Image processing of glass fiber reinforced plastics

Number of Fiber
Less ——————————— More
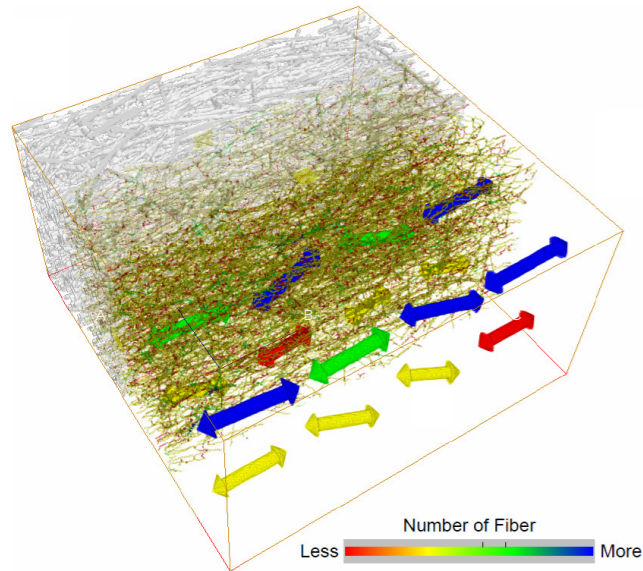
The above figure shows the same region of a volume data in four different representation, layered from the back to the front, in the order of processing procedure.

The first layer in gray scale is the original CT image displayed semi-transparently, and the second layer is the same image with Medial Axis overlaid on it. The fourth layer shows the vectors that indicate local trends in fiber orientation, and the third layer is the same image with Medial Axis overlaid on it.

The vectors were obtained by dividing the volume data into 4 x 4 x 2 cuboids and calculating the average moment of inertia of all Medial Axes for respective regions. Colors in the rainbow spectrum shows the quantity of fibers detected. The quantity becomes larger toward the blue end and smaller toward the red end.

Application Fields

Material engineering in general

including petroleum, rubber, plastics, resin, polymer, granules (dosage form), methane hydrate, concrete/gravel, fuel cell, carbon nanotube, paper, pulp fiber, ceramic, catalyst, bone, dental/medical material, precision/electronic component, semiconductor.

Input data format

A series of tomographic image obtained through imaging devices such as X-ray CT, CLSM and TEM tomography

Before conducting 3D image analysis on ExFact Analysis, the image stack needs to be preprocessed, including the extraction of the region of interest, on ExFact VR. ExFact VR supports various file formats including tiff, bmp, dicom and original forms of different devices.

Specification and release time may change without notice.Company and product name are registration of trademark.

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Case Example

Presentations at the 18th Annual Meeting of the Japan Society of Polymer Processing (July, 2007), and the 6th Symposium on Non-destructive Evaluation using Ionizing Radiation

Title: 3D image analysis by X-ray CT for glass fiber within resin cast

When casting resin added with glass fiber, the orientation of the fiber have strong connection with its mechanical properties and casting defects such as warpage. We used an industrial X-ray CT device as a convenient method to observe fiber orientation in a cast plate. The shapes and distribution of the fibers were examined based on three-dimensional images. We used ExFact Analysis to analyze the fiber orientations in the skin and core layers, whose results were then compared to the ones obtained through computer simulations.

Skin Layer
Core Layer
Skin Layer
thickness direction
perpendicular direction
flow direction
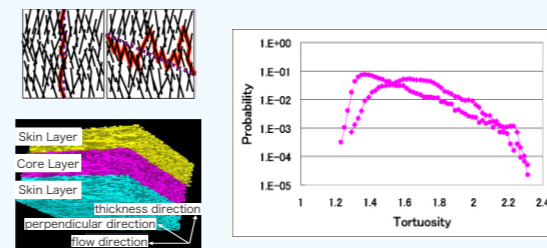
		ratio of fibers to volume	number of fibers detected	number of fiber intersections
Sample1	skin layer	0.101	3129	3098
(plate thickness 1.0mm,	core layer	0.132	4151	4717
gate thickness 0.7mm)	skin layer	0.107	3171	3318
Sample2	skin layer	0.167	7869	9833
(plate thickness 2.0mm,	core layer	0.187	9056	11425
gate thickness 1.0mm)	skin layer	0.171	7340	9213
Sample1	skin layer	0.133	5691	7687
(plate thickness 3.0mm,	core layer	0.191	10174	12803
gate thickness 1.5mm)	skin layer	0.147	6429	8234

ExFact® Analysis Product Lineup/ Specification Details

Product Lineup
· ExFact® Analysis for Porous/Particles
· ExFact® Analysis for Fiber
Please use either or both, depending on the types of object materials.

Required Software
· ExFact® VR Windows (64-bit version)
* for preprocessing and rendering/display of image data.

Software Licensing
· USB Software Protection Device

System Requirements
· Operating System : All editions of Microsoft Windows 7/8, Japanese/English versions supported.
· At least 4GB of RAM
· 1280 x 1024, full color screen resolution or higher
· A USB port (for USB Software Protection Device)

Three-dimensional Image Analysis Software

ExFact® **Analysis** for Fiber

Three-dimensional analysis of fiber structure

MA (Medial Axes)
11um ← fiber width → 55um

ExFact Analysis Series
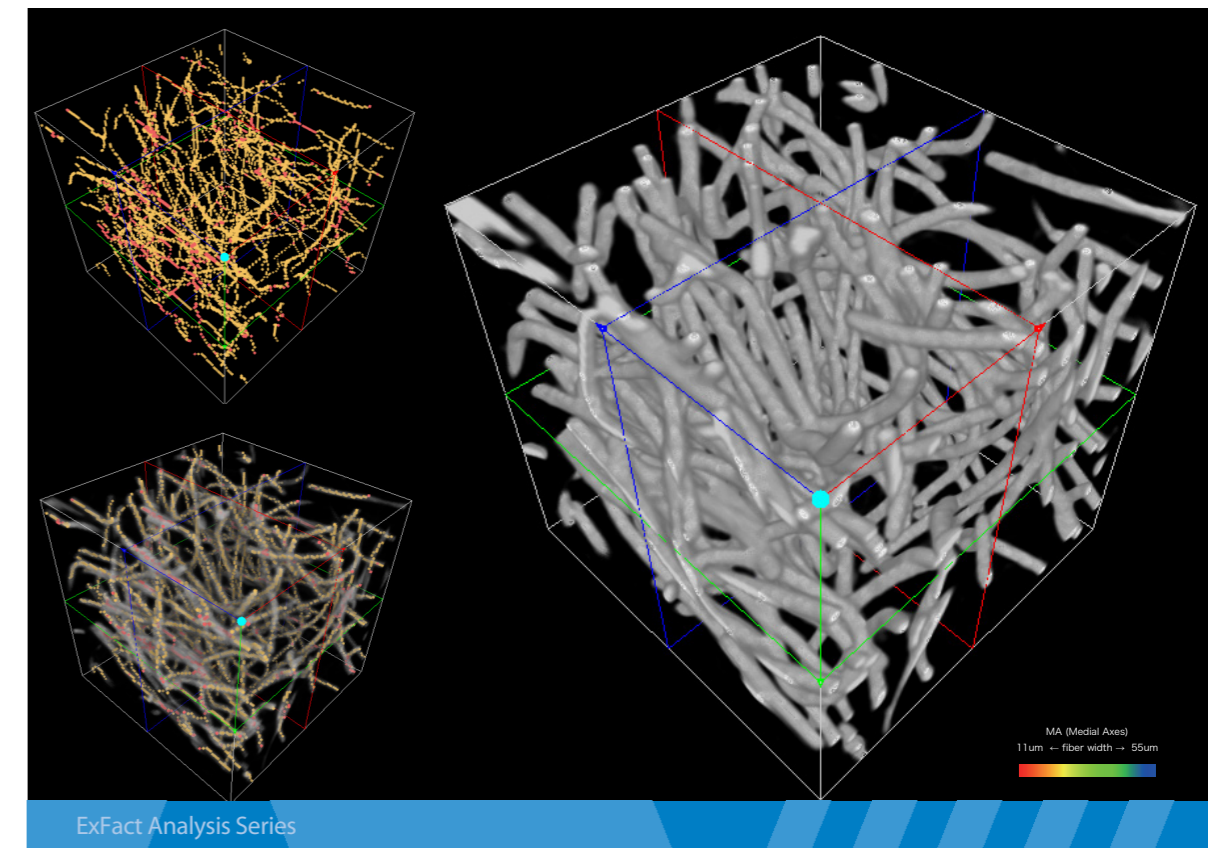
Visualize your imagination

Imaging technologies such as X-ray CT, CLSM and TEM tomography provide a series of tomographic image of industrial products and materials for the construction of their 3D images. ExFact® Analysis, a software based on the novel concept of "Medial Axis" to capture the complex structure of various objects, offers a tool to conduct statistical evaluation/analysis on the properties of those 3D images, including shapes/distributions of grains/voids, as well as orientations of fibers.

Basic Concepts

Original Image

Binarization

Existing Method

New Method

Medial axis
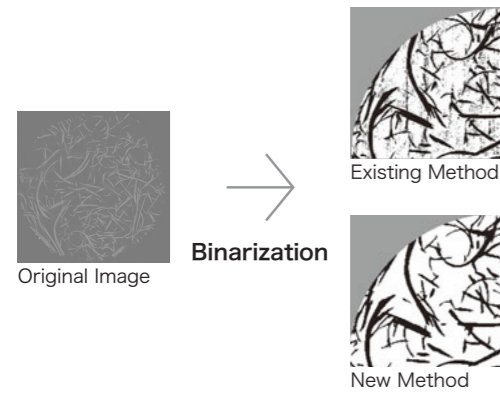
Newly Developed Segmentation Process

A cross sectional (tomographic) image obtained with imaging devices, such as X-ray CT, basically consists of pixels of various gray values. Each of these pixels represents the corresponding point of imaged object, with their gray values corresponding to the material density of the points. On a digital image, whose spatial resolution has a certain limitation, the intensity values of marginal region become lower than their true values (which is called "partial volume effect"). This effect, along with noises and artifacts, makes it difficult to obtain an ideal image in which material phase and pore space are clearly separated.

Equipped with a newly developed segmentation algorithm, ExFact Analysis carries out binalization process based on its three-dimentional scanning of highly-intricate material/ void-space structure. The software sets two thresholds (high and low) on a 3D image histogram, where the voxels with gray values higher than the high threshold are classified into material phase, while those with lower values than the low threshold into void space. Those with in-between gray values are classified into either of the two categories after the software statistically processces the gray values of their neighbouring voxels, providing more probable contour estimation. The resultant output file after the segmentation can be used on ExFact® VR for further image processing.
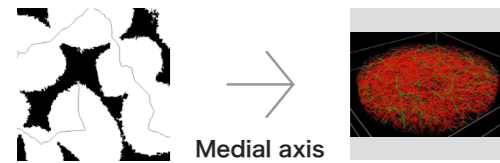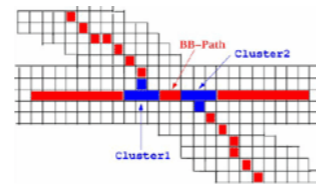
Medial axis

ExFact Analysis constructs the "Medial Axis" of the object - skelton of void space represented in a union of one dimentional curves. This lower dimentional representation of the object, while preserving important geometric properties, is easier to analyze than a 3D image. ExFact Analysis uses the medial axis as the basis for understanding the complicated 3D properties of the original object.

Preparations for quantitative analysis

First, fibers are divided where they contact, intersect or diverge, into individual paths. These points are defined as "clusters," shown in blue in the figures on the right. The angles between paths at clusters are then calculated. Paths are connected so as to make the straightest lines possible. These straight lines are extracted as individual fibers. The fibers are then calculated for their properties including length, orientation and crossing angles.

Flow Steps

Objects of analysis

Fibrous materials such as fibers, fuel cells and wires.

ExFact. VR

Loading image data, extracting the region of interest, and converting the file to a format readable on ExFact Analysis.

ExFact. Analysis for Fiber

Conducting binarization on a 3D volume data, separating material phase and void space, and proceeding with analysis process

Observing the 2D slice images processed by ExFact Analysis

3D visualization of the medial axis processed by ExFact Analysis

Plotting graphs of various indices for statistical evaluation of materials

Graphs Plotted Based on Analysis Results

ExFact Analysis calculates various statistical values for material evaluation.

Distribution of number of bonds on individual fibers

Bonds are defined as the points at which a fiber contact other fibers.

Fiber orientation distribution

The three principal axes of inertia for fibers are calculated, normalized to unit length and plotted on a sphere.

Distribution of crossing angles between fibers

A crossing angle is defined as the smallest of the angles made by two crossing fibers.

Shortest path distribution

Medial Axis which are connected from "m" to "n" interface

a-1

b-2

b-3

b-4

b-3 is the shortest path for medical axis of "b", so a-1 and b-3 are counted

All :
a-1 , b-2 , b-3 , b-4

Shortest paths :
a-1 , b-3

Shortest paths represent the flow channels of liquid, air and electricity in materials such as porous filter and polymer.

All channels (white) and the flow channels from left to right interfaces (red)

Fiber length Distribution

Cluster: a point that joints paths

LL (leaf-leaf): a path that has no cluster connection at either end

BB (branch-branch): a path that connects to a cluster at each end

BL (branch-leaf): a path that connects to a cluster only at one end

Tortuosity

Tortuosity (T) = $\dfrac{f}{s}$

Tortuosity of a fiber is defined as its length divided by the distance between two ends.
The value of tortuosity becomes the lowest, 1, when the length is equal to the distance. The value increases as the fiber becomes more tortuous.

Tortuosity is calculated for different types of fibers (all, LL, BB and BL).

Visualization of 3D fiber orientation by voxel mesh.
Each colored vector is composed of all the fibers in the corresponding regions, interpreting the fibers as vectors. Their color represent the number of fibers.

In this case, the volume data of 400 x 400 x 400 voxels is divided into 4 x 4 x 4 = 64 blocks of 100 x 100 x 100 voxels.
Voxel mesh images can be made semi-transparent and overlaid on the original CT image for a single layered image output.