Pakistan Journal of Science (Vol. 66 No. 1 March, 2014)

REDUCED PROPELLER SPEED EFFECTS ON LCPC ROCK ABRASIVITY TEST

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ABSTRACT: Twenty one samples from all three generic rock types were tested for the evaluation of their abrasivity by Laboratoire Central des Ponts et Chaussées (LCPC) test. The LCPC tests were conducted at 2250 rpm, i.e., half of the suggested speed of 4500 rpm. The statistical analyses on the choice of lower speed has shown reasonably good correlations with the suggested speed of 4500 rpm for the measurement of LCPC Abrasivity Coefficient, ABR (g/t) for all the selected rock samples. Further the relationships developed between one group of sedimentary rocks and other group containing igneous and metamorphic rocks has also shown moderate to very good correlations of ABR (g/t) for the lower and suggested speeds tested.

INTRODUCTION

Before the commencement of excavation projects one of the issues of concern to rock engineers is the abrasivity of rock, which is a major factor influencing the overall budget of the project. If underestimated, the project costs usually exceed and cause delays, leading to disputes between the client and the contractor. The assessment of rock abrasivity during a project is also important where the envisaged life of the cutting tools is not being realized. Abrasiveness quoted in quantitative terms can allow alteration in the composition of tool material to fit to the rock conditions thereby saving cost and time in tool replacement.

For measuring the abrasivity of rocks a variety of rock abrasivity measurement methods are availabe including Centre d'Etudes et de Recherches des Charbonnages de France (CERCHAR) abrasivity index test, LCPC test, modified taber abrasion test, core abrasion test, and the NTNU test among many others. Review of different rock abrasivity measurement methods can be found elsewhere (West, 1981; Fowell and Abu Bakar, 2007 and Gharahbagh et al., 2011).

The CERCHAR abrasivity index test is being widely used for the assessment of rock abrasivity in connection with the design of cutting tools of various excavation machines. Thuro et al. (2006) reported that the CERCHAR test can be used for testing individual components such as a gravel sample but the procedure is not feasible for small grains or mixed soil samples. The LCPC abrasivity test on the other hand allows the testing of mixtures containing different grain sizes and representative soil samples.

For LCPC test 500 g of rock ground to grading corresponding to the 4-6.3 mm fraction are used. The test sample is placed in a vertical cylindrical mould of 100 mm diameter. Steel insert (50 x 25 x 5 mm), placed in a horizontal plane at the end of a vertical metallic shaft is immersed in the material. The shaft is aligned on the axis of the mould and driven by a motor at a speed of 4500 rpm. The test consists of turning the insert of grade XC-12(Rockwell B hardness between 60 and 75 HRB or 108 to 136 VPN) steel for 5 minutes and determining the mass, it loses. The mass of the insert is accordingly measured before and after the test, and the abrasiveness is stated as the ratio of loss of mass to initial mass in ten-thousandths (AFTES, 1982).

The use of LCPC test is still not very common, while in the past few years its use for preliminary investigations for underground development projects has been reported in few cases (Fowell and Abu Bakar, 2007). In other studies, the results of LCPC test have been reported to correlate with the wear of the parts of a quarry rock crusher (West, 1981). LCPC test did not gain much recognition among researchers, engineers, and laboratories due to the fact that it does not simulate the actual wear process that occurs in mechanized excavation.

The typical rotational speed of TBM cutter head in soft ground is 1.5 to 2 rpm (Nilsen et al., 2007). The speed of rotation in LCPC test is very high in comparison to the real cases, whereas the contact stresses between rock and the wear plate is not similar to those in field applications. Also, impact has a significant role in the wear process of this method while it is not a very important factor in the wear of mechanized excavation machines, specifically, TBMs (Ghasemi, 2010). Moreover, the suggested speed of 4500 rpm for LCPC test is quite unusual to achieve in ordinary commercial rotating devices (Abu Bakar, 2006).

Apart from the effects of very high propeller rotational speeds the low metal hardness of the LCPC test differs considerably in some cases from the steel qualities used in practice (Büchi et al., 1995). Commonly, alloy and tool steels treated to about 56 to 60 HRC (612 to 698 VPN) are utilized for manufacturing of disc cutter rings (Frenzel, 2011), whereas the steel insert used in LCPC test is 5-6 times softer (XC12 carbon steel of 60-75 HRB or 108 to 136 VPN) than the steel used on a commercial disc cutter rings.

The current study was aimed at analyzing the effect of variation in the propeller rotational speed on the results of LCPC test. Effort has been made to develop a possible correlation between ABR (g/t) measured at half of the suggested speed of 4500 rpm for LCPC test for the selected rock groups.

Experimental Setup

Test samples: Twenty one samples of igneous, metamorphic and sedimentary rocks were selected for the LCPC tests. The rock samples were crushed and sieved to achieve the desired particle size range of 4-6.3 mm as specified by AFTES (1982). Sized rock was weighed to obtain the specified 500 g mass for each test.

Test setup: The LCPC abrasivity testing device is described in the French standard P18-579 and has been developed by the *Laboratoire Central des Ponts etChaussées (LCPC)* in France for testing rock and aggregates (Käsling and Thuro, 2010). For the current research an industrial pillar drill machine provided by Draper Tools Ltd., at the University of Leeds, UK was utilized (Figure 1). The drill was modified to achieve the lower rotational speed of 2250 rpm which was one half of the suggested speed for the LCPC test. For test inserts, mild steel bars of Vickers hardness 170 VPN were cut into pieces of required dimensions. Holes of 10 mm diameter were drilled in the center of each insert for mounting them at the end of a 16 mm diameter metal shaft (Figure 2).

Figure 1. Pillar drill machine at the University of Leeds, UK used for LCPC test.

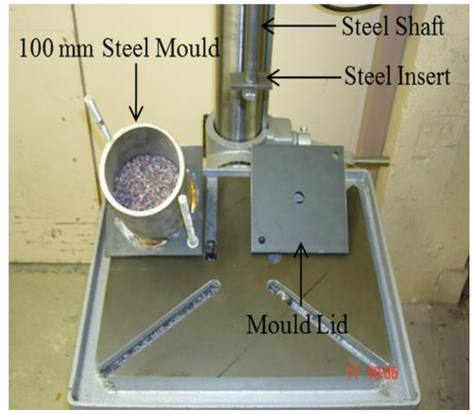

Figure 2. LCPC test setup with steel insert mounted in place and ready for rotation.

Experimental methodology: For each test the weight loss in grams of the steel insert per ton of sample was measured to calculate the LCPC Abrasivity Coefficient, ABR (g/t) by the following equation (Büchi et al., 1995):

$$ABR(g/t) = \frac{P_{o-}P}{G_0} \qquad (1)$$

Where

P_o= Weight of steel insert before test (g)

P= Weight of steel insert after test (g)

G_0= Weight of sample (t).

RESULTS AND DISCUSSION

The LCPC abrasivity test results at propeller rotational speeds of 2250 rpm and 4500 rpm are given in Table 1, whereas Figure 3 shows a bar chart for ABR (g/t) values at speeds of 2250 rpm and 4500 rpm for the selected rock types. The rationale behind the choice of propeller rotational speeds was the fact that rotation at 4500 rpm for 5 minutes makes 22500 revolutions, which is equal to rotation at 2250 rpm for 10 minutes. The lower speed of 2250 rpm was chosen to establish whether the mass loss at lower speed is the same as with the higher speed of 4500 rpm.

The scatter plot of LCPC test results at the reduced speed of 2250 rpm for the selected rock types is shown in Figure 4. Reasonably good correlation between ABR (g/t) 2250 and ABR (g/t) 4500 exists with R^2 value of 0.86.

If plotted separately (Figure 5), most of the soft sedimentary rocks show a distinct trend with R^2 value of 0.72; whereas hard igneous and metamorphic rocks show a different trend with very good R^2 value of 0.95. Some high values of ABR (g/t) were noted in the case of sedimentary rocks at both 2250 and 4500 rpm, which may be attributed to the hard mineral content especially quartz present in those samples showing that strength of the rock was not a dominant factor in abrading the steel inserts. Some outliers in the sedimentary rock samples showed very different values of ABR (g/t) at both the tested speeds, which is attributed to the very high uniaxial compressive strength (UCS) of those rock samples. In case of igneous and metamorphic rocks very high values of ABR (g/t) were noted at the suggested speed of 4500 rpm. An approximate 50-60% reduction in ABR (g/t) was noted at lower speed of 2250 rpm, showing that the strength of the rock is the dominant factor playing its role in abrading the steel insert used in the LCPC test.

Table 1: Summary of ABR_{2250} (g/t) and ABR_{4500} (g/t) for Tested Rock Samples

Rock Tested	ABR_{2250} (g/t)	ABR_{4500} (g/t)
Anhydrite	20	20
Limestone	40	40
Sandstone 2	340	180
Sandstone 3	200	180
Penrith Sandstone	60	280
St.Bees Sandstone	220	120
Siltstone	260	180
Greywacke	580	1080
Grey Granite	700	1100
Dark Pink Granite	720	1300
Pink Granite	560	940
Dolerite	580	1080
Minnesota Gray Granite	720	1460
Granite	740	1480
Felsic Gneiss	840	1300
Pennant Sandstone	700	740
Woodkirk Sandstone	540	240
Flint	660	1420
Peridotite	40	40
Serpentinite	20	20
Fe-Ni Ore	500	880

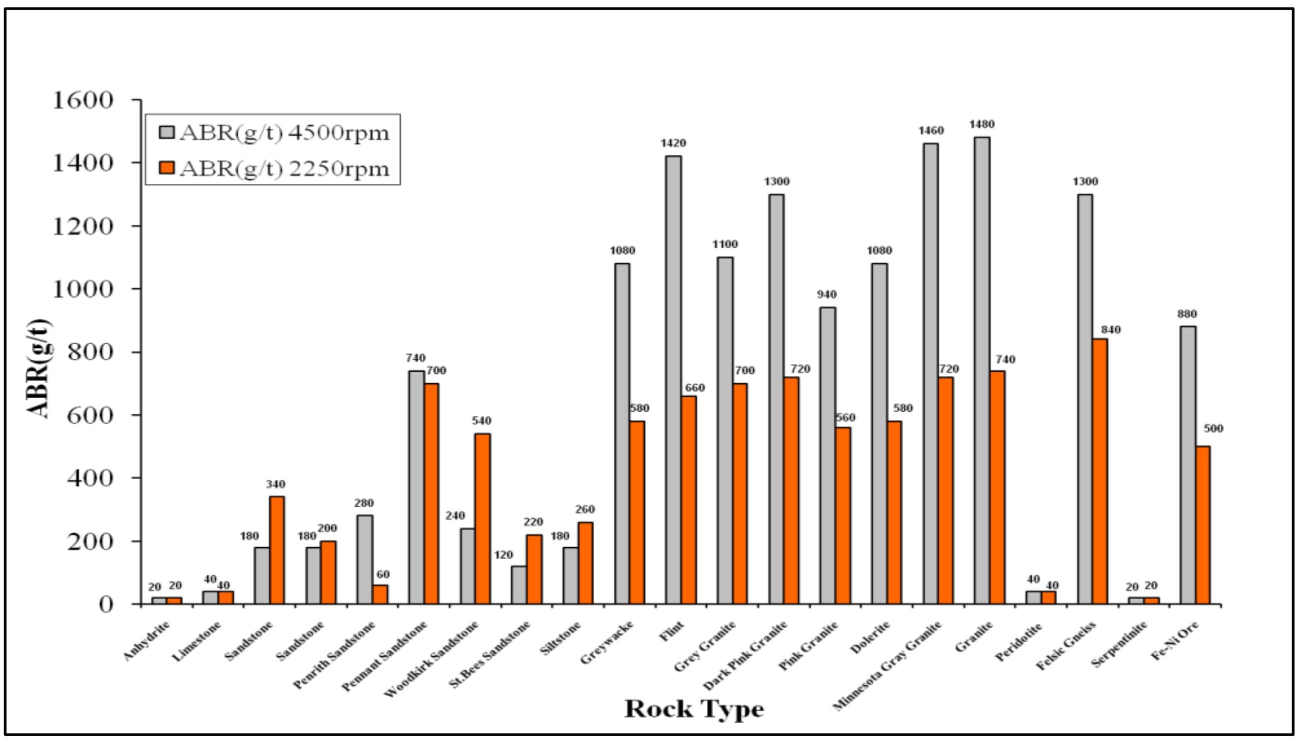

Figure 3: Comparison of ABR (g/t) values for 4500 rpm and 2250 rpm.

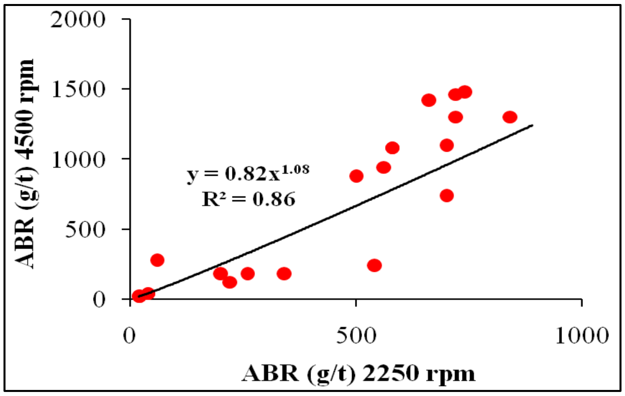

Figure 4. Correlation between ABR (g/t) values for two tested speeds all rocks.

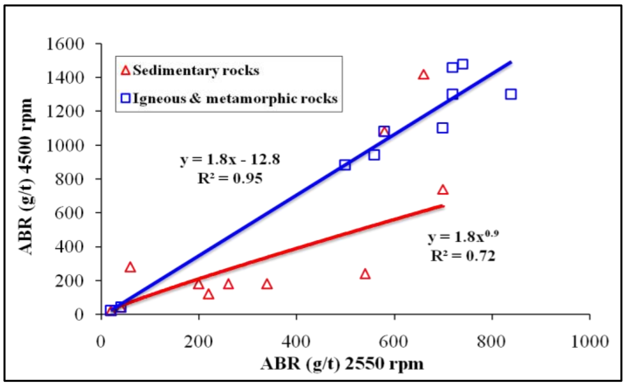

Figure 5. Correlation between ABR (g/t) values for two tested speeds for two rock groups

Conclusions: The representative rock samples belonging to all three generic rock types were tested for their abrasivity evaluation by adopting a reduced speed of 2250 rpm and the suggested speed of 4500 rpm for the LCPC tests. The LCPC abrasivity coefficient ABR (g/t) values at 2250 rpm and 4500 rpm for all rock types showed reasonably good correlation with R^2 value of 0.86. When the LCPC test results were examined group wise, the sedimentary rocks showed a moderate correlation with R^2 value of 0.72; whereas very good correlation with R^2 value of 0.95 existed for the combined group of igneous and metamorphic rocks. Comparison of LCPC test results illustrate that twelve rock samples showed higher ABR (g/t) values at the suggested speed of 4500 rpm which may be due to high strength of the rocks abrading the steel insert by elevated impact energy. On the other hand five samples demonstrated very high ABR (g/t) values at the reduced speed of 2250 rpm possibly due to the presence of hard mineral content especially quartz. Finally four rock samples gave equal ABR (g/t) values showing that two speeds have no effect on the abrasion of steel insert that may be attributed to the absence of hard mineral contents or low uniaxial compressive strength (UCS) of the samples.

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