

Application of Image Processing Methods in analyzing microstructure of a material

Mrs. Vishakha Yadav¹, Ms. Mari Kritima², Mrs. G. Y. Durga Devi³

1 Department of CSE, BMSIT, Avalahalli, Yelahanka, BANGALORE, INDIA
ph no: 9480525365.

2 Department of CSE, BMSIT, Avalahalli, Yelahanka, BANGALORE, INDIA
ph no: 9880043718.

3 Department of CSE, BMSIT, Avalahalli, Yelahanka, BANGALORE, INDIA
ph no: 9480613001.

ABSTRACT The 'microstructure' is a term which is used to describe the appearance of the material on the nm-cm length scale. The microstructure features such as size of the grain, grain boundary morphology, and texture of grains of a given material may vary greatly when observed at different length scales. The physical properties such as strength, ductility, and electromagnetic properties of materials are strongly dependent on the microstructure such as boundaries of grain or particle or reinforcements of fiber. Integration of composition of material with its microstructure and information about mechanical properties enables many product development activities such as design a product, analysis the different processing such as mechanical deformation, treatment on heating and other often complex processing steps the product will undergo during manufacturing, and manufacturing of final product. A fundamental understanding of the changes happening in microstructure of materials during thermo-mechanical processing is of great importance to develop the future generations of engineering materials. In this paper, we will focus on three different image processing methods which help in analyzing the microstructure of materials after processing. The image processing methods can be used to find particle or reinforcement to fibre, by finding edges and extracting features from those edges. So using the analyses report Computer aided model can be build which can give process-structural relationship.

Keywords: Microstructure, Computer Aided Design (CAD), Image Processing, grain, particle, reinforcement

Corresponding Author: Dr. Thippeswamy G, HOD, Department of CSE, BMSIT, Avalahalli, Yelahanka, BANGALORE, INDIA.

Introduction

Materials are important in the identifying the civilization that we are associated with. Understanding of behavior of materials and their different properties was possible only by understanding the atomistic of materials by quantum mechanics study. Then Materials Science was developed which mainly focuses on the relationship between the properties of a material and its microstructure. The development of this science allowed to design materials and provided a knowledge base for the applying this material in engineering process called Materials Engineering. There are two different levels of structure in material science first is at the atomic level based on the arrangement of atoms in different ways. For example atom arrangement gives different properties for graphite and diamond as both are forms of carbon. Second level is at the microscopic level which is based on the arrangement of small grains of

material that can be identified by microscopy. For example because of this arrangement transparent and frosted glass gets different properties.

Properties of a material depend upon the way the material reacts to the environment. For instance, the *mechanical, electrical, magnetic, thermal, optical and chemical stability properties* are the responses to mechanical, electrical and magnetic forces, respectively, thermal properties are responses to transmission of heat, optical *properties are responses to* absorption, transmission and scattering of light and the *chemical stability properties is responses to* contact with the environment like corrosion resistance.

Microstructures on material can be formed by various processes methods such as a

- Phase transformation when a material is subjected to change in temperature and/or pressure for example a melt to crystallize the material and solid on cooling.
- Deformation or processing of the material For example when a material is rolled, pressed or welded.
- Combining different materials to form a composite material For example carbon-fiber reinforced plastic.

Why Microstructures of Materials Science needed?

Now there is increase in usage of Advanced Materials in high performance and most expensive applications like Engine of automobiles who's efficiency increases at high temperatures so it requires high temperature structural materials, Use in nuclear energy requires solving problem with residues, or advances in nuclear waste processing. Hypersonic flight requires materials that are light, strong and resist high temperatures. Optical communications require optical fibers that absorb light negligibly. Civil construction needed materials for unbreakable windows. High level infrastructures needed materials that are strong like metals and resist corrosion like plastics.

For many years, down the line practitioners in the manufacturing industry have problem in identifying and use a suitable engineering materials. Others hand user complains about various and unpredictability of mechanical properties of processed materials. Both the problems can be solved by computer-aided design (CAD) tools which use material information with geometry. [8]In existing methods, material composition is specified in form of parameter using volume fractions where continuous distributions of material compositions are modeled. But it is appropriate for macro-scale part models and microstructures of material due to different manufacturing processes, heat treatments, or other material limitations are not considered. Furthermore, this model can examine whether the material is in the specification or desires of the designer but the physical behavior of the actual materials is not considered.

So to capture the microstructure of a material first the material is sliced and image of material is capture in particular resolution and scale. Then image processing method is applied to that image to make analyses of microstructure of material.

IMAGE PROCESSING METHODS

In this section we are going to analyze the various methods including heterogeneous transform of surface let models.

A.Heterogeneous modeling

Heterogeneous materials are composed of different constituent materials. It displays continuously changing composition and/or microstructure. These materials have increasingly been used in engineering applications . Current CAD systems have limited ability to model

heterogeneous materials. Recently, several studies of heterogeneous material modeling systems have been explored. It deals with the modeling of geometry and material composition. There are three broad categories of research identified recently[1] Evaluated, Unevaluated and Composite approaches. Evaluated representations are based on discretizations where materials and geometry are modeled separately using mesh based and voxel based methods[2] or general cellular decomposition[3]. In unevaluated approaches in opinion of few researchers the representation of material compositions and properties from the underlying part of geometry are separated[4], while others are using a common mathematical model for both material decomposition and geometry[5,6].

In composite method a part is decomposed into several sub-objects each of which belongs to either evaluated or unevaluated class[7]. The limitation with these approaches is that they do not take into consideration the actual material behavior and the material's physics.

An approach proposed by Rosen, Jeong, Wang [8] concentrates on material microstructure understanding and association of microstructure features with composition of materials and its mechanical properties. The proposed model in [8] can be integrated with process-structure-property relationships and then into CAD models.

B.Surfacelet Models

A surfacelet model can be generated by a combination of Radon-like surfacelet and wavelet transforms as introduced in [9]. In this analysis, we consider a Radon, Radon-like transforms in the analysis. The Radon, Radon-like and wavelet transform will be summarized here.

B.1 Radon Transform

Generally, the Radon transform is based on a function of integrals over straight lines. It is also an integral transform whose inverse is used to reconstruct an image from medical CT scans [10]. The inverse Radon transform is used to reconstruct the original image from the sensor data obtained during the imaging step. The Radon transform is based on integrals over straight lines. The geometric features with linear geometry if exists in the object to be imaged, the linear features can be recognized easily. This know-how has been used in applications using image compression, image reconstruction, and feature recognition. The Radon transform is defined as the line integral along each line, L , in the XY plane:

$$R_f(L) = \int_L f(\mathbf{x}) |d\mathbf{x}| \quad (1)$$

or

$$R_f(\alpha, b) = \int_{-\infty}^{\infty} f((u \sin \alpha + b \cos \alpha), (-u \cos \alpha + b \sin \alpha)) du. \quad (2)$$

If a parametric model of the line is used:

$$\mathbf{p}(u) = ((u \sin \alpha + b \cos \alpha), (-u \cos \alpha + b \sin \alpha)) \quad (3)$$

where u is the parameter along the line, α is the angle of the line, and b is its distance from the origin.

The Radon transform can be protracted to three or higher dimensions. In three-dimensional cases, the linear geometry is a plane. Some extensions to the Radon transform have enabled invariance under translation, scaling, and rotation.

B.2 Wave let Transform

In the domain of 2D shape representations, wavelets are the most popular multi-resolution

representations. The functional space for wavelet analysis is decomposed, based on a scaling function $\phi(t)$ and a wavelet function $\psi(t)$ with one-dimensional variable t for multi-resolution analysis. Wavelets are self-similar and can be scaled up and down. More specifically, the wavelet function

$$\psi_{a,b}(t) = a^{-1/2} \psi(a^{-1}(t-b)) \quad (4)$$

is scaled by a scaling (dilation) factor a and translated by a translation factor b . Although certain forms (e.g. Haar, Daubechies, Morlet, etc.) have been used extensively, $\psi(t)$ is actually general and can be customized for specific problems. Wavelets are localized in both real (time) and reciprocal (frequency) spaces due to the property of regularity and vanishing moments, which makes its one of the strongest features. In the geometric modeling domain, the wavelet transforms were used to describe planar curves.

B.3 Surfacelet Transform

The surface let transform is a generalization of the Radon transform so that the integral is applicable to 2D curves or 3D surfaces of any shapes. The simplest one is the ridgelet transform, which is the 1D wavelet transform of the surface integral resulting from the Radon transform (Eq. (2)) as [1]:

$$2D: \Psi_{b,a} = (R_f(\alpha, b), \Psi(\alpha, b)) \quad (5a)$$

$$3D: \Psi_{b,\alpha,\beta} = (R_f(\alpha, \beta, b), \Psi(\alpha, \beta, b)) \quad (5b)$$

Eq. (5) can be generalized for other types of surface lets.

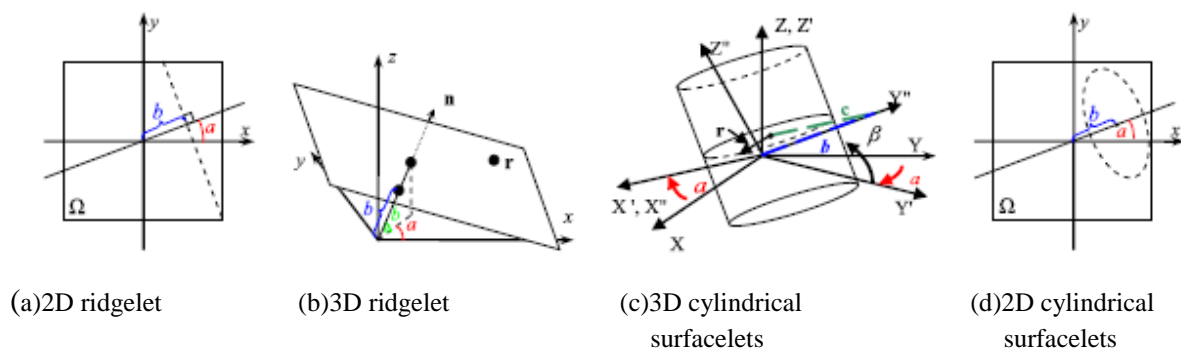


Fig 1. Geometric interpretation of surfacelets

Lower resolution models can be generated by using the wavelet decomposition operation, where the high frequency content of the wavelet is discarded (half of the wavelet coefficients are kept). Successive wavelet decompositions can be performed to generate progressively lower resolution microstructure models. From these lower resolution models, models at larger size scales will be generated.

A surface let basis function is generally defined as

$$\psi_{a,b,p}(\mathbf{r}) = a^{-1/2} \psi(a^{-1} \rho_{b,p}(\mathbf{r})) \quad (6)$$

where $\mathbf{r} = (x, y, z)$ is the location in the domain Ω in the Euclidean space, $\psi : \mathbb{R} \rightarrow \mathbb{R}$ is a wavelet function, $\rho_{b,p} : \mathbb{R}^3 \rightarrow \mathbb{R}$ is a surface function so that $\rho_{b,p} = (x, y, z) = 0$ implicitly defines a surface, with the translation factor b and the shape parameter vector $\mathbf{p} \in \mathbb{R}^m$

determining the location and shape of surface singularities, respectively. For instance, the 2D ridgelet is formed by introducing angular element $\alpha \in [0, \pi)$ as

$$\begin{aligned}\Psi_{a,b,\alpha}(r) &= \Psi_{a,b}(x \cos \alpha + y \sin \alpha) \\ &= a^{-1/2} \Psi(a^{-1}(x \cos \alpha + y \sin \alpha - b))\end{aligned}\quad (7)$$

2D ridgelet is shown schematically in Fig.1(a).

The 3D ridgelet represents plane singularities and is defined as

$$\Psi_{a,b,\alpha,\beta}(r) = a^{-1/2} \Psi(a^{-1}(\cos \beta \cos \alpha \cdot x + \cos \beta \sin \alpha \cdot y + \sin \beta \cdot z - b)) \quad (8)$$

parameter about the local X axis, and b is a translation along the local Y -axis, as shown in Fig. 1(b). Here the shape parameter vector is $\mathbf{p} = (\alpha, \beta)$. Similarly, a surfacelet that represents cylindrical singularities can be defined as

$$\Psi_{a,b,c,\alpha,\beta,r_1,r_2}(r) = a^{-1/2} \Psi(a^{-1}[r_1(\cos \beta \cos \alpha \cdot x + \cos \beta \sin \alpha \cdot y + \sin \beta \cdot z - b)^2 + r_2(-\sin \alpha \cdot x + \cos \alpha \cdot y - c)^2]) \quad (9)$$

where c is the X axis translation and parameters r_1 and r_2 describe the major and minor radii of the cylindrical shape.

The parameters of surfacelets can be geometrically interpreted. For 3D ridgelets as in Fig. 1(b), any point on a plane $\cos \beta \cos \alpha \cdot x + \cos \beta \sin \alpha \cdot y + \sin \beta \cdot z = t$ has the same evaluation of the wavelet function $\psi(a^{-1}(t - b))$. Therefore, the isosurfaces of Eq. (8) are planes. The cylindrical surfacelet is shown in Fig. 1(c), where the isosurfaces of Eq. (9) are seen as cylinders. The 2D version of cylinderlets is shown in Fig. 1(d).

Conclusion

Features like fiber and grain boundary can be recognized by Radon and surfacelet transforms. From this paper, the linear structures can be easily identified, the fiber and grain boundaries from 2D images can be identified as lines using 2D ridge let transforms. The grain boundaries from 3D images can be identified as planes using 3D ridge let transforms.

Future Scope

The result of analysis using image processing methods given in the paper can be used to build a microstructure model. After building microstructure model, it can be used as a platform to implement computer aided design model which can embed process-structure-properties information with the microstructure details.

References

- [1] Computer-Aided1.KouXY,TanST. Heterogeneous object modeling: a review. Computer-Aided Design2007;39(3):284–301
- [2] Bhashyam S, Shin KH, Dutta D. An integrated CAD system for design of heterogeneous objects. Rapid Prototyping Journal 2000; 6(2) : 119–35.
- [3] Adzhiev V, Kartasheva E, Kunii T, Pasko A, Schmitt B. Hybrid cellular-functional modeling of heterogeneous objects. ASME Journal of Computing and Information Science in Engineering2002;2:312–22.

- [4] TanST, SiuYK. Source-based heterogeneous solid modeling Design 2002;44(1):41–55.
- [5] Ganter M, Wahlborg J, Schwartz D, Storti D. H-ISM: an implementation of heterogeneous implicit solid modeling. In: Proc. ASME design automation conference, paper# DETC2002/DAC-34139. Montreal: September 29–October 2, 2002.
- [6] Rvachev VL, Sheiko TI, Shapiro V, Tsukanov I. Transfinite interpolation over implicitly defined sets. Computer Aided Geometric Design 2001;18:195–220
- [7] Kumar V, Burns D, Dutta D, Hoffmann C. A framework for object modeling. Computer-Aided Design 1999;31:541–56.
- [8] David W. Rosen, Namin Jeong, Yan Wang. A method for reverse engineering of material microstructure for heterogeneous CAD. Computer Aided Design 2013;45:1068-1078
- [9] Wang Y, Rosen DW. Multiscale heterogeneous modeling with surfacelets. Computer-Aided Design & Applications 2010;7(5):759–76.
- [10] Kak AC, Slaney M. Principles of computerized tomographic imaging. SIAM; 2001