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THE IMPACT OF THE IMAGE RESOLUTION ON THE VALUE OF MEASURED GEOMETRIC PARAMETERS ON THE EXAMPLE OF DUCTILE IRON STRUCTURE

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Abstract: Paper presents the influence of the image resolution on measurement geometric parameters of the objects. Employing as test images the ductile iron structure images allow to analyze the effect of resolution distortion on a model of objects with regular shape. Authors showed on the example images, how decreasing resolution of digital images distorts the value of the parameters describing the shape of the objects, its perimeter and its quantity. The analysis was performed by an automatic algorithm applying image analysis and stereological method.
Keywords: image processing, stereology, digital measurement

1. INTRODUCTION

Image resolution and its quality have a significant influence on the accuracy of measurements, which was confirmed by the example of the comparative analysis presented in (Wojnar and Gadek, 2006). The problem of shape analysis of objects is related to the measurement accuracy of the determined stereological parameters. Image resolution, i.e. the number of pixels representing objects, is an issue strictly related to the problem of digital discretization of continuous signals. In digital images, sampling is the registration of signals by detectors that allow for image recording. If we record the image in digital form, the number of samples is equal to the number of pixels that make up the image. The credibility of the object mapping, which is affected by the image resolution, is essential for the reliability of the obtained results of the quantitative analysis of the microstructure (Russ, 1995). Measurements of objects of too small size introduce an error that is difficult to estimate because it depends on both the size of the object and its shape.

Unfortunately, this issue has not been considered in international standardization, and the recommended minimum number of pixels representing the object, which would allow the assessment of its shape to be reliable is not defined. Admittedly, in one norm, ASTM E2567 (ASTM, 2014), there is a record of the minimum object that can be subjected to shape analysis, but its size is determined by the average Feret diameter

expressed in micrometres (10 µm) at 100x magnification. Although it is a standard for the analysis of graphite precipitates by image analysis methods, no minimum pixel size has been specified. In the paper, authors presented the examples of a situation where even in a recognized standard, we encounter defects. The authors overlooked the crucial fact that the number of pixels mapping the object depends not only on its size and magnification of the lens but also on the resolution of the camera recording the image, which can change even several times.
The problem of the insufficient number of pixels creating an image of the objects is connected with the problem of proper enlargement of the observed structure. The magnification of the observed structure should ensure excellent visibility of all analyzed objects what increases the number of fields of view for analysis.
Until now, no literature or standardization document has ever addressed the impact of the number of pixels representing objects on digital images on the results of quantitative analysis. The parameter that is particularly sensitive to the resolution is undoubtedly the aspect ratio.

2. MATERIALS AND METHODS

In order to verify the effect of resolution on the results of quantitative analysis of the example structures, an analysis of images of microstructures of nodular (**Figure 1**)and flake graphite precipitates (**Figure 2**) was performed. Both images resolution was degraded successively by 25, 50, 75, 85, 95% to initial image. Quantitative analysis of initial images and the images with the reduced resolution was carried out, determining the shape factor (*circularity*), perimeter determined by the Crofton method (L_C), and analysis of the next four neighbours (L_{4conn}), number of objects per area unit (N_A) determined Jeffries method (Rys, 1970; Underwood, 1970; Russ and DeHoff, 2000).
Due to assess the effect of the resolution of the image and the size (in pixels) analyzed objects, the analysis of generated images was performed with strictly the same parameters of the detection algorithm. Detection of the graphite precipitates was conducted applying the threshold transformation. All detected objects considered in the analysis. Parameters of the object which value might be changed depending on the size of the analyzed object were selected. The analysis was performed applying the Aphelion 4.3 image processing and analysis software.

3. RESULTS AND DISCUSSION

Result of analysis of the structure with spheroidal graphite precipitates was presented in **Table 1**. As can be observed on the NA and circularity significantly changed the value for the same image but with different resolution. Decreasing area of detected precipitates leads to the increasing value of the shape factor and decreasing number of the objects per area unit. Hight dispersion of the values between the initial image and degraded confirmed the assumption that the size of the analyzed objects on the image has a strong influence on the results of the measurements. This problem is illustrated more clearly on the example of the objects with more sophisticated shape than the nodular graphite precipitates. Authors consider as an example the flake graphite practices. As can be observed in **Table 2**, presented the results of the analysis, in this case, the circularity increased the value from 0.64 for the initial image to 0.98 for the most degraded (95%). The NA parameter decreases its value of 50%.

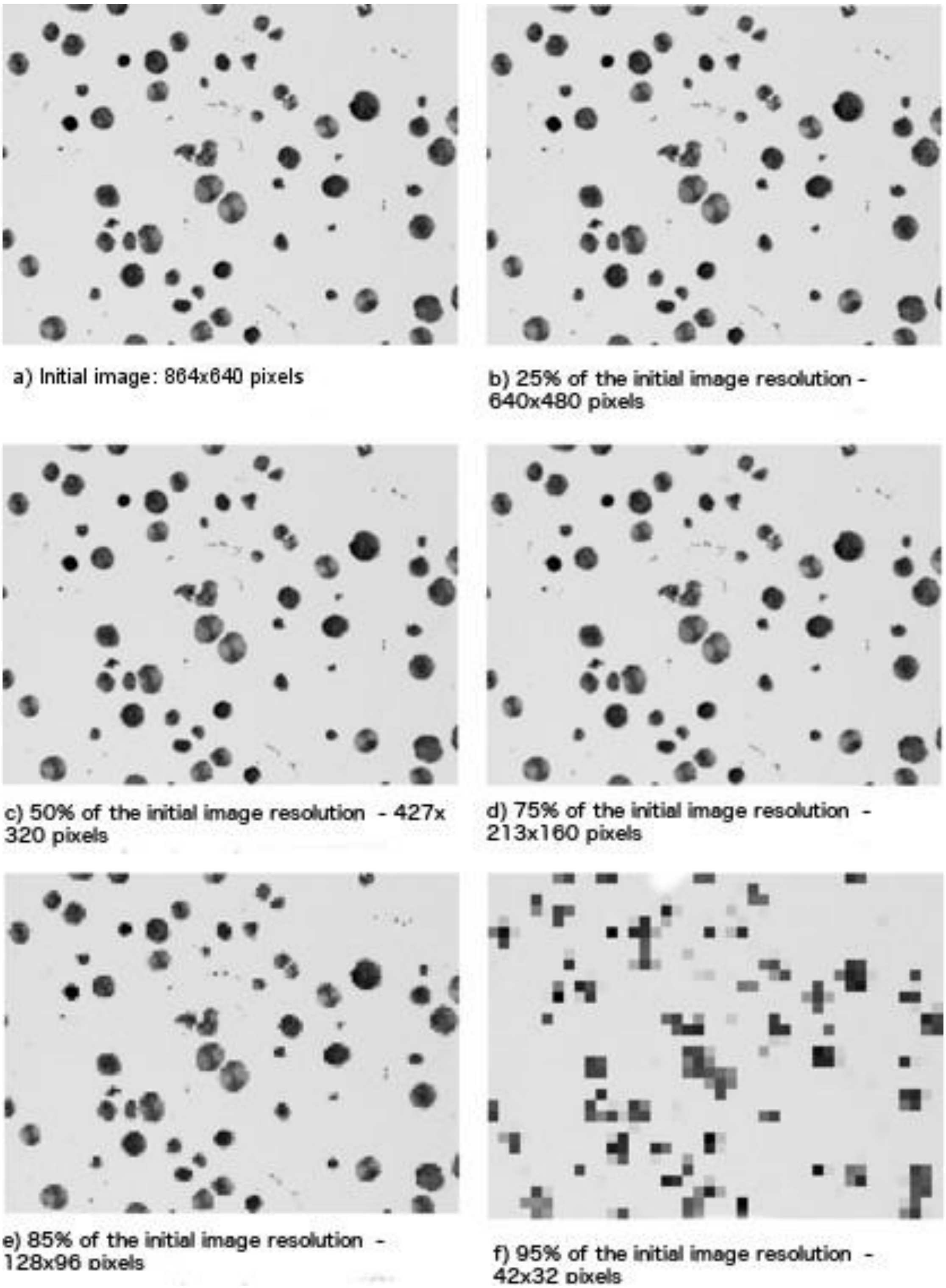
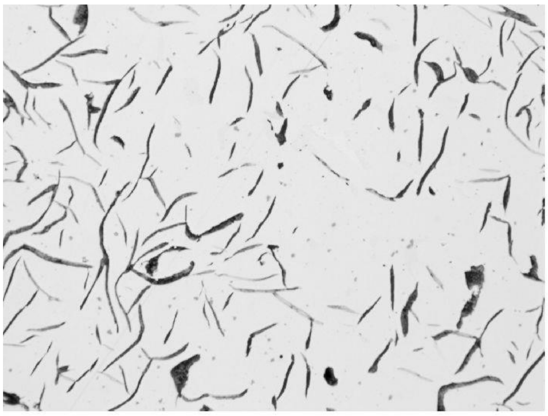
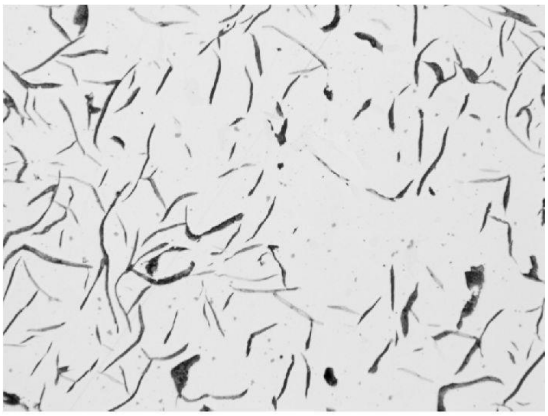


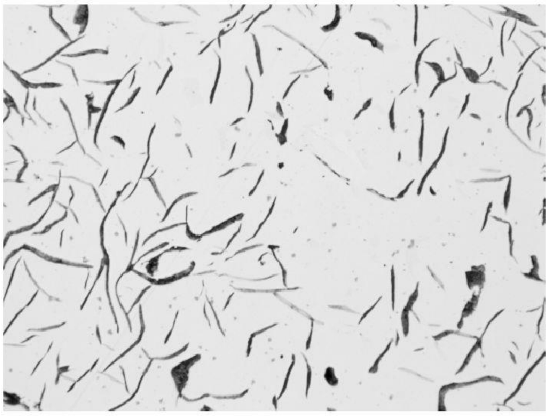
Fig. 1. Gradual degradation of the resolution of the nodular graphite precipitates on the initial image (a) resolution from 25 (b) till 95% (f).



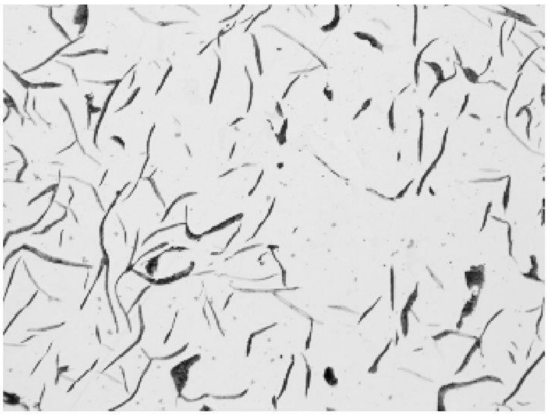
a) Initial image: 1280x960 px



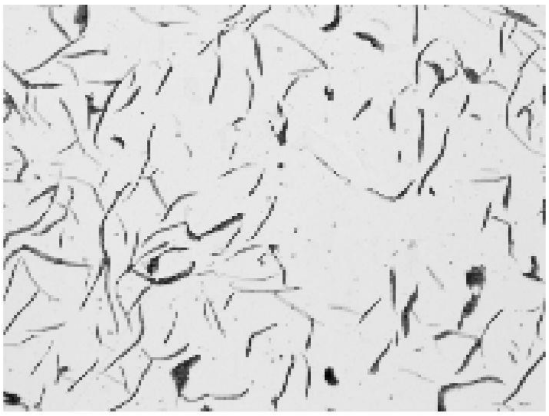
b) 25% reduction of the initial image resolution: 960x720 px.



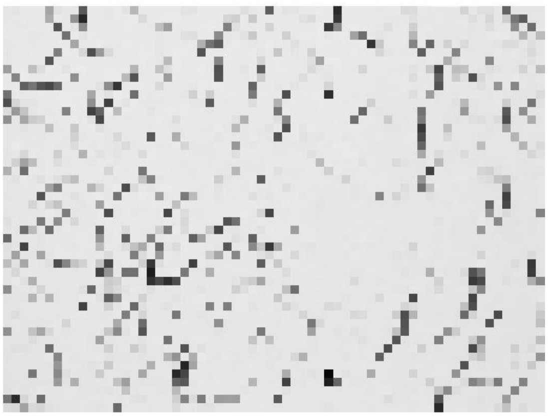
c) 50% of reduction the initial image resolution - 640x480 pixels.



d) 75% reduction of the inital image resolution - 320x240 pixels



e) 85% of reduction the initial image resolution - 192x144 pixels.



f) 95% reduction of the initial image resolution - 64x48 pixels.

Fig. 2. Gradual degradation of the resolution of the flake graphite precipitates on the initial image (a) resolution from 25 (b) till 95% (f).

Table1
Results of the analysis of nodular graphite

The degradation the resolution of initial image [%]	$\overline{A}$ [pixels]	Mean length of projection $\overline{l}$ [pixels]	*circularity*	$\overline{L}_C$ [pixels]	$\overline{L}_{4conn}$ [pixels]	N_A
Initial image	557.37	20.00	0.87	67.49	86.02	110
25	348.07	16.76	0.90	54.67	69.72	99.5
50	170.98	12.36	0.92	39.51	50.53	90.0
75	45.97	6.53	0.94	20.89	26.81	81.5
85	19.68	4.61	0.96	14.27	18.52	69.0
95	2.78	1.72	0.97	5.19	6.95	46.0

Table 2
Results of the analysis of flaker graphite

The degradation the resolution of initial image [%]	$\overline{A}$ [pixels]	Mean length of projection $\overline{l}$ [pixels]	*circularity*	$\overline{L}_C$ [pixels]	$\overline{L}_{4conn}$ [pixels]	N_A
Initial image	249.0	26.40	0.64	78.12	99.66	333
25	166.2	23.12	0.60	67.59	86.29	288
50	72.8	15.05	0.63	43.25	55.37	295
75	13.3	5.34	0.78	14.97	19.34	409
85	4.3	2.53	0.90	7.02	9.21	505
95	1.4	1.26	0.98	3.47	4.87	172

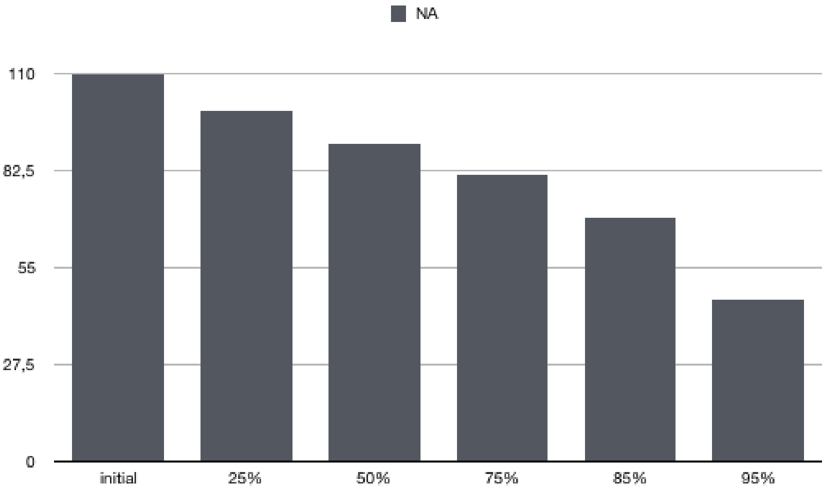


Fig.3 . N_A value on the images with different percentage of resolution degradation on the image of nodular graphite structure

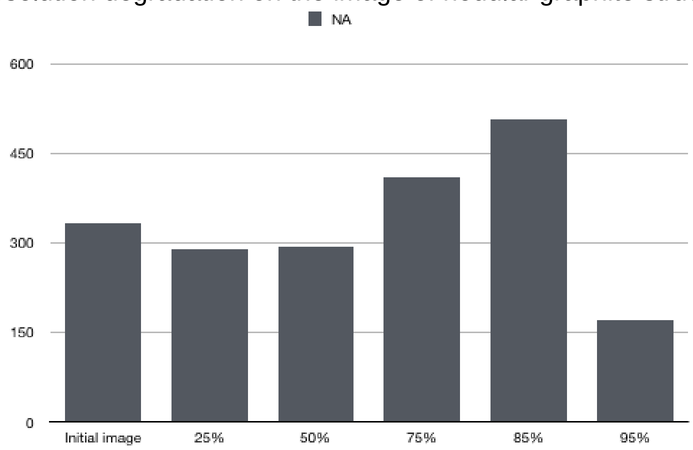


Fig. 4. N_A value on the images with different percentage of resolution degradation on the image of flake graphite structure

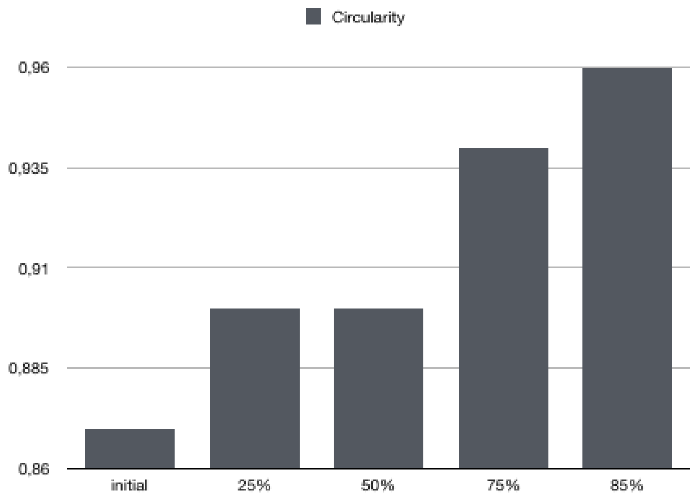


Fig. 5. The effect of the degradation percentages
on the shape factor *circularity* for the nodular graphite structure

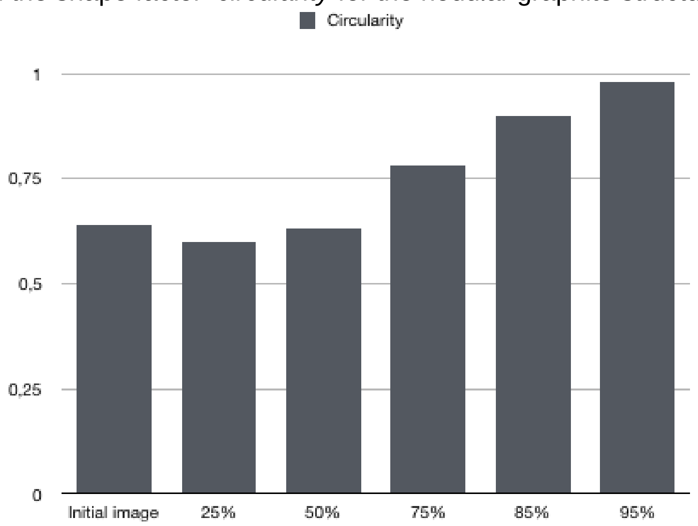


Fig. 6. The effect of the degradation percentages
on the shape factor *circularity* for the flake graphite structure

On the **Figures 3-6**, it can be observed the dynamics of the changes of the values for nodular (**Figure 3** and **4**) and flake (**Figure 5** and **6**) precipitates in order to decrease the resolution of the image area of analyzed image.

Detection errors in the process of image processing, even small ones, in combination with small objects, in the final effect are the cause of a significant (up to several dozen per cent) variations in results. Therefore, the first step to increase the repeatability and reliability of the measurement results is to adjust the magnification of the microstructure observation and the resolution of the recorded image according to the size of the observed elements. Elements of the structure should be visible on the pictures, and their cross-sectional area should be represented by at least several dozen, and preferably several hundred pixels. The size of the analyzed objects affects not only the correctness of the detection, which is a necessary condition for the correct quantitative analysis of the structure, but also the accuracy of digital measurements.

During more advanced analyzes of material structures, it is almost always necessary to evaluate the geometry of individual objects, e.g. grains or precipitates. Then an

essential question arises, what conditions must be met by these objects so that their geometrical characteristics would be assessed reliably.
If individual objects are very small and contain one or several or even several dozen pixels, we can only record their presence or determine their number. Any measurements of geometric features have no reason to exist. If we have an object containing 4 pixels, it can map both the square and the circle. We have no way of saying anything more about its shape.
Let us assume evaluation of the circle with a diameter of 10 pixels. As a result of changes in the detection threshold, we can include more or fewer points in this circle. If the object is symmetrical, then changing the detection threshold may cause addition or subtraction of one pixel layer, i.e. our circle will have a diameter of 8 or 12 pixels. Such a change will cause the circumference to drop or increase by 20%. In the case of surfaces, the change will be even more visible. If the diameter of the circle is equal to or less than 10 pixels, errors would have an even more dramatic effect on the results.
The basis for deciding which objects to be further analyzed may be potential changes to the perimeter and surface caused by minor changes in objects as a result of fluctuations in the detection threshold. The shape of objects is also important here, although one must be aware of the lack of the possibility of unambiguous characteristics of most shapes for an object represented by a small number of pixels.

4. CONCLUSION

Summing up the considerations regarding the repeatability and reliability of digital measurements, it should be emphasized that these measurements are unfortunately not standardized. The lack of commonly accepted recommendations that would define the criteria for the classification of objects for analysis is the cause of the appearance of significant discrepancies in the results of the analysis of the same images by independent laboratories (Wojnar and Gadek, 2006). It needs to work out the recommended value in pixels the minimal analyzed objects what would be the part of good practice rules in image analysis of materials microstructure or become a part of international standard regulations.
The results presented in this paper may be interesting for researchers and engineers using quantitative methods of image analysis in their practice e.g. protective coating for trains (Pasieczynski et al., 2018), welding (Strzelaczak and Dudek, 2018), surface improvement and machining (Lisiecka and Dudek, 2018; Ulewicz and Selejdak, 2018), laser texturization for friction modification (Radek et al., 2018), prototype building from polymers (Pacana and Pacana, 2018), boilers improvement (Orman et al., 2018a; Orman et al., 2018b) or pipe creeping (Osocha, 2018). The knowledge about large subjective factor in image analysis methods may be also useful in museum revitalization (Karpisz and Kielbus, 2019). It also seems that fuzzy approach may more appropriate method to analyze results than strict quantitative comparison e.g. fuzzy assessment of ANOVA results (Pietraszek et al., 2016).

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