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Full Length Research Paper

Predicting Los Angeles abrasion of rocks from some physical and mechanical properties

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Rock aggregate is widely used in building constructions and most public projects including roads, bridges, railroad etc. Aggregates, which do not have adequate toughness and abrasion resistance, may cause construction and performance problems. To assess the abrasion resistance of aggregates, the most common method is the Los Angeles abrasion (LAA) test determining the relative competence or resistance to abrasion of the aggregates. The aim of this study was to predict the LAA of rocks from some physical and mechanical properties. For this purpose, LAA and some physical and mechanical tests were performed on 32 different rocks, ten of which were igneous, eleven of which were metamorphic and eleven of which were sedimentary. To investigate the possibility of predicting the LAA from some rock properties, the results of the tests were analyzed using regression analysis. Good correlation between LAA and some physical and mechanical properties of rocks were found. Concluding remark was that derived equations could reliably be used for the prediction of LAA.

Key words: Los Angeles abrasion, aggregate, rock properties, correlations, regression analysis.

INTRODUCTION

Rock aggregate is a material used in very different construction works. It is widely used in building constructions and most public projects including roads and highways, bridges, railroad etc. An enormous amount of aggregate is used in the world each year. The demand of crushed stone aggregates has increased from day to day, because of increasing expansion of highway and other construction works and decreasing natural aggregate resources in the world (Kahraman and Fener, 2007). The suitability of aggregates for use in a given type of construction is determined by evaluating the material in terms of its physical and mechanical properties. Most specifications for aggregates require the material to be strong (Al-Harthi, 2001; Ugur et al., 2010). Aggregates used must be tough and abrasion resistant to prevent crushing, degradation and disintegration when stockpiled, fed through an asphalt plant, placed with a paver, compacted with rollers, and subjected to traffic loadings. Aggregates, which do not have adequate toughness and abrasion resistance, may cause construction and performance problems (Wu et al., 1998).

Abrasion resistance is an important property of aggregates. The abrasion resistance of aggregates is generally tested using the Los Angeles (LA) testing machine. The LAA test reflects the aggregate resistance to abrasion and fragmentation due to impact and it has a considerable utility in determining the quality of the aggregates for the specification of requirements for their specific usages. The test measures the resistance of aggregate to wear due to attrition between rock particles and also to impact and crushing by steel spheres (Fernlund, 2005; Kahraman and Fener, 2007; Ugur et al., 2010). Although the LAA test is relatively simple, it is time consuming and requires more samples comparing to the unit volume weight, apparent porosity, uniaxial compressive strength, tensile strength, shore hardness and point load strength test. Core samples used in these tests are generally obtained during the field investigation of a rock aggregates deposit. On the other hand, all these tests are usually carried out to determine the quality of the rock aggregate. Therefore, if these properties of rocks strongly correlate with the LAA value, they can be used for the prediction purposes. By considering this, the purpose of this study is to establish empirical equations to predict LAA value for 500 revolutions from some

Figure 1. Los Angeles testing machine.

physical and mechanical properties of rock samples.

LITERATURE REVIEW

Some researches have investigated abrasion resistance of aggregates by using LAA test. Rocks with good interlocking and strong cementation between grains produced less degradation than rocks with loose interlocking and weak cementation. Increase in the magnitude of load or increase in the number of repetitions of load increased degradation. Kazi and Al-Mansour (1980) carried out a study of the abrasion characteristics of crushed-rock aggregates obtained from a wide variety of igneous rocks of volcanic and plutonic origins.

The grain size was found to be a significant geological factor controlling the evaluation of abrasion resistance. Fine-grained rocks when compared with coarse-grained rocks having the same porosity were found to be more resistant to wear. Gandhi and Lytton (1984) indicated strong and definitive correlations between the LAA values and field performance about toughness and abrasion resistance of the aggregates.

There is enough evidence in the literature to suggest that the strength of the aggregates is closely related to strength of the rock. Kazi and Al-Mansour (1980) obtained a strong correlation between UCS determined by the Schmidt hammer and L.A. abrasion loss for the Saudi Arabian aggregates (volcanic and plutonic rocks) near the city of Jeddah. Ballivy and Dayre (1984) found an inverse relation between UCS and LAA loss for limestones, the degree of correlation being different for different types of limestone. Al-Harthi (2001) found meaningful correlation among the LAA value of aggregate, uniaxial compressive strength and point load index of rocks. Kahraman and Fener (2007) found a good correlation between uniaxial compressive strength and LAA loss. Kahraman and Fener (2008) derived an equation for the estimation of LA abrasion loss from electirical resistivity. Kahraman and Toroman (2008) revealed that crushability index can be used to estimate LA abrasion. Ugur et al., (2010) carried out laboratory tests on 12 different rocks, four of which were limestone, four of which were travertines, three of which were crystalline marbles and one of which was andesite, to investigate LAA value of each rock. Some physical and mechanical properties of rocks were determined to establish the relationship between LAA value and each rock property. They found that rock properties have certain influence on the abrasion of rocks and could be used to predict LAA value of rocks. It was found that high correlations exist between LAA/Vp and compressive strength, tensile strength, Schmidt hardness, and point load index.

Although, Kahraman and Fener (2007), (2008), Kahraman and Toroman (2008) and Ugur et al. (2010) found a good results to predict LAA loss from some physical and mechanical properties of rocks, Kahraman and Fener (2007), (2008) and Kahraman and Toroman (2008) used only one property for estimating LAA loss and Ugur et al. (2010) used all rock types together with small amount to establish the relationship between LAA value and some physical and mechanical properties of rocks. Because of this, 32 different rocks, ten of which were igneous, eleven of which were metamorphic and eleven of which were sedimentary, were used and the establishments of the empirical equations to predict LAA value from some physical and mechanical properties of rock were performed for sedimentary, metamorphic and igneous rocks separately.

METHOD OF ABRASION TESTING

ASTM method C 131-66 (2006) was used for the LAA test. The LA and impact testing machine consists of a hollow steel cylinder, closed at both ends, having an inside diameter of 710±5 mm and an inside length of 508±5 mm (Figure 1).

Test samples were oven-dried at 105–110°C for 24 h and then cooled to room temperature before they were tested. There are four aggregate sizes grading to choose from in the ASTM method. Grading D was used in the tests. 6 steel spheres weighing approximately 420 g each and having a diameter of 47 mm were placed in a steel drum along with approximately 5000 g aggregate sample and the drum was rotated for 500 revolutions at a rate of 30 to 33 rev/min. After the revolution was complete, the sample was sieved through the No. 12 sieve (1.7 mm). The abrasion loss as a percentage of the original mass of the test sample after 500 revolutions is calculated according to Equation (1).

$$K_{500} = \frac{G_0 - G_{500}}{G_0} * 100 \quad (1)$$

Table 1. The location, type and class of the rock samples.

Rock name	Rock type	Rock class	Location
Hazar pink	Limestone	Sedimentary	Diyarbakir
Elazig cream	Limestone	Sedimentary	Elazig
Daisy beige	Limestone	Sedimentary	Diyarbakir
Petroleum green	Limestone	Sedimentary	Elazig
Black pearl	Limestone	Sedimentary	Diyarbakir
Hazar beige	Limestone	Sedimentary	Diyarbakir
Cermik beige	Limestone	Sedimentary	Diyarbakir
Yesilova beige	Limestone	Sedimentary	Burdur
Sivrihisar beige 1	Limestone	Sedimentary	Eskisehir
Sivrihisar beige 2	Limestone	Sedimentary	Eskisehir
Diyarbakir beige	Limestone	Sedimentary	Diyarbakir
Usak white	Marble	Metamorphic	Usak
Kozagac white	Marble	Metamorphic	Mugla
Milas lilac	Marble	Metamorphic	Mugla
Afyon cream	Marble	Metamorphic	Afyon
Afyon violet	Marble	Metamorphic	Afyon
Kutahya green	Marble	Metamorphic	Kutahya
Afyon sugar	Marble	Metamorphic	Afyon
Kutahya violet	Marble	Metamorphic	Kutahya
Afyon white	Marble	Metamorphic	Afyon
Afyon violet 2	Marble	Metamorphic	Afyon
Kutahya green 2	Marble	Metamorphic	Kutahya
Andesite1	Andesite	Igneous	Ankara
Andesite2	Andesite	Igneous	Ankara
Andesite3	Andesite	Igneous	Ankara
Andesite4	Andesite	Igneous	Ankara
Andesite5	Andesite	Igneous	Ankara
Andesite6	Andesite	Igneous	Ankara
Andesite7	Andesite	Igneous	Ankara
Andesite8	Andesite	Igneous	Ankara
Andesite9	Andesite	Igneous	Ankara
Andesite10	Andesite	Igneous	Ankara

Where; K_{500}: Abrasion loss after 500 revolutions (%)
G_0: Original sample mass (g)
G_{500}: Sample mass after 500 revolutions (g).

ROCK SAMPLING

Laboratory testing was carried out on 32 samples taken from different areas of Turkey. They were collected in the form of large blocks from various marble factories and were consisted of mainly limestone, marble and andesite used as building stone. Rock samples were prepared from these blocks. Commercial names, types, classes and locations for these rocks are given in Table 1.

ROCK PROPERTIES

The main factors that require consideration in predicting the abrasion behaviour of rocks are the characteristics of rocks. Therefore, a testing programme was carried out to determine the physical and mechanical properties included unit volume weight (UVW), apparent porosity (AP), shore hardness (SH), uniaxial compressive strength (UCS), tensile strength (TS) and point load strength (PL) in order to investigate dependence of abrasion rate on rock properties. The results were statistically analyzed to determine the descriptive statistics including minimum, maximum, average, and standard deviations for each property of rocks.

Unit volume weight (UVW) and apparent porosity (AP)

The apparent porosity of rock samples was determined using saturation technique, as recommended by ISRM (1981) and TSE (1987). All samples were saturated by water immersion for a period of 48 h with periodic agitation to remove trapped air. Later, the samples were transferred underwater to a basket in an immersion bath and their saturated-submerged weights were measured. Then, the surface of the samples was dried with a moist cloth and their saturated-surface-dry weights were measured outside water. The dry mass of samples was determined after oven drying at a temperature of 105°C for a period of at least 24 h.

Shore hardness (SH)

The shore hardness of the rocks was determined according to the specifications outlined by the ISRM (1981) by using C-2 model shore hardness testing device. Five specimens of each rock type were prepared and 20 readings were obtained for each specimen.

Uniaxial compressive strength (UCS)

The uniaxial compression strength was determined following ISRM (1981) and tests were carried out on cylindrical shaped samples having 54 mm diameter with L/D ratio of 2:0.

Tensile strength (TS)

The indirect test commonly adopted for the tensile strength determination, known as the Brazilian Test, was conducted. Cylindrical rock cores were used for this test in accordance with the ISRM (1981). The diameter of the cores is 54 mm and thickness is 27 mm.

Point load strength (PL)

Rock specimens in the form of blocks with depth to width ratio between 0.3 and 1 were broken by application of load through a pair of spherically truncated, conical platens.

STATISTICAL ASSESSMENTS OF THE TEST RESULTS

The results obtained from all the tests given previously for all rock types and their descriptive statistics results are also be given in Table 2. As can be seen in Table 2, it is impossible to assess the results together for all rock types. It is necessary to assess the results for all rock types separately. Because of this, the results were evaluated separately for each rock types.

Some physical and mechanical properties of the examined rocks were compared using statistical analysis relative to abrasion rate of the rocks. A Pearson correlation coefficient (r) was used as a bivariant correlation analysis to determine the relationships among the parameters in the analysis. The statistical runs, including F-tests, were done using the SPSS v.17 computer software program. This provided an integrated series of data handling and statistical evaluation methods applicable to large data files. Use of correlation coefficients requires testing the significance of the statistical estimators before drawing inferences. For degrees of freedom, v=n-2 at the 95% confidence level. H0 hypotheses (null hypothesis) were tested (F-test); the correlation coefficient (r) is not significantly different from zero (no correlation).

As can be seen from Figure 2, there is a significant relationship between the LAA and the other parameters for the sedimentary rocks. However, the significant relationships are the negative except AP, which is shown in Figure 2c. If the results in Figure 2 for metamorphic rocks are considered, it can be seen that LAA has a negative significant correlation with the SH, UCS, PL and TS, but not other parameters, for example, UVW and AP, which are shown in Figure 2b and c, respectively. If the results in Figure 2 for igneous rocks are considered, it is obvious that LAA has a strong significant relationship between all the parameters (SH, UVW, AP, UCS, TS and PL). The significant relationships are the negative except AP, which is shown in Figure 2c.

The effects of each parameter on the LAA were investigated graphically for rock types for fitting a line to the set of experimental data. Based on this analysis, among the many functions tested (linear, power, logari-thmic, exponential), the power curve relation was fitted to the experimental data with higher correlations than all the other relationships. Some of these relationships are presented in Figure 2. There exist statistically high correlations for LAA with some physical and mechanical properties. The relationship between LAA and some physical and mechanical properties of the examined all rock types are given in Figure 2 together. It was observed from Figure 2 that as the SH, UWV, UCS, PL and TS increases, the LAA decreases in all rock types. The lack of a relationship between AP and LAA was also observed in sedimentary and metamorphic rocks, which is shown in Figure 2c. Moreover, as the AP increases, the LAA also increases in igneous rock.

DISCUSSION

When Figure 2 is compared with the previous studies in the literature, it can be seen that all the results obtained in this study are similar to the previous studies in terms of the trend of the curve in Figure 2d including to the relationship between UCS and LAA. The trend in Figure 2 for the relationship between UCS and LAA are similar to the trend from Ballivy and Dayre (1984), Shakoor and Brown (1996) and Kahraman and Fener (2007) in carbonate rocks, Cargill and Shakoor (1990) and Kahraman and Fener (2007) in sedimentary and metamorphic rocks and Kazı and Al-Mansour (1980) and Kahraman and Fener (2007) in igneous rocks. However, the relationships between LAA and other parameters including SH, UVW, AP, TS and PL were not revealed in the previous studies for sedimentary, metamorphic and igneous rock types separately.

According to the Figure 2 meaningful correlations between LAA and physical and mechanical properties of rocks were obtained with the prediction equations given in Table 3. The quality and significance of the predicted equations are often tested through the very well-known method of analysis of variance (ANOVA). For this reason, ANOVA was performed to test the significance of the equations. ANOVA results for the test procedures are also given in Table 3. When the Table 3 is examined, it can be concluded that SH, UWV, UCS, PL and TS for sedimentary rocks, SH, UCS, PL and TS for metamorphic

Table 2. Results of some physical and mechanical tests and descriptive statistics.

	Sample name	SH	UVW (g/cm^3)	AP (%)	UCS (MPa)	TS (MPa)	PL (MPa)	LAA (%)
Sedimentary	Hazar pink	51.0	2.67	1.23	110.30	8.13	6.66	22.50
	Elazig cream	36.0	2.51	5.15	58.40	4.75	2.65	41.20
	Daisy beige	67.0	2.69	1.29	126.80	10.38	6.82	21.20
	Petroleum green	66.0	2.66	1.20	82.20	7.66	4.77	23.50
	Black pearl	60.0	2.69	0.20	108.40	8.45	5.07	20.50
	Hazar beige	55.0	2.69	0.36	61.40	5.65	2.61	30.30
	Cermik beige	50.0	2.65	2.08	76.90	6.58	3.01	29.60
	Yesilova beige	56.0	2.66	0.30	70.50	6.95	4.65	26.50
	Sivrihisar beige 1	62.0	2.70	0.22	80.00	7.05	5.20	25.70
	Sivrihisar beige 2	58.0	2.69	0.22	68.00	6.90	3.70	28.10
	Diyarbakir beige	45.8	2.69	0.46	75.20	6.20	3.61	24.30
	Number of data	11	11	11	11	11	11	11
	Minimum	36.0	2.51	0.20	58.40	4.75	2.61	20.50
	Maximum	67.0	2.70	5.15	126.80	10.38	6.82	41.20
	Average	55.2	2.66	1.16	83.46	7.15	4.43	26.67
	Standard deviation	9.1	0.05	1.46	22.06	1.51	1.47	5.80
Metamorphic	Usak white	47.0	2.70	0.16	69.00	5.25	3.51	25.90
	Kozagac white	40.0	2.60	0.32	42.00	4.18	2.55	36.30
	Milas lilac	46.0	2.63	0.36	55.00	4.95	3.85	26.50
	Afyon cream	46.0	2.71	0.20	64.00	6.21	3.62	25.20
	Afyon violet	53.7	2.70	0.17	84.19	7.44	4.67	22.60
	Kutahya green	48.9	2.70	0.20	75.53	7.69	4.53	23.20
	Afyon sugar	49.5	2.70	0.16	58.13	6.33	2.38	31.30
	Kutahya violet	50.3	2.69	0.35	63.49	6.84	3.60	24.70
	Afyon white	40.4	2.69	0.25	46.26	5.69	2.53	32.20
	Afyon violet 2	43.3	2.69	0.41	46.33	5.39	2.90	31.30
	Kutahya green 2	43.6	2.69	0.35	55.15	5.23	3.25	28.20
	Number of data	11	11	11	11	11	11	11
	Minimum	40.0	2.60	0.16	42.00	4.18	2.38	22.60
	Maximum	53.7	2.71	0.41	84.19	7.69	4.67	36.30
	Average	46.2	2.68	0.27	59.92	5.93	3.40	27.95
	Standart deviation	4.2	0.03	0.09	12.99	1.08	0.77	4.31
Igneous	Andesite1	41.0	2.10	4.97	62.50	5.05	6.10	18.90
	Andesite2	65.0	2.42	3.10	82.50	9.55	8.30	16.10
	Andesite3	63.0	2.39	3.59	81.30	8.86	7.54	16.70
	Andesite4	43.7	2.15	4.43	71.30	6.15	7.10	18.00
	Andesite5	61.4	2.40	3.53	88.70	8.82	8.40	16.50
	Andesite6	66.7	2.45	3.16	81.50	9.25	8.50	15.90
	Andesite7	62.5	2.41	3.35	82.10	9.20	7.84	16.00
	Andesite8	59.3	2.40	3.55	85.10	8.95	8.50	15.40
	Andesite9	61.2	2.37	3.60	88.40	9.10	8.40	16.20
	Andesite10	43.0	2.18	4.70	61.50	5.53	6.58	18.50
	Number of data	10	10	10	10	10	10	10
	Minimum	41.0	2.10	3.10	61.50	5.05	6.10	15.40
	Maximum	66.7	2.45	4.97	88.70	9.55	8.50	18.90
	Average	56.7	2.33	3.80	78.49	8.05	7.73	16.82

SH= Shore hardness; UVW=Unit volume weight; AP=Apparent porosity; UCS= Uniaxial compression strength; TS= Tensile strength; PL= Point load strength; LAA= Los Angeles abrasion.

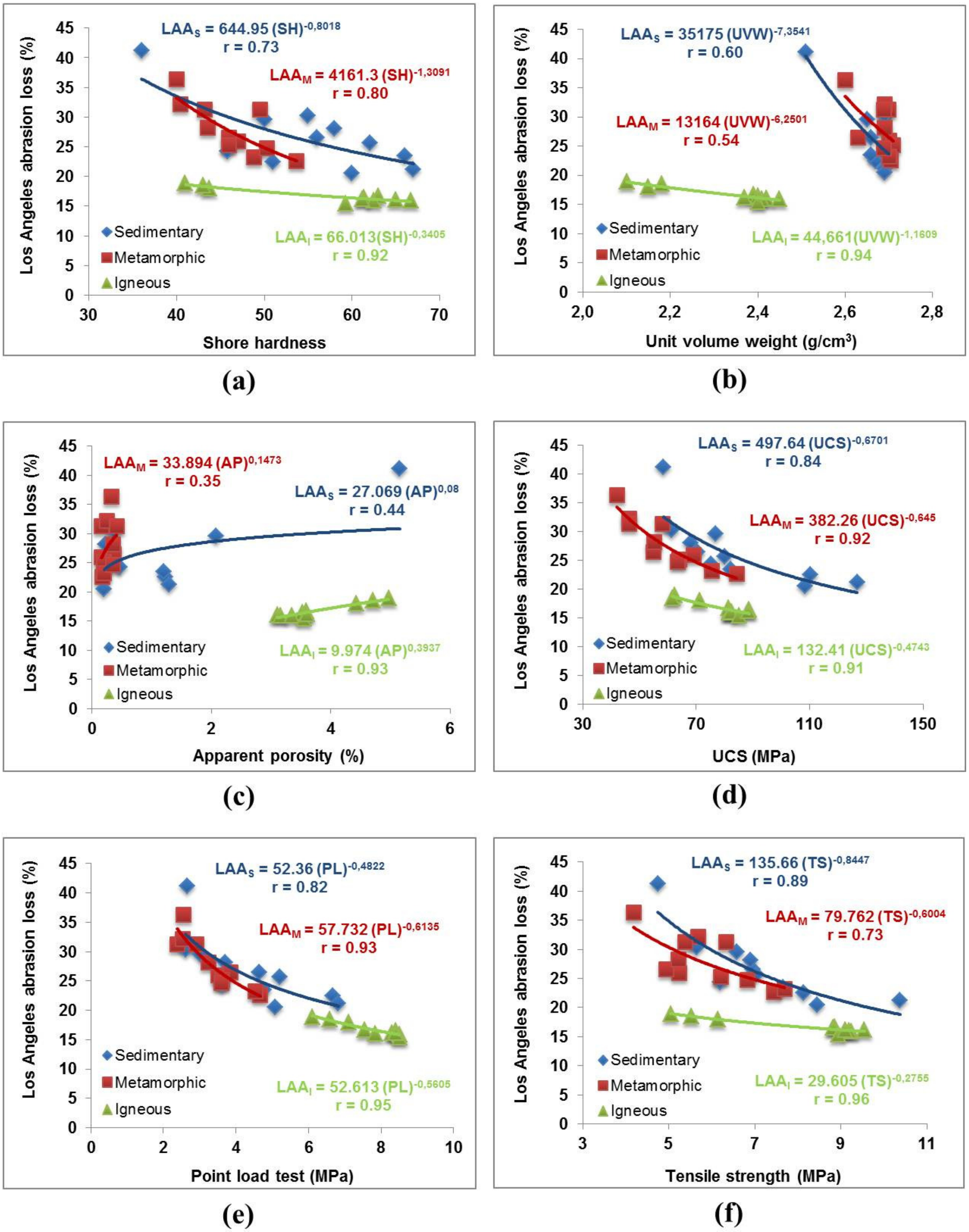

Figure 2. Effect of physical and mechanical properties on LAA loss of sedimentary, metamorphic and igneous rocks.

rocks and SH, UWV, AP, UCS, PL and TS for igneous rocks are the significant properties to predict the LAA. All these properties can be easily determined in laboratory but it is difficult to determine the LAA in the laboratory, and therefore, one of these equations given in Table 3 to predict LAA are appropriate to use.

Table 3. Prediction of LAA from some physical and mechanical properties of rocks.

Dependent variable		Independent variable	Predicted equations	R^2	Sum of squares		Degree of freedom		F-test	Significancy
					A*	B**	A*	B**		
Sedimentary	LAA	SH	$LAA_S = 644{,}95\ (SH)^{-0{,}8018}$	0,53	0,208	0,184	1	9	10,195	0,011
		UVW	$LAA_S = 35175\ (UVW)^{-7{,}3541}$	0,58	0,229	0,163	1	9	12,637	0,006
		AP	$LAA_S = 27{,}069\ (AP)^{0{,}08}$	0,19	0,075	0,317	1	9	2,124	0,179
		UCS	$LAA_S = 497{,}64\ (UCS)^{-0{,}6701}$	0,71	0,280	0,112	1	9	22,462	0,001
		PL	$LAA_S = 52{,}36\ (PL)^{-0{,}4822}$	0,68	0,266	0,126	1	9	19,005	0,002
		TS	$LAA_S = 135{,}66\ (TS)^{-0{,}8447}$	0,79	0,311	0,081	1	9	34,679	0,000
Metamorphic	LAA	SH	$LAA_M = 4161{,}3\ (SH)^{-1{,}3091}$	0,64	0,145	0,082	1	9	15,919	0,003
		UVW	$LAA_M = 13164\ (UVW)^{-6{,}2501}$	0,29	0,066	0,162	1	9	3,661	0,088
		AP	$LAA_M = 33{,}894\ (AP)^{0{,}1473}$	0,13	0,028	0,199	1	9	1,288	0,286
		UCS	$LAA_M = 382{,}26\ (UCS)^{-0{,}645}$	0,85	0,194	0,033	1	9	52,480	0,000
		PL	$LAA_M = 57{,}732\ (PL)^{-0{,}6135}$	0,87	0,198	0,030	1	9	59,870	0,000
		TS	$LAA_M = 79{,}762\ (TS)^{-0{,}6004}$	0,54	0,122	0,105	1	9	10,492	0,010
Igneous	LAA	SH	$LAA_I = 66{,}013(SH)^{-0{,}3405}$	0,85	0,038	0,007	1	8	46,455	0,000
		UVW	$LAA_I = 44{,}661(UVW)^{-1{,}1609}$	0,89	0,040	0,005	1	8	66,578	0,000
		AP	$LAA_I = 9{,}974\ (AP)^{0{,}3937}$	0,86	0,038	0,006	1	8	49,500	0,000
		UCS	$LAA_I = 132{,}41\ (UCS)^{-0{,}4743}$	0,83	0,037	0,008	1	8	37,714	0,000
		PL	$LAA_I = 52{,}613\ (PL)^{-0{,}5605}$	0,90	0,040	0,005	1	8	68,731	0,000
		TS	$LAA_I = 29{,}605\ (TS)^{-0{,}2755}$	0,91	0,041	0,004	1	8	85,089	0,000

*A: Regression and **B: Residual , LAA_S= Los Angeles abrasion for sedimentary rocks; LAA_M= Los Angeles abrasion for metamorphic rocks; LAA_I= Los Angeles abrasion for igneous rocks.

CONCLUSIONS

Laboratory tests were carried out on 32 different rocks including sedimentary, metamorphic and igneous rocks to investigate LAA value of each rock in this study. The LAA characteristics of these rocks and correlations between LAA and physical and mechanical properties of rocks were investigated and the following conclusions were drawn;

1. Among the tested rocks, igneous type rock samples showed more resistance to abrasion than sedimentary and metamorphic type rock samples.
2. Rock properties have certain influence on the LAA of rocks and can be used to predict LAA value of rocks. More abrasion-resistant rocks are likely to have high unit volume weight, uniaxial compressive strength, tensile strength, shore hardness, point load strength and low porosity.
3. Dependence of abrasion characteristics on each rock property investigated by regression analysis showed that high significant correlations exist between LAA and SH, UWV, UCS, PL and TS for sedimentary rocks, SH, UCS, PL and TS for metamorphic rocks and SH, UWV, AP, UCS, PL and TS for igneous rock.
4 As the study included sedimentary, metamorphic and igneous rocks and the LAA values ranged from 20,50 to 41,20 for sedimentary rocks, 22,60 to 36,30 for metamorphic rocks and 15,40 to 18,90 for igneous rocks, the derived equations are widely applicable.

As a result of this study, this study covers sedimentary, metamorphic and igneous rocks and the range of the physical and mechanical properties of rocks and LAA values of them are wide enough for generalization. Concluding remark is that LAA rate can be easily predicted by using the empirical equations given in this study.

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