J. Innovative Eng. Nat. Sci., vol. 2, no. 2, pp. 66-75, 2022.
http://dx.doi.org/10.29228/JIENS.62559

Original Paper

Journal of Innovative Engineering and Natural Science
(Yenilikçi Mühendislik ve Doğa Bilimleri Dergisi)
journal homepage: https://jiens.org

Investigation Friction Loss of Concrete Pavement Surface with a New Method

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ARTICLE INFO

Article history:
Received 05 June 2022
Received in revised form 14 June 2022
Accepted 20 July 2022

Available online

Keywords:
Concrete Pavement
Fine Aggregate
Abrasion Resistance
Fineness Modulus
Polishing
Friction Coefficient
Friction Loss

ABSTRACT

In this study, the effect of abrasion resistance and fineness modulus of the fine aggregates in the concrete mixture was investigated to determine the friction coefficient loss. Nine concrete mixtures samples were obtained by using three different gradations and fine aggregates with three different Los Angeles (LA) wear resistance. A new accelerated polishing test method was conducted in a laboratory. In the new method, unlike other wheel polishing methods, a constant horizontal friction force was formed alongside the vertical pressure of the wheel contact area. The wet friction coefficients of the concrete surfaces were measured by the British Friction Pendulum. Test results showed that the most friction loss occurred in the fine aggregated concrete mixtures obtained from limestone with the lowest wear resistance, while the least loss values were obtained for basalt with high abrasion resistance.

I. INTRODUCTION

Maintaining sufficient coarse texture and providing resistance to polishing is essential for ensuring adequate slip resistance on road surfaces. Macro texture, which is provided by coarse aggregate grains or tinning, increases friction by creating gaps that allow water to escape water from the contact interface between the surface and tires of vehicles traveling at high speeds in wet weather conditions. On the other hand, micro textures of aggregates or concrete surfaces are very critical for providing a dry contact area between the wheel and the road surface by breaking up the final water film remaining in the contact interface in all speed situations [1]. Increasing resistance to polishing depends on the magnitude of the resistance to abrasion of these small protrusions or the formation of new protrusions by harder parts because of the abrasion of less rigid parts [2]. Since the polished surfaces are prone to slip problems, the friction coefficient value of the pavement surface decreases significantly especially during rainy weather conditions [3-4]. As the polished road gets wet, the braking distances of vehicles can be quite prolonged. The speed of polishing is directly related to traffic density. Especially, heavy tonnage vehicles can play a significant role in polishing due to their large vertical and horizontal forces. Therefore, the resistance of the road surface materials to polishing is much more important where commercial vehicle traffic is high and in the road sections where vehicles move with great accelerations [5].

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Fine aggregates (0-4 mm) in a concrete structure can play a significant role to connect the coarse aggregates by helping cement material and they can also provide impermeability via filling the gaps. Fine aggregate properties in the mixture directly affect the friction coefficient of the surface for concrete roads [6-8]. Shape, fineness modules, amount, and mineralogical structure of fine aggregates have a significant effect on the surface properties of the concrete road. Usually, limestone is used in concretes as a mineral material. However, limestone is composed of calcite minerals that have a high tendency to polish, therefore, it is important to determine the effects of using fine aggregates with hard mineral content instead of limestone for the surface properties of concrete roads. There are, however, limited accepted laboratory test methods in the literature to determine the effects of the wheels on the polishing of the concrete surface. One of the methods is the Polished Stone Value (PSV) method developed for aggregates by Transport Research Laboratory (TRL) in the 1950s [9]. In this method, only vertical pressure is used on the contact surface. However, in the real environment, the vehicle wheel applies horizontal friction forces to the protrusions on the road surface as well as vertical pressure. Therefore, in this research study, some new design techniques have been introduced and new test equipment issued for the tests [10]. In this way, the rubber wheel, freely rotating on the standard PSV test machine, has been redesigned to rotate with constant partial braking without locking. Vertical weight is increased, and then a new test drum and new sample molds in the same diameters are manufactured. In the tests, while fine aggregate properties in concretes are changed, other material properties in the concrete remain the same. Test results showed that the most friction loss occurred in the fine aggregated concrete mixtures obtained from limestone with the lowest wear resistance, while the least loss values were obtained for basalt with high abrasion resistance.

II. EXPERIMENTAL METHOD / TEORETICAL METHOD

2.1 Materials

CEM I 42.5N was used in the concrete mixtures for this study. The cement properties are given in Table 1. As seen, limestone is used as coarse aggregate and limestone, 50% of limestone+ 50% of basalt, and basalt is used as fine aggregates. The properties of materials determined by the gravity and Los Angles tests are provided in Table 2. The maximum limit of the Los Angeles abrasion percentage of wear layer aggregate of a road is suggested as 30% by the General Directorate of Highways of Turkey in Road Technical Specification [11]. The wear resistance of the aggregates used in the tests was defined within the specification limits [12]. The gradations of the aggregates used in the mixtures are shown in Table 3. As seen, the aggregate materials contain 57% coarse aggregates, and 43% fine in volume.

Table 1. Physical and chemical properties of normal portland cement (CEM I 42.5N)

Physical and mechanical properties		Chemical Analysis	(%)
Specific gravity (g/cm³)	3.15	SiO_2	20.06
Specific surface (cm²/g)	3410.0	Al_2O_3	5.16
Retained by 200 microns in the sieve (%)	3.1	Fe_2O_3	3.16
Compressive strength (MPa), 2 days	24.5	CaO	62.43
Compressive strength (MPa), 7 days	42.0	MgO	2.82
Compressive strength (MPa), 28 days	44.4	SO_3	2.32
		K_2O	0.6
		TiO_2	0.2
		NaO_2	0.36
		Sulfur	0.17
		Chlorine	0.04
		Ignition loss	1.55
		Insoluble residue	1.05

Table 2. Properties of coarse and fine aggregate

Characteristics	Standards	Limestone		%50 Limestone + %50 Basalt	Basalt
		Course	Fine	Fine	Fine
Dry Unit Weight, (gr/cm³)	ASTM C-127	2.70	2.57	2.69	2.98
Saturated Unit Weight, (gr/cm³)	ASTM C-128	2.72	2.63	2.75	3.02
Natural Unit Weight, (gr/cm³)	ASTM C-127	2.702	2.58	2.72	3.01
Water Absorption, (%)	ASTM C-131	0.74	2.33	2.06	1.45
Water Content, (%)		0.1	0.4	1.20	1.03
Abrasion Ratio, (%) (Los Angeles)		28.5	33.1	27.8	21.3

Table 3. Gradations of aggregates used in the mixtures

Sieve size(mm)	Aggregate Types Passing (%)		
	A	B	C
16	100	100	100
8	73	73	73
4	41.7	41.7	41.7
2	31.27	27.10	20.85
1	22.93	16.68	8.34
0.5	14.60	8.34	4.17
0.25	6.25	2.09	2.09
Pan	0	0	0
Fineness modulus of finer aggregate	2.2	2.7	3.15

The concrete samples used for the accelerated polishing tests had a thickness of 100 mm in the radial direction. The roll sanding paper with an average macro roughness (texture) of 0.8 mm, which is determined by the sand patch method [13], was glued into a continuous strip on the inner surfaces of the molds to roughen the concrete specimen surfaces. After removing the mold the appearance of the rough surface of the concrete sample showed that the surface had cement mortar that contained more fine aggregate grains than the coarse aggregate.

2.2 Accelerated Polishing Test Method

A new test design model was prepared for this study [10] (Fig. 1 (A)). Illustrates the test machine developed for accelerated polishing. In this new design, the rubber wheel that makes the polishing can be rotated with adjustable partial braking without blocking. It is an electric motor that provides movement of the test machine. Firstly, the motor rotates the drum on which concrete samples are placed and then the rubber wheel with a 200 mm (8-inch) diameter, which presses on the circular surface of the 400 mm (16-inch) diameter formed by the concrete samples, also rotates a gear oil pump whose outlet pressure is set (Fig. 1 (B)) . Thus, in the contact area of the wheel that turns the pump, the frictional stress can be adjusted. The mechanical oil, which is fed from a tank and heated during the passage through the pump, is cooled by passing the temperature through radiators in constant water. The pressure limit valve at the pump outlet also compensates for the oil pressure.

In order to measure the applied on the surface of the concrete samples, a 3 mm diameter load cell was placed inside the sample as shown in Fig 1 (C). To achieve this, a rectangular prism-shaped plastic piece was glued vertically into the mold. A tube with an inner diameter of 3mm was fixed between the curved surface of the mold and this prism. 24 hours later, the mold was opened and the sample was taken out and cured in the water tank for a week. The plastic piece with one end narrower than the other was removed without damaging the concrete sample. The obtained sample with a hollow hole in the middle was cured for one month to increase its compressive strength. The load cell was adhered to this cavity so that the measuring surface coincides with the tunnel opened to the surface. The length of the pin in between was adjusted so that it does not protrude on the surface and is tangential to the surface.

First, the vertical load was adjusted by hanging a weight on the end of the arm so that the pressure value at the peak point was 10 kg/cm². Then, as it passed over the measuring point, the wheel was turned at small fixed intervals of 3 mm, which was one-fifth of the 45 mm contact length. Load values were measured at each stop. By calculating the average compressive stresses, all the compressive stresses of the bell curve were obtained in a realistic way.

Figure 1. Test setup **(a)** accelerated polishing test machine setup, **(b)** mold and small tire **(c)** vertical pressure cell inside the sample

In this study, the maximum vertical pressure was taken as 10 kg/cm² considering the heavy vehicle load [14,15]. The average friction stress between the wheel and concrete surface was 1 kg/cm². No abrasive dust or water was applied to the contact interface during the experiment. To prevent the rubber wheel from overheating, the system was run in four-minute periods and the temperature of the rubber was reduced by blowing cold air for 20 minutes. Final polishing was achieved by 100000 drum cycles.

2.3 Method of Friction Coefficient Measurement

Friction coefficients were measured for different wheel transition numbers which are zero, thousand, five thousand, twenty-five thousand, and one hundred thousand. The wet friction coefficient measurements were performed using the British Friction Pendulum with 27 specimens (3 replicates) [16]. A narrow tire friction mount was used in the tests. When the desired number of repeats was reached, five measurements were taken from each sample surface by wetting each time, and the average of the last three measurements was recorded as the result.

III. RESULTS AND DISCUSSIONS

The lowest values of compressive strengths between 62-62.5 MPa were observed in fine aggregate concretes with fineness modules of 2.2. However, the highest values between 65.6-66.0 MPa were seen for concretes with fineness modules of 3.15. As the fineness modulus value of the fine aggregate increased, the compressive strength also increased by 5% to 6.3% in all fine aggregate types. As a result of the hardening test, no change in the macro texture of the concrete surface was observed. Fine-grained aggregate grains emerged because the low strength cement mortar was more prone to wearing (Fig. 2 (A)). Additionally, it can be seen from Figure 2 (B) that the show up of very fine aggregate grains with the wearing cement mortar.

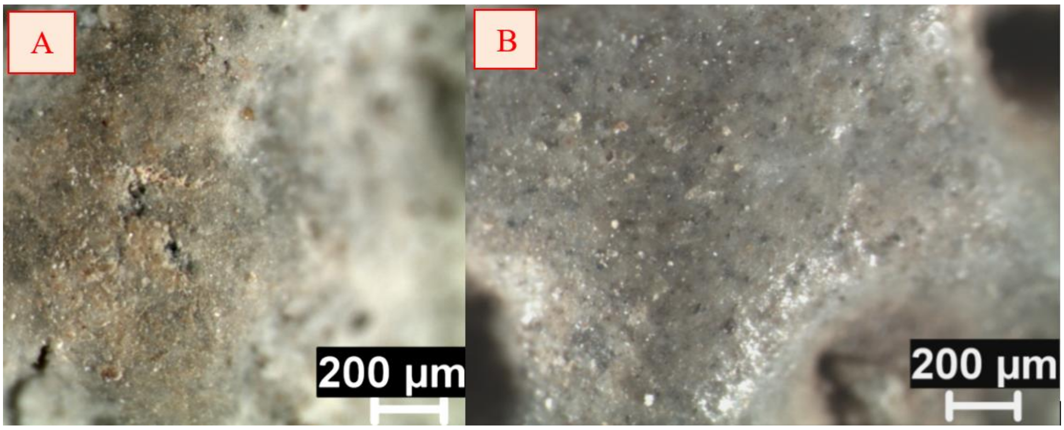

Figure 2. Scanning Electron Microscopy (SEM) pictures; **a.** image of a protrusion on the surface of the concrete specimen before polishing, **b.** image of a projection on the surface because of the polishing process

Variation of friction coefficient in limestone and fine aggregate mixtures is shown in Figure 3. Sample 23 refers to 3rd specimen representing the limestone fine aggregate concrete (C2) with a fineness of 2.7. In general, the wet friction coefficient of the concrete surface decreased as the number of wheel crossings increased. The coefficient of friction decreased rapidly after the first 5000 repetitions. The rate of friction loss decreased considerably in the pickling phase after 5000 repetitions. No significant difference was observed in decreasing friction behavior of limestone aggregates. It can be seen that different fineness module values do not make any difference in the polishing behavior of concrete samples containing limestone. Explanation of samples mixture used in the tests is given at Table 4. The friction loss in limestone and basalt mix concrete samples was lower in three concrete specimens with a fineness modulus of 3.15 (Fig. 4). Additionally, it can be observed that the fineness module has an impact on polishing behavior. However, as for the concrete samples with basalt aggregates, the fineness module did not affect the polishing behavior as much as limestone aggregates.

Table 4. Explanation of samples mixture used in the tests

Samp.	Explain	Samp.	Explain
11	Limestone and Fine Agg. Mix 1 Samp. 1	41	Limestone- Bazalt/fine Mix 4 Samp.1
12	Limestone and Fine Agg. Mix 1 Samp. 2	42	Limestone - Bazalt/fine Mix 4 Samp.2
13	Limestone and Fine Agg. Mix 1 Samp. 3	43	Limestone - Bazalt/fine Mix 4 Samp.3
21	Limestone and Fine Agg. Mix 2 Samp. 1	51	Limestone - Bazalt/fine Mix 5 Samp.1
22	Limestone and Fine Agg. Mix 2 Samp. 2	52	Limestone - Bazalt/fine Mix 5 Samp.2
23	Limestone and Fine Agg. Mix 2 Samp. 3	53	Limestone - Bazalt/fine Mix 5 Samp.3
31	Limestone and Fine Agg. Mix 3 Samp. 1	61	Limestone - Bazalt/fine Mix 6 Samp.1
32	Limestone and Fine Agg. Mix 3 Samp. 2	62	Limestone - Bazalt/fine Mix 6 Samp.2
33	Limestone and Fine Agg. Mix 3 Samp. 3	63	Limestone - Bazalt/fine Mix 6 Samp.3
71	Mixtures with the fineness modulus of 2.2	91	Mixtures with fineness modules of 3.15

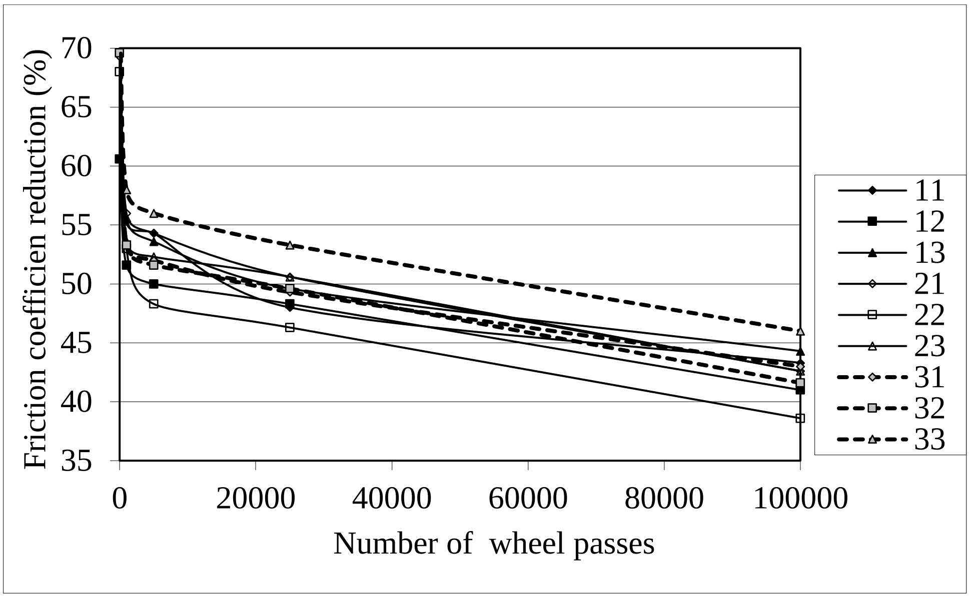

Figure 3. Variation of friction coefficient in limestone and fine aggregate mixtures

The effect of abrasion resistance for fine aggregate on the polishing behavior is demonstrated in Figure 5. The friction loss rate of concretes with the fineness modules of 2.2 was significantly less for basalt fine aggregates. The difference was more pronounced after 25000 repetitions of passing. Therefore, it can be said that the use of fine aggregates with fine abrasion resistance in fine aggregates having a modulus of 2.2 improves the polishing behavior of the concrete surface. Furthermore, the friction loss rate of three samples with basalt aggregates, which have the best abrasion resistance, was significantly lower than the others. Thus, it can be concluded that the use of fine aggregates with high abrasion resistance also affects the polishing behavior of the concrete surface as it is in the 2.2 fineness module.

As for the concretes with fineness module of 3.15, the friction loss rate for the three samples was significantly lower than the other fine aggregate types (Fig. 6). So, the same determination can be made in the results of the polishing of the concrete with a limestone-basalt mixture of various fineness modulus.

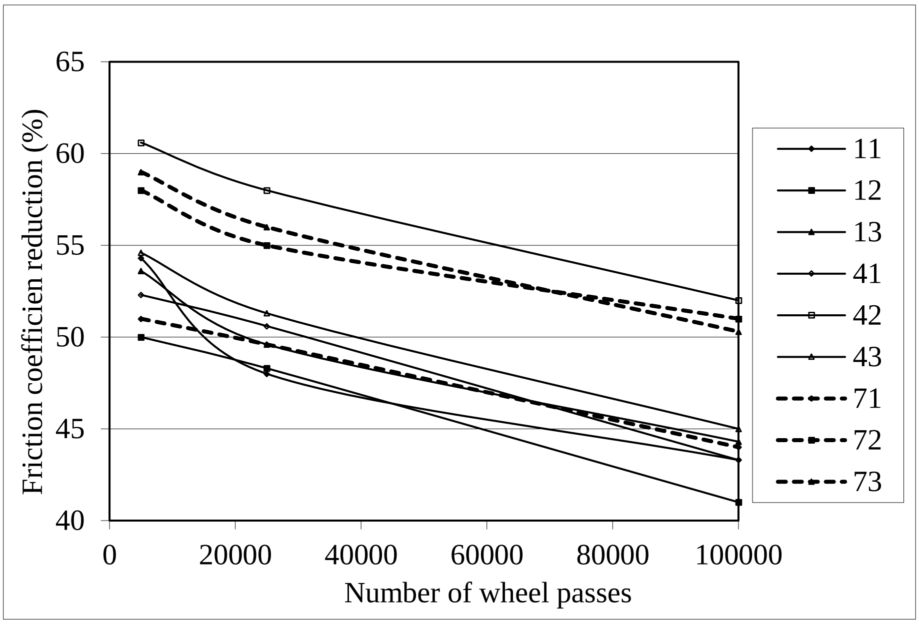

Figure 5. Variation of friction coefficient for mixtures with the fineness modulus of 2.2

The loss of friction decreases as the fine aggregate fineness module increases. Additionally, the least friction loss was observed for samples 61, 62, and 63, which were limestone and basalt mixture samples with the fineness modulus of 3.15. When the result is compared with the literature, similar results were found by a study conducted by Fwa and Tan [8]. In their study, it was reported that the aggregate surface consisted of minerals with different hardness positively affects the friction.

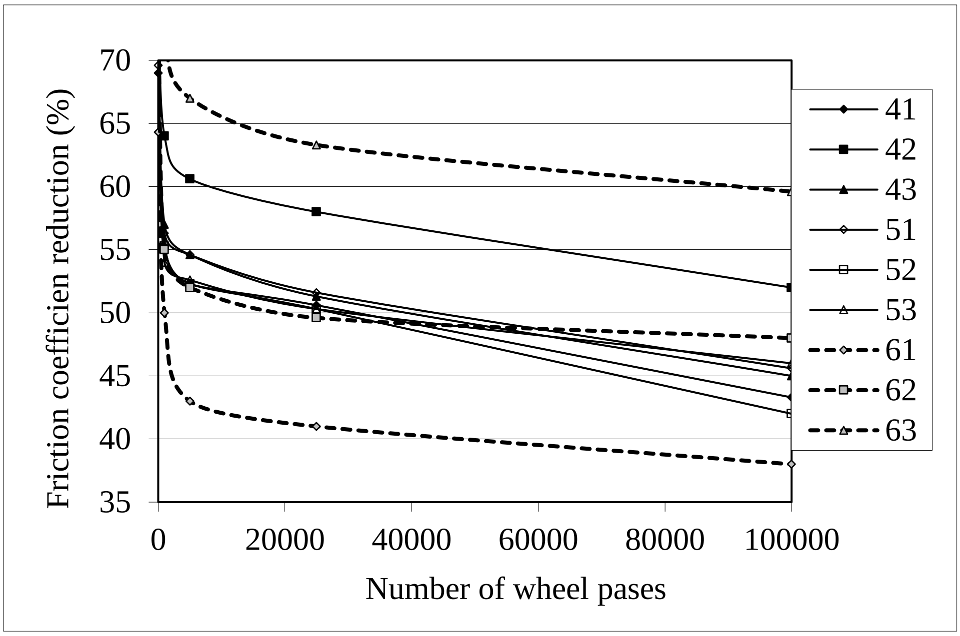

Figure 4. Variation of friction coefficient in limestone, basalt, and fine aggregate mixtures

The results that obtained in this study are compared with the other studies in the literature; In general, it has been seen that abrasion resistance and pressure resistance show different changes according to the type of material used for the change of fineness modulus. Concrete samples with different fineness modulus values were produced using the manufactured sand in a study conducted in 2010, and the pressure and abrasion resistance values were compared. It has been found that increasing the amount of fine material from 4.3% to 20% increases the amount of pressure and improves the wear resistance [17]. In the study conducted by Singh and Siddique in 2015, the fineness modulus was reduced to 1.97 with the coal bottom ash added to the concrete, but no significant change was detected in the compressive strength. However, lower abrasion resistance was observed in the samples with reduced fineness modulus with the addition of coal bottom ash [18]. In a study completed in 2021, concrete was produced in which silica fume (SF), marble slurry powder (MSP), and fly ash was used in certain proportions to produce concrete with high strength values, and as this ratio increased, the fineness value of the obtained samples increased. It has been determined that its strength and wear resistance remain at acceptable rates [19]. The results of this study, as in the studies, showed that the wear results remained within the appropriate values according to the American Society for Testing and Materials [20,21].

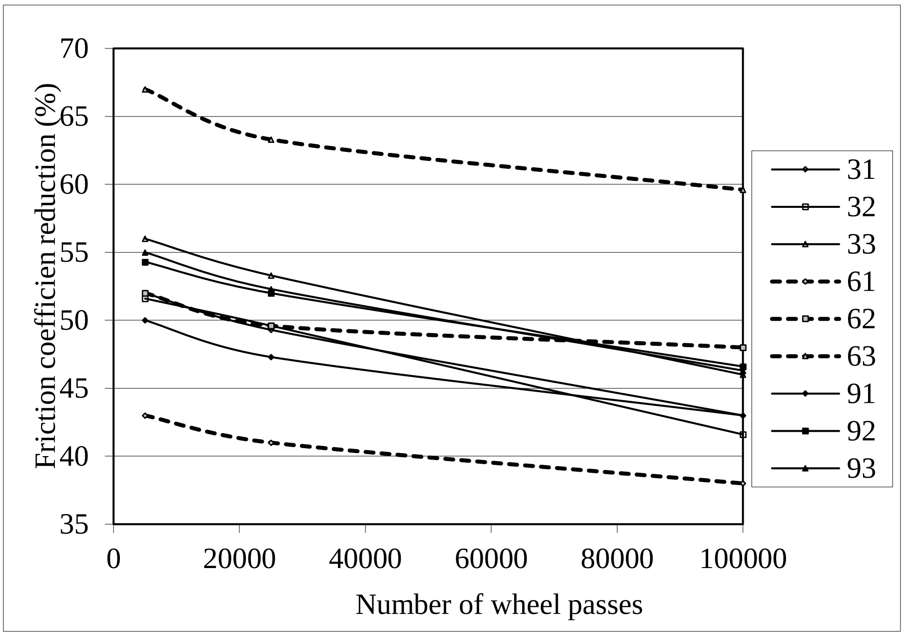

Figure 6. Variation of friction coefficient for mixtures with fineness modules of 3.15

IV. CONCLUSIONS

In this study, the effect of the fineness modulus and abrasion resistance of the fine aggregate in the concrete mixture on the friction coefficient of the road surface were investigated. In the study, the frictions between the wheel and the pavement were examined with a distinctive method, and its usability for future studies was determined. The following results were obtained from the experimental study:

1. Generally, as the fineness module of the fine aggregate increases, the compressive strength increases slightly. However, no significant change in the compressive strength for different fine aggregate types was observed. When the results were examined, similar results were seen in the studies conducted by Fwa and Tan. Accordingly, hard aggregates with high wear resistance have a low tendency to polish [8].
2. The maximum friction coefficient loss was observed for fine aggregate concrete samples containing limestone fine aggregates by considering all fineness module values. Donza et al. In their study, they reached similar results in the case of using fine aggregates [22]
3. While the friction loss in the basalt fine aggregated concrete with a fineness module of 2.7 was considerably lower, the least friction loss percentage in all concretes was obtained for the mixture containing 50% basalt and 50% limestone with a fineness module of 3.15.

REFERENCES

[1] Taneerananon, P. & Yandell, W.O. (1981) Microtexture roughness effect on predicted road–tire friction in wet conditions. *Wear*, 69(3), 321–337 https://doi.org/10.1016/0043-1648(81)90322-7

[2] Person, B.N.J., Albohr, O., Tartaglino, U., Volokitin, A.I. &Tosatti, E. (2005) On the nature of surface roughness with application to contact mechanics, sealing, rubber friction, and adhesion. *Journal of Physics Condensed Matter*, 17(1):R1-R62 https://doi.org/10.1088/0953-8984/17/1/R01

[3] David, A., Kuemmel, R.C., Sontag, J.A., Crovetti, Y.B., John, R.J. & Allex, S. (2000) Noise and Texture on PCC Pavements. Final report multi-state study, Wisconsin Department of Transportation Kinsman Blvd., Madison, Report Number WI/SPR-08-99.

[4] Thillainath, C., Peter, S., Manu, G.S., & Tim, S. (2003) Developing a Design Policy to Improve Pavement Surface Characteristics. Transportation Research Board 82th Annual Meeting, National Research Council, Washington D.C.

[5] Todd E.H., Kurt, D.S., Roger M.L., & Mark E. S. (2003) Current Practice of PCC Pavement Texturing. Transportation Research Board 82th Annual Meeting, National Research Council, Washington D.C.

[6] Henry, J.J. (2000) Eval[]uation of Pavement Friction Characteristics. NCHRP Synthesis 291 Transportation Research Board, Washington D.C.

[7] Hall, J.W. (2009) Guide For Pavement Friction. NCHRP Project 1-43, Transportation Sector of Applied Research Associates (ARA).

[8] Fwa, T. F. & Tan C.C. (1992) Laboratory Study of Microtexture-Related Skid Resistance Characteristics of Concrete Pavement Materials. Jour.of Testing and Evaluation, 20(3), 207-215.

[9] TS EN 1097-8, (2000) Tests for mechanical and physical properties of aggregates- determination of polished Stone value. TSE, Ankara, Turkey.

[10] Karpuz, O. (2008) Investigation of the Effect of Fine Aggregate Properties on the Surface Roughness of Concrete Road in Mixture. Ph.D. Dissertation, Karadeniz Technical University, Trabzon, Turkey.

[11] Road Technical Specification (2006) General Directorate of Highways of Turkey: 170/2, Ankara.

[12] TS EN 12390-3, (2002) Hardened concrete tests-Part 3: Determination of compressive strength in test samples. TSE, Ankara, Turkey.

[13] TS EN 13036-1, (2010) Macro Structure Depth Detection. TSE, Ankara, Turkey.

[14] Göktan, A. G. & Mitschke, M. (1995) Road Damage Caused by Heavy Duty Vehicles. International Journal of Vehicle Design, 16(1) https://doi.org/10.1504/IJVD.1995.061956

[15] Park, D. W., Fernando, E. & Leidy, J. (2005) Evaluation of Predicted Pavement Response with Measured Tire Contact Stresses. Transportation Research Board, 1919(1), 160-170 https://doi.org/10.1177/0361198105191900117

[16] TS EN 1341 (2004), Measurement of Resistance to Uncleaned Slip / Flush, TSE, Ankara, Turkey.

[17] Li, B., Ke, G. & Zhou, M. (2011) Influence of manufactured sand characteristics on strength and abrasion resistance of pavement cement concrete. Construction and Building Materials 25(10):3849-3853 http://dx.doi.org/10.1016/j.conbuildmat.2011.04.004

[18] Singh, M. & Siddique R. (2016) Effect of coal bottom ash as partial replacement of sand on workability and strength properties of concrete. Journal of Cleaner Production, 112(1), 620-630, http://dx.doi.org/10.1016/j.jclepro.2015.08.001

[19] Choudhary, R., Gupta, R., Nagar, R. & Jain A. (2021) Mechanical and abrasion resistance performance of silica fume, marble slurry powder, and fly ash amalgamated high strength self-consolidating concrete. Construction and Building Materials, 269, 121282, http://dx.doi.org/10.1016/j.conbuildmat.2020.121282

[20] ASTM C127-15, (2015) Standard Test Method for Relative Density (Specific Gravity) and Absorption of Coarse Aggregate.

[21] ASTM C131/C131M-14 (2014) Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine.

[22] Donza, H., Cabrera, O.ve Irassar E. F., High-strength Concrete With Different Fine Aggregate, Cement and Concrete Research, 32, 11 (2002) 1755–1761