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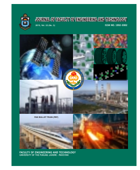

ASSESSMENT OF CERCHAR ABRASIVENESS INDEX BY LCPC ABRASIVITY COEFFICIENT AND STRENGTH PROPERTIES OF SELECTED ROCKS FROM WESTERN SALT RANGE PUNJAB

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Abstract

Ten sedimentary rock samples including sandstones, limestones and an iron ore were collected from various locations of District Khushab, Mianwali and Trans Indus area (Punjab, Pakistan). The samples were subjected to Cerchar and LCPC Abrasivity tests for determination of their abrasivity potential. The Cerchar Abrasivity tests were performed over both sawn and rough rock surfaces. Simple linear regression analysis was performed to establish possible correlations between Cerchar Abrasivity Index (CAI), LCPC Abrasivity Coefficient (ABR) and other physical properties of rocks including UCS and BTS. The validation of developed equations was done by using 95 % confidence interval limits. The work done shows that selected sedimentary rocks from Western Salt Range have low to medium abrasiveness.

Keywords: CAI_s (Cerchar Abrasivity Index over Sawn Rocks);CAI_b (Cerchar Abrasivity Index over Rough Rocks); UCS (Uniaxial Compressive Strength); BTS (Brazilian Tensile Strength); ABR (LCPC Abrasivity Coefficient).

1. Introduction

The abrasiveness of rock is one of the concerning issues for the engineers considering excavation of tunnels either by full face or partial face tunneling machines. Even if the rock is not too strong for mechanized excavation but still rockabrasiveness may lead to wear of cutting tools causing costly tool replacement at frequent rates. Not only tool wear but other associated machine components in contact with rock may also experience wear and cause replacement as well as downtime [1].

For a successful and efficient operation of any mining as well as civil project either on the surface or underground, rock engineer is frequently concerning with the mechanical parameters and abrasiveness of rock concerned. Abrasion control the wear life of cutting tools in any rock excavation operation starting from small holes drilled for blasting to large diameter tunnels bored by the TBM machines [2].

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At present, numbers of tests are available for measurement of rock abrasivity including Petrographic Thin Section, X-Ray Diffraction (XRD), Cerchar Abrasivity Index (CAI), LCPC test, Core Abrasion Test, Modified Taber Abrasion Test and NTNU Abrasivity method. However, Cerchar Abrasivity Index (CAI) is widely accepted for assessment of rock abrasivity due to its simplicity and has been considered to provide a reliable indication of rock abrasiveness [3-5].

The present research is aimed at predicting CAI values from UCS, BTS and ABR (g/ton) of the selected sedimentary rocks, belonging to Western Salt Range, Punjab. At present, most laboratories operating in Pakistan have UCS and BTS testing setups but Cerchar and LCPC testing facilities are not commonly available. The area under study is a hub of mining activities and the proposed Kalabagh Dam site is also located in Western Salt Range, Punjab.

2. Literature Review.

Plinninger et al. [5] depicted that "Abrasive wear" is the predominant wear process in most rock types. Abrasive wear leads to the removal of material from the tool surfaces while it is moving against the rock. This phenomenon is the function of hardness difference between interacting bodies. It is caused by direct contact of tool and hard particles in the rock or contacts between tools and particles in between rock and tool. Many investigators have recommended relations among CAI, ABR, UCS and other physical properties of rocks including Equivalent Quartz Content (EQC), abrasive mineral hardness etc.

W. Jaegar [6] conducted tests to examine the effect of rock strength (UCS) on a homogeneous hardening mortar-quartz mixture having constant mineralogical composition. The plotted results show a linear increase in CAI with rock strength.
Plinninger et al. [5] in a study over 60 rock samples comprising of three generic rock types proposed a fair logarithmic correlation between CAI and Rock Abrasivity Index (RAI). The assessment of RAI is the product of UCS and EQC of rock:-
RAI = UCS x Equivalent Quartz Content ------------- Eq. (1)
Rostami et al. [2] conducted investigations on 15 rock specimens regarding relation of CAI with UCS and EQC. Cerchar abrasivity tests were performed on rough rock surfaces using stylus hardness of 54-HRC. Their investigations resulted in following correlation:
$CAI_{54HRC\text{-}Rough} = 0.0151 \times UCS^{0.788} \times EQC^{0.377}$------------Eq. (2)
Buchi et. al. [7] conducted study on 40 different rock types and presented results in the form of scatter plot between LCPC Abrasivity Coefficient (ABR, g/t) and CAI values.

Thuro et al. [8] reported a linear correlation between ABR (g/t) and CAI for 56 rock samples consisting of all rock types.

3. Experimental Methodology

3.1. Sample Collection

For this research study, ten (3) representative rock boulder samples were collected from Khushab, Mianwali and Trans Indus areas of Western Salt Range Punjab, Pakistan, as shown in the Figure-1.

Figure-1: Location Map of Western Salt Range Punjab

3.2. Sample Preparation

The rock boulders were cored in the laboratory perpendicular to bedding plane using 54 mm and 42 mm core barrels for the performance of Cerchar, UCS and BTS tests. Rocks free from defects(fractures and flaws) were selected. The core preparation was conducted in accordance with ASTM D-4543 procedure [9]. The cores used for the Cerchar testing over sawn rock surfaces were also utilized for UCS and BTS testing. For LCPC testing, chunks of each rock were separated and crushed to get desired size range i.e. -6.3+4 mm.

3.3. Testing Procedure

Universal Compressive Strength (UCS) test was conducted in the laboratory in accordance with the procedure laid down in ISRM suggested methods [10]. The rock cores of length to diameter ratio of approximately2.5:1 were tested using a Schimadzu-200 tons Universal Testing Machine. Brazilian Tensile Strength (BTS) was determined in accordance with the ASTM-D3967. NX-Sized rock discs with height to diameter ratio of 0.5 were utilized to perform the test. The Cerchar test was conducted over sawn surfaces (sawn rock cores) and similarly on freshly broken rough surfaces. The test is based on ASTM D7625-10 standard [11]. Tip loss is measured in 1/10 of mm using the electronic microscope and then reported results, accordingly. Figure 2 showing the Cerchar apparatus for testing CAI.

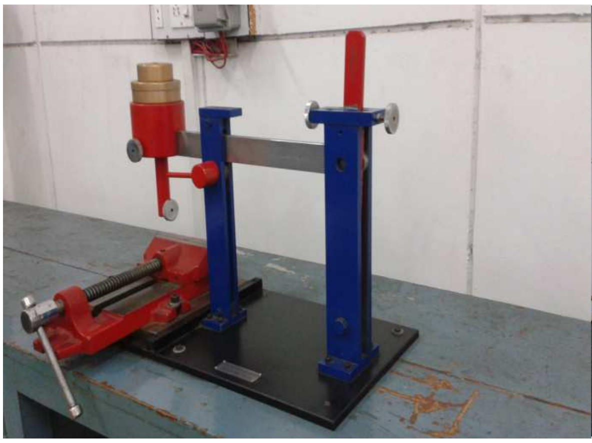

Figure-2: Cerchar Apparatus. **Figure-3: LCPC Apparatus**

LCPC apparatus is shown in Figure-3. For LCPC test performance, 500 grams of crushed rock sample of size range (-6.3+4 mm) was utilized. The steel insert having Rockwell hardness of 60-75 HRB, was placed along with crushed rock material in the mould and rotated at the speed of 4500 rpm for five (05) minutes. The difference in the loss of weight of insert from original weight was calculated as ABR expressed in (g/ton):-

$$ABR\ (g/t) = (m_0 - m) / M$$

Where; ABR= LCPC Abrasivity Coefficient

m_0= Mass of steel insert before test

m = Mass of steel insert after test

M= Mass of testing mineral

4. Test Results and Discussion

4.1. Testing Results

The experimental values of CAI_s, CAI_b, ABR, BTS and UCSof tested rocks are recorded in Table -1. It is observed from testing results that Chichali Iron Ore have lowest values of CAI_s and CAI_b while BTS value is highest. Sandstone from Hangu formation has considerable CAI values but proves to be having very less BTS. Experiments over Laki limestone proves that UCS and BTS values are high enough and corresponding inverse relation with CAI values. It is also noticed after experimentation that the CAI values of same rock type behave considerably different while test performed over sawn and freshly broken surfaces. It is also noticed that Hangu sandstone has shown highest value of ABR among the tested rocks while Chichali Iron ore proves to be very less abrasive as its ABR (g/ton) value is lowest.

Table-1: **Testing Results of Cerchar (CAI_s& CAI_b), ABR, UCS and BTS of Rocks.**

Sr. No.	Rock Sample	UCS (M Pa)	BTS (M Pa)	ABR (g/ton)	CAI_s	CAI_b
1.	Amb Sandstone	46.6	1.7	234	1.49	1.72
2.	Chidru Sandstone	61.62	7.31	224	1.79	1.26
3.	Chichali Iron Ore	51.68	8.04	4	1.04	1.07
4.	Hematitic Sandstone	21.17	2.08	134	1.57	1.47
5.	Hangu Sandstone	16.65	0.8	264	1.36	1.54
6.	Laki Limestone	92.72	7.9	8	1.21	1.2
7.	Speckled Sandstone	11.13	1.33	186	`1.54	1.25
8.	Warcha Sandstone	27.03	1.65	98	1.66	1.25
9.	Wargal Limestone	66.52	5.41	8	1.16	1.29
10.	Siwaliks	17.05	0.85	62	1.35	1.41

UCS= Universal Compressive Strength ;BTS= Brazilian Tensile Strength ; ABR= LCPC Abrasivity Coefficient; CAI_s = Cerchar Abrasivity Index(sawn surfaces); CAI_b = Cerchar

4.2. Analysis of Results

From the experimental results obtained, it is clear that all the rock types found in the Western Salt Range, Punjab, Pakistan are less abrasive but having considerable strength properties. The Values of CAI_s for all tested rock types fall within range of 1.04 to 1.79 while CAI_b values ranges between 1.07 to 1.72 which shows a specific range of abrasiveness. Laki Limestone has been calculated for UCS value of 92.72 MPa which is highest in the group whereas Speckled Sandstone from Warcha Gorge shows a lowest UCS value of 11.13 MPa. Similarly, Brazilian Tensile Strength (BTS) values scatter between 0.8 to 8.04 MPa for the selected rocks from Western Salt Range. ABR value of Hangu Sandstone which is 264 (g/ton) proves to be highest in rock group while ABR of Chichali Iron Ore is only recorded as 4(g/ton).

4.3. Correlation of Results

The past studies show relationships of Cerchar Abrasivity Index (CAI) with ABR and strength properties of rocks like UCS and BTS. Therefore, an attempt has also been made to develop the possible correlations of CAI_s and CAI_b values against corresponding UCS, BTS and ABR (g/t) of rock samples from Western Salt Range, Punjab.

Figure-4 shows a plotting of CAI_s and CAI_b values against UCS of tested rocks. The plotted curves show a decrease in CAI_s and CAI_b with the increase of rock strength which is contrary to work earlier reported by the Jaegar (1987) where in CAI values increase with the increase in UCS. It might be due to presence of softer rocks but having considerable abrasiveness in the selected rocks from the Western Salt Range, Punjab, Pakistan.

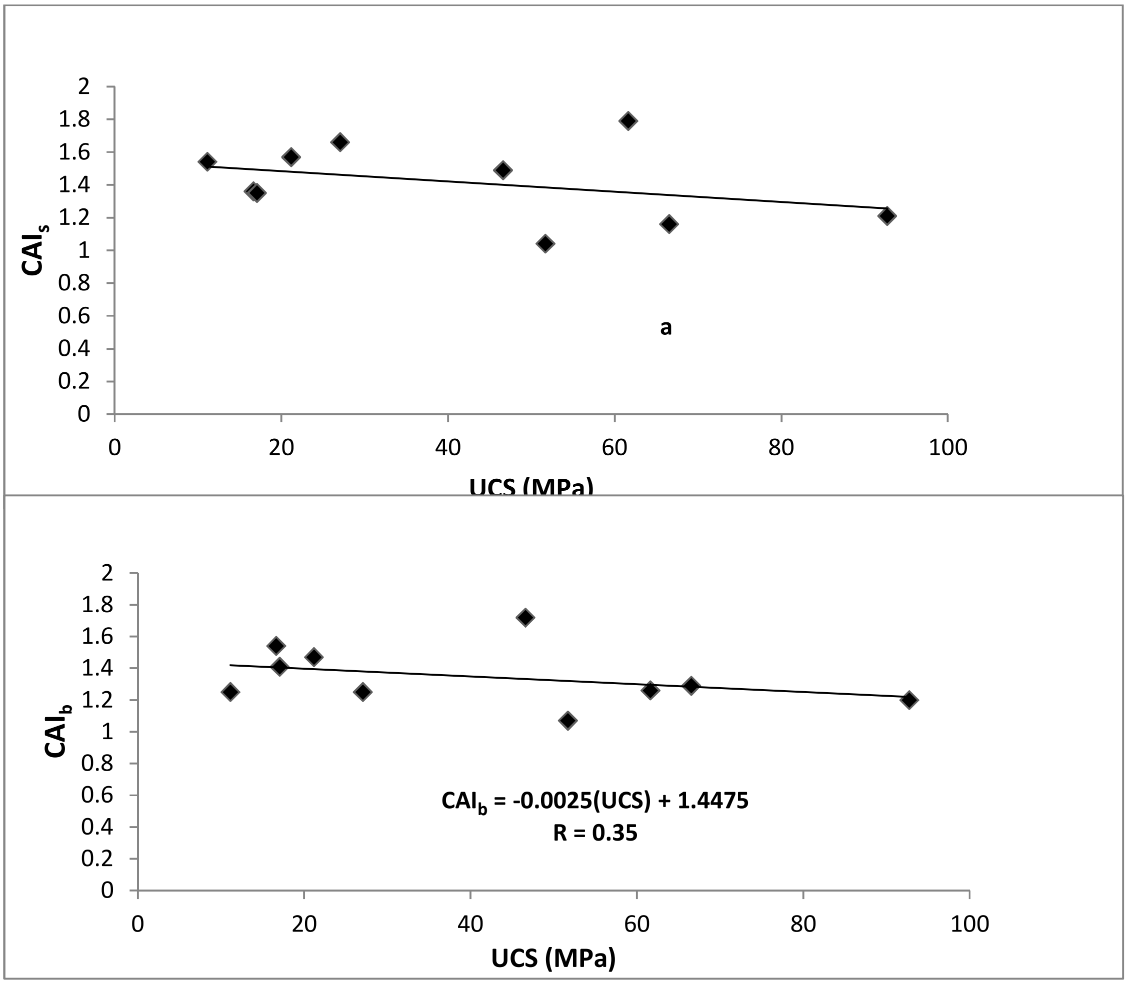

Figure-4: Relationship of CAI_s and CAI_b against UCS of Selected Rocks.

Figure-5 is a plotting of CAI_s and CAI_b values against BTS (MPa) of tested rocks. The plotted curve shows decrease in CAI_s and CAI_b with the increase of rock strength. The obtained value of correlation coefficient (R) for the sawn rock samples is 0.37 which shows scatter when dealing with natural materials like rocks. However, the correlation coefficient (R) for the relationship of CAI_b with BTS is 0.66.The deviation may be explained by the fact that Cerchar Index results obtained over freshly broken surfaces (CAI_b) are higher than those (CAI_s) from sawn surface.

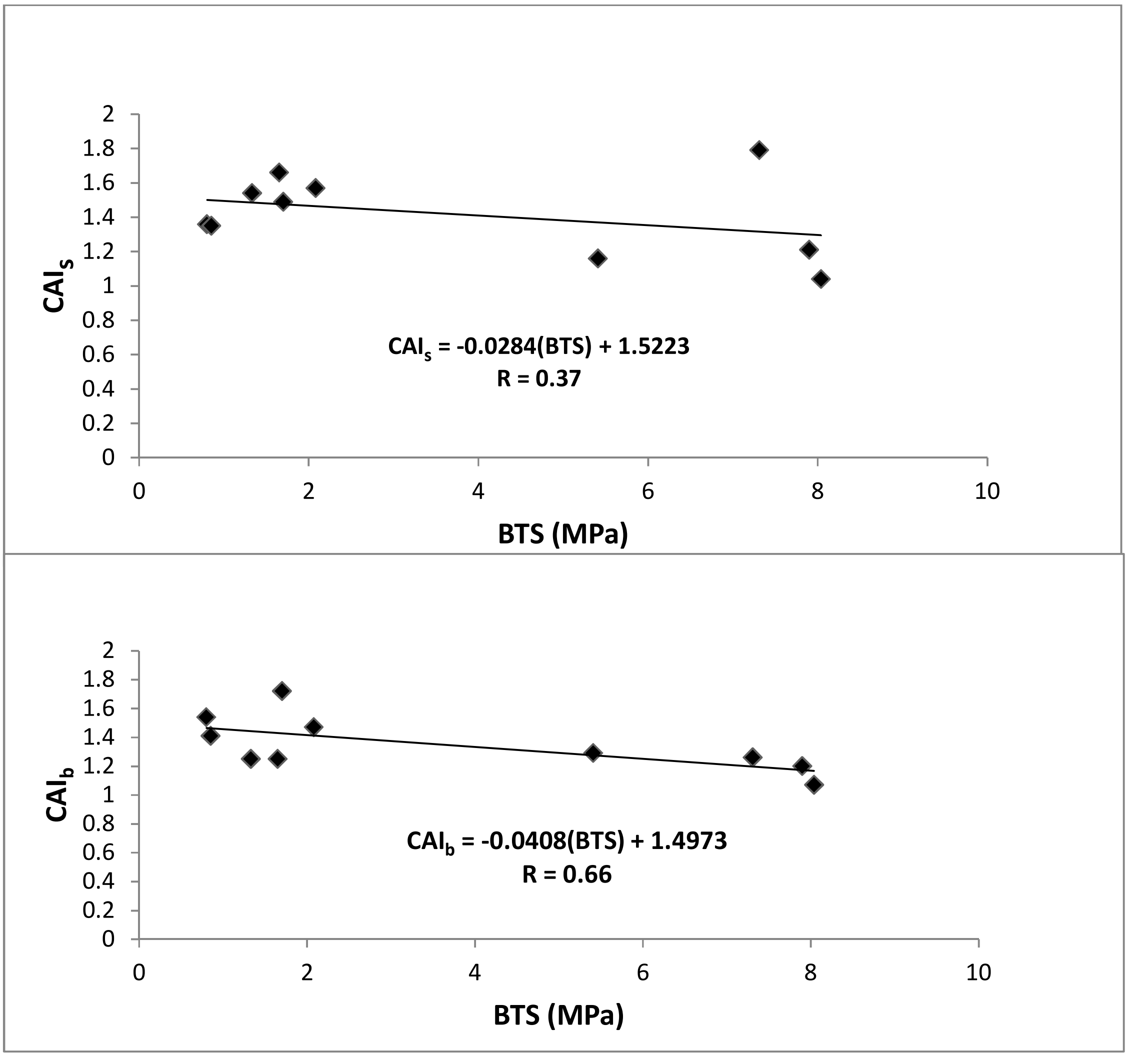

Figure-5: Relationship of CAI_s and CAI_b against BTS of Selected Rocks.

The relations between CAI_s and CAI_b with ABR (g/t) are presented in figure 6. The plotted trends show linear increase of CAI with ABR. The previous studies done by Buchi et al. (1995) [7] and Thuro et al. (2007) [8] also show similar linear trends.

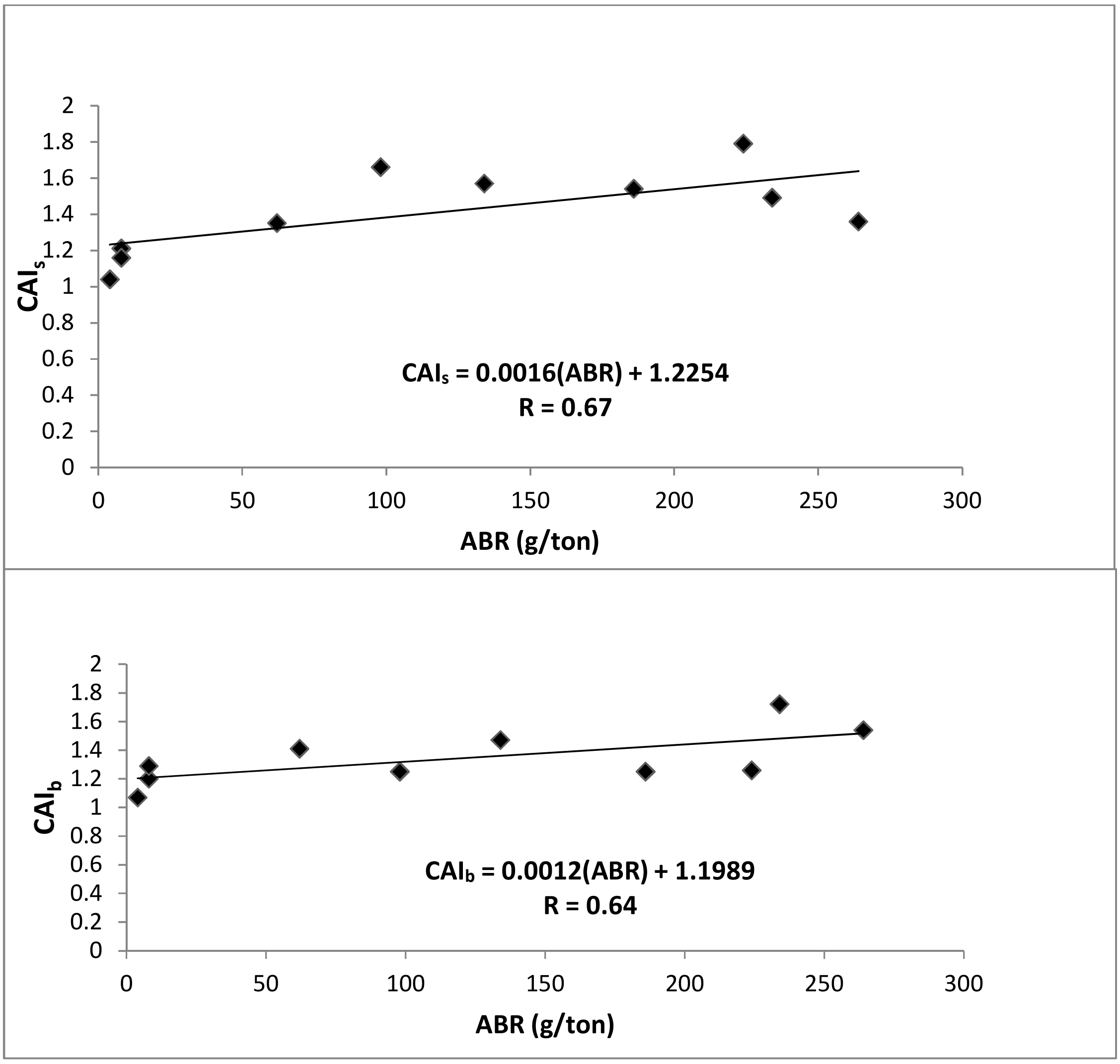

Figure-6: Relationship of CAI_s and CAI_b against ABR Value of Selected Rocks

4.4. Validation of Test Results

The statistical analysis of Cerchar Abrasivity Index (CAI) with UCS, BTS and ABR(g/t) of tested rocks as a linear function, produced the following equations:

$CAI_s = -0.0031(UCS) + 1.5453$ (R = 0.36) ----------- (1)

$CAI_b = -0.0025(UCS) + 1.4479$ (R = 0.35) ----------- (2)

$CAI_s = -0.0282(BTS) + 1.5206$ (R = 0.37) ------------(3)

$CAI_b = -0.0408(BTS) + 1.4963$ (R = 0.67) ------------ (4)

$CAI_s = 0.0016(ABR) + 1.2254$ (R = 0.67) ------------ (5)

$CAI_b = 0.0012(ABR) + 1.1989$ (R = 0.64) -------------(6)

The above mentioned equations have been derived by statistical analysis of data for estimation at 95 % confidence interval. The established relations (4), (5) and (6) show moderate correlation coefficients and therefore can be utilized for the prediction of CAI_s and CAI_b values.

5. Conclusions

The selected rock samples from Western Salt Range were tested for abrasivity evaluation by Cerchar and LCPC methods. According to the unified scale suggested by Thuro et al. (2007) [8], the abrasiveness of selected rocks fall within the range of low to medium abrasiveness. The physical properties were also determined to develop possible correlations with Cerchar and LCPC abrasivity results. The CAI_s and CAI_b values were linearly plotted against UCS, BTS and ABR of rock samples. Both CAI values obtained from sawn and rough surfaces show good linear relationships with ABR (g/t) while CAI_b only holds a fair correlation with BTS. Further, the statistical analysis of developed correlations shows that all estimated values of CAI fall within the 95 % confidence interval level which validates the test results. It is concluded that ABR and BTS values for the selected rocks can be utilized for the assessment of Cerchar Abrasiveness Index while initiating a mining or tunneling project in the Western Salt Range, Punjab, Pakistan.

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