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A COMPARATIVE STUDY ON STRENGTHENING FLEXIBLE PAVEMENT BY ADDING SELECTED MEDICAL WASTE FIBRE IN MODIFIED BITUMEN PENETRATION GRADE 60/70

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Graphical Abstract

Abstract

The COVID-19 pandemic has led to an increase in worldwide consumption of nitrile butadiene rubber (NBR) gloves and disposable face masks (DFM), resulting in environmental contamination. Thus, this research was conducted to compare the physical properties of modified bitumen penetration grade 60/70 and to evaluate the performance of modified Stone Mastic Asphalt (SMA-14) mixtures when using both materials as fibers. NBR gloves and DFM were collected around the campus of Universiti Teknologi MARA (UiTM) Permatang Pauh and were later sanitized and cut into strips of 6 mm maximum length. By applying the softening point and penetration tests, the physical parameters of modified bitumen PEN 60/70 were compared to those of bitumen with NBR and DFM as additives. The Unconfined Compression Strength (UCS) and binder drain-down tests were also conducted to compare the performance and binder-draining properties of modified SMA-14 mixtures using both dry and wet process methods when both fibers were added. The results showed that adding 3%, 6%, and 9% of NBR to modified bitumen PEN 60/70 increases the softening value and penetration depth, while DFM decreases both test values for all percentages. Besides, 3% NBR and 6% DFM strengthen the mixtures, making the bitumen less likely to drain in both dry and wet processing. All test results were compared against the Public Works Department's requirements and passed the set standard. It is concluded that adding 3% NBR and 6% DFM as pavement additives positively impacts its performance and increases the service life.

Keywords: Disposable face mask, medical waste, modified bitumen, nitrile butadiene rubber glove, SMA-14 mixtures

Abstrak

Penularan pandemik COVID-19 telah meningkatkan permintaan global untuk sarung tangan getah nitril butadien (NBR) dan topeng muka pakai buang (DFM), sekali gus mengakibatkan pencemaran alam sekitar. Penyelidikan ini dijalankan untuk membandingkan sifat fizikal gred penembusan bitumen modifikasi 60/70 dan menilai prestasi campuran SMA-14 modifikasi apabila menggunakan kedua-dua bahan sebagai serat. Sarung tangan NBR dan DFM dikumpulkan di sekitar kampus Universiti Teknologi MARA (UiTM) Permatang Pauh dan kemudiannya disanitasi dan dipotong menjadi jalur dengan panjang maksimum 6 mm. Ujian titik lembut dan penetrasi dijalankan untuk membandingkan sifat fizikal bitumen modifikasi PEN 60/70 dengan NBR dan DFM sebagai aditif. Ujian *Unconfined Compression Strength* dan *binder drain-down* turut dijalankan untuk membandingkan prestasi dan sifat penyaliran pengikat bagi campuran SMA-14 yang diubahsuai menggunakan kaedah proses kering dan basah apabila kedua-dua serat ditambahkan. Dapatan kajian menunjukkan bahawa menambah 3%, 6%, dan 9% NBR kepada bitumen PEN 60/70 yang diubahsuai meningkatkan nilai pelembutan dan kedalaman penetrasi, manakala DFM mengurangkan kedua-dua nilai ujian untuk semua peratusan. Selain itu, 3% NBR dan 6% DFM menguatkan campuran tersebut, menjadikan bitumen kurang cenderung untuk mengalir bagi kedua-dua pemprosesan kering dan basah. Semua hasil ujian dibandingkan dengan spesifikasi Jabatan Kerja Raya dan melepasi standard yang ditetapkan. Dapat disimpulkan bahawa penambahan 3% NBR dan 6% DFM sebagai aditif dalam turapan memberikan impak positif terhadap prestasi dan meningkatkan hayat perkhidmatan.

Kata kunci: Bitumen modifikasi, campuran SMA-14, nitrile butadiene rubber gloves, sisa perubatan, topeng muka pakai buang

1.0 INTRODUCTION

In December 2019, a new onset of respiratory disease called coronavirus (SARS-CoV-2), also known as COVID-19, was identified in Wuhan City, Hubei Province, China. The World Health Organization later declared the epidemica global public health emergency on 30 January 2020 [1]. Its rapid spread necessitated limits to reduce the number of infections. The main restrictions included seclusion, the ban of large assemblies, physical distancing, prohibitions on travel, and the shutdown of educational institutions, commercial establishments, eateries, shopping malls, and other communal spaces [2]. Among the recommended preventative measures were frequent hand cleansing, avoiding face-to-face contact, and social separation [3]. Additionally, disposable masks and gloves were the predominant Personal Protective Equipment (PPE) used for preventing infections.

Since the emergence of COVID-19, the demand for medical gloves and face masks has increased substantially. The virus's ability to remain viable on surfaces for extended periods, ranging from hours to even days, has prompted individuals, including frontline medical staff, to rely on PPE in order to protect themselves from infections [4, 5]. This led to the increased production of medical products alongside the volume of medical waste, with PPE emerging as a new waste category during the pandemic [6].

Research and development in the pavement sector are focused on using recyclable materials in asphalt mixtures. The incorporation of waste materials into asphalt offers both economic and environmental advantages by decreasing the use of primary resources and redirecting garbage from landfills. Some of the key waste materials that have been evaluated for application in asphalt mixtures include plastics like polyethylene, polypropylene, and polyvinyl chloride (PVC). These materials serve as potential additives to enhance the characteristics of asphalt binders, such as resilience and rutting resistance [7].

Stone Mastic Asphalt (SMA), created in Germany during the 1960s, is a type of asphalt mixture that has gained global recognition and acclaim. It has been utilized in numerous European nations for more than 20 years due to the increased resistance to rutting and studded tire wear. However, higher initial cost and binder drainage are the primary disadvantages of SMA mixes. The former is caused by the high price of imported Polymer Modified Bitumen PG76-22 while the latter is used for stabilization to prevent the binder (e.g., polymer or fiber) in the mixture from draining.

The Permanent International Association of Road Congresses (PIARC) recently proposed that pavements must be designed and constructed to become more resilient [8]. This involves considering traffic and climate changes as well as utilizing innovative materials and techniques, even though they have yet to analyze specific methods that can minimize recovery time. Conversely, the inclusion of medical waste into asphalt pavement has been propounded to facilitate flexible pavement designs through enhanced performance and service life. A study by Wasfi Al-Mistarehi *et al.* [9] reported that the use of medical waste ash has a notable influence on the frequency and temperature of rutting, making it a viable choice for road construction. This stands as a feasible solution for managing medical waste generated during the pandemic and improving asphalt pavement durability with minimal cost. Table 1 presents a compilation of previous studies examining the potential use of medical waste in pavement engineering.

Table 1 Past Findings in the Utilization of Medical Waste in Flexible Pavement

References	Methodological	Findings
Gedik *et al.* [10]	1. Scanning electron microscope (SEM) with Energy Dispersive X-ray (EDX) to identify the morphological characteristics of disposable medical gloves (DMG)-modified specimens. 2. Dynamic shear rheometer (DSR) test and Fourier transform infrared spectroscopy (FTIR) analysis for viscoelastic behavior and modification processing.	1. DMG waste improves bitumen properties, enhancing rutting resistance and stiffness. 2. Recycled DMGs can be used as a viable modifier in bitumen.
Hasban *et al.* [11]	1. Medical plastic waste used in modified bitumen for pavement. Wet process of incorporating waste plastics into bituminous mixes. 2. Marshall method of mix design using Penetration grade 60/70 binder.	1. Improvement of up to 8% plastic and 15% steel slag. 2. The cost of road construction can be reduced significantly.
Al-Mistarehi *et al.* [9]	1. Marshall test was used for adding waste materials as fillers. 2. Universal Testing Machine (UTM) was used for creep and fatigue tests	1. In high concentrations, the addition of waste medical ash gave the highest value of complex shear modulus.
Crusho & Verghese [12]	1. Tested autoclaved medical plastic waste in bituminous road construction. 2. Compared performance of aggregate and bitumen with biomedical plastic waste.	1. Improved properties for Plastic Coated Aggregate compared to normal aggregates. 2. Biomedical waste in bituminous road construction enhances road quality.
Shah & Khan [13]	1. Hospital plastic waste was used as a partial replacement for coarse aggregates. Plastic waste was shredded, heated, and pulverized manually and mechanically. 2. Replacement of natural aggregates with plastic aggregates in asphalt mixes.	1. Stability increases up to 20% replacement, then decreases suddenly. 2. Flow increases with plastic aggregate percentage and decreases at 25% replacement.

The findings of prior research demonstrate that medical waste can effectively serve as a bitumen modifier, therefore improving the quality of roads. Four studies investigated the application of medical waste in asphalt, which is a key component of flexible pavement. First, Gedik *et al.* [10] employed Scanning Electron Microscopy (SEM) and Energy-Dispersive X-Ray (EDX) to investigate the morphological features of DMG-modified asphalt. They also used Dynamic Shear Rheometer (DSR) test and Fourier Transform Infrared Spectroscopy (FTIR) analysis to assess the asphalt's viscoelastic properties and its modification process. The results found that adding disposable medical gloves (DMGs) improved the bitumen's properties, making it more resistant to rutting and stiffer. Second, Hasban *et al.* [11] investigated the use of medical plastic waste in bitumen for pavement. A wet method was employed to add plastic residues into the bituminous mixtures. They discovered that incorporating up to 8% plastic and 15% steel slag resulted in improved outcomes, which can substantially reduce road construction expenses. Third, Al-Mistarehi *et al.* [9] investigated the use of waste medical ash as fillers in asphalt. They employed the Marshall method of mix design and the Universal Testing Machine (UTM) for creep and fatigue tests. It was discovered that adding a significant amount of medicinal ash resulted in the highest value of complex shear modulus, which quantified rigidity. The final study by Crusho & Verghese [12] tested autoclaved medical plastic waste in the construction of bituminous roads. The effectiveness of aggregate and bitumen was compared to biomedical plastic waste. They reported that the plastic enhanced the characteristics of Plastic-Coated Aggregate (PCA) in comparison to regular aggregates. This shows that incorporating biological waste into bituminous road construction improves the overall condition of the road. Overall, these findings suggest that using medical waste in asphalt engineering can improve the performance of pavement and reduce construction costs.

The purpose of this study is to evaluate the physical characteristics of bitumen penetration grade 60/70 by including different medical waste materials in comparison to the costly imported bitumen (i.e., Polymer Modified Bitumen PG76-22). Various medical wastes, including disposable face masks (DFM) and nitrile butadiene rubber (NBR) gloves, were used as fibers in the asphalt mixture. Softening point and penetration tests were conducted to assess the bitumen's physical characteristics following the addition of each medical waste fiber. This study also investigated the performance of the modified asphalt mixtures in dry and wet conditions via the binder drain-down test (T305) and the Unconfined Compression Strength (UCS) test (AASHTO T167). The findings hope to shed light on whether the integration of medical waste in asphalt can serve as a sustainable way to improve pavement performance.

2.0 METHODOLOGY

Figure 1 illustrates the procedures and tests involved in this study.

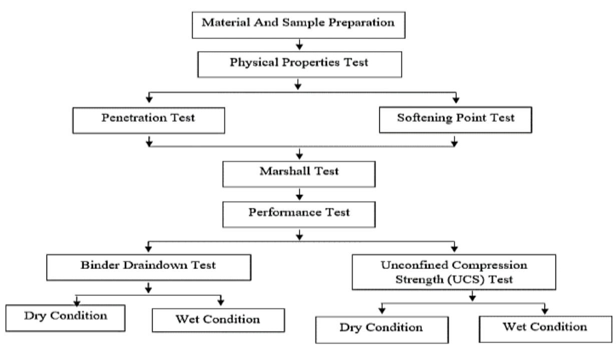

Figure 1 Flowchart of research methodology

2.1 Materials Used

The following subsections explain the materials used in this study.

2.1.1 Aggregate

This study utilized granite, which was sourced from Kuad Sdn. Bhd. in Penanti, Bukit Mertajam, Pulau Pinang. The Ministry of Works Malaysia generally uses aggregate grading for moderate traffic conditions. Table 2 shows the aggregate gradation of SMA-14.

Table 2 Aggregate Gradation of SMA-14

Sieve Size (mm)	Specification Limits* (% passing)	% passing
19.0	100	0
12.5	100	0
9.5	72–83	77.5
4.75	25–38	31.5
2.36	16–24	20
0.600	12–16	14
0.300	12–15	13.5
0.075	8-10	9

*Standard Specification for Roadworks of Flexible Pavement set by the Public Works Department (PWD), Sec. 4, Table 4.7.4 Gradation Limits of Combined Aggregates (S4-63).

2.1.2 Asphalt

Bitumen penetration grade 60/70 and polymer-modified bitumen PG76-22 were applied in this study. Both materials were supplied by Kemaman Bitumen Company (KBC) Sdn. Bhd. in Terengganu, Malaysia.

2.1.3 Medical Wastes

The medical wastes used in this study were DFM and NBR gloves. These wastes were collected from on-campus staff and students of Universiti Teknologi Mara (UiTM) Permatang Pauh, Pulau Pinang, Malaysia.

2.2 Material Preparation and Testing

The main objective of this study was to compare the physical properties of modified bitumen penetration grade 60/70, which was added to each medical waste fiber, with the properties of polymer-modified bitumen PG76-22. It was followed by a performance evaluation of the modified SMA-14 mixtures when using each material as fiber in dry and wet conditions.

2.2.1 Material Preparation

The DFM and NBR glove wastes were disinfected with alcohol sanitizer liquid to break the outer coating of viruses and bacteria and left for several days. Subsequently, the waste materials were manually trimmed into strips with a maximum length of 6 mm (0.25 inches), following the specifications outlined in the Public Works Department's Standard Specification for Roadworks of Flexible Pavement. Figures 2 and 3 demonstrate the process of preparing the medical waste fibers.

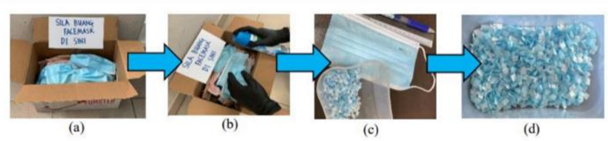

Figure 2 Disposable face masks (DFM) (a) collected in boxes, (b) disinfected with alcohol sanitizer liquid, (c) manually cut to 6 mm length strips, and (d) DFM strips

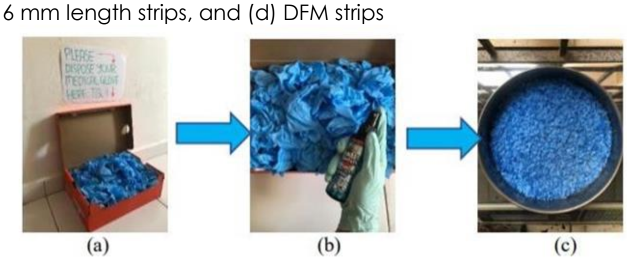

Figure 3 Nitrile butadiene rubber (NBR) gloves (a) collected in special barrel, (b) disinfected with alcohol sanitizer liquid, and (c) cut into strips

2.2.2 Los Angeles Abrasion Test

Los Angeles abrasion test is a widely applied technique for evaluating the aggregates' toughness and abrasion properties. The maximum allowable loss caused by abrasion and impact on the Los Angeles machine should not exceed 25% when evaluated in line with ASTM C 131 [14].

2.2.3 Aggregate Impact Value

Aggregate impact value is a British Standard as part of the BS 812 series. It can be examined in either dry or soaking (wet) conditions. The impact load imposed by moving vehicles often causes significant aggregate degradation. Toughness refers to a material's capacity to endure an impact load.

2.2.4 Elongation and Flakiness

The elongation index test measures the proportion of aggregate particles with a minimum dimension of less than 0.6 times their mean dimension. On the other hand, the flakiness index defines the proportion of aggregate particles with a maximum size exceeding 1.8 times their mean dimension. Both tests apply to aggregates that have a diameter larger than 6.3 mm. According to MS 30 and Malaysia, flaky and elongated aggregates should not exceed 25%.

2.3 Physical Properties Test

This study chose bitumen penetration grade 60/70 following its common usage in Malaysian pavement works. The local bitumen is also more cost-effective compared to the imported bitumen of polymer-modified bitumen PG76-22. The bitumen was modified by adding medical waste fiber, followed by a comparison of its physical properties with the imported bitumen. Softening point test (ASTM D 36) and penetration test (ASTM D 5) were used to determine the physical properties of modified bitumen PEN 60/70 with NBR and DFM fibers as additives. All the fibers in different percentages (3%, 6%, and 9%) of the mixture's total weight were mixed with the bitumen PEN 60/70 before testing using a mechanical mixer. The selection of the bitumen percentage was done following past research by Noura *et al.* [15].

2.3.1 Penetration Test

The penetration test aims to determine the bitumen's penetration efficiency. Varied penetration-grade bitumen shows a bitumen's different viscosities and hardness. The depth of penetration for bitumen PEN 60/70 should range between 60 to 70. Such test adhered to the standard in ASTM D 5-06.

2.3.2 Softening Point Test

A softening point test was performed to ascertain the bitumen's softening temperature using a pair of brass rings and steel balls. The procedure adhered to the standard in ASTM D36.

2.4 Marshall Test

Three samples were prepared for each type of fiber material to assess the effectiveness of modified SMA-14 combinations under both dry and wet conditions. Each condition underwent two performance evaluations. The optimum binder content (OBC) in the modified SMA-14 mix was 6.5% of the mixture's overall weight. The OBC value was selected based on Noura [15]. All samples contained 2% ordinary Portland cement (OPC) as an anti-stripping agent. Fibers were added to the aggregate prior to mixing with the bitumen in the dry process samples. Meanwhile, the wet process samples consisted of fibers that were incorporated into the bitumen and subsequently mixed with the aggregate. A mechanical mixer was used to mix the fibers and the PEN60/70 bitumen. Each fiber was individually blended into different samples. Additionally, the Marshal Mix design, which consists of 50 blow processes, was selected to represent medium traffic.

2.5 Performance Test

The first performance test involved the binder drain-down test (T305), which was performed using a loose asphalt mix to obtain the drainage property. It was done on three separate loose asphalt mixes through the average optimal binder content to determine the adequacy of the mix's binder-draining characteristics. Meanwhile, the second performance test was the Unconfined Compression Strength (UCS) test (AASHTO T167). It analyzed the compacted asphalt mixture's strength to ascertain the ultimate UCS at which the SMA-14 combination would fail.

3.0 RESULTS AND DISCUSSIONS

This study investigated whether the integration of medical waste fiber in asphalt can serve as a sustainable way to improve pavement performance. The results presented in this section provide valuable insights into studying the properties and performance of medical waste fiber in modified bitumen.

3.1 Penetration Test

Figure 4 depicts the outcome of the laboratory penetration test. The penetration values vary with the different percentages of NBR glove and DFM fibers used in the PEN60/70 bitumen. The penetration values for NBR-modified bitumen increased as the amount of NBR glove fiber increased. The results showed that the control sample penetrated 61.50 d-mm while the bitumen mixture with percentages of 3%, 6%, and 9% of NBR glove fiber had penetration values of 62.0, 64.0, and 65.5 d-mm, respectively. On the other hand, adding the DFM and NBR glove fibers lowered the penetration values and decreased the bitumen's stiffness, respectively. Typically, bitumen with higher hardness will have a lower penetration value, whereas those with lower hardness will have a higher penetration value. In hot climate regions, a lower penetration value is preferred so that the bitumen will not soften easily; a higher penetration value is recommended for a cold climate region to prevent the brittleness of bitumen. Penetration is related to viscosity, which increases at the end of the mixing process. A hardened mixture is formed once it has cooled and solidified. Hardening bitumen can have advantages as it enhances the rigidity of the material and improves the structure's capacity to distribute loads; it can also cause fretting or crack formation [16].

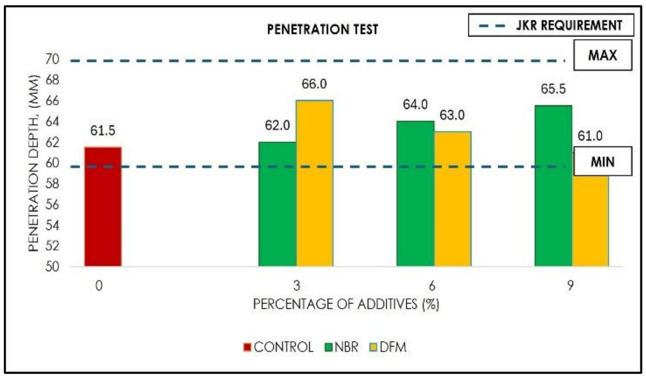

Figure 4 Penetration test results

3.2 Softening Point Test

Figure 5 depicts the results of softening point values for various percentages of NBR glove and DFM fibers utilized in the PEN60/70 bitumen. Compared to the control sample, adding 3%, 6%, and 9% of the NBR glove fiber increased the softening point values by 51, 52.5, and 54.3 ˚C, respectively. It indicates that the NBR-modified bitumen exhibits greater resistance to excessive temperatures than the conventional bitumen. Past study reported that the softening point values can be increased since raising the polymer content leads to higher polymer swelling. This will increase the apparent asphaltene content, resulting in a denser matrix that is more resistant to softening [17]. Meanwhile, the softening point values for DFM-modified bitumen decreased as the amount of DFM fiber increased. Adding the DFM fiber also increased the softening point values as opposed to the control sample. This is because Polypropylene Plastic (PP) commonly employed in the production of disposable medical masks belongs to the thermoplastics category, with melting points ranging between 160 and 166 °C. Conversely, PP can be heated and shaped while retaining its structure and strength. It also exhibits less variation in softening point, which is attributed to the homogeneity obtained during polypropylene's blending with bitumen base due to its low molecular weight and polarity. Thus, adding polypropylene can also improve the softening point values and increase road pavement's resistance to rutting at higher temperatures [16].

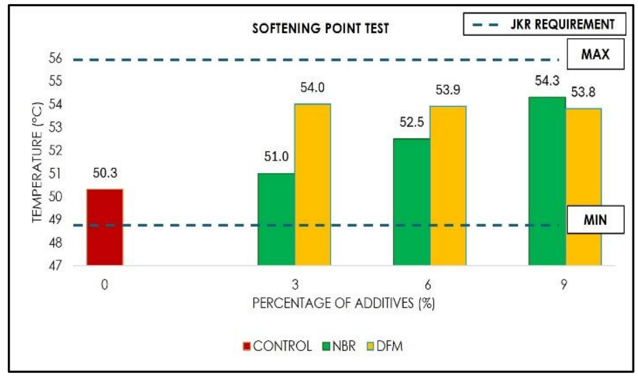

Figure 5 Results of softening point

3.3 Binder Drain-Down Test

Figures 6 and 7 show the binder drain-down test results in dry and wet conditions for both NBR and DFM SMA-14 mixtures. Compared to the control mixture, adding the NBR glove and DFM fibers into the mixture reduced the binder drain-down value, indicating its positive impact on the binder draining properties. In SMA mixtures, fiber binds the mastic together and regulates the drain-down process [19]. Meanwhile, other research reported that fiber enhances the toughness of SMA mixtures [18]. The 3% addition of both fibers through the dry process method recorded the highest binder drain-down values of 0.042% and 0.18%, respectively. Previous studies found that the dry process tends to have a higher drain-down value compared to the wet process because the fibre used has a different density, viscosity, and chemical compatibility to the PEN60/70 bitumen, which increases the possibility of separation during hot weather [18]. Compared to conventional SMA-14 mixtures, there is a huge difference in binder drain-down values for both additives. Therefore, the use of NBR glove and DFM fibres in SMA pavements can reduce the amount of binder lost through drainage alongside environmental pollution due to waste disposal. The addition of both fibres in bitumen acts as a hardening agent and necessitates the bitumen to have a higher melting temperature. This can reduce drainage issues during the transportation of the mix.

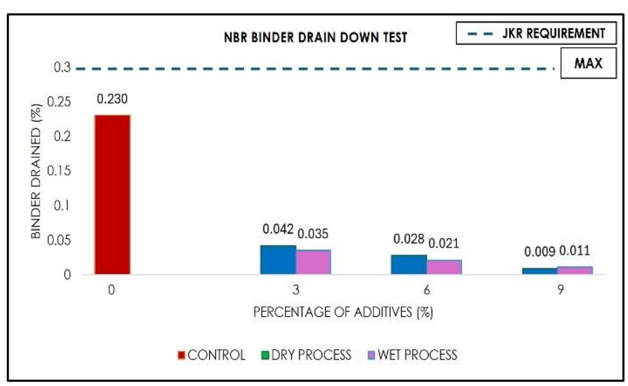

Figure 6 NBR binder drain-down results

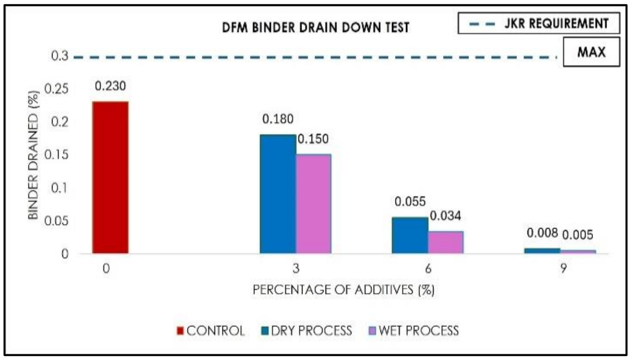

Figure 7 DFM binder drain-down results

3.4 Unconfined Compression Strength Test

Figures 8 and 9 display the Unconfined Compression Strength (UCS) Test results with the addition of NBR glove and DFM fibers as additives in SMA-14 mixtures. For DFM, optimal performance was observed at 6% for both dry and wet processes; the optimal performance for NBR was at 3% for dry processes and relatively stable performance starting at 3% in the wet processes. The wet processes influence compressive stress in the NBR mixture due to aggregate particles interacting with one another and their skeletons begin to play a role. Eskandarsefat *et al.* [20] mentioned that the presence of rubber in the mixture increased its resistance to permanent deformation due to the higher viscosity of the rubber. These findings denote that both fibers exhibit higher overall strength values and perform best at specific percentages under dry and wet conditions.

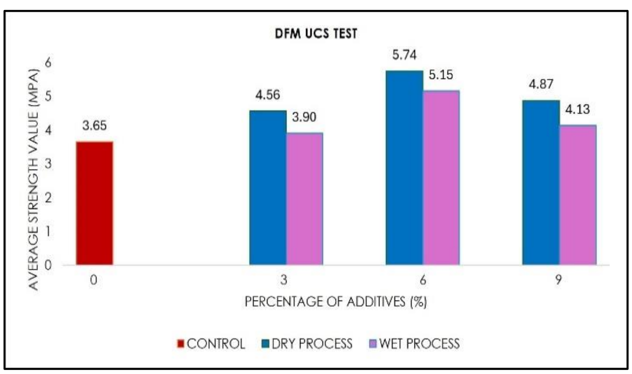

Figure 8 UCS test results of DFM

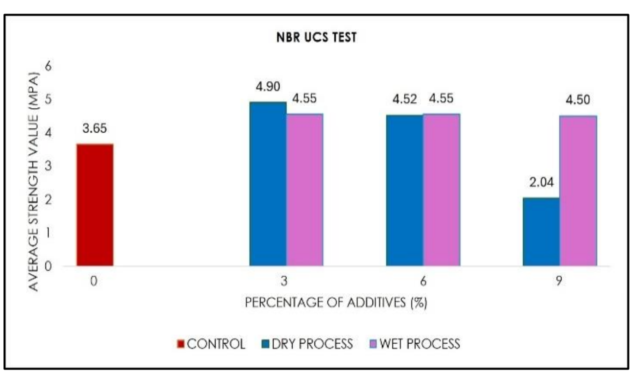

Figure 9 UCS test results of NBR

4.0 DISCUSSIONS

There appears to be a general inverse correlation between softening point and penetration depth. NBR was observed to have a slightly greater effect on softening points compared to DFM, especially at higher percentages. Both NBR and DFM affect penetration depth with the latter having a slightly more pronounced effect, especially at higher percentages. Both materials were also compared across different performance tests in two different processing conditions. This study highlights the importance of different processing conditions on the properties of NBR and DFM. Both mixes met the respective requirements for dry and wet processing conditions. As for the binder drain-down test, PWD Malaysia's specifications state that the maximum drain-down value is 0.3% of the total mixture. Overall, the dry process possesses higher drain-down and average strength values than the wet process for both NBR and DFM. Further investigation into the mechanisms at play and the impact on final product performance is needed to determine the best process for a specific application. Table 3 summarizes the findings of different processing conditions.

Table 3 Summary of Different Process Conditions

Material	Test	Process	Drain-Down (Ave. %)	Average Strength (Ave. MPA)	JKR Limit
NBR	Binder	Dry	0.026		
	Drain-	Wet	0.022	-	Max
DFM	Down	Dry	0.081		0.3%
		Wet	0.063		
DFM		Dry		5.06	2.0
	UCS	Wet	-	4.39	to
NBR		Dry		3.82	6.0
		Wet		4.53	MPa

5.0 CONCLUSION

This study found that the addition of 3%, 6%, and 9% of NBR and DFM fibers to PEN60/70 bitumen influences the softening point and penetration depth values at each tested percentage. The addition of NBR into the modified PEN60/70 bitumen increases the softening value and penetration depth, which is beneficial for pavement in hot climate areas and helps to settle the binder's bleeding problem. On the other hand, adding DFM decreases both test values. The softening and penetration results seem to suggest that the modification mechanism of disposal face masks involves the stiffening of the base asphalt PEN 60/70 for DFM fiber. Besides, 3% NBR and 6% DFM strengthened the mix further and the bitumen will be less likely to drain during both dry and wet processing. The addition of NBR to the SMA-14 mixture helps to increase the strength, enabling the pavement to resist greater stresses from moving automobile loads without suffering significant long-term deformation. The binder drain-down results demonstrate that a greater proportion of

DFM leads to less binder drain. Using both the dry and wet methods, modified asphalt containing 6% DFM produced the highest unconfined compressive strength with the compressive strengths of dry and wet samples were 5.15 MPa and 5.74 MPa, respectively. All test results met and passed the PWD's requirements. Overall, the dry process possesses higher drain-down and average strength values than the wet process for both NBR and DFM. Hence, it is concluded that adding both fibers as additives to pavement positively impacts its performance and increases the pavement's service life.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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