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# EVALUATION OF THE EFFECT OF VARIOUS SURFICIAL POLLUTANTS AND ENVIRONMENTAL CONDITION ON SURFACE FRICTION PERFORMANCE OF ROAD PAVEMENT

**Summary.** Skip resistance of asphalt is an important parameter that can influence the safety of drivers on roads. Although there is a linear relationship between slipping on road surfaces and accidents, the impacts of pollutants for decreasing friction of roads is clear to researchers. Moisture and temperature influence friction and safety. In this research in *SMA* samples, three different gradations with the maximum nominal sizes of 19, 12.5 and 9.5, based on international standards were used. For polluting the surface, five materials that are found on roads were used, including fine-grained soil, sand, oil, soot and rubber powder. To measure the skip resistance, the British pendulum tester was used and for analysing macro-texture, the sand patch method was used. The results of this research showed that by increasing the maximum nominal size of aggregates, the depth of macro-texture in surfaces are grown and this is due to the decrease of fine aggregates in larger gradations. Because of the higher flexibility of pure bitumen, the applied compression pressure on rigid aggregates can cause indentations in the substrate

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and result in declining the roughness height of aggregates in the mixed surface. This leads to declining the hysteresis part of friction by increasing temperature.
**Keywords:** road safety, skid resistance, pollutants, British pendulum tester, decision tree

## 1. INTRODUCTION

Every day around the world, road accidents occur. Driver errors, poor transportation system and poor road infrastructure contribute to these accidents [1-5]. Accumulated pollutants on roads surfaces decrease skid resistance significantly and increase the risk of accidents. Skid resistance of asphalt is a crucial parameter that affects the safety of drivers. Additionally, there is a linear relationship between slippery road surfaces and accidents [6]. In the dry season, road surfaces have sufficient skid resistance, however, in the winter skid resistance is reduced when the surface of the road is covered with mud, snow, ice, etc. Environmental situations are largely influential in skid resistance between road and vehicle wheels. When the surface of roads are covered, skid resistance is influenced significantly [7].

The increase in the number of accidents after the first rainfall during a dry period is due to the existence of particles on road surfaces (dust, rubber debris, exhaust fumes, equipment, etc.) [8]. It seems that the accumulated particles during the dry periods and water from the first rain create a mixture of high viscosity and decreases friction [9]. Fine particles from the road, rubber debris or traffic and dispersion of industrial materials can be the source of safety issues such as accidents on the first day of rain after a dry period or season change of skid resistance [10]. This article provides an experimental study under a controlled situation, analysing the accumulation of particles and cleaning by flow and surface water.

## 2. REVIEWING SOURCES

Wilson [11] observed that friction ratio decreases significantly at the beginning of rain (pollution stage), and then upon reaching a stable amount (cleaning stage) it increases. Kulakowski and Harwood [12] showed that a water layer with 0.025 thicknesses on road surfaces can decrease friction by 75%. The fine particles on roads are recognised as an additional element that declines the wet friction.

Lambourn and Viner [13] experimented with different waste materials (clay, sand, etc.) on the road surface and they realised that when the surface of roads are polluted, friction ratio decreases strongly in comparison with a dry situation. Moreover, other researchers found out that these particles can result in the lubrication of road surfaces. Li et al. [14] investigated the friction between shoes and surfaces and they discovered that particles can decrease friction even in dry situations. Although, with increase in particle sizes, friction ratio decreases. Mills et al. [15] studied dry surface friction covered with waste particles and it was found that the critical size of particles is about 50-60 μm. When a rubber layer is slipped on the surface, the larger particles than the critical size, slip on each other. However, particles with lower size than the critical size, stick to each other because of stitches force and they result in a slippery behaviour between the surface and the rubber. On the other hand, surface roughness can trap some of the particles, preventing particle passage from the surface bulge, resulting in cutting the particle layer.

Heshmat [16] showed that solid particles can make a thin layer of lubricant, which behaves like a thin layer of fluid. For a complete perception of the effect of precipitated particles on the friction of tyre and road, then we need to investigate the dry situation.

In another research by Hichri [17], the influence of fine particles on skid resistance was investigated. In this research, a British pendulum tester was used for friction measuring. Surfaces with rough and eroded aggregates were studied. In addition, a container was used for the simulation of rain that controlled the sprayed water on the surface of the sample. It was defined that friction recovery in dry and wet situations for eroded aggregates was slower than rough aggregates. Based on this study, friction and mass of particles are changed similarly but in adverse direction. This means that when the mass of particles is decreased, friction is increased. There is a mass threshold, above it, friction is low and approximately stable but under this threshold, the friction increases due to direct contact between surface roughness and rubber tyre.

This article advances previous studies with new data and friction experiments from the application of *SMA* asphalt on road surfaces. In the first section, the experiments are described based on particles properties, type of pollutants and method used. In the second section, the results of friction experiments in different temperatures and moistures are provided. Then the analyses with different statistical approaches are implemented in the third section and the effect of facial wetness, fine-grained texture and pollutants are surveyed on friction.

## 3. MATERIALS

### 3.1. Aggregate and Bitumen

In this research for *SMA* samples, three different aggregates with maximum nominal sizes of 19, 12.5 and 9.5 mm based on *NCHRP* 9-8 were used. Also, the aggregates are made of lime. Table 1 and Figure 1 show the definition of these gradations. The physical properties of aggregates are listed in Table 2. For preparing samples, pure 60-70 bitumen was used, and its properties are given in Table 3.

Tab. 1

Gradation of *SMA* by *NCHRP*

| Sieve size (mm) | Maximum nominal size | | |
|---|---|---|---|
| | 9.5 mm | 12.5 mm | 19 mm |
| 25 | - | - | 100 |
| 19 | - | 100 | 95 |
| 12.5 | 100 | 95 | 62 |
| 9.5 | 95 | 52 | 42.5 |
| 4.75 | 43 | 24 | 24 |
| 2.36 | 24 | 20 | 20 |
| 1.18 | 17 | 17 | 17 |
| 0.6 | 15 | 15 | 15 |
| 0.3 | 13.5 | 13.5 | 13.5 |
| 0.075 | 9 | 9 | 9 |

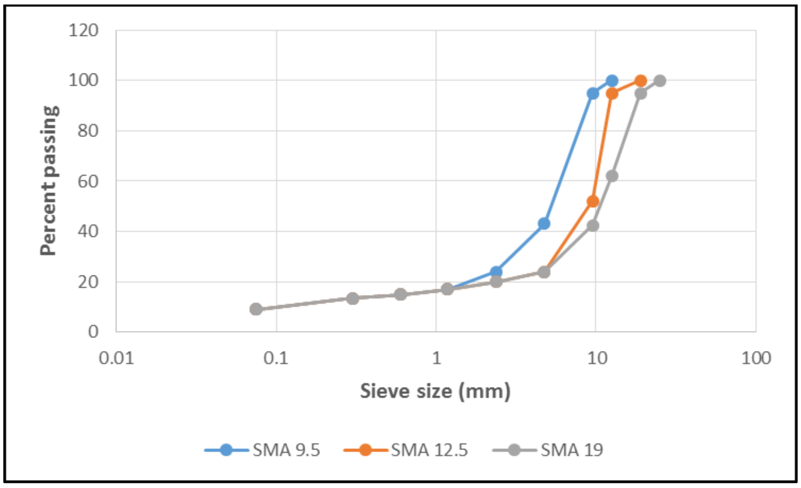


Fig. 1. Gradation of aggregates

Tab. 2

Physical properties of aggregates

| Experiment | Standard | Results |
|---|---|---|
| Coarse aggregate specific gravity (gr/cm$^3$) | ASTM C127 | 2.68 |
| Fine aggregate specific gravity (gr/cm$^3$) | ASTM C128 | 2.58 |
| Sodium sulfate soundness (%) | ASTM C88 | 2.5 |
| Los Angeles abrasion value (%) | ASTM C131 | 25.2 |
| Sand equivalent (%) | ASTM T176 | 63 |
| Flakiness (%) | BS-812 | 15.78 |

Tab. 3

Properties of used bitumen

| Experiment | Temperature of experiment (°C) | Standard | Results |
|---|---|---|---|
| Penetration (0.1 mm) | 25 | ASTM D5 | 65 |
| Ductility (cm) | 25 | ASTM D113 | 106.3 |
| Specific gravity (gr/cm$^3$) | 25 | ASTM D70 | 1.013 |
| Softing point (°C) | - | ASTM D36 | 54.3 |
| Flash point (°C) | - | ASTM D92 | 304 |
| Rotational viscosity (mPa.sec) | 135 | ASTM D4402 | 436 |

### 3.2. Pollutants

In this research, five common and most important pollutants that are seen on road surfaces with low seasonal rainfall and deserts were used for the simulation. These pollutants are fine-grained soil, sand, oil, soot and rubber powder and are shown in Figure 2.

Fig. 2. Various pollutants used in this research

## 4. PREPARATION OF SPECIMENS

In this research, preparing the samples were implemented in two stages. In the first stage for determining the optimum bitumen content, samples based on the following standards were made and tested: bulk specific gravity (ASTM D2726), stability and flow (ASTM D1559), and the maximum theoretical specific gravity (ASTM D 2041). For compressing the *SMA* samples, 50 impacts of Marshal Hammer were used [18]. The optimum bitumen content for different gradation is listed in Table 4.

As shown in Table 4, by decreasing the nominal size, the optimum bitumen content increases. In the second stage, *SMA* samples were made based on the ASTM D5581 standard with 6 inches (15 cm) diameter for the skid resistance experiment (Figure 3).

Tab. 4

Optimum bitumen content of *SMA* samples

| Maximum nominal size (mm) | Optimal pitch percentage (%) |
|---|---|
| 9.5 | 6.5 |
| 12.5 | 6.3 |
| 19 | 6.14 |

Fig. 3. SMA sample with 6 inches diameter.

## 5. PREPARATION OF SPECIMENS

### 5.1. Measuring friction

In this research, the British pendulum tester (*BPT*) was used for measuring friction. This device was designed by the Road Research Laboratory (*RRL*), and it is one of the simplest devices for measuring skid resistance since 1960. This method is described in the ASTM E303 standard. This device has a rubber slipper at the end of its arm, which slips on the surface and measures friction. The measured values (Britain pendulum number – *BPN*), shows the skid resistance of the surface, and it is between 0 and 150. A larger BPN shows higher skid resistance. For experimental samples, the dimensions of the rubber slipper are 6*25*76 mm and the length of slip is between 124 and 127 mm so that the 6 inches (15 cm) samples cover this length [19]. Before every experiment, this rubber slipper should pass five times on the aggregate surface. This operation results in removing the sharp edges of the rubber slipper before every experiment [17].

### 5.2. Sand Patch Method

One of the most common methods for measuring the macro-texture of pavement surfaces is the sand patch method described in the ASTM E965 standard. In this method, a certain volume of standard sand is dispersed on a dry and clean surface in a circular shape. The level of dispersed sand should be at the same level of the top point as aggregate, and then the diameter of the cycle is measured. The mean texture depth (*MTD*) is calculated by dividing volume by cycle area as follows [19]:

$$MTD = \frac{4V}{\pi D^{2}} \qquad (1)$$

Where:
*MTD*= the mean texture depth (mm),
*V*= sand volume (mm$^3$),
*D*= average of cycle diameter (mm),
As the *MTD* is larger, the surface is rougher.

### 5.3. Simulating rainfall

One simulator for rainfall was implemented for controlling the water splash on the surface of the sample. This system included a rectangular container (20*30*40 cm) and a nozzle attached to a water pump that stored a stable flow of water and made small drops (Figure 4). This system can simulate high and low rainfalls (low water volume and the surface remained viscose and slippery).

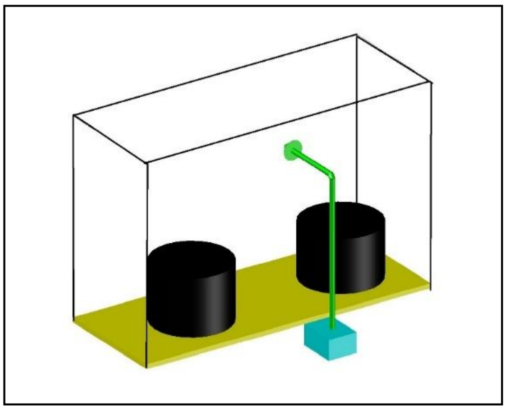

Fig. 4. The simulating rainfall container

## 6. RESULTS

For the sand patch experiment, for every asphalt mixture, two samples were made, and every sample was experimented twice. Figure 5 shows the average amount of sand patch. As seen, by increasing the maximum nominal size of aggregates, the depth of macro-grained texture increases, and this is due to decreasing the amount of fine aggregate in the larger gradation. As *MTD* increases, the drainage of surface water happens more rapidly, and friction increases at the end.

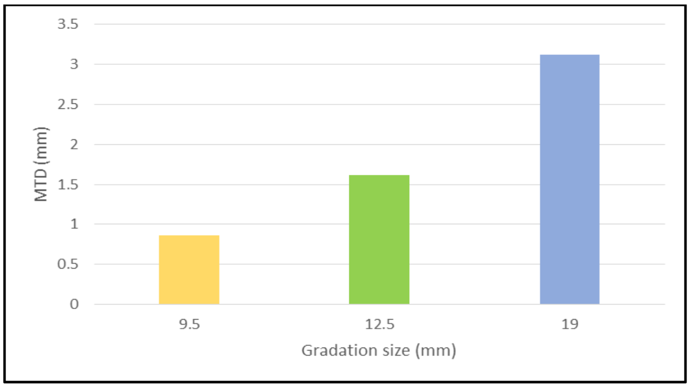


Fig. 5. The result of sand patch

Figures 6-8 illustrate the variation of the sample's friction in dry and wet situations for three gradations. As expected, friction in a dry state is higher than in a wet state. As witnessed, the highest loss of friction was seen in oily pollutants. Because oil is an insoluble liquid, when it mixes with water, a thicker layer is created on the surface, which leads to more decrease in friction.

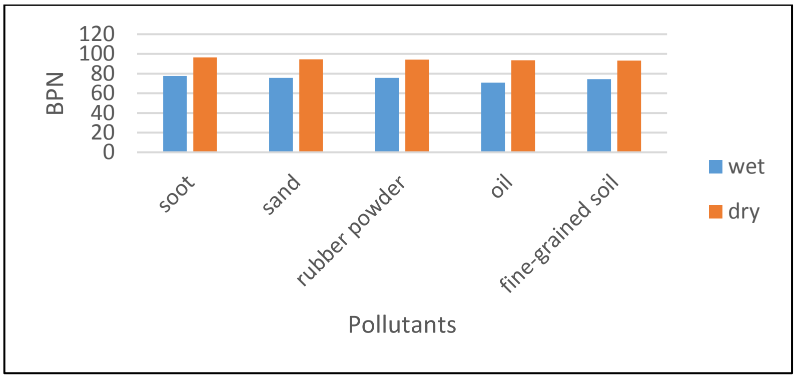


Fig. 6. The comparison of *BPN* in dry and wet situations for samples with 9.5 mm aggregates

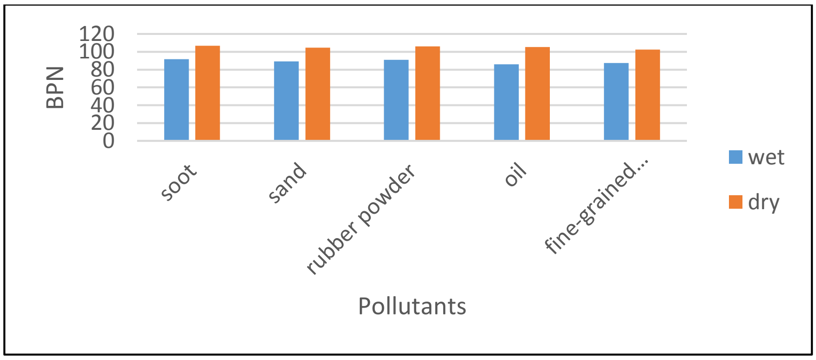


Fig. 7. The comparison of *BPN* in dry and wet situations for samples with 12.5 mm aggregates

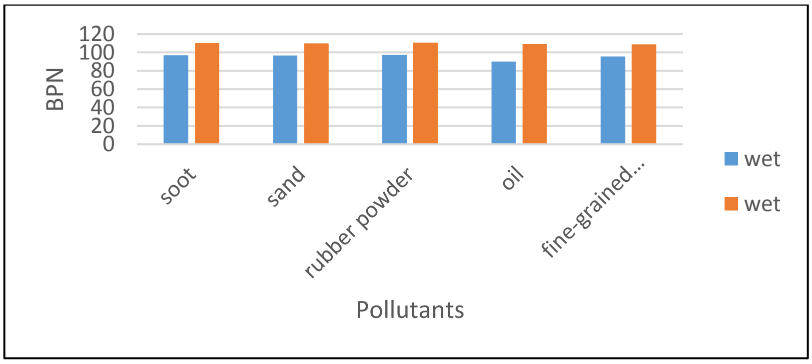


Fig. 8. The comparison of *BPN* in dry and wet situations for samples with 19 mm aggregates

Figure 9 shows the variation in the *BPN* amount based on gradation and type of pollution. As noticed, by increasing the maximum nominal size of aggregates, sample's friction rises due to *MTD* increase. In addition, the lowest amount of *BPN* in every gradation relates to fine-grained soil. In samples with maximum nominal sizes of 9.5 and 12.5 mm, the highest amount of *BPN* is related to soot pollution but in the sample with the highest nominal size, 19 mm, the biggest amount *BPN* is for rubber powder.

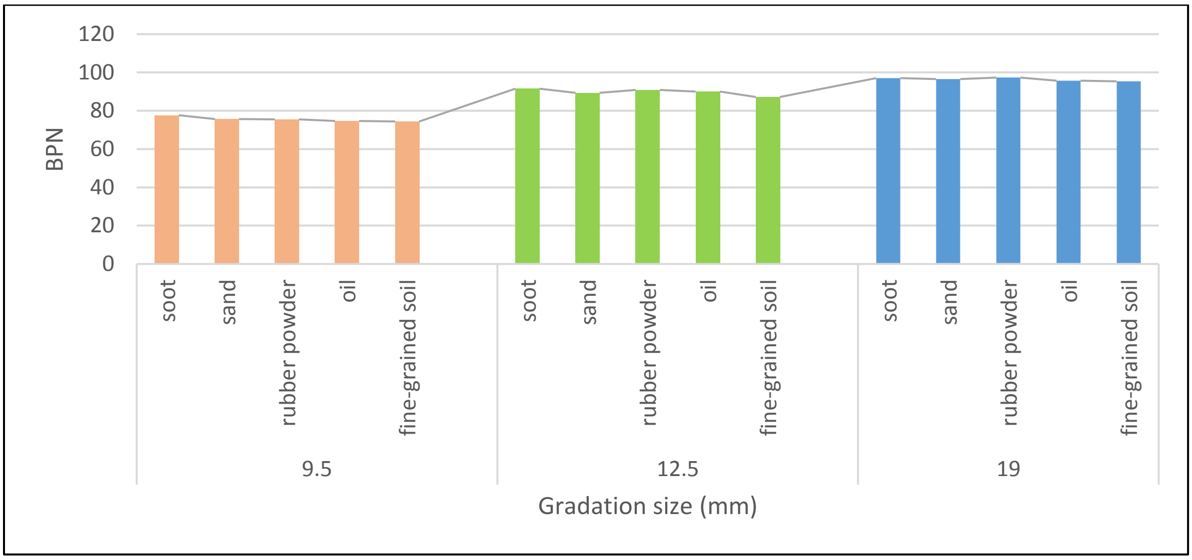


Fig. 9. The gradation variation based on type of pollutant

Figure 10 shows the *BPN* amount for three different temperatures (25, 45 and 65°C). As seen, by increasing the temperature of the experiment, the *BPN* amount decreases in all plots of the Figure. This effect can be attributed to variation in bitumen stiffness in addition to variations in water viscosity on the surface of the sample. These two factors can be effective in both hysteresis and adhesion. Since the mixture of asphalt in the surface of pavements and rubber tyre from vehicles are viscoelastic materials, temperature affects the friction properties. Stiffness of the slider in the British pendulum tester and bitumen decreases with the increase in temperature. As temperature increases, total loss energy in vehicle wheel for deformation decreases, and finally the hysteresis part declines for a certain amount of shape change. Moreover, because of more flexibility in higher temperature, the applied compressive pressure on rigid aggregates can cause indentations in the substrate, thus reduce the roughness height of aggregates in the surface of the mixture. This phenomenon helps to decrease the hysteresis part of friction with temperature rise. The adhesion part of friction is influenced by the change in the hydrodynamic properties of water with temperature change. Shear stress in Newtonian fluids such as water depends on viscosity and strain time rate. As viscosity decreases with temperature rise, shear stress drops and finally the adhesion part of friction decreases [20].

## 7. DECISION TREE

The decision tree method is one of the ways for classifying data and it is a subset of the numerical taxonomy method. The decision tree is a method of non-parametric data analysis; it is a powerful tool for predicting and classifying problems. In this method, the result of data analysis is shown graphically, making the tree easier to understand and interpret. Using the decision tree, important and insignificant variables can be identified and eliminated. The decision tree consists of several nodes. In Figure 11, the zero node, which is the root and the first node, shows the amount of friction (*BPN*). This node is divided into three branches. This indicates that the most important variable affecting the *BPN* value is the size of the aggregates. As observed, when the aggregate size is 19 mm, the largest amount of friction was obtained (42.1% of the largest *BPN* is for samples with a maximum size of 19 mm). Each of its 1 to 3 nodes is divided into 2 separate nodes. This phenomenon shows that after the maximum size of aggregates, the variable of water content on the surface of the samples is the most important factor affecting the amount of *BPN*. As seen, there is more *BPN* in low rainfall than in heavy rainfall. This phenomenon is true for all three gradations. Samples with a size of 19 mm have the highest amount of *BPN*, which is due to the rapid drainage of rainwater. Further, Node 6 is divided into three branches. This shows that temperature has the greatest effect on the samples with 12.5 aggregate size with low precipitation. As temperature increases, the amount of friction increases, which is expected.

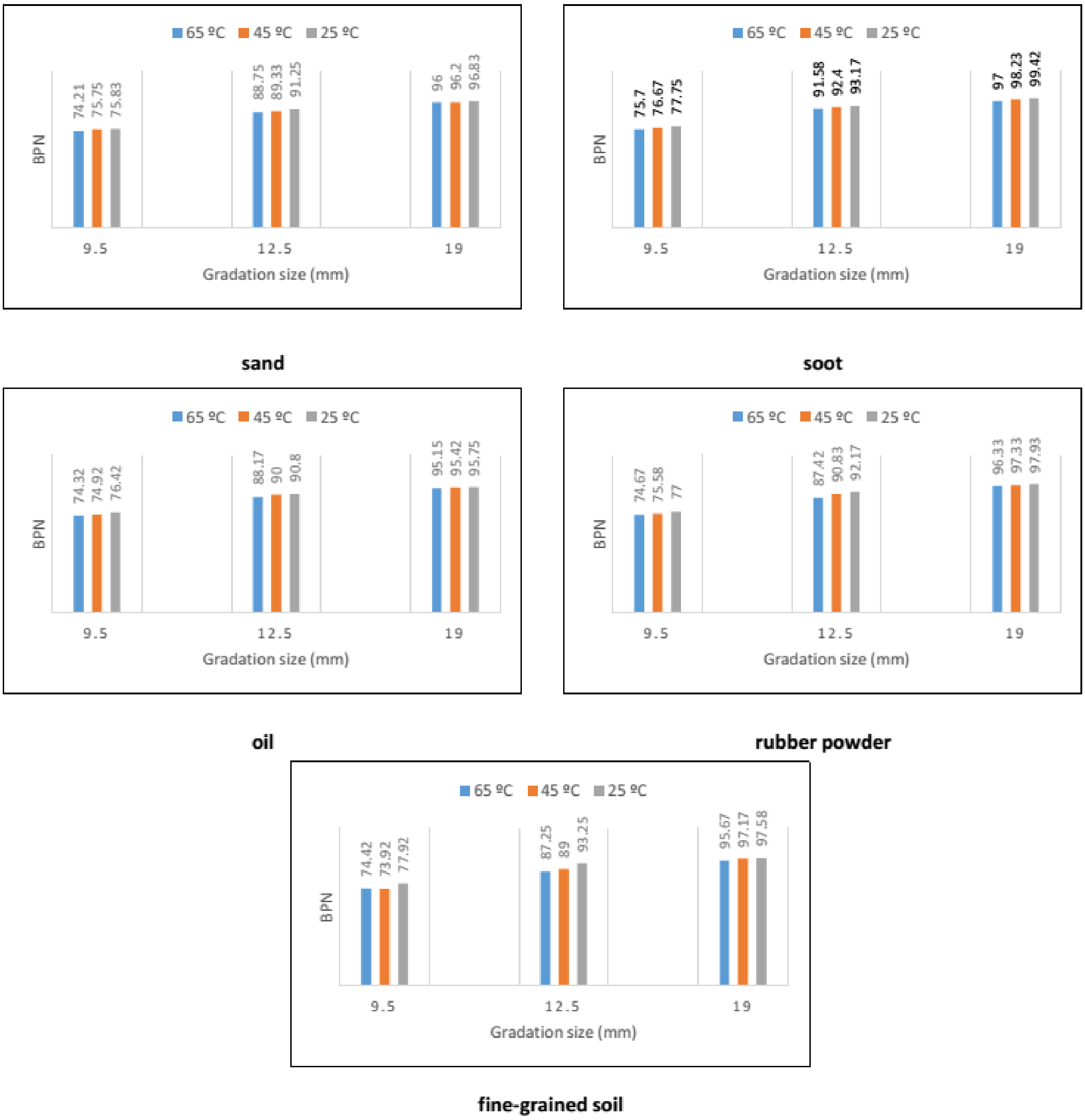


Fig. 10. The plot of friction change by temperature

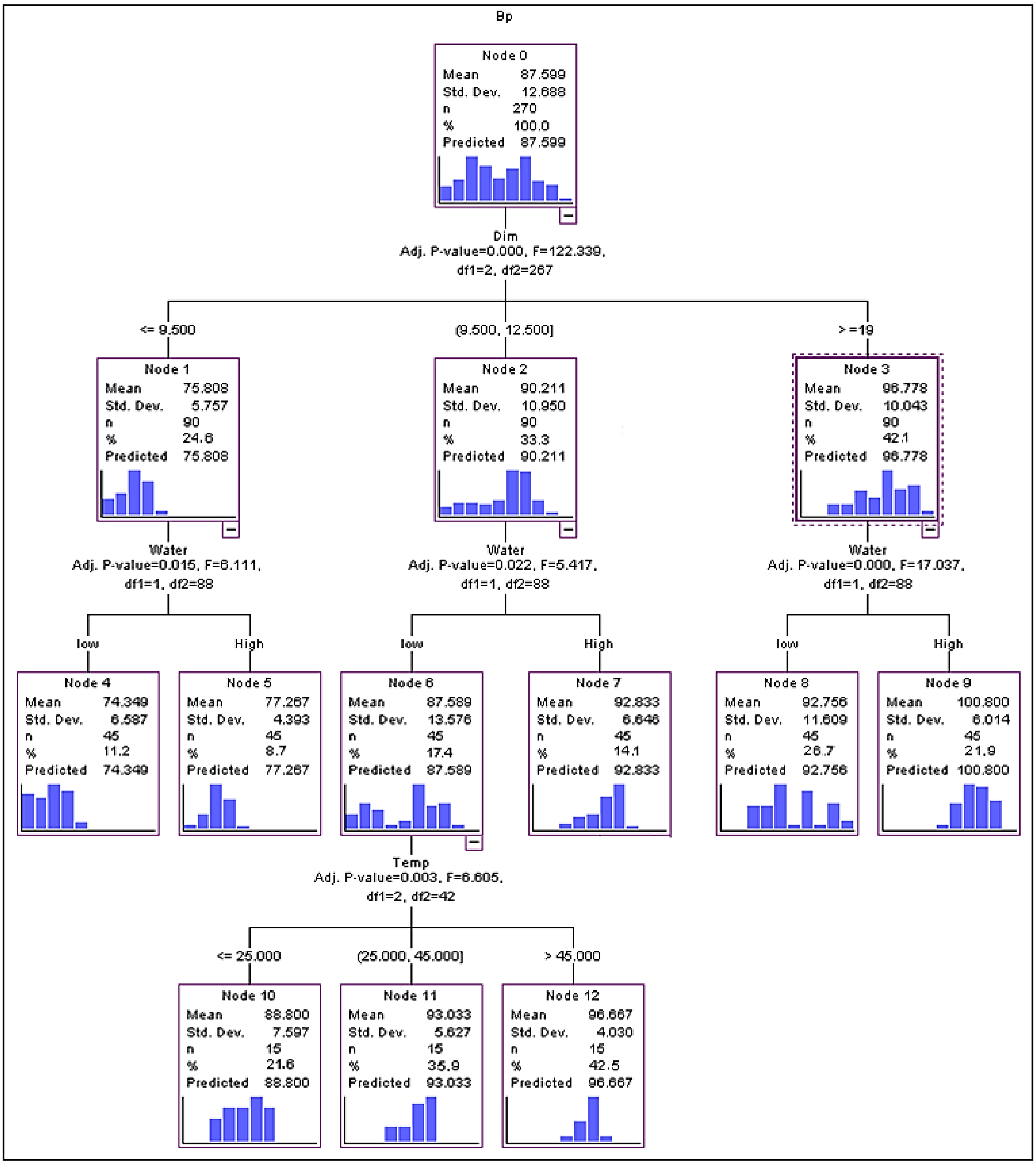


Fig. 11. The decision tree of pollutant impact and environmental factors on friction

## 8. CONCLUSION

1- By increasing the maximum nominal size of aggregates, *MTD* of pavement increases due to decline in fine particles in higher granules.
2- The maximum friction loss is for oil pollution. Because oil is an insoluble liquid, when mixed with water, it creates a thicker layer on the surface that further reduces friction.
3- By increase in the maximum nominal size of aggregates, friction of the samples increases and this is because of increase in *MTD*.

4- The minimum amount of *BPN* in every three gradation is for fine-grained soil. In samples with a maximum nominal size of 9.5 and 12.5 mm, the highest amount of *BPN* is related to soot pollution, but in the case of samples with a maximum nominal size of 19 mm, the highest amount of *BPN* is related to rubber powder.
5- The amount of friction decreases with increasing the test temperature. This effect can be due to changes in bitumen hardness plus changes in the viscosity of water on the surface of the sample, which can affect both hysteresis and friction adhesion.
6- Because of the higher flexibility of bitumen at higher temperatures, the compressive pressure applied to the rigid aggregate can cause indentations in the substrate and finally reduce the roughness height of the surface aggregates. This phenomenon also helps to reduce the hysteresis component of friction by increase in the temperature.
7- Based on the decision tree, the most important factor influence on friction is the size of the aggregates. In addition, the second factor that has the most significant effect on friction is the amount of water on the surface of the samples.

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