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An Investigation into the Behavior of Disposable Face Masks in Modified Bitumen for Sustainable Transportation Pathways

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ABSTRACT

Since December 2019, COVID-19 infection rates have risen considerably, and the virus is currently widespread around the world. Following the COVID-19 outbreak, the production of medical waste has skyrocketed. Disposable face masks are considered medical waste. Alternative measures must be implemented to assist in reducing medical waste disposal, which can result in serious public health problems and have a negative influence on the environment. In this regard, this research was conducted to investigate the effect of disposable face mask (DFM) ash with varied rates ranging from 5% to 20% by weight on bitumen with a 5% increment to be utilised as an alternative material in asphalt pavement. A series of physical and rheological tests were conducted on the bitumen samples to study the behavior of the DFM ash in bituminous material. Overall, the physical and rheological test results revealed that introducing 20% DFM ash to the modified bitumen was unable to achieve the same properties as with the conventional SMA14 asphalt binder. However, the modified bitumen penetration grade PEN 60/70 has improved the properties and quality of the asphalt in the flexible pavement. In addition, utilising the DFM waste in road construction would be a sustainable technique for protecting the environment by minimising face mask waste caused by the COVID-19 epidemic while lowering the pavement's construction cost. These research findings may be commercialised to generate revenue in the construction industry for sustainable transportation pathways.

Keywords: Disposable face mask; bituminous materials; physical properties; rheological properties

INTRODUCTION

Bitumen is commonly used as a binder in constructing pavements. Due to current situations, conventional bitumen used in asphalt mixtures is unable to meet the current demands. Hence, to improve bitumen's performance, a variety of additives have been added to conventional bitumen to improve its binder properties and durability. Previous research has demonstrated that adding a modifier to a binder increases its elasticity and stiffness as well as reduces the pavement's permanent deformation caused by environmental factors and recurrent traffic loads (Jailani et al. 2021). Recyclable materials are frequently used in road pavement construction for economic, technological, and environmental concerns. Several studies have attempted to investigate the potential and method of using waste material from various sources in modified asphalt.

Coronavirus disease 2019 (COVID-19) caused by a novel coronavirus (SARS-COV-2) was first detected in Wuhan, China, in December 2019. Following the initial epidemic of COVID-19, medical waste output and demand have skyrocketed. Disposable face masks are considered medical waste. The city of Wuhan in China generated nearly 247 tonnes of medical waste per day at the pandemic's peak, almost six times more than before the pandemic (Singh et al. 2020). It shows a massive increase in medical waste, and other countries also face similar challenges. Alternative actions must be put in place to help reduce medical waste disposal, which can further spread COVID-19 and the emergence of other diseases. Improper handling of medical waste also can cause serious public health problems and significantly impact the environment.

The disposable face mask commonly has three layers and is made from fabric polypropylene, which is the most frequently manufactured plastic. Its widespread use has resulted in significant waste accumulation in the environment (Sevwandi Dharmadasa et al. 2021). Polymers are one of the waste materials most widely used as additives for modifying asphalt (Gökalp 2021). The properties of polypropylene include a lower density, a higher softening point (does not melt below 160°C), and higher rigidity and hardness (Zachariah et al. 2021). Polymers have rapidly expanded their application in the asphalt industry to improve the performance characteristics of bituminous materials, resulting in asphalt mixes producing long-lasting pavements (Lugeiyamu et al. 2021).

This research selected disposable face mask waste as the bitumen modifier. The purpose of this research is to see if disposable face mask waste can be used as a bitumen modifier in flexible pavements, which potentially improves the quality of asphalt pavement and searches for sustainable solutions. The objective is to determine the physical and rheological properties of bitumen when combined with disposable face mask ash, as well as to compare the cost of producing Stone Mastic Asphalt (SMA14) mixtures using conventional and modified bitumen. Besides, this research can indirectly protect the environment by reducing the production of medical waste from the COVID-19 pandemic.

METHODOLOGY

PREPARATION OF ASH MATERIALS

The modifier material used in this research was ash from the disposable face masks. The disposable face masks were collected from students and staff at Universiti Teknologi Mara (UiTM), Permatang Pauh, Pulau Pinang. Figure 1 shows the procedure for preparing the ash material. Several boxes were provided at different places in the UiTM to collect the face masks. The collected disposable face masks would be sanitised using liquid sanitiser spray several times and stored for at least two weeks before being used. It would help reduce the risk of viral infections.

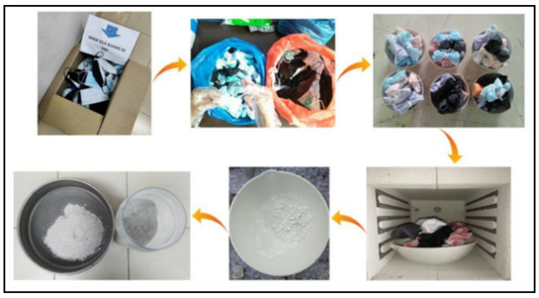

FIGURE 1. Preparation of ash materials

After two weeks, the collected disposable face masks were prepared for the burning process. Personal protective equipment (PPE), such as gloves and face masks, was used to avoid any possible infection during the handling process. The disposal face masks were folded into small sizes and burned in a Carbolite CWF furnace. This furnace brand has a capacity of 23 L and can withstand temperatures up to 1200°C. The temperature used for the burning process was at least 850°C for one hour to disinfect and ensure the proper breakdown of toxic organic substances (Ma et al. 2020; Wang et al. 2020). Roughly 15 grams of face masks burned in the furnace produced 87 percent of ash loss, approximately 13 grams. The disposable face masks in ash were then sieved through a BS 75µm sieve size. The total weight of disposable face mask ash used in the bitumen modifiers was 5%, 10%, 15%, and 20% (Ramesh et al. 2020) by the weight of bitumen used.

PREPARATION OF BITUMINOUS MATERIALS

Thirty samples of bitumen were tested for evaluation of the bituminous material's performance. Bitumen penetration grade PEN 60/70 was obtained from CMAPx Aggregates Sdn. Bhd. in Pulau Pinang, meanwhile bitumen performance grade PG76 was obtained from Kemaman Bitumen Company Sdn. Bhd. (HO) in Shah Alam. Six samples of bitumen penetration grade PEN 60/70 and performance grade PG76 were tested as control samples, while the other twenty-four samples of bitumen penetration grade PEN 60/70 with ash were tested as modified samples. One sample for each test was prepared for the control samples, while for the modified samples, two samples were prepared for each test.

To begin with, the bitumen was heated to 160°C until it became entirely fluid, at which point it was mixed with ash to form a homogeneous compound. The bitumen was modified with disposable face mask ash at different rates, ranging from 5 to 20% by weight of bitumen with a 5% increment. Table 1 shows the weight of the bitumen and ash used in this study.

TABLE 1. Weight of DFM ash used

Asphalt binder	Weight of bitumen (g)	Weight of recycled face masks ash used (g)
PEN 60/70	246.9	-
PG 76	170.5	-
PEN 60/70 + 5%	267.7	13.39
PEN 60/70 + 10%	298.0	29.80
PEN 60/70 + 15%	285.8	42.87
PEN 60/70 + 20%	281.7	56.34
TOTAL	1550.60	142.40

EVALUATION OF THE MODIFIED BITUMEN MATERIAL PERFORMANCE

To determine the physical and rheological properties of bitumen when mixed with disposable face mask ash, a standard penetration test, a softening test, and a dynamic shear rheometer (DSR) test were carried out. The modified and unmodified bitumen samples were analysed based on their physical and rheological properties. The standard penetration test and the softening point test were conducted to measure the physical properties, while the dynamic shear rheometer (DSR) test was carried out to measure the rheological properties. All laboratory experiments were completed at the UITM Pulau Pinang and UITM Shah Alam laboratories to investigate the behaviour of DFM ash in bituminous materials.

RESULTS AND DISCUSSION

STANDARD PENETRATION TEST

A standard penetration test of semisolid bituminous materials was conducted to determine the hardness of the binder. The test outcome is to obtain the penetration value by measuring the distance in tenths of a millimetre to which a standard needle penetrates vertically into the bitumen sample under a 100-gram load within five seconds while maintaining the bitumen temperature at 25°C. The harder the bitumen sample, the shorter the depth the needle can penetrate. As a result, the penetration value for the hard bitumen is lower than the soft bitumen.

Figure 2 illustrates that the penetration value varied with the different types of bitumen and percentages of DFM ash used in the modified sample. The figure demonstrates that the penetration values of the DFM modified bitumen decreased as the percentage of DFM ash used increased. When compared to the control sample, the addition of 5%, 10%, 15%, and 20% of DFM ash reduced the penetration values by 6%, 9%, 13%, and 17%, respectively. As expected, the modified samples had a lower penetration value than the control samples. According to the results, the addition of DFM ash hardens and increases the consistency of the modified bitumen as well as the road pavement's rutting resistance.

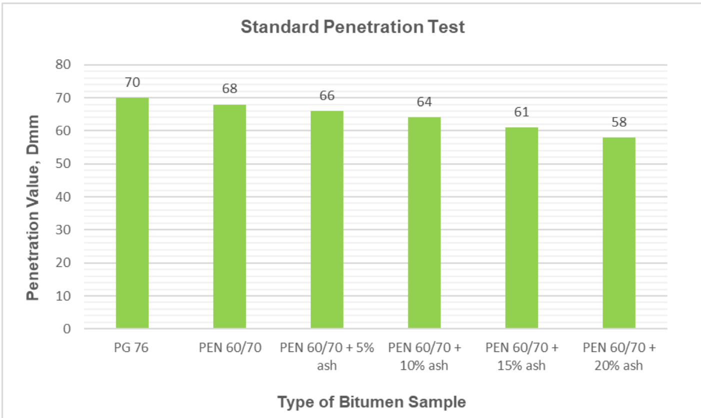

FIGURE 2. Penetration grade vs. different types of bitumen samples

SOFTENING POINT TEST

The average temperature at which the two samples of bitumen begin to melt (soften) sufficiently to allow the 3.5-gram steel ball to fall and contact the metal plate. According to the test parameters, the softening point is the temperature at which the bitumen softens to a specified degree. The softening point value is used to determine the temperature at which bitumen should be heated prior to use in road construction. Usually, the harder the bitumen is, the higher the temperature required to reach the bitumen's softening point due to the bitumen's reduced temperature sensitivity. In hot climates, this type of bitumen is preferred.

Figure 3 shows the softening point value for different bitumen samples. From the results, adding the DFM ash to the modified bitumen seemed to have less effect on the softening temperature. The softening temperature for the modified bitumen samples is not significantly different from the control sample as the thermoplastic modification has no significant impact on the softening point (Habib et al. 2011). The modified samples also had less variation in softening temperature due to the homogeneity obtained when mixing the DFM ash with base bitumen because the ash is in powder form. Thus, when tested at higher temperatures, it may offer good rutting resistance to the road pavement (Habib et al. 2011).

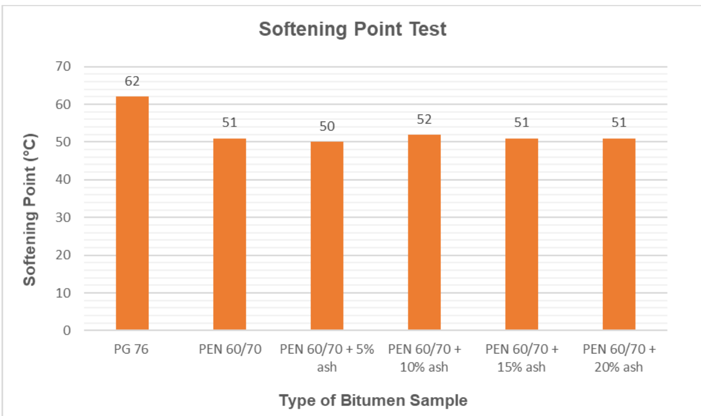

FIGURE 3. Softening point vs. different types of bitumen samples

DYNAMIC SHEAR RHEOMETER (DSR) TEST

Under oscillating stress at various temperatures, the complex shear modulus (G*) and phase angle (δ) of bitumen can be measured by this test. The bitumen was placed between the fixed and oscillating plates with a diameter of 25 mm and a gap of 1 mm. To produce a shearing effect, the top plate oscillated back and forth across the bitumen sample at a fixed frequency of 10 rad/sec (1.59 Hz) over a temperature range starting at 46°C with a 6°C increment. The oscillation rate represents the shearing action at a traffic speed of approximately 90 km/h (Abdelaziz and Mohamed Rehan, 2010). To reduce rutting in the road pavement, the value of shear modulus (G*) should be high, while the higher value of phase angle (δ) indicates more viscous than bitumen.

Figure 4 and Figure 5 illustrate the relationship between the complex shear modulus and phase angle, respectively, with the temperature range. As shown in both figures, as the temperature increased, both the modified and unmodified bitumen demonstrated a trend toward decreasing complex modulus and increasing phase angle. According to Yan et al. (2015), despite having similar rheological properties with increasing temperature as the unmodified bitumen, the modified bitumen has distinct values for complex modulus and phase angle. When DFM ash is introduced to the bitumen, the complex modulus of the bituminous mixture has a higher value than the original binder over the temperature range. The higher the percentage of DFM ash, the higher the complex modulus. High complex modulus shows greater binder strength, which can be associated with higher rutting resistance.

Furthermore, Gökalp (2021) stated that greater values of complex modulus at lower temperatures indicate higher failure temperatures. Figure 4 shows that PG 76 had the highest value of complex modulus and the highest failure temperature. Apart from that, PEN 60/70 and PEN 60/70–5% had the lowest failure temperature, which was 70° C. Even though PEN 60/70 had the same failure temperature as PEN 60/70–5%, the value of the complex modulus of PEN 60/70–5% was greater. Modified bitumen with 10%, 15%, and 20% DFM ash showed the same failure temperature of 76°C.

On the other hand, for the phase angle, Figure 5 shows that PG 76 had the lowest phase angle value, which can be considered as being more elastic than the modified bitumen. However, compared to the PEN 60/70, the modified bitumen had a lower phase angle value. Moreover, the phase angle value showed no significant difference between the modified bitumen. Nevertheless, the more DFM ash percentage is added to the binder, the smaller the phase angle value over the temperature range. It indicates that the bitumen has good elastic characteristics with a low phase angle value (Yan et al. 2015).

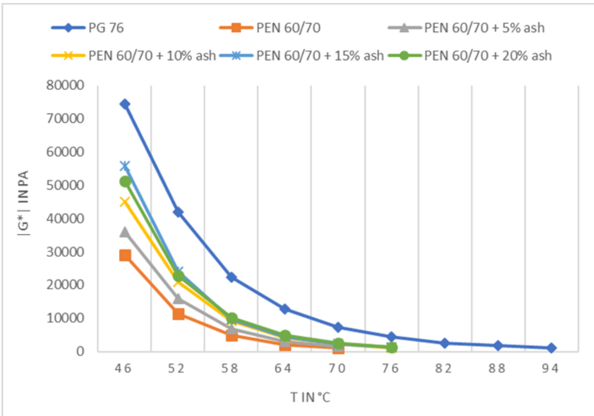

FIGURE 4. Complex shear modulus (G*) vs. temperature range (T)

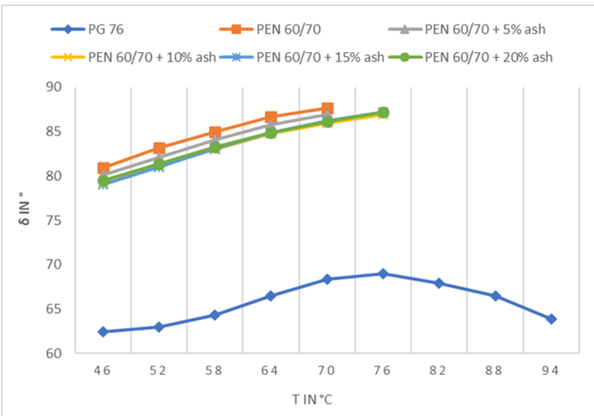

FIGURE 5. Phase angles (δ) vs. temperature range (T).

SUMMARY OF THE DISCUSSION

According to the research findings, the modified sample containing 20% DFM ash showed satisfactory performance throughout the test compared to the other percentage of DFM ash used in the modified bitumen.

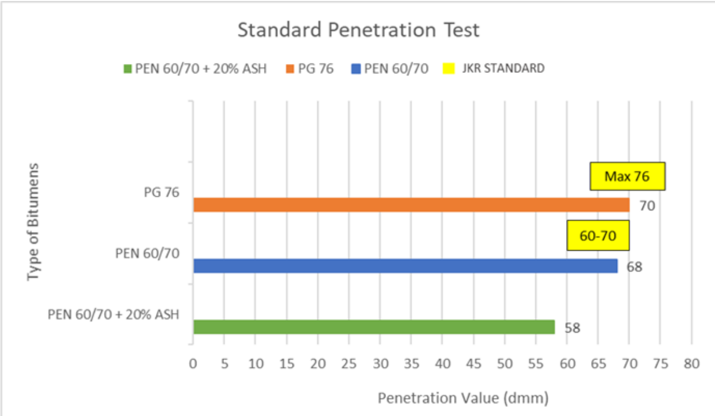

FIGURE 6. Comparison of the standard penetration value

As illustrated in Figure 6, the penetration values for both control samples complied with JKR's specification. Compared to the modified samples containing different percentages of DFM ash, 20% DFM ash showed the lowest penetration value of 58 dmm. The results indicate that the modified sample had a slightly lower penetration value than both control samples, but it is not significantly different. Thus, it can be justified that adding 20% DFM ash to the modified sample can improve the bitumen performance in terms of hardness in comparison to the control samples.

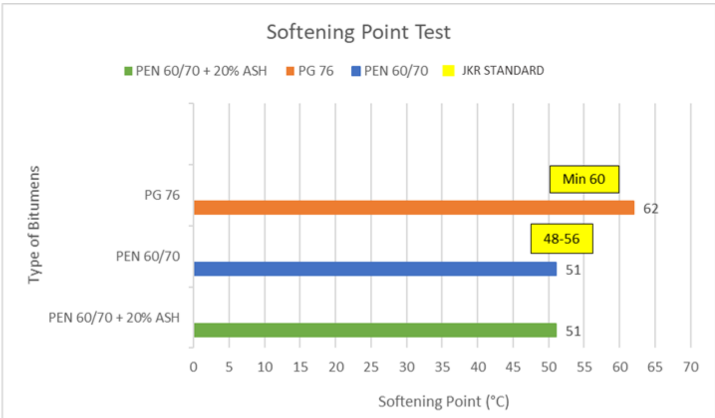

FIGURE 7. Comparison of the softening point value

As seen in Figure 7 above, the softening values for both control samples complied with JKR's specification. The control sample PG 76 had a softening temperature of 62°C, which was more than the minimum required value by JKR's standards, whereas the control sample PEN 60/70 had a softening value of 51°C, which was in the range of 48–56°C from the standard value. From this observation, the modified sample containing 20% DFM ash was still unable to meet the standard requirements for the bitumen grade PG76, making it unsuitable to replace bitumen grade PG76 in the SMA mixture. However, further research can be done by adding a higher percentage of DFM ash to the modified bitumen to observe if the modified bitumen could achieve equivalent or better performance with bitumen grade PG76 compared to the current study. On the other hand, it was observed that the modified sample containing 20% DFM ash achieved the requirements for conventional bitumen grade PEN 60/70. Evidently, this research has resulted in the development of an initiative for the road industry in which modified bitumen is produced using waste materials, thereby reducing the impact on the environment.

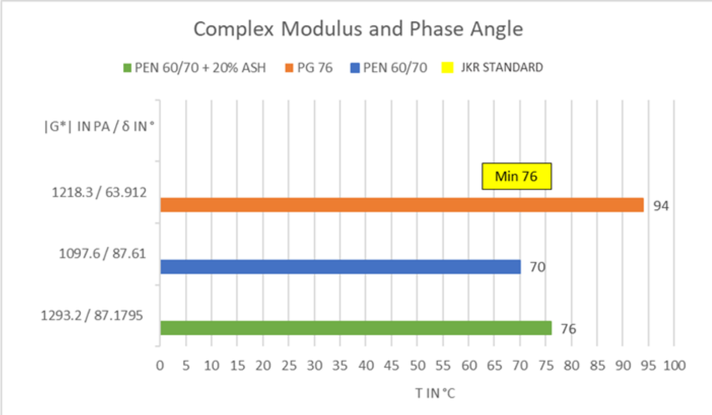

FIGURE 8. Comparison of the complex modulus and phase angle

Figure 8 demonstrates a comparison of the complex modulus, phase angle, and temperature between different types of bitumen. The figure shows a large difference in the complex modulus and phase angle between the control sample PG 76 and the other two bitumen samples. The modified bitumen was still unable to compete with the control sample PG 76, which had the highest complex modulus and the shortest phase angle. However, the results reveal an improvement in the characteristics of bitumen when higher complex modulus and lower phase angle were observed in the modified sample with 20% DFM ash, in comparison to the control sample PEN 60/70. This indicates that the modified bitumen would exhibit superior rutting resistance due to its increased strength and elastic properties when compared to conventional bitumen.

Apart from that, based on the specifications of the Strategic Highway Research Programme (SHRP), bitumen has great viscoelastic performance on pavements at the maximum temperature, where G*/sin δ is equal to 1 kPa. The figure shows that control sample PG 76 had the highest temperature and met the minimum required temperature in the JKR's standards, whereas the control sample PEN 60/70 had the opposite result. However, it is observed that the temperature for the modified sample containing 20% DFM ash reached the minimum requirement temperature in the JKR's standards for the control sample PG 76, which was 76°C. The results indicate that the maximum temperature of the modified binders increased compared to the control sample PEN 60/70. Hence, the modified bitumen containing 20% DFM ash will be more capable of resisting rutting than unmodified bitumen. Furthermore, the maximum temperature of the modified bitumen is sufficient to prevent the pavement from degrading throughout service.

COST COMPARISON WITH PROPERTIES PERFORMANCE

In comparison to other forms of asphalt, Stone Mastic Asphalt (SMA) is well known for its superior performance, owing to its higher content of bituminous material. However, SMA is not widely used since it is significantly more expensive than other asphalt combinations due to its performance characteristics (Lugeiyamu et al. 2021). Therefore, a study was conducted to evaluate if using DFM ash in bituminous mixtures can lower the asphalt mixture's investment cost and improve the bituminous material's performance. According to a previous study, using waste as a modifier in bitumen to enhance its properties might be environmentally responsible and might reduce construction costs (Gautam et al. 2018). From an economic perspective, Lugeiyamu et al. (2021) argued that incorporating waste plastic materials into road pavement is advantageous due to enhanced pavement performance and lower construction costs.

TABLE 2. Total Bitumen required

Content	Value	Unit
Length of road	1000	m
Thickness of road	0.05	m
Width of road	4	m
Length x Thickness x Width	200	m^3
Premix Density	2300	kg/m^3
Total	460,000	kg
Total Premix (MT)	460	mt
Total Bitumen (5%)	23	mt

TABLE 3. Cost comparison of asphalt binders

Type of Pavement	Cost / mt (MYR)	Cost / km (MYR)	Expected Lifespan (Years)	Equal cost / km / year (MYR)	Percentage of Cost Reduction
Conventional SMA14 (PG76)	3100	71,300	10	7130	51.61%
Modified SMA14 (PEN60/70 + DFM)	2250*	51,750	15	3450	

Source: KBC Trading Sdn. Bhd.
Note: * Modified asphalt is expected to have additional costs due to the manufacturing process.

Tables 2 and Table 3 show the estimated cost comparison between conventional and modified SMA14 asphalt binders. The source of the data was obtained from KBC Trading Sdn. Bhd., a company that has produced more than 20 types of high-quality asphalt with different grades. KBC Trading Sdn. Bhd. is one of the major suppliers of asphalt binders for the Traffic and Highway Engineering Laboratory in UiTM Pulau Pinang and other industries in many countries.

Table 3 shows that the cost for the conventional SMA14 asphalt binder was RM3100 per metric tonne, while the cost for the modified SMA14 was RM2250 per metric tonne. However, additional charges for the modified SMA must also be taken into account due to the manufacturing process, such as the electricity bill for the DFM burning process before it can be used in the bitumen modification. Based on Table 2 and considering a road length of 1 km with a width of 4 m, the estimated total bitumen required was 23 metric tonnes, which took into account 5% of the bitumen content in the total premix.

It is observed that the conventional SMA14 asphalt binder has a higher cost than the modified SMA14, as the waste materials in the modified binder are available for free without the need to purchase. The cost of the binder is reduced by as much as 51.61% compared to the conventional SMA14 asphalt binder. This demonstrates that using waste material in bitumen modifiers reduces both the cost of binder material and construction costs.

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this investigation was to observe the behaviour of the use of disposable face mask (DFM) ash in bituminous materials in terms of the physical and rheological properties of the bitumen. This study also compared the production costs of Stone Mastic Asphalt (SMA14) mixtures using conventional and modified bitumen. To achieve the objectives of this study, a number of physical and rheological tests were conducted on bitumen samples to observe the changes in their properties. The DFM ash was utilised as a modifier in the modification of bitumen at varying rates from 5% to 20% by weight of the bitumen, with a 5% increment. The research findings are summarised as follows:

1. The modified sample containing 20% DFM ash shows satisfactory performance throughout the test compared to the other percentage of DFM ash used in the modified bitumen.
2. The penetration value for the modified samples was less than that of other control samples. According to the results, adding DFM ash hardens and improves the consistency of the modified bitumen. This is advantageous because it has the potential to increase the resistance of the road pavement to rutting.
3. Adding DFM ash to the modified bitumen seems to have little effect on the softening temperature when compared to the unmodified bitumen. However, this research has sparked an initiative in the road sector to develop modified bitumen from waste materials, which can assist in mitigating the impact on the environment. Despite that, further research needs to be done as 20% DFM ash is still unable to meet the requirement the same as bitumen grade PG76 to be replaced in SMA mixtures.
4. There is a large difference in the complex modulus and phase angle values between the control sample PG 76 and the modified bitumen samples. However, the results indicate that the characteristics of bitumen improve when the modified sample with 20% DFM ash has a greater complex modulus and a lower phase angle than the control sample PEN 60/70. This suggests that the modified bitumen exhibits superior rutting resistance due to its increased strength and elastic properties when compared to conventional bitumen.
5. The temperature of the modified sample containing 20% DFM ash is able to reach the minimum requirement temperature of the JKR's standards for control sample PG. The results show an increase in the maximum temperature of modified binders compared to that of the control sample PEN 60/70. Hence, the maximum temperature of the modified bitumen containing 20% DFM ash is sufficient to prevent the pavement from degrading throughout the service.
6. In terms of cost, the improved binder is 51.61% less expensive than the normal SMA14 asphalt binder. From the analysis, it can be concluded that using waste material as bitumen modifiers lowers the investment cost of binder material as well as reduces the construction cost.

Overall, the findings of physical and rheological tests indicated that adding 20% DFM ash to the modified bitumen was insufficient to obtain the same quality as the typical SMA14 asphalt binder. However, the modified bitumen enhanced the asphalt's characteristics and quality in the flexible pavement. Additionally, utilising DFM trash in road building would be a sustainable technique for protecting the environment by minimising face mask waste caused by the COVID-19 pandemic while lowering the pavement's construction cost.

Further research is recommended to improve data gathering and to further evaluate the potential for employing waste materials on road pavements. The following are some recommendations for future research.

1. The percentage of DFM ash used in the modified bitumen can be raised to determine if the modified bitumen's performance can be improved over the current study.
2. Additional laboratory tests, including ductility, viscosity, Marshall test and the rutting performance, may be used to determine additional attributes of the modified sample.

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DECLARATION OF COMPETING INTEREST

None

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