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Laboratory investigation of the effect of temperature on frictional properties of concrete pavements containing crushed glass

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Abstract

In this research the effect of temperature on skid resistance of concrete pavements has been evaluated. An experimental approach has been used for this purpose and concrete mixtures containing crushed glass as fine aggregate with different surface textures were tested at different temperatures using British Pendulum Tester, so that concrete mixtures containing crushed glass with 3 different surface textures with different patterns of contact surface (smooth, brushed, grooved) were evaluated at temperature range from 0 °C to 50 °C. The optimum amount of crushed glass in concrete mixtures was determined using the compressive strength test and the mixtures produced by virgin lime aggregates were taken as control mixture. The results indicated that the skid resistance of concrete mixtures with brushed surface had the highest amount compared to other surface textures. Crushed glass aggregates had a positive effect on compressive strength, flexural strength and skid resistance of concrete pavements. It was also found that the skid resistance of all mixtures decreased with an increase in temperature.

Keywords: Skid resistance; British Pendulum Test; Concrete pavement; Glassy concrete; Surface texture

1. Introduction

In the last few decades a lot of fatalities and injuries have occurred due to car accidents. Although the majority of these accidents are related to driving faults, highways have a significant effect on this high percentage of traffic accidents. Skidding on wet pavements contributes to 13.5% of fatal and up to 25% of all accidents and a substantial part of the overall highway toll [2]. Skid resistance is the force developed when a tire that is prevented from rotating slides along the pavement surface [7]. In addition to increasing stop distance while breaking, loss of skid resistance reduces steer controllability and affects driver's ability to control vehicle and slippery roads may cause irreparable damages to inexperienced drivers [10]. Thus providing adequate skid resistance is paramount and one of the best ways to reduce skid related accidents.

The objective of constructing pavements is to prepare a smooth and safe surface for vehicles to commute. In recent years concrete pavements have been widely used throughout the world because of its high strength, good service and long durability [4]. However, as the skid resistance of untextured concrete pavement may endanger road safety, providing surface texture is necessary for improving the friction of concrete pavements. There are two primary functions of textures, providing paths for water to escape from beneath the tires of aircraft or other vehicles and

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providing enough sharpness for the tire to break through the residual film remaining after the bulk water has escaped [12]. Therefore, different textures were provided in this study in order to evaluate and compare the skid resistance of concrete pavements with different textures.

Glass is widely used in our lives and each year about 10 million tons of waste and crushed glass is produced in large cities world-wide, which compose about 3–5% of all household wastes [18]. Recycling waste material can save a lot of energy. One of the alternatives of recycling crushed glasses is using them in different sections of industry [6]. Waste glass has been used as aggregate in highway construction in many countries recently [9,14]. Hence, it would be a good idea to use them in concrete pavements. This paper aims to evaluate the frictional properties of concrete pavement containing crushed glass as aggregate.

There are many methods for measuring the skid resistance of surfaces of which British Pendulum is one. This technique involves measuring the force required to drag a non-rotating tire over a wet pavement [3]. The British Pendulum is used in this study as it can measure the frictional properties of surfaces in laboratory scale. The skid resistance is known to be the function of many factors such as tire type, surface porosity, polishing of surface aggregate, tire wear, inflation pressure, vehicle speed, whether the wheel is rolling or locked and whether the pavement is wet or dry. Therefore all the factors must be fixed or clearly defined during measuring skid resistance of surfaces [7,3].

Temperature is one of the factors that affects the frictional properties of road pavements. Researchers have found that the interactions between pavement surface and tires were affected by climate related factors such as temperature and rainfall [5]. Therefore, the effect of temperature on concrete pavements was investigated in this study.

Many researchers have investigated the skid features of different surfaces and the parameters affecting them. LUO [13] investigated the effect of temperature on frictional properties of Hot-Mix asphalt. For this purpose the skid resistance of asphalt surfaces was measured under different environmental conditions. He illustrated that the skid number decreased by increasing temperature of surface at low speed. However, at high speed, the effect was reverted and pavement friction tended to increase by increasing pavement temperature [13]. Khasawneh and Liang [11] investigated the effect of temperature on skid properties of HMA. They showed that the friction of asphalt surface decreased by increasing the temperature. They also introduced a method for agencies who desire to record skid number (SN) at a reference temperature for a long-term monitoring purpose [11]. Wang and Flintsch [17] investigated the frictional properties of asphalt surfaces in terms of temperature and time. For this purpose they studied the surface characteristic of different sections of Virginia Smart Road pavement facility over a 6-year time period. They confirmed that temperature had a significant effect on the seasonal and multi-year variations of pavement surface friction [17]. The effect of pavement temperature on skid properties of HMA pavement surfaces was also investigated by Flintsch et al. (2003). A total of seven HMA surfaces were periodically evaluated using an ASTM skid trailer with both ribbed and smooth tires over two and half years. The analysis showed that pavement temperature had a significant effect on pavement frictional measurements [5,13].

In this study the skid resistance of concrete surfaces containing fine crushed glass and virgin lime stone aggregates was investigated in terms of temperature and surface texture. For this aim a laboratory study has been conducted on 2 different concrete mixtures with 3 different textures (smooth, brushed and grooved). Compressive strength tests were carried out in order to find the optimum amount of crushed glass and British Pendulum Test were conducted in different temperatures from 0 °C to 55 °C to compare the frictional properties of surfaces.

2. Material and methods

The main procedure of this study was divided into three steps. At first different percentages of crushed glass were replaced in concrete mixtures as fine aggregate (from 250 μ to 600 μ) in order to find the optimum amount of crushed glass. The optimum amount of crushed glass was chosen based upon the maximum compressive strength of concrete which was carried out in accordance with ASTM C39 [6]. After the optimum amount of crushed glass in mixtures had been chosen, compressive strength and flexural strength tests were conducted for all of the specimens at the end of 1th, 3rd, 7th, 28th and 90th days of moist curing. After that British Pendulum Test was conducted to compare the frictional properties of concrete surfaces with different textures and at different temperatures.

Crushed limestone was provided from quarries around Tello (located in north east of Tehran) which are mainly used for highway construction. In order to find out the properties of limestone aggregates, specific gravity (ASTM C127-07, ASTM C128-12), Los Angeles abrasion resistance test (ASTM C131-12) and water absorption test (ASTM C127-12) were conducted on limestone aggregates. Crushed glasses were obtained from Rashid recycling company of Tehran and the physical properties of crushed glass and limestone aggregates (LA) are shown in Table 1. Both types of aggregates met the grading requirements of ASTM

Table 1
Physical properties of crushed glass and LA aggregates.

Physical properties	Lime aggregate	Crushed glass
Specific gravity (fine agg.)	3.87	2.54
Water absorption	0.4	0.34
Specific gravity (coarse agg.)	2.63	-
Los Angeles abrasion (%)	24.1	-

C 33 for concrete pavements and the midline gradations of the aggregates used in the mix design are presented in Figs. 1 and 2.

Standard Type 1 Portland cement provided from Abyek Cement Company was used for the laboratory production of the specimens. The cement satisfies the requirement of IS: 8112–1989. The specific gravity was 3.11 and fineness was 2940 cm^2/g.

The mix proportions and fresh properties of the concrete mixtures are summarized in Table 2.

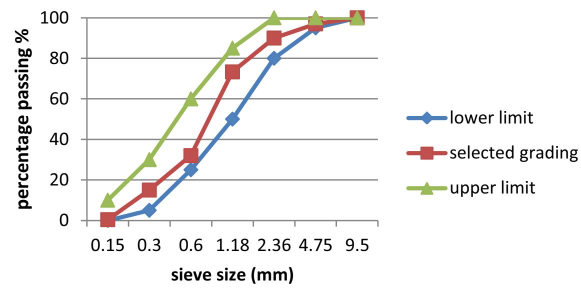

Fig. 2. Gradation of designed fine aggregates.

2.1. Sample preparation

At first 24 specimens with 4 different percentages of crushed glass were made to conduct the compressive strength of specimens at 3 and 7 days of curing. Having found the optimum content of crushed glass in concrete mixtures, 30 specimens (3 specimens for each test) of size 15 × 15 × 15 cm were prepared in order to determine the compressive strength of concrete with and without crushed glass at 1, 3, 7, 28 and 90 days of curing. Then 18 beams of size 70 × 15 × 15 cm were prepared in order to carry out flexural strength test for both concrete gradations. The major samples for BPT were made and cured for 28 days with 3 different textures (smooth, brushed and grooved) for both concrete and concrete containing crushed glass mixtures. Grooves were done with depth and width of 3 mm and spacing of 12 mm [4]. Fig 3 shows the surface textures of specimens.

2.2. Testing program and discussion

2.2.1. Compressive strength test

The results of compressive strength tests for mixtures containing different percentages of crushed glass are presented in Fig. 4. It should be noted that the results are an average of 3 specimens and the error bars are provided. As it is shown in Fig. 4, the compressive strength of mixtures increased by replacing up to 10% of crushed glass with lime aggregates and then it fell. Thus, the optimum amount of crushed glass in mixtures would be 10%. It should be noted that previous studies [16,8] have also investigated the optimum amount of crushed glass in concrete mixtures using compressive strength which have led to different results of optimum crushed glass contents

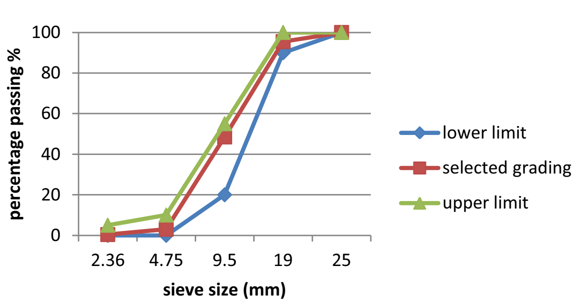

Fig. 1. Gradation of designed coarse aggregates.

from 15% to 20%. Moreover, in another research [1], two peaks of compressive strength are resulted by increasing the amount of crushed glass. The reason of these differences is that the optimum amount of crushed glass depends on different factors such as aggregate gradation, crushed glass physical properties, etc., which were different in these studies.

Fig. 5 presents the results of compressive strength tests for both mixtures (ordinary concrete mixtures and mixtures made with optimum amount of crushed glass) at 1th, 3th, 7th, 28th and 90th days from the day of casting. All of the mixtures met the minimum requirements according to ASTM C 33. It was also seen that adding crushed glass as fine aggregates resulted in a slight increase in compressive strength.

A one-way analysis of variance (ANOVA) was performed using Minitab software to check the significance of the effect of crushed glass on the compressive strength. The compressive strength was considered as the dependent variable, and the fixed factor considered was crushed glass content. The results of one-way ANOVA are presented in Table 3. *P*-value indicates the significance of the coefficients. The less the *p*-value (<0.05), the more the level of significance will be. The error bars are also provided using standard deviation of 3 repetitions. Statistical analysis shows that the crushed glass significantly affects the compressive strength of mixtures, and the differences are meaningful. The Tukey method was also performed to rank the results with 95% confidence. The results which are shown in Table 4 indicate that the specimens with 10% crushed glass have the highest compressive strength among others.

2.2.2. Flexural strength test

Flexural strength is often used to evaluate the tensile strength of concrete mixtures and also is known to be a criterion for designing concrete pavements. It is a measure of an unforced concrete beam or slab to resist failure in bending. It is measured by loading 150–150 mm concrete beams with a span length at least three times of the depth [15]. Flexural tests were conducted on concrete beams at 7th, 28th and 90th days from the day of casting according to IS 516:1959. The flexural test results are indicated in Fig. 6. As shown in Fig. 6 the specimens containing 10% crushed glass had more flexural strength

Table 2
Concrete mixtures proportions.

Unit weight, kg/m^3	Fine aggregates, kg/m^3	Coarse aggregate, kg/m^3	Slump, mm	Cement, kg/m^3	w/cm
2375	676	1109	50	380	0.475

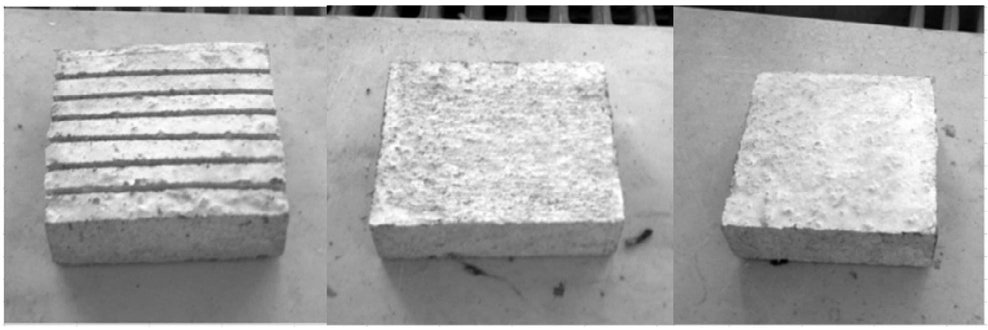

Fig. 3. Grooved, brushed and smooth concrete surfaces.

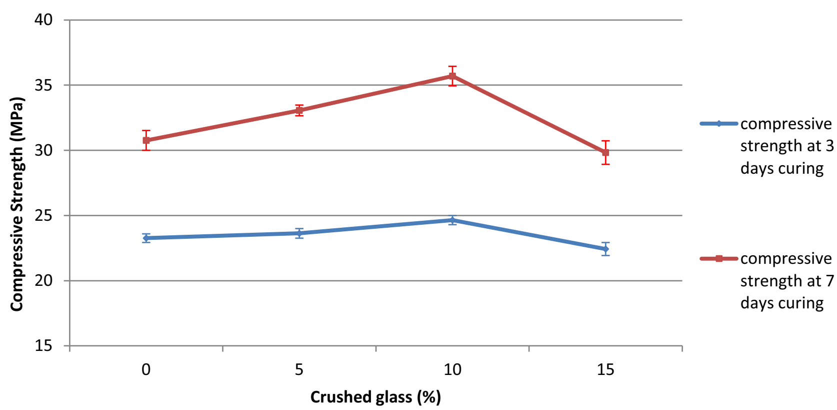

Fig. 4. Compressive strength of concrete containing different percentages of crushed glass.

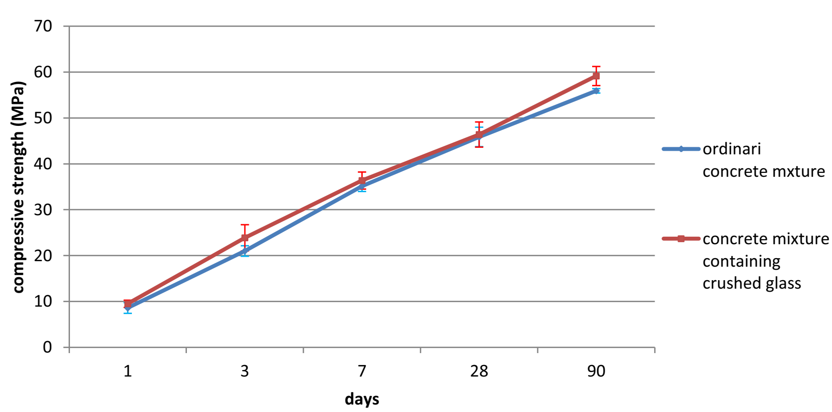

Fig. 5. compressive strength of concrete mixtures at 1st, 3rd, 7th, 28th and 90th days.

than concrete specimens made with 100% lime aggregates. It was also concluded that the ability of concrete mixtures to resist flexural failure enhanced by increasing the curing time.

2.2.3. Skid resistance measurements

The British Pendulum, which is one of the most common methods of measuring the friction of surfaces, was used in this research. The British Pendulum Tester is a

Table 3
One way ANOVA: compressive strength versus crushed glass (%).

	Source	DF	Adj SS	Adj MS	F-value	P-value
3 day curing	Source	DF	Adj SS	Adj MS	F-value	P-value
	Crushed glass (%)	3	3.903	1.3008	4.77	0.034
	Error	8	2.18	0.2725		
	Total	11	6.082			
7 day curing	Source	DF	Adj SS	Adj MS	F-value	P-value
	Crushed glass (%)	3	61.729	20.5764	25.88	0.000
	Error	8	6.36	0.795		
	Total	11	68.089			

Note: DF, degrees of freedom; MS, mean square; SS, sum of the squares.

Table 4
Grouping information using the Tukey method and 95% confidence.

	Crushed glass (%)	N	Mean	Grouping
3 day curing	10	3	24.567	A
	5	3	23.767	A B
	0	3	23.267	A B
	15	3	23.1	B
7 day curing	10	3	35.7	A
	5	3	33.067	B
	0	3	30.767	B C
	15	3	29.833	C

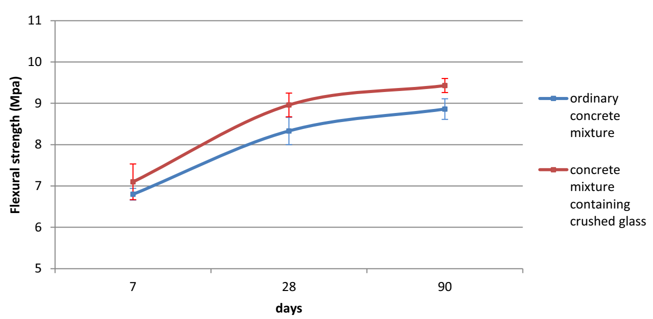

Fig. 6. Flexural strength of concrete mixtures at 7th, 28th and 90th days.

dynamic pendulum impact type tester which is based on the energy loss occurring when a standard rubber slider that is positioned to barely come in contact with the test surface rubber is propelled across a test surface [3] British Pendulum is used for the determination of low-speed microtexture-related skid resistance (British Pendulum Number, BPN) of pavement surface materials. The skidding of 2 mixtures (with and without crushed glass) with 3 different textures (smooth, brushed and grooved) was measured in different directions at different temperatures ranging from 0 °C to 55 °C. The tire slider of pendulum and 28 days cured specimens had been placed at target temperature for 24 h before testing. An infrared thermometer was used to measure the temperature of surface continuously in order to increase the accuracy of testing. The results of skidding tests are shown in Fig. 7. As shown in the Fig. 7, the surfaces that belonged to glassy mixtures showed more resistance against skidding. In other words, replacing crushed glass increased the skid resistance of concrete surfaces by about nine percent. It would be because of the toughness of crushed glass aggregates which affected the pavements microtexture.

Figs. 8–10 represent the BPN results for different textures at temperature range from 0 °C to 60 °C. The results indicated that the skid resistance of concrete surfaces fell in an almost constant rate by increasing the temperature. It could be because of the less viscosity of surface water which decreases by increasing temperature [19]. It can be inferred from the results of Figs. 8–10 that the slope of the friction-temperature relation did not change substantially by adding crushed glass into the mixtures. The reason was that changing temperature mainly affected the tire slider and the water on the surface, and its effect on concrete was little. Therefore, although adding crushed glass increased the friction of the concrete surface, it did not affect the friction-temperature relation slope.

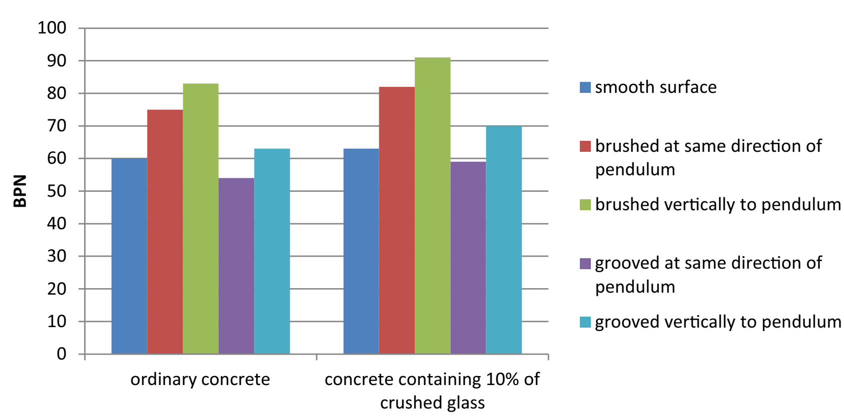

Fig. 7. The BPT results at 20 °C.

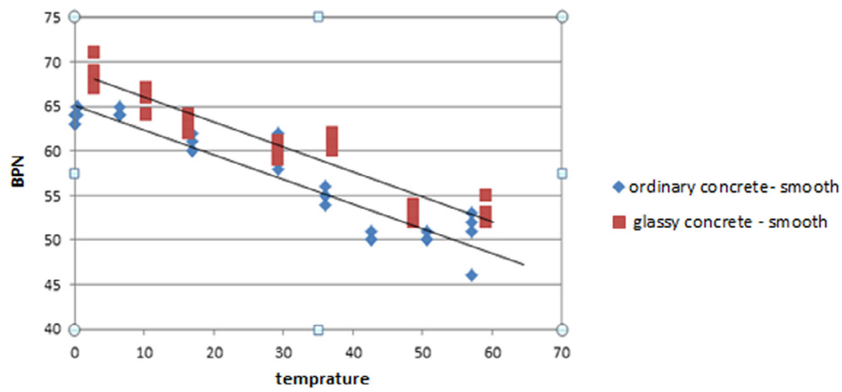

Fig. 8. The BPT results at different temperatures for smooth surfaces.

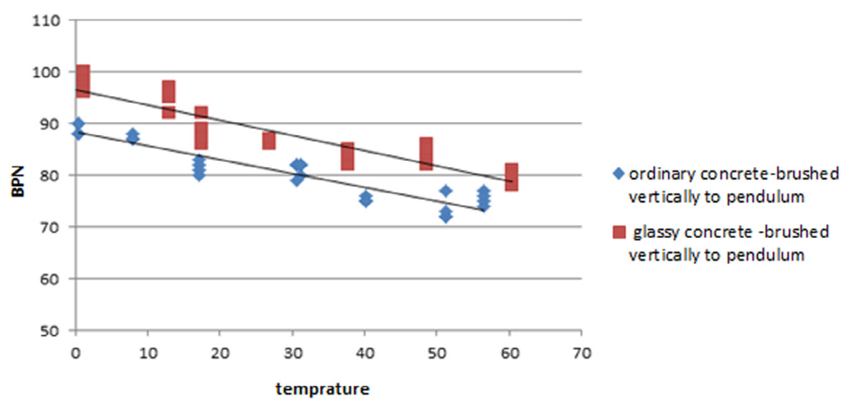

Fig. 9. The BPT results at different temperatures for brushed surfaces placed vertically to pendulum.

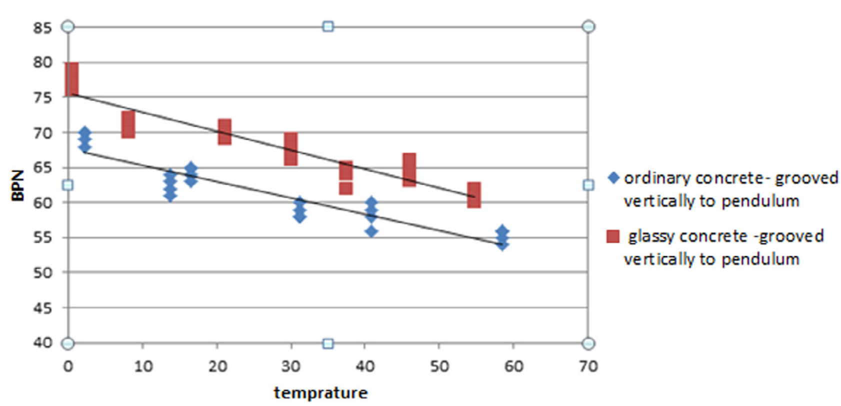

Fig. 10. The BPT results at different temperatures for grooved surfaces placed vertically to pendulum.

The results also showed that brushed surfaces had higher resistance to skidding than grooved surfaces. However, the skid resistance is dependent on grooving depth, width and space and the number of grooves the tire is in touch with, which can influence the BPN. Therefore, before making decision about the best texturing method, it is needed to study the skid resistance of surfaces with different grooving depth, width and spacing and other texturing methods such as diamond ground surfaces. Moreover, as the tire slider of British pendulum is much smaller than real tires, full scale tests are also recommended.

The direction of brushing and grooving had a substantial effect on the skidding and surfaces as well. The surfaces, on which brushing direction had been placed vertically to the direction of pendulum, had much more resistance to skidding than the surfaces that were placed at the same direction of pendulum.

3. Conclusions

This study investigated the effect of temperature, surface textures and fine crushed glass aggregates on skid resistance of concrete pavements. According to the findings of the experimental results, the following main conclusions can be drawn:

- According to compressive strength test results, replacing up to 10% of fine crushed glass by weight of total aggregates led to an enhancement in compressive strength of mixtures. The compressive strength fell substantially by adding more than 10% of crushed glass. However, the optimum amount of crushed glass might change for mixtures with different gradation and aggregate type.
- The flexural strength test results agreed with the compressive strength results and there was a slow rise in flexural strength by adding 10% of crushed glass in mixtures.
- Regarding the limited investigation in this study, addition of crushed glass leads to increase in frictional resistance of concrete pavements. Therefore, it can be considered as a skid resistant alternative for use in highways and intersections. However, more investigations such as resistance to polishing and full scale performance are needed.
- Temperature had a significant effect on skid resistance of concrete pavements. Briefly, the skid resistance of all mixtures fell by increasing temperature.
- Brushed surfaces had the highest amount of BPN among grooved and smooth surfaces. The direction of brushing was also important and it was more effective when done vertically to pendulum tire. However, more investigations are needed to evaluate the skid resistance of other surfaces such as diamond ground surfaces and grooved surfaces with different depths, width and spaces.

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