

Grain size measurement by image analysis: An application in the ceramic and in the metallic industries

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Abstract. *Materials physical properties are the results from its microstructures characteristics. So, it is very important to quantify these characteristics in an accurate way. This task can be accomplished by various methods, among them, the visual inspection and the semi-automatic inspection by image analysis. The visual inspection, which is more utilized in the industry, presents a high subjectivity degree, as it depends on the operator experience, and also is very slow and exhaustive. Otherwise, the image analysis inspection, which is becoming more and more used, has greater operator independence, usually greater accuracy and high productivity time analysis. This research's objectives are to present the adopted methodology for obtaining segmented grain images and to realize a comparative statistical analysis between visual inspection and image analysis grain size measurements for magnesian sinters and low carbon steel samples.*

Keywords: *ceramics, microstructure characterization, image analysis, statistical methods*

1. Introduction

The magnesian sinter is a refractory frequently used in industry. Among its applications are to serve of prime substance for basic refractory products used in internal walls covering and in vault boilers, electrical ovens, etc. The magnesian sinters are also present in the steel, cement and glass industries. Most of the magnesian oxides are obtained through natural ores calcination, among them; the magnesite ($MgCO_3$) is the most common. Other important sources of magnesium are the kelps, the subterranean deposits and the deep salt deposits.

For low carbon steels, visual grain size analysis requires a highly skilled operator and the results obtained can have a high degree of subjectivity. The ASTM Designation: E1382-97 requires five hundred data points for a given sample and this analysis is time-consuming and tedious for the analyst. According to (0), the manual classification has a standard deviation of more than 5% from an operator to another, while the recommended by (0) is about 2%.

In this paper we propose a method for semi-automatic grain size determination using tools implemented in the Imago microstructural characterization software. The main problem in using a method of this nature is concerned to grain contours not correctly delineated. This occurs due to fails in the preparation process, generating contours that appears discontinuous in the image. The methodology showed itself a satisfactory solution for image analysis. This problem was solved using a segmentation algorithm entitled "attribute-based watershed", researched by (0).

The method presents a topological image segmentation algorithm based on the geometric attributes of catchment basins, the ABA method (attribute based absorption). The method was inspired on the watershed and dynamics transformations. Its theoretical background is based on Digital Topology and Mathematical Morphology. It treats gray level images as a topographic relief which is gradually filled with water. The image segmentation is achieved by discrete flooding simulation which gives rise to a set of catchment basins. These basins are selectively merged by a set of elementary rules, based on their geometric attributes: depth, area and volume. Merging is accomplished through a hierarchical process by applying two basic topological operations on the connected components of the image. The complete relief immersion produces the segmented image. The mathematical achievement of this method can be observed in Andrade (1998).

This research's objectives are to present the adopted methodology for obtaining segmented grain images and to realize a comparative statistical analysis between visual inspection and image analysis grain size measurements for magnesian sinters and low carbon steel samples.

2. Experimental

For starting the analysis process, it is necessary to determine how many images we have to acquire by sample for having a statistical representation, regarding an error factor. In the visual inspection method, the operator analyses several samples, calculating the average grain size and sometimes, the standard deviation, but it is not known, how

representative the analyzed samples are. For obtaining how many images it is necessary to acquire and analyze for a know error factor, we used the Eq. 1:

$$n = \left(\frac{zs}{d} \right)^2 \quad (1)$$

where:

- n is the number of grains to be acquired and analyzed;
- z is the t from the t-Student table, which is 1.960 for big samples;
- s is the standard deviation calculated in a preliminary acquisition;
- d is the error factor. In this case, we used 2% of the grain size mean of the preliminary acquisition.

The samples were prepared following standards for each material: they were grinded, polished and etched using its specific reagent. As it is not know a priori, the standard deviation, we made a preliminary acquisition to estimate this parameter. For this acquisition, we took 5 samples (3 from magnesian sinter and 2 from low carbon steels) and acquired 5 images from each. All images were acquired using a BX41M microscope and a Moticam 1300 camera. The images had a 1280x1240 pixels resolution. This acquisition resulted in the data exposed in Table 1.

Table 1: Determination of how many grains have to be acquired for obtaining the specified error.

Sample	Mean (μm)	Standard Deviation	Grains required
Magnesian Sinter 034	100,36	36,74	1287
Magnesian Sinter 41	88,34	29,65	1082
Magnesian Sinter 63	78,53	28,12	1231
Low carbon steel 1020	89,48	29,95	1075
Low carbon steel 1010	89,31	32,50	1272

Note that the result of the formula is measured in grains, so it is needed another table with the average grains number per image for knowing how many images we have to acquire. This data is shown in Table 2.

Table 2: Determination of how many images have to be acquired for obtaining the specified error.

Sample	Grains required	Average grains/image	Required images
Magnesian Sinter 034	1287	342	4
Magnesian Sinter 41	1082	251	4
Magnesian Sinter 63	1231	367	3
Low carbon steel 1020	1075	221	5
Low carbon steel 1010	1272	314	4

As the required image numbers were satisfied for all the samples, no more images were acquired. The process used for analyze the images is exposed in Figure 1.

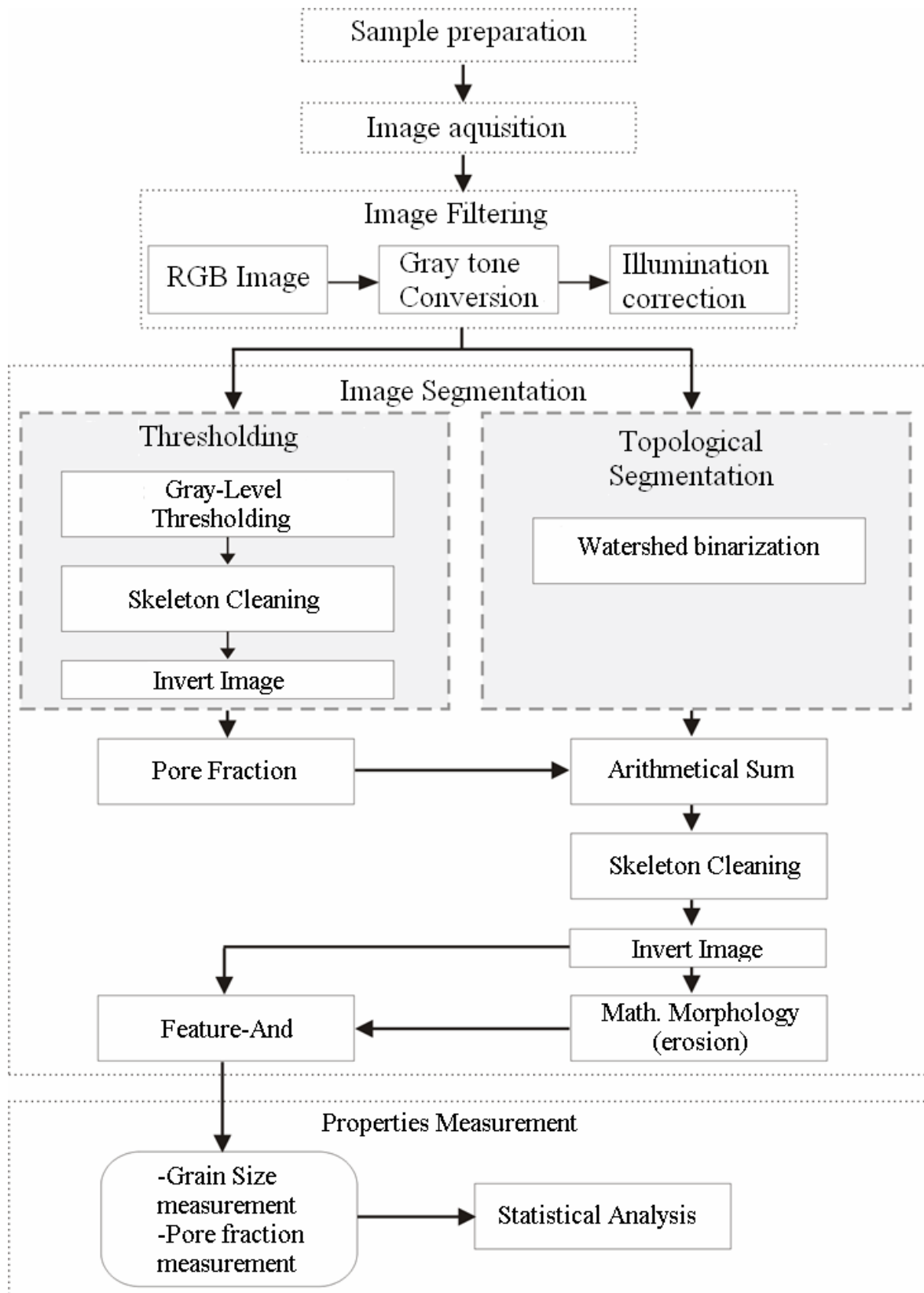


Figure 1: Flowchart of the procedure adopted for measuring the grain size in the samples through image analysis.

After the acquisition process, several filtering process were realized. It started with a gray-level conversion objecting to filter the image illumination. The Figure 2 shows the illumination correction process. As one can see, the center from image (a) is brighter than its edges. This characteristic harms the segmentation process. In the image (b) this problem is corrected.

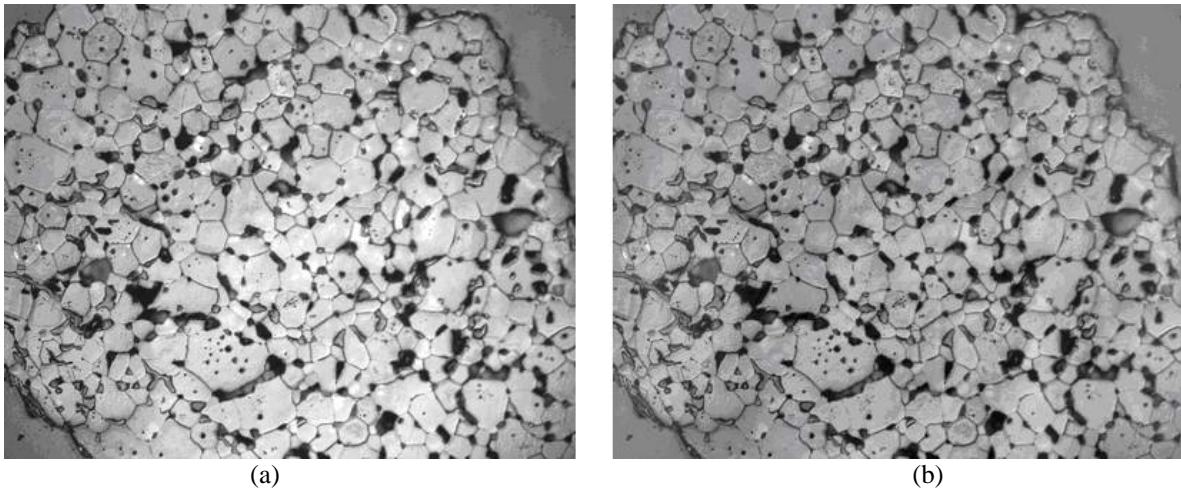


Figure 2: Original magnesium sinter gray-level image (a) and the image after the illumination filtering (b).

After the image filtering, the analysis divided into two segmentation process. One for segmenting the grain contours, other for segmenting the dark objects (pores for the magnesium sinter and perlite for the low carbon steels). For the grain contours, the method adopted was the attribute based watershed, with attributes area and depth. The resulting images are exposed in Figure 3. For the dark objects, the image was thresholded.

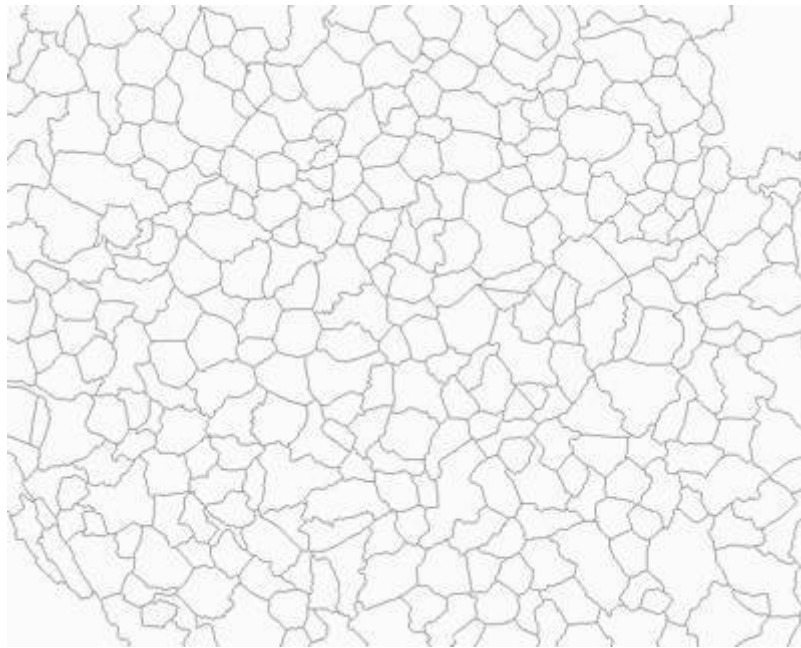


Figure 3: Attribute based watershed segmentation result applied in the Figure 2 (b).

For achieving better dark objects segmentation, the image resulting from the objects segmentation was summed to the grain contour segmentation result. In the magnesium sinter images, some pores had still some noise, which is indicated by the red arrows in the Figure 4 (a). For filtering it, the skeleton cleaning process was applied, resulting in Figure 4 (b).

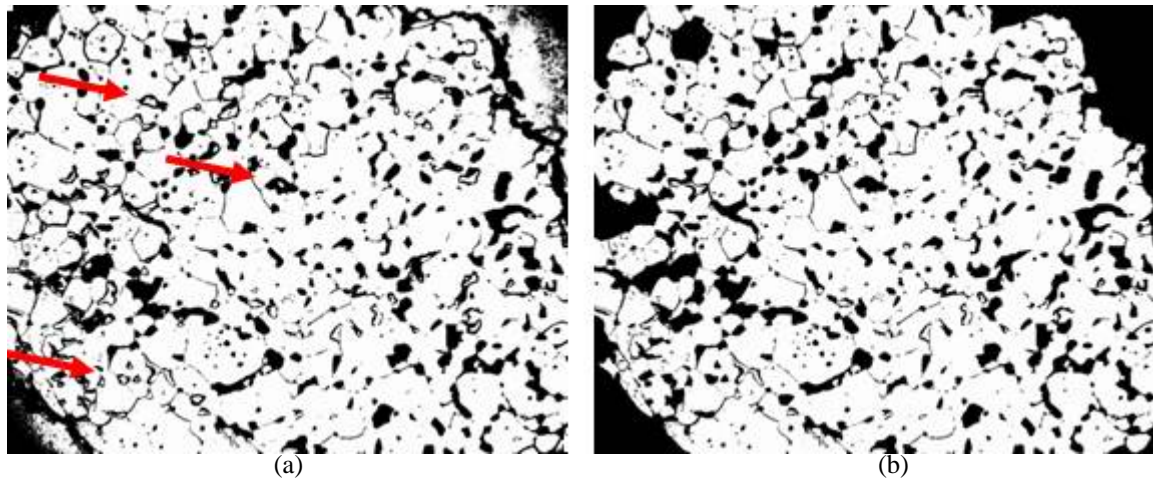


Figure 4: Binarized pores with noise (a) and filtered (b).

For having a correct grain size, it is necessary to clean some pores that are in the grains interior, in the magnesium sinter images. This process is not necessary when measuring the grain size in low carbon steels. The Figure 4 (b) was inverted again and the skeleton cleaning process was applied. The final noise is an eventual isolated pixel which doesn't corresponds to a grain. The process for filtering it was to realize an morphological operation called erosion and a feature-and with the prior image. It results in the Figure 5, which corresponds to the grains in the sample region and offers the correct grain size quantification. However, the attribute based watershed segmentation method tends to mesh grains which have smooth contour or to divide grains which have irregular surface. This can be seen in Figure 5, through the red marks indicating a division and with the blue marks indicating meshing.

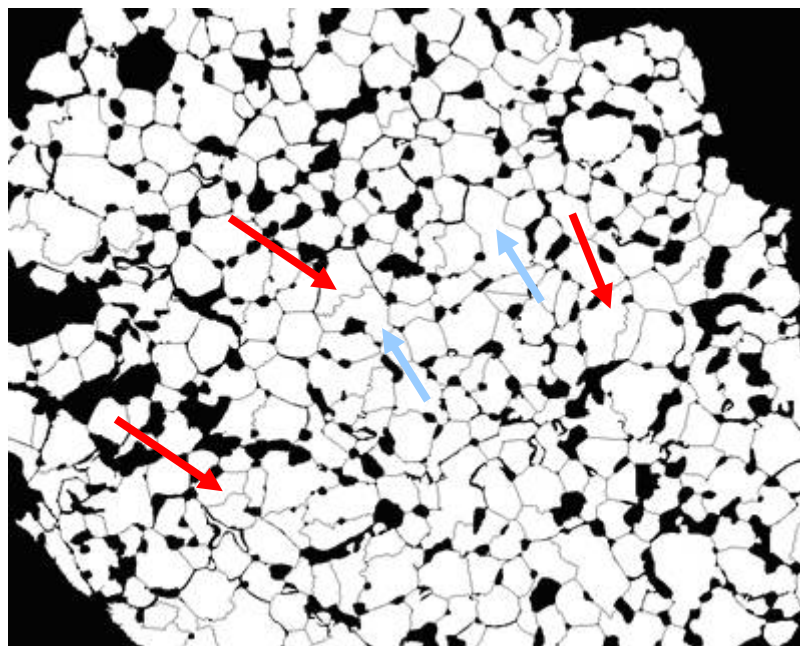


Figure 5: Resulting image.

The visual inspection was realized by an operator with 15 years of experience in sample analyzing. He measured the grain size using a grid coupled to the microscope ocular.

The process for comparing the results measured by image analysis and visual inspection is called paired analysis, which determines if two methods follow the same distribution, i.e., if they are statistically dependents regarding a know significance factor (Shimakura, 2002). This analysis was used to verify if the grain size measured by image analysis is similar to the visual inspection measurement. It was randomly choose 25 grain size measurements from both methods and the results were compared.

3. Results

The presented methodology allowed obtaining the results showed in Table 3, while the operator results are presented in Table 4. These results are for 10 randomly choose samples.

The Figure 6 shows the paired analysis result among the visual inspection and the image analysis methodology for 25 samples randomly choose. Another result that should be mentioned is that the visual inspection took up to 40 minutes/sample, while the image analysis methodology took 20 minutes/sample.

Table 3: Grain size means for randomly choose analyzed samples using the image analysis methodology.

Sample	Analyzed grains	Grain size mean(μm)	Standard deviation
Magnesian Sinter 034	1239	100,49	16,74
Magnesian Sinter 41	1530	89,14	19,65
Magnesian Sinter 63	1877	81,72	8,12
Magnesian Sinter 80	1476	85,50	14,95
Magnesian Sinter 163	1426	84,71	12,50
Magnesian Sinter 170	1423	96,92	17,13
Low carbon steel 1020	1397		
Low carbon steel 1012	1505		
Low carbon steel 1010	1510		
Low carbon steel 1008	1451		

Table 4: Grain size mean for randomly choose analyzed samples using the visual inspection methodology.

Sample	Analyzed grains	Grain size mean(μm)	Standard deviation
Magnesian Sinter 034	100	98,12	30,14
Magnesian Sinter 41	100	86,39	42,36
Magnesian Sinter 63	100	83,34	47,54
Magnesian Sinter 80	100	87,20	39,97
Magnesian Sinter 163	100	83,99	27,45
Magnesian Sinter 170	100	96,01	29,85
Low carbon steel 1020	100		
Low carbon steel 1012	100		
Low carbon steel 1010	100		
Low carbon steel 1008	100		

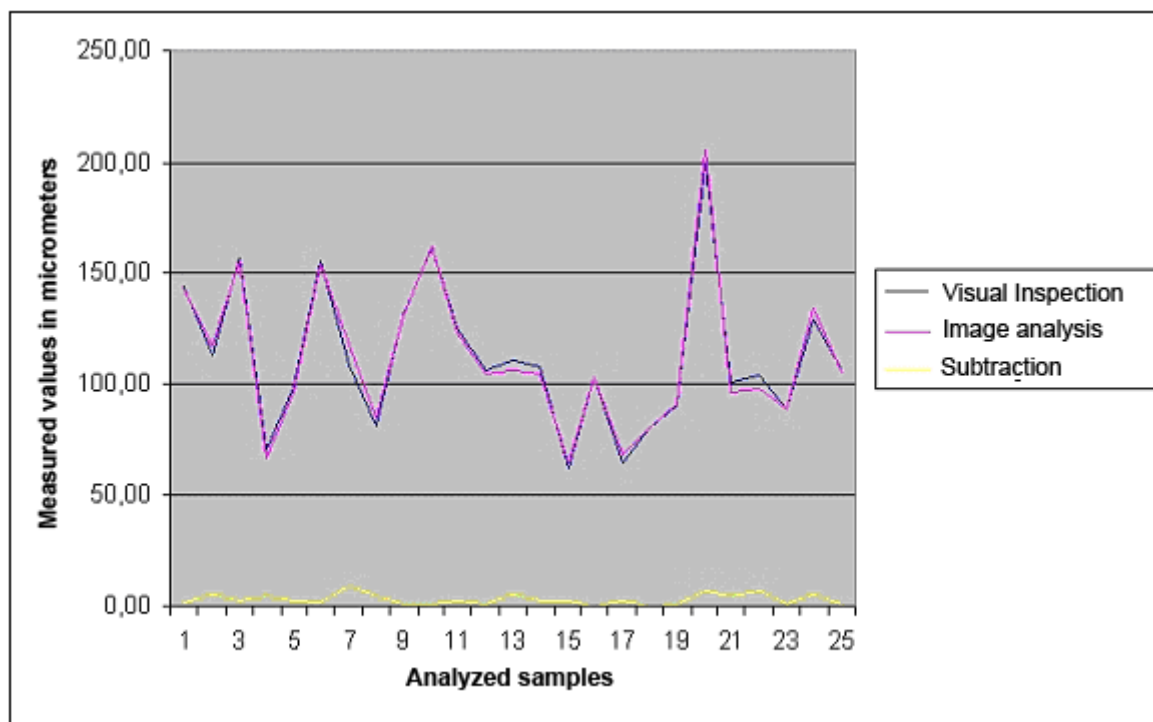


Figure 6: Paired analysis among the visual inspection and the image analysis grain size measurement methods.

4. Discussion

The grain size could be measured for all the analyzed samples. The methodology was fast and accurate in comparison to the visual inspection methodology. The analysis time also was shorter in the image analysis methodology. From the image acquisition to the final result, the process took up to 20 minutes/sample, while the visual inspection took up to 40 minutes/sample. An interesting result is that the operator had similar results to the image analysis system, but the operator's standard deviation still is significantly greater than the image analysis' one.

Despite the good results, several grains were incorrectly segmented in the images. If the analyzed grain contour is too smooth, the attribute-based watershed method tends to mesh it to another neighbor grain. There is a need of using some shape parameters, as area and contour smoothness to discard the fake grains. However, as shown in results, these fake grains don't affect the final results, in comparison to the human analysis, as the paired analysis showed.

5. Conclusion

The semi-automatic grain size measurement methodology through image analysis was satisfactory regarding the presented results. It obtained better and faster results than the visual inspection method. The better improvement, although, is the greater number of analyzed grains, which brings a greater statistical representation to the grain size measurement. Another point is that the image analysis can be repeated, as the images are physically stored in a computer, while the samples, specially the metallic ones, tend to oxide.

6. References

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7. Responsibility notice

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