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Spark testing to measure carbon content in carbon steels based on fractal box counting

Kexing Deng *, Deng Pan, Xiaobo Li, Fucheng Yin

School of Materials Science and Engineering, Xiangtan University, Hunan 411105, China

A R T I C L E I N F O

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A B S T R A C T

Spark testing is an effective and inexpensive way to classify the steel materials in industrial practice. Especially, it could determine carbon content in a moment. However, this method has reliance upon the skill and experience of operator. Therefore, computer recognition of spark has been developed to determine carbon content for increasing reliability and efficiency. The numerable high-resolution images of sparks emitting at high speed are taken pictures by camera or mobile phone, then input the images into computer, and calculated the fractal dimension of spark based on fractal box counting method. Result shows that the fractal dimension has a good correlation with carbon content, and the similar natural logarithm function is obtained by a least squares fit through plots of carbon content against fractal dimension. Carbon content measurement error is about 0.06%. It means a convenient and accurate way to identify an unknown carbon steel may be achieved.

1. Introduction

There has been a long history of classifying the steel materials by observing sparks emitted by the grinding wheel [1]. An experienced worker would observe the spark of the unknown piece of steel, and then compare it to the spark patterns of the known steel [2]. Spark observation is not only a simple and effective method, but also a quick and inexpensive way in industrial practice. The force applied to the grinding wheel can change the amount and configuration of the spark [1], and the spark observation method is only suitable for experienced workers. To overcome those limitations, computer recognition is adopted to identify spark images captured by mobile phone or camera, which make restriction smaller and raise spark testing efficiency. Computer recognition has high speed development and widespread applications in recognition field, such as Fingerprint Recognition and face recognition [3,4], but seldom applied to spark recognition. Takeo Nakata [5] developed an automated spark testing technique to measure carbon content in steel material based on image processing. This technique detected the explosion spark and the streamline sparks in all captured images, and calculated the explosion spark ratio, which is defined as the number of explosion spark divide by the number of all spark. There is relationship between the explosion spark ratio and carbon content. However, the detecting method only applies a narrow carbon contents range 0.1%-0.44%, and the explosion spark ratio is difficult to recognition accurately. Spark displays approximate self-similarity, and could be described by fractal dimension quantitatively. Box counting method is a typical method to calculate fractal dimension and widely used in measurement field, in recent years it was developed to determine the phase fraction [6] and evaluate surface quality [7]. The fractal dimension will change, along with the carbon content change. So it's feasible to measure carbon content by image processing and box counting analysis.

2. Experimental

2.1. Equipment and procedure

Fig. 1 shows the equipment of experimental procedure. The measurement system (Fig. 2) mainly consists of a grinder, a mobile phone (or a camera), and a computer. Firstly, the carbon steel sample is held by the sample holder or hand. The spark is grinded by grinding wheel with high-speed rotation and taken pictures by a

* Corresponding author.
E-mail address: 873477122@qq.com (K. Deng).

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Fig. 1. Photograph of experimental procedure.

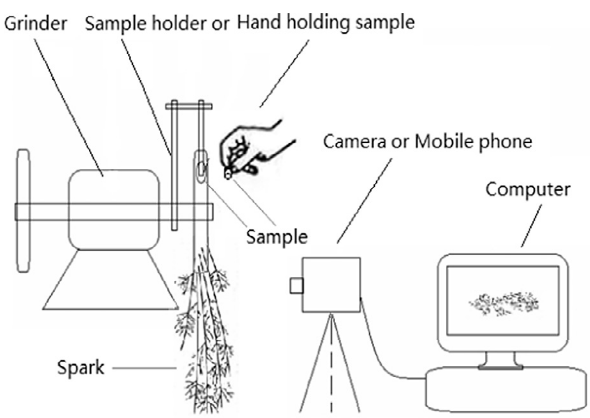

Fig. 2. Schematic diagram of measurement system.

mobile phone (or a camera). In order to facilitate the computer recognition, the black backboard is put behind the spark and used to provide contrast with the spark [2]. Then the spark pictures are acquired and edited by the computer. Finally, the fractal dimension of spark image is calculated and the different kind of carbon steel is characterized by fractal dimensions for identification.

2.2. Measurement principle

The characteristic appearance of the spark is apparently to be attributed chiefly to the oxidation of the carbon and iron in the steel and the reaction of carbon and iron oxide. The entire spark streams consist of the trajectories of a multitude of glowing particles ('Streamline') with the accompanying 'bursts'. The number and intensity of the 'streamline' and 'bursts' will increase when the carbon content of the steel is increased [1]. The sparks exhibit some statistical self-similarity. The part of the spark image possesses fractal characteristics with the entirety. To analyze the characteristic of the spark image, it is necessary to crop sparks image. The cropped color spark image is transformed into gray image and the grayscale threshold method is used to create binary image. The fractal dimension is get from the processed binary image using box counting analysis.

Box counting analysis is an efficient method to estimate fractal dimension of statistical self-similarity pattern [8,9]. From Fig. 3e, The uniform grid covers date points with as short as possible spacing, r, in that way the full data can be overlaid by the minimum number of boxes. The number of boxes (N) containing any data points are counted [10]. The grids are called 'boxes' vividly. A box with reduced r is then laid over the data point, and the counting processing is repeated with different r. N is the number boxes. The absolute value of the gradient is the fractal dimension, D_f when there is a linear relation between log r and log N. Mathematical expression for the fractal dimension expressed as

$$D_f = -\lim_{r\to 0} \frac{\log N}{\log r} \tag{1}$$

where D_f is the fractal dimension, r is the length of the side of box, N is the number of boxes. The image processing and calculation of the fractal dimension of the spark is shown in Fig. 3. The minimum number of boxes to divide the spark picture is 4 (Fig. 3e), and the maximum number of boxes obtained by dividing the spark picture is 512 (Fig. 3f). D_f can be estimated, the fractal dimension, from the slope of a least-square linear fit of log(N) against log(1/r) (Fig. 3h).

3. Results

The different kind of carbon steels (their chemical compositions shown in Table 1) are used to get spark images. The fractal dimensions of these images are calculated. The results are plotted in Fig. 4. It shows a good correlation between the fractal dimension and carbon content. D_f approximation apply only one basis function to make the simplest possible data fitting. The approximation function is fitted to be:

$$D_f = D_0 + Ae^{Bx} \tag{2}$$

where D_0, *A, and B* are constants, *x* is the carbon content. Least squares analysis of the fractal dimension yielded $D_0 = 1.88506$, $A = -0.23932$ and $B = -1.31578$. Fig. 4 shows the comparison between the experimental data and the computed approximation. It is concluded that an exponential function is employed to describe most of the qualitative characteristics of the given fractal dimension.

After the functional approximation is performed, its inverse function is:

$$x = \frac{1}{B}\ln\left(\frac{D_f - D_0}{A}\right) \tag{3}$$

One can compute the corresponding carbon content from the fractal dimension. The carbon content measurement accuracy is evaluated for carbon steel sample included 0.006%–1.22% carbon content. Fig. 5 shows the carbon content measurement and calculated result for carbon steels. The experimental data is closer to the calculated value and the carbon content measurement error is about 0.06%. But the accuracy depends on the consistency of the experiment condition of the collecting spark and the artificial cropping the middle part of spark image for different types of carbon steel.

4. Conclusions

The spark observation and imaging processing by computer are combined to distinguish the steel materials effectively. A mobile phone (or an ordinary camera) are used to take some spark pictures and then calculated the box-counting dimension of spark images on computer. This method to measure carbon content based on spark observation and image processing shows a good correlation between fractal dimension and carbon content of steel. And the carbon content measurement error is 0.06%. Which means a convenient but also accurate test to identify an unknown carbon steel sample may be achieved.

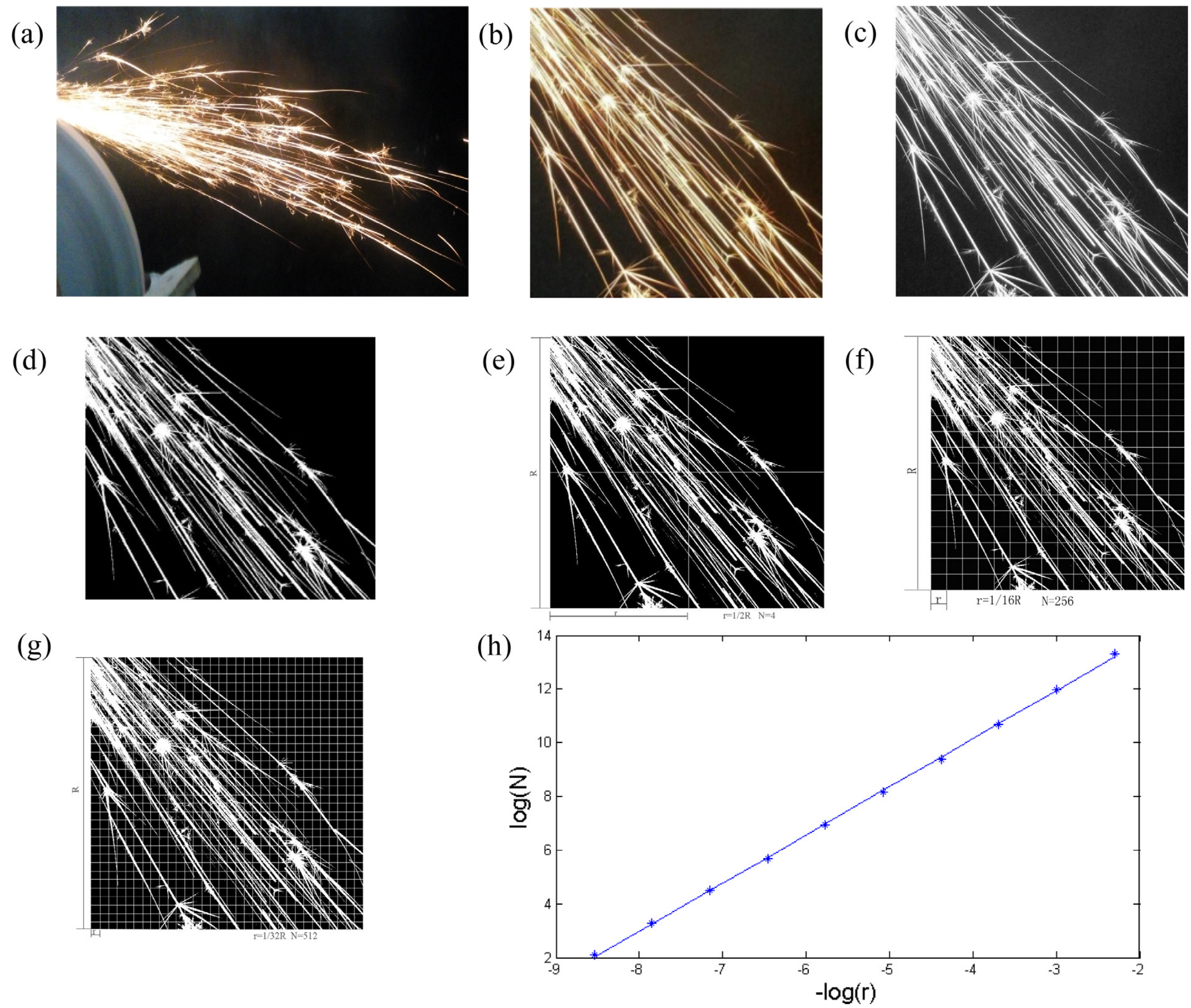

Fig. 3. The specific processing of the spark (a) the original spark image (b) the cropped spark image (c) the gray spark image (d) the binary image (e) the binary picture is divided into 2*2 boxes (f) the binary picture is divided into 16*16 boxes (g) the binary picture is divided into 32*32 boxes (h) plot of log(N) vs. −log(r). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1
The chemical components of steel samples.

Elements designation	C(%)	Si(%)	Mn(%)	P(%)	S(%)
Pure iron	0.006	0.009	0.072	0.011	0.001
20 carbon steel	0.19	0.25	0.53	0.01	0.01
45 carbon steel	0.46	0.26	0.67	0.01	0.01
65 carbon steel	0.64	0.28	0.66	0.009	0.003
T10 carbon steel	0.97	0.26	0.27	0.012	0.002
T12 carbon steel	1.22	0.32	0.36	0.01	0.01

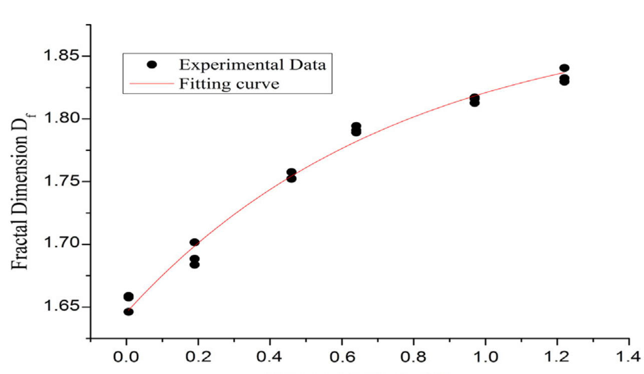

Fig. 4. The correlation of fractal dimension and carbon content.

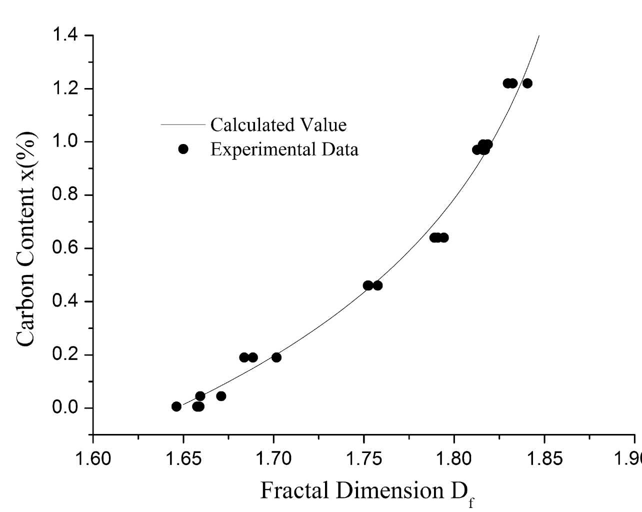

Fig. 5. The calculated value and experimental data of carbon content.

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