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RESEARCH PAPER

# Effect of Surface Condition on the Skid Performance of the Stone Matrix Asphalt

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**ABSTRACT:** Road traffic accidents are one of the major issues that have been investigated by many researchers in transportation communities. One of the effective factors in reducing accidents is to improve the surface friction of the road pavements, which is often measured by the skid resistance. The presence of dust would reduce drivers' field of view and also the skid resistance of the road surface, and thereby contributes many road accidents in these areas. In this research, the existing dust particles were collected from the surface of the roads. These fine dust with variable amounts were scattered as contaminants on the surface of asphalt samples and skid resistance was measured for HMA and SMA asphalt samples with different gradations and temperatures. The results showed that dust deposition on the pavement surface in three months causes pavement skid resistance in the two types of HMA and SMA asphalt mixtures, decreasing 9 to 16% in the dry state and 25 to 35% in the wet state. According to the obtained results, it is recommended to apply SMA asphalt with a nominal size of 19 mm as a Topeka layer in the areas that are exposed to fine dust, especially in conditions of high traffic and high ambient temperature.

**Keywords**: British Pendulum, Dust, Road Surface Pollutants, Skid Resistance, Stone Matrix Asphalt.

## 1. Introduction

Skid-resistance is one of the important properties of road pavements. Lack of enough friction and skid resistance of the pavement surface are known as important factors in traffic accidents(Jalalkamali et al., 2021; Jalal-Kamali et al., 2019). Extensive research on pavement friction has been conducted for decades. Pavements constructed with conventional, unmodified asphalt binders and aggregates grading may not sustain the adverse environmental conditions and traffic load (Raufi et al., 2020; van Bijsterveld and del Val, 2016). Skid-resistance property is defined as a deterrent and resistive force that prevents the vehicle's wheels from skidding on the road surface during the wheels' lock. On the wet surface, it also plays a decisive role in controlling vehicles by their drivers. There are various pollutants on the road surface, which contribute to the skiddiness of the road surface (Chan et al., 2010; Dan et al., 2017). The natural pollutants include sand dune on the surface of roads located in the

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desert areas and also the dust caused by the pollutants. The variation in the road surface temperature and humidity would also affect the skid-resistance of road pavements.

There could be a direct link between the roughness or skid resistance of a road surface and its accident rates. Dust has caused severe environmental problems in many countries with roads passed through desert areas, e.g. Iran. In a situation where the dust in the air is too high, the road surface would likely be skiddy and the sight vision of drivers would also be reduced. For instance, in research conducted in an area closely located to the city of Zabol in the sought-east of Iran, it was found that the maximum accidents in this area have occurred in the summer and during the annual 120 days' storm period. Dust storms, which mostly occur in the arid and semi-arid regions of the world carrying a large amount of suspended particles and therefore are considered as one of the most important international environmental issues. Dust is very small and light particles with a diameter lower than 10 μm, which are moved and transported to a very long distance as a result of wind erosion and desertification. Over the last four decades, the dust phenomenon has been observed in vast areas of the world, e.g. in Southwest Asia, Central Asia, North America, and North Africa, which is called the "global dust belt" (Sharafati and Mishmast Nahi, 2017).

Wallman and Astrom (2001) carried out comprehensive research on the friction and rate of accidents and concluded that increasing road friction would greatly decrease the accident rate (Wallman and Åström, 2001). Xiao et al. (2000) proposed a model to predict the accidents in the wet condition. This research was performed under the supervision of the Pennsylvania Department of Transportation. They found that if the skid value increases from 33.4 to 48, the accidents could be reduced by about 60%. Kamel and Gartshore (1982) researched on the hazardous highways of Ontario, Canada. They found out that friction should be increased in these locations, which could then lead up to 29% reduction in accident rates.

For the effect of the dust on the accidents, Sharafati and Mishmast Nahi (2017) concluded that the maximum number of accidents in Zabol city have occurred in the summer and during the 120-days storms. Abdoulahi (2016) investigated the quantitative changes of the dust in Zahedan province, using a marble sediment trap for sampling. The results showed that the average weight of the dust fall in Zabol city over the winter of 2014 and spring 2015 were 9.625 and 6.319 gr/m$^2$, respectively.

Cao et al. (2010) investigated the effect of pollutants on the skid-resistance and found out that the skid-resistance of the asphalt pavement will be affected when the surface is covered with the pollutants, and the maximum effect of the pollutants on the skid-resistance occurs when all the surface covers with the pollutants. Wang et al. (2015) investigated the effect of the sand and gravel materials, sprinkled on the road surface of an asphalt pavement during the winter service, on the skid-resistance. They realized that the quartz sand powder as an anti-freeze factor would only eliminate a fraction of bitumen from the top of the aggregates in the asphalt pavement, and also noticed that the micro-texture of the aggregates would also slowly be polished. By using the quartz sand, the bitumen is completely eliminated from the surface, and the sharpening edge of the aggregates will highly be eliminated. Also, Tyfour (2009) investigated the effect of pollutants on the skid-resistance of the wet surface and concluded that the rain would reduce the surface skid-resistance of the pavement and that the existence of the other pollutants has an important role in a further reduction of the skid-resistance. In research conducted by Do et al. (2014) the effect of pollutants on the skid-resistance was investigated. The pollutants of this research were selected from a filling level near Nantes, France. Their selected sample was a 450 × 210 × 35 mm rectangular slab, and since their objective was to investigate the effect of the pollutants, only one asphalt mixture sample was used. The surface of the test was a 100 × 150 mm rectangle with an area of 0.015 $m^2$. Three weights of 1.25 gr, 2.5 gr, and 5 gr of pollutants were used for the test.

Blake et al. (2017) investigated the effect of volcanic ash from four different volcanic resources in New Zealand on the skid-resistance of the airport and road surfaces. The result indicated that road markings in either dry or wet conditions when covered with a thin layer of ash led to a reduction in friction and more importantly the biggest change in the skid-resistance of a surface covered with ash occurred at dry conditions. In research carried out by Zhang et al. (2015) the effect of the aggregates' size on the skid-resistance of the porous asphalt was numerically investigated. The results of the numerical simulation showed that the asphalt pavements constructed from the higher size aggregates produced higher skid-resistance than lower sized aggregates. This was attributed to the better drainage and lower thickness of water flowing on the pavement surface.

One conclusion that can be drawn from this literature review is that the macro and micro texture of a road surface is an initiation factor in the friction force between the wheel and surface of the road pavement. This is affected by the roughness, type, size, classification, and grading of the aggregates. To measure the roughness, the sand patch method, and to measure friction, the English friction pendulum was used at different temperatures. The main objectives of this study were therefore to evaluate the effect of the aggregates grading on the skid -resistance of the SMA asphalt mixtures using coarse- and fine-grained mixtures, to evaluate the effect of changes in ambient temperature, and also combined effects of the temperature changes and dust on the skid -resistance of the asphalt mixtures.

## 2. Research Methodology

One of the main objectives of this research was to investigate the effect of dust on the skid-resistance of the SMA asphalt mixtures comprising three different grading with a maximum nominal size of 9.5, 12.5, and 19 mm, respectively. For this purpose, an experimental method was used by Irfan et al. (2019). The optimal bitumen content for making the samples was obtained using the Marshall Strength test (ASTM D-1559), and then the samples were produced. At first, the coarse texture of the samples was measured using the sand distribution method, and then the skid-resistance of the samples was measured in the desired conditions using a British Pendulum skid resistance tester. These conditions include the presence or the absence of dust. Also, the effect of the dust at different temperatures was investigated, and the effect of dust and temperature changes and the combination of these two factors on the skid-resistance were measured and compared to each other. The required aggregates were obtained from the crushed local limestone rocks used in the highway construction projects crashed to the required size. Rock wool fibers were also obtained from a producer and used in making the SMA asphalt. The dust was collected from the surface of the Zahedan-Iranshahr highway that is passed through the deserts in the southeast of Iran. The bitumen used to produce SMA samples was a PG-grade binder (ASTM D7643-16), with the specifications indicated in Table 1.

To prevent bitumen flow in the mixture, the fibers are used in the SMA asphalt mixtures. The fibers used in these types of asphalt mixtures can be organic or mineral types such as mountain cotton, stone wool, glass wool, and cellulose (Terrones-Saeta et al., 2020). In this research, due to the ease of access and compliance with safety, health, and environmental issues, Rockwool was used which is a mineral fiber. To comply with the SMA standards, the amount of the Rockwool fiber used to make the samples was 0.4% of the total weight of the mixture, the length of the fibers was about 1 mm.

The technical specifications of the aggregate materials used in the asphalt samples have an important effect on their skid-resistance; as a result, the relevant standard tests were performed to determine their technical specifications (Kogbara et al., 2016). The results of the tests are presented in Table 2 and compared with their corresponding standard limits. In this research, three grading types with the maximum aggregate nominal size of 19%, 12.5%, and 9.5% were used to produce the SMA samples. The SMA mixture design was conducted to determine the optimal grading for different mixtures (grading with different nominal size) and optimal bitumen content under the method provided in NCHRP Report 425 (1999). Four different grading are proposed for the SMA asphalt mixtures, comprising maximum nominal sizes of 19%, 12.5%, 9.5%, and 4.75% (NCHRP Report 425, 1999).

For each mixture, the optimal grading was obtained to comply with the following triple requirements. The first requirement is the value of the Voids in the Mineral Aggregates (VMA). The value of the VMA should be more than 17%. Because of the failure possibility during compaction and a reduction in VMA, the minimum value of the VMA was selected in the range between 17.5 to 18%. The second criterion is to ensure the existence of stone-stone contact in the coarse-grained mixture. For this purpose, the ratio of air void available in the mixture to the dry case was considered to be equal to or less than 1.

As it was likely that two and/or even all three considered grading could meet the desired conditions; therefore, the optimal grading was selected so that the minimum value of the bitumen content is used whilst the desired air void ratio ($V_a$ = 3 to 4%) is also met.

Figure 1 shows the resulting grading for mixtures corresponding to each maximum nominal size used in this research. The curve with power 0.45 is linear which according to the Fowler formula, shows the maximum grading density, indicating that the density of the mixture would be increased as it gets closer to this line. Following the determination of optimal grading, the optimal bitumen content for the mixture was also determined.

**Table 1.** Results of the tests done on the consumed bitumen

| Test title | Dim. | | Result | Standard |
|---|---|---|---|---|
| | | | min | max |
| Humidity | Prec. | 18% | | |
| Viscosity @ 135 (RV) | °C | 0.332 | --- | 3 Pa.s |
| Flash point temperature | °C | 334 | 230 | --- |
| Original dynamic shear | Kpa | 1 | 1.14 | --- |
| RTFO, percent change of mass | Prec. | 5.7 | --- | 1 |
| MSCR test, standard traffic"s", Jnr3.2 | | 3.9 | --- | 4.5 |
| MSCR Test, Standard traffic"s", Jnrdiff% | Prec. | 19 | --- | 75 |
| RTFO, dynamic shear | Kpa | 2.31 | 2.2 | --- |
| PAV, dynamic shear @25 °C | Kpa | 1632 | --- | 5000 |
| PAV, creep stiffness @-12 °C | Mpa | 96.23 | --- | 300 |
| m-value, (slope) @-12 °C | | 0.302 | 0.3 | --- |
| PAV, direct tension | Prec. | --- | 1 | --- |

**Table 2.** Technical specifications of the aggregates

| Specification | Standard coarse aggregates | Results | Regulations limit |
|---|---|---|---|
| Actual specific weight (g/cm$^3$) | ASTM C127 | 2.594 | - |
| Specific gravity (g/cm$^3$) | ASTM C127 | 2.672 | - |
| Water absorption (%) | ASTM C127 | 0.6 | 2.5Max |
| Los Angeles Wwear (%) | ASTM C131 | 17.1 | 25 Max |
| Weight loss with sodium sulfate (%) | ASTM C88 | 3.6 | 8 Max |
| Fracture value (%) | ASTM D5821 | 97 | 90 Min |
| | Fine aggregates | | |
| Actual specific weight (g/cm$^3$) | ASTM C127 | 2.689 | - |
| Specific gravity (g/cm$^3$) | ASTM C127 | 2.734 | - |

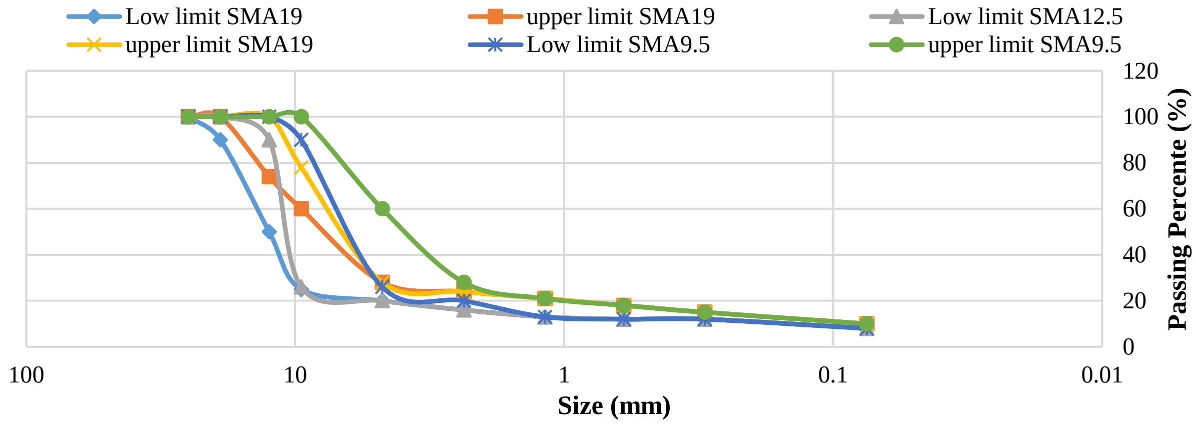


**Fig. 1.** Grading curves of the mixtures used in the present study

### 2.1. Optimum Bitumen Content

To determine the optimal bitumen content, its content should be varied to obtain the optimal bitumen content. In this stage, 9 Marshall samples include 3 samples at three different bitumen content levels were produced using optimal grading. The variation in bitumen content was considered 0.4%. Then, given the real specific weight of the compressed sample and the maximum theoretical specific weight of the mixture, the air void was obtained, and the *Va* curve was plotted against the bitumen and the optimal bitumen content at a point where the air content is 4% was selected using the interpolation. The optimal bitumen content for different mixtures was obtained as presented in Table 3.

It can be seen from Table 3 that by increasing the nominal size, the optimal bitumen content would increase. It should be noted that in designing the SMA mixtures, the flow and Marshall strength can not be used, because the Marshall strength is not an appropriate criterion for designing these mixtures. In NCHRP Report 425 (1999), the minimum value of Marshall strength for SMA mixtures is specified as 6200 N.

Moreover, the performance of the Marshall method in designing SMA mixtures has been promising. Table 4 shows the Marshall strength of the different mixtures produced in this research.

### 2.2. Measuring the Coarse Texture and Determining the Skid Value

The SMA samples produced with the 6-inch diameter Marshal test molds were used to conduct the skid-resistance test (see Figure 2). The reason for using 6 in diameter samples, is that according to the ASTM E303 Standard, the path needed for passage of the rubber slider of the British Pendulum is in the range of 12.4-12.7 cm (Zealand, 2002).

**Table 3.** The optimum bitumen content of different mixtures

| Bitumen content (%) | Maximum nominal size (mm) |
|---|---|
| 6.12 | 19 (Up-Limit) |
| 6.3 | 12.5 (Med.-Limit) |
| 6.5 | 9.5 (Dow.--Limit) |

**Table 4.** The results of the Marshall test

| Maximum nominal size (mm) | Bitumen content (%) | Marshall strength (N) |
|---|---|---|
| | 5.7 | 6250 |
| 19 (Up-Limit) | 6.1 | 6600 |
| | 6.5 | 6400 |
| | 6.1 | 7300 |
| 12.5 (Med.-Limit) | 6.5 | 7550 |
| | 6.9 | 7430 |
| | 6.2 | 8200 |
| 9.5 (Dow.--Limit) | 6.6 | 8730 |
| | 7.0 | 8600 |

The sand patch distribution test was conducted on the samples with different grading. The sand patch distribution test measures the coarse texture of the pavement surface (Mean Texture Depth) using the volumetric method according to the ASTM E465 Standard. To determine the skid value, the British Pendulum test was performed (ASTM E303-93, 2018). This test has been described in different standards; e.g. a comprehensive description of this test is provided by the UK Transport and Road Research Laboratory (TRRL) and ASTME-303 Standard. In this research, the ASTME-303 Standard has been used. In Figure 3, the British Pendulum available in the Asphalt and Bitumen Laboratory of the Yazd university is shown. In this research, the dust and dust as pollutants were collected from the surface of the Zahedan-Iranshahr Highway (Figure 3). According to the previous researches, the dust has a diameter of less than 100 μm; therefore, the collected dust was sieved using a sieve No. of 200 (75 mμm) (ASTM E303-93, 2018).

The British Pendulum test was performed on the samples in various desired humidity, pollutant, and temperature conditions, and the skid resistance value was obtained. For scattering dust on samples, first, they were weighted, and then dust was scattered on them in a specific amount, and then distributed on the samples with a knife and brush. For obtaining assurance, every experiment was repeated three times.

- To obtain the skid value in the dry condition, three gradings were used each of the SMA asphalt mixtures, and for each related grading, two samples were made. Therefore, in total, 12 samples were made for dry condition.
- The skid value for each case in dry condition was measured at three temperatures including 10, 35, and 60 °C and three different dust values on the surface of the sample were measured. Temperatures 10 °C, 35 °C, and 60 °C were the average winter temperature, average summer temperature, and maximum temperature, respectively.
- Then, the skid value was measured for all samples in the wet condition, at 10 °C, and three different values of the dust on the sample surface.

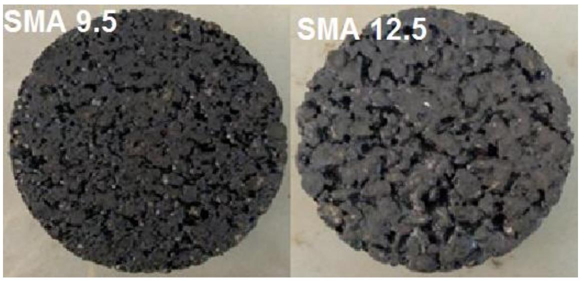


**Fig. 2.** The surface image of the 6 in samples made


**Fig. 3.** The images of the tests' process

According to the definition of ASTM Standard, a skid number is a resistive force created between the wheel and the surface of the pavement during the braking and the wheel lock situation, which prevents the wheel from slipping. Also, the skid number has been defined as follows (ASTM E465, 2017).

$$SN = 100\,\mu = 100\,(\frac{F}{N}) \tag{1}$$

where $\mu$: is friction coefficient, $F$: is friction force (the horizontal force applied on the wheel in the wheel-pavement contact location) and $N$: is the vertical force applied on the surface. For the samples used in this research, $SN$ can be calculated using the following relation (Liu et al., 2019):

$$SN = (1.38BPN - 31)e^{[-0.96V\times(25.5\,MTD)^{-0.52}]} \tag{2}$$

where $SN$, $BPN$, $V$, and $MTD$: are skid numbers, skid numbers calculated by the British Pendulum device, standard speed (40 mile/h ≈ 65 km/h), and the mean texture depth of the pavement (mm), respectively.

## 3. Results and Discussion

To investigate the effect of the grading type and Nominal Maximum Aggregate Size (NMAS) in the coarse texture, the sand distribution test was used the following results were obtained. The variations trend of the SMA coarse texture mixture in terms of NMAS are shown in Figure 4.

It is evident from Figure 4 that Mean Texture Depth (MTD) and the NMAS have a direct relationship. This means that by increasing the value of the NMAS, the value of MTD and as a result of the skid resistance would be increased. Among the SMA samples, the sample with a nominal size of 19 mm and the sample with a nominal size of 9.5 mm have the maximum and the minimum MTD, respectively. The grading with higher MTD uses more sand volume to fill the empty space of its surface. As a result, with an increase in sand volume on the sample surface, the MTD would increase.

### 3.1. BPN Result by Changing the Dust Weight

To investigate the effect of the dust content and NMAS on the coarse texture, the British Pendulum test was performed at environment temperature, and the following results were obtained. The variation trend of the coarse texture of the SMA mixture in terms of NMAS and dust content is shown in Figure 5.

As indicated in Figure 5, by increasing the amount of dust content over the sample surface, the skid resistance is decreased. According to the results, when the maximum amount of dust is applied, the skid number is reduced in the range of 9 to 16% for the SMA samples, and 15 to 24% for the Hot Mix Asphalt (HMA). For the dusted surface samples with 19 mm NMAS, the highest and the lowest skid number were observed for the SMA samples, and the HMA samples, respectively, Given that dust, is very small particles with the size of less than 100 µm diameter, these particles could move into the air void spaces on the road surface, and because of their small size, they would fill the pores in the asphalt pavement, which would decrease the wheel-pavement surface contact and consequently, would reduce their skid resistance.

### 3.2. The Effect of Sample Surface Temperature on the Skid Resistance

The temperature variations of the pavement surface cause a change in the skid resistance of the surface (Liu et al., 2019). Since the asphalt mixtures applied on the pavement surface are viscoelastic material, the temperature affects their measured frictional specifications. The effect of the temperature on the skid resistance could be caused by the changes in the bitumen stiffness. In this research, to investigate the effect of temperature on the skid resistance, the British Pendulum test at 10, 35, and 60 °C were performed on the samples and the results were recorded. A heater was used to achieve these surface temperatures. To observe the simultaneous effect of temperature and dust content on the skid resistance, 3D plots were used as indicated in Figure 6.

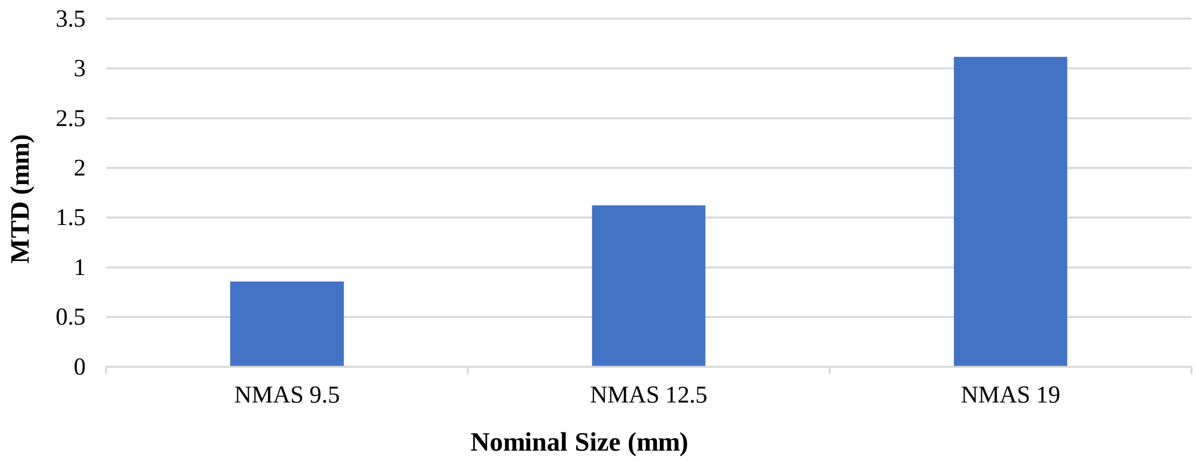



**Fig. 4.** The variations trend of the SMA coarse texture mixture concerning the NMAS

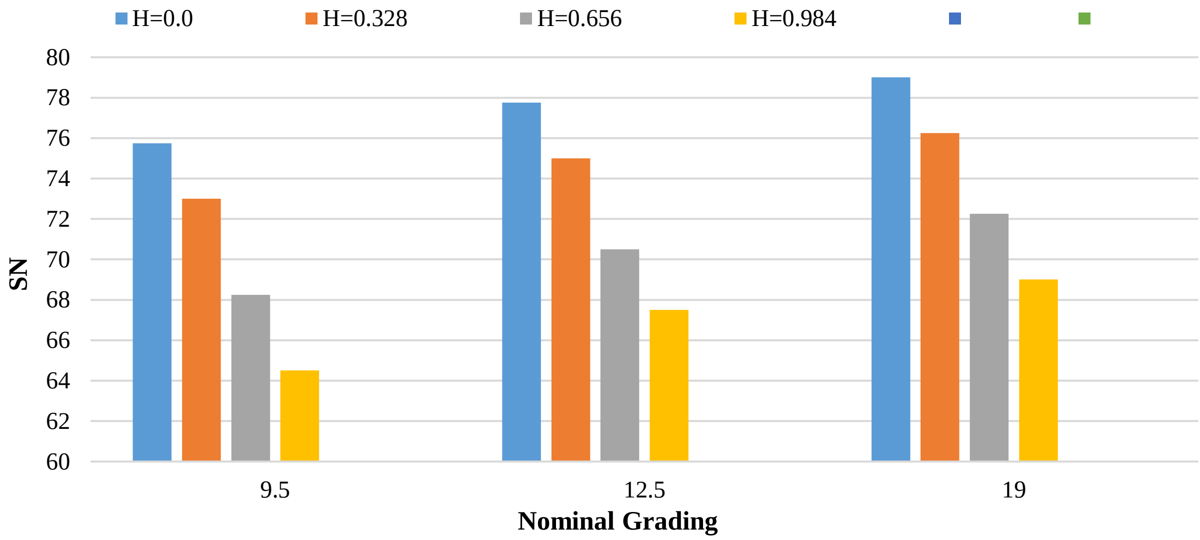
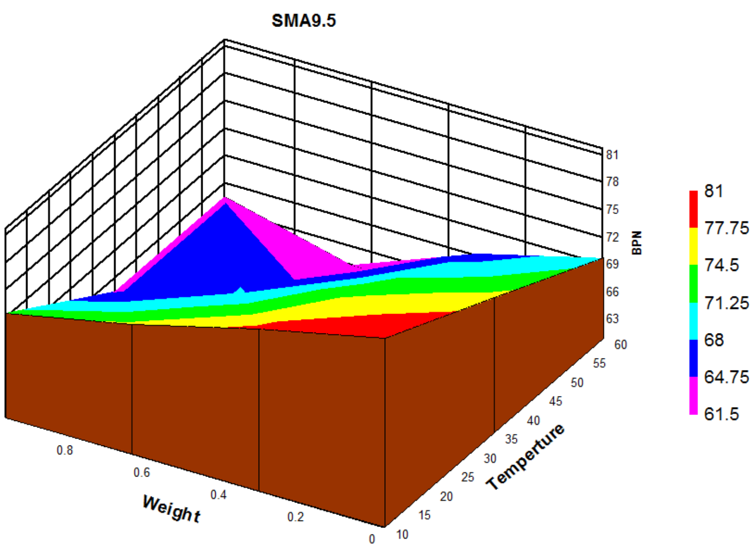
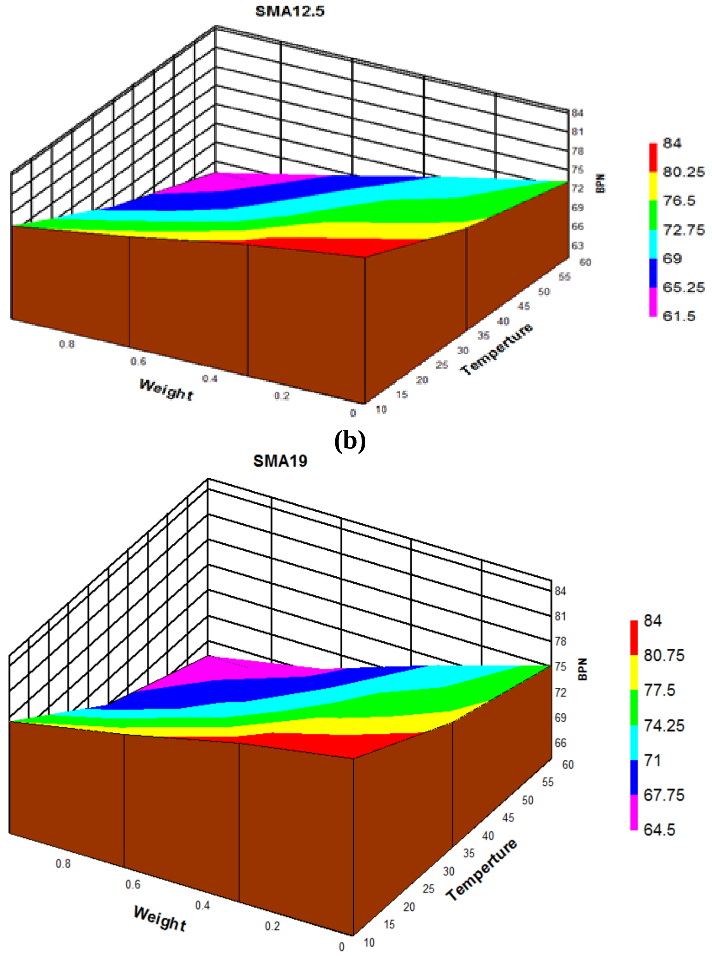



**Fig. 5.** The effect of grading and dust content at normal ambient temperature on the sample surface




(a)




(b)

(c)

**Fig. 6.** 3D plots of the simultaneous effect of temperature and dust content on the skid resistance for SMA asphalt mixture with nominal sizes 9.5 mm to 19 mm

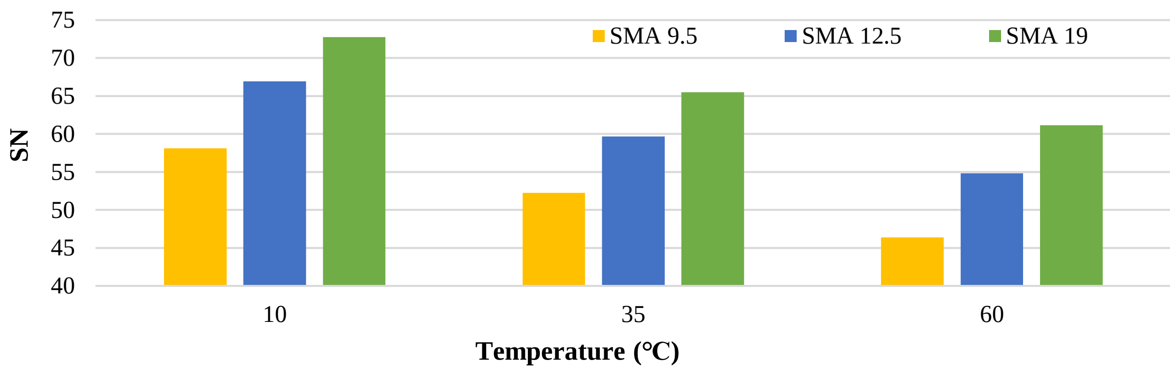
As can be seen from the 3D plots in Figure 6, the simultaneous increase in dust content and temperature would reduce the skid resistance significantly. By increasing the temperature from 10 °C to 60 °C and increasing the dust content from zero to 0.984 gr, the skid resistance of the HMA mixtures was decreased 36-40% and the skid resistance of the SMA mixtures was reduced 25-29%; the minimum decrease in skid resistance (25%) was for SMA with 19 mm NMAS.

As can be seen, the best skid resistance is achieved for SMA samples with 19 mm NMAS. At 10 °C and in the absence of dust, by increasing the nominal size of SMA samples from 9.5 mm to 19 mm, the skid resistance is increased up to 4%.

In the case of zero dust content, increasing the nominal size of SMA to 19 mm would increase the skid resistance by 15% at 10 °C, by 18% at temperature 35 °C and by 23% at temperature 60 °C, which is inconsistent with the results of Elkin et al. (1980). Moreover, by increasing the NMAS in SMA and HMA, the skid resistance would increase, which is inconsistent with the results of Fakhri and Tarikhbakhsh (2014). These results could be explained by the Fowler diagram of these samples, shown in Figure 3. As mentioned earlier, as the grading curve gets closer to the 0.45 power line, the grading density would increase. Given that the samples with higher NMAS are located at a further distance from the Fowler line, they would have lower density and a more open grading which could lead to an increase in their BPN value.

The results indicate that combined effects of the dust on the road surface and high ambient temperatures would lead to a higher reduction in the skid resistance. By increasing the temperature from 10 °C to 60 °C (in the absence of dust on the sample surface), the skid resistance of the SMA samples decreased in the range of 12-15%, which is inconsistent with the results of Khasawneh and Liang (2012). When 0.984 gr of the dust was spread over the sample surface, an increase in the temperature from 10 °C to 60 °C, resulted in a 14-17% reduction in the skid resistance of the SMA samples The maximum reduction in skid number was observed for the HMA mixture with grading No. 6 in Iranian Road Pavement Design Code (i.e.19 mm NMAS). The latter could be attributed to the higher proportion of fine aggregates and the higher bitumen content of HMA samples in comparison with the SMA samples. Under the same temperatures, the maximum skid number was observed for the SMA mixture with a nominal size of 19 mm.

The SN values are calculated based on the relations defined in the previous section for the experimental samples. SN for other temperatures at different dust contents applied on the sample surface was calculated, and the results are presented in Figure 7. The results indicate that the simultaneous effect of the fine texture (indicated by the British Pendulum skid number) and coarse texture (MTD) at SN number has caused that SMA mixtures demonstrate considerably higher skid resistance at different ambient temperatures and different dust contents. The maximum SN number in all conditions is obtained for the SMA samples with a 19 mm NMAS due to their maximum BPN and MDT.

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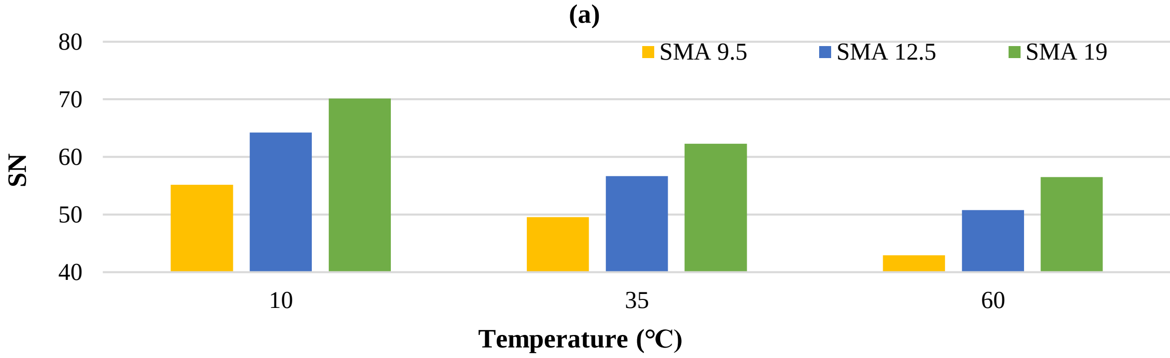


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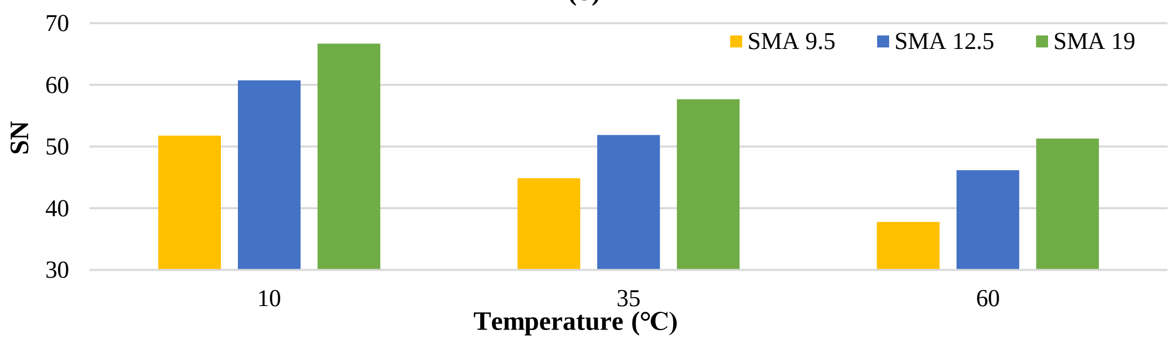


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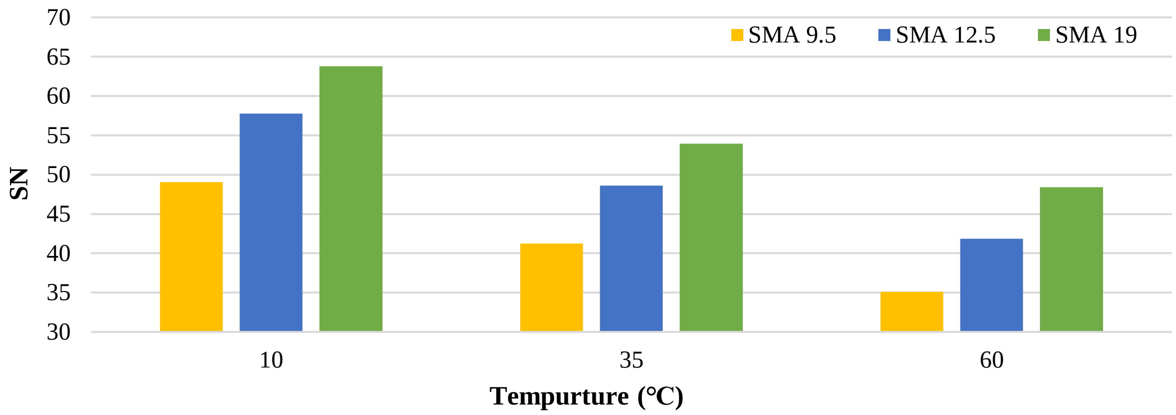


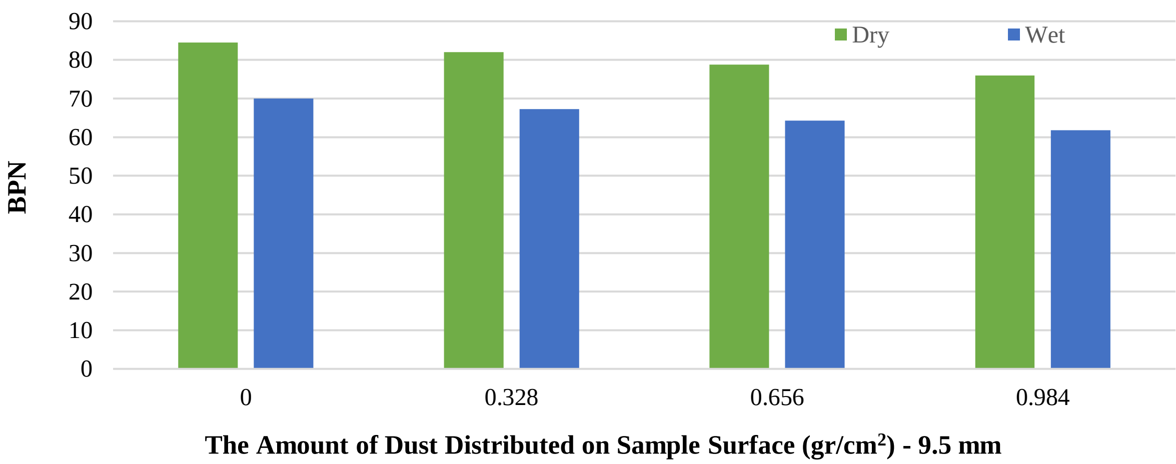

**(d)**

**Fig. 7.** SN numbers for samples with different values of dust spread over the sample surface with 6 in diameter: a) 0 gr; b) 0.328 gr; c) 0.656 gr; and d) 0.984 gr

### 3.3. Results of the BPN Test on the Asphalt Samples in Wet Conditions

The skid resistance of the asphalt samples in the wet and dry conditions at 10 °C under different dust contents was compared with each other as indicated in Figure 8.

The results indicate that the humidity on the surface of the samples in the presence and absence of the dust would lead to a reduction in the skid number. In humid conditions, a thin layer of water is formed between the pavement surface and the rubber surface of the pendulum device and covers the fine texture, which causes a reduction in the surface contact and would significantly reduce the skid resistance. According to the results, the existence of the humidity causes the skid resistance to reduce in the range of 17 to 21% in the samples, which is inconsistent with the results of Henry (1983). It was observed that in the case of zero dust content, the skid resistance would reduce by 17 to 19%. However, in a case where 0.984 gr of the dust was spread over the sample surface, the effect of the humidity on the reduction of skid number was 19 to 21% more than the dry situation with the same dust content. In other words, the existence of 0.984 gr dust on the wet sample surface reduced the skid number in the range of 25-35% in comparison with the dry with zero dust content situations. This reduction in SMA samples was in the range of 25-28%, which is consistent with the results of Tyfore (2009). The main reason for this could be attributed to proper drainage in SMA mixtures, which originates from the wide grading of this mixture. In the same condition in terms of the presence or absence of the dust, the SMA asphalt mixture with 19 mm NMAS created the best skid resistance in wet conditions.

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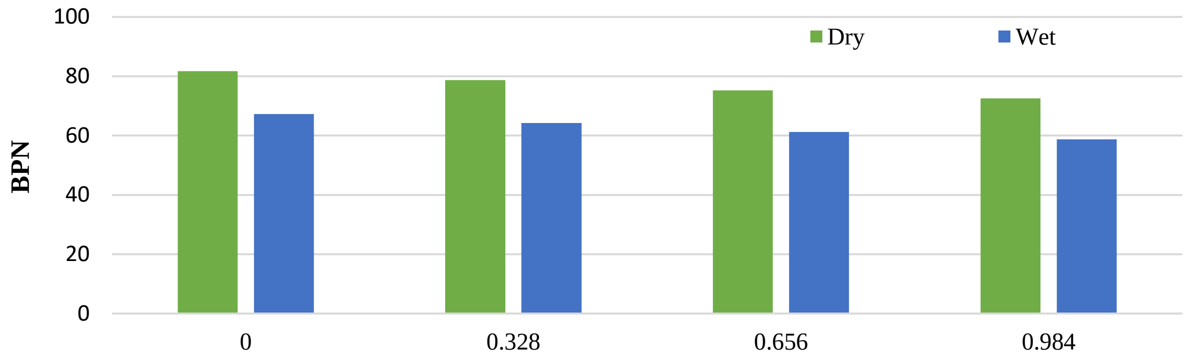


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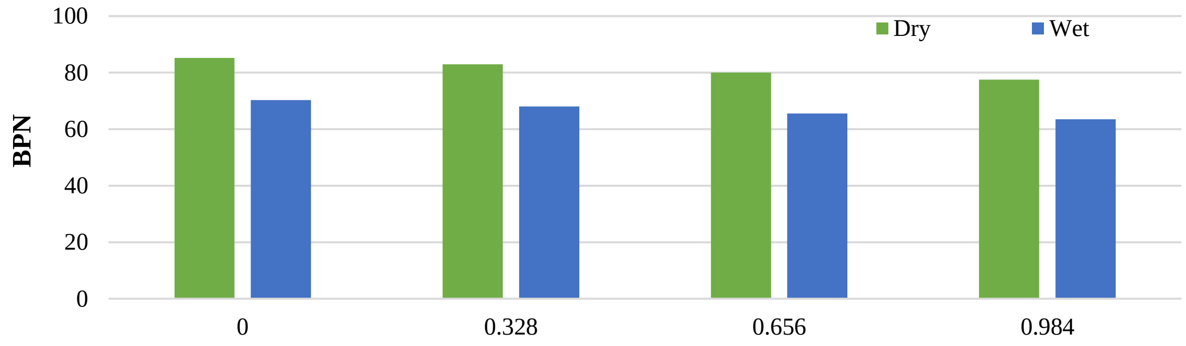


(c)

**Fig. 8.** The results of the BPN test for SMA asphalt mixture with a nominal size of 9.5 mm to 19 mm in the wet and dry conditions (temperature = 10 °C)

### 3.4. Analysis Using Taguchi Method

There are different methods to design a test. One of these methods which have been proposed in this field is the factorial method. The main disadvantage of this method is a large number of tests due to a large number of variables which could be time-consuming and costly in many situations. One of the modifications proposed to this method is to use the Taguchi method. This method makes it possible to reach the overall results by a fewer number of tests. Taguchi developed a family of fraction factorial schemes and utilized them in different applications. In this research, the results of the Taguchi method were obtained, and finally, the analysis of the results was performed between the Taguchi results and the factorial results. The related orthogonal arrays for test design with three factors and three levels are indicated in Table 5. Three different factors were considered in this study as follows:

**Factor A:** Grading type (at three levels: level 1: SMA with nominal size 9.5 mm, Level 2: SMA with nominal size 12.5 mm, and level 3: SMA with nominal size 19 mm).

**Factor B:** Temperature (at three levels: level 1: 10 °C, level 2: 35 °C, and level 3: 60 °C)

**Factor C:** Dust content (at three levels: level 1: 0.328 gr of dust content spread over the sample surface, level 2: 0.656 gr of dust content spread over the sample surface; and level 3: 0.984 gr of dust content spread over the sample surface).

The results obtained using the Taguchi method were analyzed using Minitab software and the output results are indicated in Figure 9 from the Minitab software. As it is seen in this figure, by increasing the maximum nominal size of aggregates, the friction also increases which is under the results of other researches (Khasawneh and Alsheyab, 2020).

**Table 5.** Orthogonal array L9($3^3$), and BPN results for defined test conditions

| Test condition | Three factors A | B | C | BPN test results |
|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 78.75 |
| 2 | 1 | 2 | 2 | 68.25 |
| 3 | 1 | 3 | 3 | 58.25 |
| 4 | 2 | 1 | 2 | 78.25 |
| 5 | 2 | 2 | 3 | 67.5 |
| 6 | 2 | 3 | 1 | 65.5 |
| 7 | 3 | 1 | 3 | 77.5 |
| 8 | 3 | 2 | 1 | 76.25 |
| 9 | 3 | 3 | 2 | 66.75 |

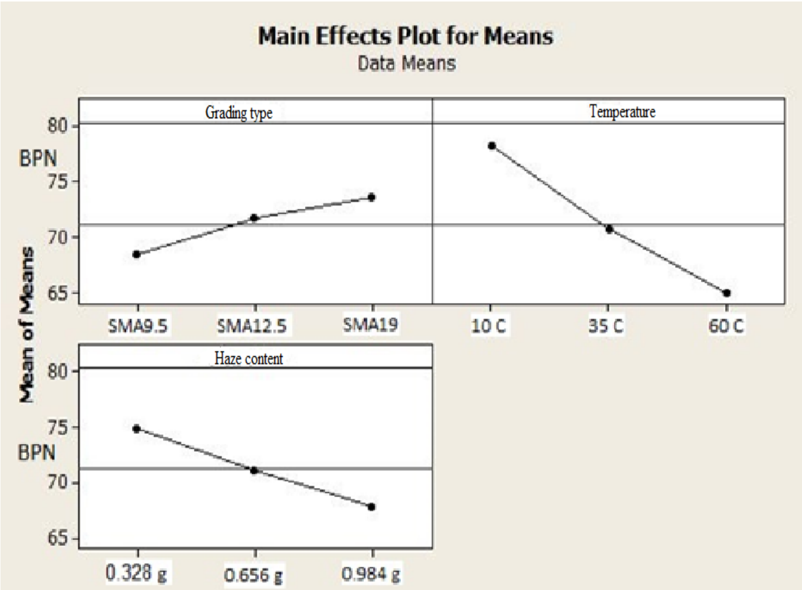


**Fig. 9.** The output plots of the Minitab software for SMA results

## 4. Conclusions

In this research, the effect of various dust contents observed in the real world on the skid resistance of the SMA asphalt mixture at different grading and ambient temperatures has been addressed. The results were analyzed using Taguchi and factorial methods and were compared. The following conclusions can be drawn from the tests performed on the samples produced for this purpose:

- When the maximum dust content (0.984 gr) was spread over the pavement surface, the skid number was reduced in the range of 9-16% for SMA samples with different grading. The SMA samples with 19 mm NMAS demonstrated the best skid resistance, irrespective of the dust content value.
- In the presence of different dust contents on the sample surface, the skid number was reduced by an increase in the sample surface temperature from 10 °C to 60 °C, i.e. the skid resistance of the SMA samples reduced in the range of 12-17%.
- The simultaneous increase in the dust content and surface temperature would decrease the skid resistance significantly. By increasing the temperature from 10 °C to 60 °C and increasing the dust content from zero to 0.984 gr, the skid resistance of the SMA mixtures was decreased in the range of 25-29%.
- The maximum SN values on all cases related to SMA mixtures with 19 mm NMAS could be attributed to the combined effect of the fine texture and MTD on the SN values resulted in to observe.
- The surface humidity of the samples in

the presence and the absence of the dust would reduce the skid resistance. The surface humidity alone caused 17 to 19% reduction in the skid number of the samples. However, when 0.984 gr of dust were spread on the surface of the sample, the effect of the humidity on the reduction of skid number was 19-21% more than the dry surface with the same dust content.

- The presence of 0.984 gr of dust spread over the wet sample surface resulted in a 25 to 28% reduction in the skid resistance compared to clear and dry sample surfaces.
- The SMA asphalt samples with 19 mm NMAS created the highest skid resistance in comparison with the samples produced with another grading, irrespective of having dust on their surface or not.
- By performing fewer tests (9 BPN test) for the SMA samples, via using the Taguchi method, the same results as the factorial method were obtained.

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## 6. References

AbdullahI, S. (2016). *Investigation of quantitative changes in precipitation dust in Zahedan city*, M.Sc. Thesis, Department of Natural Resources. Yazd University.

ASTM E303-93, (2018). *Standard test method for measuring surface frictional properties using British Pendulum tester*, West Conshohocken, PA, USA.

ASTM E465, (2017). *Standard test method for measuring mean profile depth using sand patch method*, West Conshohocken, PA, USA.

Blake, D.M., Wilson, T.M., Cole, J.W., Deligne, N.I. and Lindsay, J.M. (2017). "Impact of volcanic ash on road and airfield surface skid resistance", *Sustainability*, 9(8), 1389.

Cao, P., Yan, X., Bai, X. and Yuan, C. (2010). "Effects of contaminants on skid resistance of asphalt pavements", In *Traffic and Transportation Studies 2010*, 1341-1351.

Chan, C.Y., Huang, B., Yan, X. and Richards, S. (2010). "Investigating effects of asphalt pavement conditions on traffic accidents in Tennessee based on the pavement management system (PMS)", *Journal of Advanced Transportation*, 44(3), 150-161.

Dan, H.-C., He, L.-H. and Xu, B. (2017). "Experimental investigation on skid resistance of asphalt pavement under various slippery conditions", *International Journal of Pavement Engineering*, 18(6), 485-499.

Do, M.-T., Cerezo, V. and Zahouani, H. (2014). "Laboratory test to evaluate the effect of contaminants on road skid resistance", *Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology*, 228(11), 1276-1284.

Elkin, B.L., Kercher, K.J. and Gulen, S. (1980). "Seasonal variation in skid resistance of bituminous surfaces in Indiana", *Transportation Research Record*, 777, 50-58.

Fakhri, M. and Taribakhsh, M. (2014). "Studying the effect of gradation and macro texture generating by the method of gravel distribution, on the skid resistance of the concrete pavements", *Journal of Civil and Environmental Engineering*, 43(73), 69-78.

Henry, J.J. (1983). "Comparison of the friction performance of a passenger car tire and the ASTM Standard test tires", In *Frictional Interaction of Tire and Pavement*, ASTM International.

Irfan, M., Ali, Y., Ahmed, S., Iqbal, S. and Wang, H. (2019). "Rutting and fatigue properties of cellulose fiber-added stone mastic asphalt concrete mixtures", *Advances in Materials Science and Engineering*, Hindawi, Article ID 5604197, 8 p.

Jalal-Kamali, M.-H., Hasani, A. and Sodagari, J. (2019). "Introduction and application of rotational abrasion device to determine concrete pavement abrasion", *Civil Engineering Infrastructures Journal*, 52(2), 295-308.

Jalalkamali, R., Dibaee, M.M., Jalal Kamali, M.H. and Hassani, A. (2021). "An investigation of the relationship among skid resistance, mean texture depth and abrasion resistance for different macrotextures of concrete pavements", *Civil Engineering Infrastructures Journal*, 54(2), 301-317.

Kamel, N. and Gartshore, T. (1982). "Ontario's wet pavement accident reduction program", In *Pavement Surface Characteristics and Materials*, ASTM International.

Khasawneh, M.A. and Alsheyab, M.A. (2020). "Effect of nominal maximum aggregate size and aggregate gradation on the surface frictional properties of hot mix asphalt mixtures", *Construction and Building Materials*, 244, 118355.

Khasawneh, M.A. and Liang, R.Y. (2012). "Temperature effect on frictional properties of HMA at different polishing stages", *Jordan Journal of Civil Engineering*, 6(1), 39-53.

Kogbara, R.B., Masad, E.A., Kassem, E., Scarpas, A.T. and Anupam, K. (2016). "A state-of-the-art review of parameters influencing measurement and modeling of skid resistance of asphalt pavements", *Construction and Building Materials*, 114, 602-617.

Liu, Q., Hossain, S.M.K., Tighe, S.L. and Shalaby, A. (2019). "Field assessment of three-dimensional surface texture and frictional properties of experimental Canadian road pavements", In *Pavement and Asset Management*, 73-80, CRC Press.

National Cooperative Highway Research Program (NCHRP). (1999). *Designing stone matrix asphalt mixtures for rut-resistant pavements*, Report 425, Project D9-8 FY'94, Auburn, AL, United States, 88 p.

Raufi, H., Topal, A., Sengoz, B. and Kaya, D. (2020). "Assessment of asphalt binders and Hot Mix asphalt modified with nanomaterials", *Periodica Polytechnica Civil Engineering*, 64(1), 1-13.

Sharafati, A. and Mishmast Nahi, A. (2017). "Analysis of the effect of 120-day storms on the increase of road accidents, Case study: Roads to Zabol city", *Rahvar Scientific Promotional Quarterly*, 14(38), 137-148.

Terrones-Saeta, J.M., Suárez-Macías, J., Iglesias-Godino, F.J. and Corpas-Iglesias, F.A. (2020). "Evaluation of the use of electric arc furnace slag and ladle furnace slag in stone mastic asphalt mixes with discarded cellulose fibers from the papermaking industry", *Metals*, 10(11), 1548.

Tyfour, W.R. (2009). "Tire skid resistance on contaminated wet pavements", *JJMIE*, 3(2).

van Bijsterveld, W. and del Val, M.A. (2016). "Towards quantification of seasonal variations in skid resistance measurements", *Road Materials and Pavement Design*, 17(2), 477-486.

Wallman, C.-G. and Åström, H. (2001). "Friction measurement methods and the correlation between road friction and traffic safety: A literature review", Swedish National Road and Transport Research Institute (VTI) Report, 47 p.

Wang, D., Xie, X., Oeser, M. and Steinauer, B. (2015). "Influence of the gritting material applied during the winter services on the asphalt surface performance", *Cold Regions Science and Technology*, 112, 39-44.

Xiao, J., Kulakowski, B.T. and EI-Gindy, M. (2000). "Prediction of risk of wet-pavement accidents: Fuzzy logic model", *Transportation Research Record*, 1717(1), 28-36.

Zealand, T.N. (2002). "Specification for skid resistance investigation and treatment selection", NZTA T10 Specification, NZ Transport Agency, New Zealand, 21 p.

Zhang, L., Ong, G.P. and Fwa, T.F. (2015). "Numerical study on the influence of aggregate size on skid resistance performance of porous pavements", *Asian Transport Studies*, 3(3), 284-297.