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EFFECT OF ASPHALT MIXTURE AGGREGATE ON TIRE SLIP ON THE WET SURFACE OF ASPHALT PAVEMENTS

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Abstract

The existence of any liquid on the pavement surface causes a decrease in skid resistance. Heavy rain storm or improper surface grading leave a water film on the pavement surface. By increasing water film and vehicle velocity, there is a moment in which hydroplaning phenomenon can occur and causes the vehicle linear speed to become disproportionate to wheel rotational speed. In this study, a new laboratory-scale simulator is designed and manufactured that can simulate the occurrence of hydroplaning on asphalt pavements, facilitating the study of different parameters on the occurrence of this phenomenon such as vehicle speed, water film thickness, tire thread, pavement surface physical properties, etc. The lack of proportion between the linear movement of vehicle shaft and wheel rotation was considered as an important principle in designing of this machine. The designed apparatus involved electrical, mechanical, water transfer and asphalt mixture parts. The obtained results showed that the ratio of wheel rotational speed to its longitudinal speed is a proper index for identifying hydroplaning threshold. The results showed that by increasing frequency from 27.5 to 35 Hz, the ratio of wheel rotation to axle rotation in rpm is reduced by almost 10% in wet condition and hydroplaning occurred.

Keywords: *Laboratory-Scale machine; Friction; Hydroplaning; Asphalt Pavement; AUT Simulator.*

1. Introduction

One of the important issues in road safety is friction between the vehicle tire and road surface. When the road surface is exposed to rain, a thin water film is established on the pavement surface. Water film performs as a lubricant and having the obvious result of decreasing skid resistance. The downfall in the level of skid resistance establishes dangerous situation for vehicles. On the one hand, pavement macrotexture is as the most important factor in skid resistance and present micro drainage capacity in the pavement surface. In a way that current protrusions on road surface and distance between rough stones cause to decrease water film thickness which is formed between pavement and tire. In another hand, vehicles traffic on the road, decrease pavement macro texture gradually. At high speeds and intensive rainfalls, tire tread can't scatter accumulated water between tire and pavement and a water film is formed between tire and pavement, totally eliminating any direct contact between the tire and the pavement surface [1]. This phenomenon is called hydroplaning which is affected by various related factors to vehicle tire pressure and thread, fluid and pavement surface [2].

The fluid thickness and its density are effective parameters which are related to the fluid. According to Ong *et al.*, when the thickness of water film increases to 0.1 to 2 mm, hydroplaning speed decreases drastically [3]. Micro-texture and macro-texture of pavement surfaces are important related factors in road surface which are influential in hydroplaning occurrence. According to the studies of Ong *et al.*, if the mean texture depth is in the range of 0.2 to 0.5mm pavement micro-texture can postpone hydroplaning through increasing hydroplaning speed by up to 20% [3]. In another study, Yager used sand patch test to identify the level of texture depth and its relation to the potential of hydroplaning for various pavement surface [4].

2. Background

According to Figure 1, contact surface between tire and pavement composed of 3 areas [1]: Area (A): (sinkage zone), there isn't any contact between the tire and the pavement in this area. The tire floats on a wedge of water.

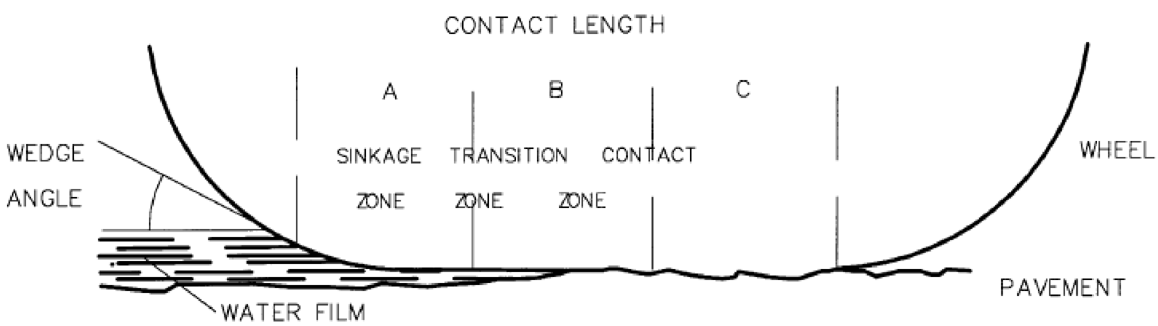

Figure 1. Contact surface between pavement and tire

Area (B): (transition zone), in this area water film being cut in some parts by some aggregates and friction force could develop due to existing micro-texture on coarse aggregates. Connection to aggregates resulted in tire deformation in this area.

Area (C): (tractive zone), there isn't any contact between tire and water layer in this area, and the whole micro-texture of the surface is active to increase friction.

By increasing vehicle speed, accessible time decreases to escape water from the interface between pavement and tire and increase the lubricating effect of water. According to previous studies, by increasing speed of the vehicle, area C would be small. Both areas A and B would be larger proportionally. If the tractive area is equal to zero and formed layer under tire wouldn't be interrupted, the contact between tire and pavement are removed completely. In this situation, the vehicle slide on the water. In this case, the hydroplaning phenomenon occurs.

Cerezo *et al.* are proposed a hydroplaning speed model calculating the water-film thickness by using road characteristics measurements [2].

If a tire is in full contact with the pavement surface and can roll freely, the relative speed between tire circumference and pavement which is called slip speed is equal to zero. The mathematical relationship for slip speed is as follows [5]:

$$S = V - V_p = V - (20.73 \times \omega \times r) \qquad (1)$$

where, S = Slip speed km/h; V = Vehicle speed km/h; V_p = Average peripheral Speed of the tire km/h; ω = Angular velocity of tirthe e, radians /sec; r = Average radius of the tire, cm.

In the state of free tire roll, V_p is equals to vehicle speed and S is zero. For a fully locked wheel, V_p is equals to zero and slip speed is equals to vehicle speed. Slip ratio (SR) can be calculated from Equation 2 [5]:

$$SR = \frac{V - V_p}{V} \times 100 = \frac{S}{V} \times 100 \qquad (2)$$

In another research in the university of Texas A&M, a study is performed on the relationship between wheel slip ratio and hydroplaning. The main finding of this research was that if the level of slip ratio is more than 10%, a considerable reduction in friction will occur and hydroplaning will happen [6].

A review of the present literature did not reveal the existence of any lab-scale apparatus for studying hydroplaning. Most studies are based on field tests and apparatus that are used for testing skid resistance and surface texture in the field [2,7]. For example, NCHRP has introduced outflow meter (ASTM E 2380) which is used for measuring macro texture surface as hydroplaning evaluator apparatus [8]. One of the tire manufacturing companies, designed and invented a lab-scale apparatus with the aim of studying the effects of different tire thread patterns on hydroplaning initiation [9]. The advantage of this apparatus is a simple mechanism in its performance, low cost, the possibility of performing the test in short time and controlled environmental. On the other hand, the performance of the apparatus is contrary to what actually happens in a real situation. In a way that in a real situation, vehicle move in high speed on fluid. While in this apparatus, water move under fixed wheel by high pressure. One of the disadvantages of this apparatus is that the lack of wheel is moving on the surface by different velocities. For this reason, hydroplaning occurrence speed can't be measured.

Another machine called Skid Resistance Interface Testing Machine has been designed and built by TU-Delft University in the framework of the SKIDSAFE project to study the effect of the various phenomena occurring at the tire and pavement interface. This machine enables various combinations of slip velocity and pressure to be applied with concurrent measurement of temperature in the interface regions. With this device, it is also possible to study the raveling resistance of a surfacing material [10].

In another study Hichri et al. are developed a laboratory test method to reproduce the deposit of contaminant particles on the road surface and measure the friction coefficient on dry and wet contaminated surfaces [11].

3. Methodology

In the designed apparatus, which is named AUT Simulator, one wheel with linear suspension system and defined vertical load is connected to a central shaft through a crank, and it moves with an electromotor. Water splash operation performs with a definite pressure to the surface between wheel and asphalt mixture through water nozzle which is mounted in front of the wheel. With the use of a compactor on another crank, asphalt mixture has been compacted. By using a tachometer which is installed on the wheel and central shaft, the slipperiness of wheels and the part of a wheel rolling that is transferred to wheel skid are identified, and the hydroplaning phenomenon is evaluated in different conditions.

One magnetic brake is connected to wheel shaft to apply different friction factor and make negative torsion which has the ability of continuous range operation of brake changes. Also, for the observation of apparatus outputs, the software was used which can show the amounts of wheels revolution per minute (rpm) and central shaft on display machine momently by setting revolution frequency and apparatus speed in definite intervals.

By using AUT simulator, it is possible to compact different asphalt mixtures in the mold and evaluate the impact of pavement surface texture on hydroplaning initiation. Asphalt mixture is compacted in the molds using a similar procedure to ensure a constant mix void ratio and compaction percentage [12].

The number of revolutions is registered by two tachometers momently. By comparing these amounts in dry and wet conditions of the pavement surface, one can predict the occurrence of hydroplaning. In other words, the lack of proportion between a number of wheel rotation and the amount of wheel longitudinal movement is identified as the occurrence of this phenomenon. This is similar to the slide of moving car which doesn't roll its wheel the same amount of space which has moved and some part of rolling has transferred to wheel skid. Also, with designing and manufacturing of this apparatus, different tests can be done for evaluating tire air pressure impact, wheel load and water film thickness on hydroplaning speed. The schematic drawing of the machine is shown in Figure 2.

4. Material and manufacturing process

In this part, designing and manufacturing process of apparatus are described by separating mechanical, electrical, water transfer and asphalt mixture properties.

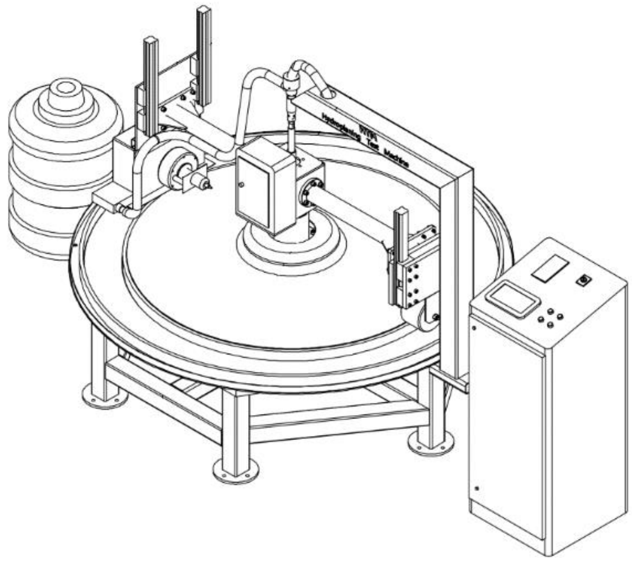

Figure 2. Schematic drawing of the AUT Simulator

4.1.Mechanical parts

The platform that asphalt layer is constructed on has a circular shape. In this structure, there is the possibility of continuous movement on a circular route and this to some extent is the nearest case to the real life situation. In previous apparatuses for assimilating the skid of the wheel, the wheel has been fixed, and fluid crosses under it with pressure [9] or two drams which are connected together, have been used.For ease of pouring and removing asphalt materials from the mold, the aluminum mold was constructed in many segments. A pneumatic tire with 24 cm diameter and 8 cm width was used in this apparatus. Also, to decrease tire thread impact on the hydroplaning phenomenon, a tire without thread has been used. Linear Motion Guide (LM-Guide) suspension was used for smooth circular rotation of the wheel. Mechanical components of the apparatus are shown in Figure 3.

Figure 3. General view of components of apparatus

4.2. Electrical parts

For providing apparatus propellant, one gear electromotor AC has been used. To have a smooth wheel operation at the start and end of the movement and also speed control, one inverter is connected to electromotor which has engine driver role. For connecting electromotor to the central shaft and transferring monotonous speed of the engine to the shaft, timing belt with lateral cogs with high accuracy has been used. In this device for exact rpm counting, the optical rotatory encoder has been used. They produce 2000 ppt in one revolution. Laser line emits on a circular glass plane as black and white continuously, and the rotational speed is identified. For transmitting electronic data, one electronic board has been placed on the apparatus central shaft. A rotary guide was used to establish electrical connections. Since in this device, data frequency from encoder has been high and pulsed to voltage proportion has been low, data is transferred wireless to the board. Microcontroller module that is inside the box acts as receptor and sender. Microcontroller read encoder in two phases and then receive and save them in the module.

4.3. Water transfer

Water nozzle is mounted on the device. For changing the water pressure, one ballast pump is connected to the water reservoir. For controlling water volumetric flow rate in the nozzle, one bypass hose is connected to the pump that can return back the extra water to the on board water reservoir. Water reaches the apparatus central shaft through a flexible hose with a definite pressure. On top of the central shaft, one Rotary Joint is placed which has the responsibility of water supply from the reservoir to the rotating wheel. From another side of Rotary Joint, another flexible tube leads water to a point just in front of the wheel (Figure 4). The front plate of water nozzle pond has the possibility of movement as sliding and exhausting of water with different thicknesses.

Figure 4. Water transfer between tire and asphalt mixture

4.4. Asphalt mixture

For compacting asphalt mixture in the molds, steel compactor has been placed on the other side of the wheel arm symmetrically, as can be seen in Figure 5. To facilitate the movement and making one monotonous surface, there is one suspension system similar to wheel for the compactor. Also, compactor height is changeable with two buckles. When apparatus is performing the test, the compactor is in upper height, and it has no contact with the surface, and when the mixture should be compacted, the compactor is on asphalt mixture and wheel has no connection to surface anymore. All samples were compacted with the same number of wheel rotation to prepare similar samples.

Figure 5. Asphalt mixture compaction

5. Results

Performance grade bitumen PG58-16 was mixed with aggregate to produce asphalt mixtures. The softening point of used bitumen is 51 °C, the penetration at 25°C is 6.8 mm and its ductility is over 100 cm. The aggregate used had a grading in accordance with Iran national code of practice No. 234 as shown in Table 1.

Table 1. The grading used in asphalt samples preparation

Sieve Size	Mix Types		Sieve Size	Mix Types	
	Mix A	Mix B		Mix A	Mix B
	Percent Passing			Percent Passing	
19	-	100	# 16	92.5	-
12.5	-	95	# 30	82.5	-
9.5	-	-	# 50	60	13
# 4	100	59	# 100	30	-
# 8	97.5	43	# 200	14.5	6

To evaluate the introduced apparatus, 2 types of asphalt mixture, namely A and B with different grading are prepared according to national standards and optimum bitumen content.

Asphalt mixture is poured in molds and compactor which is connected to crank machine, compacts asphalt mixture with definite speed and cycle number. Then asphalt mixture texture is measured by sand patch method (ASTM E965). The wheel is on asphalt mixture surface and compactor is fixed at its higher location 10 cm above pavement surface. At first, the test is done in a dry condition of the surface at 15 to 35 Hz frequency with rising steps of 2.5. In each frequency, 150 complete cycle of wheel crosses on asphalt mixture surface. Secondly, the test is done in a wet condition of asphalt mixture surface. Water is sprinkled with specified pressure and thickness of 1 mm between wheel and surface through the nozzle. Similar to the previous mode, wheel and axle rotation in rpm are registered momently. Obtained results for one asphalt mixture with 0.49 mm depth surface texture is presented in Table 2.

Table 2. Tests result in dry and wet conditions in Mix A

Frequency (Hz)	Condition	MTD (mm)	Number of Cycles	Thickness of water film (mm)	Rotation of axle	Rotation of wheel	Ratio
15	Dry	0.49	150	0	29548	171879	5.817
20	Dry	0.49	150	0	34198	199272	5.827
25	Dry	0.49	150	0	49031	285409	5.821
27.5	Dry	0.49	150	0	55411	322989	5.829
30	Dry	0.49	150	0	58727	342262	5.828
32.5	Dry	0.49	150	0	61918	361046	5.831
35	Dry	0.49	150	0	67040	391176	5.835
15	Wet	0.49	150	1	32785	190186	5.801
20	Wet	0.49	150	1	35623	206328	5.792
25	Wet	0.49	150	1	48921	266375	5.445
27.5	Wet	0.49	150	1	55749	299707	5.376
30	Wet	0.49	150	1	58612	314219	5.361
32.5	Wet	0.49	150	1	62073	331966	5.348
35	Wet	0.49	150	1	67052	354638	5.289

As it can be seen in Table 2, in dry surface condition, with an increase of frequency, the shaft rpm ratio to wheel rpm increases slightly so that it can be regarded as constant in different frequencies. In wet conditions of the surface until the frequency of 20 Hz with little difference, almost this ratio is similar to dry surface conditions, but for the frequency of 25 Hz and higher speeds, more differences are observed in this ratio as can be seen in Figure 6. In this case, the surface connection between wheel and surface is slight because of water intercepting and amount of wheel rpm is less than the dry surface mode. In fact, this position is hydroplaning occurrence threshold. Some references call this case partial hydroplaning. When the speed increases, there is not enough time for water to escape from the contact surface between wheel and asphalt mixture and it reduces the wheel contact area with the surface. In the 35 Hz frequency, the ratio of shaft rpm to wheel rpm has been decreased by 10 percent compared with the dry mode.

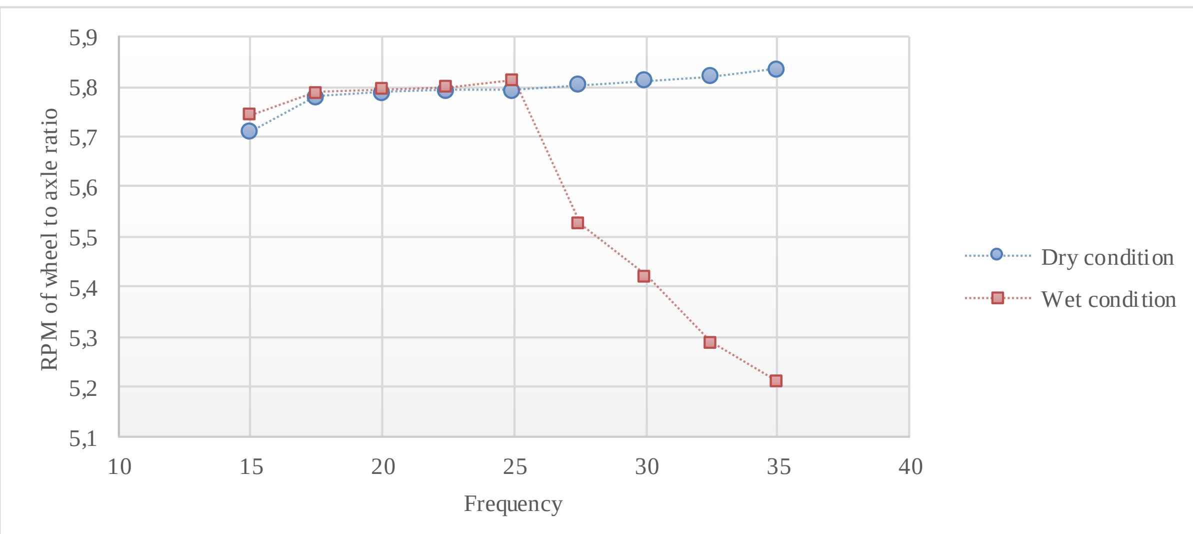

Figure 6. Rotation of wheel to axle ratio in wet and dry conditions

Moreover, rotation of the wheel to axle ratio in wet and dry conditions in Mix B at different frequencies is showed in Figure 6. In this mixture, MTD value is equal to 1.38 mm. The partial transition is observed in this ratio in Mix B up to 30 Hz. But in the frequency of 32.5 Hz, this proportion decreased about 5% in comparison to 30 Hz. Transition in this proportion results from hydroplaning occurrence. Obtained results demonstrated that hydroplaning occurrence potential is declined by increasing pavement surface texture.

6. Conclusion and future work

This paper refers to the process of designing and making new testing apparatus for identifying hydroplaning occurrence. Difference between longitudinal speed and the rotational speed of wheel has been considered as an index for determining the hydroplaning threshold in this apparatus. The result showed that this ratio is a proper index for evaluating a hydroplaning phenomenon. Also, results demonstrated that hydroplaning occurrence potential is declined by increasing pavement surface texture. The designed machine has the following abilities which can be used in future researches to evaluate various parameters affecting this phenomenon.

- The ability of a comparative study for selecting proper grading and a minimum depth of surface texture to be used in asphalt mixtures for better surface draining and improved safety in high speed.
- The possibility of creating different types of asphalt pavements with different texture and materials.
- Evaluating the impact of different tire thread on sliding and hydroplaning.
- Examination of effects of different fluids viscosity on pavement surface on sliding.

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