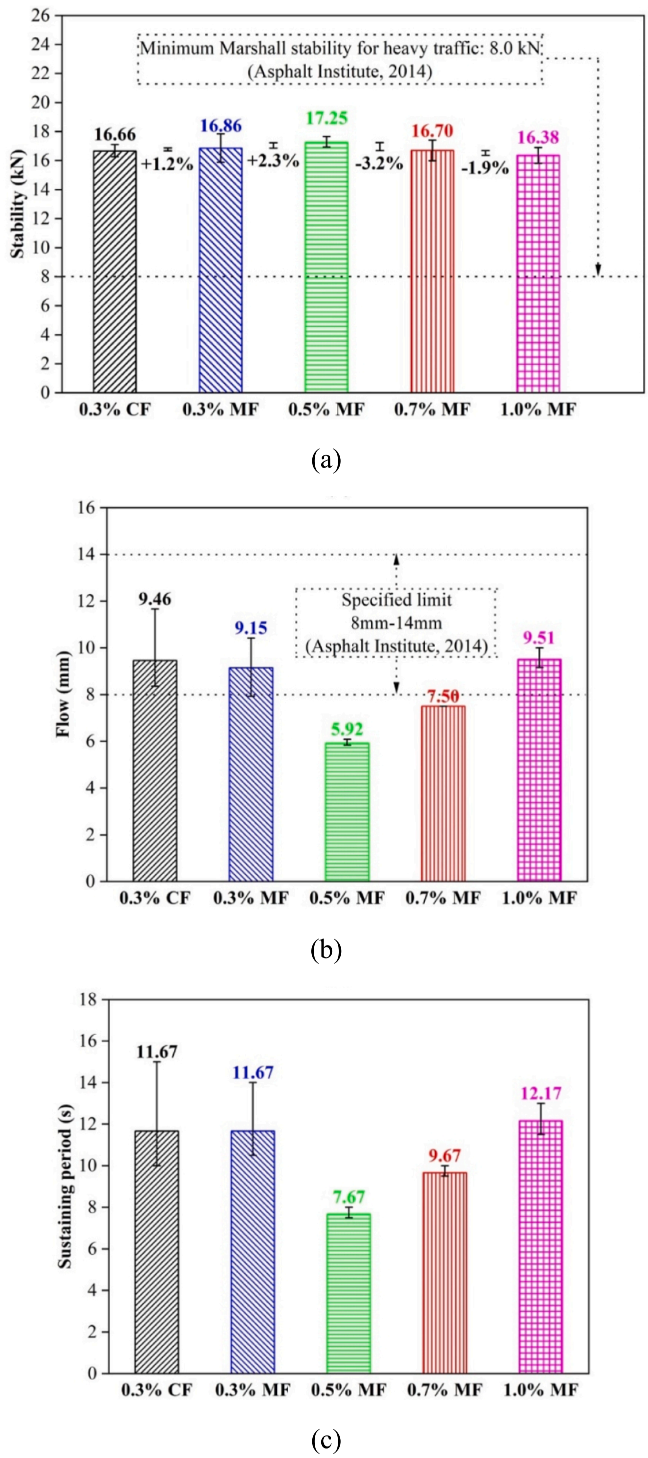



**Fig. 9.** Results of Marshall stability and flow test; (a) Marshall stability (b) Flow (c) Sustaining period of SMA.

hardness of the SMA specimens due to the replacement of aggregates by MF is also responsible for the reduced rutting performance. Lavasani et al. (2015) and Yin and Wu (2018) also observed similar results on the use of nylon fibre, polyester, and rockwool for stone mastic asphalt [26,46].

### 4.4. Moisture susceptibility test results

Moisture damage is defined as the progressive loss of durability and strength of asphalt mixtures through the loss of adhesive strength between the surface of aggregates and bitumen and the loss of cohesion within the binder due to the effect of water [55,56]. It is important to ensure that the asphalt pavement is not susceptible to moisture damage because the presence of moisture in asphalt causes damages such as potholes and stripping. The moisture susceptibility test was conducted on all SMA specimens and presented in terms of the tensile strength ratio (TSR).

Fig. 13 (a) illustrates the split indirect tensile strength of both unconditioned (dry) and conditioned (wet) SMA specimens. The replacement of CF with MF could effectively increase the split indirect tensile strength of SMA specimens. The split indirect tensile strengths of the dry and wet SMA specimens containing 0.3% MF were 19.3% and 19.5% higher than those of the SMA incorporating 0.3% CF, respectively. The split indirect tensile strengths of both unconditioned and conditioned SMA specimens reached the maximum values of 1.616 and 1.575 MPa, respectively, when the MF content was 0.5%. The improvement in the split indirect tensile strength is attributed to the presence of MF in SMA, providing the network effect, the bridging effect of cracking, and the stress redistribution. The addition of fibre greatly affected the absorption and stabilisation of the asphalt, enhancing the interfacial adhesion and improving the stiffness and viscosity of the asphalt mixture [57]. Nevertheless, the split indirect tensile strength decreased as MF content exceeded 0.5%. The decrease in tensile strength is due to the softness of the asphalt mixture caused by the excess of MF, as mentioned previously. Furthermore, the excessive addition of MF led to agglomeration and created weak areas in the asphalt mix, which in turn negatively impacted the interlocking effect between the aggregate particles. It is worth emphasising that although further increases in MF addition resulted in a reduction in split indirect tensile strength, the SMA specimens containing 1.0% MF still exhibited a greater tensile strength than SMA containing 0.3% CF. It can be concluded that the addition of a suitable amount of MF provided a significant improvement in the indirect tensile strength, which is consistent with the findings of Yin and Wu (2018), who concluded that incorporating nylon fibres in appropriate content significantly increased the splitting strength of SMA [26].

Fig. 13 (b) illustrates the results of the moisture susceptibility test and the percentage of changes in the TSR for different SMA specimens. The TSR value of SMA specimen containing 0.3% MF is slightly higher compared with the SMA mixed with 0.3% CF. It is evident that the SMA specimen mixed with 0.3% MF had a comparable resistance to moisture damage as the control specimen. The resistance to moisture damage increased with the increase of MF content in SMA specimens. When the MF content was increased from 0.3% to 1.0%, the TSR increased from 0.967 to 0.995. The increased resistance to moisture damage can be attributed to the presence of face MFs forming a thin protective layer around the bitumen and the aggregate particles, which weakened the ability of the aggregate particles to absorb water. The addition of MF increased the adhesion between the asphalt binder and the aggregate making the integral hard to become loose. Moreover, MF improved the anti-cracking performance of the asphalt mix, thus preventing the generation and development of surface cracks which protected the SMA mixture against moisture. These results are consistent with previous investigations, where researchers found that adding nylon and polypropylene fibres in appropriate amounts contributed to improving the resistance of SMA mixtures to moisture damage [26,38]. Following AASHTO M 323 (2013), a minimum TSR value of 0.8 is required for pavement construction [58]. The TSR values for all SMA specimens are above 0.8, demonstrating that all the specimens meet the requirement regarding moisture sensitivity.

### 4.5. Binder drain-off test results

Fig. 14 illustrates the results of the binder drain-off test and the maximum limit suggested by VicRoads and Austroads. SMA mix prepared with 0.3% CF showed a 0.090% of binder drain-off. As the addition of MF increased from 0.3% to 1.0%, the binder drain-off values

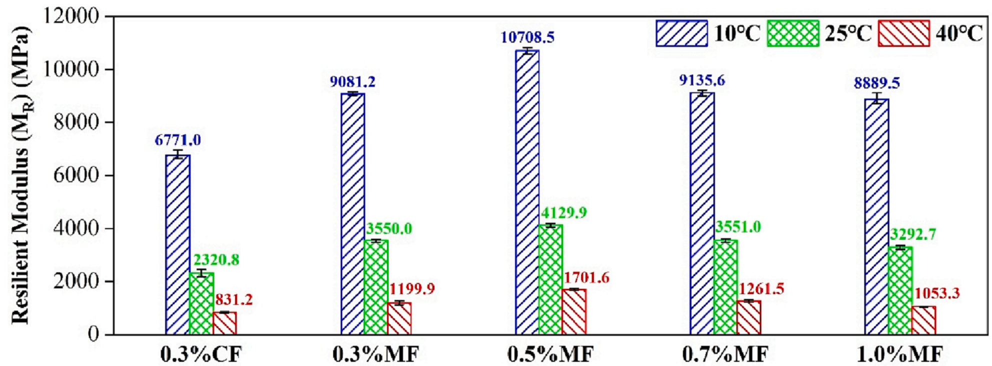



**Fig. 10.** Resilient modulus test results of SMA specimens at 10 °C, 25 °C, and 40 °C.

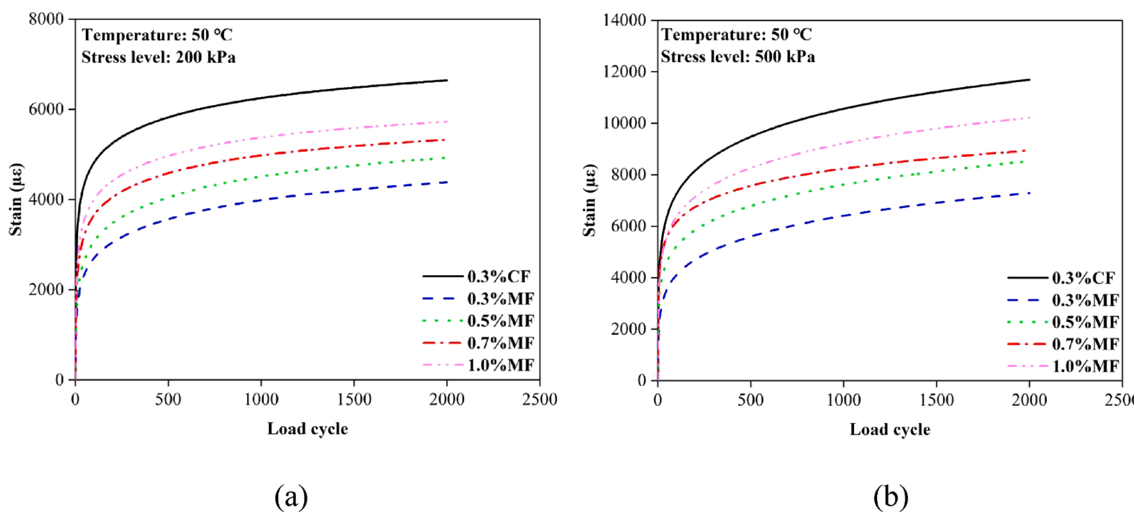


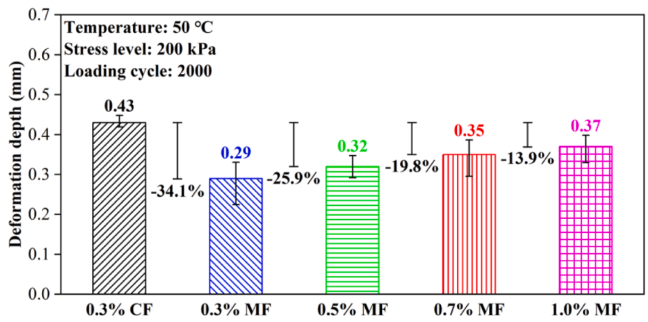

**Fig. 11.** Number of load cycles versus permanent strain of SMA under (a) 200 kPa and (b) 500 kPa conditions.

decreased from 0.080% to 0.053%. The results indicate that introducing MF contributed to a reduction in drain-off, decreasing the loss of binder during transportation from the plant site to the paving site and during the mixing process. Previous studies demonstrated that the addition of ethylene–vinyl acetate [59], polyethylene terephthalate [60] and cigarette butt fibre [61] to SMA mixture improved resistance to binder drain-off. The incorporation of fibrous materials into the asphalt mixture increases the viscosity of the mix and offers the capacity to retain the asphalt as the temperature rises during the drain-off process [62]. The melted MF at high temperatures (185 °C) increased the stiffness of the bitumen, thus reducing the risk of binder drain-off due to the high bitumen binder content. The maximum binder drain-off should not exceed 0.3% according to VicRoads and Austroads regulations [29,30]. The binder drain-off values for all types of SMA samples are well below 0.3%, satisfying the requirements of the abovementioned regulations.

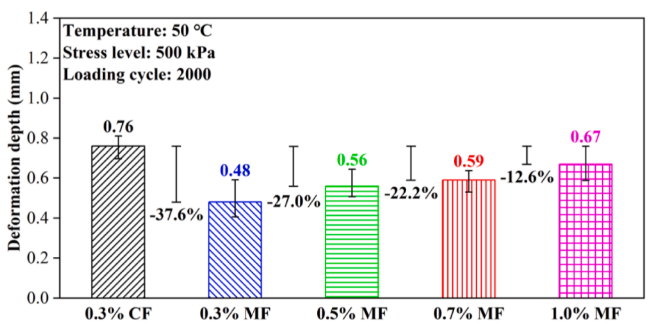
## 5. Conclusions and recommendations for future studies

The increasing amount of pandemic-related mask waste has become a global challenge. This study proposes a sustainable solution to reduce pandemic-related waste by recycling used face masks in the surface layer of flexible pavement. For the first time, the masks were used as fibre additives in the stone mastic asphalt mixture. Various tests were performed to assess the performance of the asphalt mixtures. The following findings can be summarised from the experimental results of this study.

- It was observed that the inclusion of MF reduced the density and increased the VMA and VFA of the SMA mixes. The VMA and VFA of all SMA specimens were within the standard limits (i.e., VMA:13%-20%; VFA: 65%-80%).
- The Marshall stability and flow test results showed that the inclusion of MF improved the stability of SMA. The stability of all the SMA specimens was above the minimum value required by the guideline (i.e., 8.0 kN). SMA prepared with 0.3% and 1% MF showed a flow value within the standard specified range (i.e., 8–14 mm).
- The variation of resilient modulus was investigated at three different temperatures, and it was concluded that MF in SMA increased the stiffness. All SMA specimens had resilient modulus values above the standard requirement at 25 °C (i.e., minimum resilient modulus of 1500 MPa).
- The dynamic creep test results indicated that the SMA prepared with 0.3% MF showed the highest resistance to rutting and permanent deformation.
- The incorporation of MF increased the TSR value, indicating an improvement in the resistance of SMA to moisture damage. The TSR values of all SMA samples were higher than the minimum requirements (i.e., minimum TSR of 0.8); therefore, it was concluded that the SMA prepared with MF exhibited adequate water susceptibility.
- The inclusion of MF improved the binder drain-off property, which contributed to the reduction of binder loss during transport from the plant site to the paving site. The binder drain-off values for all SMA specimens were well below the maximum binder drain-off value specified by the standard (i.e., 0.3%).
- This study determined the different parameters and properties of SMA prepared with different MF additions and found that all




(a)




(b)

**Fig. 12.** Permanent deformation of the SMA under (a) 200 kPa and (b) 500 kPa conditions at 2,000 loading cycles.

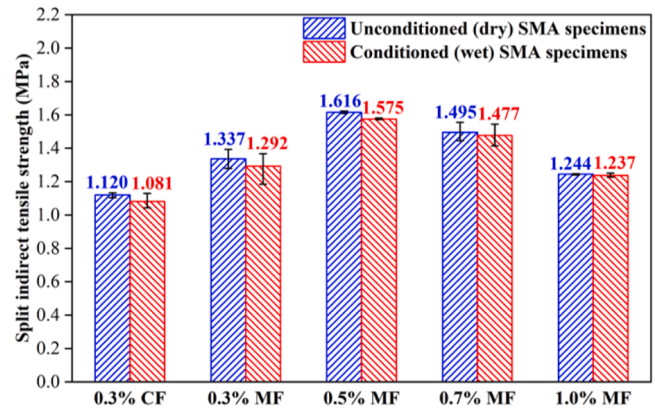
parameters of SMA specimens containing 0.3% and 1% MF met the regulations of the standards. Considering the performance of the mixes as mentioned above, SMA containing 0.3% MF showed more potential for SMA applications.

- Including 0.3% of MF in stone mastic asphalt could recycle approximately 7.2 kg of used masks in each cubic meter of SMA. It is estimated that up to 405.2 t of used face masks can be recycled and reused during the construction of a conventional 100 km long two-lane highway with a surface layer thickness of 40 mm.
- Overall, this research demonstrated that face masks have a great potential to be used as fibre additives to replace virgin cellulose fibres in stone mastic asphalt.

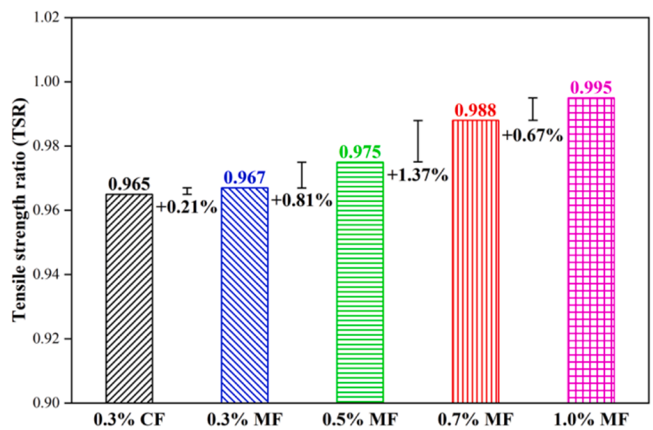
Considering that other types of face mask wastes (e.g., cloth masks) are generated, the presented testing methodology can be adopted for different types of mask wastes. For future works, it is recommended to conduct feasibility studies similar to the one carried out here to assess the potential applications of other types of masks in asphalt mixture.

## CRediT authorship contribution statement

**Jiasheng Zhu:** Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Mohammad Saberian:** Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – review & editing. **Jie Li:** Conceptualization, Formal analysis, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – review & editing. **Ehsan Yaghoubi:** Data curation, Formal analysis, Investigation, Methodology, Supervision, Validation, Visualization, Writing – review & editing. **Md Tareq Rahman:** Methodology, Validation, Investigation, Visualization, Writing – review & editing.




(a)




(b)

**Fig. 13.** Results of moisture susceptibility test; (a) Spilt indirect tensile strength (b) Tensile strength ratio of SMA specimens.

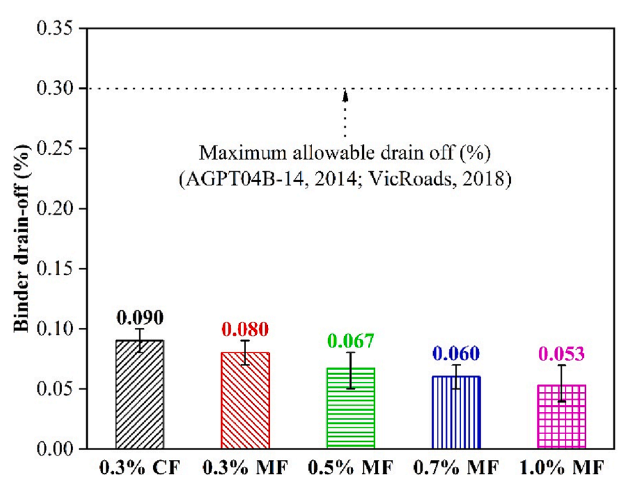



**Fig. 14.** Binder drain-off test results.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

## Acknowledgments

This research was supported by a veski fellowship to Mohammad Saberian and Philanthropy and the RMIT Sustainable Development Research Grants 2022.

## References

[1] S. Kilmartin-Lynch, R. Roychand, M. Saberian, J. Li, G. Zhang, Application of COVID-19 single-use shredded nitrile gloves in structural concrete: Case study from Australia, Sci. Total Environ. 812 (2022), 151423.
[2] S.A. Abbasi, A.B. Khalil, M. Arslan, Extensive use of face masks during COVID-19 pandemic:(micro-) plastic pollution and potential health concerns in the Arabian Peninsula, Saudi J. Biol. Sci. 27 (12) (2020) 3181–3186.
[3] M.A. Royo-Bordonada, F.J. García-López, F. Cortés, G. Andrés Zaragoza, Face masks in the general healthy population. Scientific and ethical issues, Gaceta Sanitaria 35 (2022) 580–584.
[4] M. Saberian, J. Li, S. Kilmartin-Lynch, M. Boroujeni, Repurposing of COVID-19 single-use face masks for pavements base/subbase, Sci. Total Environ. 769 (2021), 145527.
[5] A. Goli, P. Sadeghi, Evaluation on the use of COVID-19 single-use face masks to improve the properties of hot mix asphalt, Road Mater. Pavement Design (2022) 1–18.
[6] M. Boroujeni, M. Saberian, J. Li, Environmental impacts of COVID-19 on Victoria, Australia, witnessed two waves of Coronavirus, Environ. Sci. Pollut. Res. 28 (11) (2021) 14182–14191.
[7] WHO (2020). Shortage of personal protective equipment endangering health workers worldwide. https://www.who.int/news/item/03-03-2020-shortage-of-personal-protective-equipment-endangering-health-workers-worldwide. Retrieved August 3, 2022.
[8] S. Sangkham, Face mask and medical waste disposal during the novel COVID-19 pandemic in Asia, Case Stud. Chem. Environ. Eng. 2 (2020), 100052.
[9] A.L.P. Silva, J.C. Prata, T.R. Walker, A.C. Duarte, W. Ouyang, D. Barcelò, T. Rocha-Santos, Increased plastic pollution due to COVID-19 pandemic: Challenges and recommendations, Chem. Eng. J. 405 (2021), 126683.
[10] R. Dhawan, B.M.S. Bisht, R. Kumar, S. Kumari, S.K. Dhawan, Recycling of plastic waste into tiles with reduced flammability and improved tensile strength, Process Saf. Environ. Prot. 124 (2019) 299–307.
[11] S. Kilmartin-Lynch, M. Saberian, J. Li, R. Roychand, G. Zhang, Preliminary evaluation of the feasibility of using polypropylene fibres from COVID-19 single-use face masks to improve the mechanical properties of concrete, J. Clean. Prod. 296 (2021), 126460.
[12] S.B. Lee, J. Lee, Y.F. Tsang, Y.-M. Kim, J. Jae, S.-C. Jung, Y.-K. Park, Production of value-added aromatics from wasted COVID-19 mask via catalytic pyrolysis, Environ. Pollut. 283 (2021), 117060.
[13] R. Akhbarizadeh, S. Dobaradaran, I. Nabipour, M. Tangestani, D. Abedi, F. Javanfekr, F. Jeddi, A. Zendehboodi, Abandoned Covid-19 personal protective equipment along the Bushehr shores, the Persian Gulf: an emerging source of secondary microplastics in coastlines, Mar. Pollut. Bull. 168 (2021), 112386.
[14] M.B. Haddad, G.E. De-la-Torre, M.R. Abelouah, S. Hajji, A.A. Alla, Personal protective equipment (PPE) pollution associated with the COVID-19 pandemic along the coastline of Agadir, Morocco, Sci. Total Environ. 798 (2021), 149282.
[15] A. Khoironi, H. Hadiyanto, S. Anggoro, S. Sudarno, Evaluation of polypropylene plastic degradation and microplastic identification in sediments at Tambak Lorok coastal area, Semarang, Indonesia, Mar. Pollut. Bull. 151 (2020), 110868.
[16] S. Kilmartin-Lynch, R. Roychand, M. Saberian, J. Li, G. Zhang, S. Setunge, A sustainable approach on the utilisation of COVID-19 plastic based isolation gowns in structural concrete, Case Stud. Constr. Mater. 17 (2022) e01408.
[17] M.R.J. Rakib, G.E. De-la-Torre, C.I. Pizarro-Ortega, D.C. Dioses-Salinas, S. Al-Nahian, Personal protective equipment (PPE) pollution driven by the COVID-19 pandemic in Cox's Bazar, the longest natural beach in the world, Mar. Pollut. Bull. 169 (2021), 112497.
[18] Z.u. Rehman, U. Khalid, Reuse of COVID-19 face mask for the amelioration of mechanical properties of fat clay: A novel solution to an emerging waste problem, Sci. Total Environ. 794 (2021), 148746.
[19] M.M.A. Aziz, M.T. Rahman, M.R. Hainin, W.A.W.A. Bakar, An overview on alternative binders for flexible pavement, Constr. Build. Mater. 84 (2015) 315–319.
[20] Asphalt Magazine (2018). Asphalt is the pavement of choice in Australia. http://asphaltmagazine.com/asphalt-is-the-pavement-of-choice-in-australia/. Retrieved August 10, 2022.
[21] M.T. Rahman, A. Mohajerani, F. Giustozzi, Recycling of waste materials for asphalt concrete and bitumen: A review, Materials 13 (7) (2020) 1495.
[22] L.D. Poulikakos, C. Papadaskalopoulou, B. Hofko, F. Gschösser, A.C. Falchetto, M. Bueno, M. Arraigada, J. Sousa, R. Ruiz, C. Petit, M. Loizidou, M.N. Partl, Harvesting the unexplored potential of European waste materials for road construction, Resour. Conserv. Recycl. 116 (2017) 32–44.
[23] B.J. Putman, S.N. Amirkhanian, Utilisation of waste fibers in stone matrix asphalt mixtures, Resour. Conserv. Recycl. 42 (3) (2004) 265–274.
[24] S. Tapkın, The effect of polypropylene fibers on asphalt performance, Build. Environ. 43 (6) (2008) 1065–1071.
[25] Q. Xu, H. Chen, J.A. Prozzi, Performance of fiber reinforced asphalt concrete under environmental temperature and water effects, Constr. Build. Mater. 24 (10) (2010) 2003–2010.
[26] J. Yin, W. Wu, Utilisation of waste nylon wire in stone matrix asphalt mixtures, Waste Manag. 78 (2018) 948–954.
[27] G. Wang, J. Li, M. Saberian, M.H.H. Rahat, C. Massarra, C. Buckhalter, J. Farrington, T. Collins, J. Johnson, Use of COVID-19 single-use face masks to improve the rutting resistance of asphalt pavement, Sci. Total Environ. 826 (2022), 154118.
[28] M.T. Rahman, A. Mohajerani, Use of bitumen encapsulated cigarette butts in stone mastic asphalt, Constr. Build. Mater. 261 (2020), 120530.
[29] AGPT04B-14 (2014). Pavement; Guide to Pavement Technology Part 4B: Asphalt. https://austroads.com.au/assets/pavements/guide-to-pavement-technology. Retrieved August 10, 2022.
[30] VicRoads (2018). Section 404 - Stone Mastic Asphalt. http://webapps.vicroads.vic.gov.au/VRNE/csdspeci.nsf/webscdocs/8E8D8459884F87F2CA2582F800196756?OpenDocument. Retrieved August 14, 2022.
[31] VicRoads (2014). Section 407 - Hot Mix Asphalt. https://webapps.vicroads.vic.gov.au/VRNE/csdspeci.nsf/webscdocs/1775DC9756592F32CA257DA4001D4C6D?OpenDocument. Retrieved August 14, 2022.
[32] AS 1141.15 (1999). Methods for sampling and testing aggregates, method 15: Flakiness index. Australian Standard 1141.15, Sydney, NSW, Australia, Australian Standard, 1-8.
[33] J. Zhu, M. Saberian, S.T.A.M. Perera, R. Roychand, J. Li, G. Wang, Reusing COVID-19 disposable nitrile gloves to improve the mechanical properties of expansive clay subgrade: An innovative medical waste solution, J. Clean. Prod. 375 (2022) 134086.
[34] N.V. Doremalen, T. Bushmaker, D.H. Morris, M.G. Holbrook, A. Gamble, B. N. Williamson, A. Tamin, J.L. Harcourt, N.J. Thornburg, S.I. Gerber, J.O. Lloyd-Smith, E. De Wit, V.J. Munster, Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1, N. Engl. J. Med. 382 (16) (2020) 1564–1567.
[35] Y. Xiang, Q. Song, W. Gu, Decontamination of surgical face masks and N95 respirators by dry heat pasteurisation for one hour at 70 C, Am. J. Infect. Control 48 (8) (2020) 880–882.
[36] AS/NZS 2891.2.2 (2014). Methods of sampling and testing asphalt, method 2.2: Sample preparation - Compaction of asphalt test specimens using a gyratory compactor. Australian Standard/New Zealand Standard 2891.2.2, Sydney, NSW and Standards New Zealand, Australia, Australian Standard/New Zealand Standard, 1-12.
[37] AS 2891.5 (2004). Methods of sampling and testing asphalt, method 5: Determination of stability and flow - Marshall procedure. Australian Standard 2891.5, Sydney, NSW, Australia, Australian Standard, 1-12.
[38] B. Evirgen, A. Cetin, A. Karslıoğlu, A. Tuncan, An evaluation of the usability of glass and polypropylene fibers in SMA mixtures, Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi 27 (3) (2021) 319–329.
[39] N. Morova, Investigation of usability of basalt fibers in hot mix asphalt concrete, Constr. Build. Mater. 47 (2013) 175–180.
[40] AS 2150 (2020). Asphalt - A guide to good practice. Australian Standard 2150, Sydney, NSW, Australia, Australian Standard, 1-45.
[41] AS/NZS 2891.13.1 (2003). Methods of sampling and testing asphalt, method 13.1: Determination of the resilient modulus of asphalt - Indirect tensile method. Australian Standard/New Zealand Standard 2891.13.1, Sydney, NSW and Standards New Zealand, Australia, Australian Standard/New Zealand Standard, 1-12.
[42] AS 2891.12.1 (1995). Method of sampling and testing asphalt, method 12.1: Determination of the permanent compressive strain characteristics of asphalt - Dynamic creep test. Australian Standard 2891.12.1, Sydney, NSW, Australia, Australian Standard, 1-8.
[43] A. Khodaii, A. Mehrara, Evaluation of permanent deformation of unmodified and SBS modified asphalt mixtures using dynamic creep test, Constr. Build. Mater. 23 (7) (2009) 2586–2592.
[44] T.B. Moghaddam, M. Soltani, M.R. Karim, Evaluation of permanent deformation characteristics of unmodified and Polyethylene Terephthalate modified asphalt mixtures using dynamic creep test, Mater. Des. 53 (2014) 317–324.
[45] A. Mohammed Babalghaith, S. Koting, N.H. Ramli Sulong, M.R. Karim, B. Mohammed AlMashjary, Performance evaluation of stone mastic asphalt (SMA) mixtures with palm oil clinker (POC) as fine aggregate replacement, Constr. Build. Mater. 262 (2020), 120546.
[46] M. Lavasani, M.L. Namin, H. Fartash, Experimental investigation on mineral and organic fibers effect on resilient modulus and dynamic creep of stone matrix asphalt and continuous graded mixtures in three temperature levels, Constr. Build. Mater. 95 (2015) 232–242.
[47] M.T. Rahman, A. Mohajerani, Recycling waste cigarette butts in dense graded asphalt, J. Mater. Civ. Eng. 33 (11) (2021) 04021313.
[48] E.R. Brown, P.S. Kandhal, J. Zhang, Performance testing for hot mix asphalt, NCAT Rep. 1 (05) (2001).
[49] Diab, A., Singh, D., & Pais, J. C. (2017). Moisture susceptibility of asphalt mixtures: A literature review. In *4th Conference of Transportation Research Group of India (CTRG)*.
[50] AASHTO T 283 (2017). Standard method of test for resistance of compacted asphalt mixtures to moisture-induced damage. AASHTO T 283. Washington, DC: AASHTO.
[51] AG:PT/T235 (2006). Asphalt binder drain-off. AGPT-T235-06. Austroads.

[52] H. Chen, Q. Xu, S. Chen, Z. Zhang, Evaluation and design of fiber-reinforced asphalt mixtures, Mater. Des. 30 (7) (2009) 2595–2603.
[53] N.M. Asmael, A.I. Ahmed, Q.S. Kareem, Effect of additives types and contents on the properties of stone matrix asphalt mixtures, Eng. Technol. J. 28 (21) (2010) 6414–6426.
[54] Asphalt Institute (2014). Asphalt mix design methods, Chapter 7 Marshall method of mix design. Manual Series No. 02 (MS-2). Asphalt Institute. Lexington, KY. https://www.researchgate.net/profile/Yasir_Jebur/post/what_are_the_limits_of_thicknesses_of_asphalt_wearing_or_surface_binder_layer_base_materials_asphalt_base_and_the_full_depth_asphalt_layer/attachment/5c13e9eccfe4a76455091d0d/AS:703793855483904@1544808939808/download/Asphalt-Institute-MS2-7th-Edition-Asphalt-Institute-Mix-Design.pdf. Retrieved October 25, 2022.
[55] A.E.A.E.M. Behiry, Laboratory evaluation of resistance to moisture damage in asphalt mixtures, Ain Shams Eng. J. 4 (3) (2013) 351–363.
[56] Lu, Q. (2005). Investigation of conditions for moisture damage in asphalt concrete and appropriate laboratory test methods. (Doctoral dissertation, University of California, Berkeley).
[57] H. Chen, Q. Xu, Experimental study of fibers in stabilising and reinforcing asphalt binder, Fuel 89 (7) (2010) 1616–1622.
[58] AASHTO M 323 (2013). Standard specification for superpave volumetric mix design. AASHTO M 323. Washington, DC: AASHTO.
[59] A. Chegenizadeh, L. Tokoni, H. Nikraz, E. Dadras, Effect of ethylene-vinyl acetate (EVA) on stone mastic asphalt (SMA) behaviour, Constr. Build. Mater. 272 (2021), 121628.
[60] N. Mashaan, A. Chegenizadeh, H. Nikraz, Performance of PET and nano-silica modified stone mastic asphalt mixtures, Case Stud. Constr. Mater. 16 (2022) e01044.
[61] M.T. Rahman, A. Mohajerani, F. Giustozzi, Possible recycling of cigarette butts as fiber modifier in bitumen for asphalt concrete, Materials 13 (3) (2020) 734.
[62] A.K. Arshad, S. Mansor, E. Shafie, W. Hashim, Performance of stone mastic asphalt mix using selected fibres, Jurnal Teknologi 78 (7–2) (2016).