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THE FRACTAL ANALYSIS OF IMPACT FRACTURE OF BEARING STEEL

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ABSTRACT

The relationship between the fracture surface, impact energy, microstructure and fractal dimension of bearing steel by isothermal quenching blow the low bainitic range at different temperatures has been studied in this paper. It revealed that the fractal dimension varied linearly with the roughness of fracture surface, total length per square micron and density of tear ridge and impact energy which were affected by both the size of acicular bainite and amount of martensite.

Key words: impact fracture, impact energy, microstructure, fracture surface, fractal dimension.

INTRODUCTION

Metal fractures by mechanical test are irregular shapes which can not be measured in the past. In the middle of 1980s, Mandelbrot(1983) put forward a method which used the fractal dimension to quantitative analyse. Recently, some people have done some research on the issue and found that the fractal dimensions were closely associated with fracture toughness, superconductivity, fatigue threshold etc. (Chen D L et al. ,1988, 1989; Mu Z Q et al. , 1988) for metal material. It has shown that the fractal dimension could be an effective method for quantitative describing fracture feature, and for studing or deducing the mechanical properties of metal materials. In this paper, effects have been made to apply the fractal method to study the relationship between fracture surface, impact energy and microstructure for quasi—cleavage fracture of bearing steel by isothermal quenching at different temperatures.

MATERIAL AND METHODS

The Mesnager test specimens were prepared from a bearing steel bar which was spheroidizingly annealied, late on, took five groups isothermally quenched below the low

bainite range at different temperatures and one group were quenched and tempered. There are three pieces per group. The impact tests were made at room temperature. The main chemical composition of the steel is shown in Table 1.
The heat treatment procedures for the speimens are shown in Table 2.

Table 1. Chemical composition(wt%) of the steel

C	Si	Mn	Cr	P	S
0.95	0.15	0.25	1.40	≤0.025	≤0.025
—1.05	—0.35	—0.45	—1.65		

Table 2. The heat treatment procedures for specimens

Specimen No.	Heat treatment procedure
1	850℃, 15m., 300℃, 40m., OC
2	850℃, 15m., 280℃, 40m., OC
3	850℃, 15m., 260℃, 50m., OC
4	850℃, 15m., 240℃, 50m., OC
5	850℃, 15m., 220℃, 90m., OC
6	850℃, 15m., OC+160℃, 2h., AC

Note: Ms point is 240℃, OC=oil cooled, AC=air cooled

The microstructure was observed with TEM and both size and amount were determined with image analyser.
Fracture surface was defined with both the roughness and fracture feature. The roughness of fracture surface was measured with XSG microscopy and the values were obtained from the mean values of difference between "peaks" and "valleys". The fracture features were observed with SEM, and the feature photographs were measured with image analyser.
The fractal dimensions were measured with image analyser. The mathematic model was according to formula(1) (Chen D L et al., 1988).

$$\log P = \text{constant} + (D_f/2)\log A \qquad (1)$$

Where P is the perimeter and A is the area of the isiand, Df is fractal dimension. When measuring n group data of log P and log A in a specimen, we can make linear regression by using method of least squares to obtain the D_f(Kong S et al., 1988).
The specimens were made by SIM (slit island method)(Mu Z Q et al., 1989) at first, then photographed to isolate islands in high multiplying power with SEM. The relations between areas and perimeters for islands on the photos were measured with image analyser, and the mean values of fractal dimensions per group were gotten from at least ten islands. According to the report by Mu Z Q and Long Q W(1989), only if the

yardstick was small enough, can the dimension values measured approach real dimension values D_f. Therefor in this test adopted different yardsticks, such as 1.05, 0.5, 0.21, 0.12, 0.10, 0.08, micron etc., found that the dimension values were increased accordingly as the reducing of the yardstick and tended to constant below 0.12 micron, so 0.08 micron was used as the final yardstick.

RESULTS

The values of microstructure feature and impact energy by different heat treatment procedures are shown in Table 3.

Table 3. Different isothermal treatments (IT) in ℃ and quench tempering (QT) with bainite length (BL) in μm, martensite amount (MA) in % and impact energy (J)

IT	300	280	260	240	220	QT
BL	1.19	0.84	0.66			
MA				30	70	100
J	12	6	5	4	3	1

The linear variaton of impact energy (J) was in a inverse proportion with fractal dimension (D_f) as show in Fig. 1. Through linear regression, the following relationship was obtained:

$$D_f = 1.257 - 0.017J \quad (2)$$

The coefficience of correlation of formula (2) is 0.975.

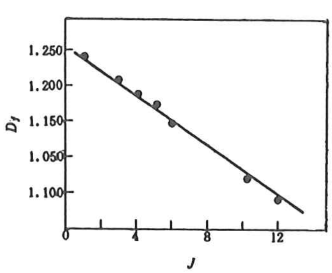

Fig. 1. Linear variation of impact energy (J) with fractal dimension (D_f)

The results of SEM observation are all quasi—cleavage fracture feature, and number of intergranular planes increase gradually below the Ms point. The results by image analyser showed that direct linear variations of total length(L), density(C) of tear ridge per square micron with D_f respectively were obtained above the Ms point. Since quasi—cleavage feature becomes smaller and more shallow below the Ms point, the inverse linear variations between the parameters mentioned above were obtained at the same photo condition, but the area fraction(A) of intergranular planes with the D_f is in direct proportion. The quasi—relationships were shown as formula (3) to (6) and the linear variations were shown in Fig. 2 to 4.

$$L=28.333D_f-26.896 \quad \text{(Above Ms point)} \tag{3}$$
$$L=-54.314D_f+69.784 \quad \text{(Below Ms point)} \tag{4}$$
$$C=11.056D_f-10.455 \quad \text{(Above Ms point)} \tag{5}$$
$$C=-15.529D_f+20.389 \quad \text{(Below Ms point)} \tag{6}$$

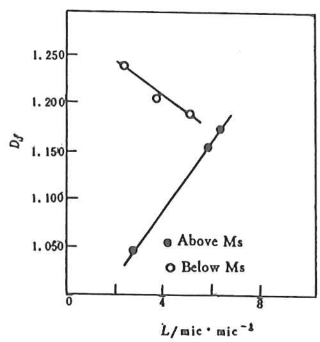

Fig. 2. Linear variation of fractal dimen— sion(D_f) with total length of tear ridge per square micron(L)

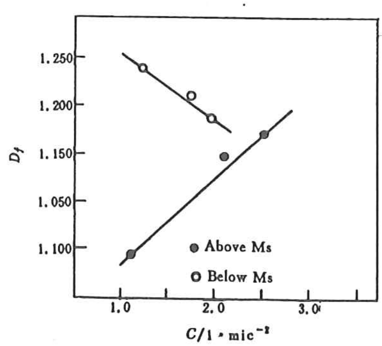

Fig. 3. Linear variation of fractal dimen— sion(D_f) with density of tear ridge per square micron(C)

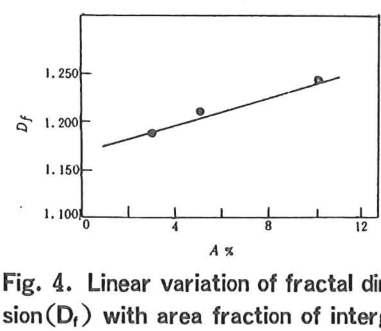

Fig. 4. Linear variation of fractal dimen— sion(D_f) with area fraction of intergranu— lar plane(A)

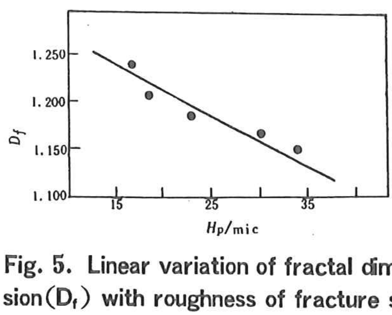

Fig. 5. Linear variation of fractal dimen— sion(D_f) with roughness of fracture sur— face(Hp)

The linear variation of roughness (Hp) with D_f was also in inverse proportion as shown in Fig. 5. By linear regression, the formula (7) was obtaines to be:

$$Hp=-192.400D_f+254.101 \tag{7}$$

The coefficience of correlation of formula (7) is 0.950.

DISCUSSION

By comparing the original specimens and "SIM" specimens observed with SEM, the results showed that, the larger the roughness of fracture surface, the bigger the field size of quasi—cleavage feature; The sparser and thicker the tear ridge, the more regular the island; The tear ridge which are corresponding to smaller size of quasi—cleavage feature are denser, more complicate and become more shallow gradually. So the D_f of quasi—cleavage fracture is directly proportional to the irregularity but is inversely proprtional to roughness or impact energy of quasi—cleavage feature.

Further comparing microstructures observed with TEM and fracture features with SEM, the results showed that, above the Ms point, the acicular bainites which obtained by different isothermal quenching have different length and density. The smaller sizes of acicular bainite are corresponding to the smaller fields of quasi — cleavage, ie. corresponding to higher total length and density per square micron of tear ridge. Below Ms point it is increasing gradually in amount of martensite obtained by different heat treatment temperature, and also increases gradually in the amount of carbide particles precipitated on base. Furthermore, the more martensite and carbide particles are corresponding to smaller fields of quasi—cleavage and the more fields of intergranular plant. So it is clear that the fracture principle of quasi—cleavage have it feature. It differ from dimples fracture and cleavage fracture. The size of microstructure boundary, the number of second—phase particle and cleavage plane affect markedly the extension way of quasi — cleavage crack (ASM, 1986), consequently affect the complexity of "slit island". This is why the quasi—cleavage fields tend towards small but fractal dimensions tend towards high. So the relationships between parameters mentioned above were determined by microstructures and corresponding fracture principle.

The SEM photographs corresponding acicular bainite for different size and the martensite for different amount were shown in Fig. 6. and 7. The order of photographs are as Table 3.

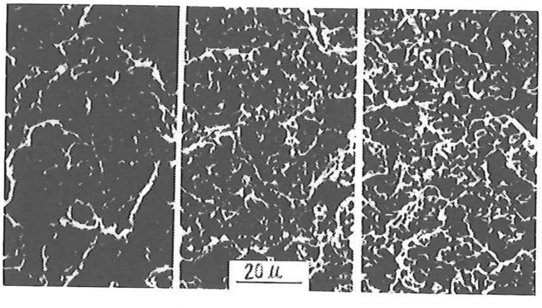

Fig. 6. SEM photographs corresponding acicular bainite of different size

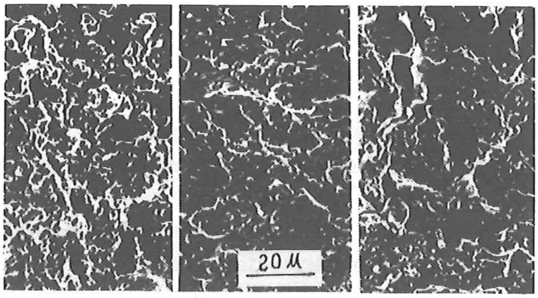

Fig. 7. SEM photographs corresponding martensite of different amount

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