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Study of Properties of Modified Asphalt by Using Waste Oil as Replacement

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Abstract: Crude oil is one of the most mismanaged resources on the world. Inappropriate used oil handling can lead to environmental problems. However, waste oil may be recycled in a variety of methods and used in technical applications, such as a rejuvenator for asphalt binder. The objective for this study is to study the chemical properties of waste engine oil from heavy vehicle and light vehicle. In addition, the mechanical characteristics of modified asphalt are evaluated, and the performance of standard asphalt and modified asphalt with waste oil is compared. Fourier Transform Infrared Spectroscopy (FTIR) Test, Softening Point, Penetration Test and Ductility Penetration testing reveals the stiffness of changed asphalt, and stiffness of sample car waste engine oil reveals a large increase in comparison to sample motorcycle waste engine oil. Data for the motorcycle waste oil sample, contrasted, reveal that the higher the value of the waste oil mixture, the more flexible the properties of the modified asphalt. In compared to traditional asphalt, modified asphalt with vehicle waste oil was able to change the properties of asphalt because the waste engine contains chemical compounds that influence the changed.

Keywords: Waste Oil, Asphalt, Bitumen, Modification

1. Introduction

Oil is mainly used in industries such as mobilization, engineering and culinary industry. Transportation sector is the largest contributor to the problem of waste oil because it consumes a large amount of petroleum products. Engine oil can be defined as one of many energy fuels of crude oil

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composed of long-chain saturated hydrocarbon or basic oil additives [1]. Oil and bitumen have the same waste disposal problems - disposal process takes a long time and increases operating costs.

Waste oil can have a significant impact on the environment if it is not properly managed. If waste oil is spill or improperly disposed of, it can seep into the ground and contaminate soil and water sources. This has a detrimental effect on plants, animals, and the overall ecosystem. According to [2], the development goal of providing clean and affordable drinking water to all may be met by 2030. When waste oil is released into the environment, it can contaminate soil and water sources. In soil, waste oil can create a barrier that prevents air and water from reaching the roots of plants. Deeper waters may potentially be affected by oil contamination, which would have much more serious effects on the environment [3].

Waste oil can also have negative effects on human health when it is burned. The oil air pollution can have an effect on the residing organism in a range of approaches such as direct contact with the skin, thru inhalation, via ingestion or by eating contaminated food. The recycling technique of waste asphalt pavement is becoming increasingly appealing from the viewpoint of energy and environmental preservation across the world [4]. This research is to study the benefits of waste material particularly on engine oil for asphalt binder to improve the characteristic of pavement. Several proper experiments were conducted to determine the characteristic of asphalt mixture with waste engine oil.

The objective for this study is to study the chemical properties of waste engine oil from heavy vehicles and light vehicles. In addition, the mechanical characteristics of modified asphalt are evaluated, and the performance of standard asphalt and modified asphalt with waste oil is compared. The work on this project included everything from inception to completion.

The scope of work contains all tasks required to complete the project. The entire scope of operation consists of collecting waste engine oil from heavy and light vehicle workshops in the Pagoh area. Chemical bound containment in waste engine oil was determined using a Fourier Transform Infrared Spectroscopy (FTIR) test. The standard ratio of bitumen grade 60/70 to waste engine oil is used. The sample proportion ranges from 0% to 5%. Softening Point, Penetration Test, Test, and Ductility Test are the experiments performed. The American Society for Testing and Materials prescribed the testing procedures (ASTM). UTHM Pagoh and Parit Raja conduct all laboratory tests.

Based on this study, the main significance is sustainable projects. This project can save the environment by recycling the used oil as material for asphalt binder. The combination of waste engine oil with bitumen can lead to new inventions, improvements in roadway engineering and reducing construction costs. It will be applied in the real construction industry, and the outcomes of the experiment on the samples will be used as a reference in future research.

2. Methodology

A few actions must be taken by preparations to secure the smooth study work in order to complete the purpose of this research. Firstly, a literature review is necessary to evaluate the project title. A lot of previous research may be used as references and recommendations to create effective experiments from here.

The first steps allow for the generation of ideas on how to carry out research, whether through laboratory testing or other methods. After reading and analyzing all of the literature the focus of study can be limited to ensure that the project is finished within the period given. Every activity must have an exact strategy in order to fulfill the objectives and synchronize with the objectives determined at the start of the research. The standard laboratory test was performed applying penetration, softening point ductility and FTIR as specified by the American Society for Testing and Materials (ASTM).

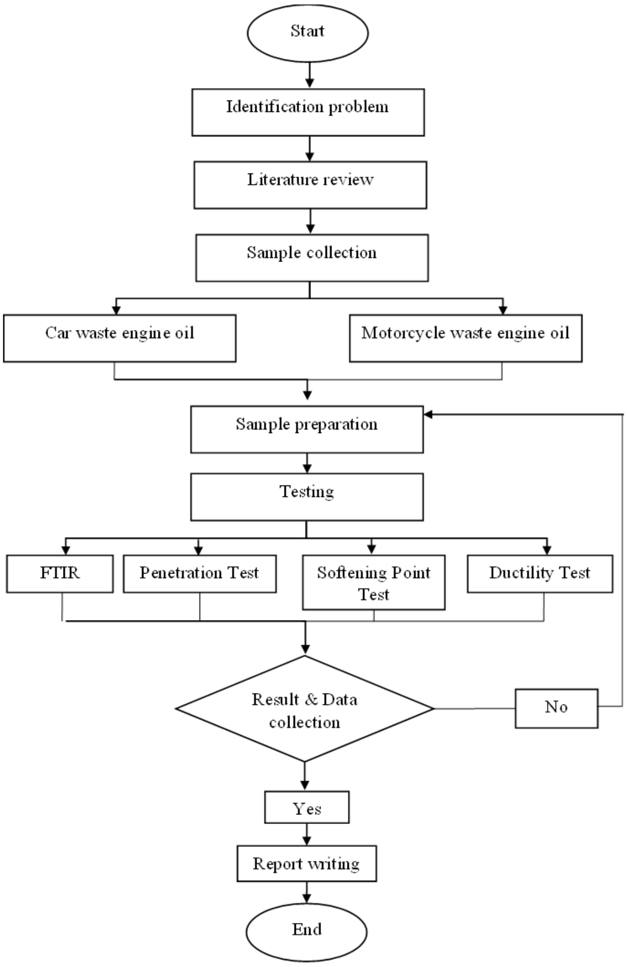

Figure 1: Flow chart for methodology.

2.1 Sample Collection

Waste oil was used as a modifier in an asphalt binder. Waste oil collected from the workshop in the Pagoh area. 2 different workshops selected represented different vehicles which are cars and motorcycles. For cars, waste engine samples are collected using an oil pump straight from the engine. For motorcycles, the method used as current engine oil services at the workshop.

(a) (b)

Figure 2: a and b shown two workshops for waste oil collection.

Waste oil that has been collected is stored in a barrel to ensure that the quality of the used oil is not affected by any debris. Each barrel is also labeled according to the type of waste oil i.e., car and motorcycle to ensure there is no problem in identifying the type of sample of waste oil. The barrel was kept in a dark place to avoid light that could wash away the viscosity of the waste oil. Any carelessness in the storage of samples of waste oil can affect the readings for the tests carried out.

2.2 Sample Preparation

The grade of bitumen used for this study was 60/70 grade bitumen for the base asphalt binder. The 500 g bitumen was heated until it became liquid, then the waste oil was applied to the base asphalt mix with proportion of 0%, 1%, 2%, 3%, 4% and 5% from the total mass of the bitumen. The High Shear Mixer was equipped with a hot plate and the modified bitumen were blended at 160ºC mixing temperature, 30 minutes mixing time and 800 rpm mixing steering speed.

The sample for this study is based on the percentage of waste oil. The distribution of the samples, 0% of waste oil sample, represents a base asphalt binder or also known as a control sample to be analyzed with other proportions of waste oil. Table below shows sample composition.

Table 1: Sample composition for car and motorcycle waste oil.

Bitumen (g)	**Percentage wasted oil**	**Mass of wasted oil (g)**	**Quantity**	
			Waste Car Engine Oil	**Waste Motorcycle Engine Oil**
500	0%	0	1	1
500	1%	5	1	1
500	2%	10	1	1
500	3%	15	1	1
500	4%	20	1	1
500	5%	25	1	1

2.3 Testing

The FTIR spectroscopy test helps in the classification of changes in functionality compounds and chemical changes in base asphalt caused by the addition of waste engine oil. Some common functional groups and associated wavenumber ranges discovered by FTIR (stretching vibration, bending vibration, stretching vibration, strong intensity, asymmetric or symmetric stretch etc). Waste engine oil sample was placed on glass and placed under the detector to send readings in the form of an interferogram to the software in the computer. The FTIR test consists of a detector and computer.

According to ASTM D5-97, the specimen was prepared in a sample container and put in a water bath at the recommended temperature of the test for 60 to 90 minutes before the test. The total load of both spindle and needle should be around 100 + 0.05 g, for normal tests the precisely dimensional needle is brought to the surface of the specimen at right angles, allowed to penetrate the bitumen for 5 + 0.1 s. The temperature of the specimen must be kept constant at 25 ºC. The penetration measured in 10 mm (deci-millimeter, dmm). A clean needle needed for each determination. In making repeated determinations, start each with the tip of the needle at least 10 mm for the side of the container and at least 10 mm apart.

Softening point test apparatus are thermometer, ring, steel ball, ball centering guide, ring holder and brass pouring plate. The procedure of the softening point test is based on ASTM D36-95. To begin, the asphalt binder must be heated in an oven at 100 ºC for 30 minutes or until it is sufficiently warm to pour. The brass rings must be coated with glycerine to prevent the bitumen sticking. The bitumen is then poured into the rings and allowed to cool for at least 30 minutes. After cooling, the top of the specimen must be removed and placed on a flat smooth brass plate with ball centering guides and a thermometer in place. Then fill the beaker with distilled water at depth not less than 102 mm and not more than 108 mm and keep temperature maintained at 5ºC for 15 minutes after the balls are placed in position. The temperature must increase at a constant rate until the ball may penetrate through the asphalt and sink downward at a distance of 25 mm, at which time the temperature is recorded as its softening point.

The ductility test was performed to determine the maximum stretching length before breaking. The Ductilometer is simply a moving carriage that travels along a guide. A ductilometer is used to determine bituminous ductility, which is the distance that a briquette of molten binder can be stretched before breaking under controlled conditions. The carriage is powered by an electric motor and is housed inside a big tank equipped with a digital thermostat, immersion electric heater, cooling coil for cold water circulation, and pump unit. The water bath for this test was set at a temperature of 25 ºC. All procedures of ductility test. This test procedure is according to ASTM D113 to collect the accurate data.

3. Results and Discussion

This section described the implications of the results in relation to the research problem statement or hypothesis. The limitations of the study and future research directions also stated for this chapter.

3.1 FTIR Analysis

The resulting absorption spectrum can be used to identify the functional groups present in the sample and to quantitatively determine the relative amounts of each functional group. Figure 3 and 4 show the graph of FTIR for waste engine oil for car and motorcycles.

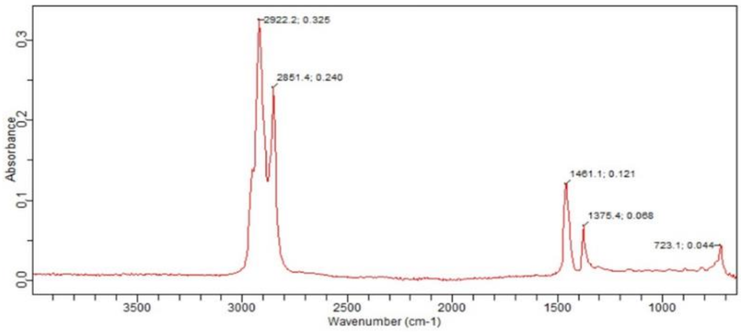

Figure 3: Absorbance graph for waste car engine oil.

Based on a graph for waste car engine oil, the absorbance peaks for waste oil were observed in range based on the graph in Figure 3.1, the absorption peaks of waste oil were observed in the range of 3000 cm−1 to 1500 cm−1. Table below shows the presence of a chemical bond between the peak range of wavenumber.

Table 2: Chemical bond between peak range for waste car engine oil.

Wavenumber (cm^{-1})	Bond	Mode	Group
1475-1435	CH	Antisymmetric, Deformation	$C\text{-}(CH_3)_3$ - Alkanes
2882-2862	CH	Symmetric, Stretching	$C\text{-}(CH_3)_3$ - Alkanes
2972-2952	CH	Antisymmetric, Stretching	$C\text{-}(CH_3)_3$ - Alkanes
3000-2800	O-H	Stretching	$C\text{-}SO_2\text{-}OH$ – Sulfur Compounds

Based on Table 2, chemical bonds for peak range are Alkanes and Sulfur Compounds. Alkanes are a form of hydrocarbon, meaning it were made up entirely of carbon and hydrogen atoms. Alkanes are known as saturated hydrocarbons because it contains the most hydrogens that could be bound to the carbon atoms in the molecule. Alkanes were used as starting materials in the production of a wide variety of chemical products, including plastics, resins, and synthetic rubber. Sulfonic acids are organic acids defined by the presence of a sulfur compounds group bonded. They are classified as strong acids, which indicates the compounds totally oxidize in water to create ions.

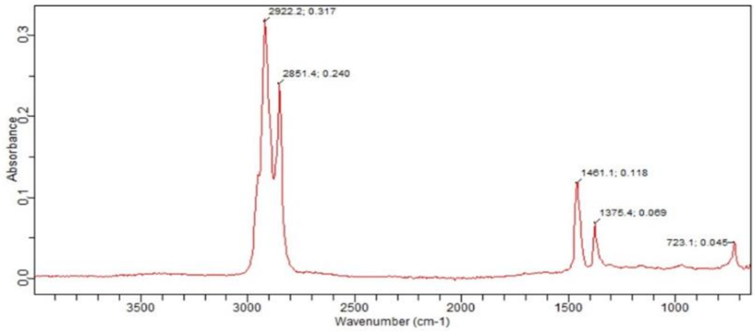

Figure 4: Absorbance graph for waste motorcycle engine oil.

Based on a graph for waste motorcycle engine oil, the absorbance peaks for waste oil were observed as in graph waste car engine oil as the range of 3000 cm−1 to 1500 cm−1 based on the graph in Figure 4. Table below shows the presence of a chemical bond between the peak range of wavenumber.

Table 3: Chemical bond between peak range for waste motorcycle engine oil.

Wavenumber (cm^{-1})	Bond	Mode	Group
1725-170	C=O	Stretching	C-C-COOH - Carbo-Acids
3100-2900	O-H	Stretching	C-C-COOH - Carbo-Acids
3000-2900	CH	Symmetric, Stretching	Cyclohexyl - Alkanes
2924-2875	CH	Symmetric, Stretching	Cyclobutyl - Alkanes

Based on Table 3, the chemical bond for peak range is Carbo-Acids and Alkanes. Carbon acids are carboxylic acids present in fats, oils, and other forms of lipids. Its classification was determined on the length of their carbon chain and the degree of saturation. Unsaturated carbo acids have one or more double bonds between the carbon atoms, and saturated carbo acids have none.

3.2 Penetration Analysis

Higher penetration depths indicate a softer, more flexible binder, and lower penetration depths indicate a harder and more rigid binder. Standard penetration for bitumen grade 60/70 is 60 mm to 70 mm. Table 4 and Table 5 shown result from penetration test.

Table 4: Result penetration test for Sample waste car engine oil (WCEO).

Sample	Trial 1	Trial 2	Trial 3	Average
0% WEO	7.07	6.96	5.68	6.57
1% WEO	10.45	10.92	9.39	10.24
2% WEO	13.04	12.72	12.99	12.92
3% WEO	17.02	19.43	16.55	17.67
4% WEO	18.42	17.91	18.05	18.13

5% WEO	20.19	20.58	19.76	20.18

Based on table 4, the value of average penetration for car waste engine oil was increased along with percent of waste engine oil. The result for the control sample, which is 0% presented was 6.57 mm, which corresponds to the penetration standard for bitumen grade 60/70. Between 1 until 5 percent of waste oil, the highest value recorded was 20.18 mm which has been done on a 5% sample of waste engine oil. The sample is softer and more flexible based on the value of penetration. For the lowest value stated as 10.24 mm depth from 1% sample, it is more stiff than other samples.

Table 5: Result penetration test for Sample waste motorcycle engine oil (WMEO).

Sample	Trial 1	Trial 2	Trial 3	Average
0% WEO	7.07	6.96	5.68	6.57
1% WEO	6.53	6.87	6.38	6.59
2% WEO	5.76	5.97	6.78	6.17
3% WEO	7.65	7.21	6.10	6.99
4% WEO	9.59	8.20	8.84	8.87
5% WEO	10.00	7.89	8.60	8.83

Table 5 showed the value of average penetration for motorcycle waste engine oil was increased along with percent of waste engine oil. The highest value recorded between 1% and 5% waste oil was 8.84 mm, which was done on a 4% sample of waste motor oil. Based on the penetration measurement, the sample is more flexible and softer. The lowest result, 6.17 mm depth from 2% sample, has higher rigidity than the other samples. Figure 5 below shown graph for penetration value between car and motorcycle waste engine oil. The graph shown sample waste car engine oil (WCEO) has high value of penetration than value for sample waste motorcycle engine oil (WMEO).

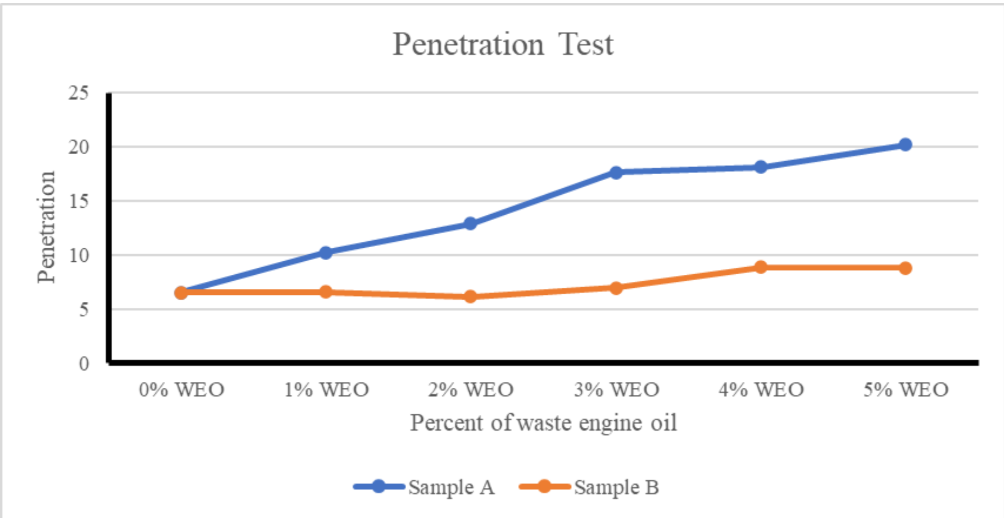

Figure 5: Graph of penetration value for sample waste car engine oil (WCEO) and sample waste motorcycle engine oil (WMEO).

3.3 Softening Point

An asphalt binder with a low softening point may be prone to rutting or deformation at high temperatures, while an asphalt binder with a high softening point may be too stiff to work with at lower temperatures. The softening point test is therefore an important tool for evaluating the performance of different asphalt binders under various temperature conditions. Table below shows the result for the softening point.

Table 6: Softening Point result for Sample waste car engine oil (WCEO).

Sample	Trial 1 (°C)	Trial 2 (°C)	Average (°C)
0% WEO	48	49	48.5
1% WEO	46	48	47
2% WEO	46	47	46.5
3% WEO	44	46	45
4% WEO	40	44	42
5% WEO	43	43	43

The temperature for the softening point for the control sample (0%) was 48.5°C. The result showed the value of temperature was decreased for softening test samples 1% to 4%. The highest temperature recorded was 47°C, it proved the 1% sample of car waste engine oil has stiffness properties for low temperature conditions. The sample that has lowest stiff properties was sampled for 4%, the softening point recorded was 42°C.

Table 7: Softening Point result for Sample waste motorcycle engine oil (WMEO).

Sample	Trial 1 (°C)	Trial 2 (°C)	Average (°C)
0% WEO	48	49	48.5
1% WEO	45	46	45.5
2% WEO	45	45	45
3% WEO	44	45	44.5
4% WEO	43	44	43.5
5% WEO	40	42	41

Based on Table 7, the result for softening point of motorcycle waste engine oil was also decreased as sample waste car engine oil (WCEO). The difference between each softening point for every sample waste motorcycle engine oil (WMEO) was closer than sample waste car engine oil (WCEO). For the 5% sample, the result showed the lowest temperature value which was 41°C when the steel ball reached the bottom plate. The highest data recorded was 1% sample with 45.5°C. Figure 6 shows the graph for both results for sample waste car engine oil (WCEO) and sample waste motorcycle engine oil (WMEO) to analyze the difference between two results of softening point. The graph shown all results was above the standard softening point temperature for grade 60/70 which is 49 °C to 56°C.

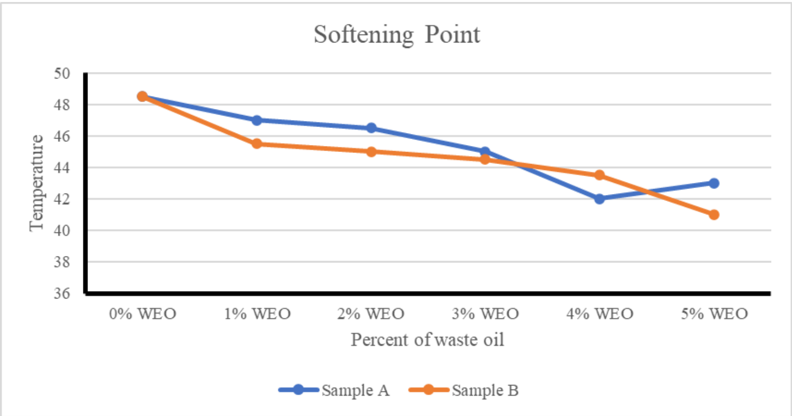

Figure 6: Graph of softening point for sample waste car engine oil (WCEO) and sample waste motorcycle engine oil (WMEO).

3.4 Penetration Index

The penetration index is used to determine the temperature susceptibility of asphalt binder and classify according to their performance at different temperatures [5]. The penetration index value was a measure of an asphalt binder's softness or hardness. It was calculated by measuring the depth to which a standard needle will penetrate a binder sample at a certain temperature. The data obtained from penetration test and softening test were being used to calculate penetration index by using the formula below.

$$PI = \frac{1952 - 500\, log\, log\,(P)\ - 20SP}{50\, log\, log\,(P)\ - SP - 120} \tag{4.1}$$

A higher penetration index value represents a softer and more elastic asphalt binder, and a lower value represents a harder and more brittle binder. As a result, the penetration index value is used to evaluate the performance of an asphalt mixture in different temperature conditions and to choose a binder with the suitable qualities for a certain application. Table 8 shows the penetration index for car waste engine oil.

Table 8: Penetration Index value for Sample waste car engine oil (WCEO).

Sample	Penetration	Softening Point	Penetration Index
0% WEO	65.7	48.5	-0.9
1% WEO	102.4	47	-0.1
2% WEO	129.2	46.5	0.6
3% WEO	176.7	45	1.4
4% WEO	181.3	42	0.4
5% WEO	201.8	43	1.3

The calculation for penetration index value shown in Table 8. The result increased from negative value to positive value. The crucial part was in between peak value 3% and 4% sample, the value dropped from 1.4 to 0.4 with the difference was 1.0. Then, the value increases to 1.3 for the last sample of car waste engine oil. The result for sample waste car engine oil (WCEO) was different from sample waste motorcycle engine oil (WMEO) which decreased the form of penetration index value. Table 9 proved the result for sample waste motorcycle engine oil (WMEO).

Table 9: Penetration index value for Sample waste motorcycle engine oil (WMEO).

Sample	Penetration	Softening Point	Penetration Index
0% WEO	65.7	48.5	-0.9
1% WEO	65.9	45.5	-1.8
2% WEO	61.7	45	-2.1
3% WEO	69.9	44.5	-1.9
4% WEO	88.7	43.5	-1.6
5% WEO	88.3	41	-2.4

All results calculated for sample waste motorcycle engine oil (WMEO) were constantly negative values. The first three samples decreased to -2.1 and the data shown increased value until 4% sample for -1.6. But the final sample showed a sharp drop result to -2.4. The susceptibility of the binder additives incorporated influences the outcome for 2% and 5%. The graph plot for the result of penetration index for sample waste motorcycle engine oil (WMEO). The highest value recorded between 1% to 5% was -1.6 which was obtained from a 4% sample.

3.5 Ductility Test

Ductility test was used to calculate the maximum stretching length that a binder sample may reach before breaking or failing. Table 3.9 and 3.10 showed the ductility value for sample waste car engine oil (WCEO) and B in cm. A high ductility binder is more flexible and can stretch longer before breaking, and a low ductility binder is less flexible and breaks at a shorter stretching length.

Table 10: Ductility value for Sample waste car engine oil (WCEO).

Sample	Ductility (cm)
0% WEO	>150
1% WEO	144
2% WEO	130
3% WEO	128
4% WEO	125
5% WEO	122

Based on Table 10, the ductility value for sample waste car engine oil (WCEO) was decreased from 144 cm to 122 cm along with the percent of waste engine oil. The control sample was recorded >150 because the ductilometer machine limitation distance was only 150 cm. The longest distance asphalt able to extend was recorded 144 cm for 1% sample. This showed the sample was the most flexible asphalt binder than another sample. For the 5% sample, the asphalt was cut off at distances of 122 cm caused by the mix of waste engine oil that impacted the ductility properties of the standard asphalt. Result for sample waste motorcycle engine oil (WMEO) shown in Table 3.10 has a different trend of value of ductility.

Table 11: Ductility value for Sample waste motorcycle engine oil (WMEO).

Sample	Ductility (cm)
0% WEO	>150
1% WEO	123
2% WEO	131
3% WEO	135
4% WEO	148
5% WEO	>150

Based on Table 11, the ductility value for sample waste motorcycle engine oil (WMEO) was improved than sample waste car engine oil (WCEO). The result was increased from 123 cm to >150 cm along with the percent of waste engine oil. For the 1% sample, the asphalt was chopped off at 123 cm intervals due to the presence of waste motor oil, which affects the ductility qualities of standard asphalt. The farthest distance asphalt could stretch was >150 cm for a 5% sample, and it can go even further. This proved that the sample was the most flexible asphalt binder compared to the other samples.

4. Conclusion

In comparison to traditional asphalt, modified asphalt with vehicle waste oil was able to change the properties of asphalt because the waste engine contains chemical compounds that influence the change. It is possible to obtain data as standard grade 60/70 bitumen, however modified asphalt might be used for base course paving to support the binder and surface course of the road. The following suggestions have been made: Additional tests should be performed to establish the qualities of used engine oil in terms of oil content, moisture content, and element composition. More testing, such as density, viscosity, and fatigue, should be performed. This approach could lead to more data on the physical and chemical properties of changed asphalt. Add more varied percentages of waste oil as a binder modifier to calculate the limit of waste oil as an asphalt binder. Prove the modified asphalt by combining it with aggregates to generate a paving sample. Conduct paving sample tests to collect data on the overall density, water absorption, and strength properties of modified asphalt as a binder.

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