Determining the LCPC abrasivity of sand and gravel in project of Hanoi pilot light metro line, section Nhon – Hanoi railway station

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ABSTRACT: For underground construction, the abrasivity of sand and gravel need to determine because it affects the tool wear and excavation performance. The paper represents the abrasivity properties of sand and gravel distributed in Nhon – Ha Noi station Metro line. The abrasivity parameters include LCPC Abrasivity Coefficient (LAC) and the LCPC breakability coefficient (LBC). For determining these parameters, the apparatus LCPC was designed in the laboratory of LAS -XD 442 in order to meet the requirement stipulated of the French Standard P18-579 (2013). A lot of abrasivity tests were carried out on sand and gravel. The results of experiment showed that, sand can be classified LAC. LAC varies from 52 g/l to 1683.45 g/l, abrasivity of sand ranges from not very abrasive, slightly abrasive to extremely abrasive. For gravel, besides the LAC, the LBC was also determined. LBC of gravel varies between 45 and 55%. Gravel can be classified as extremely to medium breakability. The results also indicated that the factor affecting the sand and gravel abrasively is particle size (gravel content, sand content).

1. INTRODUCTION

Nowadays, construction of underground grows rapidly in Vietnam. Many projects are being implemented such as Nhon – Ha Noi station Metroline, Ben Thanh - Suoi Tien Metroline in Ho Chi Minh city. TBM technology is often used for tunnelling construction. For TBM technology, the abrasivity of soil (sand, gravel...) needs to be determined. It affects the tool wear, excavation performance and causes damages to TBM cutter ads on hundreds of tunnel projects around the world (Nilsen et al., 2006, 2007). In addition, the soil abrasion also affects the TBM tunneling in soft ground (Kim et al., 2019).

There are four methods often used to determine the abrasivity properties of rock and soil, including the Cerchar abrasivity test, LCPC abrasivity test, NTNU/SINTEF soil abrasion test and Penn State Soil Abrasion Index (PSAI) test (Kahraman et al., 2016). The comparison between Cerchar abrasivity test and LCPC abrasivity test are shown in Büchi et al. (1995). Penn State Soil Abrasion Index (PSAI) test is performed for soft ground. For sand and gravel, the suitable method is LCPC abrasivity test.

LCPC abrasivity device is described in the French standard P18-579 and was developed by the Laboratoire Central des Ponts et Chausées (LCPC) in France (Thuro et al., 2007; Käsling et al., 2010). Thuro et al. (2007) studied a new approach to rock and soil abrasivity testing. It found that the LCPC abrasivity coefficient can be used to classify soil and rock. Thuro et al. (2009) established the chart for classification of the abrasiveness of soil and rock. Käsling et al. (2010) used the Cerchar abrasivity test to predict the abrasivity assessment of rocks and tool wear. They confirmed that the Cerchar Abrasivity Index and the LCPC Abrasivity Coefficient were used for abrasivity classification. It is the basic to

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determine the abrasivity of rock and soil in the world.

The abrasivity depends on many factors (Kahraman et al., 2016). After carrying out some the LCPC abrasivity tests of coarse-grain igneous rocks, the authors stated that the LAC was correlated to the abrasive mineral content, shape and size coefficient.

In Vietnam, there are limited to study about this subject. Thus, the paper aims at:

- Designing and madding equipment for LCPC abrasivity test;
- Testing and classification the coarse soil (gravel and sand soil) in Nhon – Ha Noi station Metroline;
- Indicating some factors that affect the abrasivity of sand and gravel.

2. DESIGNING AND MADDING EQUIPMET FOR LCPC ABRASITIVY

The apparatus LCPC was designed in the laboratory of LAS - XD 442 which meets the requirement stipulated in the French Standard P18-579 (2013). This apparatus can determine the abrasivity of sand and gravel.

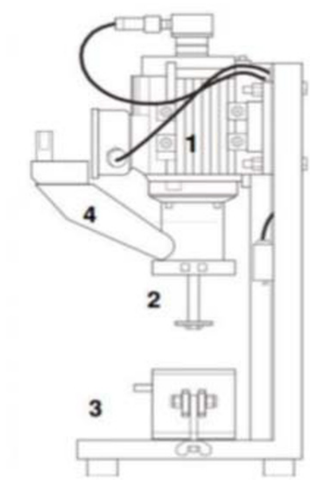

Figure 1. LCPC abrasivity testing device. 1-motor; 2-metal impeller; 3- sample container, 4- funnel tube (Thuro, 2007; Kahraman et al., 2016).

Test equipment was designed similarly to Thuro's LCPC abrasivity testing device (Figure 1). Test equipment for LCPC abrasivity test includes some key components as follows:

- *Motor of apparatus* (Figure 2a). The minimum capacity of motor is 750 W and the speed of motor is 4500 rpm.
- *Metal impeller* (Figure 2b): The 25×50×5 mm rectangular impeller is made of standardized steel with a Rockwell hardness of HRB 60-75 (NF EN10277-2).
- *Sample container*: Cell body of 93 mm in internal diameter and 100 mm in high is made of standardized steel (Figure 3a).
- *Funnel tube*: is fixed to the body of device for safe (Figure 3b).

The LCPC abrasivity apparatus designed by the LAS - XD 442 is shown in Figure 4.

Figure 2. (a) Motor; (b) Metal rectangular impeller

Figure 3. (a) Sample container (b) Funnel tube

Figure 4. (a) LCPC abrasivity apparatus, (b) LCPC abrasivity apparatus when testing.

3. MATERIALS AND METHODS

3.1 *Test site and soil types*

For studying the abrasivity of soil, all samples were taken from the boreholes in Nhon - Ha Noi station

Metro line, Hanoi, Vietnam. The sand and gravel samples belong to the Vinh Phuc and Ha Noi formation respectively. Sand, gravel soil is distributed at the depth from 10 to more than 30 m. The N_{SPT} value changes from 12 to more than 50.

Some physical properties of sand samples were determined. The particle size analyses and the classification of soil were carried out according to ASTM D422, D2487 in respective. All testing was conducted in the laboratory of LAS - XD 442 of Institute of Foundation and Underground Engineering, GOLDEN EARTH Infrastructure Engineering Consultants JSC.

The results are shown in Table 1. The classification of soil showed that soils are heterogeneous, compose of poorly graded sand (SP), Well- graded sand (SW), poorly graded sand with silt (SP-SM), Silty sand (SM) and Silty, clayey sand (SC-SM), and poorly graded gravel (GP). The SP, SW, SP-SM, SW-SM soils contains less than 12% of silt, clay content. SM, SC-SM contains more than 12% of silt, clay content. The abrasivity test procedures include steps as follows

3.2 *Sample preparation*

First, collecting about 2 kg of soil samples and drying in oven at temperature of $110^0 \pm 5^{oC}$. Then, the sample was weighed and sieved through the following set of sieves of 6.3 mm, 4 mm. The mass of soil retained on each sieve was measured.

The soil mass passing through 6.3 mm and retained on 4 mm were used for abrasivity test. It means that the LCPC test was used for particle size between 4 and 6.3 mm.

3.3 *Test procedures*

Mass of steel impeller was recorded. The steel impeller was placed on the spindle, the soil sample was then put on and the device spinned at a speed of 4500 ± 50 rpm for 5 minutes. Then, the mass of steel impeller also was recorded.

After the rotation is completed, the sample was sieved through the 1.6 mm sieve. Finally, the materials which do not pass through the 1.6 mm sieve was weighed.

Table 1. The results of particle size and specific gravity of gravel, sand sample

No	No. sample	Bore hole	Depth of sample m	Cobble and gravel > 4.75 mm %	Sand 4.75-0.075 mm %	Silt and clay < 0.075 mm %	Δ, g/cm^3	Soil classification ASTM D2487
1	TN1	K1	15.8	0.0	94.3	5.7	2.71	SP-SM
2	TN2	K1	23.7	2.3	93.1	4.6	2.65	SP-SM
3	TN3	K2	17.7	0.0	92.9	7.1	2.65	SP-SM
4	TN4	K2	21.7	0.4	95.5	4.1	2.64	SP
5	TN5	K3	16.5	0.8	68.6	30.6	2.64	SP
6	TN6	K3	21.5	0.6	74.1	25.3	2.68	SC-SM
7	TN7	K4	15.7	0.3	82.0	17.7	2.66	SC-SM
8	TN8	K4	25.7	0.5	75.4	24.1	2.65	SC-SM
9	TN9	K4	27.7	0.0	89.9	10.1	2.67	SP-SM
10	TN10	K4	29.7	0.3	88.1	11.6	2.64	SP-SM
11	TN11	K4	36.0	54.1	44.9	0.9	2.66	GP
12	TN12	K5	13.6	0.6	72.7	26.7	2.66	SC-SM
13	TN13	K5	15.0	2.4	55.2	42.3	2.66	SC-SM
14	TN14	K5	22.7	1.0	69.0	30.0	2.67	SM
15	TN15	K5	24.7	1.2	68.4	30.4	2.65	SC-SM
16	TN16	K5	26.7	0.2	70.1	29.7	2.67	SM
17	TN17	K6	14.6	0.0	70.4	29.6	2.66	SC-SM
18	TN18	K7	21.5	3.6	54.4	42.0	2.66	SC-SM
19	TN19	K7	29.5	27.8	67.6	4.6	2.66	SW
20	TN20	K7	33.5	82.5	17.5	0.0	2.65	GP
21	TN21	K8	13.6	0.0	96.6	3.4	2.69	SC-SM
22	TN22	K8	27.6	1.2	82.8	16.0	2.67	SC-SM

The parameters of abrasivity of sand include LCPC Abrasivity Coefficient (LAC) and the LCPC breakability coefficient (LBC) (Thuro et al., 2007) are calculated as bellow:

The LCPC abrasivity coefficient (LAC) is defined as the mass loss of the impeller divided by the sample mass (500 g):

$$LAC = (m_0 - m) / M \quad (1)$$

where LAC is LCPC abrasivity coefficient (*g*/*t*); m_0 is mass of the steel impeller before test (*g*); m is mass of the steel impeller after test (g); M is mass of the sample material (= 0.0005t).

The LCPC breakability-coefficient (LBC) is defined as the fraction below 1.6 mm of the sample material after the test:

$$LBC = \frac{M_{1.6} 100}{M} \quad (2)$$

Table 2. Classification of the LAC according to Thuro et al. (2007)

LAC (g/t)	Abrasivity classification
0-50	not abrasive
50-100	not very abrasive
100-250	slightly abrasive
250-500	medium abrasive
500-1250	very abrasive
1250-2000	Extremely abrasive

where LBC is LCPC-Breakability-Coefficient (%); $M_{1.6}$ is mass fraction < 1.6 mm after LCPC test (g); M is mass of the sample material (= 0.0005*t*).

The abrasivity classification can be based on the LCPC abrasivity coefficient LAC (Table 2). The breakability classification can be based on the LCPC Breakability-Coefficient (Table 3).

Table 3. Classification of the LBC according to Büchi et al. (1995)

LBC (%)	Breakability classification
0-25	low
25-50	medium
50-75	high
75-100	very high

4. RESULTS AND DISCUSSION

The results of LCPC abrasivity are shown in Table 4 and Figure 6.

It can be observed from Table 4 and Figure 5 that:

- The LAC of sand (SP, SM, SC-SM, SP-SM) changes from 52 *g/l* to 244.52 *g/t*.
- The LAC of Well – graded sand with gravel (SW) is 1636.10 *g/t*.
- The LAC of poorly graded gravel (GP) varies from 1582.83 *g/t* to 1683.45 *g/t*.
- The LBC changes from 45 to 55% due to the content of sand and gravel.

According to the abrasivity classification in Table 2, sand (SP, SM, SC-SM, SP-SM) can be classified from not very abrasive to slightly abrasive. Well – graded sand with gravel (SW) can be classified as extremely abrasive. Poorly graded gravel (GP) can be classified as extremely abrasive. According to the breakability classification in Table 3, gravel (GP) and sand with gravel (SW) can be classified as medium level.

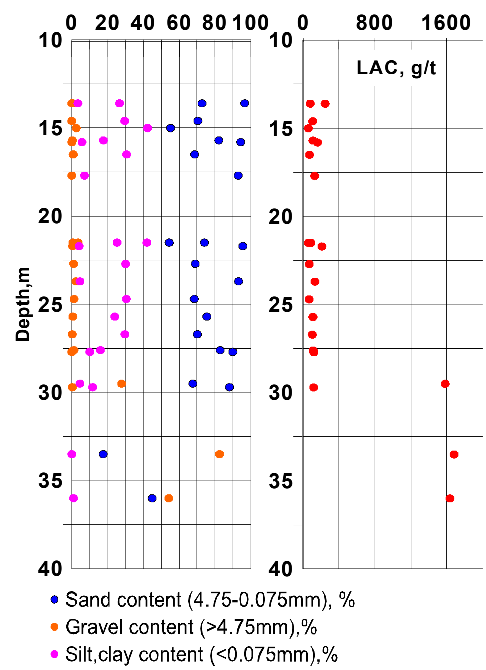

Figure 5. The result of particle size analysis and the LCPC testing.

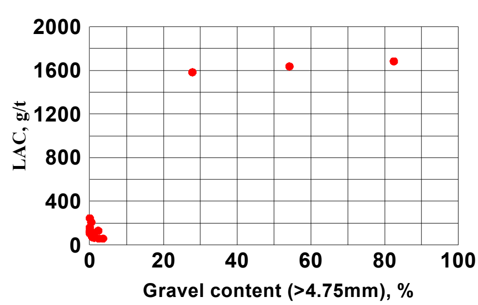

Figure 6. The relationship between LAC, g/t and gravel content, %.

Table 4. The result of test

No sample	No steel	Before test: Weight steel (g)	Before test: Weight of Dry sand (g)	After test: Weight steel (g)	After test: Wei. of sand above 1.6 (g)	After test: Wei. of sand pass 1.6 (g)	The LCPC Abrasivity Coefficient LAC, g/t	The LCPC break ability Coefficient LBC, %	Abrasivity classification (Thuro et al. 2007)
TN1	8	50.07	500.82	49.99			159.74		slightly abrasive
TN2	11	49.88	500.98	49.82			129.75		slightly abrasive
TN3	20	48.86	501.52	48.79			127.61		slightly abrasive
TN4	22	49.22	508.12	49.12			206.64		slightly abrasive
TN5	32	50.163	501.36	50.13			69.81		not very abrasive
TN6	35	47.43	500.20	47.38			85.97		not very abrasive
TN7	45	47.92	500.40	47.86			107.91		slightly abrasive
TN8	50	48.85	501.12	48.80			107.76		slightly abrasive
TN9	51	51.31	501.00	51.25			119.76		slightly abrasive
TN10	52	48.79	500.15	48.74			115.97		slightly abrasive
TN11	101	49.56	500.58	48.74	262.87	237.71	1636.10	47.49	extremely brasive
TN12	63	48.89	500.16	48.85			77.98		not very abrasive
TN13	64	49.08	501.65	49.05			57.81		not very abrasive
TN14	68	48.55	500.86	48.52			67.88		not very abrasive
TN15	69	50.07	500.66	50.03			65.91		not very abrasive
TN16	70	48.52	500.58	48.47			101.88		slightly abrasive
TN17	82	47.85	501.12	47.79			105.76		slightly abrasive
TN18	97	47.85	500.07	47.82			57.99		not very abrasive
TN19	53	50.21	500.37	49.42	208.95	291.42	1582.83	58.24	extremely abrasive
TN20	103	50.69	501.35	49.84	265.21	236.14	1683.45	47.10	extremely abrasive
TN21	113	49.91	507.11	49.79			244.52		slightly abrasive
TN22	119	48.35	503.87	48.29			109.16		slightly abrasive

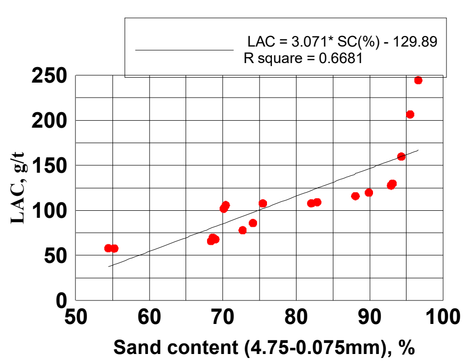

Figure 7. The relationship between LAC, g/t and sand content in sandy soil, %.

The results indicate that the factor affects the abrasivity of sand and gravel which is gravel content in soil sample (Figure 6), the abrasivity of sand is influenced by sand content (Figure 7).

Figure 6 shown that the LAC increases as the gravel content increases. It can be found that the abrasivity of gravel is higher than that of sand, silt and clay.

The abrasivity of sand is also affected by sand content (Figure 7). It can be found that the LAC increases as the sand content increases. This is consistent with the research result of Thuro et al. (2007).

5. CONCLUSIONS

Based on the analysis of research results, the following conclusions can be drawn:

The Abrasivity Coefficient (LAC) of sand and gravel varies between 52 g/l and 1683.45 g/l.

The abrasivity of sand ranges from not very abrasive, slightly abrasive to extremely abrasive.

The LBC of gravel varies from 45 to 55%. Gravel (GP) and sand with gravel (SW) can classified as extremely abrasive and medium breakability.

The sand and gravel abrasivity depend on particle size such as gravel content, sand content.

The abrasivity of gravel and sand sample is extremely abrasive and higher than that of sand, silt and clay sample.

6. REFERENCES

Büchi E., Mathier J.-F., Wyss. Ch. (1995). Rock abrasivity – a significant cost factor for mechanical tunneling in loose and hard rock. *Tunne*l, No 5, pp 38-43.

Kahraman S., Fener M., H (2016). The influences of textural parameters of grains on the lcpc abrasivity of coarse-grained igneous rocks. *Tunnelling and Underground Space Technology*. 58, pp216–223.

Käsling H. & Thuro K. (2010). Determining rock abrasivity in the laboratory. *Conference: European Rock Mechanics Symposium EUROCK 2010*, Lausanne, Switzerland.

Käsling H. & Thuro K. (2010). Determining abrasivity of rock and soil in the laboratory. *Geologically Active – Williams et al. (eds)*, Taylor & Francis Group, London, ISBN 978-0-415-60034-7.

Kim D. Y., Kang H.B., Shin Y.J., Jung J.H., Farrokh E. (2019). Chapter 3, Soil abrasion and penetration test for the evaluation of soft ground TBMs' excavation performance and cutter life. Tunnels and Underground Cities. Engineering and Innovation Meet Archaeology, Architecture and Art. *Proceedings of the WTC 2019 ITA-AITES World Tunnel Congress,* Naples, Italy.

Nilsen B., Dahl F., Holzhäuser J. & Raleigh P. (2006). Abrasivity testing for rock and soils. *Tunnels and Tunneling International*. April 2006, pp47.

Nilsen B., Dahl F., Holzhäuser J. & Raleigh P. (2006). Abrasivity of soils in TBM tunneling. *Tunnels and Tunneling International*. March 2006, pp36.

Nilsen B., Dahl F., Holzhäuser.J & Raleigh.P (2007). New test methodology for estimating the abrasiveness of soils for TBM tunneling. In: Traylo, M.T., Townsend, J.M. (Eds.), *Rapid excavation and Tunning Conference (RETC),* Toronto, Canada, pp. 104-116.

NF P18-579 Février (2013). Granulats - Détermination des coefficients d'abrasivité et de broyabilité.

Thuro, K. & Käsling, H (2009). Classification of the abrasiveness of soil and rock. *Geomechanics & Tunnelling.* 2: 179188.

Thuro, K., Singer, J., Käsling, H. & Bauer, M. (2007). Determining abrasivity with the LCPC Test. In E. Eberhardt, D. Stead & T. Morrison (eds.). *Proceedings of the 1st Canada – U.S. Rock Mechanics Symposium*, Vancouver B.C., London: Taylor & Francis.