ANALYSIS AND CHARACTERIZATION OF DENDRITE STRUCTURES FROM MICROSTRUCTURE IMAGES OF MATERIAL

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Abstract

Digital Image processing (DIP) and Computer vision (CV) techniques have great support role in material manufacturing by providing precise insight of materials. The morphology of constituents in metal alloys basically depends on the process of solidification. The solidification method (air, oil or water) and time are the reasons for definite morphology of constituents. Dendrite structures are one of the, such morphological structures and many important properties of materials are closely related to the morphology of the dendrite. The information about solidification process of materials is a must-know information in the process of production of materials which can be extracted through characterization of dendrite structures. In this paper, an automated and robust method that comprises of image processing, computer vision and serial sectioning techniques as a means of 3D characterization of the solidified microstructures of magnesium-based alloys is presented. The phase fraction and morphologies of intermetallics of magnesium –aluminium alloy material are determined. The results obtained by proposed method are compared with the manual computations based on the Scheil–Gulliver solidification model [12,13] for the authenticity of proposed method. The comparison of results indicates that the results of the proposed method are much accurate compared to other methods. Therefore, the proposed method will enable a comprehensive understanding of solidification variables, microstructure, and properties.

Keywords: *Dendrite, three-dimensional analysis, serial sectioning, Scheil–Gulliver solidification model.*

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1. INTRODUCTION

The applications of digital image processing and computer vision techniques have not only secured place in material science field but also have become almost the sole alternatives to manual method of characterizing the materials [5,7,8,9]. The ever demanding investigation challenges of materials have made image processing and computer vision techniques good tools. These two techniques are fulfilling most of the requirements of material characterizing processes. In characterizing the material using microstructure images of materials, dendritic structures that are observed in microstructure images pose difficult challenges in characterization process [5,14]. These dendritic structures in microstructures are observed in a wide range of solidification processes, and play a vital role in determining the properties of the material.

1.1 Serial Sectioning and Image Acquisition

As discussed in [1,2,3,4,10], the sample is cut from the top and polished by following serial sectioning technique (Fig. 1). In the proposed system, a square region of interest is selected from the sample by indenting four equally spaced marks as shown in Fig. 4, called fields. Using this subjective criterion, the size of the microstructural region of interest was taken as approximately 250 X 250 µm, depth is of approximately 160 µm and the size of each field is 50x50 µm. The thickness of each slice is of 1.0 µm. Then, the exposed surface is polished using silicon carbide abrasives. The microstructure image of 400x300 pixels is acquired from each of the five different fields of surface using light optical microscope. The process is repeated to get 60 images from each field from top to bottom. A total of 300 microstructure sectional images are acquired.

Fig.1. Metallography: (a) Serial sectioning machine, (b) Microscope fitted with digital camera-interfaced with computer, (c) Serial sectioned material mounted on microscope and (d) Stack of Serial section images of material.

1.2 Dendrite Morphology

Dendrites are geometrically complex structures that are found in material. Dendrites are tree-like structures (Fig. 2) formed due to a morphological instability of the solid–liquid or solid–vapor interface and generally are in a connected solid network in whole region that is undergoing a phase transformation [5,14]. The characterization of the morphology of the dendritic structure is of high importance as dendrites constitute the primary growth morphology during the early stages of solidification processes. Many important properties of materials are closely related to the morphology of the dendrite. In nearly all systems dendrites begin coarsening immediately upon formation. During the coarsening process, the average length scale of the system increases and the dendrite shape evolves resulting in a microstructure determined largely by the coarsening process.

Although the importance of characterizing and understanding the processes that shape the morphology of dendrites is clear, experiments as well as simulations aimed at measuring or predicting the morphology have proven to be challenging. A limited number of studies have focused on the evolution of solidification patterns and their impact on manufactured material. The literature survey reveals that, till today, only a few studies on dendritic microstructures in magnesium alloys have been carried out [14]. A significant fraction of commercial magnesium-alluminium (Mg-Al) alloys exhibit a mixture of primary α-Mg dendrites surrounded by a eutectic network eutectic with Mg–Al intermetallic precipitates. Thus, understanding and quantifying the dendritic microstructural features of Mg alloys (in binary) and other multi-component systems have practical importance. A fundamental knowledge of the microstructures of materials in three dimensions (3D) is necessary to accurately model the evolution and formation of their microstructures [8]. Therefore, the objective of this paper is to present a 3D analysis method to investigate the dendrite morphologies and determine phase fraction of microstructures of Mg–Al alloy. The Serial sectioning technique is used to acquire series of microstructure images of material for analysis.

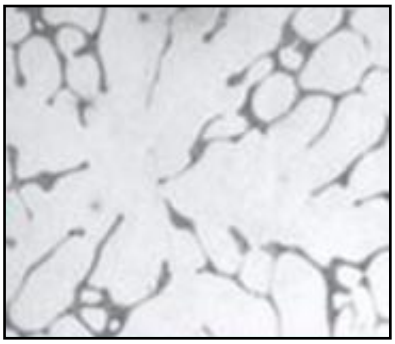

Fig.2. Dendrite structures in microstructure image

1.3 Scheil–Gulliver Solidification Model

Scheil-Gulliver solidification model is a widely used manual method for computing the volume fraction of a particular phase. The volume fraction of the beta phase can be computed using the Eq. 1 [12,13].

$$C_S = kC_0(1 - f_S)^{k-1} \quad (1)$$

where C_S is the solid composition at the given temperature, C_0 is the alloy composition, k is the solute partition coefficient in terms of the equilibrium phase diagram and f_S is the mass fraction of the solid phase. In this paper, this method is used for comparing the authenticity of results obtained by proposed method.

2. MATERIALS USED

In our experimentation, Mg–9 wt.% Al alloys cast specimens were used in experimentation. The alloy prepared is water cooled. Then the material is serial sectioned. After every section, the fresh surface was etched slightly with 3% nitric acid in ethanol to give good contrast in image acquisition.

3. PROPOSED METHOD

In Fig.3, the frame work of the proposed system is presented.

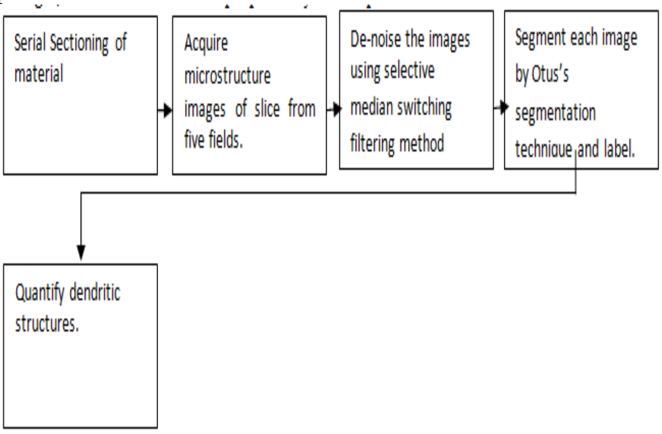

Fig.3. Framework for the work

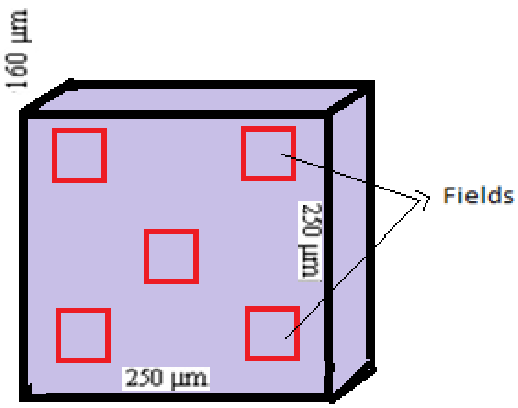

Fig.4. The 5 distinct fields on surface of the material sample marked for acquiring microstructure images using light optical microscope

3.1 Image Preprocessing

In order to perform measurements on the image, the image needs to be pre-processed. The speckles found in the image background could lead to deviations in measurement values. It is therefore recommended to filter the images to prepare for further processing. The noise in the image is suppressed by applying Selective Switching Median Filter (SSMF) [6]. The SSMF filters the image without losing the edge information. Then the filtered image is segmented by applying Otsu's thresholding [11] to extract targets from its background on the basis of the distribution of gray levels or texture in image objects. Otsu's method is a 1-D thresholding method with a nonparametric approach. It finds the threshold automatically that minimizes the weighted within-class variance. i.e. maximize the between-class variance. Otsu's thresholding method works directly on the gray level histogram. Fig.5 shows the resultant image after preprocessing. The outcome of the pre-processing is a binary image that is free from unwanted information. The quantitative image analysis [7] is performed on this binarized image (Fig. 5).

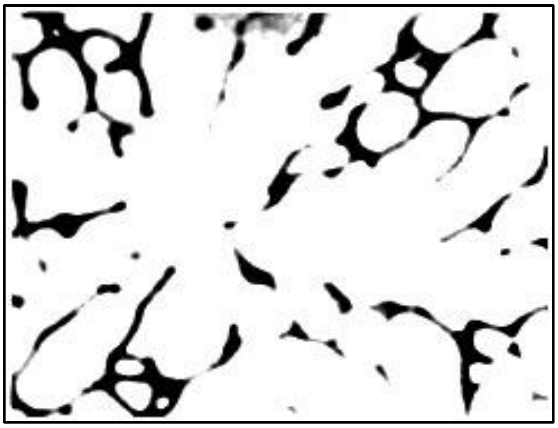

Fig.5: The resultant image after applying filtering by selective median switching filter and Otsu's segmentation methods on microstructure image shown in Fig. 1.

The following Algorithm 1 is developed for the purpose of 3-dementional analysis of microstructure images to determine quantitative information.

Algorithm 1:

Step 1: Slice and polish the specimen from top of material.
Step 2: Acquire the microstructure image (RGB) of polished surface.
Step 3: Input the RGB microstructure image of polished top slice and convert it into
grayscale image.
Step 5: Apply 'selective median switching filter' method to filter the image [6].
Step 6. Segment the image by applying Otsu's segmentation method [11].
Step 7: Determine the volume fraction of dendrite structures using Eq. 1.
Step 8: Repeat Step 1 to Step 7 for each slices from top to a required depth.
Step 9: Determine the volume fraction of dendrite structure by using relation [5,9],

$$V\% = \frac{\sum_{s=1}^{n} \ Area\ of\ dendrite\ structures}{\sum_{s=1}^{n} area\ of\ image} x100$$

where, s is slice number and n is number of slices.

4. RESULTS AND DISCUSSION

By imaging the serial sectioned and polished portions of material, a group of dendritic with clearly formed secondary and tertiary arms and inter-dendritic eutectic structure is observed under light optical microscope as shown in Fig. 4.

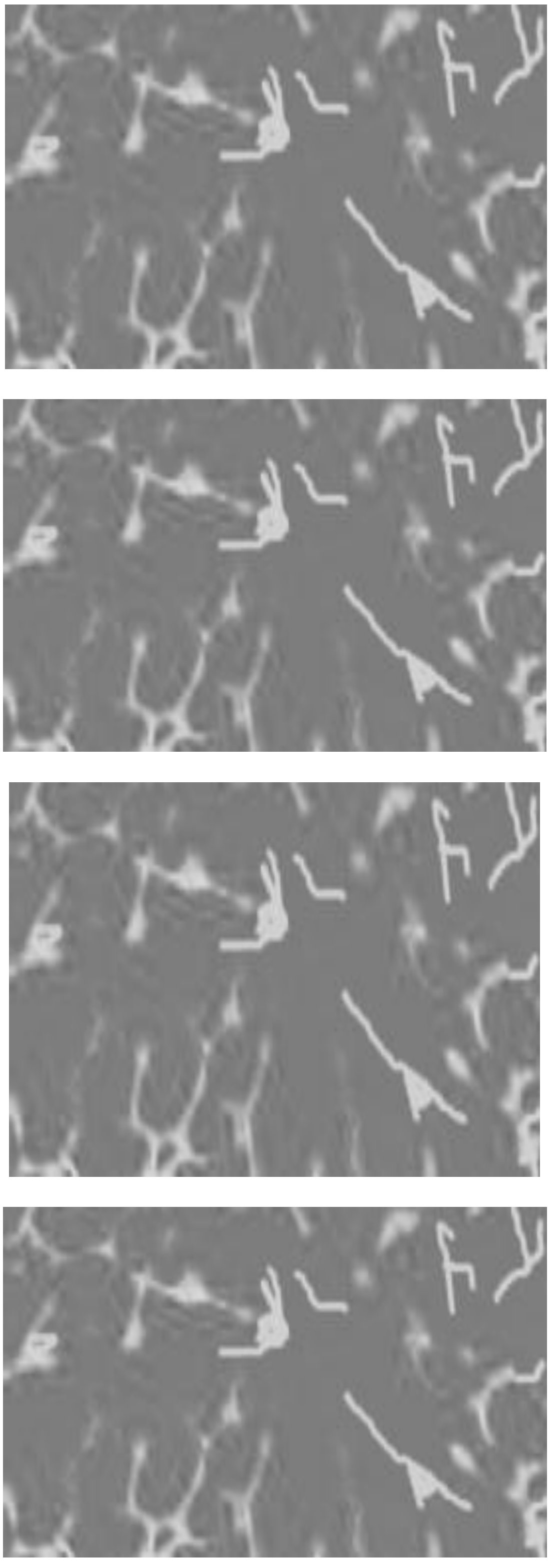

Fig. 6. 2D slices showing highly interconnected network of β-$Mg_{17}Al_{12}$.

The Fig. 6 microstructure images, made of a stack of 60 aligned sections for the region, with a slice spacing of 1.5 µm. The α-Mg dendrites and β-$Mg_{17}Al_{12}$/Mg eutectic both exhibit a highly tortuous and interconnected distribution. Table 1 shows volume fractions of α-Mg dendrite matrix and β phase in Mg–9Al alloy.

Table 1: Volume fractions of β phase in Mg–9Al alloy, along with comparison with literature data

Phase	Phase fraction (%)	Measurements based on the Scheil–Gulliver solidification model (%)	Absolute difference
α-Mg dendrite matrix	80	--	--
β-Mg17Al12	12.9	11.2	1.7

5. CONCLUSION

The quantification of dendrite structures by manual method is challenging because of their complex network-like structures. Segmentation of individual dendritic structure like graphite grains is impossible task. This issue has been successfully addressed through this work. The serial-sectioning method to characterize and quantify the dendrite structures from microstructure images of Mg–9Al in three dimensions is successfully adopted. The volume fraction phases were obtained. The phase fraction of β-Mg17Al12 is in close correlation with measurements based on the Scheil–Gulliver solidification model. The quantitative results are used in validating phase-field modeling and as an input in microstructure-based finite element analysis to better understand the structure–property relationships in these materials.

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