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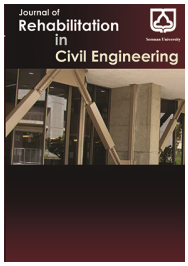

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The Effect of Asphalt Concrete Micro & Macro Texture on Skid Resistance

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ABSTRACT

Skid resistance and road condition are common indices of road safety; therefore providing adequate skidding resistance will reduce the incidence of road accidents. The surface macrotexture has a large effect on the characteristics of road surface skidding, which is the focus of this research. During the study, the mean texture depth of the road surface was measured, in order to determine the conditions that ensure the maximum contact area between the vehicle tires and road surface during wet conditions. The Pavement Guideline No. 234 was consulted for the test procedure and road surface composition, which used open and dense graded crushed lime aggregates with varying percentages of bitumen applied to the mix design. The samples were then tested to assess their stability using the Marshall and Gyratory Tests. The results showed that with the application and evaluation of the sand patch method, where the effect of the macrotexture on skidding resistance was analyzed with various gradations, there was an improved higher skidding resistance and a subsequent projected reduction of accidents with an increased safety.

1. Introduction

In Iran, where more than 90% of transportation takes place on the road transportation network, transportation and safety are of prime importance [1]. Various studies have shown that pavements and surface conditions play an important role in accident rates and safety levels; therefore combining safety parameters and characteristics of pavement surfaces is necessary to improve highway safety. Friction and pavement surface are the most common indices of safety issue, and according to several reports, many accidents occur on the roads that can be attributed to these. It is well known that every year, more

than one million people are killed in driving accidents round the world. The majority of these accidents are related to human error (human factors), although pavement surface has a significant effective on these accident rates [2].

Collected statistics have shown that loss of human resources is the worst consequence of road accidents. In Iran many people are killed in accidents, for example, in 2010 each day an average of more than 64 people were killed in a road accident, or an equivalent of one person killed every 22 minutes. Table 1 shows the number of fatalities as a result of accidents between 1996 and 2010 [6].

According to the ASTM E867 standard, skid resistance is the existence of a resisting force or frictional force between the automobile tire and the pavement surface at the moment of braking and tire locking. Its value is determined from the division of the longitudinal reaction force by the vertical force, or weight that is in the tire [3].

The other factors that have a significant effect on the skid resistance of pavement surfaces are the climate condition, traffic fluctuation, wind pressure, type and shape of tire arch, brake system and speed of the vehicle [2, 4]. Researchers have also determined that skid resistance depends on the temperature, where there is a decrease in the skid resistance with an increase in temperature [5].

Skid resistance is important in industrial countries and considerable funds have been dedicated to haltering of skid on the pavement surfaces. This study considers the skid issue in three sections, which are design, fulfillment and pavement maintenance. In the design phase, pavement skid resistance is improved by the design of mixtures that have suitable properties with regards to friction. This is achieved by the use of resistance aggregates to mitigate the effects of trituration, grinding and atmospheric factors. There is also selection of suitable grade and consideration of rough and coarse surfaces.

Table 1. Statistics regarding accidents, fatalities and injuries from driving incidents [6]

Year	Accidents		Fatalities		Injuries	
	Number (people)	Percentage Change	Number (people)	Percentage Change	Number (people)	Percentage Change
1996	50348	-	12583	-	62466	-
1997	54676	8.6	13676	8.7	67796	8.5
1998	65152	19.2	14966	9.4	79289	17
1999	70683	8.5	15482	3.4	91084	14.8
2000	76976	8.9	17059	10.2	108300	18.9
2001	83499	8.5	19727	15.6	117566	8.6
2002	96499	15.6	21873	10.9	167372	42.4
2003	109023	13	25722	17.6	222309	32.8
2004	115979	6.4	26089	1.4	245754	10.5
2005	150324	29.6	27746	6.4	274257	11.6
2006	164986	9.8	27567	-0.6	276762	0.9
2007	127606	-22.7	22918	-16.9	245418	-11.3
2008	136619	7.1	23362	1.9	272877	11.2
2009	144172	5.5	22974	-1.7	294702	8.0
2010	155125	7.6	23249	1.2	312745	6.1

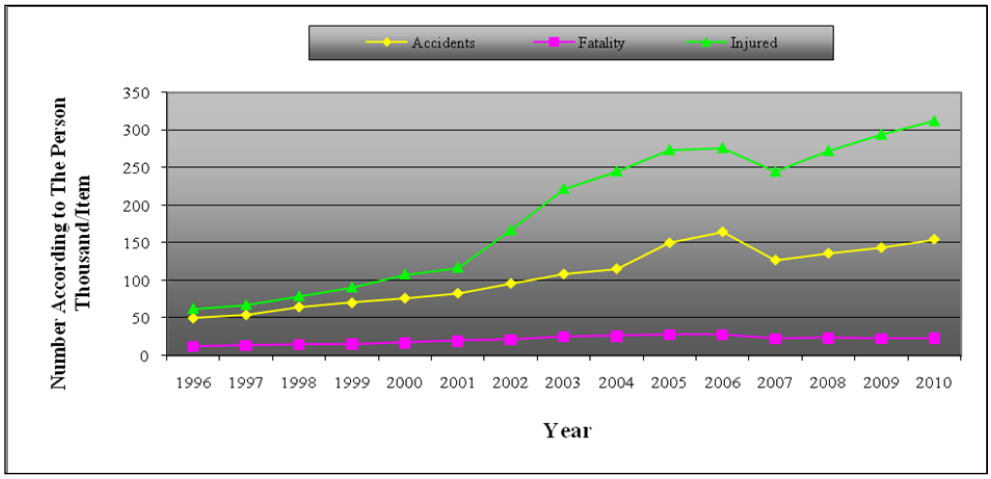

Fig. 1. Increase in mortality on state roads during the last 12 years [6]

In developed countries, considerable research has been conducted in universities and research centers regarding the results of accidents and their prevention methods; however, this matter has not been considered in great detail in Iran. Due to the increase in serious driving accidents involving vehicles in that country, it is necessary to investigate and apply safety principles in this field.

2. Laboratory Activities

In this research study, laboratory-based activities have been carried out on asphalt cement 60-70 and crushed mountain calcareous aggregates. In addition, asphalt samples with dense grade (No. 4, 5) and open grade (No. 4, 5) have been subjected to the Marshall method for determination of optimized bitumen percentage according to the Iran Road Pavement Code [7]. Following this, samples of Gyratory asphalt were made in the Superpave Gyratory Compactor (SGC), with this optimized percentage of bitumen and six variations of bitumen percentage for each grade. To analyze the effect of grade and asphalt aggregates on the pavement texture, and the subsequent effect of this road texture on the asphalt skid resistance, gyratory asphalt samples have been examined by the British Pendulum test for determination of microtexture, according to the ASTM E303-93 standard [8] based on the aggregate grade. The samples have also been tested under the sand patch method for determination of macrotexture according to the ASTM E965-96 standard [9]. The rate of aggregate superficial texture has been determined and its effect on skid resistance has been reviewed. The outcome of this study is that one type of comparison has been fulfilled from the four types of grade, based on their effects on the skid resistance of highway pavements. With the intention of improving highway safety, the most suitable grade has been selected from the resistance to skid perspective.

3. Preparation of Materials

Aggregate material was extracted from a mountain stone mine, which was crushed into maxillary and cubit lithoclast. The materials were graded immediately after breaking by riddling, and they were stored separately as coarse grain, middle grain and fine grain to be included as filler [7]. Aggregates for inclusion in asphalt concrete should be tough,

stable, resistant, clean and cubic, and they should be free from organic or clay materials, dusty coverings and weak grains. If necessary, the separated coarse, middle and fine grain materials may be cleaned [7].

4. Results from Aggregate Tests

The results of material tests on the aggregates are shown below in table 2.

Table 2. Characteristics of consumed aggregates in asphalt mixture

1- Materials with Coarse Grain	Properties of Crushed Mountain Calcareous Aggregate	Test Standard
Los Angeles Abrasion (percent)	22	ASTM C131
Breakage Percent	One Ward 99 - Two Ward 98	ASTM D5821
Actual Density (gr/cm^3)	2.699	ASTM C127
Density of Apparent (gr/cm^3)	2.770	ASTM C127
Percent of Water Absorption	1.0	ASTM C127
2- Materials with Fine Grain	Properties of Crushed Calcareous Aggregate	Test Standard
Actual Density (gr/cm^3)	2.665	ASTM C128
Density of Apparent (gr/cm^3)	2.775	ASTM C128
Percent of Water Absorption	1.2	ASTM C128

5. Grade of Hot Mixture Asphalt

Focusing on the main purpose of this research to review the effects of grade and the characteristics of consumed materials in the skid resistance of asphalt, the aggregate grade has been calculated according to the middle limit of the grade.

Table 3. Dense Grade No. 4, 5, Open Grade No. 4, 5 selected according to Code No. 234 [7]

Percentage of Passing Weight From Each Sieve (gr.) (Iran Road Pavement Code)				
Grade Type	**Dense**		**Open**	
Grade Number	**4**	**5**	**4**	**5**
Sieve Size	**Limitation of Desirable Grade**			
¾ inch	100	-	100	-
½ inch	90 - 100	100	85 - 100	100
⅜ inch	-	90 - 100	60 - 90	85 - 100
# 4	44 - 74	55 - 85	20 - 50	40 - 70
# 8	28 - 58	32 - 67	5 - 25	10 - 35
# 16	-	-	3 - 19	5 - 25
# 50	5 - 21	7 - 23	0 - 10	0 - 12
# 100	-	-	-	-
# 200	2 – 10	2 - 10	-	-

6. Consumed Bitumen

Consumed bitumen was selected to include in the asphalt mixture according to the type of admixture design and geographical condition of the consume place [11]. Bitumen that was used to make the hot asphalt concrete was a type of asphalt cement with penetration grades of 40-50, 60-70, 85-100 and 120-150. Suitable penetration grades were chosen according to the atmospheric conditions of the zone and rate of road use of heavy vehicles [10].

Considering the factors mentioned above, the bitumen consumed in the present research was a type of asphalt cement with a 60-70 penetration grade, which was prepared from the Tehran Refinery and Pasargad Petroleum Company with consideration of the multiplicity of the moderate climate conditions in Iran.

Table 4. Guidance for selection of Asphalt Cement [7]

Atmospheric Condition (normal level of annual heat)	Penetration of Bitumen	
	Light and Heavy Traffic	Heavy Traffic
Cold Weather: Less Than 7 ^{O}C	120 – 150	85 - 100
Hot Weather: Between 7 - 24 ^{O}C	85 – 100	60 - 70
Very Hot Weather: More Than 24 ^{O}C	60 – 70	40 - 50

7. Tests Carried out on the Bitumen

The results of the tests carried out the bitumen are shown below in table 5.

Table 5. Results of tests on the consumed bitumen and its application

Characteristics of Bitumen	Amount	Application	Test Standard
Density at 25^{o}C	1.01	In asphalt mixture plant	ASTM-D70
Penetration (10^{th} millimeter)	66	This test has been carried out at 25^{o}C, and it showed suitable relationships between resistance and fatigue for determination of proportional stiffness	ASTM-D5
Softening Point by Ring and Ball Method (^{o}C)	50	This test is a criterion for characteristics of bitumen	ASTM-D36
Ductility at 25^{o}C (centimeters)	102	The criterion for covering of aggregate by bitumen	ASTM-D113

8. Construction of Marshall Sample

In this research, Marshall samples were constructed according to the ASTM D1559 standard [12], and were compacted with 75 strokes of the Marshall Hammer on two sides of the samples as specified for heavy traffic conditions. The Marshall stability parameters, the density of the asphalt mixture and percentage of air voids in the asphalt mixture for compacted samples were distinguished for determination of the optimized percentage of bitumen, flow parameters and percentage of Voids in Mineral Aggregate (VMA) according to the standard of the Iran Road Pavement Code.

9. Determination of Percentage of Optimized Bitumen

The main purpose of determining the most suitable percentage of bitumen is that it will allow preparation of asphalt with the best characteristics for improving road safety. After making the Marshall samples according to the ASTM D1559 standard [12], with bitumen ratios of 4, 4.5, 5, 5.5, 6 and 6.5 percent, and fulfillment of the Marshall stability, density, percentage of air voids in the asphalt mixture, flow and Void in Mineral Aggregate (VMA) percentages, then by consideration of the above diagram and control of the factors in the Iran Road Pavement Code, the optimized percentage of bitumen was determined for 72 Marshal samples for each type of dense and open grade (Table 6).

10. Construction of Gyratory Samples (Superpave Gyratory Compactor)

After preparation of Marshall samples and determination of optimized percentages of bitumen, the asphalt samples were prepared for fulfillment of the Skid resistance test by application of the Superpave gyratory compactor for 28 gyratory samples.

10.1. Advantages and Disadvantages of the Marshall Compaction Method

1. Allows detailed analysis of the characteristics of density and air voids in asphalt mixtures.
2. Uses cheap and easily transportable equipment, and the control of the workshop is easier.
3. In action, the compaction method does not conform to the existence condition
4. At the moment of sample compaction on the mold, there is the possibility of aggregate brakeage and a probability of changes in the material behavior.
5. Results acquired from the Marshall test do not give an indication of the resistance against rutting or fatigue, and no details of the pavement action due to low temperatures and pavement ageing.
6. Marshall Stability is not an exact criterion for cutting asphalt resistance [11].

10.2. Advantages and Disadvantages of Gyratory Compaction Method

1. Compaction conforms to real conditions when compacted by a roller.
2. There is no possibility of aggregate breakage at the moment of compaction.
3. There is a facility for the construction of asphalt samples by this machine and a reduction of human errors at the moment of construction and compaction of samples.
4. According to the ASTM E303-93 standard [8], the necessary path for passing of British Pendulum tire slippers is between 12.4 and 12.7 Cm, which is covered by constructed samples on the mold with 6-inch diameter (15.24 Cm with 5±1 Cm height) Fig. 3.
5. Related laboratory equipment is expensive in comparison with the Marshall test [11].

Table 6. Results of Percentages of Optimized Bitumen.

Grade Type	Grade Number	Percentage of Optimized Bitumen
Dense	4	5.042
	5	5.39
Open	4	4.3
	5	4.625

Dense Grade No. 4, 5 Open Grade No. 4, 5

Fig. 2. Preparation of 6 inch Samples for Determination of Skid Resistance using the British Pendulum Tester and the Sand Patch Method

Dense Grade No. 4, 5

Open Grade No. 4, 5

Fig. 2. Preparation of 6 inch Samples for Determination of Skid Resistance using the British Pendulum Tester and the Sand Patch Method

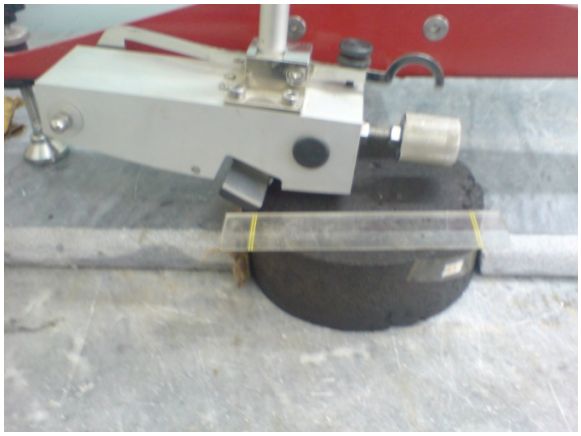

Fig. 3. Manner of Drawing up the Slip Length (125±1.6 Millimeter) on the British Pendulum Tester, with 15 cm Diameter Samples

11. Analysis of the Test Results

11.1. Microtexture

The British Pendulum Tester was set up according to the ASTM E303-93 standard for tests on the asphalt surfaces in the laboratory, which was fulfilled on the site as well, as it had been used for aggregate polished samples on the test convex mold, which had a Polished Stone Value (PSV). This tool measures the reduction of energy at the moment that the skid edge (tire pad) is put forward on the sample [8].

Measured amounts were determined by the British Pendulum Pointer, which is noted as the title of the British Pendulum Number (BPN) or Skid Number (SN). In the case of increased friction between the skid edge of the pendulum and the surface of the sample,

the fluctuation was slow and skid number was increased [2, 18].

In this research study, 7 gyratory samples were constructed for each grade, and for each sample, 5 test runs were carried out. Figures 4-7 show the results from the British Pendulum Test. Note that the first number relates to the drying condition of the sample surface and the four later numbers represent the humidity conditions of the sample surface.

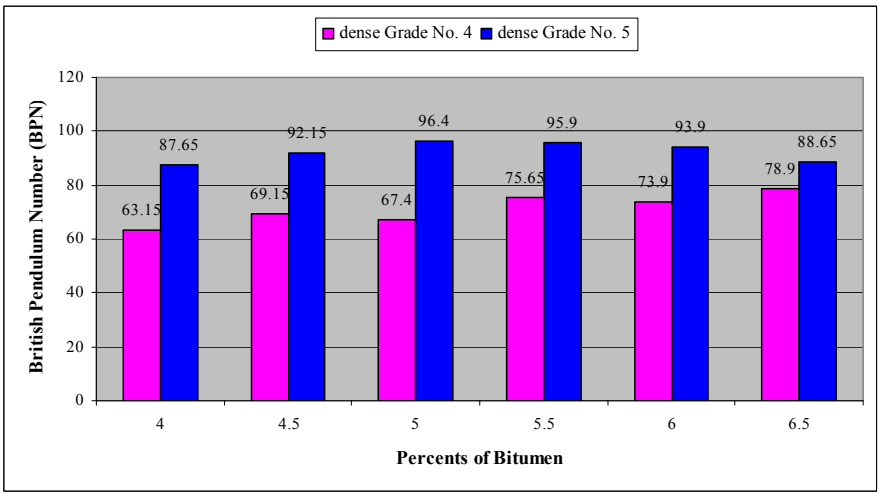

Fig. 4. British Pendulum Number (BPN) For Dense Grade No. 4, 5 for Different Percentages of Bitumen

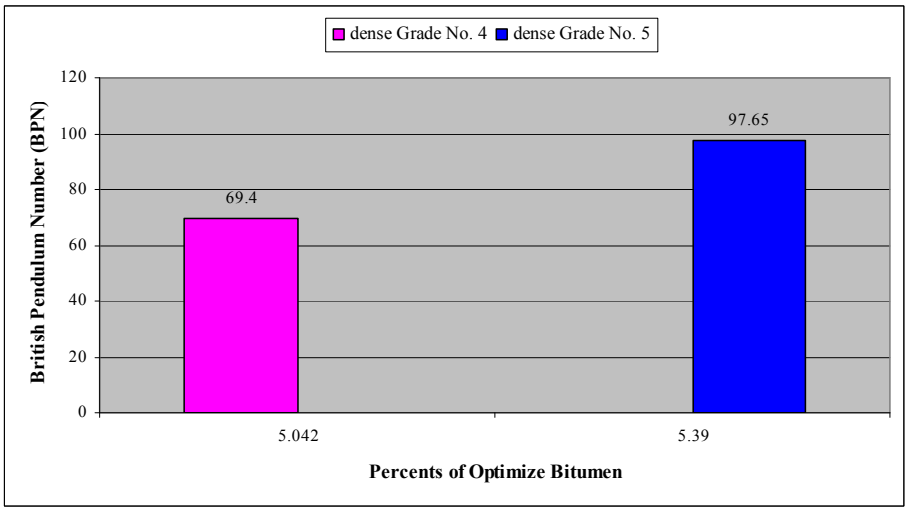

Fig. 5. British Pendulum Number (BPN) For Dense Grade No. 4, 5 for Percentage of Optimized Bitumen

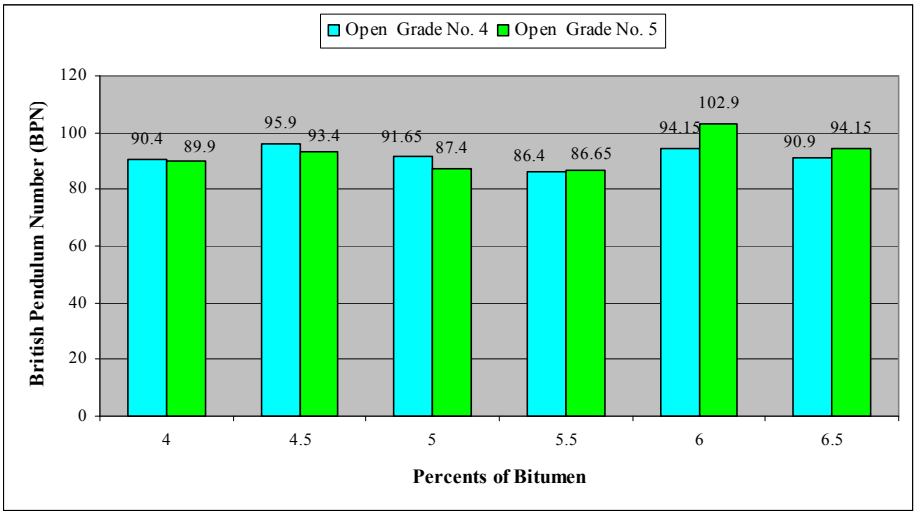

Fig. 6. British Pendulum Number (BPN) For Open Grade No. 4, 5 for Different Percentages of Bitumen

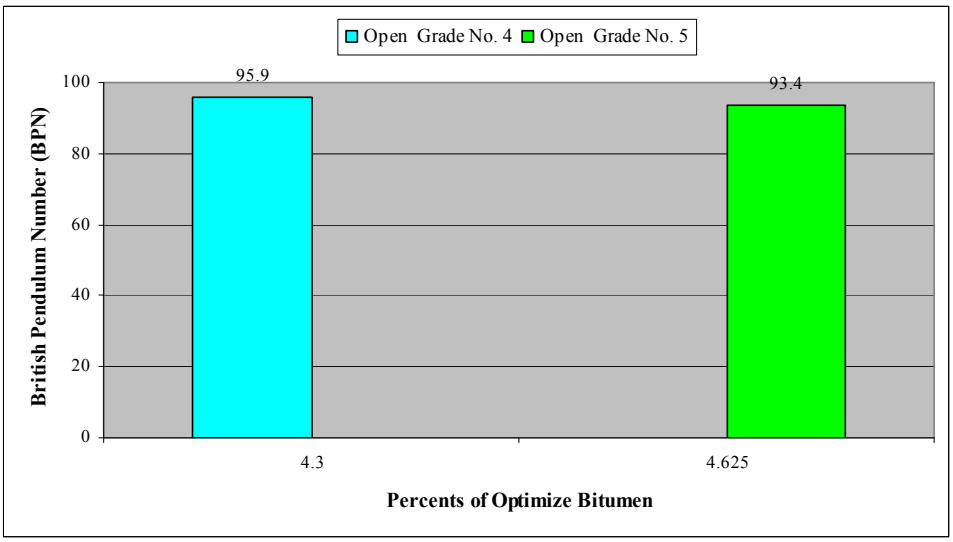

Fig. 7. British Pendulum Number (BPN) For Open Grade No. 4, 5 for Percentage of Optimized Bitumen

Analyzing the acquired results of the skid resistance tests, it can be seen that asphalt samples with an open grade have better skid resistance due to asphalt samples with dense grade. The permissible limit of skid resistance is shown in table 7 for three groups of highways according to the Road Notes 27 Magazine [13].

The values in this table are for real condition on site; however, the acquired SN results from the test may show a lot of variation with those shown in table 7. This is possible because the constructed samples have not been subjected in the laboratory to real traffic conditions, and generally, the laboratorial conditions are only applied to the samples and are not accurately representative of the real conditions.

Table 7. Suggested values of skid resistance for use with the portable tester [13]

Category	Types of Site	Skid-Resistance on Wet Surface	Standard of Skidding Resistance Required
A	Most difficult sites, which are: (1) Roundabouts (2) Bends with a radius less than 500 ft (150m) at derestricted roads. (3) Gradient of 1 in 20 or steeper, with a length greater than 330 ft (100m). (4) Approaches to traffic lights on derestricted roads.	Above 65	"Good", fulfilling the requirements even of fast traffic, and making it most unlikely that the road surface will cause repeated skidding accidents.
B	General requirements, i.e. roads and conditions not covered by categories A and C.	Above 55	"Generally satisfactory", meeting all but the most difficult conditions encountered on the roads.
C	Easy sites, e.g. straight roads, with easy gradients and curves, and without junctions, and free from any features, such as mixed traffic that are especially liable to create conditions of emergency.	Above 45	"Satisfactory only in favorable circumstances"
D	All sites	Below 45	"Potentially slippery".

11.2 Macrotexture

After preparation of samples according to the ASTM E965-96 standard, sand was distributed on the surfaces of the samples Fig. 8, then the acquired results were drawn as a diagram for different percentages of bitumen and optimized bitumen.

Fig 8. Preparation of river roundness sand passed through sieve No. 60 and retained on sieve No. 80 and distribution of specific volume of sand on the surface of the asphalt mix sample with open and dense grade

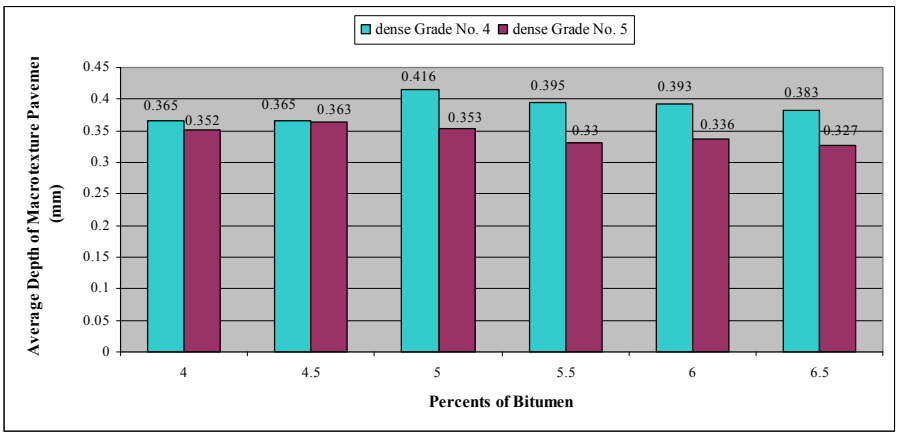

Fig 9. Average Depth of Macrotexture of Pavement with reference to the Percentage of Bitumen for Dense Grade No. 4, 5

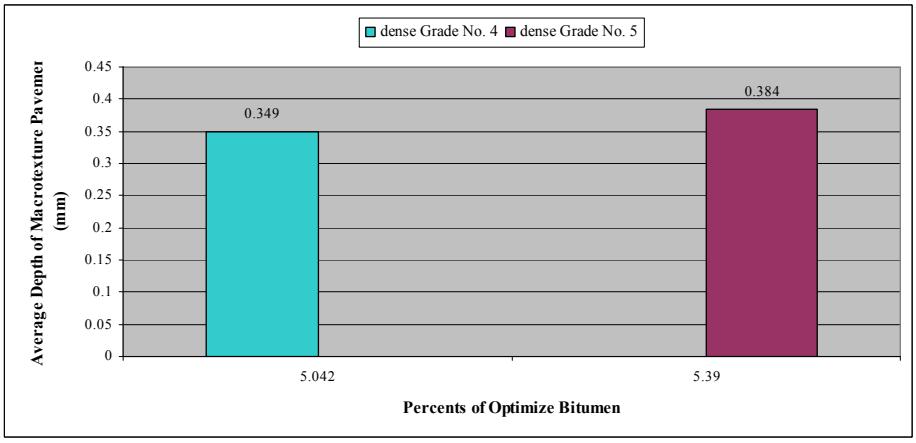

Fig 10. Average Depth of Macrotexture of Pavement with reference to the Percentage of Optimized Bitumen for Dense Grade No. 4, 5

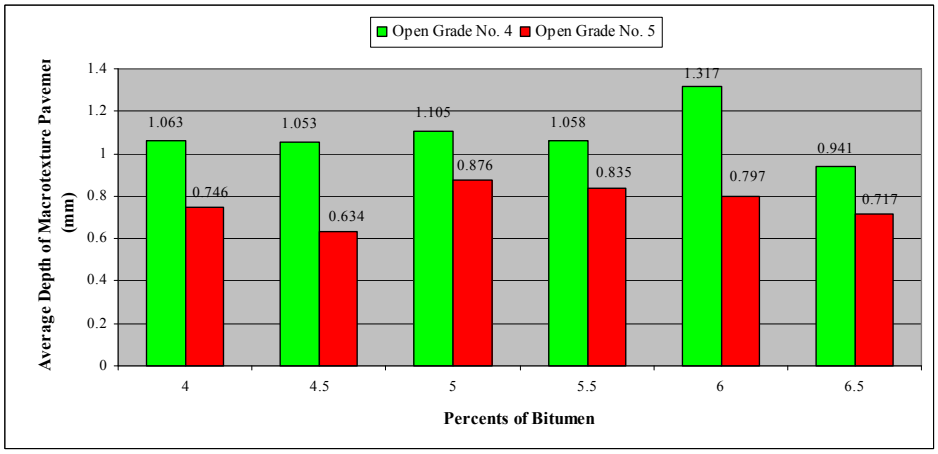

Fig. 11. Average Depth of Macrotexture of Pavement with reference to the Percentage of Bitumen for Open Grade No. 4, 5

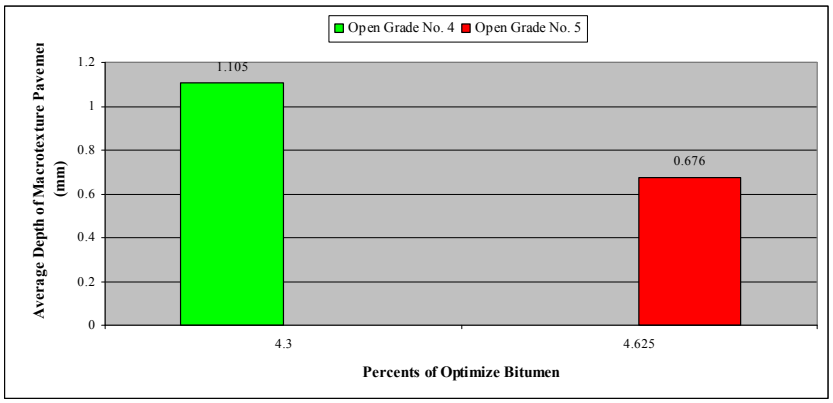

Fig. 12. Average Depth of Macrotexture of Pavement with reference to the Percentage of Optimized Bitumen for Open Grade No. 4, 5

12. Conclusions

By analyzing the effect of microtexture and macrotexture of surface pavement on the skid resistance of asphalt samples, the following results have been acquired according to the type of grade and texture of the pavement surface:

12.1. Microtexture

1. Investigation of the skid resistance of asphalt samples with different grades is desirable, as well as the response of minimum permitted amounts under dry conditions.
2. In the moisture condition of samples, skid resistance has been reduced by increasing the percentage of bitumen, which in this study is also for less void space. As a result, there is more bitumen on the surface of samples, which results in a reduction in the skid resistance.
3. Dense grades, especially dense grade No.5, are suitable for highways where skid resistance is significant, as well as there being an importance of the Marshall stability, such as squares and conjunctions.
4. For the moisture conditions of surfaces, asphalt samples with open grades have responded better than those with dense grades with respect to skid resistance, due to the fact that the samples are porous and therefore they have suitable drainage conditions. It must be considered that open grade samples have no suitable amounts from related parameters of mixture design, such as stability and percentage of mixture void space.
5. In the zones in which skid resistance is significant from a safety respect, such as in the Northern zones of Iran, for the case of traffic, open grade No. 5 is a good alternative.
6. It is necessary to assess the skid resistance of asphalt surfaces during the pavement period to consider the effect of different conditions of climate, traffic and vehicle conditions on skid resistance and safety of pavements.
7. Attention should be aid to the Hydroplaning effect, because of the effect on the control of vehicles in rainy conditions.

12.2. Macrotexture

1. Because there is more fine grain and less coarse grain than for grade No.4, the average depth of macrotexture for

dense grade No. 5 is less than for grade No. 4. Therefore, the eruption of surface water (drainage) is better for grade No.4 such that the contact of tire with the surface of the road is reduced, and the friction power that exists as the effect of the vehicle brakes on the surface of the road shows improved performance, such that there is an improvement in control during road accidents.

2. For the optimized percentage of bitumen for dense grades Nos. 4 and 5, dense grade No.5 exhibits 10% more than dense grade No. 4, which is contrary to the different percentages of bitumen arising from result No. 1. Therefore, the macrotexture is suitable for percentage of optimized bitumen for dense grade No.5.
3. Macrotexture of asphalt surface for open grades is more than for dense grades, due to the fact that there is more void space. The surface of dense grade asphalt samples that processes eminence of surface is because of the existence of coarse grains in the mixture.
4. For open grading, open grade No. 5 has a 0.8 Ml. macrotexture, which is more suitable for the surface of asphalt, with a Marshall stability that conforms to the Iran Road Pavement Code. This is contrary to Grade No. 4, which has a low Marshall stability and a large macrotexture.

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