Texture and morphology based conductivity analysis of fuel cell - bipolar plate using scanning electron microscopic images

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The main objective of this work is to analyze strength and conductivity of the fuel cell bipolar plate using microstructural analysis. This paper focuses on the structural characterization of fuel cell by texture and morphological analysis of its composite bipolar plate which is the major component of the proton exchange membrane (PEM) fuel cell stack. The composite plates were prepared with compression molding technique using activated charcoals and epoxy (araldite) at various temperatures ranging between 170°C and 190°C with the pressure of 20 bar. Texture and morphological structures of a composite are directly related with the strength and conductivity of the material. The internal structures of the composite bipolar plate are acquired using scanning electron microscope (SEM) which provides microstructural information of the specimen. In this paper, nature of bonding in SEM image is detected using texture and morphological features. Texture features derived from Gray level co-occurrence matrix (GLCM) and Tamura is used to characterize the arrangement of molecules and nature of bonding, Gray level co-occurrence matrix (GLCM) and Tamura based approach is used to calculate texture features. These textural features analyze the internal textures of each samples prepared. Morphological operations are used to find the area covered by each discontinuous region where the discontinuity affects the bonding and thus the strength and conduction. The image processing approach analyses the internal structure of the prepared samples and validates its flexural strength and electrical conductivity performed experimentally. The sample prepared at 190°C and pressure 20 bar has met the target value defined by the US, Department of Energy (DOE) and has homogeneous internal structure with less discontinuities and better bonding among the prepared samples.

Keywords: Bipolar plate, Fuel cell, Scanning electron microscope, Gray level co-occurrence matrix, Morphological analysis, Texture analysis

The composite bipolar plate is a multifunctional component within the proton exchange membrane fuel cell (PEMFC) which conducts electric current from the anode of one cell to the cathode of next cell and these plates should possess functional properties like mechanical strength, electrical conductivity, and thermal conductivity¹,². These properties directly depend on its internal structure. Preparation and analysis of composite bipolar plate plays an important role in determining the conductivity of the fuel cell¹,².

Over decades literatures have documented preparation of bipolar plate using different materials and processes. Antunes et al.³ states that there is a strong relationship between the material used in the manufacturing of bipolar plate and its final properties moreover structural characteristics such as morphology and size have decisive influence on its properties.³ Artyushkova et al.⁴ suggested textural features, based on GLCM, provide measures of homogeneity, randomness or directionality; inclusion of morphological characteristics, such as roughness, texture and shape parameters provide for more inclusive description and therefore more complete structure-to-property correlations of corrosion behavior of carbon blacks.⁴ Newbury and Titchie⁵ proposed that the combination of SEM imaging with EDS X-ray microanalysis has given the materials community one of its most powerful microstructural characterization tool. Kundu et al.⁶ categorized scheme of causes, modes and effect related to fuel cell degradation and failure. In their work a number of defects like cracks, surface roughness, orientation, delamination have been observed and mechanism have been proposed by which these features can lead to catalyst-coated membrane degradation. Hermann et al.¹ reviewed various types of materials and proposed for bipolar plates and critically evaluated their physical and chemical properties. Williams et al.⁷ in their work the interfacial area between the B₄C and SiC has been quantified and they showed the effect on both densification and the resultant microstructure of the composite. Harris et al.⁸ considers the

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microstructural characterisation of composite materials with relatively uniform feature size and randomly distributed particles of various phases. Kim et al.\(^2\) evaluated the electrical resistance of hybrid composite plate in which top and bottom layers were made up of carbon fiber with a graphite liner inside and used matrix as phenolic resin to adhesively bond both fibers and graphite. Sulong et al.\(^10\) used carbon nano-tubes along with metal fillers and found that mechanical properties were enhanced with increased concentration of polypropylene matrix; hardness increases with decreased concentration of polypolyethylene matrix; electrical properties also increases with decreased concentration of polypropylene matrix. Adroja et al.\(^11\) evaluated the mechanical and electrical properties of sandwich bicomposites epoxy resin. Nedelcu et al.\(^12\) studied microstructure and material properties of injection molded Arboform parts using Taguchi methodology with two levels and six input parameters. Du et al.\(^13\) focused on the influences of the microstructure on the physical properties of the thin epoxy/CEG composites (the thickness is 1 mm) and the optimum preparation conditions are obtained. It is demonstrated that the mechanical property and the impermeability of the composites increases evidently with the resin content changing from 4% to 30%. Considering the DOE targets of the bipolar plates, the epoxy (30%)/EG composite bipolar plate was considered to be the most suitable candidate for PEMFCs. Hui et al.\(^14\) TGA result shows that the novolac epoxy/NG composite has excellent thermal stability and the optimum processing conditions for preparing composite bipolar plate are resin content about 15% by weight; molding pressure 200 MPa; curing temperature 180°C. Lee et al.\(^15\) proposed that the bipolar plate for automotive fuel cells was developed with carbon fiber composite by compression moulding due to the fact that carbon/epoxy composite has not only high electrical and thermal conductivities, but also high specific stiffness and strength also it states that high-modulus pitch based carbon fiber reinforced polymer composite is a very promising material compared with conventional materials. Hwang et al.\(^16\) established a woven carbon fabric coated with graphite liner using an epoxy resin as matrix medium here graphite composites were fabricated by compression moulding. To achieve desired electric properties, specimens made with different mixing ratio, processing pressure and temperature were tested. Sever et al.\(^17\) analysed electrical and mechanical properties of high density polyethylene and transmission electron microscopy was used to observe the morphology of the nano-composite. Kakati et al.\(^18\) prepared bipolar plate using compression molding technique and evaluated electrical conductivity, flexural strength.

Several types of materials are used for the bipolar plates, e.g., metal plates, polymer-coated metal plates, graphite, carbon–carbon composites and graphite–polymer composites\(^19-21\). The attractive properties of graphite bipolar plate include excellent corrosion resistance, high electrical conductivity, and low bulk resistivity\(^2\). However, difficulties to machine flow fields, low mechanical strength, and brittleness limit the competency of graphite bipolar plate. Due to the brittleness of graphite, the bipolar plate needs to have several mm thicknesses, which make the fuel cell stack voluminous and bulky. Therefore, researchers are giving more attention towards the development of composite bipolar plate. Metal is another competent material for a bipolar plate, however, it is unable to resist corrosion in fuel cells\(^14\). As a candidate to fulfill those requirements for fuel cell bipolar plate, carbon composite has been developed extensively and reported to be corrosion resistive\(^14\) with good performance in electrical conduction and mechanical strength\(^18\).

Even though many methods are available to prepare composite bipolar plates, these methods are deficient in analyzing the internal structure of the plate to check its electrical and mechanical properties. However various non-destructive testing methods like visual, radiography, acoustic emission, ultrasonic inspection are available; SEM image processing is a suitable solution for this analysis. Vision based analysis has been a fundamental open problem, with industrial applications, such as automation and production of quality products but those methods mainly focused on the surface characteristics and it fails to analyze the internal characteristics of the materials. Here SEM image plays a vital role in analyzing the internal characteristics which can provide resolution better than 1 nm, so that it can provide the spatial variations even in microstructures. The spatial variations are analyzed morphologically to find the nature of bonding, which is directly related to the electrical and mechanical properties of the bipolar plate.

**Methodology for Structural Characterization**

Figure 1 shows the proposed methodology for structural characterization of composite bipolar plate.
In this work, activated charcoal with epoxy (araldite) is prepared using the compression moulding process with respect to various temperatures at constant pressure. Flexural test are carried out to examine the bending strength of the specimen (composite bipolar plate). Four point conductivity test is applied to obtain its highest electrical conductivity. The microstructural image of the specimen is obtained from SEM and it is subjected to texture and morphological analysis. Image interpretation is done based on the estimated texture indices and morphological features to infer its internal structural characterization.

**Structural characterization**

Characterization of a material’s internal structure is fundamentally significant to examine its property for scientific understanding of the material. Internal morphology is one of the most important factors affecting the property of the material, thus the functional performance of the bipolar plate composite. The main reason for good mechanical and electrical properties of the composites were the good dispersion and strong interface adhesion of carbon-epoxy over the entire polymer matrix. These factors vary with different temperature, pressure and processing conditions. This work mainly concentrates on the characterization of internal structures with respect to change in temperature. This characterization of materials is predominantly done by means of non-destructive testing (NDT) methods for its accurate and reliable internal information. The internal structure can be interpreted by its textural and morphological characteristics.

**Preparation of composite bipolar plate**

Activated charcoal and epoxy (araldite GY257) are used in this experiment, since the carbon-polymer composite which is commercially available has a good resistance towards corrosion, with less weight yielding sensible electrical conductivity and mechanical strength at nominal cost. Table 1 shows the properties of activated charcoal and Table 2 shows the properties of epoxy resin. Here the composite is prepared using the compression molding technique where content of resin is 30 wt%. Aradur 3986 curing agent is used; activated charcoal was dried at 75°C in vacuum oven for 10 h to remove the moisture content. Pre-heating of the resin was done in an oven for half an hour at 60°C. Epoxy resin and activated charcoal were mixed in a kneader for 2 h for uniformity. The mixtures were introduced in an oven at 100°C before

<table>
<thead>
<tr>
<th>Table 1 — Properties of activated charcoal</th>
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</thead>
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<tr>
<td><strong>Tensile strength</strong> (MPa)</td>
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<tr>
<td>3445</td>
</tr>
</tbody>
</table>

| **Service temperature** | Up to 190°C |
| **Tensile strength** | 85 Nmm$^{-2}$ |
| **Tensile modulus** | 10500 Nmm$^{-2}$ |
| **Elongation at break** | 0.8 |
| **Flexural strength** | 112 Nmm$^{-2}$ |
| **Flexural modulus** | 10000 Nmm$^{-2}$ |
| **Compressive strength** | 90 Nmm$^{-2}$ |
| **Chemical structure** |

![Activated charcoal and epoxy (araldite GY257) properties](image)
pressing process to reduce porosity. The mixtures (molds) were kept for 8 h in the compression moulding machine at three different temperatures (170°C, 180°C and 190°C) with constant pressure (20 bar). Finally, the specimen (100 × 100 × 3 mm) is post heated in an oven for 2 h. Figure 2 shows the fabricated specimen at various temperatures.

**Acquisition of SEM image**

NDT methods that are widely used in characterizing micro-structures are X-ray diffraction, electron microscopy (EM) including scanning electron microscopy (SEM) and transmission electron microscopy (TEM), and scanning probe microscopy (SPM). Among these SEM owes its popularity for the visualization of surfaces, to the diversity of types of information that it can produce, and to the fact that images and analytical information can readily be combined.

The SEM was performed on Hitachi, Japan model S-3000H instrument. The images were acquired at a resolution about 3.5 nm in size with magnifications (× 1000) having specimen size (max. 150 mm diameter) and accelerating voltage (15 kV).

**Texture analysis of SEM image**

Generally, electrical and mechanical properties of the composites depends on its bonding structure; highly bonded structures will have excellent properties. The textural characteristics examines the internal bonding nature. Highly bonded structure can be identified by smooth textures with uniform gray level distribution or correlated pixels. These uniform pixels will occur only if there is no interruption in its structure. The interruptions or discontinuities in its uniform structure may occur due to voids, pores and cracks. SEM image provides internal structure of composite material which can be characterized by extracting meaningful features like porosity, solidity and textural descriptors from Haralick and Tamura.

The extracted texture features are given in Table 3. From the set of available features the most compatible texture features are selected by trial and error method based on their usability in our application. The scope of the selected features is to define the discontinuities like voids, pores and cracks. In this regard the following texture features are found to be appropriate.

<table>
<thead>
<tr>
<th>Features</th>
<th>GLCM</th>
<th>Energy</th>
<th>GLCM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GLCM</td>
<td>$\sum \sum p(i, j)^2$</td>
<td>$\sum \sum (i-j)^2 p(i, j)$</td>
</tr>
<tr>
<td></td>
<td>Homogeneity</td>
<td>$\sum \sum \frac{1}{1+(i-j)^2} p(i, j)$</td>
<td>$\sum \sum \frac{1}{1+(i-j)^2} p(i, j)$</td>
</tr>
<tr>
<td>Tamura Coarsness</td>
<td>$f_{crs} = \frac{2^k}{n^2} \sum_i^n \sum_j^n p(i, j)$</td>
<td>$f_{con} = \frac{\sigma}{(\mu / \sigma^4)^{1/4}}$</td>
<td>$f_{rg} = f_{crs} + f_{con}$</td>
</tr>
<tr>
<td>Compactness</td>
<td>$4\pi \frac{area}{perimeter}^2$</td>
<td>$Pore volume / bulk volume$</td>
<td>$Pore volume / bulk volume$</td>
</tr>
</tbody>
</table>

The extracted texture features are given in Table 3. From the set of available features the most compatible texture features are selected by trial and error method based on their usability in our application. The scope of the selected features is to define the discontinuities like voids, pores and cracks. In this regard the following texture features are found to be appropriate.

The GLCM, proposed by Haralick is a tabulation of how often different combinations of pixel intensity
values (gray levels) occur in an image with fourteen textural features among which energy, correlation and homogeneity remains meaningful descriptors for analysing the bonding nature. Energy, a statistical measure also called as uniformity, measures the textural uniformity that is pixel pair repetitions. It detects disorders in textures. High energy values occur when the gray level distribution has a constant or periodic form. The sample with small number of pores and voids will have higher energy value. Correlation measures linear dependency of grey levels of neighboring pixels, with values of 0 for uncorrelated and 1 for perfectly correlated pixels. Homogeneity is a measure of self-similarity, i.e., measure of probability that pixels of each region have the same values. Uniform structures without voids, pores or cracks tend to have higher homogeneity.

Tamura features provides a prominent solution for human perception of textures at micro-structural level. Features like coarseness, contrast and roughness have high potential to distinguish different textures. Coarseness ($F_{crs}$) relates to distances of notable spatial variations of grey levels, that is, implicitly, to the size of the primitive elements (texels) forming the texture. Contrast ($F_{con}$) measures the way in which gray levels vary in the image and to what extent their distribution is biased to black or white. It calculates the local variations present in the gray level image. High contrast values are expected for heavy textures and low for smooth, soft textures; uniform bonding results in smooth textures. Roughness ($F_{rgb}$) feature is given by simply summing the coarseness and contrast measures: $F_{rgb}=F_{crs}+F_{con}$. Highly bonded structures will have lower coarseness, contrast, roughness.

Compactness is a characteristics quantity by calculating image or region’s area and perimeter, it expresses the complex degree of shape. Using this parameter the object can be extracted from the background, which can be extended to extract the discontinuities, pores or voids. Higher the bonding, higher the compactness. Porosity describes voids present in a stricture. The voids between the particles were occupied by the furnace atmosphere. The vacuum created during combustion pushes the air out of the carbon-epoxy particles which results in pores. The porosity should be minimum for better conductivity and strength.

Morphological analysis of SEM images

SEM image helps in characterizing physical properties such as morphology, shape, size and distribution of materials at the micro scale level. This approach is based upon logical relations between pixels, rather than arithmetic relations, and can extract geometric features by choosing the suitable structuring shape as a probe. In industrial vision applications, morphology can be used to implement fast object recognition, image enhancement, segmentation, and defect inspection.

Morphological analysis remains a predominant technique for determining discontinuous region and the area covered by it. The specimen is said to be homogeneous only if there is less number of discontinuities; where these discontinuities occur mainly due to improper bonding, voids and pores due to the release of large amount of gases during combustion process. To determine the discontinuity; the morphological operation is done using a disk shaped structuring element ($f_{SE}$) with radius $R$ represented by Eq. (1). Let $x=0; y=0$; be the position of the centre pixel of the structuring element with radius $r=R$ where $i$ and $j$ the rows and columns, respectively.

$$N = [(x-i)^2 + (y-j)^2] \quad \forall -r \leq i \leq r; \quad \forall -r \leq j \leq r$$

$$f_{SE} = \begin{cases} 1 & \text{if} \quad 0 < N \leq r^2 \\ 0 & \text{else} \end{cases} \quad \ldots (1)$$

Reconstruction-based opening and closing are more effective in estimating foreground markers (discontinuities). Morphological opening-by-reconstruction ($I_{obr}$) is an erosion ($f_{ero}$) followed by a morphological reconstruction ($f_{mor-rec}$) given by Eq. (2)

$$I_{obr} = f_{mor-rec}(I_{Erode}, f_{SE}) \quad \ldots (2)$$

Morphological erosion is given by Eq. (4)

$$I_{Erode} = f_{ero}(image, f_{SE})$$

Let $C$ be the convolution sum of $f_{ero}$

$$C = \sum_{i,j} (f_{SE} \cdot I) \quad \ldots (3)$$

$$I_{Erode} = \begin{cases} 1 & \text{if} \quad C = \sum f_{SE} \\ 0 & \text{else} \end{cases} \quad \ldots (4)$$

Reconstruction is a morphological transformation involving two images and a structuring element. The
reconstruction of $I$ from $I_{ero}$, is denoted by $f_{mor-rec}$, is defined by the following iterative procedure:

(i) Initialize $h_i$ to be the marker image, $I_{ero}$.

(ii) Create the structuring element $f_{SE}$ using Eq. (1)

(iii) Repeat:

$$h_{k+1} = f_{dil}(h_k, f_{SE}) \cap I$$

until $h_{k+1} = h_k$

(iv) $f_{mor-rec} = h_{k+1}$

where

$$I_{dilate} = f_{dil}(image, f_{SE})$$

where $C$ is the convolution sum of $f_{dil}$ derived from Eq. (3). Erosion retains significant discontinuities and the subsequent reconstruction restores its original shape. Accuracy of this restoration depends on the similarity between its shape and that of the structuring element, hence choosing the shape of the structuring element plays a vital role. Discontinuities are generally irregular and has no definite shape hence disk shaped structuring element remains an optimum solution for determining them.

The extracted discontinuities are then numbered and the corresponding areas occupied by them are determined. If the area covered by the discontinuities is less, then the sample possess excellent electrical and mechanical properties.

**Results and Discussion**

Carbons with 30% epoxy were thermo gravimetrically analyzed (TGA) to find the degradation characteristics. The composite produces a gradual weight loss region as shown in Fig. 3. The weight loss is fairly constant between 0-170°C and the initial weight loss occurs at 170°C due to evaporation of small amount of moisture content and there is drastic reduction in weight after 204°C. From the figure it is evident that there is no degradation occurs at the working temperature of the fuel cells (70°C-100°C).

During combustion sintering of carbon-epoxy particles occur at their point of contact. The sintered carbon-epoxy particles try to flow and fill up the pores and void spaces. It might be persumed that number of discontinuities, pores and voids in the sample were due to incomplete sintering of the particles and inability of them to flow and fill up the air spaces completely.

**Flexural strength and electrical conductivity**

Table 4 shows the values of electrical conductivity and flexural strength at various temperatures at 20 bar pressure. From Table 4, it is seen that electrical conductivity and flexural strength increases as the temperature increases. The conductivity and flexural strength is maximum at 190°C having value of 107 S/cm and 44 MPa, respectively. The above result also satisfies the technical target value defined by the United States of America Department of Energy (DOE) which is >100 S/cm and >25 MPa for electrical conductivity and flexural strength respectively.

Figure 4 shows the SEM micrograph results for the samples at (×1000) magnification. SEM images for the original samples were acquired and are represented as sample1, sample2, sample3 for the temperatures 170°C, 180°C and 190°C, respectively. These images were further subjected to texture and morphological analysis.

**Texture analysis**

Table 5 shows the extracted GLCM and Tamura features for the SEM image of each sample. The energy value is higher for sample 3 which shows that carbon-epoxy composite is uniformly distributed compared to the other samples. For bonding of materials to be uniform the contrast feature should be low while homogeneity should be high. Comparatively sample 3 gives better values for both the features, proving to exhibit good properties. The minimal value for Tamura features like coarseness, contrast and roughness of sample 3 shows that it has less notable spatial variations than the other samples, which is evident for uniformity in its structure. This uniform distribution in structure yields uniform bonding thus leads to fewer discontinuities; hence conductivity and flexural strength of sample 3 are comparatively better.

Sintering between carbon and epoxy particles plays a prominent role in deciding the bonding strength, and hence it’s electrical and mechanical characteristics. Values of compactness and porosity for sample 3 are found to be minimum than the other samples.
At temperature 190°C, the sintering process was efficient for the particles to flow and fill up the pores and voids than at the lower temperatures. From these results it is prominent that the nature of bonding is superior for sample 3 (190°C).

**Morphological analysis**

Figures 5 and 6 show the results of morphological analysis. Reconstruction-based opening and closing are more effective than standard opening and closing at removing small blemishes without affecting the overall shapes of the objects. Regional maxima are connected components of pixels with a constant intensity value (discontinuities, voids, pores, etc.), and whose external boundary pixels (non-defected areas) all have a lower value. The regional maxima of opening-closing by reconstruction are estimated to obtain good foreground markers (discontinuities) and these discontinuities are numerated and the area of discontinuities for each sample is calculated. Regional-maxima for samples 1 and 2 gives more number of defects/discontinuities and hence results in low flexural strength and conductivity with respect to sample 3.

**Calculating area of discontinuities**

Figure 7 shows the discontinuity regions of SEM image for sample 3, here the regions are numerated and their respective area is estimated and given in Table 6. The total number of discontinuities in sample 3 is 14 and the area is $5.4531\text{e}+06$ $\mu$m² similarly the discontinuities for sample 2 is 39 and sample 1 is 57 and their respective areas are $1.3320\text{e}+07$ $\mu$m² and $9.8535\text{e}+06$ $\mu$m², respectively. Which shows that number of discontinuity regions and its area in sample 3 is much lesser when compared to other samples.

<table>
<thead>
<tr>
<th>Pressure (MPa)</th>
<th>Temperature (°C)</th>
<th>Flexural strength (MPa)</th>
<th>Electrical conductivity (Scm⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>170</td>
<td>32</td>
<td>94</td>
<td></td>
</tr>
<tr>
<td>180</td>
<td>39</td>
<td>105</td>
<td></td>
</tr>
<tr>
<td>190</td>
<td>44</td>
<td>107</td>
<td></td>
</tr>
</tbody>
</table>

**Table 5 — Results for texture analysis**

<table>
<thead>
<tr>
<th>Texture features</th>
<th>Sample 1 170°C</th>
<th>Sample 2 180°C</th>
<th>Sample 3 190°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>GLCM output</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy</td>
<td>0.7905</td>
<td>0.8303</td>
<td>0.9083</td>
</tr>
<tr>
<td>Contrast</td>
<td>0.0413</td>
<td>0.0293</td>
<td>0.0179</td>
</tr>
<tr>
<td>Correlation</td>
<td>0.7573</td>
<td>0.7926</td>
<td>0.7579</td>
</tr>
<tr>
<td>Homogeneity</td>
<td>0.9794</td>
<td>0.9853</td>
<td>0.9910</td>
</tr>
<tr>
<td>Tamura output</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarsness</td>
<td>0.2476</td>
<td>0.2159</td>
<td>0.1884</td>
</tr>
<tr>
<td>Contrast</td>
<td>1.1182</td>
<td>0.4206</td>
<td>0.2157</td>
</tr>
<tr>
<td>Roughness</td>
<td>1.3658</td>
<td>0.6365</td>
<td>0.4042</td>
</tr>
<tr>
<td>Compactness</td>
<td>0.6298</td>
<td>0.4669</td>
<td>0.4375</td>
</tr>
<tr>
<td>Porosity</td>
<td>14.1298</td>
<td>19.9524</td>
<td>10.0823</td>
</tr>
</tbody>
</table>
Otsu method is used to automatically perform clustering-based image thresholding. The algorithm assumes that the image possesses bi-modal histogram with foreground pixels and background pixels. In other words, it divides the histogram plot based on the threshold value into high and low bonded regions. This method goes over all the probable threshold values (ranges between 0 and 255) and then determines the pixels and measures the spread of pixel levels on either side of the threshold value. For each probable threshold value the sum of the two variances multiplied by their corresponding weights (occurrence of gray levels) is determined. The threshold value with minimum intra class variance is selected. For the sample with ample high bonding variance is selected. For the sample with ample high bonding region the threshold value will be greater increasing the background which is the defect free regions.
Histogram of Otsu thresholding technique is applied to all the samples and the plot is given in Fig. 8. The threshold values are estimated to be 63, 96 and 111 for the samples respectively. Sample 3 (Temp. 190°C and Pr. 20 bar) has higher threshold thus highly bonded region is more when compared to sample 1 and sample 2.

Conclusions

In this work, the internal structures of composite bipolar plate are characterized by SEM image Analysis and its results are validated mechanically and electrically. The composite plates are prepared at 170°C, 180°C and 190°C temperatures at pressure 20 bar. The experimental result shows that the maximum electrical conductivity 107 S/cm obtained at 190°C, with flexural strength of 44 MPa. The SEM image is obtained for each sample, to analyse its internal structure by texture and morphology. The internal structure is characterized by features like porosity, solidity and textural descriptors from Haralick and Tamura. Morphological analysis is applied to determine the discontinuous regions and the area covered by it. The image processing based analysis shows that the internal structure is more homogenous with fewer discontinuities for the sample prepared at 190°C temperature, and hence it has better conductivity and flexural strength which validates the experiments conducted mechanically and electrically. This work can be an optimal solution for applications that analyzes relational conductivity and mechanical strength.

Acknowledgement

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References