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Beneficial Image Preprocessing by Contrast Enhancement Technique for SEM Images

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In this paper a morphological filtering algorithm using an exposure thresholding and measures of central tendency has been proposed for solving the low contrast of Scanning Electron Microscopic (SEM) images of composite materials for accurate Filler Content Estimation. SEM image of a composite material comprises visible morphological structures like fillers such as silica nanoparticles. The SEM image analysis via segmentation will assist in the study of distribution of these structures. The estimation of the filler content is more accurate only when the SEM images have proper contrast for analysis if not the results lead to less accuracy. To overcome this drawback, we have proposed a preprocessing technique to increase the contrast of SEM images. So that the preprocessed image can be used for post processing namely segmentation and hence the error is less for filler content estimation. We introduced the transformations using morphological processing to extract the bright and darker features of the images. The optimum threshold value is determined by the image exposure. A detailed comparative analysis with other existing techniques has been performed to prove the superior performance of the proposed method.

Keywords*:* Morphological filtering, SEM images, Nanocomposites, Contrast enhancement, Filler, Exposure, image Analysis

1 Introduction

SEM image analysis of material like polymer composite reveals its several morphological as well as mechanical properties. SEM image analysis is used for estimation of filler content. An expected result of embedding nanoparticles into a polymer matrix is enhanced bonding between the polymer matrix and filler, which resulting in the nanoparticles high interfacial energy[1,2].

SEM image analysis can efficiently quantify the morphological structures of the polymer nanocomposites[3]. But it is difficult when the images having low contrast. The SEM images have been captured through the microscopy and due to experimental conditions and bad light leads to low contrast images and hence it shows effect on the accuracy of the filler estimation. By considering these problems, there is need for a contrast enhancement for SEM images to reduce the error. Hence, we proposed a contrast enhancement technique for SEM low contrast images. The sample SEM low contrast image is as shown in Fig. 1.

There are several techniques exists for contrast enhancement. HE is widely used technique for contrast enhancement[4-18]. It may significantly change the image brightness and causes undesirable artifacts. The general HE formula for pixel intensity v is,

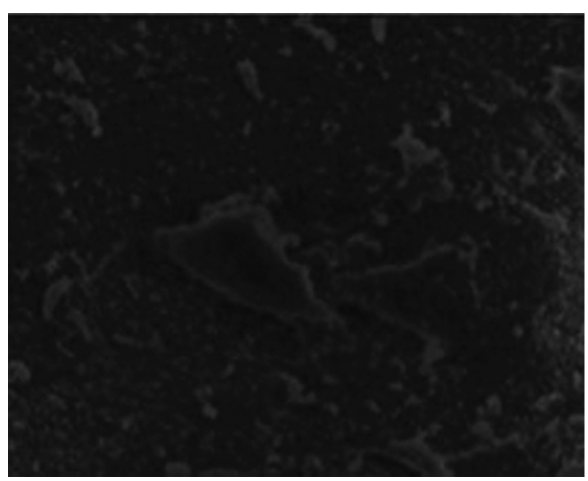

Fig. 1 — Low contrast SEM image sample.

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$$H(v) = \left\lfloor (L-1)\frac{CDF(v)-CDF_{min}}{mn-CDF_{min}} \right\rceil \quad \ldots (1)$$

In contrast limited adaptive HE (CLAHE) performs contrast limited HE on each blocks[5,8]. The contrast limiting is carried out by clipping the histogram before HE and hence, this tends to more localized enhancement. Another technique, The QDHE does not consider the mean brightness preservation and hence, may cause saturation. Other contrast enhancement techniques having their own limitations.

2 Materials and Methods

The SEM image is of size $m \times n$ is denoted by $f(x, y)$ withx, y are pixel coordinates in the width and height dimensions, respectively such that $1 \leq x \leq m$ and $1 \leq y \leq n$.

2.1Morphological Filtering

Morphological operations namely erosion and dilation can be employed for many image analysis and meets the condition as shown in Eqn. (5).

$$H(k) = \sum_{t \in T} \delta(X_t - k) \quad \ldots (4)$$

$$\sum_{k=0}^{L-1} H(k) = mn \quad \ldots (5)$$

The average brightness of the luminance image can be calculated by, applications like edge detection, image enhancement, classification and segmentation. The dilation $D_G(f, s)$of a SEM image $f(x, y)$ by a structuring element $s(u, v)$ makes image becomes lighter and dark details are reduced. The erosion $E_G(f, s)$of $f(x, y)$ by a structuring element $s(u, v)$ makes image becomes darker and light details are reduced. The selection of mask has a key role in achieving desired result and reducing calculation time. The effect of using morphological operations on the luminance image $f(x, y)$ will show effect on the input image.

Based on the above two morphological operations, define a transformation $T_W(f)$ which is used to extract bright features of image by using 3X3 kernel as follows:

$$T_W(f(x, y)) = f(x, y) - D_G(E_G(f, s), s) \quad \ldots (2)$$

Conversely, the transformation $T_B(f)$ is used to extract darker features of an original image as follows:

$$T_B(f(x, y)) = E_G(D_G(f, s), s) - f(x, y) \quad \ldots (3)$$

2.2 Image histogram processing

In a general mathematical sense, a histogram of an image $f(x, y)$with intensity levels in the range $[0, L-1]$ is a function shown in the Eqn. (4) and meets the condition as shown in Eqn. (5).

$$H(k) = \sum_{t \in T} \delta(X_t - k) \quad \ldots (4)$$

$$\sum_{k=0}^{L-1} H(k) = mn \quad \ldots (5)$$

The average brightness of the luminance image can be calculated by,

$$E(H(k)) = \sum_{i=0}^{L-1} i \times \mathrm{p(i)} \quad \ldots (6)$$

where,

$$p(i) = \mathrm{H(i)} \Big/ \sum_{i=0}^{k} \mathrm{H(i)} \quad \ldots (7)$$

Subject to the constraints,

$$\begin{cases} p(i) \geq 0 \\ \sum_{i=0}^{k} p(i) = 1 \end{cases} \quad \ldots (8)$$

The two extreme values are obtained by using histogram of the luminance image, as shown in Eqns. (9) and (10).

$$f^m(x, y) = \mathrm{Arg}\,\underset{k}{\mathrm{Min}}\{kH(k) > 0\} \quad \ldots (9)$$

$$f^M(x, y) = \mathrm{Arg}\,\underset{k}{\mathrm{Max}}\{kH(k) > 0\} \quad \ldots (10)$$

2.3 Exposure threshold

An image intensity exposure is defined as the amount of lighter per unit area and is obtained by Eqn.(11). The normalized range of exposure (E_p) value is 0-1. If E_p is less than 0.5 indicates the underexposed image.

$$E_p = \frac{1}{L}\left[\sum_{k=0}^{L-1} kH(k) \Big/ \sum_{i=0}^{L-1} H(k)\right] \quad \ldots (11)$$

The threshold value T_E related to exposure is defined, which assists the contrast value computation.

$$T_E = L(1 - E_p) \quad \ldots (12)$$

2.4 Computation of Contrast

Contrast is the separation between the darkest and brightest areas of the image. Consider the set based on extreme values from histogram of a luminance image is, $A = \{f^m(x, y), f^M(x, y)\}$. The contrast of a luminance image is calculated by using the following mathematical expression.

$$C(x,y) = \frac{1}{2}\left[\frac{f^M(x,y) - f^m(x,y)}{E(A)}\right] \quad \ldots (13)$$

Where $E(.)$ denotes statistical expected value.

Define parameter by using contrast of an image as,

$$\alpha = (L-1) * C(x,y) \quad \ldots (14)$$

If $\alpha > T_E$ then contrast defined in Eqn. (15) is consider for further processing, otherwise the modified contrast is defined by adding a small positive quantity Δ as shown in Eqn. (16).

$$C(x,y) = \frac{1}{2}\left[\frac{f^M(x,y) - f^m(x,y)}{E(A)}\right] + \Delta \quad \ldots (15)$$

$$\Delta = \frac{9f^m(x,y) - f^M(x,y)}{5f^M(x,y) + 5f^m(x,y)} \quad \ldots (16)$$

2.5 **Enhanced Image**

The scaling criteria $'\beta'$ for SEM image based on contrast, mean brightness and median can be computed by using Eqn. (17) as follows.

$$\begin{cases} \dfrac{(L-1)C(x,y)}{E[H(k)]}, & M[H(k)] - E[H(k)] < 0 \\ \dfrac{(L-1)C(x,y)}{M[H(k)]}, & elsewhere \end{cases} \quad \ldots (17)$$

Where $M[H(k)]$ is the median of histogram of $f(x,y)$.

Therefore, in order to get contrast enhanced SEM image $f^*(x,y)$, each pixel intensity value of $f(x,y)$ is transformed to new intensity value by using the proposed transformation function as shown in in Eqn. (18).

$$\begin{cases} \left[\frac{(L-1)C(x,y)}{E[H(k)]}\right][T_w(f) + f - T_B(f)], \\ \qquad if\ M[H(k)] - E[H(k)] < 0 \\ \left[\frac{(L-1)C(x,y)}{M[H(k)]}\right][T_w(f) + f - T_B(f)], \\ \qquad if\ M[H(k)] - E[H(k)] \geq 0 \end{cases} \quad \ldots (18)$$

3 Results and Discussions

3.1 Evaluation Measures

The measures NDE and EBCM, which are usually employed to assess the image quality [4-7] and the detailed description about these measures discussed in the following subsections.

3.1.1 NDE The entropy of the input image $f(x,y)$ with n-distinct intensity-levels is defined by [4,21],

$$DE[f(x,y)] = \sum_{i=1}^{n} p(x_i)\log\left[\frac{1}{p(x_i)}\right]$$

$$= -\sum_{i=1}^{n} p(x_i)\log p(x_i) \quad \ldots (19)$$

where,

$$\sum_{i=1}^{n} p(x_i) = 1, \quad 0 \leq p(x_i) \leq 1 \quad \ldots (20)$$

In similar way, the discrete entropy for the contrast enhanced image $g(x,y)$ is defined as,

$$DE[g(x,y)] = -\sum_{i=1}^{n} p(y_i)\log p(y_i) \quad \ldots (21)$$

The normalized discrete entropy (NDE) between input image $f(x,y)$ and enhanced image $g(x,y)$ is defined as[19],

$$NDE[f,g] = \frac{1}{1+\tau} \quad \ldots (22)$$

where $\tau = \left[\frac{(\log(256) - DE(g(x,y)))}{(\log(256) - DE(f(x,y)))}\right] \quad \ldots (23)$

Where, $NDE(f,g) \in [0,1]$. For $NDE(f,g) > 0.5$, the enhanced image has higher DE than that of the original image, and vice versa.

3.1.2 EBCM

In general, the original image has less edge pixels than the contrast enhanced image [6]. The mean edge intensity level denoted by $e(x,y)$ and can be calculated by Eqn. (24).

$$\sum_{(z,w)\in\Psi} h(z,w)f(z,w) \Big/ \sum_{(z,w)\in\Psi} h(z,w) \quad \ldots (24)$$

Where $\Psi(x,y)$ is the set of all neighboring pixels and $h(z,w)$ is the edge value. Thus, by using Eqn. (25), the contrast of $f(x,y)$ is defined.

$$C(x,y) = \frac{|f-e|}{|f+e|} \quad \ldots (25)$$

Hence EBCM for original image $f(x,y)$ is $EBCM[f(x,y)]$ as shown in equation (26).

$$\sum_{x=1}^{m}\sum_{y=1}^{n} C(x,y) \Big/ \sum_{k=0}^{L-1} H(k) = \frac{1}{mn}\sum_{x=1}^{m}\sum_{y=1}^{n} C(x,y) \quad \dots (26)$$

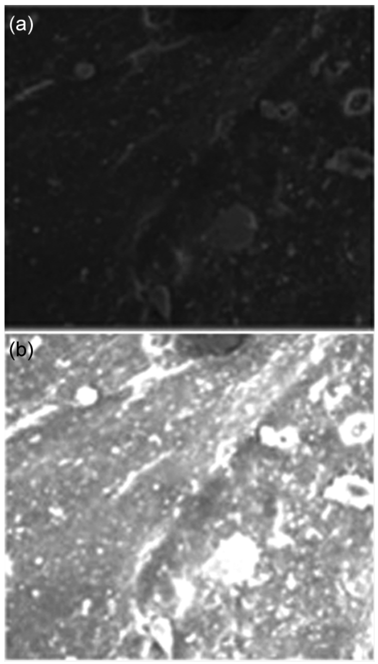

Fig. 2 — Enhancement results of SEM images: (a) low contrast image, and (b) contrast enhanced image.

The contrast improved image should satisfy the constraint as shown in Eqn. (27).

$$EBCM[g(x,y)] > EBCM[f(x,y)] \quad \dots (27)$$

3.2 Comparison

The proposed preprocessing technique contrast enhancement of low contrast SEM images are shown in Fig. 2. Besides, the proposed technique will be compared with some other our implementation methods: HE and CLAHE [9,20] . The proposed technique enhanced SEM images along with HE, CLAHE techniques applied to the original images for better contrast results are shown in Fig. 3 and the proposed yields the good contrast enhancement when compared to these methods. The histograms of original, HE, CLAHE and proposed methods are clearly indicates the contrast enhancement better with the proposed one and hence, the proposed histogram reveals the better enhancement when compared to the other methods. which reveals the better enhancement when compared to other existing methods. Table 1 reveals that the NDE[19,21] value is best for the proposed method and for all images which more than 0.5 indicates that the entropy closer to original image. The EBCM values shown in Table 2 show that the contrast image by the proposed method has higher values than the original image, showing that this

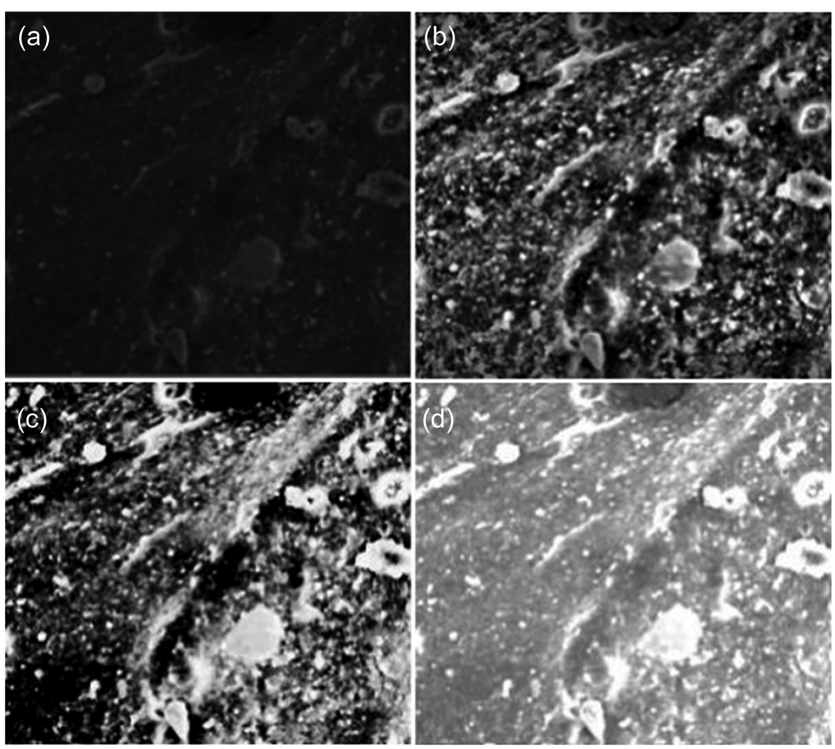

Fig. 3 — Enhancement results of SEM low contrast images of polymer samples: (a) Original, (b) HE, (c) CLAHE, and (d) Proposed.

Table 1 — Quantitative measurement results as NDE.

Image No.	HE	CLAHE	Proposed
1	0.2021	0.3432	0.5155
2	0.3982	0.2786	0.6212 0.5271
3	0.3788	0.5102	0.6132 0.5763
4	0.4732	0.2108	
5		0.2310	

Table 2 — EBCM results.

Image No.	Original	HE	CLAHE	Proposed
1	230.41	169.92	234.41	239.71
2	159.35	136.78	127.22	171.43
3	146.34	124.17	116.29	162.85
4	156.46	127.26	127.43	184.78
5	229.27	217.40	176.211	239.57

method ensures good enhancement of an SEM images.

4 Conclusion

In this paper, a preprocessing contrast enhancement technique to enhance the low contrast SEM images has been presented based on mathematical morphology and contrast via exposure thresholding. One more advantage of the proposed technique is that no parameters need to be tuned. A detailed comparative analysis with other existing enhancement techniques such as HE and CLAHE has been performed to prove the superior performance of the proposed technique. The NDE and EBCM (shown in Table 1 and Table 2) indicate the accuracy of the proposed technique. The proposed method is useful for Preprocessing Technique for estimation of filler content during SEM image analysis. In future we plan to use the concept of deep learning-based feature extraction for segmentation of SEM images using the proposed contrast enhanced SEM images for accurate filter content estimation.

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