

The Impact of Incorporating Medical Mask Waste Fiber on the Rheological Properties of Asphalt

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ABSTRACT

The impact of incorporating medical mask waste fibers on the rheological properties of asphalt in the review of the asphalt stiffness modulus (E^*) using the dynamic shear rheometer (DSR) tool needs to be done, to determine the improvement of asphalt rheological properties, so that the garbage from masks produced during the Covid-19 pandemic might be utilized as an additive for asphalt. The method used is laboratory experiments by adding mask waste fibers with variations in levels of 1%, 2%, and 3% to the total weight of asphalt and making a test specimen design. This test is conducted under three conditions: initial condition, rolling thin film oven test (RTFOT) condition, and pressure aging vessel (PAV) condition. In the initial condition, the asphalt stiffness modulus increased by 6–78% with 1% mask fiber, 39–148% with 2% mask fiber, and 70–253% with 3% mask fiber. The decrease in the asphalt stiffness modulus of asphalt with 3% mask fiber indicates higher asphalt temperature during deformation (rutting), with initial conditioning at 75.1 °C and RTFOT residual asphalt at 69.7 °C. Conversely, the large asphalt stiffness modulus (E^*) value with 3% mask fiber suggests a tendency for earlier fatigue cracking at low temperatures, evidenced by the increasing asphalt stiffness modulus (E^*) value during fatigue cracking in PAV residual asphalt conditioning at 26.0 °C. This study is limited to laboratory testing, so using mask fibers in asphalt requires long-term evaluation for real-world reliability. The research proposes using medical mask waste to improve asphalt's rheological properties, potentially reducing environmental impact and enhancing performance. Initial results are promising, but further research is needed to confirm sustainability and effectiveness in practical applications.

Keywords: recycling, COVID-19, mask waste, asphalt rheology, asphalt stiffness modulus.

INTRODUCTION

The global COVID-19 pandemic has given rise to significant challenges in health, finance, and the environment on a global scale in the present era (Garel and Petit-Romec, 2021). The use of personal protective equipment (PPE) has risen significantly since the pandemic began (Made-ruelo-Sanz et al., 2021), Mainly because of compulsory regulations mandating the use of PPE, particularly medical masks (Rowan and Laffey, 2021). Medical masks are a valuable tool in our fight against the spread of coronavirus, acting as a barrier to the virus (Royo-Bordonada et al., 2021). The supply of medical masks is expected

to grow by approximately 20% annually from 2020 to 2025 (Ilyas et al., 2020). On a daily basis, an estimated 6.8 billion disposable masks are utilized globally (Novena, 2021). Although wearing surgical masks is necessary, disposing of them properly poses a risk to the environment (Boroujeni et al., 2021). Lightweight face masks can easily be blown away by wind or rain, even if thrown in trash cans or landfills, causing litter and potential environmental hazards. Consequently, used face masks are commonly found littered in cities, parks, parking lots, and even our own neighborhoods. The improper disposal of face masks can lead them to rivers and oceans, presenting a significant threat to marine life (Kilmartin-Lynch et

al., 2022). Current calculations suggest that every year, over 0.15–0.39 million tons of mask waste are dumped into the ocean, endangering marine ecosystems (Chowdhury et al., 2021). Disposing of masks through traditional methods like high-temperature incineration creates a double environmental whammy. They worsen global warming by releasing greenhouse gases, and can also pollute the air with harmful toxins (Xu et al., 2021). Throwing away used masks in landfills isn't a good solution. It can pollute the soil, and masks take hundreds of years to break down, creating long-term problems (Silva et al., 2021). The massive amount of discarded masks during the pandemic has become an environmental concern. To tackle this issue, researchers are exploring innovative recycling methods. One promising approach involves incorporating shredded mask waste into asphalt mixtures, potentially paving the way for more sustainable roads.

Medical masks are typically made from non-woven fabric, resulting in a soft, thin surface that's surprisingly durable for its weight. This material also offers good absorption capacity and strength for everyday wear. They exhibit usability at temperatures of 100 °C for brief periods (Ririn et al., 2021). The predominant chemical component in masks is polypropylene, a plastic material akin to the primary substance found in road pavements, namely asphalt. Asphalt is a valuable resource that takes a very long time to form naturally. Given its plastic nature, polypropylene is widely employed to enhance the rheological properties of asphalt. Researchers unanimously affirm that the addition of polypropylene to asphalt can diminish its penetration, elevate its softening point, and reinforce its resistance to deformation (viscosity). The DSR test is commonly employed to scrutinize the rheological properties of polypropylene-modified asphalt. The DSR test assesses asphalt by measuring its complex shear modulus (G^*) and phase angle (δ) at medium to high temperatures. These parameters are instrumental in gauging the viscous and elastic characteristics of asphalt. DSR testing is conducted on both fresh, non-aged asphalt and asphalt subjected to the RTFOT and PAV testing (Pavement Interactive, 2022).

Results from prior research suggest that the integration of polypropylene can notably enhance the elasticity and stiffness of asphalt binder (Chang and Zhang, 2022). Meanwhile, this research aims to understand the enhancement of

asphalt rheological properties through the addition of medical mask waste fibers, potentially enabling the use of mask waste as an additional asphalt material. Ultimately, this approach could contribute to reducing the environmental impact of waste generated from discarded masks during the Covid-19 pandemic. Therefore, the novelty of this study lies in investigating the influence of adding recycled medical mask fibers on the rheological characteristics of asphalt, particularly concerning the asphalt stiffness modulus with 3 conditions: initial condition, RTFOT condition, and PAV condition, utilizing a DSR.

MATERIALS AND METHODS

The process begins by gathering used face masks from homes. To ensure safety, these masks are then sanitized in an oven for one hour at a temperature of 70 °C. Before you wear the masks, take off the metal strip from the nose area and the loops that go around your ears. Next, the masks are trimmed down to a specific size. After that, a shredder machine is used to cut the masks into smaller pieces, resulting in mask fibers in the form of small fragments. Shredded medical mask waste is added to asphalt in different amounts, like 1%, 2%, or 3% of the asphalt's weight. They use a specific type of penetration-grade 60/70 asphalt for this mixture. The mixing process of asphalt and mask fibers involves the following steps:

1. Increase the asphalt's temperature to around 150 °C for proper mixing. This process may take longer than 30 minutes.
2. Slowly add the shredded mask fragments to the warmed-up asphalt.
3. Mix using a mixer for 40 minutes at a temperature of 170 °C to ensure uniform mixing of mask fiber fragments and asphalt. Let the mixture cool down to ambient temperature.

The mechanistic rheological properties of asphalt are tested using the DSR instrument under three conditioning conditions: initial (pure) condition, RTFOT condition, and PAV condition. Testing under the RTFOT condition aims to simulate short-term aging of asphalt resulting from the mixing and construction processes. The standard RTFO testing procedure follows ASTM D 2872-04 (2004) (Effect of Heat and Air on a Moving Film of Asphalt). On the other hand, testing under the PAV condition is intended to simulate the long-term aging of asphalt, as asphalt undergoes

oxidation during its service life on the road. PAV testing adheres to the ASTM D 6521-08 (2008) (Accelerated aging of asphalt binder using a pressurized aging vessel). The parameters used in this article are based on the asphalt stiffness modulus (E^*) expressed by the following equation (Read and Whiteoak, 2003):

$$E^* = 2(1 + \mu) G^* \quad (1)$$

where: E^* = asphalt stiffness modulus (Pa), G^* = complex shear modulus (Pa), μ = Poisson's Ratio

Measurements and calculations using the DSR involve several important steps. Here is a detailed explanation of this process:

1. Prepare the asphalt sample to be tested. Ensure the sample has suitable dimensions and shape for DSR testing.
2. Place the asphalt sample between two DSR plates. Ensure perfect contact between the plates and the sample to avoid measurement errors.
3. Set the testing temperature according to the range of 58 °C to 82 °C with an increment of 6 °C for the initial condition and RTFOT, while for PAV, set the temperature range from 34 °C to 28 °C with a decrease of 3 °C.
4. Measure the parameter G^* , which is the resultant (vector sum) of elastic behavior (storage modulus G') and viscous behavior (loss modulus G''), with the equation as follows (Read and Whiteoak, 2003):

$$G^* = \sqrt{(G')^2 + (G'')^2} \quad (2)$$

where: G' = storage modulus = $G^* \times \cos \delta$, G'' = loss modulus = $G^* \times \sin \delta$, δ = phase angle

From the measurements, obtain the value of G^* (complex shear modulus) for each temperature and ensure that G^* includes both components G' (storage modulus) and G'' (loss modulus).

5. Next, to calculate the asphalt stiffness modulus (E^*), use formula 1 and perform this calculation for each temperature within the tested range.

In testing the quality of asphalt, the asphalt stiffness modulus (E^*) is a critical parameter measured to evaluate its resistance to deformation, particularly rutting caused by repeated shear stress at the early stage of pavement life. The resistance of asphalt to deformation (rutting) due to repeated shear stress at the early age of pavement can be analyzed based on the value of asphalt stiffness modulus (E^*) in the initial conditioning.

In this condition, asphalt is expected to exhibit elastic and rigid properties, meaning that there should not be excessive deformation, and the asphalt can return to its original shape after the load is removed. Testing the asphalt stiffness modulus under RTFOT residue conditions is intended to determine the resistance of asphalt to deformation (Rutting) due to repeated shear stress from the early to mid-life of the pavement. In this condition, asphalt should have rigid properties, with minimal deformation and elasticity, allowing it to return to its original shape after the load is removed. Various types of asphalt are used in this study, including RTFOT residue of penetration-grade 60/70 asphalt, simulating the asphalt at the early to mid-life of the pavement. The testing of Asphalt Stiffness Modulus under PAV residue conditions is aimed at evaluating the asphalt's resistance to fatigue cracking due to repeated shear stress at the end of the pavement's life. To simulate asphalt under these conditions, PAV testing has been conducted on the RTFOT residue asphalt. In this condition, asphalt should exhibit elasticity, meaning it can return to its original shape after the load is removed, and it should not crack. The asphalt is also expected not to be excessively rigid, as excessive stiffness can easily lead to cracking. The resistance of asphalt to fatigue cracking is evaluated according to AASHTO T 315.

RESULTS AND DISCUSSION

Initial asphalt stiffness modulus

The results obtained from these measurements will indicate how the addition of medical mask waste fiber affects the stiffness modulus of the asphalt under different temperature conditions. This data is crucial for assessing the feasibility of using medical mask waste fibers as an additive in asphalt and understanding its impact on pavement performance, particularly in terms of rutting resistance and overall durability. Table 1 shows the E^* values over the temperature range of 58–82 °C with a temperature increase variation of 6 °C.

Among the asphalt samples, differences in asphalt stiffness modulus (E^*) values can be observed at the same temperature and loading time. Asphalt with 3% mask waste has the highest asphalt stiffness modulus (E^*) value, indicating higher deformation resistance compared to other asphalt samples. This suggests that the addition of 3% mask waste fiber can increase the asphalt stiffness modulus (E^*) value and tends to

Table 1. Asphalt stiffness modulus (E^*) in the initial condition

Temp. (°C)	Asphalt stiffness modulus E^* ($G^*/\text{Sin } \delta$) (kPa)			
	Base asphalt	1% Mask fiber	2% Mask fiber	3% Mask fiber
58	2.93	3.11	4.08	4.98
64	1.31	1.57	2.05	2.55
70	0.615	0.844	1.11	1.43
76	0.313	0.492	0.654	0.886
82	0.169	0.301	0.419	0.596
Fail temp. (°C)	66.5	69.0	72.0	75.1

exhibit a more rigid (solid) and elastic behavior compared to other asphalt samples. There is an increase in E^* with the addition of 1% mask fiber ranging from 6% to 78%, the addition of 2% mask fiber ranging from 39% to 148%, and the addition of 3% mask fiber ranging from 70% to 253%. In terms of deformation (Rutting), AASHTO T 315 specifies the occurrence of deformation (Rutting) in initial conditioning based on E^* in the elastic portion ($G^*/\text{Sin } \delta$) = 1 kPa. In this context, the deformation (Rutting) of penetration-grade 60/70 asphalt at a temperature of 66.5 °C is smaller than that of asphalt with 1% mask waste (69.0 °C), asphalt with 2% mask waste (72.0 °C), and asphalt with 3% mask waste (75.1 °C). Based on the above data, it indicates that E^* values are influenced by temperature changes that alter its viscoelastic characteristics. These findings are consistent with the study conducted by Li et al. (2022), where the rutting factor of mask waste-modified asphalt decreases rapidly with increasing temperature, resulting in increased

asphalt viscoelasticity and decreased deformation resistance. Conversely, the rutting factor of mask waste-modified asphalt increases at the same temperature, indicating that the addition of mask waste additive enhances asphalt deformation resistance. The pattern of decreasing E^* values with increasing temperature can be observed in Figure 1.

Asphalt stiffness modulus in RTFOT conditions

The results obtained from this testing will provide insights into how the addition of medical mask waste fibers affects the asphalt's stiffness modulus under RTFOT residue conditions. This data is crucial for evaluating the potential use of medical mask waste fibers as additives in asphalt and their impact on rutting resistance and overall pavement performance during the early to mid-life stages. Table 2 shows the E^* values over the temperature range of 58–82 °C with a temperature increase variation of 6 °C. At the same temperature, Asphalt

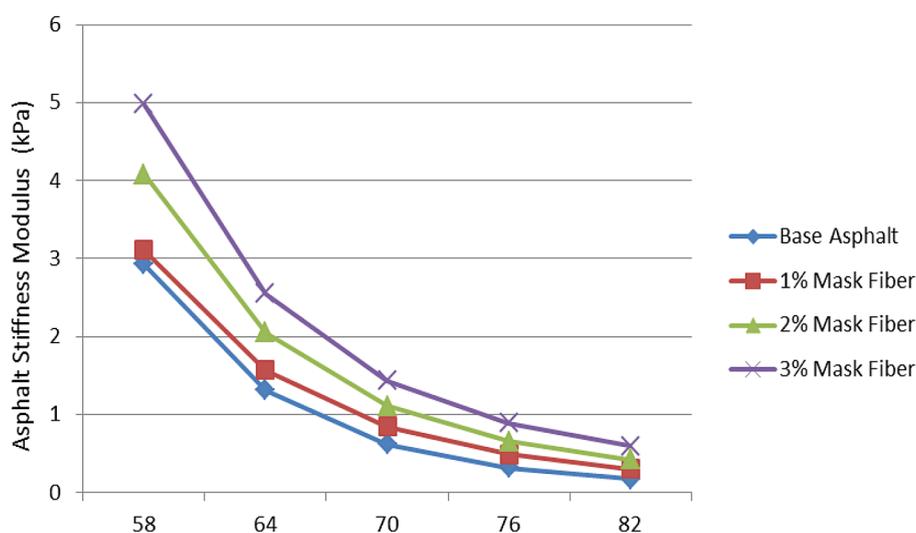
**Figure 1.** Relationship between temperature and asphalt stiffness modulus (E^*) in initial conditions

Table 2. Asphalt stiffness modulus (E^*) in RTFOT conditions

Temp. (°C)	Asphalt stiffness modulus E^* ($G^*/\text{Sin } \delta$) (kPa)			
	Base asphalt	1% Mask fiber	2% Mask fiber	3% Mask fiber
58	6.27	5.71	6.77	8.70
64	2.64	2.54	2.99	3.99
70	1.19	1.20	1.40	1.99
76	0.571	0.612	0.711	1.04
82	0.292	0.337	0.385	0.606
Fail temp. (°C)	65.7	65.5	66.8	69.7

with 3% mask waste consistently has the highest E^* value, ranging from 39% to 108% of the penetration-grade 60/70 asphalt. This indicates that the addition of 3% mask waste fiber can increase the asphalt stiffness modulus (E^*) value and tends to exhibit a more rigid (solid) and elastic behavior compared to other asphalt samples. The RTFOT residue of penetration-grade 60/70 asphalt and asphalt with 1% mask waste have relatively similar E^* values. Theoretically, both of these asphalts have the same age (Aged). AASHTO T 315 specifies the occurrence of deformation (Rutting) in the conditioning of RTFOT residue asphalt with a $G^*/\text{Sin } \delta$ value of 2.2 kPa. For the RTFOT residue of penetration-grade 60/70 asphalt, deformation (Rutting) occurs at a temperature of 65.7 °C, asphalt with 1% mask waste at 65.5 °C, asphalt with 2% mask waste at 66.8 °C, and asphalt with 3% mask waste at 69.7 °C. Based on the above data, it indicates that E^* values are influenced by temperature changes that alter its viscoelastic characteristics. The pattern of decreasing

E^* values with increasing temperature can be observed in Figure 2.

Asphalt stiffness modulus under PAV conditions

The results obtained from these tests provide insights into how the addition of medical mask waste fibers affects the asphalt’s stiffness modulus under PAV residue conditions. This data is crucial for assessing the potential use of medical mask waste fibers as additives in asphalt and their impact on fatigue resistance and overall pavement durability at the end of the pavement’s life. Table 3 shows the E^* values with constant loading time (1.59 Hz or 90 km/h) over the temperature range of 34–28 °C with a temperature decrease variation of 3 °C.

Asphalt with 3% mask waste still maintains the highest E^* value compared to other asphalt samples. This indicates that the addition of 3% mask waste fiber can increase the asphalt stiffness modulus (E^*) value and tends to exhibit a more rigid (solid) and elastic behavior compared to other asphalt samples. This difference is likely

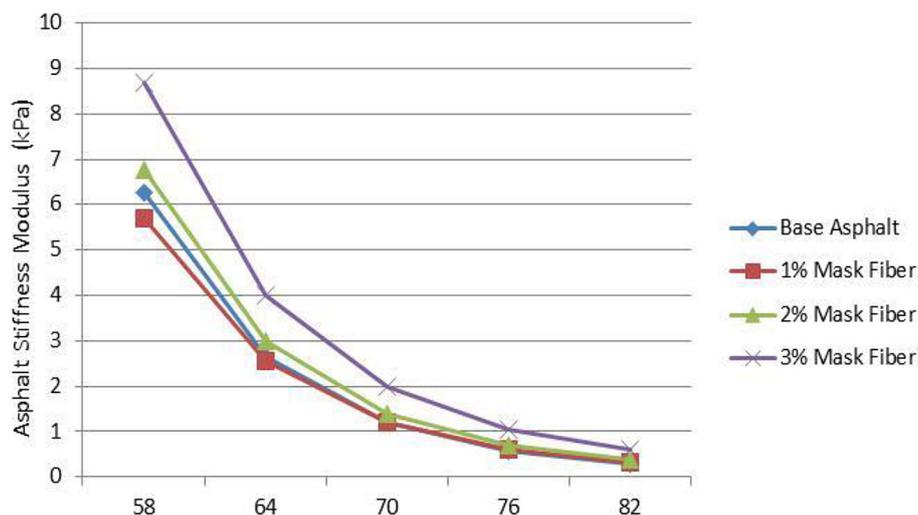


Figure 2. Relationship between temperature and asphalt stiffness modulus (E^*) in RTFOT conditions

Table 3. Asphalt stiffness modulus (E^*) in PAV conditions from RTFOT residue asphalt

Temp. (°C)	Asphalt stiffness modulus E^* ($G^* \cdot \sin \delta$) (kPa)			
	Base asphalt	1% Mask fiber	2% Mask fiber	3% Mask fiber
34	1100	1260	1500	1829
31	1780	1950	2280	2750
28	2840	2980	3390	4130
Fail Temp. (°C)	24.5	24.4	25.2	26.0

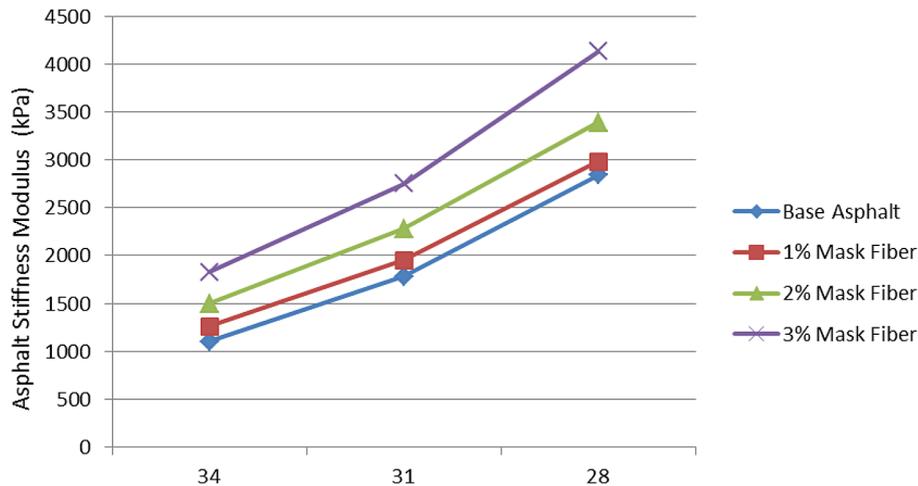


Figure 3. Relationship between temperature and asphalt stiffness modulus (E^*) in PAV conditions

to result in variations in asphalt resistance to fatigue cracking at low temperatures. AASHTO T 315 specifies the occurrence of fatigue cracking when $G^* \sin \delta = 5000$ kPa. For the PAV residue of penetration-grade 60/70 asphalt, fatigue cracking occurs at a temperature of 24.5 °C, asphalt with 1% mask waste at 24.4 °C, asphalt with 2% mask waste at 25.2°C, and asphalt with 3% mask waste at 26.0 °C. The pattern of increasing E^* values with decreasing temperature under PAV residue conditions can be observed in Figure 3.

CONCLUSIONS

This research has successfully achieved the goal that adding mask fiber to asphalt can significantly increase the asphalt stiffness modulus (E^*), especially at concentrations of 1%, 2%, and 3%. This demonstrates the potential to enhance asphalt resistance to deformation (Rutting) due to repeated shear stresses during early pavement life. The effect of these new findings is that asphalt with added mask fiber exhibits improved elasticity and stiffness, capable of preventing or reducing excessive deformation under load and recovering its original shape after load removal.

However, the results also indicate that at 3% fiber concentration, there is a decrease in E^* , particularly at high temperatures during Rutting. This suggests that at higher temperatures, asphalt with higher fiber concentrations tends to exhibit reduced elasticity. Conversely, excessively high E^* values under these conditions can also pose a risk of early fatigue cracking at low temperatures, as evidenced by increased E^* values during PAV residue conditions. These findings open prospects for further research to optimize asphalt formulations with mask fiber to enhance asphalt’s resistance to deformation and address practical challenges in field applications, thereby filling significant gaps in knowledge regarding the use of mask fiber to improve asphalt’s resistance to deformation and mechanical performance. The insights into temperature effects and the risk of early fatigue cracking contribute significantly to ongoing development in more effective and sustainable asphalt technologies.

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