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Abrasion Behavior of Natural Aggregates and Slags in Turkey Aided by Micro-Deval Test

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Keywords

Abrasion Resistance
Micro Deval
Slags
Natural Aggregate
Durability

Abstract

The properties of aggregates over their lifetime vary depending on their petrographic origin, procurement and sampling methodologies, regional characteristics and testing procedures. This study was designed to investigate the short and long-term wear properties of aggregates, including slags, using a simple, effective and inexpensive Micro-Deval (MD) test. To accomplish this, ten types of products were obtained from different regions, including natural aggregates and slags of different origin. The aggregates were abraded with different MD drum speeds ranging from 5250 to 52500 in accordance with ASTM D6928 standard. Percentage mass losses (PML) were determined after the treatments to analyze the extent of abrasion caused by short and long term abrasive forces depending on the aggregate type. Scanning electron microscopy (SEM) images of representative aggregates were taken to monitor the effect of abrasion on aggregate microstructure. According to the results, the PML of natural aggregates was observed significantly higher than that of slags, and the PML of slags after certain abrasion treatment tends to be stable, but not for natural ones. Based on regression analyses, a strong relationship between PML for individual aggregates was calculated, but a weak relationship was found based on the origin of the samples and total samples. SEM images taken from the surface of the aggregates confirmed the compatibility of the PML results with the abrasion characteristics showing the current situation.

Cite

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1. INTRODUCTION

The properties of aggregates such as size, shape, texture, cleanliness, toughness, abrasion, polishing resistance, durability, robustness and chemical compositions significantly affect both the functional and structural performance of road pavements (Gökalp et al., 2016). Aggregates are exposed to different abrasive forces and environmental influences that can cause crushing, degradation, fragmentation and abrasion (Saghafi et al., 2024). Considering these, the selection of suitable aggregates is an important consideration for pavement construction that can withstand traffic loads and environmental conditions throughout its service life (Yildirim & Prezzi, 2011). In order to decide on the use of any material as an aggregate for pavement, a series of tests must be carried out according to the material specification. These can be listed as fragmentation, polishing, abrasion, segregation resistance tests, etc. These tests are used to determine toughness, durability and strength properties for short and long periods (Omary et al., 2015). Existing literature (Tutumluer & Pan, 2008; Kwon et al., 2017; Gökalp at al., 2018) has proved that the aforementioned properties of aggregate vary significantly depending on petrographic origin, procurement and sampling methodology, regional characteristics and testing procedures, etc.

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The Micro Deval (MD) test can be implemented on samples with numerous standard test methods (Strzałkowski & Kaźmierczak, 2021). In this study, the most common test method for measuring abrasion resistance aggregates was used to evaluate short and long-term abrasion characterizations based on ASTM D6928 (2017), which provide different grade type for evalution. This test method has been widely used by some researchers in combination with some other tests such as Polishing Stone Value, Wehner-Schulze, Auckland Veneer Polishing, Los Angles Fragmentation, Soundness with $MgSO_4$, Aachen Polishing Machine and Road Testing Machine, Scanning Electron and Fluorescence Light Microscopy, and Image Processing. To summarize the general results of those studies (Cafiso & Taormina, 2007; Mahmoud & Masad, 2007; Lane et al., 2011; Shabani et al., 2013; Ortiz & Mahmoud, 2014; Wang et al., 2015), the following can be emphasized that the MD test were used for abrasion assessment by percentage mass losses (PML) before and after different abrasion levels is not taken into account. This situation, which is seen as a gap in scientific studies, is thought to be worth studying, and in this context, this study was established.

As the need for new roads and rehabilitation and maintenance of existing roads increases, so does the demand for aggregates of the required quality. Unfortunately, sources of raw materials available in nature are diminishing (Gao et al., 2017) Researchers' interest has in recent years turned towards exploring alternative materials for sustainable transportation. The substitution of natural aggregates with alternatives is considered as an urgent need to overcome the supply problem and the search for alternative construction materials has focused on industrial waste or by-products (Aslani et al., 2023). The steel industry is the second largest in the world after oil and gas, and steel is a versatile material used as a main component in industries such as machinery, automobiles, construction, infrastructure, shipbuilding and electronics. Therefore, by-products (slags) account for 10-15% of crude steel production, which means that more than 210 million tons of slag has the potential to be generated after steel production (Gökalp et al., 2018; Yonar & Dikbaş, 2022)

In the light of prior studies, it can be concisely stated that they have some superior properties compared to natural aggregates, such as resistance to polishing; abrasion, etc. Pasetto et al. (2023) indicate that researchers have also investigated both their possible uses and their impact on the environment. These studies have indicated slags as inert and/or hazardous materials and highlighted their environmentally friendly properties in a wide range of areas, including concrete-based construction works and granular particle-based coating applications for different layers. Using these materials instead of natural aggregates can reduce the supply problem and help conserve natural resources, which are dwindling day by day. Environmental regulations also require minimizing the disposal of such industrial by-products and mandate the reuse of these waste materials in many countries around the world. This problem must be overcome for present and future generations to live in a healthier environment.

In this study, the abrasion behavior of aggregates of different origins including slags simulated for short and long periods of time by MD device, which is widely used in determining the abrasion resistance of materials, was investigated. The aggregate materials used in this study were selected from a wide range of mineralogical properties from various quarries, industrial plants and/or disposal sites in different geographical regions of Turkey, with a total of ten types including limestone, basalt, rock and steel slags. A series of tests were performed to demonstrate the specific properties of each aggregate. Short and long term abrasion was achieved with the MD apparatus according to the B rating of ASTM D6928 (2017) standard with the number of revolutions ranging from 5250 to 52500. After the treatments, the PML was determined for all aggregates to examine the extent of wear caused by short and long term abrasive forces depending on the aggregate type. Relative differences in percentages with respect to the result obtained from standard practice are presented. SEM visually monitored the microstructure of the aggregate for representative aggregates before and after abrasion to show the effect of each abrasion level. As a result, the results of all laboratory-based experiments were analyzed in detail, not only with PML, which shows the wear characteristics of each material at certain levels, but also with SEM images, which provide information on the physical, mechanical and chemical properties and show the surface micro-texture development at certain wear levels.

2. MATERIAL AND METHOD

There was a rationale for material selection based on the geological structure of Turkey. Limestone was chosen because it is the most common natural aggregate and is widely used in construction works. Basalt and boulders were preferred based on their better physical and mechanical properties (Gökalp et al., 2018). Therefore, ten types of coarse aggregates, both natural aggregate and slag were evaluated in this study. These materials, consisting of boulders, limestone, basalt, ferrochrome slag and electric arc furnace steel slag, were obtained from privately operated quarries located in different regions of Turkey and from the facilities and/or disposal areas of companies operating in steel production. The identification number, material lithology, types of rocks source region and regional distribution of the aggregates are presented in Table 1. For shpwing the region of supplied aggregate and slags in a map, locations of the material sources on geological map of Turkey is given in Figure 1.

Table 1. *Aggregate distribution and identification*

Sample ID	Lithology	Types of Rocks	Source District	Region
LS-1	Limestone	Sedimentary	Adana- Ceyhan	Mediterranean
LS-2	Limestone	Sedimentary	Antakya - Kırıkhan	Mediterranean
LS-3	Limestone	Sedimentary	Mersin- Tarsus	Mediterranean
BS-1	Basalt	Igneous	Niğde - Bor	Central Anatolia
BS-2	Basalt	Igneous	Kayseri	Central Anatolia
BLD	Boulder	River-Basin Aggregate	Kahramanmaraş- Aksu	Mediterranean
EAF-1	EAF Slag	By-Product	Antakya- İskenderun	Mediterranean
EAF-2	EAF Slag	By-Product	Osmaniye	Mediterranean
EAF-3	EAF Slag	By-Product	Antakya- İskenderun	Mediterranean
FER	Ferrochrome Slag	By-Product	Elazığ	Eastern Anatolia

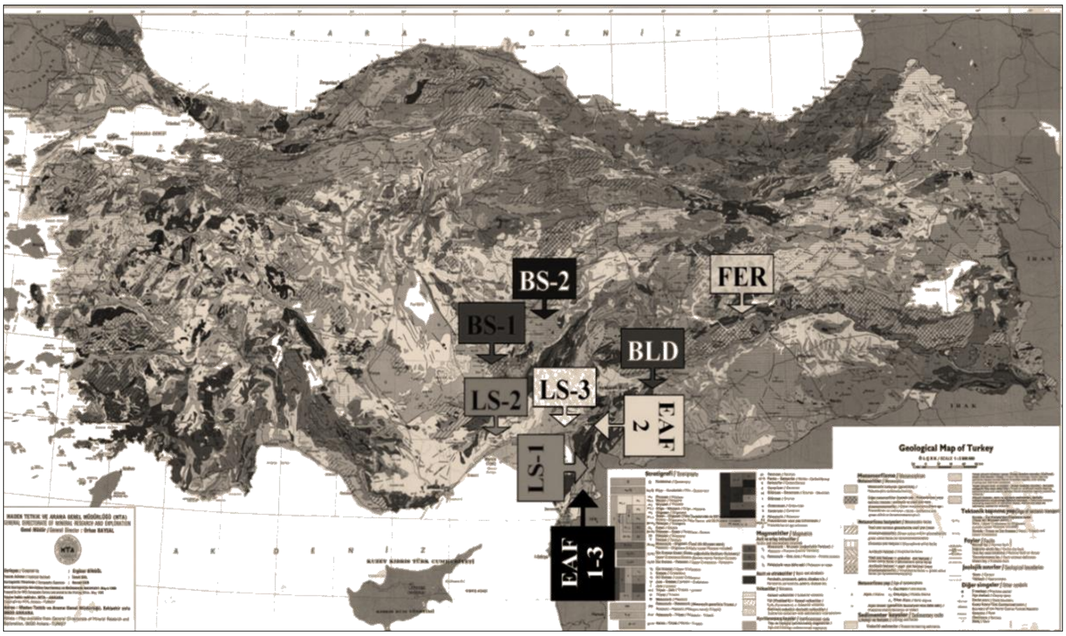

Figure 1. *Locations of the material sources on geological map of Turkey*

2.1. Material Characterization

The materials used in this study were characterized for their physical and mechanical properties by a series of standard tests. These tests included fragmentation, polishing resistance, soundness with $MgSO_4$ solution, dry unit weight and water absorption. Table 2 shows the average test results obtained for all specimens. Chemical composition determination of materials is an extremely important issue. In this context, the chemical composition of each aggregate was determined by X-ray fluorescence analysis according to the standard test method EN 15309 (2007). Figure 2 shows the chemical composition of each aggregate.

The results in Table 2 showed that naturally occurring aggregates exhibited different properties depending on their source. Among them, polishing resistance of natural aggregates are week compared to slags except of EAF-3. Dry unit weight of slags are higher than that of natural ones due to their chemical composition. Figure 2 indicated that the chemical composition of aggregates varies depending on their geological formation in nature and production processes in industrial plants, and all samples have chemical contents reflecting their formation.

Table 2. *Aggregate physical and mechanical properties*

Sample ID	Fragmentation Resistance (%) (EN 1097-2)	Soundness (%) (EN 1367-2)	Polishing Resistance (PSV) (EN 1097-8)	Dry Unit Weight (g/cm^3) (EN 1097-6)	Water Absorption (%) (EN 1097-6)
LS-1	24.4	2.4	41.2	2.7	0.4
LS-2	16.2	3.0	43.2	2.7	0.2
LS-3	24.4	8.1	41.6	2.7	0.3
BS-1	12.0	6.9	61.0	2.6	2.0
BS-2	25.9	9.4	52.4	2.7	1.4
BLD	17.6	6.2	57.9	2.7	0.9
EAF-1	22.9	2.3	76.1	3.4	1.8
EAF-2	25.3	8.3	59.0	3.4	2.5
EAF-3	29.7	3.7	54.1	3.3	2.9
FER	16.5	6.1	61.7	2.9	1.1

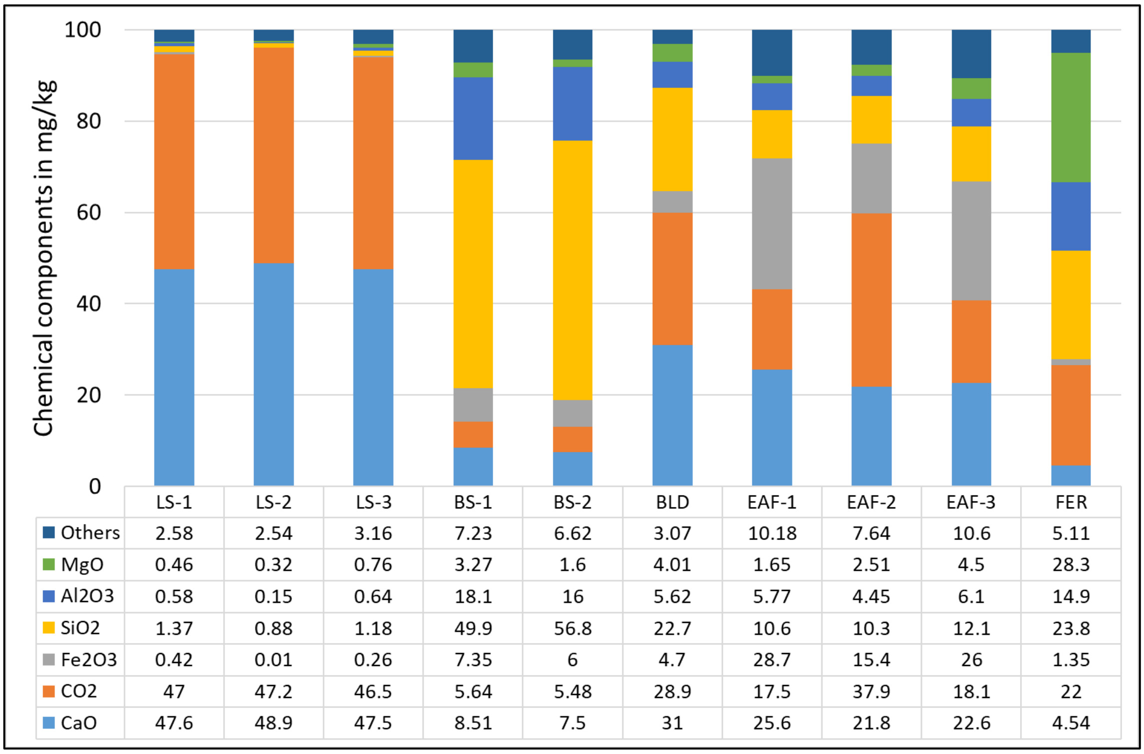

Figure 2. *Chemical compositions of aggregates*

2.2. Aggregate Abrasion Process

The standard size of the aggregate tested in accordance with ASTM D6928 (2017) was varied. The aggregate sizes ranged from 19.0 mm to 4.75 mm according to three different application types. Table 3 presents the aggregate sizes and mass configurations defined in the standard. It is worth noting here that all aggregates collected were extracted from such long and platy aggregates according to ASTM D4791 (2012) and the cubic particles remaining after separation were subjected to tests. Our concern was to avoid misleading test results and to obtain specimens that standardized in shape. The abrasion levels of the aggregates were evaluated according to the rotation numbers (RNs) of the MD test according to the ASTM D6928-B standard given in Table 4.

Table 3. *Aggregate physical and mechanical properties*

Sieve Size (mm)	**Passing (mm)**	**19.0**	**16.0**	**12.5**	**9.5**	**6.3**
Grade of ASTM D6928	**A (g)**	375	375	750	-	-
	B (g)	-	-	750	375	375
	C (g)	-	-	-	750	750

Table 4. *Abrasion level identification*

Abrasion Level	**Abrasion-Free**	**1st**	**2nd**	**3rd**	**4th**	**5th**
Revolution Numbers	0	5250	10500	21000	31500	52500
Case of Standard RN	None	Half	Standard	Double	Triple	Quintuple

The application steps for the test are as follows:

1. 1500 ± 5 g of test samples are taken from a given amount in the pile.
2. The samples are washed to remove dust and dried in an oven at 110 ± 5 ºC to evaporate moisture until reaching constant mass.
3. 2.0 ± 0.05 liters of water is added to the MD drum at a given temperature and the aggregate is poured over the water-filled drum for conditioning for at least 1 hour.
4. A 5000 ± 5 g steel sphere with a diameter of 10 ± 0.5 mm is placed inside the drum and the drum is closed for being ready to rotate.
5. Rotation is conducted with 100 ± 5 rpm for three cases as follows;
   - 12000 ± 100 revolutions for 19/9.5 mm classification (Grade A),
   - 10500 ± 100 revolutions for 12.5/4.75 mm classification (Grade B), and
   - 9500 ± 100 revolutions for 9.5/4.75 mm classification (Grade C).

After the test, the aggregates are dried and sieved through a 1.18 mm sieve. The mass (m) of aggregate retained on the 1.18 mm sieve is weighted and operator determines PML in percent with the Equation 1.

$$\text{PML}\ (\%) = (1500 - \text{m})/1500 \tag{1}$$

3. RESULTS AND DISCUSSION

This part of the present study consists of two parts. Firstly, the results of the wear properties for each aggregate at the applied wear levels are presented and discussed in detail. Secondly, SEM images for representative aggregates in the original condition and at the highest wear levels are given and concisely discussed.

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3.1. Abrasion Characteristic of Aggregates

The abrasion levels achieved by the MD apparatus with reference to different drum speeds in the B classification standard according to ASTM D6928-B Grade is described here. PML results at different abrasion levels and statistical data is given in Table 5.

Table 5. *PML at different abrasion levels with statistical data*

Abrasion Level	Revolutions Numbers	Sample ID	LS-1	LS-2	LS-3	BLD	BS-1
1st	5250	Mean	5.42	9.85	5.30	4.98	4.00
		Std Dev	0.164	0.147	0.385	0.065	0.092
		CoV	0.030	0.015	0.073	0.013	0.023
2nd	10500	Mean	9.05	16.28	9.70	8.14	8.14
		Std Dev	0.115	0.200	0.040	0.189	0.195
		CoV	0.013	0.012	0.004	0.023	0.024
3rd	21000	Mean	14.94	26.08	13.57	13.70	11.43
		Std Dev	0.084	0.081	0.085	0.193	0.465
		CoV	0.006	0.003	0.006	0.014	0.041
4th	31500	Mean	19.83	32.93	18.26	17.57	15.35
		Std Dev	0.026	0.886	0.001	0.255	0.020
		CoV	0.001	0.027	0.000	0.015	0.001
5th	52500	Mean	27.33	51.71	26.05	23.15	22.20
		Std Dev	0.030	0.037	0.250	0.030	0.300
		CoV	0.001	0.001	0.010	0.001	0.014
Abrasion Level	**Revolutions Numbers**	**Sample ID**	**BS-2**	**EAF-1**	**EAF-2**	**EAF-3**	**FER**
1st	5250	Mean	4.80	5.64	5.33	8.97	5.47
		Std Dev	0.020	0.184	0.120	0.191	0.125
		CoV	0.004	0.033	0.023	0.021	0.023
2nd	10500	Mean	6.81	8.01	8.01	12.24	8.31
		Std Dev	0.020	0.290	0.175	0.011	0.185
		CoV	0.003	0.036	0.022	0.001	0.022
3rd	21000	Mean	10.33	11.61	10.69	16.63	11.68
		Std Dev	0.050	0.078	0.190	0.137	0.077
		CoV	0.005	0.007	0.018	0.008	0.007
4th	31500	Mean	14.01	14.25	14.46	19.91	15.67
		Std Dev	0.060	0.146	0.265	0.360	0.010
		CoV	0.004	0.010	0.018	0.018	0.001
5th	52500	Mean	18.65	16.91	17.70	20.84	19.95
		Std Dev	0.150	0.053	0.100	0.230	0.250
		CoV	0.008	0.003	0.006	0.011	0.013

Std Dev: Standard Deviation, Mean: Arithmetic Mean of results; CoV: Coefficient of Variations

From Table 5 that the abrasion characteristics of the aggregates in terms of PMLs differ from each other depending on their type and abrasion levels. Regarding the PML of natural aggregates, LS-2 showed the worst abrasion characteristics at all applied cycles, where the PML values were 9.85% at the lowest abrasion level. On the other hand, basalt and rock exhibited better abrasion properties compared to other natural materials. However, basalts were relatively better than boulders. It is important to note that the initial conditions were quite close for these. It is apparent that the level of abrasion increases and this trend of loss proceeds almost linearly. On the other hand, the slags are quite superior in terms of abrasion characteristics. This is because at the highest abrasion level the PML for slags ranges from 16.91 to 20.84, which can be a kind of close range, while for natural ones the PML ranges from 18.69 to 51.73, which means about three times far apart. It is worth noting here that the slags exhibit a stationary phase against abrasion as the abrasion level increases.

3.2. Regression Analysis and Mathematical Models

Regression analysis based on different mathematical models, different material types were used. In this context, different mathematical models were used in the study in linear, exponential, logarithmic and polynomial functional cases. Aggregates are known to exhibit different physical and mechanical properties due to their morphologic structure. For this reason, the materials were considered individually and regression analyses based on the mathematical models in question were formulated in this direction (Table 6). Based on the results of the regression analysis of the individual materials as given in Table 6, the author can state that the R^2 values for natural aggregates ranged roughly from 0.85 to 0.99. On the other hand, the values for slag aggregates ranged from 0.78 to 0.99. The higher R^2 values were calculated polynomial-based mathematical models, where the lower were for exponential one.

The other case considered for the regression analyses is related to the natural and by-product supplied methods. Thus, the use of both natural aggregates and slags in construction is based on the results obtained from the same test. Regression analysis was also carried out for each aggregate by origin separately and then all together in order to make an assessment (Table 7). According to the results presented in Table 7, lower R^2 values were observed for each combined case compared to the individual cases, ranging from 0.562 to 0.844. The R^2 values determined for slags are larger than those obtained for both natural aggregates and all aggregates. Also, lower R^2 values were observed for the sample population when all aggregates were considered. Such an analysis may be the result of a new approach.

3.3. SEM-based Visual Analyses

SEM has been used as a powerful magnification tool that focuses electron beams to obtain the desired detailed information about materials. The purpose of using SEM in this study is to monitor the aggregate surface at the micro level for the highest level of wear and no wear monitored through the instrument. Representative samples of all aggregate types selected for imaging at a fixed magnification (60 X) such as LS-3, BS-2, BLD, EAF-1 and FER are 8-10 mm in size and cubic in shape. A series of SEM images taken during the analysis of aggregate without abrasion and at the highest abrasion levels are given in Figure 3.

It is expected that the surface texture of each aggregate in its original condition is distinctly different and the surface of each becomes smoother at the highest levels of abrasion. When analyzed the figures individually, the following can be remarked;

Limestone have a smoother surface than the other aggregates before and after different abrasion level. Basalt, an igneous rock, has a naturally porous structure, which is demonstrated in the images. Boulder show both surface characteristics of limestone and basalt, where some part is smooth and some part is porous, which is expected case. Slags shows porous structure likewise in the state of abrasion free case after 5^{th} abrasion level and this can be linked with the industrial production procedure, which show re-texturing the surface by itself.

Table 6. *Different regression analysis and mathematical models for individual-based*

Sample ID	Mathematical Models (where, y= PML (%) and x: MD Drum RN number)			
	Linear	**Exponential**	**Logarithmic**	**Polynomial**
LS-1	$R^2 = 0.984$ y = 0.0005x + 4.2291	$R^2 = 0.880$ $y = 6.0758e^{3E-05x}$	$R^2 = 0.960$ y = 9.3892ln(x) - 76.709	$R^2 = 0.999$ $y = -4E-09x^2 + 0.0007x + 1.9716$
LS-2	$R^2 = 00.996$ y = 0.0009x + 6.5332	$R^2 = 0.914$ $y = 10.688e^{3E-05x}$	$R^2 = 0.920$ y = 17.176ln(x) - 140.97	$R^2 = 0.996$ $y = -2E-09x^2 + 0.001x + 5.6999$
LS-3	$R^2 = 0.988$ y = 0.0004x + 4.3484	$R^2 = 0.881$ $y = 6.0839e^{3E-05x}$	$R^2 = 0.947$ y = 8.5829ln(x) - 69.545	$R^2 = 0.994$ $y = -2E-09x^2 + 0.0006x + 3.0344$
BLD	$R^2 = 0.969$ y = 0.0004x + 4.3152	$R^2 = 0.861$ $y = 5.643e^{3E-05x}$	$R^2 = 0.975$ y = 7.9073ln(x) - 63.991	$R^2 = 0.999$ $y = -5E-09x^2 + 0.0007x + 1.6956$
BS-1	$R^2 = 0.984$ y = 0.0004x + 3.3364	$R^2 = 0.857$ $y = 4.8179e^{3E-05x}$	$R^2 = 0.949$ y = 7.485ln(x) - 61.134	$R^2 = 0.992$ $y = -2E-09x^2 + 0.0005x + 2.1318$
BS-2	$R^2 = 0.986$ y = 0.0003x + 3.8098	$R^2 = 0.916$ $y = 4.9896e^{3E-05x}$	$R^2 = 0.948$ y = 5.9757ln(x) - 47.647	$R^2 = 0.999$ $y = -2E-09x^2 + 0.0004x + 2.5317$
EAF-1	$R^2 = 0.937$ y = 0.0002x + 5.6105	$R^2 = 0.855$ $y = 6.1794e^{2E-05x}$	$R^2 = 0.989$ y = 4.9956ln(x) - 37.678	$R^2 = 0.999$ $y = -4E-09x^2 + 0.0005x + 3.2861$
EAF-2	$R^2 = 0.962$ y = 0.0003x + 5.0014	$R^2 = 0.883$ $y = 5.8023e^{2E-05x}$	$R^2 = 0.969$ y = 5.3656ln(x) - 41.349	$R^2 = 0.994$ $y = -3E-09x^2 + 0.0005x + 3.197$
EAF-3	$R^2 = 0.839$ y = 0.0002x + 9.7614	$R^2 = 0.780$ $y = 10.017e^{2E-05x}$	$R^2 = 0.979$ y = 5.5172ln(x) - 38.354	$R^2 = 0.999$ $y = -8E-09x^2 + 0.0007x + 5.6302$
FER	$R^2 = 0.974$ y = 0.0003x + 4.9074	$R^2 = 0.891$ $y = 5.9455e^{3E-05x}$	$R^2 = 0.965$ y = 6.2416ln(x) - 48.955	$R^2 = 0.997$ $y = -3E-09x^2 + 0.0005x + 3.0921$

Table 7. *Different mathematical models for origin and unified-based*

Aggregate Type	Mathematical Models (where, y= PML (%) and x: MD Drum RN number)			
	Linear	**Exponential**	**Logarithmic**	**Polynomial**
Natural	$R^2 = 0.604$ y = 0.0005x + 4.428	$R^2 = 0.696$ $y = 6.1403e^{3E-05x}$	$R^2 = 0.578$ y = 9.4194ln(x) - 76.666	$R^2 = 0.608$ $y = -3E-09x^2 + 0.0006x + 2.8442$
Slag	$R^2 = 0.793$ y = 0.0003x + 6.3202	$R^2 = 0.738$ $y = 6.7978e^{2E-05x}$	$R^2 = 0.833$ y = 5.53ln(x) - 41.584	$R^2 = 0.844$ $y = -5E-09x^2 + 0.0005x + 3.8013$
Combined	$R^2 = 0.572$ y = 0.0004x + 5.1853	$R^2 = 0.632$ $y = 6.3953e^{3E-05x}$	$R^2 = 0.562$ y = 7.8636ln(x) - 62.633	$R^2 = 0.582$ $y = -4E-09x^2 + 0.0006x + 3.227$

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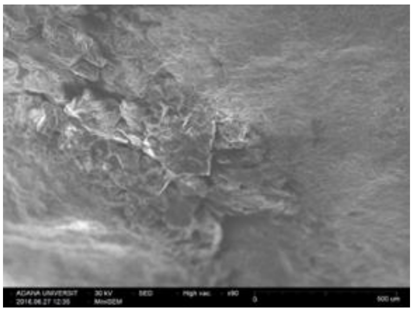
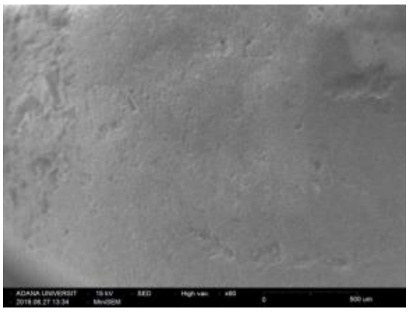
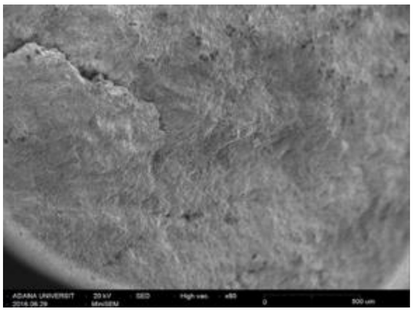
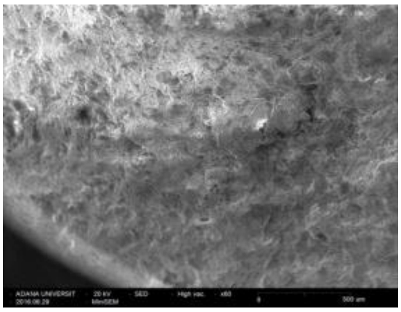
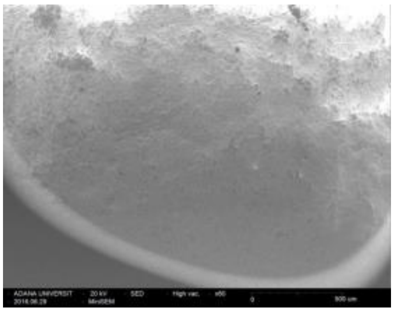
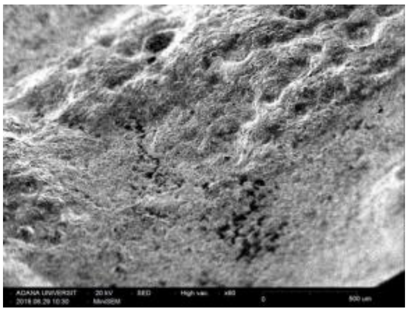
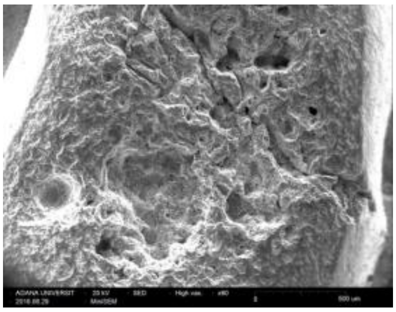
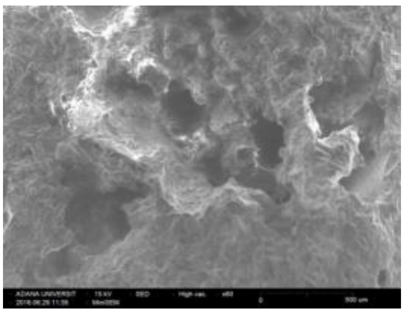
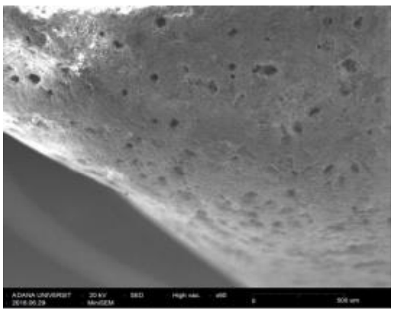
Sample ID	Abrasion-free	5^{th} Abrasion Level
LS-3		
BS-2		
BLD		
EAF-1		
FER		

Figure 3. *Visual analyses with SEM images of representative aggregate and slags*

4. CONCLUSION

In the present study, the short and long term abrasion properties of aggregates obtained from different sources containing slag were investigated by simulating abrasion with different drum speeds between 5250 and 52500 according to the B grading of ASTM D6928 with MD apparatus. In this context, a total of ten types of aggregates including limestone, basalt, rock and steel slag were obtained from different regions of Turkey. A series of tests were performed on each aggregate to determine certain physical, mechanical and chemical properties. The PML after abrasion treatments for all aggregates was determined to assess the status caused by short and long term abrasion. Finally, SEM images were taken for representative aggregates to provide a visual comparison of the effect of wear on the surface structure of the aggregate. According to the laboratorial test and statically and visual analyses, followings can be highlighted.

1. Slags have significant superior properties compared to natural aggregates by means of abrasion resistance tested with MD.
2. The abrasion properties of aggregates differ from each other depending on their origin and abrasion levels.
3. The PMLs of natural aggregates were significantly higher than that of slags at each abrasion level.
4. The abrasion level increases and the PML progresses for natural aggregates, but this trend is not observed for slags, as they exhibit a more stable phase against abrasion.
5. Slags have a more porous surface than natural aggregates, as clearly seen from the SEM images.
6. Individual, origin and compound based regression analyses showed significantly different R^2 values and mathematical models.

As a result, aggregate is an important component in the production of bituminous mixtures, concrete, mortars to be used in buildings, filling materials, railway ballast, etc. in all areas of the construction industry. Aggregates must be robust and abrasion resistant under mechanical forces that cause fragmentation, polishing, crushing and deterioration during storage, mixing, paving, and compaction and under traffic loads of different intensities. This is because the properties of aggregate significantly affect both the functional and structural performance of any construction work. The selection of suitable aggregates is of utmost importance when considering their short and long-term performance for both economic and safety reasons. Slags can be considered the most abrasion resistant materials when their properties can become more stable after a certain abrasion process. Therefore, the use of slags in pavements when their surfaces are subjected to intense abrasion can bring not only technical, but also economic and ecological benefits.

AUTHOR CONTRIBUTIONS

Conceptualization, İ.G. and V.E.U.; methodology, I.G. and V.E.U.; title, I.G.; validation, I.G. and V.E.U laboratory work, İ.G.; formal analysis, İ.G.; research, I.G. and V.E.U.; sources, V.E.U.; data curation, I.G. and V.E.U.; manuscript-original draft, İ.G.; manuscript-review and editing, I.G. and V.E.U; visualization, İ.G.; supervision, V.E.U.; project management, V.E.U funding, V.E.U. All authors have read and legally accepted the final version of the article published in the journal.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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