2D and 3D Roughness Coefficient of Marble Joint Surface

Chenlin Wang[1], Baohua Guo[1,2]*

1 *School of Energy Science and Engineering, Henan Polytechnic university, Jiaozuo 454000 China*

2 *Collaborative Innovation Center of Coal Work Safety, Jiaozuo 454000 China*

**Corresponding Author, e-mail:* guobaohua@139.com

ABSTRACT

JRC (Joint Roughness Coefficient) is always used to evaluate the roughness of joint surface. In this paper, the artificial tensile joint samples were made of coarse-grained marbles, and then the joint surfaces were scanned by high-precision 3D laser scanner. 2D profile parameters and 3D morphology parameters of joint surface were obtained by using professional software. JRC values were analyzed based on the empirical relationships between JRC and several parameters i.e. Z_2(root mean square slope of 2D morphology parameter), R_p(roughness profile index), *i*(roughness angel). The fractal dimension of joint surface was calculated by using Fractalfox2.0 fractal analysis software, and fitting analysis was carried out in terms of relationship between 3D fractal dimension of joint surface and 3D morphology parameters. The result shows that JRC for different profiles on same sample joint surface varies greatly, so the real roughness cannot be obtained by using JRC determined from only one profile; There is a positive linear correlation relationship between fractal dimension of rock joint and S_A(3D contour area ratio), which can be used to evaluate the roughness of joint surface.

KEYWORDS: rock mechanics; joint surface; joint roughness coefficient; fractal dimension; morphology parameters

INTRODUCTION

There is discontinuities in the natural rock mass, such as joint, fracture and fault, which always control the stability of engineering rock and the underground water would seepage into these joints further weakening the strength of rock mass[1-3], so it is necessary to study the mechanical properties of rock joint surface[4]. The morphology of rock joint surface is an important factor affecting the mechanical properties of rock joint. Therefore, to effectively describe rock joint roughness is the foundation to study the mechanical properties of joint [5].

Barton[6] proposed the concept of JRC (Joint Roughness Coefficient) to describe the rock joint roughness and the value was divided into 10 intervals ranging from 0 to 20. Domestic and foreign scholars have done some exploratory research in order to describe the JRC quantitatively, most of them calculated the JRC value by establishing a relationship between JRC and the statistical parameters of contour curve or fractal dimension. R.Tse et al[7] established the empirical formula between JRC and Z_2(which is the root mean square of first derivative for the waviness of rock joint profiles) as well as SF(structure function). Maers et al[8] established the formula between JRC and R_p(roughness profile index) by using projection profile method. Xia et al[9] established the relationship among JRC and a series of joint surface contour curve parameters including amplitude, wavelength, angle etc. Guo Baohua[10] found that there is logarithmic relationship between JRC and R_p by analyzing 188 joint profiles from 47 cylindrical specimens of seven rock groups. Li Hua et al[11] proposed Ra (relative waviness) and elongation R indicated JRC collectively, and experiential formulas were established based on this discovery. Li Yanrong et al[12] found that the JRC have strong correlation with Z_2, SF, R_q etc. And they established fifteen empirical formulas to predict JRC based on 112 digital joint contour profiles.

The fractal dimension has been widely used in the description of joint roughness since Mandelbrot[13] created the fractal geometrical theory. Lee et al[14] established a relationship between JRC and fractal dimension by using fractal dimension to describe joint roughness. Xie Heping[15] provided six methods of fractal dimension measurements for joint, and he discussed fractal description of joint roughness and established relationship between JRC and fractal dimension. Xu Hongfa et al[16] simulated the profiles of rock joints on the basis of Hurst exponent method, and the relationship between JRC and fractal dimension was analyzed, then two empirical formulas with high fitting accuracy were suggested. Feng Xiating et al[17] established a regressive formula to describe relationship between fractal dimension and JRC. Cao Ping et al[18] used fractal geometric theory to analyze joint 3D surface topography characteristics, and put forward the function between fractal dimension and JRC. Sun Futing et al[19] proposed a new roughness index SRI based on joint profiles, and the relationship between SRI and JRC was established.

In order to describe the joint surface roughness, rock joint surfaces were scanned by high-precision Tenyoun OKIO-typed 3D laser scanner, then 2D profile parameters and 3D morphology parameters of joint surfaces were obtained using professional software. JRC values of joint surface profiles for different location were calculated and analyzed according to empirical formulas. Fractalfox2.0 fractal analysis software was used to calculate the fractal dimension of joint surfaces, finally the relationship between fractal dimension D and 3D morphology parameter was established by fitting analysis.

MEASUREMENT OF THE JOINT SURFACES TOPOGRAPHY

All samples are coarse-grained marble with grain size of about 5 mm, and the cylindrical samples with the diameter of 50 mm and the height of 100 mm are prepared by hydraulic drill method in the laboratory. Tensile joints of coarse-grained specimens were made at the midpoint of the long axis by splitting method. A total of 20 joint surfaces were produced by splitting 10 cylindrical specimens.

This test high-precision Tenyoun OKIO-typed 3D laser scanner was used to measure joint surface morphology, which includes high-configuration computer, two high-precision CCD cameras, frame, marked points etc. By means of digital grating projection device, grating stripe with continuously differential width was projected on the surface of the sample, and then deforming stripes was produced by scanning irregular shape of the surface; two cameras captured and recorded the scan results, finally the three-dimension coordinates of joint surfaces were obtained.

A datum line was selected in the horizontal direction and the line is also through the circle center, then the contour profiles were chosen which with the angle between datum line 0°, 45°, 90°, 135°respectively; The length of all contour profiles is equal to the diameter of joint surface; 2D profile parameters on the contour lines were calculated. Rectangular frame was used to select the entire area of rock joint surface, then clicking the matrix sampling to obtain 3D morphology parameters of the joint surface.

Using professional software, Z_2[5] and R_p[21] were obtained in terms of 80 contour lines from the 20 coarse-grained marble joint surfaces, then S_A(3D morphology parameters contour area ratio)[24] was calculated.

2D JRC OF JOINT SURFACE

Using Z2 to calculate JRC

Tse et al[7] found that the relationship between JRC and Z_2 is a logarithmic function (fitting precision R=0.986) by studying a relationship between JRC and Z_2on the rock joint surface profiles as is shown in formula (1). Yang[20] proposed formula (2) Based on formula (1) as follows.

$$\mathrm{JRC} = 32.2 + 32.47\log_{10} Z_2 \quad (1)$$

$$\mathrm{JRC} = 32.69 + 32.98\log_{10} Z_2 \quad (2)$$

The Z_2 for 4 contour profiles of every joint surface were calculated by professional software, then the formula (1) and formula (2) were used to calculate the JRC for the joint surface profiles of specimens respectively as shown in Figure 1.

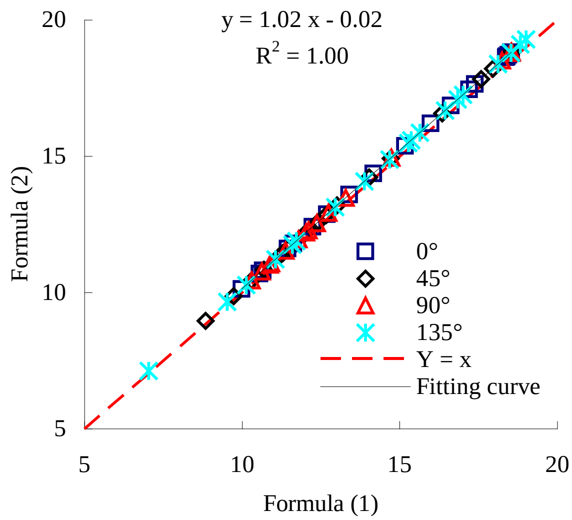

Figure 1: JRC value calculated by the formula (1) and formula (2)

From Figure 1 we find that the JRC obtained by formula (1) ranges from 7.04~19.01 with a root mean square 3.31, while the JRC obtained by formula (2) ranges from 7.13~19.29 with a root mean square 3.36. The JRC values dispersion varies largely according to different contour profiles of joint surface. There is tiny difference of JRC characteristic values from 20 joint surfaces calculated from equation (1) and equation (2) respectively, and a linear relationship exists between JRC values calculated by the formula (1) and formula (2). JRC values obtained from formula (2) are slightly larger than those obtained from the formula (1).

Using Roughness Profile Index R_p Calculated JRC Value

Maerz et al[8] proposed shadow contour method digitized contour profiles. He found that there is a good linear correlation between JRC and R_p, which is expressed as follow (fitting precision R=0.984):

$$JRC = 411(R_p - 1) \tag{3}$$

Guo Baohua[10] found that JRC and R_p has a logarithmic relationship by analyzing 188 joint profiles from 47 cylindrical specimens of seven rock groups, (fitting precision R^2=0.984):

$$JRC = 7.3224\ln(R_p - 1) + 38.428 \tag{4}$$

The JRC values of contour profiles for joint surfaces of all test specimens calculated by R_p according to the formula (3) and the formula (4) are shown in Figure 2.

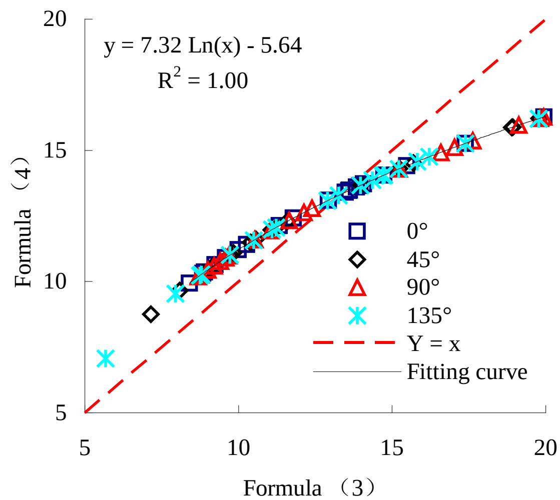

Figure 2: JRC value calculated by the formula (3) and formula (4)

As is shown in Figure 2, JRC values calculated using the formula (3) range from 7.04 to 19.01 and JRC values calculated using the formula (4) range from 7.13 to 19.29, and the mean square deviation is 3.81 and 2.17 respectively. The dispersion of JRC values for different contour profiles of joint surface of specimens was fairly large, and the dispersion of JRC values calculated using the formula (3) is larger. There is fairly large difference between the JRC characteristic values calculated from above two formulas, and there is a logarithmic relationship between them. When the JRC value is less than 3.47 or larger than 13.31, the JRC value calculated by the formula (3) is smaller than that of the formula (4). When the JRC value is range from 3.47 to 13.31, the JRC value obtained by the formula (3) is larger than that of the formula (4). Because the JRC value ranges from 5.68 to 19.94, there is no intersection when JRC value equal to 3.47. Therefore, the JRC value has large difference between the two formulas when the JRC increases far away from 13.31.

Roughness Angle *i* Applied to Calculate JRC

i can be calculated by Z_2 and R_p respectively, which is from literature [7] and [20].

$$i_{Z_2} = \arctan(Z_2) \tag{5}$$

$$i_{R_p} = \cos^{-1}(\frac{1}{R_p}) \tag{6}$$

Z_2 and R_p were used to calculate the roughness angle *i*. Tse et al[7] established the relationship between JRC and roughness angle *i* :

$$\mathrm{JRC} = -5.05 + 1.20 i_{Z_2} \tag{7}$$

$$\mathrm{JRC} = -5.05 + 1.20 i_{R_p} \qquad (8)$$

The JRC values of joint surface profiles calculated by the formula (7) and (8) were shown in Figure 3.

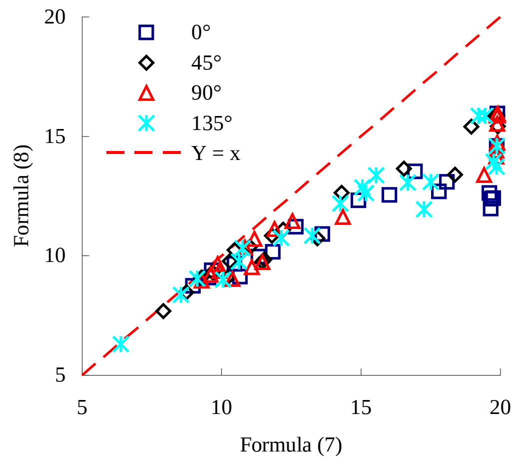

Figure 3: JRC values calculated by the formula (7) and formula (8)

From Figure 3 we find that the JRC values calculated by the formula (7) calculated range from 6.39 to 19.91, whose mean square deviation is 4.22; the JRC values calculated by the formula (8) ranges from 6.31 to 15.95, whose mean square deviation is 2.43. The dispersion of JRC values is fairly large for different joint surface profiles, and the dispersion calculated from the formula (7) is larger. The difference of JRC characteristic values calculated from the two formulas were fairly large, but the relationship between the two series is a positive relationship. The JRC values are close when JRC less than 10; The JRC calculated by formula (8) are less than those obtained by the formula (8). Totally speaking, the difference increases as the JRC increases.

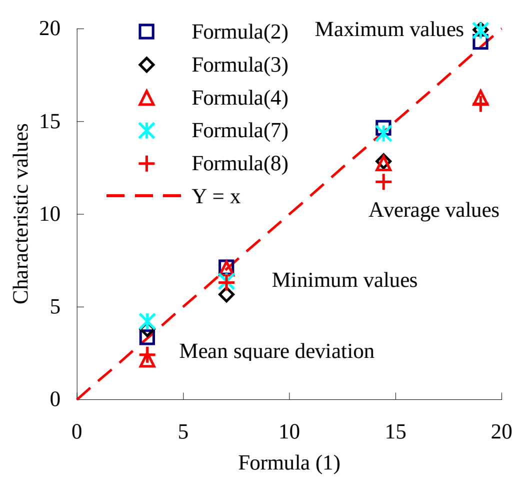

Figure 4: Comparison of characteristic values

In order to simplify analysis, the maximum values, average values, minimum values and mean square deviation of JRC were listed in Figure 4, which were obtained from the above six formulas. Maximum values, average values, minimum values and mean square deviation of JRC calculated from the formula (1) have a good positive relationship with those obtained from other formulas. The largest JRC maximum value was obtained by formula (3), and the smallest JRC maximum value was obtained by formula (8). The largest JRC average value was obtained by formula (2), and smallest JRC average value was obtained by formula (8) is the largest. The largest JRC minimum value was obtained by formula (2), and the smallest JRC minimum value was obtained by formula (3). The mean square deviation obtained by formula (7) is the largest, and the mean square deviation obtained by formula (4) is the smallest. Because of the uncertainty of the true value of JRC, so it’s difficult to evaluate which formula is the best to obtain JRC and describe the true morphology of joint surface. All in all, there is fairly large dispersion in terms of 2D morphology parameters and a single or only several characteristics profiles are not enough to describe the integral morphology. Based on this conclusion, it’s necessary to use 3D morphology parameters to describe the joint morphology.

RELATIONSHIP BETWEEN FRACTAL DIMENSION AND 3D MORPHOLOGY PARAMETERS SA

In 1982, French mathematician B. B. Mandelbrot[7] developed the fractal geometry, which is used to describe the heterogeneous and non-uniform phenomenon and behavior distributed in the natural world. Most of the irregular geometric objects have fractal characteristics in nature, and the irregular shape of rock joint surface also has the fractal characteristics. Fractal dimension can be used to describe the rock joint surface roughness. There are many different methods to calculate fractal dimension, which involves: Hausdorff dimension D_H, self-similarity dimension D_s, box dimension D_B, information dimension D_i, correlation dimension D_g etc. Because of the relative simplicity of box dimension D_B in terms of its mathematical approximate calculation, it has become one of the most widely used methods to calculate fractal dimension[22-23].

The “Tri. Prism surface area” algorithm in Fractalfox 2.0 fractal analysis software as is shown in Figure 5. The abscissa represents the logarithm of box size, and the ordinate represents the logarithm of joint area under box size accounting for the number of boxes. In Figure 5, the absolute value of fitting linear slope plus 2 is the fractal dimension of joint surface.

The relationship between fractal dimension and 3D contour area ratio S_A was obtained as shown in Figure 6 after calculating the fractal dimension of 20 marble joint surfaces. From Figure 6 we can see that fractal dimension D ranges from 2.24 to 2.30. There is a positive linear relationship between fractal dimension and contour area ratio S_A, with the fitting correlation coefficient R^2 of 0.90. Therefore, S_A can be used to characterize the joint surface roughness, and the larger S_A is, the greater rough the joint is.

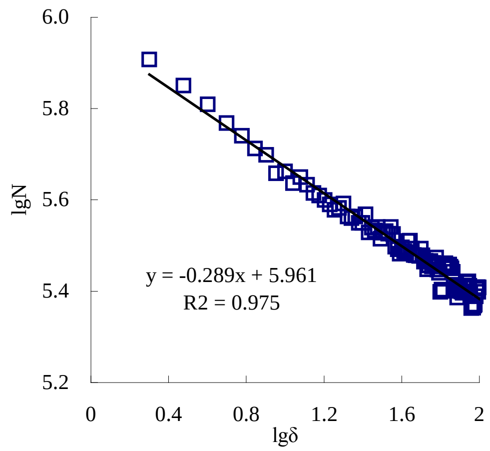

Figure 5: The calculating demonstration of fractal dimension

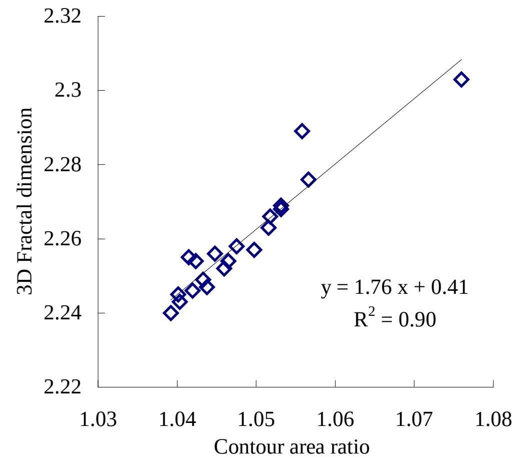

Figure 6: The relationship between fractal dimension D and contour area

CONCLUSIONS

(1) There are obvious deviations among JRC values for different profiles on same sample joint surface, and a single or several profiles are not enough to reflect the real roughness of whole joint surface, so there is a limitation within the application of JRC assessing the joint surface roughness.

(2) There is positive linear relationship between fractal dimension and 3D contour area ratio S_A, and fractal dimension increase with 3D contour area ratio S_A. The results have certain help to evaluate rock joint roughness.

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