Microstructure analysis of spheroidal graphite iron (SGI) using hybrid image processing approach

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Abstract— **The microstructure analysis is a process to be carried out on ready castings. The main purpose of this paper is to present image processing methodology for microstructure analysis of Spheroidal Graphite Iron (SGI) castings to determine the quality assessment parameters of SGI casting such as nodularity, nodule count, nodule size and percent of ferrite-pearlite. The strength and hardness of the SGI castings is dependent on these quality parameters. Sample images of SGI casting obtained from inverted microscope were subjected to segmentation and boundary detection algorithm to find the nodules present. Further classification of SGI based on nodule size as per ASTM standard was carried out by giving SGI quality parameters as input to Artificial Neural Network (ANN). Our database consisted of one hundred and fifty three image samples of SGI castings. Nodularity obtained by our methodology was 97.1% which is within the acceptable tolerance of ±3% and accuracy of nodule size obtained by our algorithm was 100%. However our algorithm could give only 84% accuracy for nodule count in SGI. The results for percent ferrite-pearlite approximately agree with those obtained from laboratory.**

Index Terms— Segmentation, Boundary Detection, Microstructure, Spheroidal Graphite Iron.

I. INTRODUCTION

The use of spheroidal graphite iron castings has been increasing constantly all over the world. In the recent years there has been increasing interest in the microstructure analysis of SGI castings. Most of the work on this subject has been based on metallurgical examination after solidification and cooling to room temperature. The microstructure of typical commercial spheroidal graphite irons consists of graphite nodules number, nodularity and percent of ferrite- pearlite present in the casting.
In the present traditional methods the microscopic image of the SGI casting is taken and observed by the metallurgist and analysed manually. For analysis of the quality parameters the experts refer to the standard defined ASTM values.

From the literature survey it is seen that, much research has been carried out on the microstructure analysis of different flat surfaces. But very few have concentrated on the microstructure quality parameters of SGI. B.I.Imasogie et.al. used the computer based image analyser for the characterization of graphite with 0.2% yield strength. They have defined a procedure and specification for characterizing graphite shape/ form in SGI using 3-D morphological processing with the help of MACROS III software. A correlation has been established between variations in graphite degree of spheroidization. They showed that the properties of the iron depend largely on the form and/or morphology of graphite precipitated in the casting [1]. Victor Albuquerque et.al. presented a new solution to segment and quantify the microstructures from images of nodular, gray and malleable cast irons, based on an Artificial Neural Network using multilayer perception, with back propagation training algorithm. The network analyzed each pixel of an input image, and then performed the microstructures' segmentation. During this phase, each pixel of the input image is classified and counters are used to quantify the microstructures identified [2]. Similarly H.Sarojadevi et al. had worked on the microstructure analysis using segmentation applied on a enhanced image. They focussed on changes in the intensity of the image to study the properties of grains accurately and also to count the spheroids in the microstructure. The results obtained from this approach were in the form of new microstructure image with smoothed grain areas and precisely detected grain boundary. Analysis results of microstructure images help to correlate certain mechanical properties like ductility, malleability, brittleness etc. [3]

Review of the present state-of- art shows that the new technologies for the microstructure analysis of SGI are very expensive keeping the small scale foundries in view. Though the computer based image analysers for casting are available, but yet the interpretations are carried out manually (partially or fully). Hence looking at the research review and present state-of-art, we have developed a method for the microstructure analysis of SGI using image processing and neural network, which eliminates need of metallurgical expert. The brief related theory, experimentation carried out, results and future scope thereof are presented further.

II. THEORETICAL BACKGROUND

For the microstructure analysis we have used segmentation, boundary detection algorithm and artificial neural network. Hence brief theory on all these is explained here.

Segmentation using Global Thresholding:

The image segmentation is carried out using the Otsu's thresholding method.

Boundary detection:

In an image, an edge is a curve that follows a path of rapid change in image intensity. Edges are often associated with the boundaries of objects in a scene. Edge detection is used to identify the edges in an image. Matlab edge function be used to find edges. This function looks for places in the image where the intensity changes rapidly, using one of these two criteria:

- Places where the first derivative of the intensity is larger in magnitude than some threshold.
- Places where the second derivative of the intensity has a zero crossing.

The morphological equation used for detecting boundaries of an object is expressed as below:

$$A - (A \oplus B) \qquad (1)$$

The matlab equation B = bwboundaries (BW) traces the exterior boundaries of objects, as well as boundaries of holes inside these objects, in the binary image BW. BW must be a binary image where nonzero pixels belong to an object and 0 pixels constitute the background.

Artificial Neural Network:

Artificial neural network is used here for the classification of nodule size and nodularity of the nodules in the SGI castings. The parameters the total number of nodules and diameter of nodules extracted from image processing algorithms are given as input to the neural network. The output layers of neural network define the nodularity and nodule size as defined by ASTM. The configuration of the neural network used here is as shown in figure 1.

As the quality parameters of SGI such as nodularity, nodule count and nodule size are necessary for microstructure analysis using artificial neural network, hence theoretical background of these parameters are as given below.

Quality parameters for SGI

The theory necessary for computing the quality parameters of SGI i.e. Nodularity, nodule count and nodule size are as further:

a. Nodule Count k = Total number of nodules in the image

b. The exact round shape of the nodules is decided by the roundness metric given by the expression

$$Roundness\ metric = 4 * \pi * \frac{area}{perimeter^{\ 2}} \qquad (2)$$

A threshold value of 0.8 is set as roundness metric to check the roundness of nodule. The nodules having metric value greater than threshold are counted as exact round nodules as per standard.

c. Nodularity is the ratio of exact round shaped nodules to the total number of nodules. It is defined as:

Nodularity = Number of exact round nodules / Total number of nodules

$$= c/k \qquad (3)$$

Where c is the number of exact round nodules calculated from (2).

d. Nodule size is calculated from diameter of Nodules

$$Area\ of\ nodule = \pi r^2$$

$$r^2 = \frac{Area\ of\ nodule}{\pi}$$

$$Diameter, d = 2r \qquad (4)$$

The relationship between pixels and mm is used to convert the obtained diameter of nodules from number of pixels to mm or inches.

96 ixels = 25.4 mm

III. IMAGE ACQUISITION AND DATABASE PREPARATION:

For analysis of metal surface, it is necessary to acquire metal images for two kinds of sub surfaces i.e. mirror finished surface before etching process and for etched surface. Hence two images for each sample to be tested were taken from inverted metallurgical microscope with 10X optics objective magnification and 10X eyepiece magnification. Our database consisted of 153 SGI sample images as shown in Table 1. So apart from this the images obtained from the laboratory ASTM charts were used for the further automation of microstructure analysis. Sample images of castings before etching process and after etching process are as shown in figure 1.

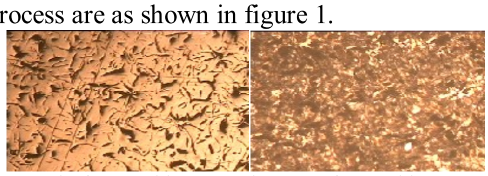


Figure 1: a. SGI before etching b. SGI after etching

Table 1: Database collection

Type of Metal	No. of samples before etching	No. of samples after etching
SGI	153	153

The metallurgical ASTM standard chart images are as shown in figure 2. The standard defined ASTM values for the classification of quality parameters of SGI are available in the form of charts. We can know the difference between the different sizes of graphite nodules in SGI from the available ASTM charts. Based on these sizes experts have assigned standard nodule size number which is as shown in Figure 2. These nodule sizes vary from size 1 to size 8 depending on the diameter of nodule.

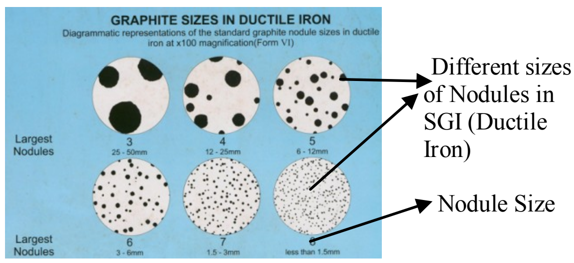


Figure 2: ASTM defined values for nodule size of SGI (Ductile Iron)

IV. EXPERIMENTATION ON SGI MICROSTRUCTURE ANALYSIS:

The procedure followed for the microstructure analysis of SGI is carried out in two workflow parts viz. Part I and part II. In workflow part I the microstructure analysis for the quality parameters like nodularity, nodule count and nodule size were carried out. In workflow part II the analysis of percentage of ferrite-pearlite present in the castings was carried out. The workflow part I and part II are explained by the flowchart as in Figure 3 and Figure 4 respectively.

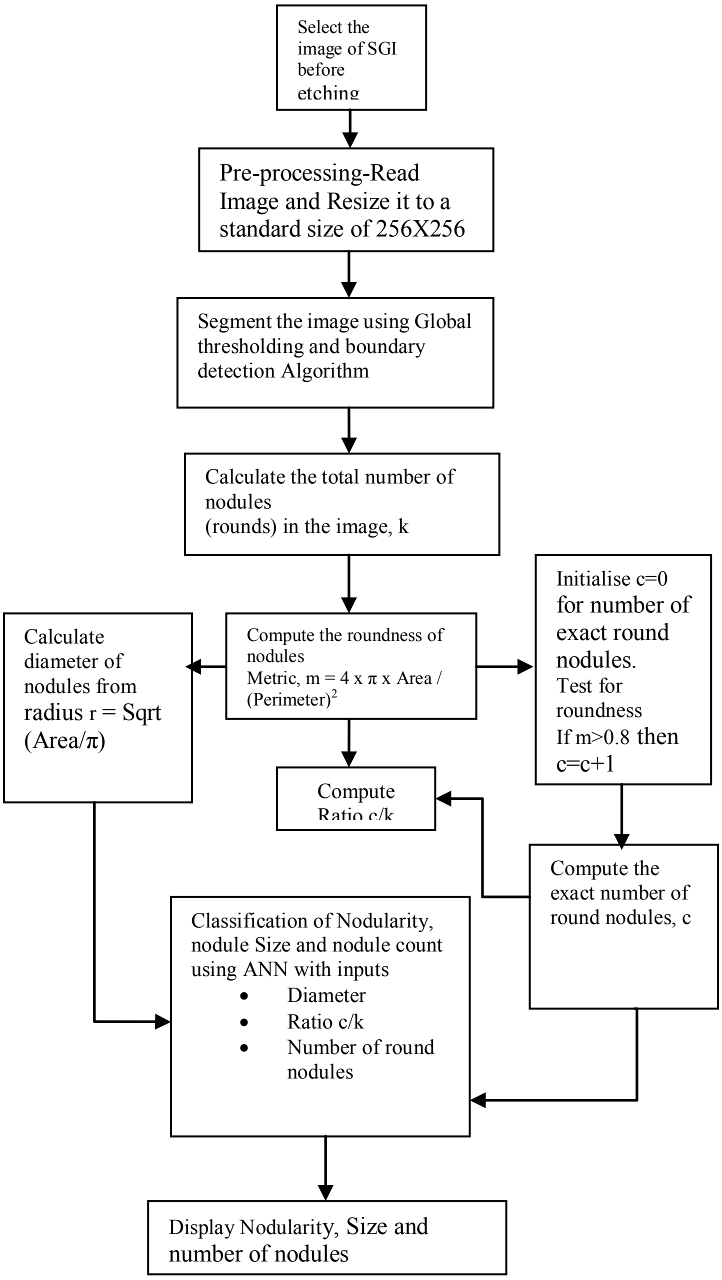


Figure 3: Workflow Part-I: Flowchart for the microstructure analysis of SGI

The steps for workflow part-I for the microstructure analysis of SGI shown in figure 3 are as follows.

a. Take the images before etching for the analysis of nodularity, nodule size and nodule count.
b. Resize images before preprocessing.
c. Segment the resized image with a threshold of 0.5 and used for finding boundaries of the nodules present in the SGI casting.
d. Count the total number of nodules, k present in the SGI casting.
e. Compute roundness metric to know the exact round shaped nodules in the casting using (2).
f. Count the number of nodules with roundness metric>0.8 passing the nodules to roundness test.
g. Compute the nodularity of the casting using (3).
h. Compute the diameter of the nodules using (4) to decide its size as per the ASTM standards.

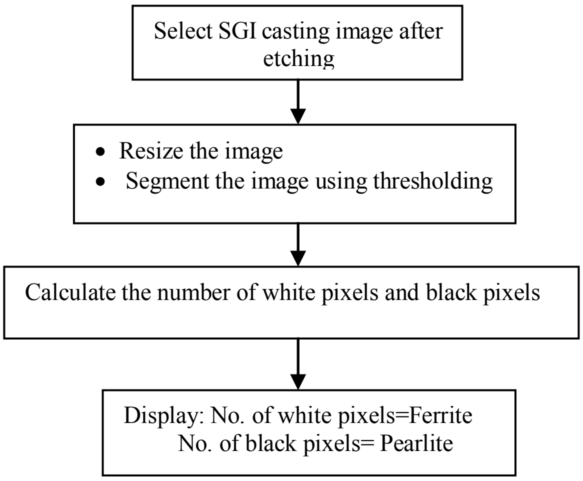


Figure 4: Workflow part-II: Flowchart for computation of %ferrite-pearlite in SGI castings

From the Figure 4, the steps for workflow part-II of the experimentation on the ferrite-pearlite percentage in the castings SGI are as follows:

a. Resize the microscopic images we get from laboratory before processing.
b. After resizing, segment the image to find percentage of ferrite and pearlite.
c. Find white region and black region and compute ferrite and pearlite percentage respectively corresponding to these regions using (5) and (6).

Pearlite= (number of Black Pixels*100)/Total no. of pixels (5)

Ferrite= (number of White Pixels*100)/Total no. of pixels (6)

d. The steps from a to c is followed for all the 173 samples of SGI in database.
e. Compare the results with those obtained from the experts.

All the quality parameters computed from steps a. to e. are given as input to artificial neural network for the classification of nodule size. The experimental procedure carried out for the above procedure is as represented by flowcharts in figure 4 and 5.

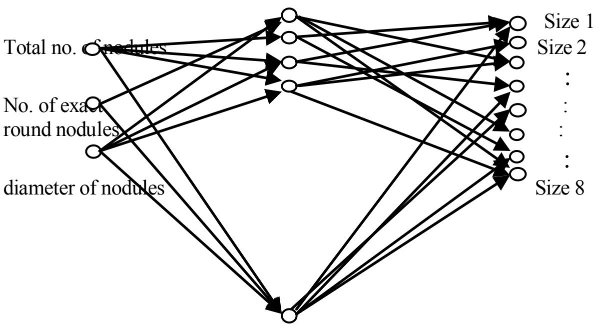
A : Classification of nodule size and nodularity using ANN:

The diameter of the nodules was calculated to decide nodule size referring to the ASTM standards as given in Table 2. Total number of nodules, number of exact roung nodules and diameter of nodules, obtained by applying image processing algorithms were given to the input of artificial neural network for the classification of nodule size.

Table 2: Diameter size of Nodules for SGI as specified by ASTM

Nodule Size defined by ASTM	Diameter in inches
Size 1	>= 4
Size 2	4 to 2
Size 3	2 to 1
Size 4	1 to 0.5
Size 5	0.5 to 0.25
Size 6	0.25 to 0.125
Size 7	0.125 to 0.625
Size 8	Less than 0.625

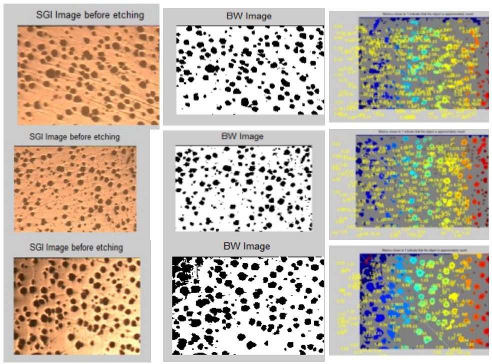
The configuration of neural network used for the analysis of microstructure analysis of SGI is as shown in Figure 5. It has three nodes in input layers corresponding to three inputs, total number of nodules, total number of exact round nodules and diameter of nodules. The output layers consist of eight neurons corresponding to the nodule size 1 to 8. The number of neurons in hidden layers chosen was twenty five. Thus the configuration used for neural network was 3:25:8. Levenberg-Marquardt training function with gradient set of ($9.5826* 10^{-6}$) and momentum, Mu of ($1*10^{-5}$) was used for training with as many as 153 samples of SGI and 25 samples for testing.



V. Results and Observations

The images shown in Figure 6 are the intermediate results obtained in the workflow part-I i.e. for calculation of nodularity, nodule count and nodule size. For the images in the Figure 6, column (a) shows the original images. The images in column (b) are the segmented images of the samples. The round nodules detected by set roundness metric values are shown in column (c) of Figure 6. The range of diameters of the nodules in the samples obtained from (4) is from 1.5 mm to 6 mm.

S1
S2
S3

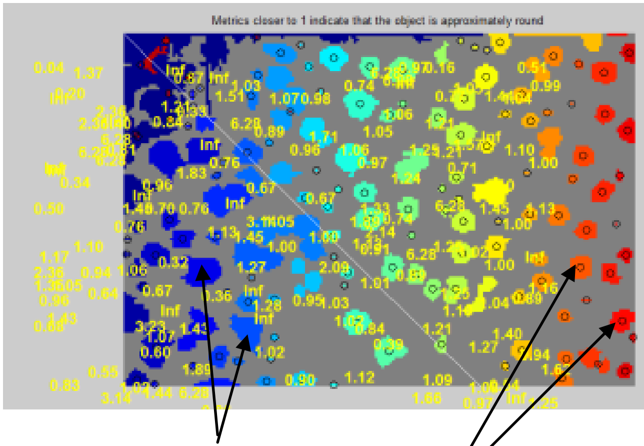


(a) (b) (c)

Figure 6: Benchmark samples after processing SGI images before etching

a: Original images
b: Segmented image
c: Boundary detected image with roundness metric > 0.8

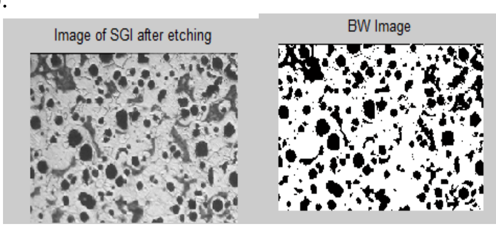
The enlarged image for the detection of exact round nodules using the set roundness metric is as shown in Figure 7.



Nodules with roundness metric < 0.8
Nodules with roundness metric > 0.8

Figure 7: Enlarged image for roundness metric calculation and nodule count

The result images of the experimentation for workflow part-II are as shown in Figure 8. The image corresponding to 8(a) is the image after etching process and that corresponding (b) is the image of SGI after segmentation. From these images we computed the ferrite-pearlite percentage using (5) and (6).



(a) (b)

Figure 8: Output results for Ferrite-Pearlite Analysis in SGI
(a) Image after etching
(b) Image after segmentation

The above procedure is repeated for all the images in database and the results of a few samples are summarised in the Table 3 which show the quantitative comparison results for nodularity, nodule count and nodule size and

Table 4 show the results for the percentage of ferrite and pearlite for few samples of SGI. The results obtained by image processing techniques fairly agree with those obtained from laboratory on the same samples. Though the nodule count obtained here seems to differ from the laboratory results, but are in the acceptable range of 150 and above as defined by metallurgical experts. The percentage of ferrite-pearlite defined by image processing technique also agree with those obtained from experts.

Table 3: Comparison of microstructure SGI IP analysis with Lab results

Name	Nodule count		Nodularity		Nodule Size	
Before Etching	Lab Report	IP Result	Lab Report	IP Result	Lab Report	IP Result
1.png	338.2	286	82.9	82.03	7 to 8	8
2.png	373	249	78.7	76.92	7 to 8,6	8
3.png	327	157	64.8	74.8	7 to 8,6	8
5.png	307	159	78.7	83.04	7 to 8	8
6.png	388.1	201	81.7	81.67	7 to 8	8
7.png	330.4	164	76.1	83.33	7 to 8,6	8
8.png	424.3	224	82.9	90.44	7 to 8	8
9.png	307	159	78.7	83.04	7 to 8	8
10.png	346.4	223	83.75	88.24	7 to 8	8

Note: Tolerance limit for nodularity = ± 3% of Lab report

Table 4: Result comparison for % ferrite-pearlite in SGI

SGI	Ferrite in percent		Pearlite in percent	
	Result from Lab.	Results by IP	Results from Lab.	Results by IP
1.png	76.92	70.28	23.07	29.71
2.png	79.01	69.07	20.98	30.93
3.png	24.53	54.53	17.46	45.47
5.png	77.60	78.52	28.39	21.48
6.png	75.38	58.48	26.61	41.52
7.png	73.27	63.87	26.72	36.13
8.png	65.89	72.72	34.10	27.28

The Figure 9 and Figure 10 represent the graphical representation of the comparison of the results by image processing techniques with that of the standard laboratory results. Acceptable range of nodule count is shown by green line i.e. above 150. Similarly for nodularity, it is above 80% as defined by lab experts and as shown in figure 9(a). We see that our results agree with the standards defined by metallurgical experts. The results for the percentage of ferrite and pearlite shown with blue colour for laboratory outputs and with red colour for image processing techniques output are as shown in figure 9 (b) and 9(c). It is found that our results are matching with those from laboratory results on the same samples. The difference in nodularity for 153 samples is ±10. This is well within the acceptable tolerance of ± 3%.

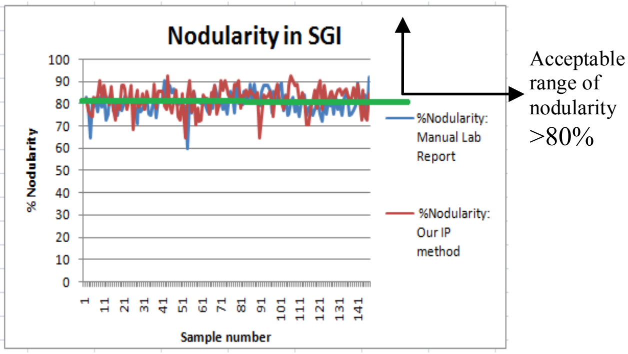


Figure 9: Graphical representation result comparison of nodularity in SGI

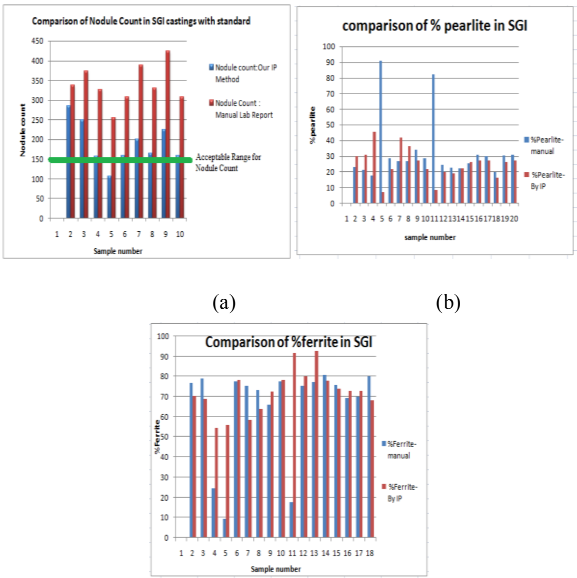


Figure 10: Graphical representation result comparison of nodule count and ferrite-pearlite %

The quantitative analysis for all the 153 samples of SGI present in database is shown in Table 5. It is seen from the table that the image processing technique gave very good results for the nodule size giving 100% accuracy, whereas for nodularity, it gave 98.5% accuracy. There is more scope of improvement in the nodule count as we see the presently applied algorithm is giving an accuracy only upto 84%.

Table 5: Accuracy analysis for nodularity, nodule count and nodule size for SGI

Metal	Total samples of SGI obtained from laboratory = 153			
SGI	Performance Parameters	Manual Lab Results	Results by our methodology *	Accuracy in % **
	Nodularity>80	101	104	98.5%
	Nodule Count>150	153	128	84%
	Nodule Size:6-8	153	153	100%

The implemented technique was made user friendly using Graphical user interface (GUI) in MATLAB. It also has the facility to generate the report automatically. Figure 11 shows the main screen of GUI and Figure 12 shows the screen after the microstructure analysis report is generated.

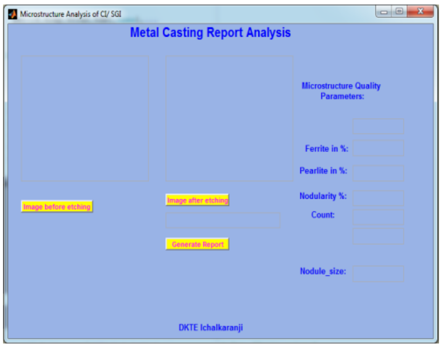


Figure 11: Main screen for Microstructure analysis of SGI

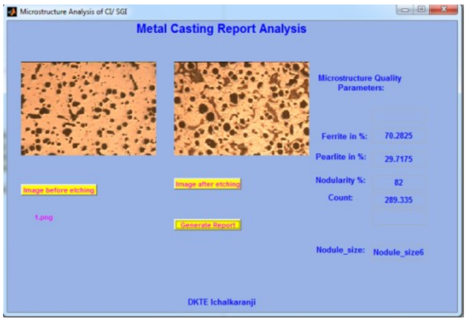


Figure 12: Screen showing the generated parameters after Microstructure analysis of SGI

VI. CONCLUSION

For microstructure analysis of SGI we computed quality parameters such as nodularity, nodule size and nodule count using the image processing algorithms like segmentation using global thresholding, boundary detection and classified for nodule size using artificial neural network. The results obtained from image processing method implemented for the analysis are found to be very close to the existing manual reports, thus proving the suitability of image processing algorithm for automation of microstructure analysis of SGI and report generation.

VII. FUTURE SCOPE

Though the accuracy of SGI results obtained for nodularity and nodule count are matching with laboratory results but the analysis result for nodule count in SGI was found to be accurate only up to 84%. It indicates that our algorithms for SGI require further modification where in it may be necessary to set a variable parameter based on customers need. This is a future scope of our work.

Hence the future scope of this microstructure analysis of castings would be to improve the accuracy for SGI by improving the image processing algorithms used. This automation can be further extended to the microstructure analysis of different materials such as wood, glass, steel, Aluminium and metal alloys.

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