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IMAGE ANALYSIS ALGORITHMS IN COMPUTER SYSTEM OF DETERMINATION OF ASH FUSIBILITY

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Abstract – The article presents the computer system to determine fusibility of ash obtained from solid mineral fuels, which is a vital parameter for proper exploitation of power and heating plants boilers. The system is based on analysis of the image of a heated ash sample. In the beginning, we describe the way in which the ash specimen is prepared, as well as its thermal processing, and also give criteria for specifying the characteristic temperature points of phase transitions according to the ISO 1171 standard. Later, we present the scheme of the apparatus for automated determination of ash fusibility and the image acquisition method. Finally, we describe the chosen criteria of automated determination of characteristic points on the basis of selected sample image geometry coefficients. The ultimate determination of the values of those points on the basis of many calculated coeffici ents, fuzzy logic is applied.

Keywords: image processing, contour analysis, fuzzy logic, fusibility of ash

1. INTRODUCTION

The ash sample should be heated under normalized conditions and under continuous observation, in order to notice and record its distinc tive shape deformations. The indication of the appropriate critical phase transition temperatures is usually performed in reducing or oxidizing atmosphere; the fact that the characteristic temperatures in the reducing atmosphere are respectively lower should not be overlooked. Heating a solid body leads to phase transitions The transitions are characterized by changes in physical properties of the material. The specimens are made of coal ash according to the ISO 1171 standard. The most popular geometric forms of specimen are:

- Pyramids;
- Cylinders or cubes;
- Truncated cones.

The samples are formed is sp ecial matrices with possibly smooth walls. Due to relative easiness of preparation, the cylinder shape is most often used, of dimensions from 3 mm to 9 mm, where its height and its diameter are equal. According to the ISO standard, the sample should be slowly heated to the start temperature of the experiment, which is 815 ^{O}C in air atmosphere, in order to remove organic matter. The whole experiment process starts at 815 ^{O}C, and terminates at temperature of about 1800 ^{O}C, assuming uniformity of heating. At the beginning of the experiment, the original shape and dimensions of the sample should be analyzed, in order to calibrate the system.

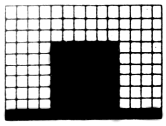

Fig. 1. The specimen at the beginning.

Several characteristic temperature points during phase transitions must be indicated:

Sintering temperature – signaled by size decrease and slight pitting of the surface (no equivalent in the ISO standard, however the temperature should be recorded in the system, for the measurement process requirements and for purposes of temperature characteristic points determination of other materials).

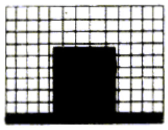

Fig. 2. The specimen' s image at the sintering phase.

Deformation temperature, i.e. softening – it is defined by the very first signs of rounding of corners, as a result of softening.

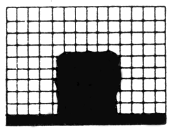

Fig. 3. The specimen' s image at the deformation (softening) phase.

Sphere temperature – indicated by round contours and the sample' s height equal to its basis length.

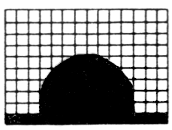

Fig. 4. The specimen' s image by the temperature of the sphere phase.

Hemisphere temperature, i.e. the melting temperature – is indicated by the shape most si milar to a hemisphere and the sample' s height equal to half the diameter of the basis.

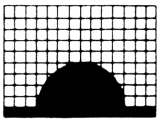

Fig. 5. The specimen' s image by the hemisphere temperature.

Flow temperature – indicated by spreading of the ash sample. The sample height is equal to 1/3 of the height in the hemisphere temperature.

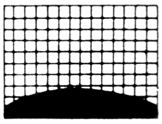

Fig. 6. The specimen' s image by the floating temperature.

Note that the composition of analyzed sample can diverse and it may cause unexp ected geometrical effects, like swelling, falling in or tilting of the sample.

2. APPARATUS AND COMPUTER SYSTEM OF DETERMINATION OF FUSIBILITY OF ASH

The apparatus contains a high-temperature tubular furnace enabling to reach the temperature of at least 1500^{o}C, which guarantees an appropriate uniformity of temperature of the heated specimen. Th e measurement process is controlled by a PC computer , via cascade PID temperature controllers, which are equipped with the serial port RS485. The apparatus enables continuous monitoring of the specimen contour changes during the heating process, by means of a vision system, inte grated with the furnace. The vision system contains an industrial CCD camera equipped with optical filters to reduce excessive light emissivity of the heated specimen. It is assumed that changing the filters with be performed automatically via the RS485. The vision unit used in the measuring computer system is responsible for the following operations [1][2] : acquisition and conversion of an image into a digital form; its preliminary processing including filtration, segmentation; localization of the specimen, evaluation of its geometrical attributes and determination of characteristic temperatures.

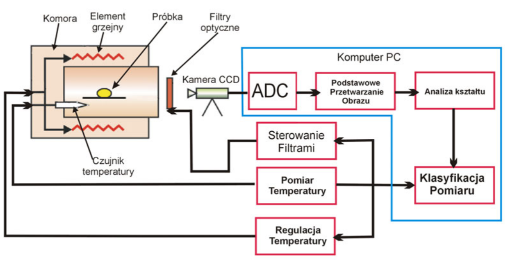

Fig. 7. Block diagram of computerized system with CCD camera for determination of fusibility of ash.

3. COEFFICIENTS OF SHAPE OF SPECIMEN

The processing of the specimen' s image, acquired from a CCD camera during heating, should be performed in two phases:

- Preprocessing;
- Geometric shape analysis.

3.1 Preprocessing

The aim of the preprocessing [1] is to transform the acquired image to a "pure" binary form, suitable for further geometrical analysis of the ch anges of the specimen' s shape. Several tasks may be performed during the preprocessing, including:

- Linear and non-linear filte ring – noise reduction;
- Image segmentation;
- Erosion and dilatation;
- Gradient filtering;
- Skeletonize.

The arrangement of location has a strong impact on the results of further image processing and analysis.

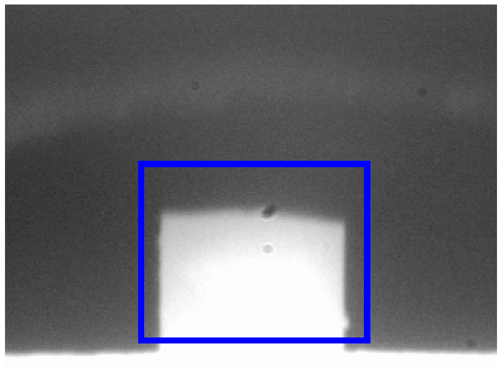

Fig. 8. The specimen' s image after the acquisition.

The initial location of the specimen in the measuring instrument is very important, especially for coal specimens, which have a tendency to swelling (Fig. 9).

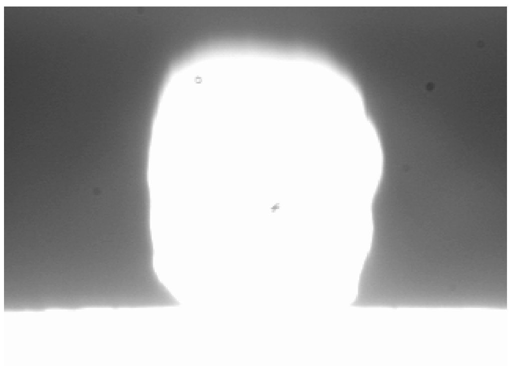

Fig. 9. Specimen' s image in the swelling phase.

The acquired image is contaminated with acquisition errors and errors introduced by lenses imperfection (incl. dust etc.) – factors which are difficult to be eliminated in industrial applications. The software has to mitigate the acquisition errors using proper image filtering algorithms.

Quite good noise reduction effects can be achieved thanks to:

- Gauss filter;
- Averaging filter;
- Median filter;
- Min and Max filters.

Noise-free image is transforme d to binary representation with a proper segmentation algorithm. A measuring process is a highly dynamic phenomenon, mostly due to constant linear temperature increase.

The segmentation, which divides the image into disjoint regions, each characterized by sp ecific features, is expected to detect the interesting part of the image, which characterizes the structure of th e tested material. Because of the analysis carried out after th e heating process of the tested material, one has to choose the most adequate method to obtain a possibly good binary image, which is then submitted to further analysis. The specimen' s image acquisition in high temperature is affected by various optical phenomena. One of the obstacles for the segmentation stage is the phenomenon of nimbus of eradiation of specimen in high temperature process.

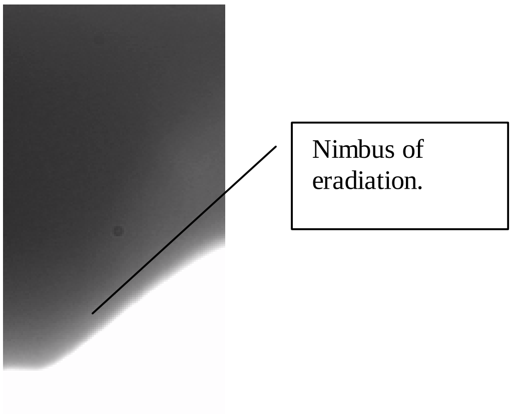

Fig. 10. Nimbus -affected specimen' s image.

A properly selected segmentation method produces a binary representation of the specimen' s image. Sometimes, when additional deformations are visible, dilatation or erosion algorithms are also needed.

Obviously, in case of gradient filters, like Sobel' s or Robert' s, which produce a set of points on the boundaries of rapid changes in intensity betw een heated elements and the background, a skieletonize algorithm must be applied, which representation contour line by means of single dot of logical checkpoint, which significant eliminate some errors of contour extraction.

3.2 Geometric shape analysis

The contour of the tested specimen is joint with the contour of the base on which the specimen is placed. Location of the specimen and disposing of the contour of the base will result allow to obtain the full contour of the examined specimen. Optical phenomena are often harmful enough to prevent from reaching satisfactory results in the preprocessing steps, therefore on the binary level some contour approximation must be performed, in order to obtain possibly reliable specimen' s shape, which will be used in further analysis.

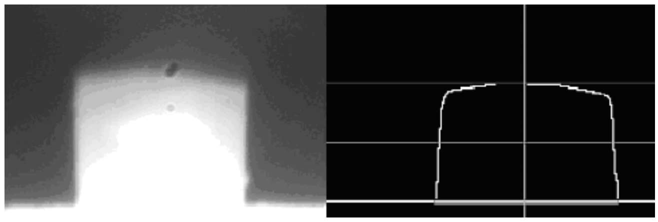

Fig. 11. Original image; c ontour' s the binary image.

The main geometric parameters describing the shape (1) of a specimen are its height H_x and width W_y, that enable to calculate the area P_k (1) of the inspected specimen, which – as a basic parameter – may indicate swelling or shrinking of the sample.

$$P_k = \sum_{i=0;\, j=0}^{i=n;\, j=m} H_x * W_y \qquad (1)$$

The parameters of maximal height (H) and maximal width W_y give some preliminary information about the shape of the examined specimen.

The area P_k is however a better indicator of the true shape under examination.

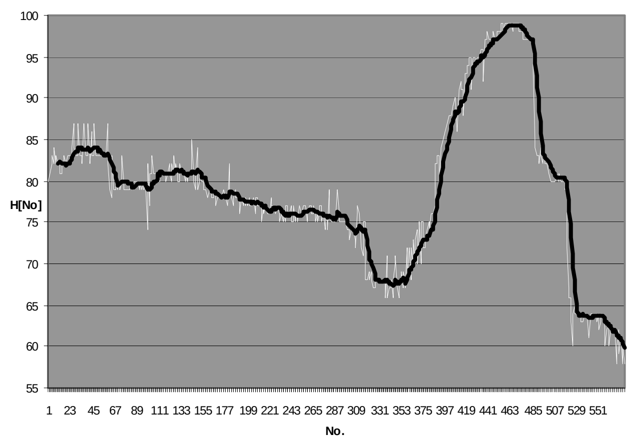

Fig. 12. Diagram of height.

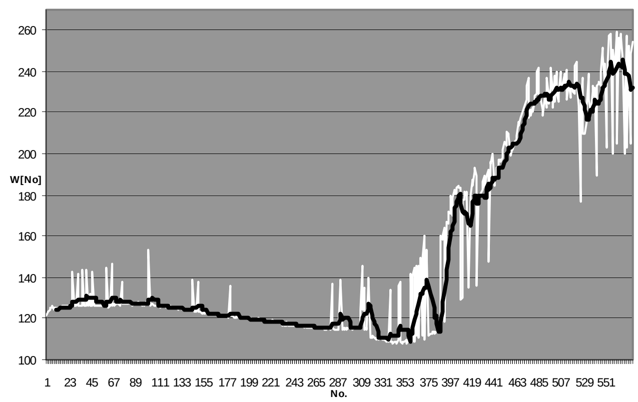

Fig. 13. Diagram of width.

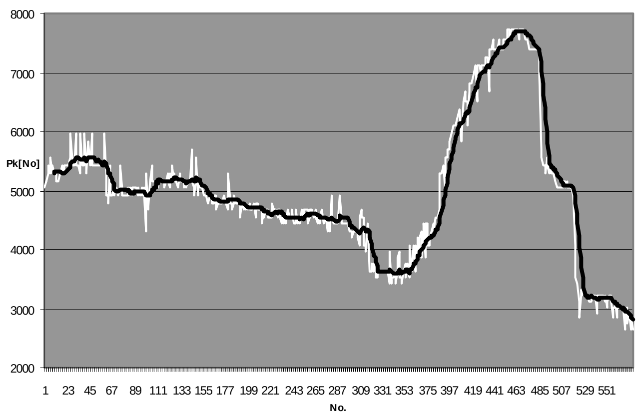

Fig. 14. Diagram of area.

Another shape indicator is elliptical shape factor (2), which achieves 1 for a square or a circle.

$$W_e = \frac{d_{oke}}{d_{ode}} \qquad (2)$$

where:
d_{oke}- shorter ellipse axis circumscribe of specimen.
d_{ode}- longer ellipse axis circ umscribe of specimen.

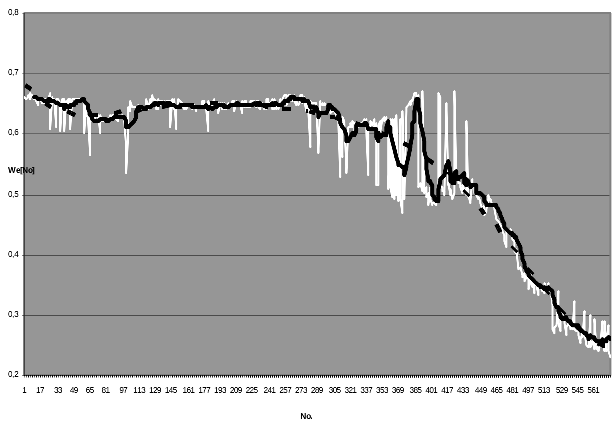

Fig. 15. Elliptic shape factor in full experiment.

A parameter strongly related to the circumference and the area is Malinowska’ s coefficient (3).

$$W_M = \frac{O_k}{2\sqrt{\pi P_k}} - 1 \qquad (3)$$

where:

O_k - the circumference of specimen.

P_k - the area of specimen.

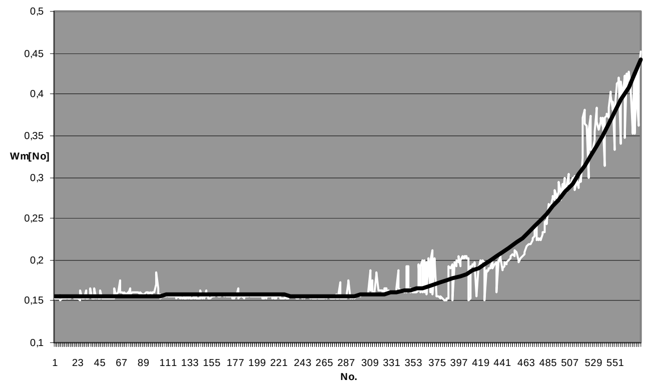

Fig. 16. Diagram of Malinowska’ s coefficient.

Another geometric parameter of the shape, which appears useful, is circular shape factor (4). It is equal to 1 to a circle and less than 1 for other shapes.

$$W_k = \frac{4\pi P_k}{O_k^2} \qquad (4)$$

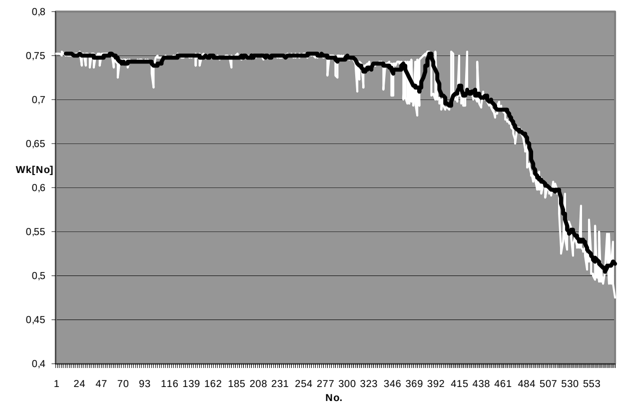

Fig. 17 Diagram of circular shape factor.

Yet another geometric parameter of the shape is the compactness coefficient (5), which reaches 4 π (approx. 12.56) for the shape of a circle.

$$W_z = \frac{O_k^2}{P_k} \qquad (5)$$

where:

O_k - the circumference of specimen.

P_k - the area of specimen.

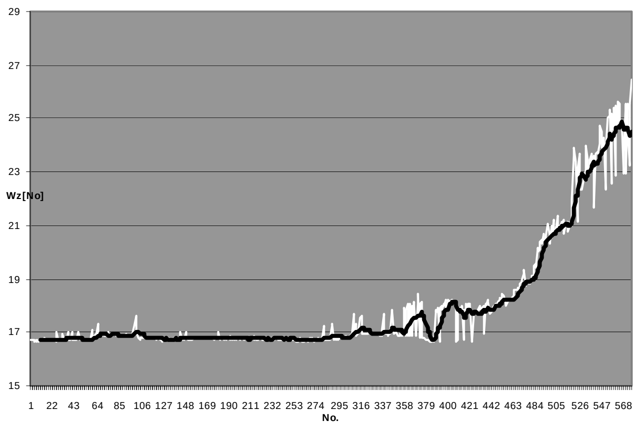

Fig. 18 Diagram of compactness coefficient.

The obtained shape parameters are based on extraction of features related to the base line of the specimen.
Another approach to shape feature extraction is considering the gravity center (6) of the examined material of specimen.

$$Xsc = round\left[\frac{1}{n}\sum_{i=1}^{n} x_i\right]$$
(6)
$$Ysc = round\left[\frac{1}{n}\sum_{i=1}^{n} y_i\right]$$

Taken into account the distances from the contour pixels to the gravity center of the whole specimen, the Haralick's coefficient may be calculated (7).

$$W_H = \sqrt{\frac{(\sum d)^2}{n\sum d^2 - 1}} \qquad (7)$$

where:
d – distances of contour pixels to specimen's gravity center;
n – number of pixels belonging to the contour.

Other criteria dealing with the considered spectrum are Martin's radii, i.e. the greatest, the mean and the least length of the radius from the gravity center and the specimen's contour.

The presented coefficients, used separately, do not enable unique specification of the values of characteristic temperature points of phase transitions. However, taking into account several such coefficients may enable to accomplish the task. One may assume that certain values of those coefficients indicate that the necessary conditions of a given phase transitions are occurring with some probability. Because of that, the authors believe that a proper tool for the analysis would be fuzzy logic.

The specimen's shape estimation on the basis of multiple shape parameters is performed with a fuzzy logic algorithm (FLC – fuzzy logic controller) [3]. As the standards strictly define the geometrical parameters of specimens in their characteristic temperature points, a knowledge base of fuzzy-set belongness of coefficients values is created. A FLC base of rules is sometimes called as a strategy of common sense controlling; such a strategy of linguistic controlling is grounded in human experience.

Currently, algorithms based on this approach are being implemented. The results obtained so far are promising, however not always fully satisfactory, so the research must be continued.

4. CONCLUSIONS

The presented system includes an algorithm for detection of characteristic temperature points of phase transitions, designed for determination of solid fuels properties. Because of involving fuzzy logic [3], the algorithm may successfully be applied for other materials as well. This will be the subject of the further works.

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