THE EFFECT OF FUEL ON FLEXIBLE PAVEMENT

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ABSTRACT

In this study, the effect of fuel on different types of Hot Mix Asphalt (HMA), Stone Mastic Asphalt (SMA) and Polymer Modified Asphalt (PmA) mixtures were investigated. The related Standard tests were applied to the binder, aggregate and polymer modified bitumen, to define their properties and to compare the results. The conventional binder was modified by adding different amounts of SBS to the bitumen. The Penetration, Softening point, Rolling Thin Film Oven Test (RTFOT), and Flash point tests were applied to the binder. Basalt and Limestone of aggregates were used for all types of mixes. Stripping resistance, Absorption, Flakiness,Los Angeles coefficient and Magnesium sulfate tests were applied to the aggregate. Four different types of Hot Mix samples were produced to be analyzed in the laboratory. Those are; "AC16 Wearing, PmB 25/55-55", "AC16 Wearing, PmB 25/55-60", "SMA11, PmB 25/55-60", and "AC16 Wearing, 50/70". The analysis was carried out in accordance to the standard of; "TS EN 12697-43 Bituminous mixtures-Test methods for hot mix asphalt-Part43: Resistance to fuel". According to this standard, a cylindrical test specimen with a known mass is immersed partly in a bath with the specified fuel for a specified period of time. This period differs from type to type for the mixes. The material loss after the immersion and the brush test was a measure for the resistance to fuel. The comparisons were made between the types of four mixes. The laboratory test results of the samples are presented in the "Conclusions and Recommendations" section of the study.

Keywords: Fuel on asphalt, Modifiers, Modified bitumen, Pavements resistance to fuel

1. INTRODUCTION

Bituminous binders are soluble in petroleum solvents and thus all bituminous surfacing are susceptible to damage from spillages of diesel, petrol and solvents. Spilled fuels, oils, and hydraulic fluids soften the asphalt binder of concrete pavements, causing the pavement to disintegrate and erode. Asphalt surfaces used in areas such as climbing lanes, busy intersections, toll plazas or airport aprons are more prone to damage from fuel spillage. Tests have been developed for measuring the fuel resistant properties of asphalt mixes. Evaluation of the performance of asphalt mixtures applied on wearing courses of road pavements when subjected to the action of fuel spillage. Asphalt mixtures produced with different types of bitumen were studied. Experimental program based on the test method EN 12697-43 "Bituminous mixtures - Test methods for hot mix asphalt - Part 43: Resistance to fuel”, complemented with other laboratory tests to determine the performance of asphalt mixtures. The CEN (EN 12697-43:2005) method involves soaking the asphalt briquette in fuel for a period followed by brushing system. The material loss of the briquette is a measure of the resistance to fuel for that asphalt.
The study was conducted using HMA-PmA materials (aggregates, filler, bitumen, SBS) and two types of fuel. The asphalt mixtures were made with one type of aggregate combined with three types of binder: a grade pen 50/70 (conventional) and a polymer modified bitumen with two different amounts of SBS. The resistance to fuel was determined for two different types of fuels: gasoline 95 and diesel.
The primary objective of this research was to find out how the mixtures are affected by fuels. In the process of answering that question, different types of asphalt mixture samples were prepared and the test results compared with each other and also compared to traditional hot mix asphalt (HMA) samples. The conventional binder was modified by adding different amounts of polymer modifiers to the binder (B50/70 bitumen). The Penetration, Softening point, Fraass breaking point, Flash point, Specific gravity, Loss on heating and Rolling Thin Film Oven Test (RTFOT) tests were applied to the binder to determine its physical properties. Lime stone of aggregate were used for HMA-PmA mixtures. Flakiness, Los Angeles coefficient, Absorption, Magnesium sulfate, Stripping resistance and Specific gravity tests were applied to the aggregate. Determination of the water sensitivity, Rutting, Bulk density and Stability tests were carried out on the mix specimen samples for analyzing of different mixture types.
Four different types of Hot Mix samples were produced to be analyzed in the laboratory. Those are; “AC16 Wearing, PmB 25/55-55”, “AC16 Wearing, PmB 25/55-60”, “SMA11, PmB 25/55-60”, and “AC16 Wearing, 50/70”. The analyses were carried out in accordance to the standard of; “TS EN 12697-43 Bituminous mixtures-Test methods for hot mix asphalt-Part43: Resistance to fuel”. According to this standard, a cylindrical test specimen with a known mass is immersed partly in a bath with the specified fuel for a specified period of time. This period differs from type to type for the mixes. The material loss after the immersion and the brush test was a measure for the resistance to fuel. The comparisons were made between the types of four mixes.

2. MATERIALS

Laboratory testing was performed to determine the effect of different fuel types on different types of asphalt mixtures. Hot Mix Asphalt (HMA) and Stone Mastic Asphalt (SMA) produced using different amount of modifiers with different mix designs. HMA and SMA specimen samples were prepared with limestone and basalt as aggregate, B50/70 bitumen as binder, and SBS as modifier to modify the mixes.

2.1. Aggregate

The aggregates used for this project were selected from different regions according to their properties. Conventional Hot Mix Asphalt (HMA), Modified Asphalt and Stone Mastic Asphalt (SMA) specimen samples were prepared with limestone aggregate from Cebeci quarry in Istanbul and basalt aggregate from Çorlu quarry in Tekirdağ. Some standard tests were applied to the aggregate.
The objective of the tests carried on the aggregates was to determine the properties of limestone (both coarse and fine materials) aggregate and to decide their availability of the asphalt mix. These tests include Sieve analysis, Specific gravity, Absorption, Stripping resistance, Magnesium sulfate tests, Flakiness index, Los Angeles abrasion tests. The objective of the tests, carried on the aggregates, was to determine the properties of both limestone and basalt aggregates and to decide their availability of the mix. The gradation selected for this project is the wearing course AC16 gradation of Turkish Road Authority specification. Table 1 summarizes the properties for SMA11, and Table 2 summarizes the properties for AC16 wearing course aggregate distribution and specification.

Table 1: Aggregate Size Distribution and Specification for SMA11

Sieve Size	Specification (SMA11)	Passing Percent (%)

No	mm	(%)	
1/2″	12.7	100	100
3/8″	9.52	90-100	91.8
No. 4	4.76	25-45	39.7
No. 10	2.0	20-30	24.7
No. 40	0.42	12-22	14.1
No. 80	0.177	9-17	11.5
No. 200	0.074	8-14	9.6

Table 2: Aggregate Size distribution and specification for AC16

Sieve Size		Specification (AC16) (%)	Passing Percent (%)
No	mm		
3/4″	19.0	100	100
1/2″	12.7	83-100	89.1
3/8″	9.52	70-90	78.0
No. 4	4.76	40-55	50.1
No. 10	2.0	25-38	28.9
No. 40	0.42	10-20	13.7
No. 80	0.177	6-15	9.8
No. 200	0.074	4-10	7.1

To increase the stripping resistance of the basalt aggregate and to get it inside the specification limits, polymeric additive used to modify the binder and new samples were produced and tested. These new samples were tested to insure that they were available for the mix. The results after modification were available for the mix, since their values were in the spec limits. The test results for both the basalt and limestone of aggregates are shown in Table 3 and Table 4. The specific gravity value of filler for limestone evaluated as 2.78 g/cm^3, while the same value for basalt was evaluated as 2.94g/cm^3.

Table 3: Properties of Basalt Aggregate

Properties	Unit	Test Method	Spec.	Test Results
Flakiness	%	TS EN 933-3	-	21
Los Angeles coefficient	%	TS EN 1097-2	Max. 30	12
Absorption	%	TS EN 1097-6	Max. 2.0	1.16
Magnesium sulfate test	%	TS EN 1367-2	Max. 16	2.8
Stripping resistance	%	Nicholson	Min. 50	30-40
Coarse aggregate specific gravity	g/cm^3	TS EN 1097-6	-	2.97
Fine aggregate specific gravity	g/cm^3	TS EN 1097-6	-	2.91
Filler specific gravity	g/cm^3	TS EN 1097-7	-	2.94

Table 4: Properties of Limestone Aggregates

Properties	Unit	Test Method	Spec.	Test Results
Flakiness	%	TS EN 933-3	-	14
Los Angeles coefficient	%	TS EN 1097-2	Max. 30	22
Absorption	%	TS EN 1097-6	Max. 2.0	0.61
Magnesium sulfate test	%	TS EN 1367-2	Max. 16	4.2
Stripping resistance	%	Nicholson	Min. 50	65-75
Coarse aggregate specific gravity	g/cm^3	TS EN 1097-6	-	2.74
Fine aggregate specific gravity	g/cm^3	TS EN 1097-6	-	2.72
Filler specific gravity	g/cm^3	TS EN 1097-7	-	2.78

It can be clearly seen from the tables above that, the limestone and after modification of binder, the basalt aggregate are available to be used for the mixtures HMA and SMA.

2.2. Bitumen (B 50/70)

The main goal for this study was to determine what effect different binders would have on fuel resistance of an HMA and SMA mixture. For this part of the study, B50/70 bitumen was used. The binder was obtained from Turkish Petroleum Refineries Co. (TÜPRAŞ) in Kocaeli/Turkey. The standard bitumen tests were carried out on the conventional and modified binder samples. In the first group, B 50/70 bitumen samples were tested and in the second set of tests, modified bitumen samples prepared with SBS were tested.
The standard conventional and modified bitumen tests were performed including Penetration, Softening point, Fraass breaking point, Flash point, Specific gravity, Loss on heating, and Rolling Thin Film Oven Test (RTFOT) test. Table 5 summarizes the properties of the conventional binder used in this study.

2.3. Polymeric Additives (SBS)

Many different polymers are used to modify asphalts and each has their own associated physical properties. On the basis of the demand of the available SMA additives in the industry, widely used SBS modifier were selected. Basically, two types of the processes are used to modify the mixtures. Those are wet and dry methods. In the wet process, the additive is to be added with binder prior to mixing process, while in the dry process; the additive is to be added along with bitumen into the aggregate during mixing process. The specimens were prepared by wet process for two different amounts of SBS.
Stiren-Bütadien-Stiren (SBS) was used as a bitumen modifier for this project. SBS block copolymers have a molecular structure that is characterized by a rubbery core midblock, which for bitumen applications is usually made up of polybutadiene.

Table 5: Conventional Binder Test Results and Specification

Properties	Unit	Test Method	B 50/70 Conventional	B 50/70 Specification
Penetration	0.1mm	TS EN 1426	61.0	50 - 70
Softening point	ºC	TS EN 1427	50.4	46 - 54
Fraass Breaking point	ºC	TS EN 12593	-12	Max., -8
Flash point	ºC	TS EN 2592	332	Min., 230
Specific gravity	g/cm^3	TS EN 15326	1.021	-
Loss on heating	%	TS EN 12607-2	0.4	Max., 0.5
RTFOT	%	TS EN 12607-1	0.5	-

However, for some applications out of polyisoprene, it is tipped at all ends with polystyrene end-blocks. Two different amounts of SBS were added to the binder to modify B50/70 bitumen samples; the first one was 3.5% percent of SBS, and the second one was modified by 5% of SBS. The mixture conditions were; a temperature of 180ºC, a mix velocity of 3000 rpm and duration of 150 minutes.

The standard modified bitumen tests were performed including Penetration, Softening point, Fraass breaking point, Flash point, Elastic recovery, Dynamic Shear Rheometer (DSR) and Rolling Thin Film Oven Test (RTFOT) test. Table 6 summarizes the properties of 3.5% SBS modified binder, and Table 7 presents the properties of 5% SBS modified binder used in this project.

As it can be seen clearly from Table 4, the binder used for this project is available for production of HMA samples. The result stated that 3.5% SBS modified binder is included in the rate of PmB 70/16 specifications, while 5% SBS modified binder is included in the rate of PmB 76/16 specifications of modified bitumen.

Table 6: Modified Binder Test Results, 3.5% SBS

Properties	Unit	Test Method	3.5% SBS Modified	PmB 70/16 Specification
Penetration	0.1mm	TS EN 1426	45	30 - 70
Softening point	ºC	TS EN 1427	63	Min., 62
Flash point	ºC	TS EN 2592	310	Min., 220
Elastic Recovery	ºC	TS EN 13398	85	Min., 60
DSR	ºC	TS EN 14770	70	Min., 70
RTFOT	%	TS EN 12607-1	0.2	Max., 1.0

Table 7: Modified Binder Test Results, 5% SBS

Properties	Unit	Test Method	5% SBS Modified	PmB 76/16 Specification
Penetration	0.1mm	TS EN 1426	41	20 - 60
Softening point	ºC	TS EN 1427	78	Min., 67
Flash point	ºC	TS EN 2592	315	Min., 220
Elastic Recovery	ºC	TS EN 13398	93	Min., 60
DSR	ºC	TS EN 14770	76	Min., 76
RTFOT	%	TS EN 12607-1	0.2	Max., 0.8

2.4. Fuel

Since the most spilled fuels on asphalt pavement surfaces is leaking from vehicles; the selected fuels were diesel and gasoline for this study.

3. EXPERIMENTAL PROGRAM

The experimental program has been divided into two phases. In the first phase, Marshall Specimens were prepared with different type of materials. Different polymer amounts and different aggregate types were used to produce mixture samples and to found out the improvement in the mixture properties, based on the comparison between modified and unmodified binder.

3.1. Marshall Specimens Tests

The study carried on with conventional hot mix (HMA), Polymer modified Asphalt mix (PmA) and Stone Mastic Asphalt (SMA) mixtures, for comparison of the mixtures, to determine their properties. In the second phase, Marshall Specimens were immersed into different fuel types and weight loss was calculated for all types of specimens. The Marshall design method was used to determine the optimal bitumen content for conventional, modified and stone mastic asphalt mixtures.

The binder content was obtained %4.80 for HMA, and 6.40 for SMA mixtures. Three identical samples were produced for each alternative. Two designs were realized and 36 asphalt briquettes were fabricated. Basic characteristics of HMA, and SMA specimens were measured that include Specific gravity, Marshall stability, Flow, Volume of voids in mineral aggregate (VMA), Air voids content of the specimen (V_h), and Volume of bitumen (V_f) tests for both HMA and SMA samples. Characteristics of HMA and SMA specimens are shown in Table 8.

The fuel resistant specification requires compacted mix samples to be immersed in fuel for 24 hours and the average percent weight loss of Marshall Specimens to be found. After 24 hour treatment in different type of fuel, the samples examined according to the related procedures. The weight loss of the samples were calculated and compared to the control specimens.

Table 8: Characteristics of HMA and SMA Mixes

Properties	Unit	Test Method	AC16	SMA11
Specific gravity	g/cm^3	TS EN 12697-6	2.41	2.47
Stability	kN	TS EN 12697-34+A1	15.9	11.8
Flow	mm	TS EN 12697-34+A1	3.00	5.90
Voids (V_h)	%	TS 3720	4.10	3.00
Bitumen (V_f)	%	TS 3720	70	80
VMA	%	TS 3720	14.2	17.0

Specimen is partially immersed in fuel and its loss of mass is measured afterwards. 9 cylindrical Marshall Specimens of each type of asphalt mixture prepared for each type of mixture. 3 specimens with similar characteristics according to their height and bulk density were assigned to three groups. One of the test group used as control set which was not immersed into fuels. The specimens from the other two groups were immersed in diesel and gasoline. They were subsequently kept in a fuel bath, for a period of 24 h. After conditioning, the specimens were kept at an oven at 25°C for a period of 24 h to be dried completely, and to evaluate the weight loss for each specimen.

3.2. Resistance to Fuel Tests

Resistance to fuel test was carried out according to “TS EN 12697-43 Bituminous mixtures - Test methods for hot mix asphalt - Part 43: Resistance to fuel” standard procedures. This standard specifies a test method to determine the resistance of a bituminous mixture or pavement to fuel.
A cylindrical test specimen with a known mass is immersed partly in a bath with the specified fuel for a specified period of time. For bituminous mixtures with paving grade bitumen this period is 24 h; for mixtures with a polymer-modified bitumen a 72 h period is used. After removal from the bath, cleaning with water and drying for 24 h in a ventilated oven at 25 ºC, the loss of mass of the specimen is measured and the immersed surface is visually inspected. The type of affection and the material loss of the immersed surface are also recorded. Then the test specimen is put in a steel mould with the immersed surface up.
At the bottom of the specimen a pneumatic cylinder pushes the immersed surface onto a steel brush, which is moving in epicycloids passages over the surface. After 30 s the brushing stops and the specimen removed from the mould. Then the loss of mass is measured and the brushed surface is visually inspected. After surface is that the specimen is put back in the mould and the same procedure is carried out again after 30 s and after 60 s, when the brushed surface is visually inspected again. The total brushing time is 120 s (30+30+60 s). The material loss after the immersion and/or the brush test is a measure for the resistance to that particular fuel.
Test result can be calculated by the equations below;

$$A_i = \frac{m_{1,i} - m_{2,i}}{m_{1,i}} \times 100$$

$$B_i = \frac{m_{2,i} - m_{5,i}}{m_{2,i}} \times 100$$

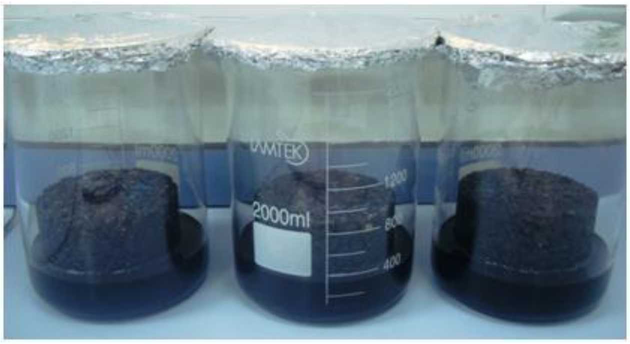
Where;

$m_{1,i}$: the initial dry mass of the test specimen *i* before soaking in fuel (g)
$m_{2,i}$: the mass of the dry test specimen *i* after soaking in fuel (g)
$m_{5,i}$: the mass of the dry test specimen *i* after soaking and 120 s in the brush test (g)
A_i, B_i : the average values are calculated and rounded off to the nearest 1%

The procedure requires that the fluid be left in contact with the surface for 24 hours. Resistance to fuel test device and immersed specimens are shown in Figure 1. The resistance to a specific fuel is subdivided in three categories, where each category has the following demands;

A ≤ 5% and B < 1 % Good resistance
A ≤ 5% and 1% ≤ B ≤ 5 % Moderate resistance
A > 5% or B > 5 % Poor resistance


Test device



Specimens

Figure 1: Resistance to Fuel, Test Device and Specimens

After a period of immersion in the fuel, samples from each set were tested for weight loss and the results were compared to the control specimens whereas to each other. Table 9 illustrates the development of evaluating the average values and rounded off to the nearest 1% for modified asphalt (%3.5 SBS) specimens.

Table 9: Evaluating of The average values for Specimens

	Fuel Type	Diesel			Densityt (g/cm^3)	2,415	
Specimen No.	m_1 (g)	m_2 (g)	m_3 (g)	m_4 (g)	m_5 (g)	A (%)	B (%)
1	1198	1172	1148	1146	1144	2,2	2,4
2	1196	1176	1158	1156	1154	1,6	1,9
3	1199	1180	1162	1162	1161	1,6	1,6
					Average value	1,8	2,0

A ≤ %5 and B < %1	: Good resistance	
A ≤ %5 and %1 ≤ B ≤ %5	: Moderate resistance	X
A > %5 or B > %5	: Poor resistance	

$$A = \frac{m_1 - m_2}{m_1} x100 \qquad B = \frac{m_2 - m_5}{m_2} x100$$

3.2.1. Conventional Mix Samples

Nine specimens were prepared (3 of each of the 3 types) for conventional mixtures, according to TS EN 12697-30 standard procedures. Three of them were used as control samples. The other 6, divided into two groups. The first group immersed into diesel, while the second one immersed into gasoline, for conditioning. The results of the tests performed in the laboratory for conventional mix specimens are presented in Table 10.

Table 10: Conventional Mixture Specimens

Specimen Group No.	Voids (%)	Unit weight (D_p)	Fuel Type
1	4.08	2.414	Control
2	4.12	2.408	Diesel
3	4.13	2.411	Gasoline

3.2.2. Polymer Modified Mix Samples

Two types of specimens were prepared (9 of each of the 2 types) for polymer modified mixture, according to TS EN 12697-30 standard procedures. Three of the mixture specimens used as control samples. The left 6 divided into two groups. The first one immersed into diesel, while the second one was immersed to the gasoline. The results of the tests performed in the laboratory for polymer modified mix specimens are presented in Table 11.

Table 11: PmA Mixture Specimens

SBS Rate (%)	Specimen Group No.	Voids (%)	Unit weight (D_p)	Fuel Type
3.5	1	4.06	2.409	Control
	2	4.00	2.415	Diesel
	3	4.01	2.412	Gasoline
5	1	3.98	2.407	Control
	2	4.05	2.411	Diesel
	3	4.06	2.409	Gasoline

3.2.3. SMA Mix Samples

Nine specimens were prepared (3 of each of the 3 types) for SMA mixtures. Three of them were used as control samples. The other 6, divided into two groups. The first group immersed into diesel, while the second one immersed into gasoline, for conditioning. The results of the tests performed in the laboratory for SMA mixture specimens are presented in Table 12, and the specimen's physical appearance after testing, for all type of mixes are presented in Figure 2 and Table 13.

Figure 2: Specimen's physical appearance after testing

As it can be seen from Figure 2, after an immersed of fuel the surface was notably softened and damage in comparison to the control specimens, which not in contact with fuel. The most deformation was on the specimens immersed of gasoline.

Table 12: SMA Mixture Specimens

Specimen Group No.	Voids (%)	Unit weight (D_p)	Fuel Type
1	3.05	2.468	Control
2	3.11	2.471	Diesel
3	3.14	2.477	Gasoline

Table 13: Fuel Resistance Tests Results

Fuel Type	Conventional Mix	PmA Mix 3.5 %SBS	PmA Mix 5 %SBS	SMA Mix
Control	Good resistance	Good resistance	Good resistance	Good resistance
Diesel	Moderate resistance	Moderate resistance	Moderate resistance	Moderate resistance
Gasoline	Poor resistance	Poor resistance	Poor resistance	Poor resistance

The resistance to fuel can be assessed by keeping asphalt specimens immersed in the fuel for a certain period of time and measuring the loss of weight. The loss of weight is measured after the treated side has been brushed during two minutes (total brushing time 120 s) with a steel brush. In Table 14 the loss of weight values are shown for all types of asphalt mixtures.

Table 14: Weight Loss of the Specimens

Fuel Type	Deformation Type	Conventional Mix	PmA Mix 3.5 % SBS	PmA Mix 5 % SBS	SMA Mix
Control	A (%)	0.0	0.0	0.0	0.0
	B (%)	0.1	0.1	0.1	0.1
Diesel	A (%)	2.0	1.8	1.7	1.4
	B (%)	2.2	2.0	1.9	2.6
Gasoline	A (%)	11.1	10.7	10.3	15.8
	B (%)	-	-	-	-

The results in Table 14 above suggested that weight loss values of gasoline are much higher than those of diesel. Again, the specimens produced with SMA mix design appeared to perform slightly higher weight loss values than HMA and PmA samples. There were no significant differences between %3.5 SBS and %5 SBS mixture values of PmA mix design test results. The improvement of resistance to fuel was more significant in the second test phase, which simulates the abrasive effect of traffic on the surface of the pavement layers subjected to the action of fuel.
Since the average values of A(%) for Gasoline, in Table 14 are higher than 5%, the fuel resistance of the specimen is evaluated as “Poor resistance” and no further tests were carried out (Last line, B(%) for gasoline).

4. CONCLUSIONS AND RECOMMENDATIONS

Based on the research of the tests carried out in the laboratory and data presented in this paper, the following conclusions and recommendations can be drawn;

- The research results show that in laboratory conditions stone mix asphalt has a better resistance to fuel than hot mix asphalt.
- There were no significant differences in loss of weight, between the PmA 3.5% SBS and the 5% SBS mix designs. The mixtures had similar properties.
- The results obtained from complementary tests showed that the use of modified bitumen does not increase the pavements resistance to fuel spillage.
- Control specimens showed a good performance against abrasion for all types of mixes.
- All mixes involved in the study are more vulnerable to degradation due to gasoline subjection than to diesel subjection. On the other hand, 5% SBS samples of PmA mixtures have the best values followed by 5% SBS and HMA mixes.
- The effects of the brush test were largest for the SMA mixture.
- On the basis of the Diesel test after brushing and the Gasoline test it is concluded that the SBS modified HMA mixtures have the best resistance against Diesel and Gasoline. The differences with other HMA mixtures is very limited and the effects of void ratio appear much more relevant
- The Researches should be continued with additional modifiers and asphalt types produced, using different types of fuels.
- The research is needed to validate the research findings for mixtures with different binders, different modifiers, and different aggregate structures and also with different types of fuel.

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