# Digital Microstructure Analysis System for Testing and Quantifying the Ductile Cast Iron

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## ABSTRACT
In this paper, we propose an automatic digital microstructure image analysis system to qualify and quantify the graphite in the form of nodular shape in ductile cast iron material based on ASTM E2567–11 standard specifications. The ASTM E2567-11 standard is for determining the nodularity and nodule count in ductile iron using image analysis method. The proposed system can distinguish between the two forms of graphite grains from microstructure images of ductile cast iron, namely, 'nodular' and 'non-nodular', based on the nodularity shape factor value. The proposed method implements the standard test procedure, proposed by ASTM E2567-11 standard. The proposed system is tested on various microstructure images of ductile cast iron. The images are obtained from the light optical microscope. The results are consistent over a wide range of images (in terms of resolution, noise and composition) in comparison with manual method. The results are compared with expert methods and they are found to be very close, reliable and reproducible in nature. The paper also demonstrates the inconsistencies and unreliability of manual method.

**Keywords**: Nodularity, ASTM E2567-11 standard, Nodularity shape factor, active contours.

## 1. INTRODUCTION
The ductile cast iron (also known as nodular cast iron / spheroidal graphitic iron), is produced with graphite in a spherulitic form. The nodularizing elements such as magnesium, cerium, lithium, sodium etc., are added to a molten metal bath of proper chemical composition to produce discrete particles of spheroidal shape graphite. The carbon in the form of graphite is often used as an additive in the production of cast iron, amounting to 2 to 4 percent by weight or 6 to 10 percent by volume in typical castings [2]. The microstructure of graphite within cast iron has major effects on the casting's mechanical properties. When graphite arranges itself as thin flakes the result is gray iron, which is hard and brittle. When graphite takes the form of spherical nodules the result is nodular iron, which is soft and malleable. If the mixing is non-uniform or the casting process is otherwise imperfect, it is possible to make a casting with variations in nodularity, or pockets of gray iron within a nodular iron casting. Because this will significantly change the mechanical properties of the metal, foundries need to check nodular iron for uniformity. It is important that the distribution of graphite in the casting be uniform, and that the graphite inclusions be of the right form (nodules rather than flakes). Nodular cast iron is used widely in the production of mechanical accessory and structural parts. It is imperative that the control of graphite shape is critical to nodular iron properties.

### 1.1 The need of nodule count
The shape and nodule count, (expressed as the number of graphite nodules/$mm^2$), influences the mechanical properties of ductile cast iron. Nodule count is a sensitive parameter in production of ductile cast iron . Generally, the high nodule count indicates good metallurgical quality, but there is an optimum range of nodule count for each section size of casting, and nodule counts in excess of this range may result in a degradation of properties [1,3]. The nodule count affects graphite size and shape. Increase in the nodule count results in a decrease in nodule size which improves tensile, fatigue and fracture properties. Inoculation practices used to improve nodule count often make the nodules more spherical. Thus, high nodule count is generally associated with improved nodularity [8]. A consistent method is required for evaluation of the cast product and to control process variability. There are standard manual methods in practice for assessing the nodularity of specimen using laser printout of microstructure image.

### 1.2 Manual methods for assessing the nodularity
The ASTM E 112 standard has proposed the manual methods, namely, planimetric or Jeffries' circle, lineal intercept, Heyn lineal intercept and circular intercept methods for determining average grain size in a microstructure image. Shape is typical parameter to assess using standard chart methods, unless the shape is very close to well recognized geometric shapes. Nodules density is also difficult to assess by chart methods as nodule size is also a variable and the chart cannot depict the nodule density variations for nodules of all possible sizes. The manual methods are inconsistent and difficult to quantity the required parameters of grains [3]. These manual methods are tedious, tire some. The manual methods need minimum of 20 to 30 minutes to analyze a sample and apart from this, the results obtained from experts on the same sample microstructure image have considerable deviations. It is due to individual's physiological capabilities and the amount of expertise. Our study with regard to assessing the quality of ductile iron based on graphite grain morphology indicates that the development of an automatic image analysis system is essential.

In our literature survey, we came across some of the attempts made to automate the microstructure image analysis. In [1], the morphological and contour analysis methods are used for grain boundary segmentation to determine the average grain size of super-alloy micrographs. In [2], the presentations discusses the grain stereology with illustrations. In [3], a digitial microstructure image analysis methods are discussed. In [7], segmentation and determining the grain size of ceramics is discussed. The morphological operations, namely, tophat, skeletonization and dilations are employed for segmentation and for revealing the grain boundaries. In [10], the characterization of graphite particles in spheroidal graphite is performed using a computer-based image analyzer using microstructure images acquired from SEM. Recently, the ASTM has approved and released an improved standard test method for determining nodularity and nodule count in ductile cast iron using image analysis (E 2567-11).

With this motivation and background, we propose an image analysis system that is developed based on ASTM E2567-11 standard that uses the digital image processing techniques. In the following section, the standard test procedure defined in E2567-11 is discussed.

## 1.3 ASTM 2567-11 standard

This standard defines a procedure for measuring the number of nodules and the quality of nodularity of spherulitic graphite in a cast iron microstructure. The gist of the standard for test practices in determining the nodularity parameters from the specimen microstructure images is : the preprocessing methods used on microstructure images shall not use the smoothing or averaging filters for enhancing grain structures; eliminate the features that are smaller than the minimum size; use a properly sized guard frame to eliminate the border touching, incomplete graphite grains; qualify a graphite grain as nodule based on two criteria. First, the particle must have a minimum of maximum ferret size of 50 pixels. Second, the grain's shape factor value must be equal to or exceed the value 0.50. The roundness or circularity is assessed by shape factor that does not require perimeter measurement. Such a shape factor is defined in Eq. 1 by the ASTM standard that does not depend on the measurement of perimeter value.

$$Shape\ Factor\ (SF) = \frac{Area\ of\ Graphite\ Particles}{Area\ of\ reference\ circle} \quad (1)$$

where,

$$Area\ of\ reference\ circle\ = \frac{\pi(Maximum\ Feret)^2}{4} \quad (2)$$

For a perfect circle, the SF value reaches 1. As the grain shape becomes less round the shape factor reduces to zero. The quantification of microstructure is performed using Eq.3 and Eq.4 are defined for $\%nodularity\ by\ area$ and $\%nodularity\ by\ count$.

$$\%nodularity\ by\ area = 100 \times \left(\frac{Area\ of\ all\ particles\ above\ acceptance\ criteria}{Area\ of\ all\ graphite\ particles\ which\ meet\ the\ min.cross\ Sectional\ area\ requirement}\right) \quad (3)$$

$$\%nodularity\ by\ count = 100 \times \left(\frac{Number.of\ all\ particles\ above\ acceptance\ criteria}{Number\ of\ all\ graphite\ particles\ which\ meet\ the\ minimum\ cross\ sectional\ area\ requirement}\right) \quad (4)$$

As per the standards, if the value of nodularity percent is equal or more than 80%, then the sample is said to be a 'good' malleable ductile cast iron, otherwise, sample is said to be a 'poor' ductile cast iron.

## 1.4 Materials used

The microstructure images used for testing are from ductile cast iron samples with various compositions, images of various resolutions (ie magnifications). The images are drawn from microstructure library [4].

# 2. PROPOSED METHOD

The proposed method is based on the test procedure proposed by ASTM E2567-11 standard.

## 2.1 Preprocessing and segmentation

Generally, the microstructure images suffer from defects of improper illumination, artifacts that are developed at the time of specimen preparation and noise. This stage is important to achieve good segmentation classification and quantification. We have used active contour segmentation method for segmentation [5]. The Otsu's segmentation method is also a widely used method for segmentation [9]. The Otsu's segmentation method needs a perfect noise suppression mechanism and generally the noise removal algorithms use the morphological methods to eliminate noise. This could effect on the final quantification results. On the other hand, the reason for choosing the active contour segmentation is that it acts very well on noise without using the morphological operations. The result of active contour segmentation is a binary image which is free from noise and regions are well delineated from neighboring regions. The grains touching the border are eliminated using a guard frame from binary segmented image. The guard frame is applied just inside the border region of the image boundary (a distance of 5 pixels inside the boundary region). In the next step, the segmented regions having ferret length of less than 50 pixels are eliminated and the binary image is labeled. Each labeled region in binary image is a graphite grain. The grains are subjected to calculate the SF, percent nodularity by area and percent nodularity by count. The following algorithm is to assess the quality of ductile cast iron.

**Algorithm:**

Step 1: Input the RGB microstructure image and convert it into grayscale image.
Step 2: (Preprocessing): Apply active contours segmentation method for segmenting the image. Label the image.
Step 3: Eliminate the border touching grains and the grains of maximum ferret length less than 50 pixels from the segmented binary image.

Step 4: Compute SF of graphite grain using the Eq. 1 and Eq. 2.
Step 5: Qualify the grain as 'nodular' if its SF value exceeds 0.50.
Step 6: Repeat the Steps 4 and 5 for all the grains.
Step 7: Compute average SF. If the average SF value of a sample is more than 0.80, qualify the sample as 'good' else 'poor'.
Step 8: Compute $\%nodularity\ by\ area$ and $\%nodularity\ by\ count$ using the equation Eq. 3 and Eq. 4 respectively for the 'nodular' grains.

# 3. EXPERIMENTAL RESULTS AND DISCUSSION

For the experimentation we have used more than 100 microstructure images of ductile cast iron of various resolutions (i.e. magnifications) & grain shapes. The etching medium used for preparing specimen is 3% alcoholic nitric acid. These images are obtained from light optical microscope. Two sample microstructures images of ductile cast iron are as shown in Fig. 1.

The Fig. 2 shows the segmentation results of microstructures shown in Fig. 1(a) and (b) by applying active contours segmentation method.

The experts are given the laser printer printout of microstructure image to carryout qualification and quantification. It is observed in this experimentation that the experts are able to complete the evaluation of the given microstructure image in 20 to 30 minutes, whereas, the time required for the proposed system is, less than a minute per sample. The Table 1 shows the nodularity decision on each graphite grain and the computed values using microstructure image shown in Fig. 1(a). The results are compared with the results that are obtained by experts. It is found that in terms of effort, amount of time and accuracy, the method proposed needs less eoffort, fast and accurate.

The Table 2 presents the final results of quality assessment of ductile iron samples along with the quantification results, namely, percent nodule by area and percent nodule by count.

## 3.1 Difference and inconsistency in manual measurements

The following Fig. 4 shows the difference in computation of shape factor between the proposed and manual method using microstructure image shown in Fig. 1 (a).

The Fig. 4 shows the deviations in computation of shape factor (SF) value by three experts. The deviation indicates the inconsistency in the manual estimation methods.
The shape factor values computed by three experts are with considerable variations, although, all have used the same set of images. Also, it is observed during our experimentation that the results are non reproducible. It is due to the human physiological capabilities and also the fatigue. The more variations in the manual results are observed when the density of graphite grains is more in microstructure images. The quantification of the percentage nodule by area is more difficult for almost all the experts and the results are more scattered in the case of microstructure that has densely populated graphite grains.

# 4. CONCLUSION

In this paper, an automatic digital microstructure image analysis system to qualify and quantify the graphite in the form of nodular shape in ductile cast iron material based on ASTM E2567–11 standard specifications is developed. The method is robust and computationally inexpensive. It demonstrates its accuracy and its usefulness by comparing the computed values with manual method. The results obtained by proposed method are reproducible and repeatable. The results are consistent over a wide variety of images. The proposed method is fast and qualifies a given sample within few seconds. The proposed method has potential for considerable industrial applications in the field of material manufacturing industry.

# 5. REFERENCES

[1] Wanda Benesova, Alfred Rinnhofer and Gerhard Jacob. Determining the Average Grain Size of Super-Alloy Micrographs. In Proc. of IEEE International conference on Image Processing (ICIP 2006),2749-2752.Atlanta, USA, 2006.

[2] George Vander Voort, http://www.georgevandervoort. com/mic_met_pdf/ IntroToStereologyGrainSize.pdf and http://www.georgevandervoort.com/mic_met_pdf/, IntroToStereologySizeShape.pdf.

[3] ASM International Handbook Committee, ASM Handbook, Metallography and Microstructures, Vol 9, ASM International, USA, 2004.

[4] Microstructure Library: http://www.doitpoms.ac.uk/miclib/ index.php

[5] T.F. Chan and L. Vese, IEEE Trans. on Image Processing, Vol. 10, No. 2, pp 266-277, 2001.

[6] Vander Voort G.F. Metallography: Principles and Practice, ASM International, 1999.

[7] Xaviour Arnold, Michel Coster, Jean-Louis Chermant, Liliane Chermant, Thierry Chartiers & Abder Elmoataz. Segmentation and Grain Size of Ceramic. Image Anal Stereol, 131-135, France, 2001.

[8] Leonard E. Samuels, Light Microscopy of Carbon Steels, ASM International, USA, 1999.

[9] Milan Sonka, Vaclav Hlavac and Roger Boyle. Image Processing, Analysis, and Machine Vision, 2e. PWS Publishing. India,1999.

[10] B.I. Imasogie and U.Wend, Characterization of Graphite Particle Shape in Spheroidal Graphite Iron using a Computer-Based Image Analyzer, Journal of Minerals & Materials Characterization & Engineering , Vol. 3, No.1, pp 1-12, 2004.

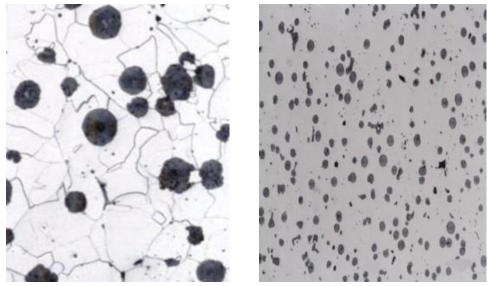
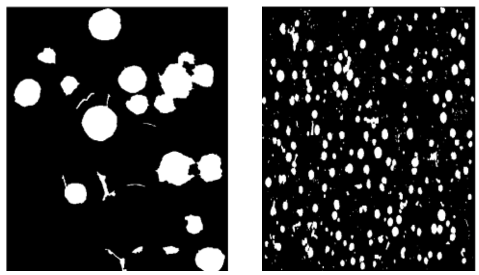


Fig. 1 (a) and (b): Two sample microstructure images of ductile cast iron



**(a) (b)**

**Fig. 2 Segmentation of microstructure images shown in Fig. 1(a) and (b).**

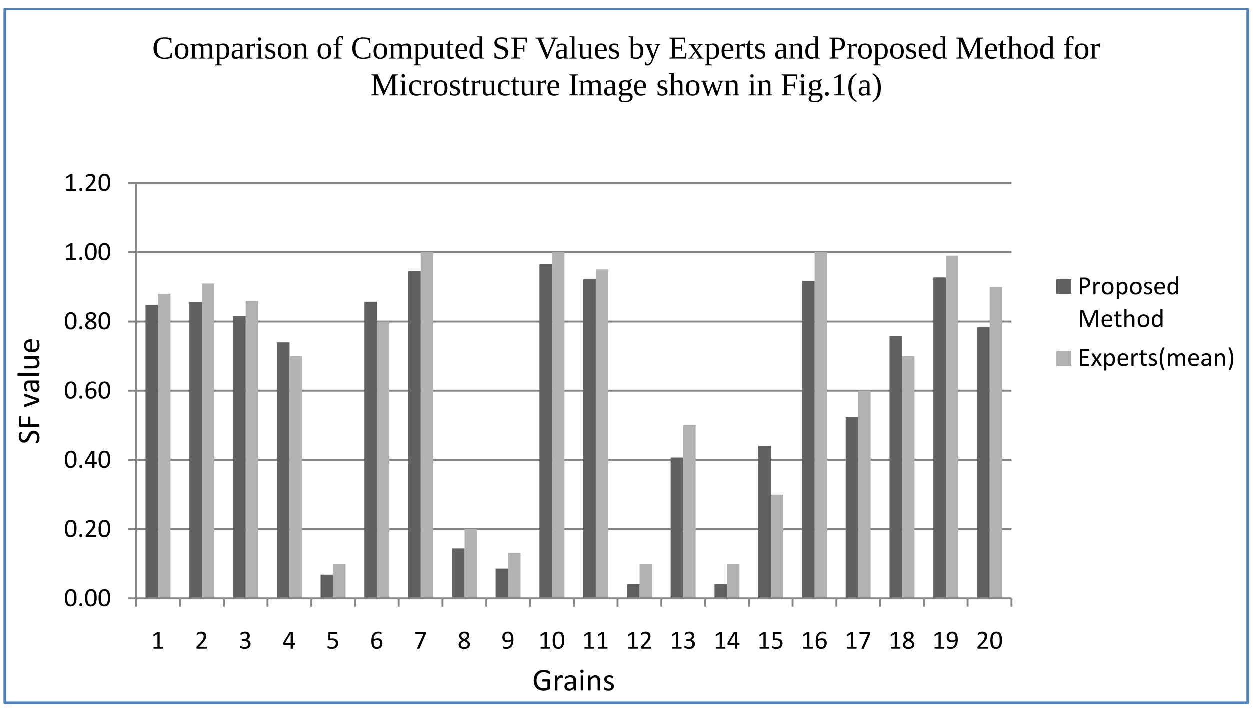



**Fig.3. Comparison of ASTM shape factor values computed using proposed system and manual methods from image shown in Fig.1 (a)**

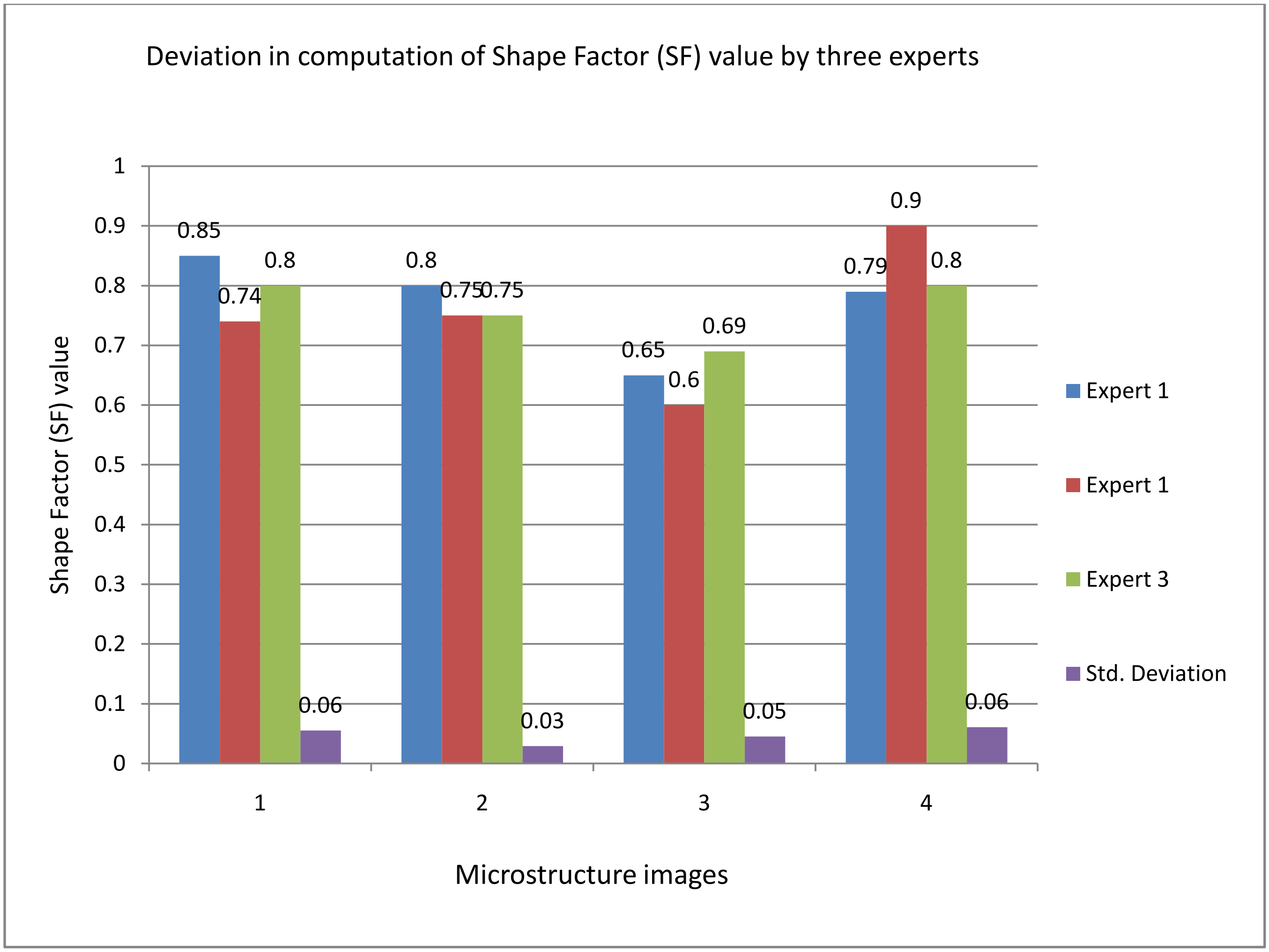



**Fig.4 Deviation in computation of Shape Factor (SF) value by three experts**

**Table 1. Decision of each graphite grain (nodular or non-nodular) seen in the microstructure image shown in Fig. 1(a)**

| Object ID | Max. ferret length of grain | Shape Factor (SF) | Decision of grain as Nodule (1) and Non-Nodule (0) |
|---|---|---|---|
| 1 | 140.11 | 0.85 | 1 |
| 2 | 85.09 | 0.86 | 1 |
| 3 | 91.04 | 0.82 | 1 |
| 4 | 124.72 | 0.74 | 1 |
| 5 | 125.18 | 0.07 | 0 |
| 6 | 182.40 | 0.86 | 1 |
| 7 | 158.58 | 0.95 | 1 |
| 8 | 161.39 | 0.14 | 0 |
| 9 | 159.79 | 0.09 | 0 |
| 10 | 133.49 | 0.97 | 1 |
| 11 | 101.77 | 0.92 | 1 |
| 12 | 98.83 | 0.04 | 0 |
| 13 | 54.39 | 0.41 | 0 |
| 14 | 69.12 | 0.04 | 0 |
| 15 | 337.20 | 0.44 | 0 |
| 16 | 169.90 | 0.92 | 1 |
| 17 | 71.84 | 0.52 | 0 |
| 18 | 98.83 | 0.76 | 1 |
| 19 | 135.64 | 0.93 | 1 |
| 20 | 141.73 | 0.78 | 1 |

**Table 2. Results of quality assessment of sample images**

| Image | Average SF computed by Proposed method | Percent nodule by area (%) | Percent nodule by count (%) | Qualification of the sample GOOD:Average SF > or =0.80 ). POOR:Average SF<0.80 |
|---|---|---|---|---|
| Image 1 (Fig. 1 (a)) | 0.85 | 75.20 | 60.00 | GOOD |
| Image 2 (Fig. 1 (b)) | 0.84 | 72.20 | 74.21 | GOOD |
| Image 3 | 0.77 | 57.27 | 39.13 | POOR |
| Image 4 | 0.83 | 76.16 | 75.22 | GOOD |