Evaluation of Cold Mix Patching Materials Along Jalan Persiaran Mokhtar Dahari, Selangor

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Abstract The increasing of road accidents and the economic loss due to maintenance operation is becoming an important issue in Malaysia asphalt industry. Potholes are the most common distress occurred in asphalt pavement which require immediate attention to minimise further pavement damage and reduce the opportunity for potential accidents. Hence, a study was conducted to evaluate the performance of six commercially available cold mix asphalt products in Malaysia. Six kinds of patching materials that is nominated as a company sample A, B, C, D, E and F currently used in practice were tested in the laboratory. The laboratory tests included the sieve analysis, density analysis, bitumen content, volumetric properties and moisture susceptibility test. The result of the laboratory tests indicates that the gradation for all the samples are close to the gradation requirements for the AC14 mix as per JKR Malaysia's specification. However, none of the samples fully complied with the gradation envelope. For density, all the samples are lower than the requirements for the AC14 mix and none of the samples fully complied with the compaction requirements due to the compaction method using the plate compactor. Meanwhile, for volumetric properties results, stability values of the various cold mix samples met the standard specification. Based on the ranking performance criteria of six different cold mix patching materials, Sample B and Sample D obtained the highest score of compliance with the requirements of the specification.

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Therefore, it is suggested that sample B and sample D are the most suitable cold mix materials to be used in patching maintenance work.

Keywords Cold mix asphalt · Patching · Hot mix asphalt · Strength · Pothole

1 Introduction

The rapid economic development over the last two decades has put tremendous pressure on Malaysia's road networks. Hot-mix asphalt (HMA) pavement is widely practiced in Malaysia for its economic and flexibility. Unfortunately, this HMA mix have deteriorated more rapidly than expected due to the increase in traffic volume, higher tire pressure, moisture, and temperature from our climatic condition. Many attempts have been carried out such as polymer modified bitumen in order to minimize the deterioration of the flexible pavement [2, 12]. Previous research has been conducted using additives/modifier in asphalt bitumen to enhance the engineering properties and performance of the conventional HMA mixes. In these, the various type of additives/modifier polymers and nanopolymers used included polyethylene (PE), polypropylene (PP), ethylene–vinyl acetate (EVA), ethylene–butyl acrylate (EBA), styrene–butadiene–styrene (SBS), nanoclay, nanocarbon, nanopolyacrylate and etc. These materials were reported to lead to some improved properties such as higher stiffness at high temperatures, higher cracking resistance at low temperatures, better moisture resistance or longer fatigue life [6, 9, 13, 14]. However, there are still shortcomings of using polymers in asphalt pavement mixes. Only a few are satisfactory with regards to the performance and costs [5, 16].

Potholes are the most common distress occurred in asphalt pavement. Potholes defined as small, bowl-shaped depressions in the pavement surface that penetrate all the way through the HMA layer down to the base course. They generally have sharp edges and vertical sides near the top of the hole. Potholes are most likely to occur on roads with thin HMA surfaces (25 to 50 mm) [1, 8, 11]. Potholes occurred due to repeated vehicle loads and heavy rainfall especially during a rainy season. These factors contribute small cracks in asphalt surface. When water penetrates into cracks with the repetitive traffic loads, the base layer becomes weak and loss of pavement structural support can be sudden. The asphalt surface layer starts to break up. Potholes are usually the result of alligator cracking. As alligator cracking becomes severe, the interconnected cracks create small chunks of pavement that can be dislodged as vehicles drive over them. Then, various sizes of potholes are created on the pavement surface [3].

Potholes require immediate attention to minimise further pavement damage and reduce the opportunity for vehicle damage potential accidents. Patching potholes in flexible pavements is an important maintenance operation because this activity is expensive and time-consuming. During the rainy season, the patching activity is even more important as pavements deteriorate more in wet weather. The selection of the best materials and patching of deteriorate areas in a road surface to secure safety and ride ability are important to repair pothole successfully. Conventionally, hot mix asphalt is used to repair pothole permanently. However, hot mix asphalt is only produced at plants and flows while it is hot. The premix asphalt hardens and thus producing a durable surface when it is cools [8]. Therefore, the need to use a new and improved cold mix patching materials are required to produce more economical and long-lasting solutions in pothole repair evaluations.

Presently, there is an increased interest in the use of cold mix asphalt as the primary patching material to be used for potholes in Malaysia. This is because cold mix asphalt offers certain advantages over hot mix asphalt such as no requirement for heating, reduction in the use of energy and lower emissions of gases and pollutants, leading to a more environmental-friendly product [7, 8]. Cold mix asphalt has generally been perceived to be less superior in quality compared to the conventional hot mix asphalt. Furthermore, potholes must be filled repeatedly are expensive to repair. Therefore, the longevity and serviceability of the pothole patching material on the repaired pothole could significantly help to the cost-effectiveness of the repairs [4]. Due to this reason, many studies have been conducted by several agencies to determine the economical, long-lasting materials and techniques [1].

Stability, stickiness, resistance to water action, durability, skid resistance, workability and storage ability are the most important properties requirement in bituminous patching mixture. Stability used to allow the patch to resist displacement by traffic. Aggregate gradation and properties may influence the stability of the mixture. Marshall stability is affected considerably by the cohesion and the internal friction of aggregate. According to [7], the dense-graded cold mix asphalts (CMAs) have higher stability values, indicating more cohesive mixes, as compared with the open-graded CMAs. Stickiness also influenced by the temperature of the mixture and the bitumen. Usually hot mixture materials have satisfactory adhesion when they are still hot, whereas cold-mixtures do not have adequate stickiness. Patching material must be resistance to water action to keep the bitumen from stripping off the aggregate. This property influences by the bitumen and the aggregate types. Durability and workability are required to ensure that the patch has a satisfactory resistance to disintegration and that the material can be easily compacted. Storage stability also important for patching materials so that the mixture can be stockpiled without hardening excessively or having the bitumen drain off the aggregate [15].

The present study aims to evaluate the performance of the commonly used cold mix asphalt used for patching of potholes in Malaysia. Instant Patchmix, Instant Tarmac, Tipco, Carboncor, Global Patch, QP Industries, Ecoinfira, Nescaya Positif and Alloy MTD, are some of the cold asphalt patching products available in Malaysia. In this study, a laboratory study was carried out to evaluate the performance of six commercially available cold mix asphalt products in Malaysia. This report presents the results and analysis of the study.

2 Materials and Method

2.1 Materials

The materials used for the patches were selected according to available cold mix asphalt products in Malaysia. Six products were the major materials for the project and were nominated as company product A, B, C, D, E and F. Each cold mix products having their own advance formulation. The section for the coring process was selected based on the site observation that is nearest to the potholes distress area in order to simulate the pavement condition due to potholes failures. Samples were cored from 2 different points on each location to be brought back to Highway Laboratory for evaluation.

2.2 Methods

The laboratory tests such as sieve analysis, density analysis, bitumen content, strength properties and resilient modulus test were carried out to evaluate the material properties of six commercially available cold mix asphalt products in Malaysia. These products were laid at two different sites located at Persiaran Mokhtar Dahari (Route B49) located in the district of Petaling, Selangor as shown in Fig. 1. For this field assessment, all potholes produced by creating a new pothole in a heavily damaged pavement. Traffic control was provided by the district personnel, while patches and potholes were prepared for patching. Existing patching material has been removed to make potholes and then filled with water. After 1 h, the patch crew swept the water and removed the debris from the holes and immediately installed the patching material. Contractors and district staff made the selection of the patching mixture used to fill the pothole appropriately. Figure 2 show the core samples from road sections.

Fig. 1 Site located along Persiaran Mokhtar Dahari, Selangor

Fig. 2 Core samples

2.2.1 Bitumen Content Test

Bitumen content is important in determining hot mix asphalt (HMA) mixture performance. The ignition test (AASHTO T 308) is the most common method used to determine bitumen content. This method involves the separation of bitumen and all other volatile substances from aggregates. It is an alternative to the conventional solvent extraction method. The remaining aggregates will be used for the determination of aggregate gradation and specific gravity. The test procedure starts by spreading more than 1200 g of loose material into the sample basket (Fig. 3a) to keep the material away from the edges. When the basket is ready, it is inserted inside the chamber, which reaches a temperature of 540 °C, to burn any flammable substance. The toxic fumes emitted during the test are reduced significantly by the afterburner, which has a temperature exceeds 900 °C. The machine monitors the temperature and changes in mass during the test; the test ends when there are no more mass changes. This test measures the bitumen content by subtracting the difference in mass before and after burning (Fig. 3b) in the ignition oven.

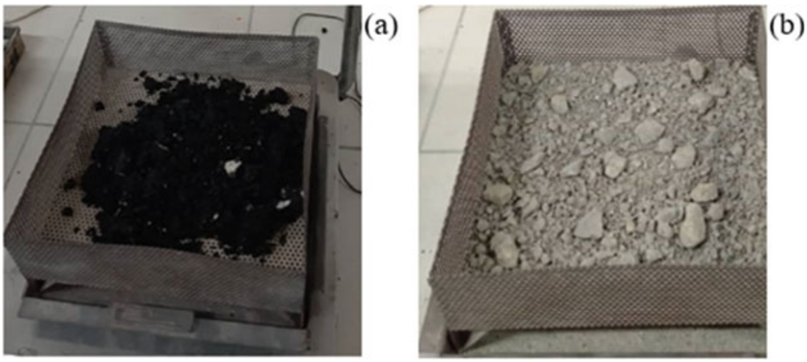

Fig. 3 Material **a** before test **b** after test

2.2.2 Particle Size Distribution Test

The particle size distribution test was performed according to ASTM D 136. This test was used to determine the particle size distribution of the extracted aggregates which obtained using the clean material derived from the ignition test. This method is performed by filtering an aggregate sample through a stack of wire mesh sieves, separating it into different size ranges. A mechanical sieve shaker (Fig. 4) is used to vibrate the sieve stack for a 7 to 15 min. On completion of sieving, the material on each sieve is weighed and the cumulative mass passing through each sieve is calculated as a percentage of the total sample mass. The results of the sieve analysis recorded graphically on a semi-log graph with particle size as abscissa (log scale) and the percentage smaller than the specified diameter as ordinate.

2.2.3 Density Analysis Test

Density analysis test was conducted to compare the level of compaction achieved on the cold mix patching materials from sections of the project according to ASTM D2726 and ASTM D2041 using a sample obtain from the selected site. Density was estimated as mass of the sample divided by the volume (dimensional volume). ASTM D2726 was used for determination of bulk specific gravity while ASTM D2041 was used for determination of theoretical maximum specific gravity. For determination of bulk specific gravity (ASTM D2726), the mass of the sample was tested under three (3) different conditions which include dry mass, mass in water and saturated surface dry mass (water fills the internal air voids). Figure 5 shows the bulk specific gravity test procedures.

For determination of theoretical maximum specific gravity, sample was prepared by heated a coring sample for ±1 h in the oven. After that, the sample immediately spread and loosen on a tray so that the fine aggregate is separated into particles

Fig. 4 Mechanical sieve shaker used for aggregates sieving

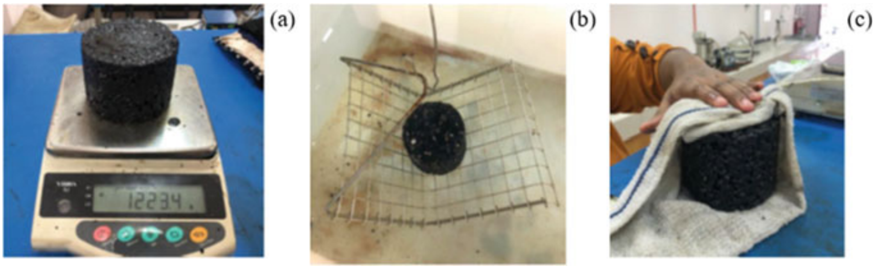

Fig. 5 Bulk specific gravity test procedures **a** Dry condition **b** Wet condition **c** Saturated surface dry (SSD) condition

Fig. 6 Corelok machine

smaller than 0.25 in. (6.25 mm). Further procedure was continued using corelok machine (Fig. 6). In corelok machine, determination of the theoretical maximum specific gravity requires inserting a loose sample inside a specially designed plastic bag, careful placement of the bag in the vacuum chamber and activation of the vacuum pump by closing the door. Internal controls regulate the vacuum pump and ensure proper operation until 99% of the total vacuum. Then, an automatic sealing strip inside the chamber heat seals the bag. At this stage, air will enter a controlled chamber and the bag will form a tight fit and conform to the shape of the loose sample. Then the vacuum chamber door opens, and the sample has been removed and immersed in 25 °C water bath to obtain a constant mass value in water. This mass is used in the calculation of theoretical maximum specific gravity by divided mass of sample in air with mass of water displaced by the sample. The density was therefore obtained by comparing the degree of compaction of each sample. As stipulated by the specification requirements of the Public Work Department (PWD) Malaysia-JKR/SPJ/2008-S4, compaction requirements of 98% of Marshall density at optimum bitumen content (OBC) were used.

2.2.4 Volumetric Properties Test

Marshall stability and flow tests were conducted to determine the volumetric properties of the asphalt mixture, such as stability (kN), flow (mm), stiffness (kN/mm) and air void (percent) to control the quality of the asphalt mixture. The Marshall stability and flow test procedure is in accordance with ASTM D 6927, which began with the immersion of the test samples in the water bath for 30 min at a constant temperature of 60 °C. As shown in Fig. 7, the test samples were then placed inside the loading head of the Marshall stability test machine. The flow meter was set to zero by inserting a 101.6 mm cylindrical metal diameter in the loading head. The test load was applied to the samples at a constant deformation rate of 50.8 mm per minute until the maximum capacity or peak resistance load was reached. The stability value is obtained by determining the maximum load that can be maintained by the samples before reaching its failure point. While the stability test was in progress, the flow metre remained firmly in position over the guide rod and was removed as the load began to decrease. The flow value of the sample is defined by the deformation at the maximum load. The stiffness value for each sample was then calculated as the stability and flow test average. The percentage of air voids was calculated from the bulk specific gravity and theoretical maximum specific gravity of the mixture performed in the density test section.

2.2.5 Moisture Susceptibility Test

Modified Lottman Test (AASHTO T283) and Boiling Water Test (ASTM D3625) were used to verify that the design test mixture formulated was susceptible to moisture damage in the pavement. These test measures the loss of strength or stiffness of an asphalt mix due to moisture induce damage. The modified Lottman

Fig. 7 Marshall stability test

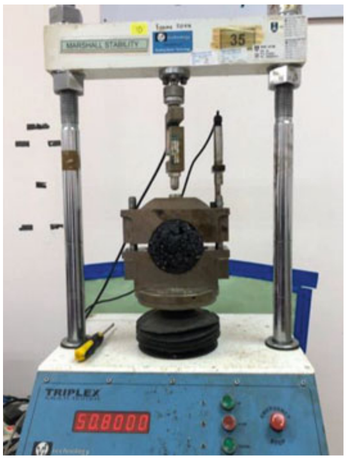

Fig. 8 Indirect tensile strength (ITS) test machine

test (AASHTO T283) is performed by compacting 7 ± 0.5% air void samples. Three samples were selected for control (tested without moisture conditioning) and another three samples were selected for conditioning by saturation with water at 70–80%, followed by 24-h immersion in water at 60 °C in a water bath. The samples were then tested for indirect tensile strength (ITS) by loading the samples at a constant head rate (50 mm/minute vertical deformation at 25 °C) using ITS machine (Fig. 8).and recording the maximum compressive force required to break the samples. An indication of the potential for moisture damage is the Tensile Strength Ratio (TSR) values in the test. A higher TSR value indicates that the mix is more resistant to moisture damage. Tensile Strength Ratio (TSR) results were determined by comparing the indirect tensile strength (ITS) of unconditioned (dry) samples to the control samples. Retained tensile strength ratio (TSR) was used at 80% as the boundary between moisture-resistant and moisture-sensitive mixtures [10]. The boiling water test (ASTM D3625) is a qualitative test which determines the effect of water on the adhesion between aggregate and asphalt bitumen. A loose mixture (passing a 9.5 mm sieve and retained on a 4.75 mm sieve) was placed in 800 mL distilled boiling water and was allowed to remain in the boiling water for 10 min. Thereafter, the retained coated area was evaluated by visual rating. According to standard specification for boiling water test, the specification limit for retained coated area minimum 95%. Those mixes above 95% retained coating is considered as resistant to moisture susceptibility.

3 Results and Discussions

3.1 Bitumen Content

According to standard Specification for Hot Mix Wearing Course: 4–6%. Table 1 shows that only cold mix asphalt for sample C and D are complied with the JKR specification. The bitumen content for Specimen A, B, E and F were not acceptable as it is exceeding minimum requirements. These excess bitumen content can lead to flushing or bleeding in the pavement thus lead to various type of pavement failure.

3.2 Particle Size Distribution

Table 2 shows the summary for gradations for cold mix asphalt samples of patching materials. The upper and lower gradation limits for all mixes type are shown in Fig. 9 which illustrate the percentage aggregate passing versus sieve size. The gradation for all the samples is close to the gradation requirements for the AC14 mix as per JKR Malaysia's specification requirements. However, none of the samples fully complied with the gradation envelope. It is possible that the gradation of these samples were slightly modified to ensure other requirements such as workability of the cold mix asphalt.

3.3 Density Test

The percentage of compaction for all the samples (Table 3) are lower than the requirements as per JKR Malaysia's specification requirements (compaction requirements of 98% of Marshall density). However, none of the samples fully complied with the compaction requirements. Company sample A achieved the highest compaction of 95.11%. It is possible that the compaction is lower than the

Table 1 Bitumen content results

Samples	Company sample					
	A	B	C	D	E	F
Mass of sample before extraction, g	1200.0	1200.0	1200.0	1200.0	1200.0	1200.0
Mass of sample after extraction, g	1077.6	1117.5	1137.3	1137.8	1106.2	1124.7
Mass loss, g	122.4	82.5	62.7	62.2	93.8	75.3
Bitumen content (%)	10.20	6.88	5.23	5.19	7.82	6.27

Table 2 Gradation for cold mix asphalt

Sieve size (mm)	Percentage passing							
	Company sample						Gradation limit	
	A	B	C	D	E	F	Lower	Upper
20.0	100.0	100.0	100.0	100.0	100.0	100	**100.0**	**100.0**
14.0	100.0	100.0	100.0	100.0	98.2	100	**90.0**	**100.0**
10.0	100.0	99.5	100.0	100.0	94.4	100	**76.0**	**86.0**
5	68.4	66.9	54.4	60.0	56.8	43.5	**50.0**	**62.0**
3.35	43.7	54.6	29.1	33.1	44.2	27.8	**40.0**	**54.0**
1.180	22.7	31.2	12.9	16.1	23.1	13.4	**18.0**	**34.0**
0.425	13.6	18.1	8.8	9.4	12.9	8.7	**12.0**	**24.0**
0.15	10.7	3.4	7.9	2.9	7.2	4.0	**6.0**	**14.0**
0.075	3.2	3.4	2.9	2.9	3.9	4.0	**4.0**	**8.0**
Pan	0.0	0.0	0.0	0.0	0.0	0.0		

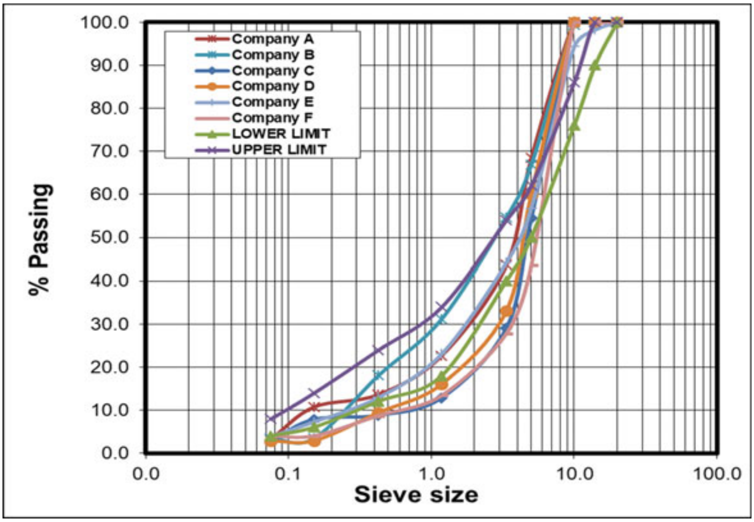

Fig. 9 Gradation Limit for all company sample patching material

requirements due to the compaction method using the plate compactor. These failures may be due to poor quality control during construction work. Insufficient compaction leads to poor performance even if other desirable mixture design characteristics are met.

Table 3 Density results for cold mix asphalt sample

Samples	Company sample					
	A	B	C	D	E	F
Bulk specific gravity	2.215	2.021	2.037	2.021	2.208	2.036
Theoretical maximum specific gravity	2.329	2.331	2.317	2.339	2.327	2.417
% Compaction	95.11	86.69	87.92	86.39	94.87	84.24

3.4 Volumetric Properties

Table 4 shows the strength properties of various samples of cold mix asphalts as compared with standard for hot mix asphalts. The stability values of the various cold mix samples met the standard specification where the samples exhibited high stability values, complying with the requirements of JKR specifications. The flow values of the various cold mix samples show that the Company A, C and D samples had flow value in the range of the hot mix standard specification. However, the company sample B, E and F had flow values slightly above the range for hot mix standard specification. The air voids content of all cold mixes asphalt samples did not comply with the hot mix standard specification except for company B cold mix sample which fall within the limits of the general asphalt specification of 3–4%.

Table 4 Strength Properties result for cold mix asphalt sample

Samples	Company sample						Standard specification for hot mix wearing course JKR/SPJ/2008-S4
	A	B	C	D	E	F	
Stability (KN)	21.4	19.7	15.1	14.1	11.0	12.8	>8 KN
Flow (mm)	3.18	4.17	2.74	3.78	4.59	5.77	2–4 mm
Stiffness (KN/mm)	6.73	4.74	5.53	3.72	2.40	2.21	>2 KN/mm
Air Voids in mix (%)	4.89	2.70	12.08	13.61	5.13	15.76	3–4%

3.5 Moisture Susceptibility

The Indirect Tensile Strength (IDT) results for unconditioned (dry) and conditioned (wet) samples for different types of patching material are shown in Fig. 10. The trend of the bar graph shows that the indirect tensile strength of conditioned (wet) samples values is lower than the unconditioned (dry) indirect tensile strength values. This shows that the moisture (wet conditioned sample) will decrease the value of indirect tensile strength. From the TSR values (Fig. 11), it clearly shows that the ratio unconditioned (dry) and conditioned (wet) samples for all mixes were complied with AASTHO T283 recommendation for hot mix asphalt except for Company sample F. This indicates that all cold mix asphalt except from company F are resistant to moisture damage which could sustain the load from vehicles and exposed to severe condition without large degradation of the structure. Test results from ASTM D3625 testing procedure (Boiling water test) are shown in Table 5. This table indicates that all cold mix samples tested except for sample C and F showed less than five percent coating loss, which showed greater than 95% coating retained or in other words these mixes were resistance to moisture damage. This shows that all the cold mixes are resistant to stripping and can sustain the load from vehicles as well as exposed to severe condition without high degradation of the pavement structure. The company C and F samples are not resistant to stripping as their values are lower than the standard requirements.

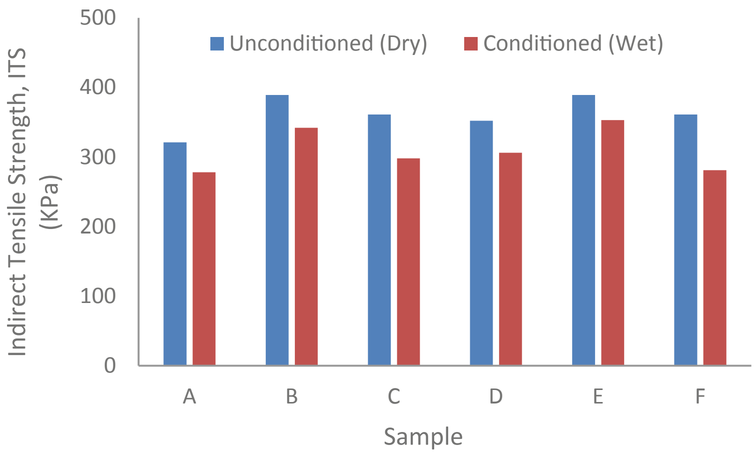

Fig. 10 Indirect tensile strength of conditioned (wet) and unconditioned (dry) samples

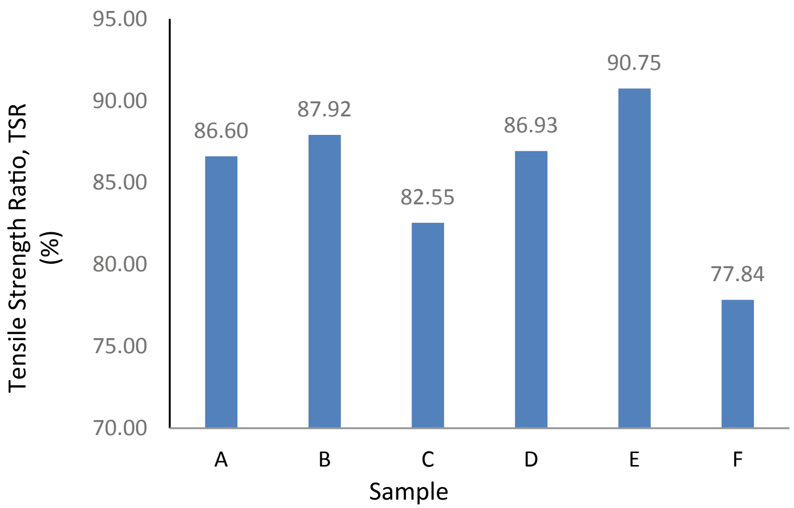

Fig. 11 Tensile strength ratio (TSR) with different cold mix asphalt sample

Table 5 Boiling water index result for cold mix asphalt sample

Samples	A	B	C	D	E	F
Percentage retained coating (%)	96	97	87	96	98	85
Retained coating greater than 95% (Yes/No)	Yes	Yes	No	Yes	Yes	No

3.6 Selection of Cold Mix Patching Materials By Using Grid Analysis

Table 6 tabulated the ranking performance criteria of cold mix patching materials which were conducted and measured in the previous sections. Table 6 presented that sign of √is indicate that the results complied with standard specification and sign of x is indicate that the result did not complied with standard specification.

Based on the laboratory tests carried out on the six different cold mix asphalt used for patching, Sample B and Sample D obtained the highest score of compliance with the requirements of the specification/standard (6 out of 8) followed by Sample A and Sample C (5 out of 8). Next is Sample E which obtained 4 out of 8 score. Sample F has the lowest compliance with the requirements of the specification/standard (2 out of 8). Therefore, based on the ranking, Sample B and sample D are the most suitable cold mix patching materials to be used in patching maintenance work.

Table 6 Ranking performance criteria of cold mix patching materials

Company samples	Bitumen content (%)	Stability (KN)	Flow (mm)	Stiffness (KN/mm)	Air voids in mix (%)	Density (%)	Tensile strength (%)	Boiling water test (%)	Score (out of 7)
A	10.2	21.4	3.18	6.73	4.89	95.11	86.60	85.6	5 of 8
	X	√	√	√	X	X	√	√	
B	6.88	19.7	4.17	4.74	2.7	86.69	87.92	82.6	6 of 8
	√	√	X	√	√	X	√	√	
C	5.23	15.1	2.74	5.53	12.08	87.92	82.55	74.4	5 of 8
	√	√	√	√	X	X	√	X	
D	5.19	14.1	3.78	3.72	13.61	86.39	86.93	83.2	6 of 8
	√	√	√	√	X	X	√	√	
E	7.82	11	4.59	2.4	5.13	94.87	90.75	94.8	4 of 8
	X	√	X	√	X	X	√	√	
F	6.27	12.8	5.77	2.21	15.76	84.24	77.84	45.1	2 of 8
	X	√	X	√	X	X	X	X	
Standard specification for hot mix wearing course	4–6%	>8 KN	2–4 mm	>2 KN/mm	3–4%	>98%	>80%	>75%	

4 Conclusions

Based on the laboratory tests carried out on the six different cold mix asphalt used for patching, Sample B and Sample D obtained the highest score of compliance with the requirements of the specification/standard. All the cold mixes except for sample C and F are resistant to stripping and can sustain the load from vehicles as well as exposed to severe condition without high degradation of the pavement structure. The Boiling water test (ASTM D3625) method is a subjective test; however the results has shown to be consistent in term of identifying stripping quality of HMA mixes. In addition, the stability values of the various cold mix samples met the standard specification where the samples exhibited high stability values, complying with the requirements of JKR specifications. In conclusion, it is suggested that Sample B and sample D are the most suitable cold mix patching materials to be used in patching maintenance work. It is recommended to conduct advance performance testing such as resilient modulus, simple performance testing and rutting testing to validate the results testing of coring sample.

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