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Study on the Influence of Ground Characteristics on Wearing of Shield Machine Cutter Bit in Gravel Ground

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Abstract

Infrastructure development in urban areas has progressed rapidly, and the demand for construction of pipes for electricity, gas, water supply and sewerage, etc. is increasing. In the urban construction of pipe, the non-open cut method is generally used to prevent traffic disturbance, building influence, noise and vibration, one of which is a Shield method. Shield method is a construction method that rotates the cutter head at the tip of the shield machine, excavates the ground, and constructs an underground pipe ditch.

In recent years, construction condition of Shield method is diversified such as long distance, great depth, high water pressure and gravel ground, etc. Bit wear is a factor affecting workability and economic efficiency in Shield method, and the various investigations have been discussed so far, but the quantitative guidelines on bit wear prediction have not been established because the wear factor is complicated in the gravel ground. This study was conducted in order to obtain fundamental knowledge for predicting bit wear in gravel ground.

Keywords: Shield Method, Bit Wear, Gravel Ground, Lathe Bit Wear Test

1. Introduction

The shield machine has the cutter head with bits as shown in Fig.1, and the ground is excavated by rotating the cutter head and pushing it by thrust jacks. However, the bit wear during cutting operation is inevitable. As the bit wear has an obvious impact on the construction progress and cost, such as lowering of drivage efficiency, increasing the frequency of bit replacement, etc (H. Shimada et al, 1989). Therefore, the prediction of cutter bit wear in advance is important. However, there is few research on the characteristics of bit wear in gravel ground and the prediction method of the bit wear in theoretically and quantitatively.

From above point of view, this paper discusses the effects of characteristics of gravel and the gravel content on the characteristics of bit wear in gravel ground based on the results of a series of laboratory tests for the simulated sample of the gravel ground in order to develop the prediction method of bit wear for excavation in gravel ground.

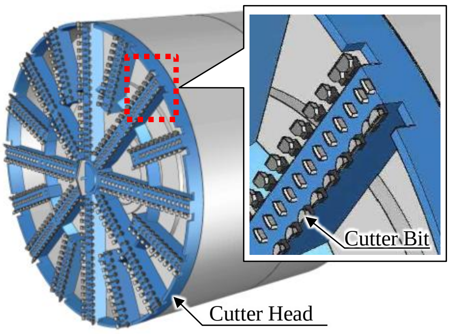


Fig. 1. Shield Machine

Table.1. Property of Gravel

Rock Type	UCS(MPa)	Quartz (%)
Sand stone	27.6	21.4
Andesite	48.1	6.3
Granite	62.9	46.9

2. Laboratory Tests-1

2.1 Preparation of the samples

Three different types of rock: sandstone, andesite and granite, were used as the gravel. As the properties of gravel seems to affect the characteristics of gravel ground, the uniaxial compressive test was conducted by using three types of rock used as gravels of specimen. And the XRD analysis was also conducted in order to measure quartz content because the quartz is high harmful mineral and has a significant impact on bit wear (K. Kataoka et al, 1960). The specimen of gravel ground was made of gravel and cement in this research as shown in Fig.2.

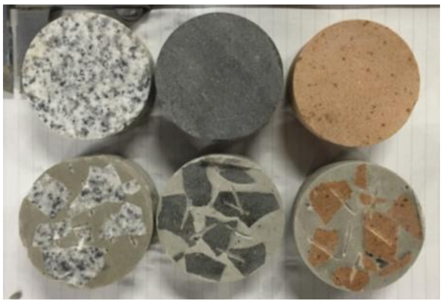


Fig. 2. Specimen of Gravel Ground

The size of gravel was from 10 to 20mm. Portland cement was used as the binding material of the specimen. The gravel contents of specimens were changed as 0, 25, 50, and 75%.

2.2 Bit Wear Tests

Cerchar Bit Abrasive Test

It is necessary to evaluate the abrasivity of gravel and gravel ground in order to predict the amount of bit wear in quantity. The Cerchar bit abrasive test was conducted using specimen of gravel ground. The Cerchar abrasive test is a laboratory method to quantify the rock abrasivity. It allows to determine an index called Cerchar Abrasivity Index (CAI) for the rock's abrasivity which can be used to evaluate the wear of excavation equipment in different application such as mining, tunneling and drilling. The method was initially developed in 70's by the Laboratory of Centre d'Etude et Recherches des Charbonnages (Cerchar) in France for coal mining purposes.

Fig.3 shows the equipment of the Cerchar bit abrasive test. The testing principle is based on a steel pin with defined geometry and hardness that scratches the surface of a rough rock sample over a distance of 10mm under static load of 10N. The pin and the dead load are moved across the rock surface. The pin is made of a standard steel and has a 90° conical tip. Cerchar Abrasivity Index is determined as shown in Fig.4.

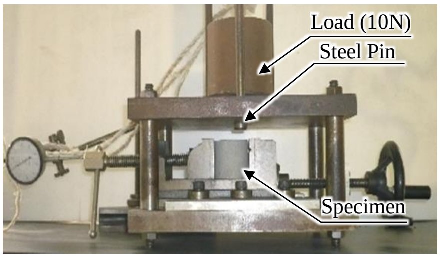
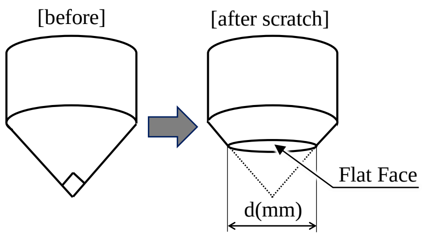


Fig.3 Cerchar Bit Abrasive Test



Cercher Abrasivity Index = 10 x d (1/10mm)

Fig.4 Cerchar Abrasivity Index(CAI)

Lathe Bit Wear Test

In order to simulate the cutting process by bit, the Lathe bit wear test was conducted (B.G. Fish, 1959). Fig.5 shows the equipment of the Lathe bit wear test.

This is an abrasion test and the basic principle is to press a test bit against a rotating specimen in a horizontal lathe. Bit wear is evaluated measuring the decrement of the bit. In this test, the size of specimen was 50mm in diameter and 100mm in length, respectively. The material of the test bit was SKC24. The rotation rate of specimen and the static load applied to test bit were determined based on the actual conditions (rotation rate and thrust). The static load of test bit was fixed as 10N and rotation rate of specimen was changed from 72 to 144rpm.

Lathe bit wear index was defined and calculated as follows:

Lathe bit wear index = Mass decrement / Travel distance (mg/m)

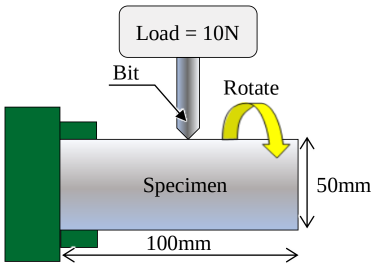


Fig.5 Lathe Bit Wear Test

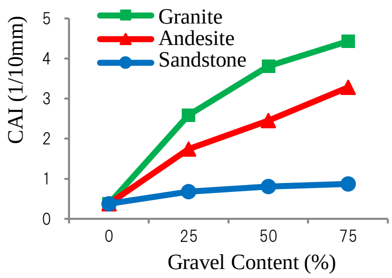


Fig.6 Result of Cerchar Test

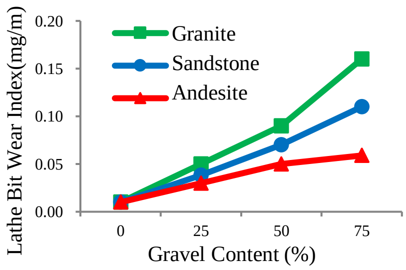


Fig.7 Result of Lathe Test

2.3 Test Results

Comparison of the results of two tests

The results of the above tests are shown in Fig.6 and Fig.7. Focusing on the relation between gravel content and bit wear, the bit wear increases along with gravel content. This trend is found in the both test results. On the other hand, focusing on the relation between quartz content and bit wear, the bit wear increases along with quartz content in the Lathe bit wear test, that is the positive correlation is found between quartz content and bit wear. This trend is not found in the test result of Cerchar Test. Furthermore, the tip shapes after the Lathe bit wear test were observed. Fig.8 shows the tip of bits after Lathe bit wear test in different gravel types of specimen. From these figures, the tip of a bit which cut the specimen of sandstone gravel was flat and smooth surface. On the other hand, those with andesite and granite gravels were uneven and irregularities comparing with that with sandstone gravel. Additionally, impact chipping

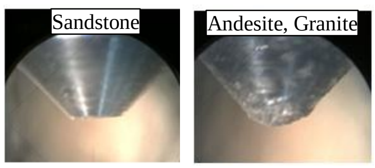


Fig.8 Tip Shape after Lathe Test

rate is evaluated as shown in Fig.9. The measured impact chipping rate of the each types of gravel are tabulated in Table.2. Large impact chipping rate was observed from andesite and granite. Fig.10 shows the results of the Lathe bit wear test of 3 kinds of rotation rate. It is found that the bit wear rate shows the positive correlation with the rotation rate. Considering the above results, following conclusion can be obtained.

1) The rate of the bit wear in Lathe bit wear test shows the positive correlation with the gravel content, quartz content and rotation rate. This is corresponding with the actual site phenomenon. Therefore, it can be assessed the Lathe bit wear test reproducing the actual bit wear phenomenon at the laboratory test.

2) Chipping of the bit caused by impact with the gravel which is serious problem in the actual shield tunnel construction site can be reproduced at the laboratory by Lathe bit wear test.

3) Chipping rate of the bit is not correlated with the quartz content of the gravel.

3. Laboratory Tests-2

Previous tests were conducted focusing on the gravel contents and the quartz content of the gravel in the gravel ground. Subsequent tests were conducted focusing on the binder material which exists between gravels in the gravel ground.

3.1 Preparation of the samples

In order to evaluate the behavior of the bit wear, only granite is used as a gravel in this test. The size of the gravel applied is from 5 to 10mm. Then, Cement (quartz; 0%), Silica sand (quartz; 64.1%) and sand from the actual shield construction site (quartz; 17.6%, called Site sand) were mixed by the rate shown in Table.3. Samples are prepared changing the gravel content 0, 15, 20, 25, 50, and 75%.

3.2 Bit Wear Tests

The behavior of the bit wear was evaluated by Lathe bit wear test, because it is verified the test can reproduce the actual bit wear phenomenon at the laboratory test. The test results are shown below.

3.3 Test Results

Binder Material : Cement + Silica Sand(Quartz 64.1%)

The results of the Lathe bit wear test changing the mixing rate of the binder material (Silica sand) is shown in Fig.11. The bit wear rate increases following the increment of the Silica sand content. This is assumed that the bit wear increases due to the effect of Silica sand.

Binder Material : Cement + Site Sand(Quartz 17.6%)

The results of the Lathe bit wear test changing the mixing rate of the binder material (Site sand) is shown in Fig.12. The bit wear rate increase following the increment of the sand content. However, the increment is smaller than Silica sand (Fig.11). It is assumed that the bit wear is less than Silica sand, because the quartz content of the site sand (17.6%) is smaller than Silica sand (64.1%).

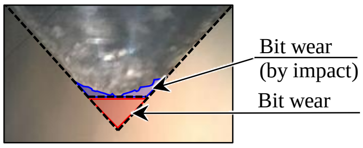


Fig.9 Evaluation of Impact Chipping

Table.2 Impact Chipping Rate

Gravel Type	Quartz (%)	Impact Chipping Rate (%)
Sandstone	21.4	24.8
Andesite	6.3	60.8
Granite	46.9	56.4

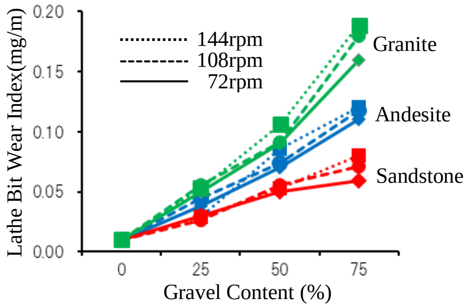


Fig.10 Tip Shape after Lathe Test

Table.3 Mixing Rate of Binder Material

Case	Cement	Silica Sand	Sand
Case-1	100	0	0
Case-2	85	15	0
Case-3	75	25	0
Case-4	65	35	0
Case-5	85	0	15
Case-6	75	0	25
Case-7	65	0	35

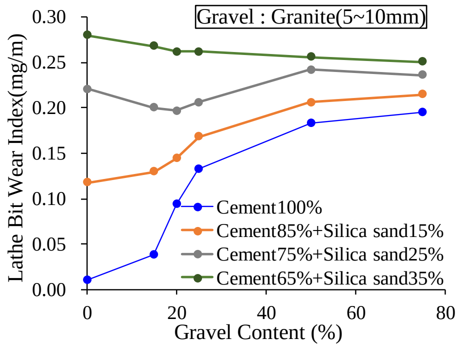


Fig.11 Result of Lathe Test (Silica Sand)

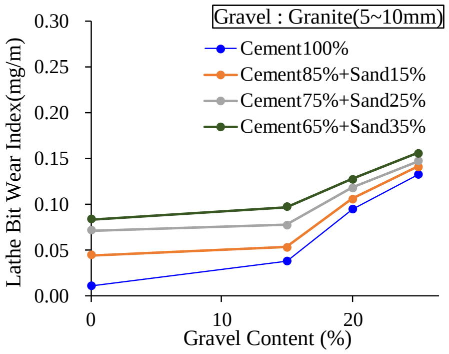


Fig.12 Result of Lathe Test (Site sand)

Another Point of View

Quartz content of the binder material used in this test is 64.1% (Silica sand) and 17.6% (Site sand). The total quartz content of the binder material can be calculated combining the mixing rate and quartz content. The calculated results are shown in Table.4. Then, the results of the Lathe bit wear test can be evaluated plotting the test result on the graph taking "quartz content" on the horizontal axis, "Lathe bit wear index" on the vertical axis as shown in Fig.13. The following conclusion can be made considering the test results.

1) It had been assumed that the bit wear increase following the increment of the gravel content in the previous test, it is found that the controlling boundary exists between gravel content and quartz content in the binder material. For example, the linear of gravel 0% and linear of gravel 15% crossing at the quartz content 12%. This crossing point is the controlling boundary between gravel content and quartz content in the binder material. This crossing point moves to the right side following increment of the gravel content, and the quartz content at the boundary increase following the increment of the gravel content.

2) In spite of the different kinds of the binder material (Cement, Silica sand, Site sand) had been mixed and applied for the test, the correlation coefficient between quartz content in binder material and Lathe bit wear index are high value ($r \geq 0.98$). It affirms the reliability of this hypothesis.

3) Bit wear increases following the increment of the quartz content in binder material. And the inclination of the linear becomes smaller following the increment of the gravel content. It is supposed that the influence by the gravel increases has a small influence on the binder material.

Table.4 Quartz % in Binder Material

Mixing Rate		Quartz Content
Sand	Cement	(%)
-	100%	0
Silica Sand 15%	85%	9.6
Silica Sand 25%	75%	16.0
Silica Sand 35%	65%	22.4
Site Sand 15%	85%	2.6
Site Sand 25%	75%	4.4
Site Sand 35%	65%	6.2

*Quartz Content : Silica Sand 64.1%
Site Sand 17.6%

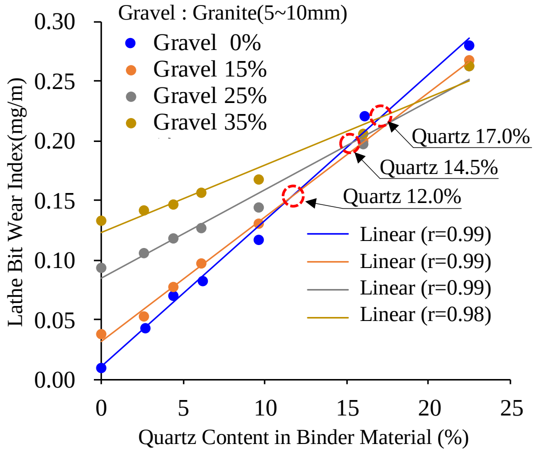


Fig.13 Relation between Lathe Bit Wear Index and Quartz Contents in Binder Material

4. Conclusions

Comparing the test results of the Cerchar bit abrasive test and the Lathe bit wear test, it is assessed that the Lathe bit wear test can reproduce the actual bit wear phenomenon at the laboratory test. The bit wear phenomenon in gravel ground is composed of thermal wear by the gravel ground and impact chipping by gravel. The Lathe bit wear test can reproduce these phenomena compared with the Cerchar bit abrasive test. Focusing on gravel content and quartz content in binder material, it is found that the controlling boundary exists between gravel content and quartz content in the binder material. Bit wear in the gravel ground is generally estimated using the wearing coefficient based on the past bit wear results. It is recommended that the wearing coefficient will be established considering the quartz content of the gravel, quartz content in the binder material, quartz content in the gravel, gravel species and gravel content considering the series of the test results.

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