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AUTOMATED FRACTAL ANALYSIS OF A NETWORK OF THERMAL FATIGUE CRACKS

AVTOMATIČNA FRAKTALNA ANALIZA MREŽE RAZPOK ZARADI TERMIČNE UTRUJENOSTI

Pavlo Maruschak

Ternopil Ivan Pul'uj National Technical University, Ternopil, Ukraine
maruschak.tu.edu@gmail.com

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We have studied continuous-casting machine rolls' surface thermal cracking images. On the fundamentals of fractals a thermal cracking procedure analysis was proposed. The achieved results show that the thermal cracks have a strong self-similarity, according to the fractal laws, and the values of the fractal dimensions range from 1.0 to 2.0. The relationship between the fractal dimensions and the distribution values of the cracks' lengths is established. A new method of diagnostics and certain ideas for the analysis of the thermal cracking of a continuous casting machine roll with fractals theory is proposed.

Keywords: multiple cracks, thermal fatigue, fractal, damage, diagnostics, surface

Raziskana je površina valjev naprave za kontinuirano litje s toplotnimi razpokami. Uporabljena je procedura fraktalne analize razpok. Dobljeni rezultati kažejo, da so po fraktalnih zakonih toplotne razpoke med seboj podobne in imajo fraktalno dimenzijo v območju 1,0 do 2,0. Opredeljena je odvisnost med fraktalno dimenzijo in porazdelitvijo dolžine razpok. Na podlagi fraktalne teorije je predlagana nova diagnostična metoda in nove ideje za analizo toplotnega razpokanja na napravi za kontinuirano litje.

Ključne besede: številne razpoke, toplotna utrujenost, fraktali, poškodbe, diagnostika, površine

1 INTRODUCTION

The timing and safety of steel pouring on a continuous billet casting machine (CCM) depend on the properties and condition of the surface of the rollers, which are the main load-bearing structures and transportation means for moving the slab[1]. Significant thermomechanical loads cause a degradation of the surface properties and the occurrence of "crazing"[1–3].

There are a number of approaches to diagnose the multiple cracking by means of processing the digital images of the analyzed surface; however, they are not widely adopted in metallurgical practice due to the underdevelopment of the theoretical and methodological background[4–6].

Some works are dedicated to the formulation of the main requirements and the assessment criteria for multiple cracking; however, they need to be further improved[7–11]. The overall and rapid assessment of the geometry of the network of cracks is possible by using fractal geometry, which allows a determination of the configuration of cracks and the self-similarity of the fractured structures[8,11].

The purpose of this work is to improve the rapid diagnosis of the degradation of the CCM roller surface affected by a network of thermal fatigue cracks.

2 RESEARCH TECHNIQUE

The algorithm for the identification of the crack position consists of the following main steps: binarisation of the original grayscale image, its filtering, and repeated binarisation of the obtained image. The complete methods for the multiple-cracks digitalization are not described in this paper, but a few articles have been published on this subject[8,9,11]. In order to establish the crack position relative to each pixel it was necessary to determine whether the pixels belong to the crack surface or the background. This task was performed using binarisation. In a binary image the white pixels corresponded to the background and the black ones to the object. The analysis of the cracked surface images was performed using the "Fractalys" software developed by Gilles Vuidel[12], which was preliminarily tested on the model image of the Sierpinsky Carpet.

The fractal dimension was determined by the cellular method[7]. In addition, each element of the image was surrounded by a frame with a square shape in order to determine the number of pixels in a limited area.

Using the progressive approximation method we magnified the analyzed window with a view to determining the number of black pixels in frames with different sizes. As a result of the image processing a series of points (empirical curve) was obtained, where the abscise axis corresponds to the size of the lateral face of the frame and the ordinate axis represents the number N (1) of elementary particles of the image (pixels) surrounded by a frame of a certain size[7]:

$$N = \varepsilon^{-D+} c \quad (1)$$

where N is the number of black pixels in the window; ε is the size of the elementary square; D is the fractal dimension; c is the parameter that allows a correct adjustment of the empirical curve.

For multiple defects the damage is distributed in a highly irregular way in reality. But it is experimentally established that multiple cracking is a fractal process in a finite range of scales[4,6]. This means that one could use a fractal dimension as a diagnosis parameter for a multiple cracking network geometry. General remarks about fractals and fractal dimensions may be found in[4–6] and particular precisions were given in[7]. The adequacy of determining the fractal dimension of the fractured structures by the cellular method was additionally checked by the net method[10].

The obtained curve was reconstructed on a logarithmic scale by means of an approximation to the exponential equation[7]:

$$\lg(N(\varepsilon)) = -D\lg(\varepsilon) + c \qquad (2)$$

Since the real image is not an ideal fractal (it is not a continuous function), the approximation of the obtained pixel array was performed, which was followed by a determination of the correlation coefficient.

3 RESULTS AND DISCUSSION OF THE FRACTAL ANALYSIS OF THE FRACTURED SURFACE

The D values testify to the ordered state of the structure for which the morphology of the fractured structure is preserved. Within certain sections of the image the D values below 1.0 were found, which are typical of the individual fractured fragments. However, with an expansion of the area of analysis the D values always exceeded 1.0. It was observed that the analyzed image contains several independent morphological sets (sections of cracks), which propagated independently, (**Figure 1a**). For the case investigated D = 1.4 ... 1.3, which testifies to a well-bound, multi-scale network of cracks with numerous free intervals of different sizes, some of which are comparable to the crack size.

The external surface of the analyzed template was milled with a step h = 0.4 mm, and a change in the numerical readings for cracking was determined at various depths relative to the external surface of the template. A local increase in D was detected at a depth of 0.8 mm, which is connected with an "increase" in the area of cracking due to the incomplete removal of the oxidized external sections of the material. Later on the D value decreases monotonously (**Figure 1b**). With an increase in the number of identified cracks the fractal dimension increases, which is typical of the adjacent

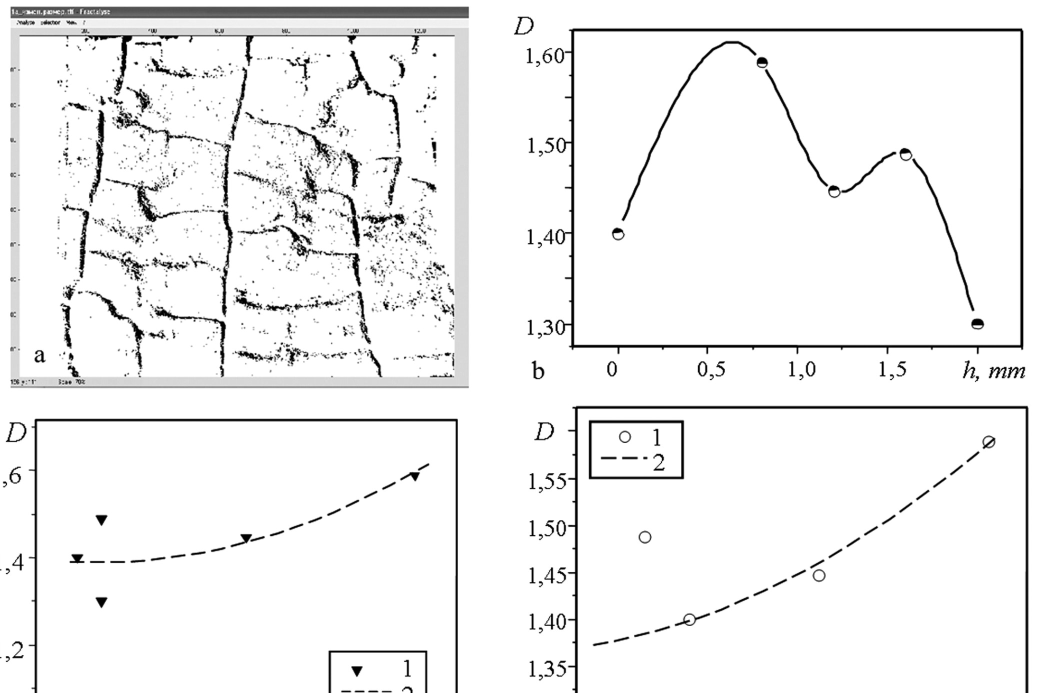

Figure 1: Analysis of the multiple cracking surface: a) image of surface; b) change a fractal dimension on the depth of analyzable area; c) dependence of fractal dimension on the quantity of identified coalesced cracks and d) individual cracks; 1 – experimental data; 2 – approximation

Slika 1: Analiza površine z mnogimi razpokami: a) slika površine, b) sprememba fraktalne dimenzije v globini analizirane površine, c) odvisnost fraktalne dimenzije od količine identificiranih koalesciranih razpok, d) posamične razpoke, 1 – eksperimentalni podatki, 2 – aproksimacija cracks and the "joint" cracks that appeared due to the coalescence (**Figure 1c, d**).

The quality of the fractal dimension evaluation was controlled with reference to the value of the correlation coefficient, which was not below 0.99.

4 NORMALIZATION OF DEFECTIVENESS USING THE FRACTAL DIMENSION

The measurement of the in-service defectiveness is important as a parameter for digital diagnostics. It was performed by the fractal dimension, taking into account possible limit states[13]. The allowable fractal dimension [*D*] under a thermomechanical loading typical for the metallurgical equipment must be lower than the critical value $D_{cr} = f(\sigma, T)$:

$$[D] \leq \frac{D_{cr}}{n_1}$$

where n_l is the fractal stock coefficient.

The fractal dimension allows a description of the spatial cracking structure, taking into account the off-orientation degree of the network of cracks. The evaluation of the fractal dimension effectively supplements the existing methods for the diagnostics of theCCM rollers[1,8–11]. Using the methods of fractal geometry we analyzed the geometrical model of the multiple cracking. Their spatial dimensions correspond to the dimensions of the statistical massifs of binary images showing real fractured structures. The value D_{cr} must be within the range 0.0–2.0, provided that the image $D_{cr} < 1.0$ contains the non-joint (separate) elements. At $1.0 < D_{cr} < 2.0$, the image is composed of the mixed elements and contains both small and large clusters with separate isolated elements.

5 CONCLUSIONS

Approaches are proposed that allow the integral assessment of the multiple cracking network geometry by means of the fractal dimension. It characterizes the anisotropy of the topological properties of fractured structures. An increase in the fractal dimension testifies to the accumulation of damage on the analyzed surface. The obtained *D* values testify to the ordered state of the structure, at which the morphology of individual elements of the network of cracks is preserved. The dependence of the fractal dimension on the number of identified single and joint cracks is established.

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