SOLID PARTICLE CHARACTERIZATION. SOME ASPECT RELATED TO THE SHAPE EVALUATION BY USING SOFTWARE CORRELATIONS

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Abstract: This article presents a method for determining the Riley circularity evaluation, a characteristic that defines the shape of a solid particle. To determine this parameter, a working methodology was identified by using Mathcad. To verify this methodology 15 anthracite particles were inserted in the working file, the shape of which is different, to determine the analyzed characteristic.

Keywords: riley's circularity, Mathcad 15, solid particle

1. INTRODUCERE

In the industrial processes, raw materials are used (in the case of the milling and bakery industry, the pharmaceutical industry, the sugar products industry etc.) whose size and shape vary greatly. And in some technological processes, products of different sizes and shapes can be obtained (the process of crushing or granulation). Identifying the dimensional elements of a solid particle, especially if they have at less than 1 cm in size, can sometimes become a challenge.

Also identifying the shape of a real solid particle is a challenge and there is no well-defined method. Such simple definitions are not sufficiently precise to evaluate different methods of measuring particle size or to incorporate them as parameters in the equations in which the solid particle form is a calculation parameter [1-3].

Some researches were attempts to identify different methods for classifying the shapes of solid particles, which is why the terminology has been enriched with a series of terms such as roundness or sphericity etc., but unfortunately, even today, there is no some general approach in these domain [4-10].

Over the years, several studies introduced some methodologies to measure particle shape. For the dimensional determination of solid particles, the classical method is generally used, respectively the dimensional determination using the binder, a rather improbable method, which is why a series of visual graphical representations have been designed, to reduce the measurement time [11-18]. Dimensional determination using the binder was introduced to determine the flattening index or elongation but is limited only to certain particle sizes, for practical reasons [19].

Recently, computer-based image analysis has been applied to dimensional research [20-22], thus obtaining practical methods for determining the particle size with good results [20, 21]. Determining the shape of particles through the computer helps a lot and reduce the measurement time [3, 23]. According to the literature, a series of terms can be used to identify the shape of a solid particle, and for the same term are use a different calculation relation.

One of the characteristics that describe the shape of a solid particle is Riley's circularity. To determine it, must determine the values of the diameters of two circles, the inscribed circle, and the circle circumscribed to the studied particle must be known (Figure 1) and can be determined with the equation:

$$\Phi_{sR} = \sqrt{\frac{2 \cdot R_i}{2 \cdot R_c}} \tag{1}$$

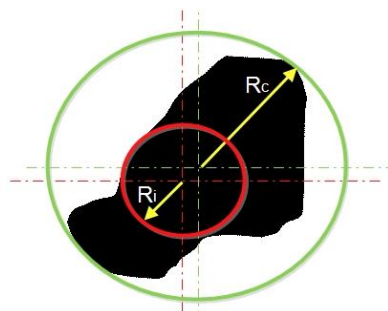were R_i represent the radius of the inscribed circle, R_c - radius of the circumscribed circle.

Fig. **Error! No text of specified style in document.**1. Determining Riley's circularity.

This article presents the calculation methodology, using the Mathcad 15 program, to determine the Riley circularity.

2. EXPERIMENTAL SETUP

2.1. Equipment and materials
To determine the Riley circularity of different types of solid particles, used as granular filter material, for example, the first stage meant creating individual pictures using a microscope, with an optical zoom of 4. The material used in this study was anthracite particles obtained as refuse on the 2 mm sieve. The methodology, for determining the Riley circularity of anthracite solid particles (Figure 1), was applied to individual 15 solid particles.

2.2. Working methodology

This article presents the working methodology (Figure 2) for determining the Riley circularity of particles with millimeter dimensions using a work program. All work operations, image reading, and data processing was performed by using the Mathcad 15 program [24].
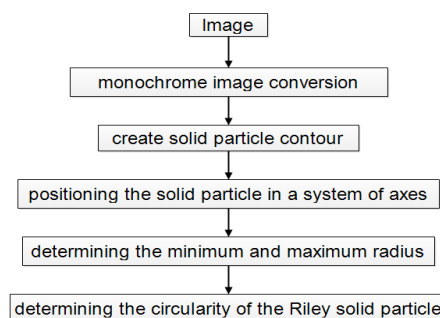

Fig. 2. Working methodology.

This method involves using the Mathcad 15 program to process the image to determine Riley's circularity. The work steps for determining Riley's circularity were:
- The image, corresponding to the solid particle (Figure 3), was uploaded in the working file, following that, to be processed, it was converted from color image to monochromatic image with a design to make the matrix corresponding to the image into a matrix within to which only two numbers 0 and 255 are inserted.

$a1 =$

	0	1	2	3	4	5	6	7	8	9
0	150	150	150	150	150	150	149	149	148	148
1	150	150	150	150	150	151	150	149	149	149
2	151	151	151	151	151	151	150	150	149	149
3	151	151	151	151	151	151	151	150	150	148
4	152	152	152	152	152	151	151	151	150	151
5	152	152	152	152	152	151	151	151	150	150
6	151	152	152	152	152	151	151	151	150	150
7	151	152	152	153	153	151	151	151	150	150
8	151	152	153	153	152	151	151	150	150	151
9	152	153	153	153	152	151	151	151	150	150
10	152	153	154	154	152	151	151	151	150	150
11	153	153	154	154	152	151	151	151	150	150
12	153	154	154	155	152	151	151	151	150	150
13	153	154	155	155	152	151	151	151	150	150
14	151	152	152	152	150	150	150	150	150	150
15	151	152	151	152	151	151	151	151	151	...

a)   b)

Fig. 3. Presentation of the working image: a) the image used; b) the matrix corresponding to the image.

For that the following functions can be used to make this change, from color image to the monochrome image:
a. function through which the values within the working matrix can be changed:

$$f(x) := if(x > a, 255, 0) \qquad (2)$$

wherein a represents a randomly chosen value, depending in particular on the color spectrum of the image under analysis, and x represents the matrix subject to transformation (in Figure 1.b it is noted by $a1$).

b. or using the function in the Mathcad 15 program "*binarize_auto*", the function that converts the color image into a black and white image.

The processing method will be chosen according to the colors contained in the processed image. In the end, of this type of processing, the image obtained is in the form of that shown in Figure 4.

$a2 =$

	0	1	2	3	4	5	6	7	8	9
0	255	255	255	255	255	255	255	255	255	255
1	255	255	255	255	255	255	255	255	255	255
2	255	255	255	255	255	255	255	255	255	255
3	255	255	255	255	255	255	255	255	255	255
4	255	255	255	255	255	255	255	255	255	255
5	255	255	255	255	255	255	255	255	255	255
6	255	255	255	255	255	255	255	255	255	255
7	255	255	255	255	255	255	255	255	255	255
8	255	255	255	255	255	255	255	255	255	255
9	255	255	255	255	255	255	255	255	255	255
10	255	255	255	255	255	255	255	255	255	255
11	255	255	255	255	255	255	255	255	255	255
12	255	255	255	255	255	255	255	255	255	255
13	255	255	255	255	255	255	255	255	255	255
14	255	255	255	255	255	255	255	255	255	255
15	255	255	255	255	255	255	255	255	255	...

a)   b)

Fig. 4. The studied particle: a) monochromatic image; b) the matrix corresponding to the studied image.

The analysis of this picture shows that in addition to the image of the solid particle other external elements are not components of the solid particle, elements that must be automatically removed from the image. For this purpose, the Mathcad 15 program *canny* function was used, that generating an image through which only the contour of the

studied particle is highlighted. This processing results in the following image that will be further worked on (Figure 5).

Fig. 5. Solid particle contour.

The next stage of image processing is its framing in a system of axes whose center corresponds to the center of the analyzed particle. For this, the following calculation conventions were performed:
a. A matrix is defined:

$$b = match\,(0, a) \tag{3}$$

where *match* represents a function in Mathcad 15, function that has the role of looking in the working matrix a defined value, in our case *0* (because the value *0* corresponds to the color black, color with which the solid particle is highlighted, and with white color, respectively with value 255, in the background highlight). The matrix subjected to coding is subsequently optimized and in the obtained result are presented the indices of each value obtained. The term *a* represent the matrix under analysis and defines the image under analysis.

b. The matrix thus obtained is processed to define the coordinates of a point to achieve the graphical representation of the image under analysis:

$$x_k = (b_k)_1 \qquad\qquad\qquad y_k = (b_k)_0$$

in which: k represents a range of values between 0 ..... N, where N is defined as a number given by the relation:

$$N = rows(b)\text{-}1 \tag{4}$$

and depends on the number of rows in the matrix *b*.

- To frame the studied particle in the center of a coordinate system, the following calculation artifice is made:

$$x1 = x - mean(x) \qquad\qquad\qquad y1 = y - mean(y)$$

in which the *mean* function generates the average value of the group of values corresponding to the parameter *x* or *y*.

Following this processing, the result obtained is shown in Figure 6.

To determine the diameter of the inscribed and the circumscribed circle, the values of the diameters corresponding to them must be known. For this purpose, the largest and smallest distance from the center of the axis system to the particle contour will be determined, respectively the radius of the circumscribed circle and the inscribed circle will be obtained (Figure 7). When determining the value of these two parameters, the relationship of calculating the distance between two points will be used, the first point being with the values for the *OX* axis equal to *0*, as well as for the *OY* axis.

$$\Delta = \sqrt{(0 - x)^2 + (0 - y)^2} \tag{5}$$

But the values of the radius of the inscribed circle, respectively circumscribed circle, are much too large reason for which, individually, for the inscribed circle and the circumscribed circle, an adjustment of the center of the circle will be made.
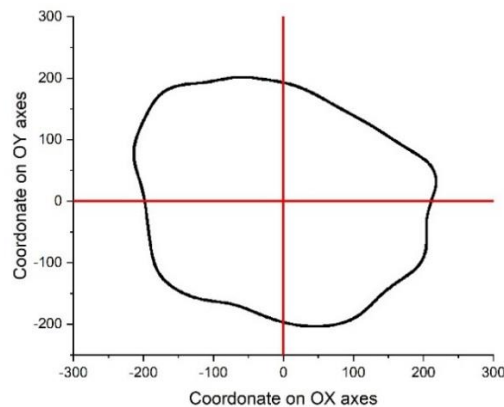
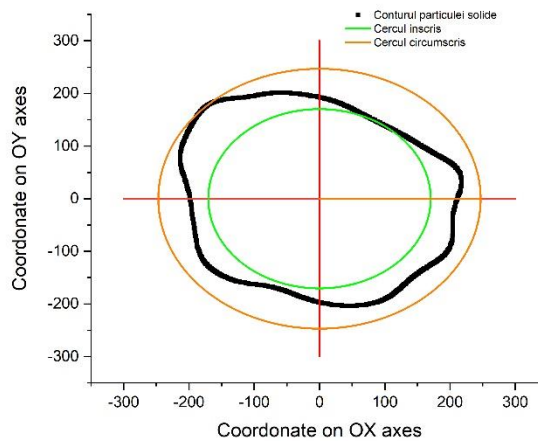Fig. 6. Framing the solid particle contour in a coordinate system.

Fig. 7. Presentation of the two circles.

For this purpose, the points of intersection between the contour of the solid particle and the inscribed circle and circumscription circle will be identified, the reason for which the following working steps has been made:

- a new matrix was created that includes the values of Δ, x and y using the function:

$$D1 := augment\,(\Delta, x, y) \tag{6}$$

- was define the three columns of the newly created matrix:

$$dd := D1^{<0>}; \; xx := D1^{<1>}; \; yy := D1^{<2>} \tag{7}$$

- was identify the coordinates of the minimum and maximum point of the parameter dd (dd being given by the distance between the center of the axis system and the contour of the analyzed particle):

$$\left\{ \begin{array}{l} amx := lookup\,(\min(dd), dd, xx) \\[2mm] amy := lookup\,(\min(dd), dd, yy) \end{array} \right. \tag{8}$$

$$\left\{ \begin{array}{l} aMx := lookup\,(\max(dd), dd, xx) \\[2mm] aMx := lookup\,(\max(dd), dd, yy) \end{array} \right. \tag{9}$$

The value of the angle corresponding to the obtained coordinates, concerning the value of *0* degrees is determined with the help of the following programming functions:

$$
\propto 1 := \left|
\begin{array}{l}
\left(\text{atan}\left(\dfrac{|amx|}{|amy|}\right)\right)\cdot\dfrac{180}{\pi}\ \ if\ |amx| > 0 \wedge |amy| > 0 \\[2ex]
\left(\text{atan}\left(\dfrac{|amx|}{|amy|}\right)\right)\cdot\dfrac{180}{\pi}+90\ \ if\ |amx| < 0 \wedge |amy| > 0 \\[2ex]
\left(\text{atan}\left(\dfrac{|amx|}{|amy|}\right)\right)\cdot\dfrac{180}{\pi}+180\ \ if\ |amx| < 0 \wedge |amy| < 0 \\[2ex]
\left(\text{atan}\left(\dfrac{|amx|}{|amy|}\right)\right)\cdot\dfrac{180}{\pi}+270\ \ if\ |amx| > 0 \wedge |amy| < 0
\end{array}
\right.
$$

$$
\propto 2 := \left|
\begin{array}{l}
\left(\text{atan}\left(\dfrac{|aMx|}{|aMy|}\right)\right)\cdot\dfrac{180}{\pi}\ \ if\ |aMx| > 0 \wedge |aMy| > 0 \\[2ex]
\left(\text{atan}\left(\dfrac{|aMx|}{|aMy|}\right)\right)\cdot\dfrac{180}{\pi}+90\ \ if\ |aMx| < 0 \wedge |aMy| > 0 \\[2ex]
\left(\text{atan}\left(\dfrac{|aMx|}{|aMy|}\right)\right)\cdot\dfrac{180}{\pi}+180\ \ if\ |aMx| < 0 \wedge |aMy| < 0 \\[2ex]
\left(\text{atan}\left(\dfrac{|aMx|}{|aMy|}\right)\right)\cdot\dfrac{180}{\pi}+270\ \ if\ |aMx| > 0 \wedge |aMy| < 0
\end{array}
\right.
$$

where *α1* has noted the angle obtained with the horizontal and the point of intersection of the inscribed circle and *α2* the angle obtained with the horizontal and the point of intersection of the circumscribed circle. Thus, the value of the angle can be identified.

Opposite the point of intersection between the contour of the particle and the circumscribed circle and the inscribed circle, there is a space that must be partially removed. The value of the angle corresponding to the respective space is determined with the calculation relation:

$$
\left\{
\begin{array}{l}
\alpha 11 = \alpha 1 + 180 \\[1.5ex]
\alpha 21 = \alpha 2 + 180
\end{array}
\right.
\tag{10}
$$

At this point, no correlation can be made between these two values of the angle with coordinates corresponding to that point. Therefore, the angular value corresponding to all points corresponding to the contour of the solid particle was identified:

$$
\alpha 3_k := \left|
\begin{array}{l}
\left(\text{atan}\left(\dfrac{|x_k|}{|y_k|}\right)\right)\cdot\dfrac{180}{\pi}\ \ if\ x_k > 0 \wedge y_k > 0 \\[2ex]
\left(\text{atan}\left(\dfrac{|x_k|}{|y_k|}\right)\right)\cdot\dfrac{180}{\pi}+90\ \ if\ x_k < 0 \wedge y_k > 0 \\[2ex]
\left(\text{atan}\left(\dfrac{|x_k|}{|y_k|}\right)\right)\cdot\dfrac{180}{\pi}+180\ \ if\ x_k < 0 \wedge y_k < 0 \\[2ex]
\left(\text{atan}\left(\dfrac{|x_k|}{|y_k|}\right)\right)\cdot\dfrac{180}{\pi}+270\ \ if\ x_k > 0 \wedge y_k < 0
\end{array}
\right.
\tag{11}
$$

the value that is entered in a second matrix that also includes the coordinates of the contour of the studied particle (*x* and *y*)

$$
k_k := augment(\alpha 3, x, y)
\tag{12}
$$

and it defines the three columns of the newly created matrix as follows:

$$dd2 := k^{<0>}; \; xx2 := k^{<1>}; \; yy2 := k^{<2>} \tag{13}$$

The values of the angles $\alpha11$ and $\alpha31$ (defined in the calculation relations (10)) in the human situations are not found in the series of values corresponding to $\alpha2$, the reason for which the following calculation artifice is realized:
- Subtract from the value of the angle corresponding to the points using which the contour of the analyzed particle is drawn the value of the angle opposite to the intersection between the particle account and the two circles. Because, in some cases, they are values lower than the value of the angle opposite to the intersection angle this difference is modulated:

$$\alpha12_k := |\alpha3_k - \alpha1| \qquad\qquad\qquad \alpha22_k := |\alpha2_k - \alpha3| \tag{14}$$

- Identify the value of the angle opposite to the angle corresponding to the intersection between the contour of the particle and the inscribed and circumscribed circle:

$$\alpha13 := \alpha11 \pm \min(\alpha12) \qquad\qquad\qquad \alpha23 := \alpha21 \pm \min(\alpha22) \tag{15}$$

As a result of this artifice, the coordinates opposite the intersection points can be identified:

$$amx1 := lookup\,(\alpha13, dd2, xx2)$$
$$amy1 := lookup\,(\alpha13, dd2, yy2)$$

$$aMx1 := lookup\,(\alpha23, dd2, xx2)$$
$$aMx1 := lookup\,(\alpha23, dd2, yy2)$$

Knowing the coordinates of the respective points can determine the distance between the center of the current system of axes and the respective points:

$$\Delta m1 = \sqrt{(0 - amx1)^2 + (0 - amy1)^2} \qquad \Delta M1 = \sqrt{(0 - aMx1)^2 + (0 - aMy1)^2} \tag{16}$$

And now it is possible to determine the value with which the coordinates of the center of the axis system will change, values necessary for translating the center of the axis system so that the two circles include and be included in the studied contour.

$$dif1 := \frac{|rm1 - \Delta m1|}{2} \qquad\qquad\qquad dif2 := \frac{|Rm1 - \Delta M1|}{2} \tag{17}$$

Therefore it will be determined, for each type of circle a different center of the axis system and another corresponding radius, the following work steps are performed:
- for the inscribed circle:

$$x1 = x - mean(x) \pm dif1 \qquad\qquad\qquad y1 = y - mean(y) \pm dif1 \tag{18}$$

$$\Delta mm_k = \sqrt{(0 - x1_k)^2 + (0 - y1_k)^2} \tag{19}$$

$$Rm2 := \min(\Delta mm) \tag{20}$$

- for the circumscribed circle:

$$xM = x - mean(x) \pm dif2 \qquad\qquad\qquad yM = y - mean(y) \pm dif2 \tag{21}$$

$$\Delta Mm_k = \sqrt{(0 - xM_k)^2 + (0 - yM_k)^2} \tag{22}$$

$$Rm2 := \max(\Delta Mm) \tag{23}$$

For the control will be made, only for the circumscribed circle, the next difference from it being made that the maximum value is as close as possible to the value 0.

$$contr_k := |\Delta Mm_k - Rm2| \tag{24}$$
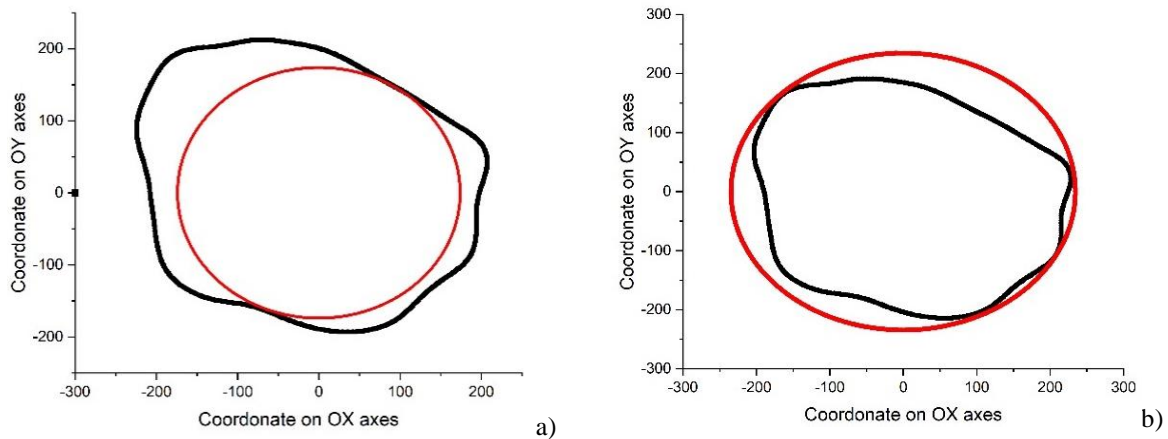
Figure 8 shows both adjustments made.

Fig. 8. The new position of the two circles: a) the inscribed circle; b) the circumscribed circle.

The values thus obtained can be used to determine the circularity of Riley to the solid particle using the calculation relation (1).

3. RESULTS AND DISCUSSION

The previously presented methodology was used on different solid anthracite particles. In Figure 9 are presented 4 used solid particles.

Fig. 9. Example of the used anthracite particles.

After processing the images from Figure 9, it was possible to graphically represent the results obtained, corresponding to the two main stages of identifying the studied parameter (before centering and after centering), respectively Riley's circularity (Figure 10).

Following the analysis of the obtained results, by implementing the methodology presented above for determining the circularity of Riley for 15 solid particles, respectively anthracite particles, it was possible to draw their variation (Figure 11) taking into account the two stages corresponding to the working methodology.

a)   b)   c)
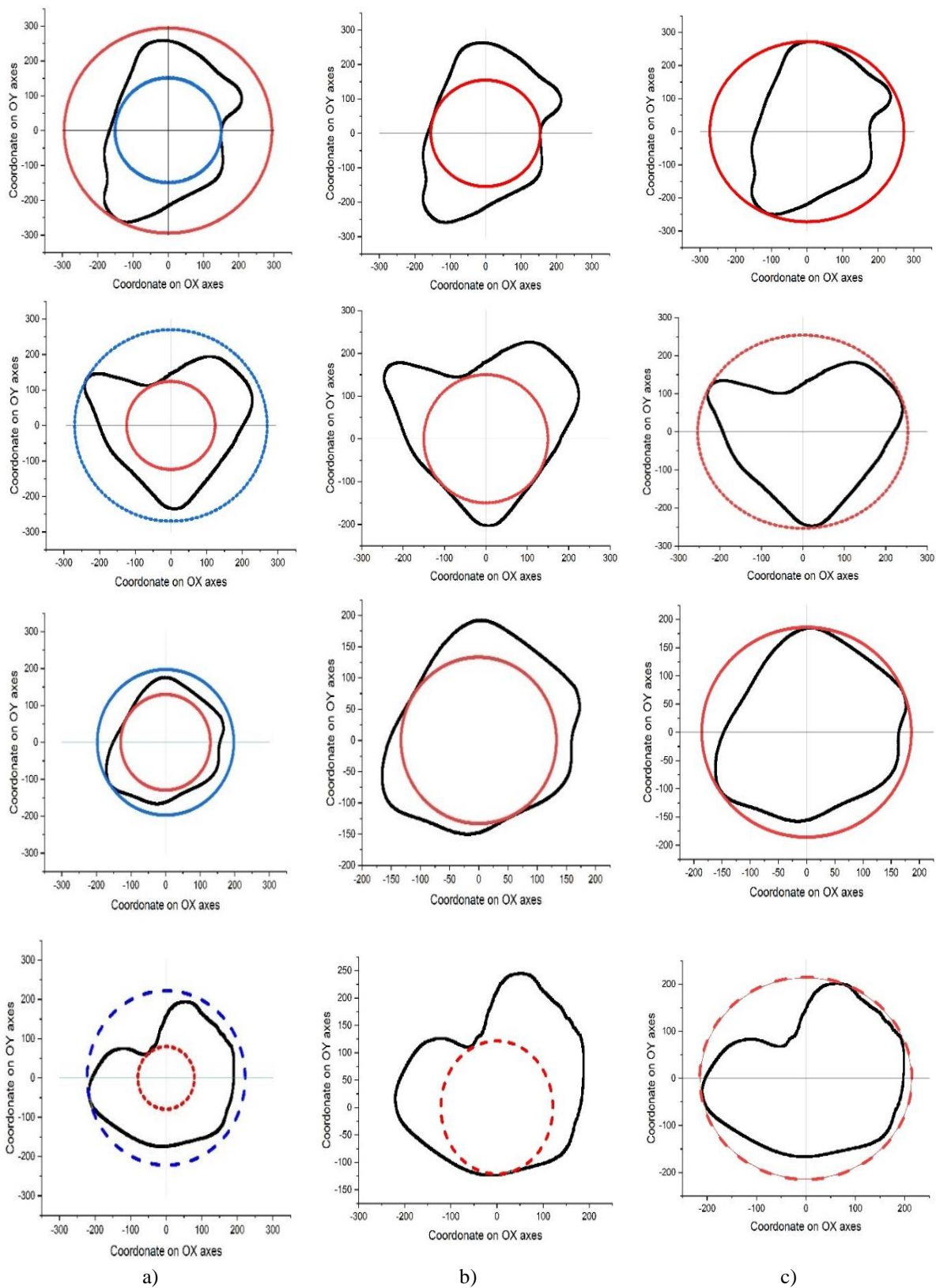
Fig. 10. Graphical representations of the inscribed and circumscribed circle: a) for the initial working situation;
b) and c) after the individual centering of the circles.

Analyzing the obtained results, it is found that the largest difference between the values obtained is for particle number 5, respectively 79.76%, and the smallest difference was obtained for particle number 7 of 99.59%.
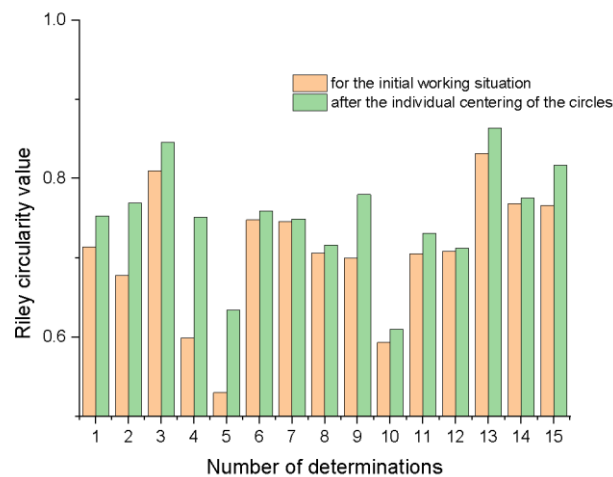
Fig. 11. Variation of the Riley circularity value for different anthracite particles.

5. CONCLUSIONS

Following the analysis of the obtained results, the following conclusions can be drawn:
- Products obtained from agriculture but also various industries are characterized by different sizes and shapes;
- The shape of the solid particle is a feature that is used in the design stages of various process equipment;
- Over time, a series of calculation relations have been generated to describe as accurately as possible the shape of a solid particle;
- Riley's circularity is that characteristic of the shape of a solid particle which is described by the ratio between the diameters of the inscribed and circumscribed circle;
- Different physical methods or different software can be used to determine this characteristic;
- This article presents a working methodology, using the Mathcad 15 program, to determine Riley's circularity;
- The working method involves the processing of an image by performing a series of computational to determine the desired characteristic.

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