Surface Defects Evaluation by Fractal Geometry and Statistical Analyses

Vlastimil Hotař, František Novotný

Technical University of Liberec, Department of Glass Producing Machines and Robotics,
Hálkova 6, 460 17 Liberec
vlastimil.hotar@tul.cz

1. Introduction

Many natural structures cannot be described by conventional methods, because they are complex and irregular. Relatively a new approach is the application of fractal geometry [1]–[3]. This geometry is successfully used in science, but an application in industry is sporadic and experimental only. However, the fractal geometry can be used as a useful tool for an explicit, objective and automatic description of production process data (laboratory, off-line and potential on-line).

The data having complex and structured character can be also met during a glass manufacturing. The data may have a form of digitalized pictures, time series (progressions) or a topologically one-dimensional interface (especially a surface roughness). When analysing this data, it is suitable to use - in addition to classic mathematical statistics - modern tools of the fractal geometry expressing the complexity degree of structured data by means of a single number, the fractal dimension [1]–[3].

A use of the fractal dimension and statistic tools together forms an interesting and powerful tool for complex data quantification, for a poor quality source searching, a production optimalization and a non-stability of production process subsystems searching.

Now, there are tools application possibilities for monitoring for three basic data format types: digitalised photos, time series and topological one dimension dividing lines (especially surface roughness) [5]–[9]. On this account, we are developing three off-line softwares that can be converted into on-line control systems in the future. The software tools use mathematical statistics and fractal geometry. They are tested in an off-line classification of surfaces and defect pictures, in a description of time series, which were obtained from outputs of a glass production control system, for evaluation of metal surfaces (iron aluminides in comparison with the carbide-nickel steel) in contact with the glass melt as well as changes of their quality and for quality control of window glass sheet (an objectification of the corrugation test).

The following article demonstrates possibilities of the fractal geometry with combination of statistic tool for the evaluation of 2D pictures of surface defects - structures of the hole cracks in costume jewellery. Software Matlab 6.5 and HarFA 4.0 [4] were used for these experimental evaluations.

2. Methods of analyses

The explicit, objective and automatic description of images complexity can be made by different methods both statistic and fractal dimension. Only some of the possibilities are presented below.

- The process of description has five steps practically:
- Preparing of samples - structure must be visible, the costume jewellery is cut, *Figure 1A*.
- Taking digital photographs. Photos of the hole cracks in costume jewellery are from an electronic microscope, *Figure 1B* (it is possible obtain “classic” photographs and they scan).
- Software preparation of the digital photographs, *Figure 1C* (cutting of the photographs, because only some parts of the photos are important for analysis).
- Analyses of the images.
- Evaluation analyses results.

Digital image is a matrix (or matrixes) of pixels (rectangular array of points, *Figure 1D*). Pixels can reach different numbers, which depend on the used format of digital images. The pixels have numbers between 0 (black) and 255 (white) for the grey 8-bit palette bitmap and the bitmap has only one matrix. (Colour bitmap has 3 matrixes for RGB colour model – one matrix of red, green and blue colour.)

Figure 1C shows two typical poor quality surfaces of costume jewellery holes. The cutting C-1 has deep cracks and C-2 has a thin structure.

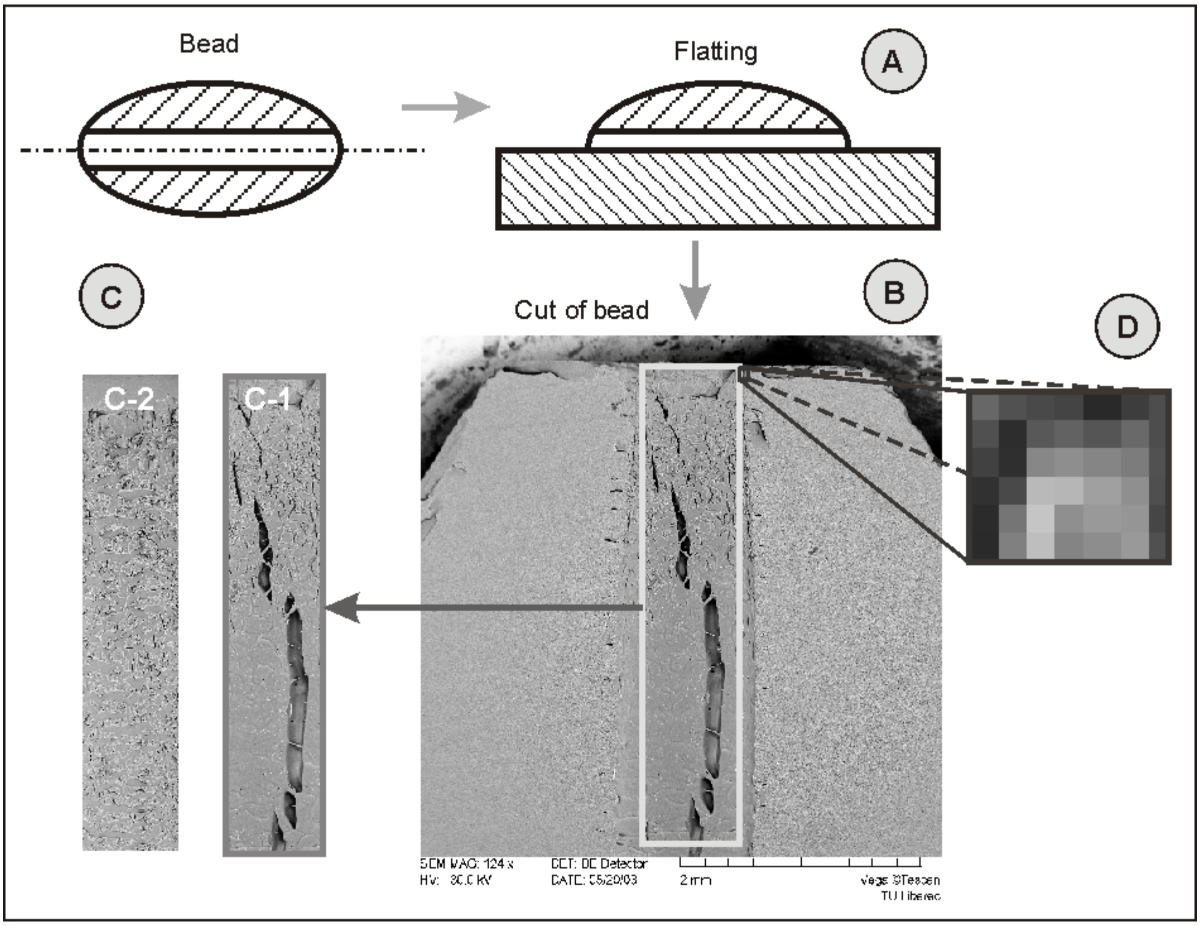

Figure 1 Preparing of samples, taking photographs, software preparation

2.1. Histogram

An evolution of a structure of the bitmap is possible by the statistical description of a histogram, *Figure 2*. Modus, median, average, range, standard deviation and other statistic tools can be used easily.

A suitable method is the histogram cut off on 5% level and the method describes the image by a single number. The analysis computes a width 90% of all pixels value of the histogram from an average value of the image, *Figure 2*.

The method is very sensitive to shadow, that can occur in the hole cracks. The analysis is easy, but describes all defects, cracks, shadows and structure together.

2.2. Thresholding

Next analyses are based on a technique called "thresholding", that transforms grey or colour image object into black & white (binary) one. The binary image can be determined from the grey 8-bit palette bitmap, where black are all pixels which fulfil condition e.g. 0 = black <= 100 and all the other pixels become white (100 < white <=255), *Figure 3*. It means, that all pixels lesser than or equal to the threshold 100 are black and greater than 100 are white. (More than one threshold can be used or the technique for matrixes of colour images can be used too.)

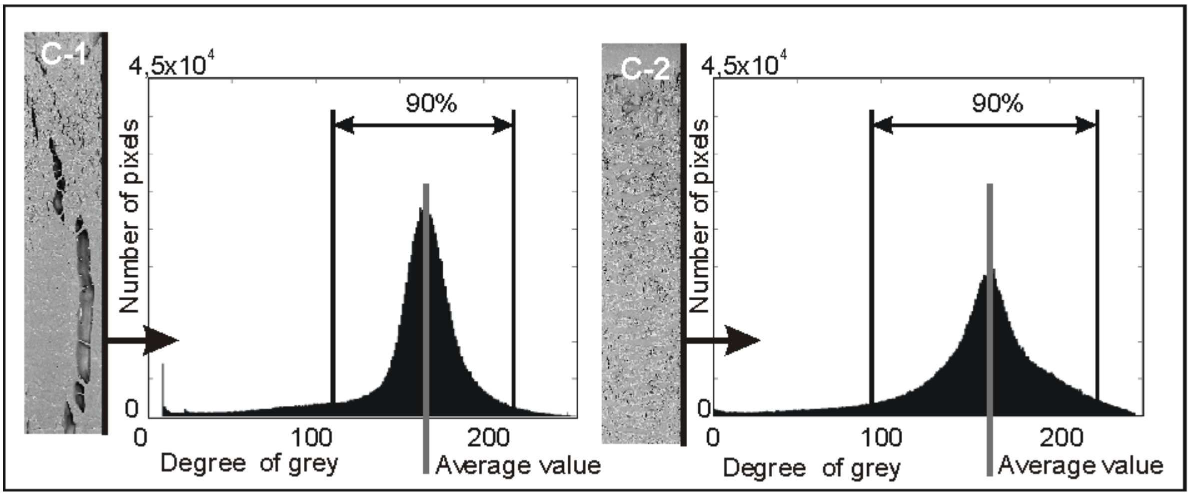

Figure 2 Histogram cut off on 5% level

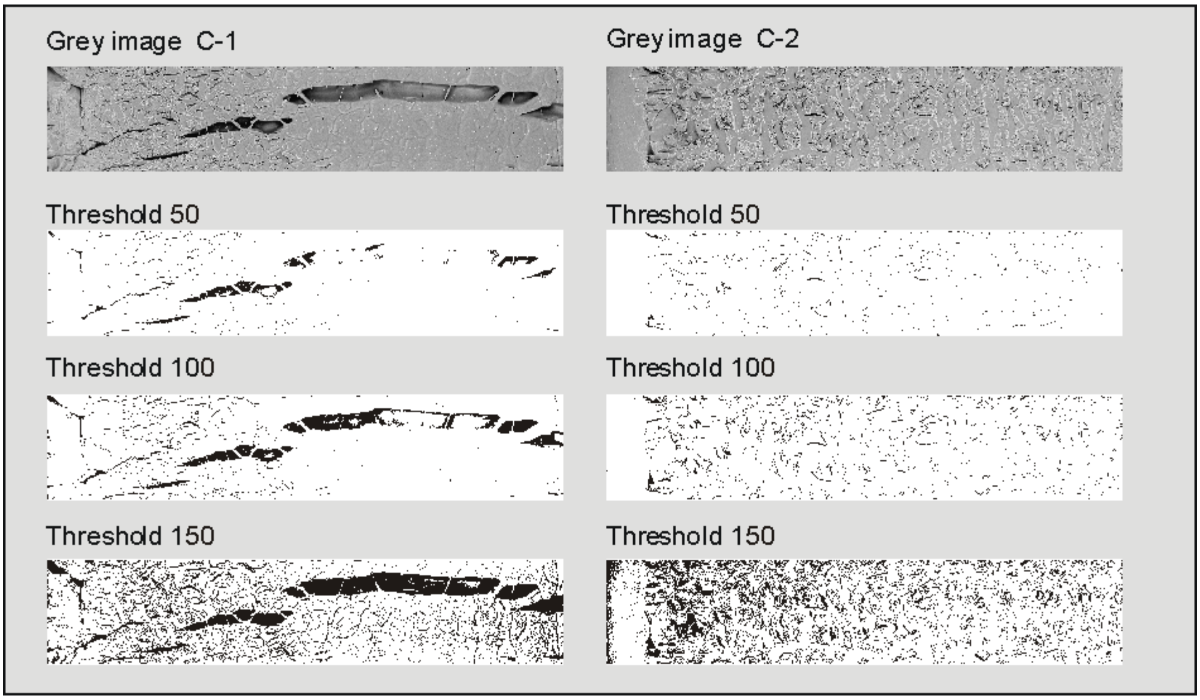

Figure 3 Thresholding of grey images

The procedure of thresholding can be used for all thresholds of the grey image, 256 binary images are obtained. An analysis is done for all binary images and as far the analysis produces single number classifying a binary image, a spectrum of dependence between single number and threshold is given (e.g. *Figure 4*).

Thresholds between 50 and 150 are suitable for the images of the hole cracks, because binary images, obtained by these thresholds, show the best structure of the surface. Thresholds between 10 and 50 show the large cracks. Binary images produced by the thresholding with thresholds over 150 contain shadow.

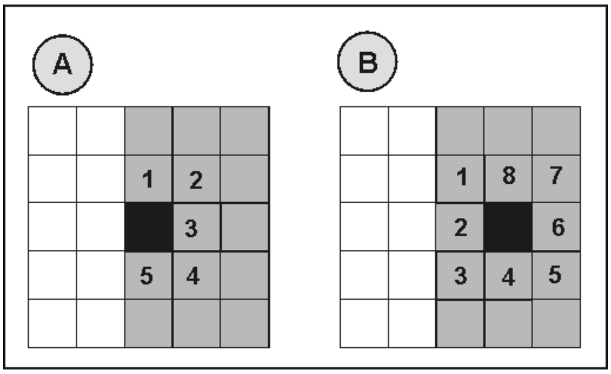

Figure 4 *Percentage of black pixels of binary images spectrum*

2.3. Percentage of black pixels

The analysis is based on computation of percentage of black pixels in binary images – the method computes number of black pixels in percents. It is supposed: a greater count of black pixels represents a greater complex structure and more defects.

A spectrum of dependence between percentage of black pixels of binary images and thresholds is in *Figure 4*. The analysis is easy, but describes all defects, cracks, shadows and structure together.

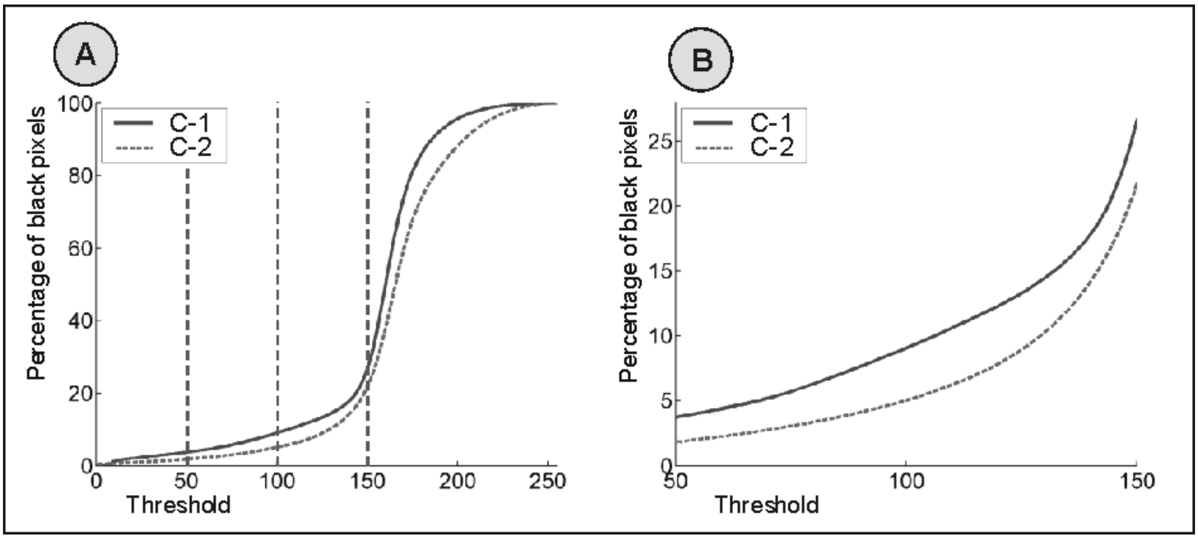

Figure 5 *Pixels on boundary crack.*

2.4. Percentage of deep cracks

The method is suitable for detection of relatively large and single cracks and defects. The method computes percentage of pixels with neighbouring pixels of the same value. The analysis searches black pixels (value 0) in a binary image, which have five or more neighbouring black pixels. The black pixels represent defect, structure, cracks, etc. Especially large cracks and defects contain black pixels with five or more neighbouring black pixels. *Figure 5* shows part of boundary crack. Black pixel in *Figure 5A* has five neighbours and in *Figure 5B* has 8.

Figure 6A shows spectrum of dependence between percentage of black pixels with five or more neighbouring black pixels of binary images and thresholds. For detection of large hole cracks in costume jewellery thresholds from 10 to 50 are the most suitable, *Figure 6B*. For the threshold 50, the cutting C-1 has more single cracks and defects, numerically: $T_{50\_C\text{-}1} = 3.17\%$ than the cutting C-2, numerically: $T_{50\_C\text{-}2} = 0.8\%$.

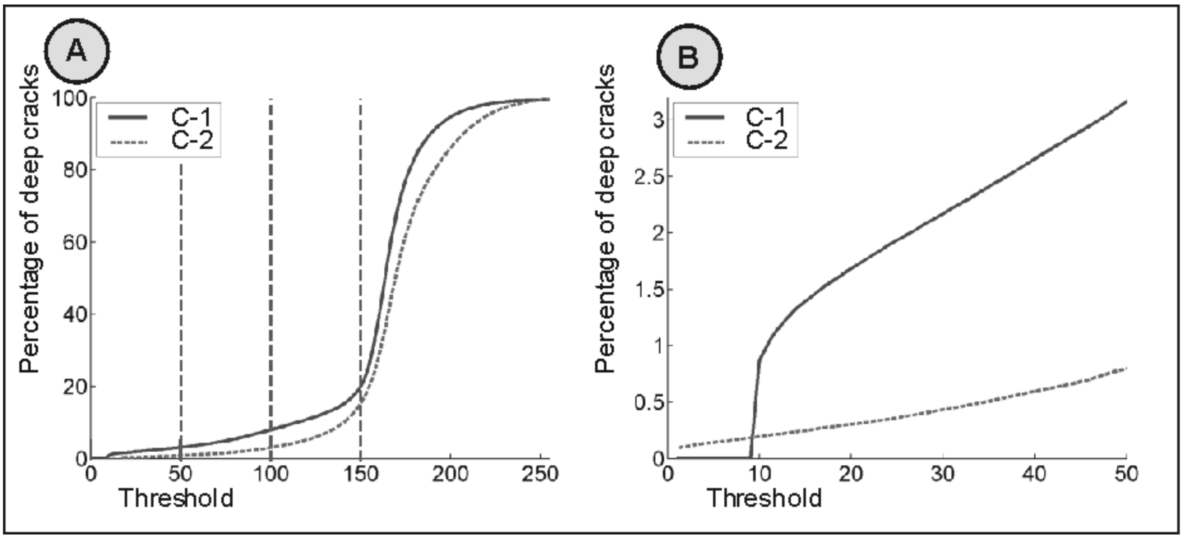

Figure 6 *Percentage of black pixels with five or more neighbouring black pixels spectrum.*

2.5. Box dimension

The software HarFA 4.0 [4] is used for the analysis and software tools developed in Matlab 6.5 makes data evaluation.

The box counting method is shown in [2] and based on fractal geometry. The analysis describes structure by single number: the box dimension D_B. The box counting method works by laying meshes of different sizes r and then counting numbers of boxes N needed to cover a binary image (*Figure 7A*) completely (*Figure 7B*, *C*). The number $N(r)$ of boxes needed to cover the structure is given by a power law:

$$N(r) = const. \cdot r^{-D_B} \tag{1}$$

D_B is the box dimension. Logarithmic dependence between $\log_2 N(r)$ and $\log_2 r$ is called Richardson-Mandelbrot plot (*Figure 7D*). The box dimension (that estimate fractal dimension) can be determined by slope s of the regression line in *Figure 7D*:

$$s = D_B = -\frac{\Delta \log N(r)}{\Delta \log r} \tag{2}$$

The box dimension is multiplied by 1000 for a better confrontation.

The fractal spectrum (that was discovered in project HarFA) of the cuttings C-1 and C-2 are shown in *Figure 8*. The box dimensions over threshold level 150 are similar, because over the value an influence of shadow is significant. Results of analysis for threshold level 120 are: $D_{B\_C\text{-}1}$ =1429.6 (C-1) and $D_{B\_C\text{-}2}$ = 1562.4 (C-2), where the higher value represents greater complexity of the structure in the image. The cutting C-2 is more structured than the C-1 and box dimension quantifies the structures.

3. Results

The most suitable methods for describing of structures of the hole cracks in costume jewellery box dimension and percentage of deep cracks counting appear. *Figure 9* and *10* show a selection of results. For whole analysis with classification to quality class both methods must be use.

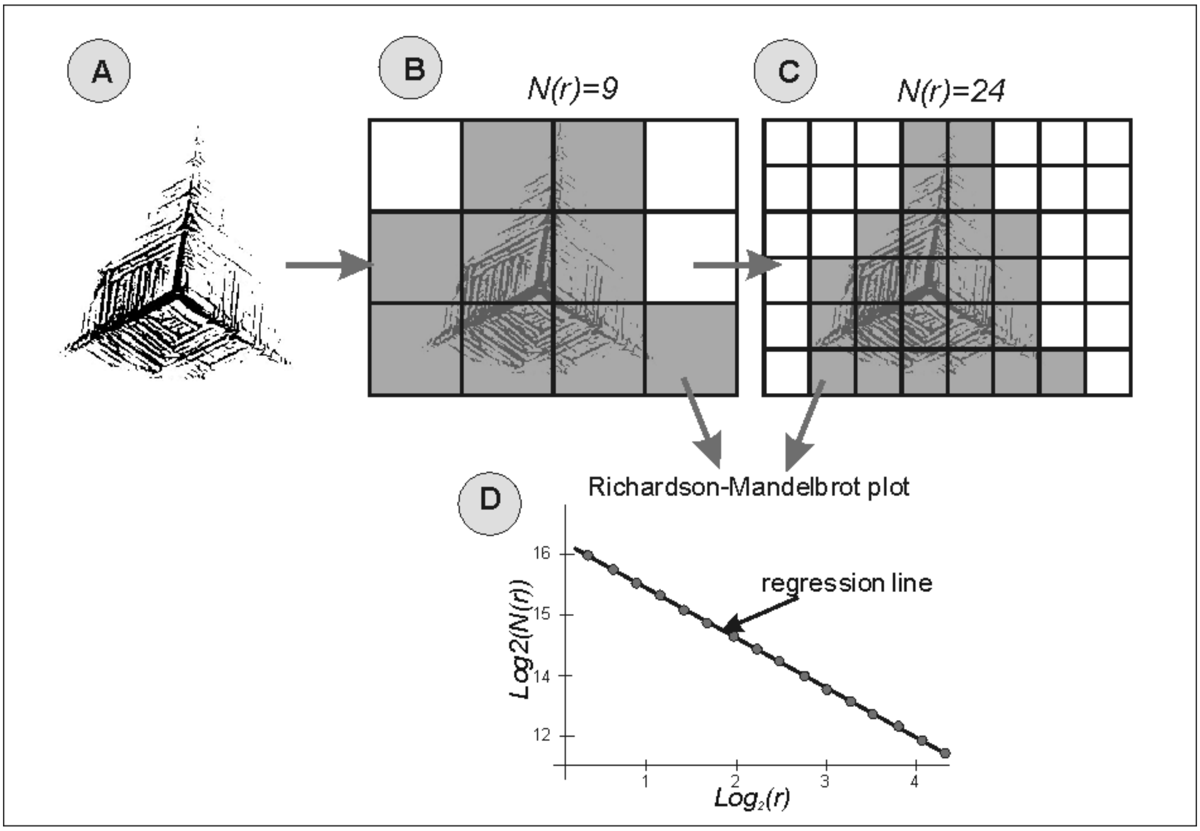

Figure 7 Box counting method.

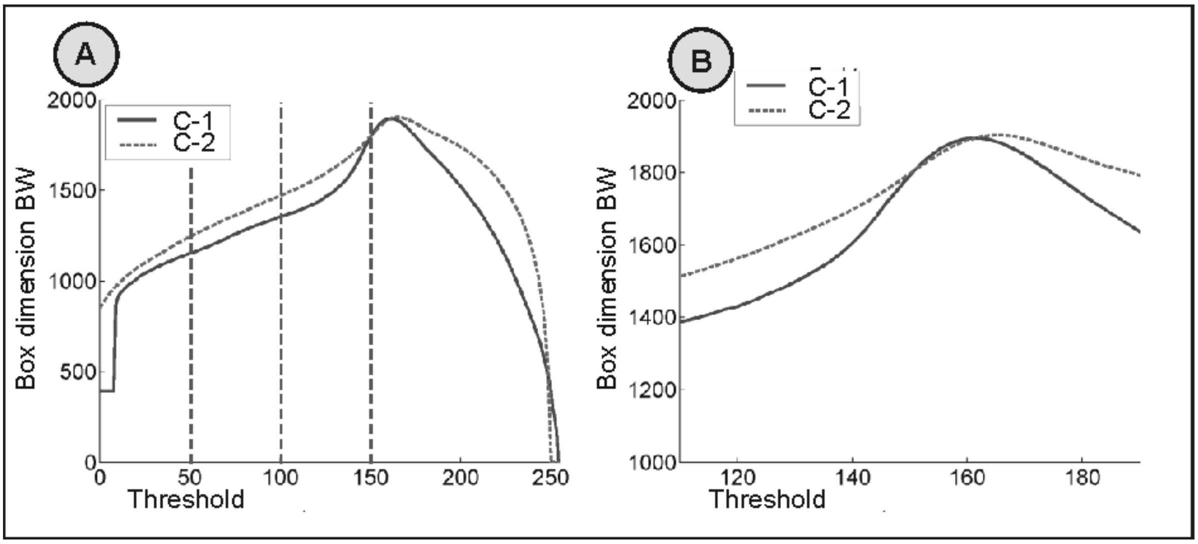

Figure 8 Fractal spectrum.

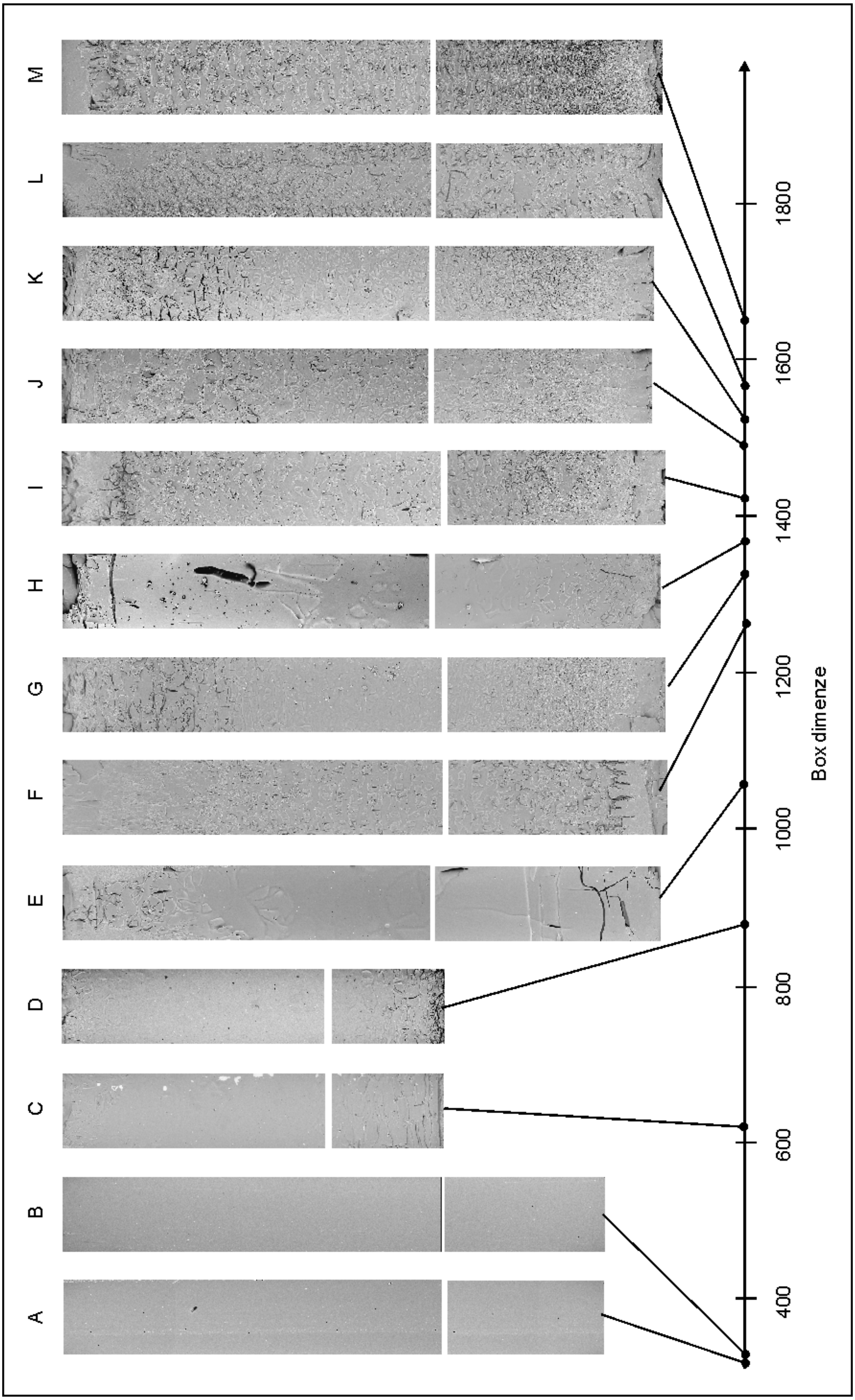

Figure 9 Selection of hole surfaces and their position in BD.

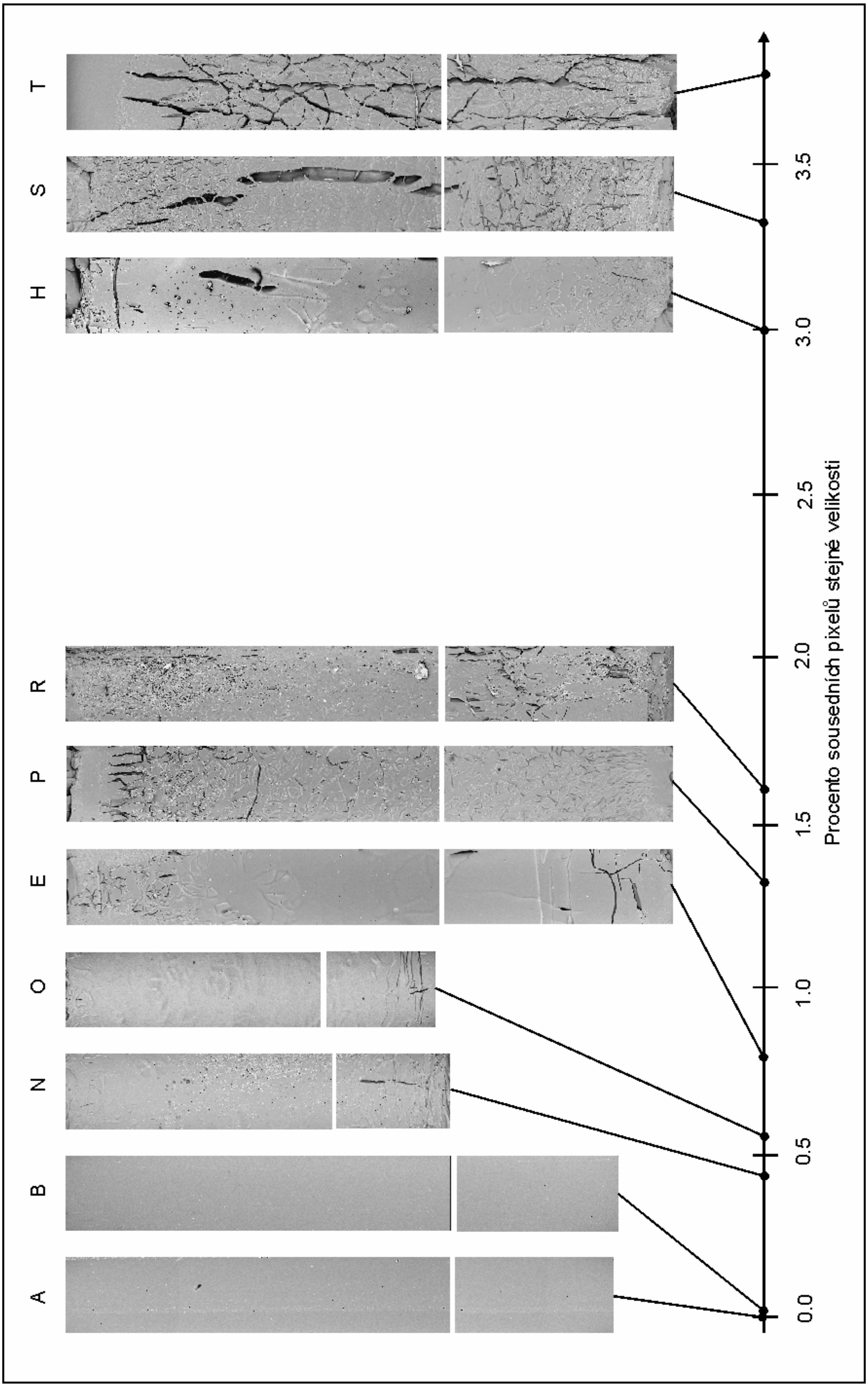

Figure 10 Selection of hole surfaces and their position in percentage of black pixels with five or more neighbouring black pixels.

4. Conclusion

Photos of structures can be described by the statistic analysis and the fractal dimension. 33 images were analysed and we found out, that percentage of deep cracks and box dimension are the most suitable for the experimental evaluation of hole cracks in costume jewellery, because two types of defects can be met in the hole: deep cracks, a thin structure. The box dimension is specialized for the thin structure and the analysis of percentage of deep cracks is specialized for the deep cracks, which is better for the explicit evaluation.

Acknowledgments

This work was created in the frame of the research project No. MSM 4674788501, which is financed by the Ministry of Education of the Czech Republic.

References

[1] Mandelbrot. B. B. *The fractal geometry of nature*. New York: W. H. Freeman and Co.,1982.

[2] Peitgen, H.O., Juergens, H. and SAUPE, D. *Chaos and Fractals: New Frontiers of Science*. New York; Berlin; Heidelberg: Springer-Verlag, 1992.

[3] Bunde, A. and Havlin, S. *Fractals in science*. Berlin: Springer, 1994.

[4] Zmeskal, O., Nezadal, M., Buchnicek, M. and Sedlak, O. *HarFA and HarFA: e-journal*. http://www.fch.vutbr.cz/lectures/imagesci/ Brno: Ústav fyzikální a spotřební chemie, 2002

[5] Hotař, V., Novotný, F. *Possibilities of Fractal Geometry Application in Glass Industry*. In: Glass Odyssey. Montpellier (France) 2002. p. 120, 6 pages.

[6] Hotař, V., Novotný, F., Hotař A. *Interpretation of the production data by means of the fractal geometry and statistical analyses*. Sklář a keramik **53** (2003), no. 7-8, p. 148-154.

[7] Hotař, V., Novotný, F. Surface *Profile Evaluation by Fractal Dimension and Statistic Tools*. In Proceedings of 11th International Conference on Fracture. Turin (Italy): CCI Centro Congressi Internazionale s.r.l., 2005. p. 58.

[8] Hotař, V., Hotař, A. *Non-conventional methods application for data evaluation in glass industry*. Sklář a keramik **56** (2006), no. 9, p. 179-184.

[9] Hotař, V. Industrial *Data Evaluation Using of Fractal Geometry*. Thesis, Liberec: Technická univerzita v Liberci, 2005.