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# The Influence Factors Analysis of Abrasiveness Based on the Grey Theory

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## Abstract
Aimed at the phenomenon of many factors affecting rock abrasiveness, classification is not clear, and the influences of each factor on abrasiveness have different increase or decrease, different weights, and the influence mechanism are also different, in addition there may be a mutual influence between various factors, this paper takes into account the mutual influence between various factors and the weight of influence on abrasiveness, found out the main influence of abrasiveness by correlation analysis and grey correlation degree, so that guide the field better work by the main influence.

**Key words:** Rock abrasiveness; Main influence; Correlation analysis; Grey correlation degree

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## INTRODUCTION
Rock abrasiveness is an important reference basis to correct design drill bit in-situ, determine the drilling parameters, and formulate a reasonable material consumption quota. Rock abrasiveness is same as all of the rock mechanics properties, and it reflects the inherent feature of rock under the condition of specific experimental work. There are many factors affecting rock abrasiveness, due to the influences of each factor on abrasiveness have different increase or decrease, different weights, influence mechanism are different, and there may be a mutual influence between various factors, so we can't determine the main influence of rock abrasiveness, it would be impossible to guide construct by controlling the dominant factor properly in-suite. This paper aims at the uncertainty of the main factors that influences the abrasiveness, through correlation analysis and grey correlation method considers the various influence factors of rock on the influence of the abrasiveness. Find out the biggest several factors influence the abrasiveness, thus will be more relativity to choose drill bit and formulate drilling parameters, which may provide convenience for site operation.

## 1. FACTORS CLASSIFICATION AND MECHANISM ANALYSIS OF ROCK ABRASIVENESS
Although the abrasiveness is a kind of feature which reflect the nature characteristics of the rock, But due to the interaction between rock and by lapping tool, different tools and different conditions will have effects on the value of the abrasiveness determination, so the nature of tool influenced by composition and structure of lapping tool and the working parameters when they are in teamwork will influence the abrasive property values. Therefore this paper classifies the factors influence rock abrasives into three categories, the first is the rocky factors which include rock composition and structure, the second is the tool factors which contains the composition

 

and structure of the lapping tool, the last is the working parameters when the rock and lapping tool interacting with each other. From different factors to consider the rock abrasiveness, that will understand the cause of it comprehensively from multiple perspectives[1].

(a) Rock is a combination of rock-forming minerals grains, the rock abrasiveness affected by natural environmental factors. Rocky factors mainly includes angle of internal friction, formation hardness, compressive strength, grain size, quartz content and shape[2].

(b) The tool factors mainly contains the rating, size, abrasion resistance of casing, bit face of the diamond bit, the content of Co and WC of the tooth and casing of roller bit[3].

(c) The working parameters chiefly covers drill pressure, rotate speed, pump pressure, delivery capacity, viscosity and degree of drill fluid[4].

Due to the complexity of geological conditions, the distinction of construction parameters level are big, the wear mode in-situ is different from the frictional wear in laboratory. The wear modes of drill bit are classified into rubbing wear, abrasive wear, fatigue wear and erosion wear. We compositely analyzed the three kinds of factors influencing the abrasive effect on the four wear modes.

The essence of rubbing wear is when drill bit in rotary drilling, grinding with rock, force of sliding friction work is done. When the friction produced the energy, which made the particles on bit drop off. From Figures 1 and 3, we can see that most of the tooth surface is all under homogeneous rubbing wear. In rocky factors, compressive strength, grain size, quartz content and shape comprehensively represent the roughness of rock surface, to a certain extent affect the friction coefficient of the rock and bit on the friction surface. In the tool factors, contains the rating, size, bit face of the diamond bit, the content of Co and WC of the tooth and casing of roller bit are also impact the relative sliding friction coefficient. In the working parameters, due to the drilling fluid filling gaps in a rock and bit of friction, Lubricating with the friction surfaces, will also affect the relative coefficient of friction. So the different of the drilling fluid viscosity and density, the different of drilling fluid, that makes abrasiveness are different[5]. At the same time, in the tool factors of grinding tools, drill pressure mainly affects the normal pressure of rock and bit, rotate speed affects the sliding distance in per unit time, they are all a certain degree of impact on the friction doing work.

**Figure 1**
**PDC Bit After Construction PDC**

**Figure 2**
**Bit Teeth Enlarge Figure After Construction**

**Figure 3**
**Roller Bit After Construction**

Abrasive wear means a kind of wear when the rock and bit wear. Because of there are many hard small bumps between the surfaces of them. or hard particles between the contact area. The most obvious feature is contact surface has obvious traces of grinding. Now we can see clearly in Figure 2, part of the tooth has obvious scratches[6], it occurs abrasive wear. In rocky factors, the content and distribution of quartz determine the rock hardness, and all the tool factors reflect the hardness of the cutter and body of the bit. When the rock is harder than the bit, it will produce abrasive wear by wearing bit. At the same time, the drill pressure and rotate speed among the working parameters also affect the occurrence and development of the abrasive wear.

When the bit is drilling, it bears alternate loading reciprocal action, on the bit surface or below a certain depth of the surface form fatigue crack. Along with the propagation of crack and interconnection, caused particles drop off from bit work surface, formed the fatigue pit due to fatigue wear. From Figures 1, 2, 3, also can be found, part of the teeth and body have some fatigue pits on them, and the tooth skipping which caused by the local stress is too large or inner crack development. The distribution of rock hardness is caused by all the factors in rocky factors, which makes bits are under alternate loading in the process of drilling. In the tool factors[7], the content of Co and WC of the tooth and casing of roller bit determine the anti-abrasive ability of bit teeth and body under alternate loading. The drill pressure and rotate speed in working parameters have impact on fatigue wear from the aspects of magnitude of force and wear distance in per unit time.

In the practical drilling process, drill fluid binds up cuttings by the way of high-speed flow scours rock, cutting edges and body causes erosion wear, which produces an effect on measuring rock abrasiveness. Figure 3 show that there are many erosion traces on body caused by drilling fluid and particle erosion obviously. Water volume can make rock powder particle size increases, the reason is that the high velocity flow quickly washed the coarse rock grains at the bottom of the bit away from the acting surface between rock and bit, reduced the chance of a secondary crushing. Wherefore, pump pressure, delivery capacity, viscosity and degree of drill fluid in the working parameters all will affect drilling fluid erosion effect, thus affects the abrasive.

In summary, three kinds of factors all have inordinate impact on various of wear mode in the process of drilling. due to the influences of each factor on abrasiveness have different increase or decrease and different weights, so find out the main factors which influence the abrasive, that makes starting from the main reason to optimize bits, make drilling plan, it will have a good guiding significance in-site[8].

## 2. THE MAIN INFLUENCE OF ABRASIVENESS

### 2.1 Initial Data Extract

Because data is from the human test and errors will be inevitably introduced, the data must first be pretreated. As a part of factor data of the rock sample is too similar, so after screening basic data, we determine the selection of data of 10 rock samples for the study. Although the quantity of data is reduced, the actual test data can be reflected for maximum. The data of primary influencing factors finished is shown in Table 1.

**Table 1**
**The Abrasive and Influencing Factors of Rock Sample**

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Abrasiveness | mm$^3$/(kN·m) | 1.94 | 1.93 | 1.62 | 1.56 | 1.45 | 1.87 | 0.76 | 0.65 | 0.86 | 0.98 |
| Internal friction angle | ° | 49.4 | 50.2 | 25.6 | 22.9 | 38.6 | 39.7 | 45.3 | 43.2 | 40.3 | 47.2 |
| Quartz grain size | mm | 0.06 | 0.05 | 0.05 | 0.02 | 0.08 | 0.09 | 0.05 | 0.04 | 0.13 | 0.14 |
| Quartz content | % | 48.7 | 18.2 | 26.8 | 52.9 | 36.3 | 48.5 | 31.2 | 60.5 | 62.5 | 67 |
| Compressive strength | MPa | 325 | 390 | 345 | 248 | 228 | 240 | 224 | 228 | 258 | 219 |
| Hardness | Mpa | 2,988 | 3,342 | 2,967 | 2,905 | 2,561 | 3,187 | 1,032 | 989 | 2,010 | 2,789 |
| Drill pressure | kN | 100 | 120 | 120 | 150 | 80 | 100 | 150 | 120 | 150 | 80 |
| Rotate speed | r/min | 75 | 90 | 75 | 80 | 80 | 120 | 120 | 75 | 75 | 90 |
| Delivery capacity | 1/s | 32 | 31 | 31 | 31 | 31 | 32 | 32 | 32 | 32 | 32 |

### 2.2 Gross Error Analysis

Gross error or mistake error is the individual of the sample, and its value is significantly deviated from the other sample's values, so it is called outlier. When processing data, if measured data mixed with the outliers are not ruled out, it will cause the result that the measurement accuracy is low; On the contrary, if the normal data are erroneously excluded as outliers, the useful measurement information will be reduced. Therefore, the reasonable judgment and processing of outliers of measurement, is precondition for the right results.

In this paper, gross errors in the original data will be analyzed by studentized residual. Basic concept of studentized residual is described as follows:

For n times independent measurements of certain value, the resulting measure is $X$:

$$X = \{x_1, x_2, \cdots, x_i, \cdots, x_n\} \ (i = 1, 2, \cdots, n) \tag{1}$$

Its arithmetic mean $\bar{x}$ and residuals $v_i$ are:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{2}$$

$$v_i = x_i - \bar{x} \tag{3}$$

The ratio of residuals and the sample standard deviation is studentized residual of samples, namely:

$$y_i = \frac{v_i}{s} \tag{4}$$

Where: $s$ is the sample standard deviation, and its value is: $s = \sqrt{\frac{\sum_{i=1}^{n} v_i^2}{n}}$

The absolute value of ratio of residuals and the sample standard deviation is the absolute value of studentized residual, namely:

$$|y_i| = \frac{|v_i|}{s} \tag{5}$$

The term "student" is a standardized treatment mainly for non-homogeneity of variance of ordinary residuals, so expect is 0 and variance is 1, which makes it easy to compare.

According to the definition of studentized residual above, the data for each factor will be calculated. When absolute value of studentized residual is greater than 3, the data can be considered as a variation of data, namely gross error, which may be excluded. The studentized residual computation graph of quartz grain size and quartz content is shown in Figures 4 and 5, the figure shows the absolute value of studentized residual is less than 3. Another calculation shows all the absolute values of the studentized residuals are less than three factors. So it is considered that the data of factors above do not contain gross error, which can be directly processed for subsequent analysis.

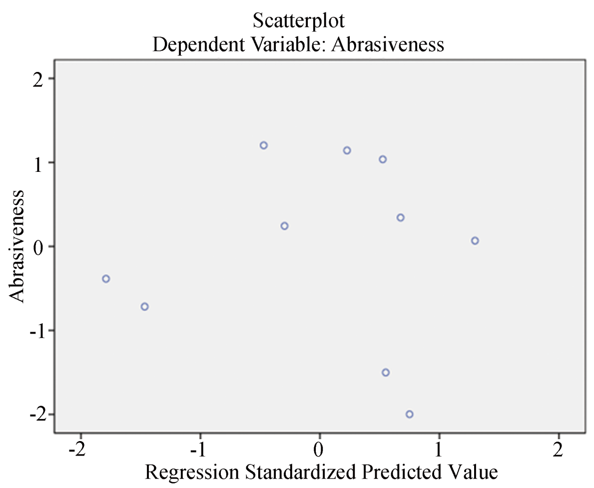


**Figure 4**
**Regression Studentized Residual of Quartz Grain Size**

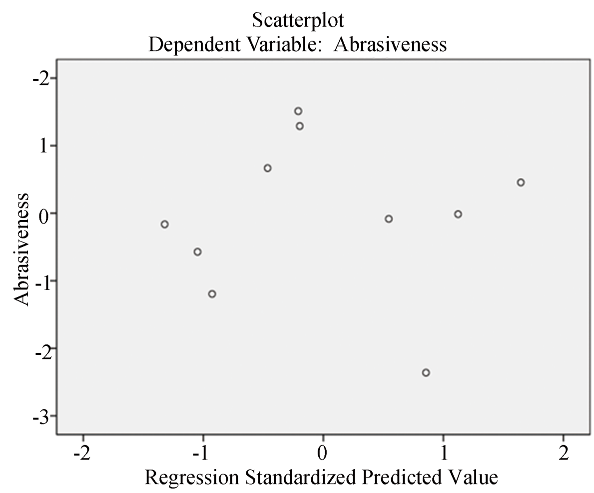


**Figure 5**
**Regression Studentized Residual of Quartz Content**

### 2.3 Data Normalization Processing

Due to the different dimensions of various factors above, the magnitude of the corresponding data vary widely. In order to overcome the adverse effects, the data of all factors must be normalized, its formula is shown as Formula (6).

$$X'_{ik} = \frac{X_{ik} - \overline{X}_k}{\sigma_k} \tag{6}$$

Where: $X'_{ik}$ is the $i$-th value of the $k$-th variable data after standardization processed. $\overline{X}_k$ is the mean of the $k$-th variable data, $\sigma_k$ is the standard deviation of the $k$-th variable data.

### 2.4 Affecting Factor Analyze Based on Correlation Analysis

Correlation analysis is a statistical method for studying the closeness of the variables. Correlation analysis can initially understand the closeness of abrasive and each factor, and thus the factors that is nor closed related will be removed, so as to achieve the objective of reducing the dimension of the model.

Pearson's correlation coefficient between any two variables ($X$) is calculated by formula ($X$)

$$\rho = \frac{\sum_{k=1}^{n}\left(X_{ik} - \overline{X}_i\right)\left(X_{jk} - \overline{X}_j\right)}{\sqrt{\sum_{k=1}^{n}\left(X_{ik} - \overline{X}_i\right)^2 \sum_{k=1}^{n}\left(X_{jk} - \overline{X}_j\right)^2}} \tag{7}$$

Where: $\overline{X}$ is mean of individual gene expression; $X_{ik}$ is the $i$-th value of the $k$-th data variable; $\rho$ is the correlation coefficient. $X$ is the $j$-th value of the $k$-th variable.

The above-mentioned data after standardized processing should be correlation analysised by SPSS software, and correlation coefficient between each factor are shown in Table 2.

It is generally believed when the absolute value of Pearson correlation coefficient greater than 0.8, there is a strong correlation between two vectors. After eliminated irrelevant variables by correlation analysis, do research the degree of association into angle of internal friction, formation hardness, grain size, quartz content, drill pressure, rotate speed and delivery capacity.

**Table 2**
**The Correlation Coefficient Between the Various Influencing Factors**

| | Internal friction angle | Quartz grain size | Quartz content | Compressive strength | Hardness | Drill pressure | Rotate speed | Delivery capacity |
|---|---|---|---|---|---|---|---|---|
| Internal friction angle | 1 | 0.381 | 0.029 | 0.069 | 0.158 | 0.33 | 0.244 | 0.547 |
| Quartz grain size | 0.381 | 1 | 0.509 | 0.326 | 0.089 | 0.409 | 0.065 | 0.474 |
| Quartz content | 0.029 | 0.509 | 1 | 0.633 | 0.234 | 0.08 | 0.217 | 0.613 |
| Compressive strength | 0.069 | 0.326 | 0.633 | 1 | 0.545 | 0.058 | 0.283 | 0.461 |
| Hardness | 0.158 | 0.089 | 0.234 | 0.545 | 1 | 0.407 | 0.094 | 0.47 |
| Drill pressure | 0.33 | 0.409 | 0.08 | 0.058 | 0.407 | 1 | 0.044 | 0.016 |
| Rotate speed | 0.244 | 0.065 | 0.217 | 0.283 | 0.094 | 0.044 | 1 | 0.326 |
| Delivery capacity | 0.547 | 0.474 | 0.613 | 0.461 | 0.47 | 0.016 | 0.326 | 1 |

**Table 3**
**The Gray Correlation Degree of Abrasive and Various Influence Factors**

| | Internal friction angle | Quartz grain size | Quartz content | Compressive strength | Hardness | Drill pressure | Rotate speed | Delivery capacity |
|---|---|---|---|---|---|---|---|---|
| Grey relational grade | 0.5004 | 0.5687 | 0.5208 | 0.5061 | 0.5068 | 0.5100 | 0.5019 | 0.5079 |

### 2.5 Affecting Factor Analyze Based on Grey Relational Degree

It is observed in Table 2, after eliminated irrelevant variables by correlation analysis, there are still some factors associated with abrasive. Use grey correlation degree to rank each factor associated with the abrasive, choose the biggest variable relationship among them.

Grey correlation degree is according to the factors between the growing trend of similar or dissimilar process to measure the correlation degree between factors. It solves the main problem is in a system contains a variety of factors, analyze the primary factor, secondary factor, big and small influence factors, the factors that needs to be developed or suppressived. More specifically, it is the development trend of quantitative comparison and analysis. Essentially, it is analyzed to compare about several curve geometry, which is that the closer the geometry is, the closer the development trends, the correlation degree is bigger.

Computing method: The correlation degree between various factors in the system size, expressed by the correlation measurement, the definition is as follows:

Let $X_0 = \{x_0(k), k = 1, 2, 3 \dots n\}$ as a reference sequence, $X_i = \{x_i(k), k = 1, 2, 3 \dots n\}$ as compare sequence. Among them $i = 1, 2, 3 \dots m$, make preliminary treatment on each sequence, namely with each sequence after the first data to divide all other data to get a new sequence.

$$\gamma_0 = \{y_0(k), k = 1,2,\dots,n\} = \left\{\frac{x_0(k)}{x_0(1)}, k = 1,2,\dots,n\right\}$$

$$\gamma_i = \{y_i(k), k = 1,2,\dots,n\} = \left\{\frac{x_i(k)}{x_i(1)}, k = 1,2,\dots,n\right\}$$

Where: $i = 1, 2, 3 \dots m$, $\gamma_0$ is the new reference sequence, $\gamma_i$ is the new comparison sequence.

The correlation degree $\xi_i(k)$ between reference sequence and comparison sequence all the time is:

$$\xi(k) = \frac{\min_i \min_k \Delta_i(k) + \rho \max_i \max_k \Delta_i(k)}{\Delta_i(k) + \rho \max_i \max_k \Delta_i(k)}$$

$$\xi(k) = \frac{\min_i \min_k \Delta_i(k) + \rho \max_i \max_k \Delta_i(k)}{\Delta_i(k) + \rho \max_i \max_k \Delta_i(k)}$$

Where: $\Delta_i(k) = |y_0(k)-y_i(k)|$ is the difference sequence between new reference sequence and $i$-th new comparison sequence, ρ is the resolution ratio, value is between 0 and 1. $\min_i \min_k |y_0(k) - y_i(k)|$ is the dipolar minimum difference value, $\max_i \max_k |y_0(k) - y_i(k)|$ is the dipolar maximum difference value.

Degree of association is: $\psi_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k)$. According to the from small to large order constitutes degree of association array, the importance of the influence factors dependence on the correlation order. According to the above definition, dimensionless impact on these factors, and calculate the grey correlation degree, concrete numerical value as shown in Table 3.

According to Table 3, the sort of each impact factor and abrasiveness sexual relations are as follows: The sort of them are quartz grain size, quartz content, drill pressure, hardness, rotate speed. Among all factors, the quartz grain size, quartz content and hardness are the main influence in rocky factors. Drill pressure and rotate speed are the main influence in the tool factors.

## CONCLUSION

(a) Classify abrasiveness influencing factors, and analysis of all kinds of factors impact on wear mechanism of various wear.

(b) By calculating, we know quartz grain size, quartz content, drill pressure, hardness, rotate speed are the main influence of abrasiveness.

(c) In site operation, we should pay more attention on drill pressure and rotate speed, it will play an important role in the scene of the reasonable construction.

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