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Development of an Automatic Polarized Microscopic Imaging System for Asbestos Qualitative Analysis

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***Abstract*—This paper describes about an automated microscopic imaging system for supporting asbestos qualitative analysis. By JIS (Japanese Industrial Standards), the dispersion staining method is designated as a visual qualitative analysis for asbestos in the construction materials. In the analysis process using the microscope, the expert monitors the particles including asbestos fibers and count them. For supporting such observation process, we developed an automated microscopic image collecting system. It realizes to take the images of the target area and store them to the database automatically. In this paper, we introduce and report the prototype system and its performance.**

I. INTRODUCTION

In past decades, asbestos-containing insulation, fireproofing and other materials were utilized in the construction of ordinary houses and other buildings. However, it has since been learned that dispersed asbestos fibers penetrate and adhere to lung tissue when inhaled and can result in lung cancer, and other health issues. Therefore, asbestos analysis is an indispensable tool in determining whether building materials now in use contain sufficient asbestos to cause health problems[1][2][3].

There are two types of asbestos analysis. One is qualitative analysis, which clarifies whether a building material contains sufficient asbestos fibers to cause health damage. The other is quantitative analysis, in which accurate asbestos content is evaluated, when it estimates that the specimen contains the asbestos by the qualitative analysis.

In the qualitative analysis process, X-ray diffraction analysis and visual inspection are experimented. Especially, the visual inspection which is called as dispersion staining method, becomes the cause of lower working efficiency.

On the other hand, the recent worsening of asbestos-related problems has resulted in increased numbers of requests for asbestos analysis and it is required to improve analytical efficiency.

The purpose of this research is to develop a system that supports the dispersion staining method, which is one of the qualitative analysis techniques used for asbestos measurements in the construction materials.

Until now, the systems such as Magiscan [4] [5], the Asbestos Fibers Automatic Counting System (AFACS)[6] [7], that utilize image evaluation are now in service, but the target specimens of these systems are airborne asbestos fibers[8], and their utility is due to the fact that, other than asbestos fibers, air specimens normally contain only ultra-fine and mostly non-visible particles.

The focus of this research is to develop the system aims to support the visual inspection process of the dispersion staining method. In our previous work, partially automated microscopic system was developed[9]. However, auto-detection function for imaging target area and image storing function were still not implemented. Such functions are indispensable for fully automated microscopic imaging system.

In this paper, we described an advanced prototype of automatic microscopic imaging system for collecting polarized images to support dispersion staining method.

II. DISPERSION STAINING METHOD

Qualitative analysis is performed to determine whether a specimen contains asbestos fibers. The two primary methods of qualitative analysis are the X-ray diffraction analysis [10] and dispersion staining method[11]. From the results of both methods, it can be determined whether a given specimen contains asbestos.

Figure 1 : An Outlook of Visual Inspection utilizing Microscope

Figure 2 : A specimen from the construction material is set on the slide glass with the refractive index liquid and it is covered by cover glass (22mm X 22mm).

Here, the dispersion staining method is a

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representative visual inspection process that allows an observer to identify asbestos fibers based on dispersive colors by immersion and polarization.

Figure 3: A typical example of dispersion color change.

Figure 2 indicates that an example of the specimen from the construction material is set on the slide glass with the refractive index liquid and it is covered by cover glass. Also, Figure 3 shows a typical example of dispersion color change of an asbestos fiber.

Here, the specimens obtained from construction materials that are suspected of containing asbestos also contain other substances or particles. Therefore, for such specimens, the dispersion staining method is often employed due to its relative ease in distinguishing asbestos fibers from other particles. The abstract of the actual procedure used for the dispersion staining method is prescribed in the JIS (Japanese Industrial Standards) [12] as follows:

1. A specimen from the construction material (Figure 1) is set on the slide glass with a cover glass and the refractive index liquid. It observed under a dispersion objective lens at ×10 magnification. If fibers with dispersive colors are found roughly, the dispersion objective lens is switched to ×40 magnification.

2. All particles in the visual field under the eyepiece lens of ×40 magnification (up to 1,000) are counted. Observed particles may be of any substance, but if fibers showing the unique colors of asbestos are found, their types and amounts are recorded.

3. The above processing is performed in three types of immersion liquid, each having different refractive indexes, in order to determine whether there are four or more asbestos fibers with aspect ratios of 3.0 or greater in a total of 3,000 particles.

Here, JIS prescribes the asbestos unique dispersive colors as listed in Table 1.

Table 1 Dispersive color of asbestos fiber

Asbestos	Refractive index	Dispersion color
Chrysotile	1.550	Red purple ~ Blue
Amosite	1.680	Pink
	1.700	Blue
Crocidelite	1.680	Orange
	1.700	Blue

From field interviews, it is known that it is better to observe 200-300 unit views on each specimens for reliable inspection. It is also known that few specimens can be usually analyzed by a single operator in a day and the inspection of single specimens takes about one hour.

III. Functional Requirements for Supporting Dispersion Staining Method

In previous section, the inspection process for specimens obtained from construction materials is introduced. This means that any new system for supporting to analyze the asbestos content of construction materials must take into consideration the requirements of the dispersion staining method.

The purpose of this research is to propose a technological development that will support efficient analysis by means of the dispersion staining method, which is currently cumbersome. While asbestos evaluation techniques that utilize image processing are already under investigation, the need to collect images (selecting a field of observation using a microscope) for evaluation in order to comply with the official procedure is burdensome in terms of time and labor.

When considering the official procedure for dispersion staining method [12], it is believed that an automated imaging system should have the following functions, at least:

- Positioning to imaging location
- Control for a polarizing plate angle
- Automatic microscopic image saving
- Synchronous computer control of the above functions

These functions are necessary because the official procedure states that particles and asbestos fibers should be counted after the arbitrary selection of a visual field. Also, the evaluation of dispersive color changes (which is characteristic of the dispersion staining method) be utilized aggressively to discriminate between asbestos fibers and the particles. Thus, these functions were implemented on our previous prototype [9] which was realized as an automated microscope system.

Here, in the present evaluation process, imaging conditions for each image data were not stored. It is difficult to specify which observation area (view) include counted particles or asbestos fibers because location information of the view are not recorded. Thus, there is no sort of evidences to visual inspection results. There is possibility that it would become the problem from a view point related to accountability. It is also better to record specimen from a view point of specimen information consistency.

Moreover, we already took that seamless observation (imaging) in target area which is specified manually. Seamless imaging is still necessary to take more accurate (realistic) inspection. However, till observation target is specified by the operator, it is still not full-automated imaging system.

Therefore, below functions would be implemented for realizing automated polarized microscopic imaging system.

- Automatic detection/decision of an imaging area (center position of a cover glass)
- Saving image data and imaging conditions in the storage
- GUI (Graphical User Interface) for registration the information related to the specimens.

In this paper, we implemented these function additionally to our prototype system. In next section, at first, we introduce prototype system which was realized in our previous work. Next, additional functions for automated polarized microscopic imaging system.

IV. Polarized Microscopic Imaging System for Supporting Dispersion Staining Method

A. Prototype System Configuration [9]

With mentioned-above points, we created an experimental automatic microscopic image observation system[9]. Figure 4 shows an external view of the system while Figure 5 shows the system configuration.

Since the use of a dispersion microscope is prescribed for the dispersion staining method, we adopted the computer-controllable System Microscope BX61 manufactured by Japan's Olympus Corporation. During system operation, a source installed under the microscope illuminates the prepared specimen for observation, which is then recorded through the microscope lenses by a system-connected CCD camera Retiga 4000R by QImaging Corporation. Settings of camera imaging conditions are controlled by use of image processing library software: Image-Pro Plus by Media Cybernetics Inc. Under current design specifications, 36-bit color (12 bits each for R, G, and B) and 24-bit color (8 bits each for R, G, and B) images can be saved in the Multi-TIFF format.

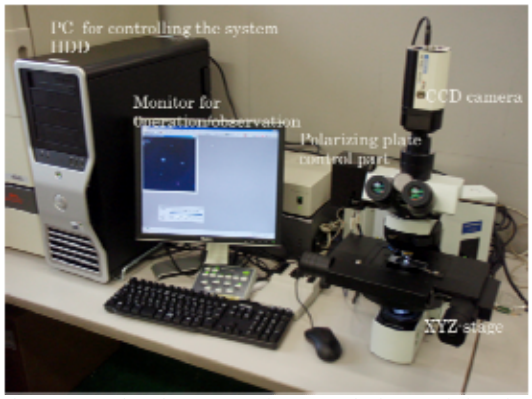


Figure 4: Developed prototype of automated microscopic imaging system

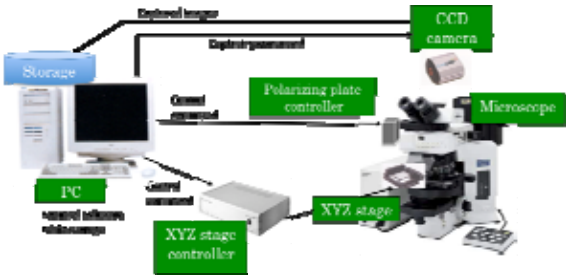


Figure 5: System configuration

Table 2 Specification of system components

Equipment/device	Specification
Computer-controllable type Phase Contrast Microscopy (OLYMPUS BX61N-33DPH)	object lens for phase contrast image （×10，×40） object lens for dispersion color （×10，×40）
Computer-controllable analyzer	Polarizing plate control precision 1° （max:0.01°）with stepping motor RS-232c I/F
Electric cooled color CCD camera (QImaging Retiga 4000R-C-Color)	1" interline CCD device resolution : 2048×2048 pixel size : 7.4×7.4um RGB resolution : 36bit IEEE1394 I/F
Computer-controllable XYZ stage (Prior Scientific ProScan H101)	travel range : 108×67mm control precision : ±1um RS-232c I/F
Computer and storage for image capturing	Dual Core Xeon 3.0GHz，4GB RDRAM，750GB HDD×2 RAID Level0 Windows XP Professional x64

Imaging is performed by shifting the computer controlled XYZ stage (Prior Scientific ProScan H101), which is installed under the objective lens of the microscope, and on which a prepared specimen is placed. The XYZ stage is automatically positioned to the point of mechanical origin prior to imaging. The official procedure prescribes the counting of particles and asbestos fibers after arbitrarily selecting a visual field. After considering our ability to count all particles and asbestos fibers in the selected visual field with higher precision, we decided to take an approach of imaging the entire observation area by shifting unit view area of the microscope and a unit imaging area observed by the microscope is 379 um X 379 um.

More specifically, the system is comprised of the devices listed in Table 2, and is centered on a personal computer for controls such devices.

However, in this system, in order to specify an imaging target area, the operator sets the stage's lower right and upper left ends by manipulating the microscope's joystick. This determines the imaging area from three points, specifically the origin, the lower right end, and the upper left end. Because, it is not pre-detemined where the cover glass (imaging target) is placed on the slide glass. However, for full-automated imaging process, it might be detected automatically.

B. Seamless Polarized Microscopic Imaging Procedure

Here, utilizing the prototype, improved procedure of microscopic imaging process is as follows:

1) Registration of specimen ID and imaging conditions: The specimen is set on the center of the XYZ stage. The operator inputs specimen ID for data management and also imaging matrix (unit size : 379 um X 379 um) size for specifying the size of the imaging target via Graphical User Interface(GUI). Moreover, the polarizing plate angles for imaging are selected by using the GUI

2) Automatic detection of target area for imaging: Here, automatic cover glass detection function based on image processing with x100 magnification microscopic image is implemented. The system scans to seek left side vertical edge of the cover glass and also seek upper side horizontal edge after detecting the vertical edge (Figure 6).

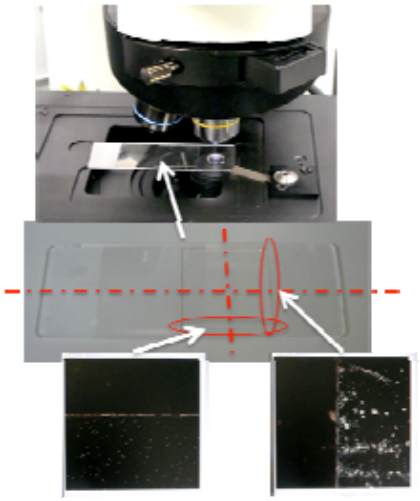


Figure 6 : Target Area Detection based on Image Processing

Edge detection process is done utilizing Intensity component of HIS (Hue, Saturation, Intensity) color space on captured image as follows:

a) extracting the pixels over threshold of Intensity value and labeling each region which extracted pixels are connected.
b) calculating the size of each labeled region and selecting labeled regions which are over threshold of the size.
d) calculating inscribed ellipses for selected regions and extracting the length of minor axis and major axis of each ellipse.
e) calculating each aspect ratio and selecting maximum one over threshold vale as the edge of cover glass.

This process is repeated for detecting both of vertical and horizontal edge of the cover glass. The system can specify the original point (center position) of the cover glass. Here, threshold value for Intensity component, the size and aspect ration are 41, 1000 and 10. Each value is determined by the basic experimental results. Using this prototype, precision of detecting the center position is ±1.5mm, because the size of an unit view with x100 magnification is 1.5mm X 1.5mm.
After the center position is estimated, the magnification is changed to x400 by switching the object lens and the system prepares for imaging.

3) Imaging with synchronized control of a polarizing plate angle and a XYZ-stage: According to the official procedure, dispersive colors can be easily recognizable if the polarizing plate is rotated 90.0° or more at each observation location. Therefore, the prototype is capable of the position control of computer controlled XYZ stage with motor driver, the polarizing plate angle control with stepping motor and the shatter control for CCD camera. Each element of the system is connected to PC via RS-232c and the system is controlled automatically and synchronously. The possible range of resolution is designed to be from 0.0° to 180.0° and the polarizing plate is positioned at specified angles in process 1) for imaging.
Here, to control the angle of the polarizing plate, the microscope controller uses a stepping motor with an angular resolution of 0.01°, which is operated from the computer by means of a software driver. The practical angular resolution for observation is set as 1.0°. Also, the XYZ stage is controlled via its own controller by the computer and control precision of the XYZ stage is ±1um.

4) Captured image storing: As mentioned before, the image is usually saved in the 36-bit color Multi-TIFF format. In order to consistent with the imaging data and its imaging conditions (specimen ID, Refractive index liquid type, unit view position on the plate (Figure 7), polarizing plate angle and so on), such conditions are involved into its own file name.
The format of the file name is as ***SpecimenID_X position ID+Y position ID_Polarizing plate angle . tif****. The examples are as follows.*

200812010001_0104_00.tif
200812010001_0104_45.tif
200812010001_0104_90.tif

The file name is utilized to reproduce the bird-eye's view based on the unit view images and so on.

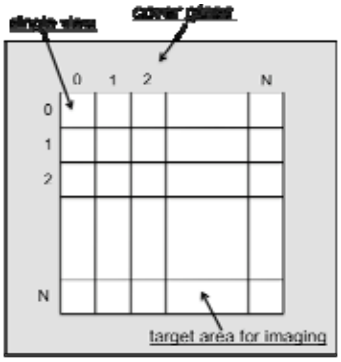


Figure 7 : Coordination of the target area for imaging

V. IMAGING EXPERIMENT

During the imaging process, the polarizing plate and camera shatter need to be alternately controlled. To accomplish them, developed system repeats the process of sending control command to the polarizing plate angle controller and also capturing command an image by the specified camera exposure time after a end response of the polarizing plate rotation is received, synchronously. Ideally, 1.0 second is necessary for image capturing and 0.5 seconds is necessary for saving image data to the storage, controlling stage movement and rotating the polarizing plate.

Figure 8 shows imaging produced by the experimental system where the polarizing plate, XYZ stage and imaging shatter are synchronously controlled (the polarizing plate is set to 0°, 45°, and 90°). The illumination of the inside monitor is changing, although only slightly. The change of dispersion color of a asbestos fiber can be seen in the upper-right area on the displayed image.

Each captured image is also stored to the HDD with a specimen ID and a location ID. The system also has GUI controlled functions that allow the operator to recall the image, enlarge or reduce the image display, and to reproduce images in a tile pattern based on the location ID. Figure 9 shows the examples of reproduced images using 36 unit images based on location ID (polarizing plate angle : 0°, 45°, 90°). In Figure 9, colored square (unit) indicates single unit of captured area at one time and the size of the area is 379 um X 379 um. In this case, the change of dispersion color of a asbestos fiber can be seen in the upper-right area.

From field interviews, it is better to observe 200-300 unit views on each specimens for reliable inspection. For capturing images consisting of three polarization patterns from the aforementioned 32.32 mm^2 (5.685mm x 5.685mm, 225 unit views) area of the cover glass, 4.5 seconds × 225 = 1,012.5 seconds (about 17 minutes) is ideally necessary at least. In case of our practical experiment, it takes 1,395 seconds (about 23 minutes). Per one specimen. It is considered to include the factors by time delay of data transferring and so on.

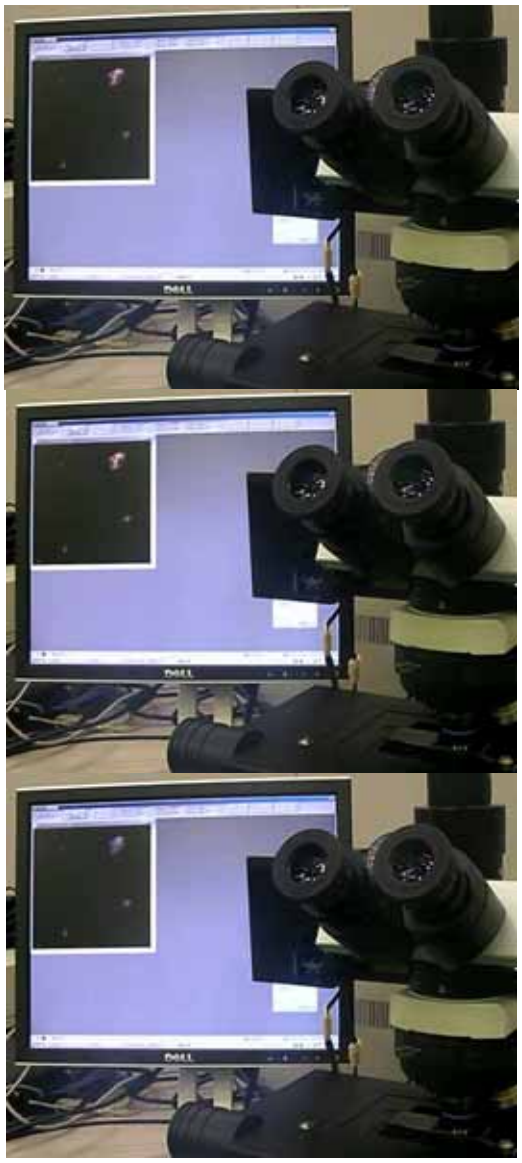
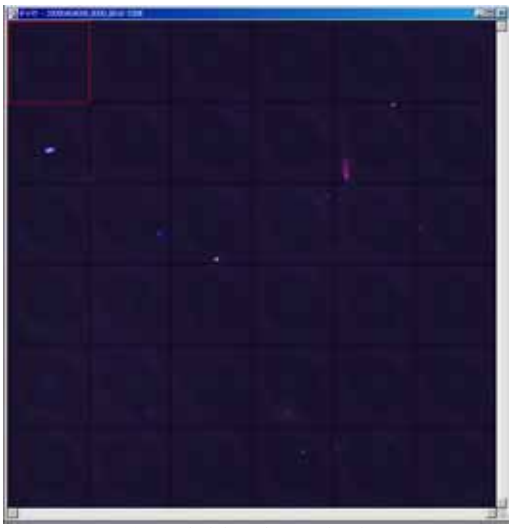
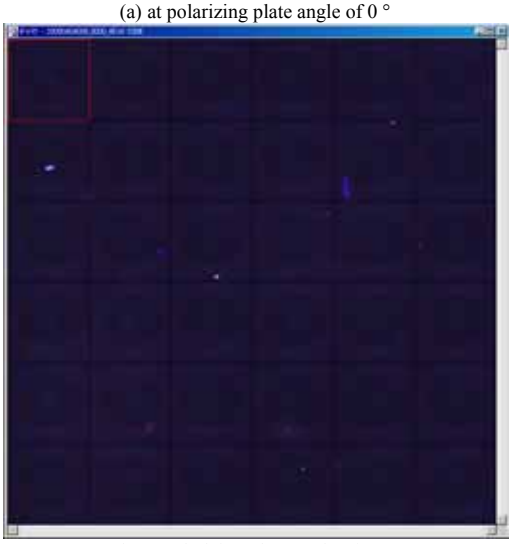


Figure 8 : Outlooks of microscopic imaging experiment

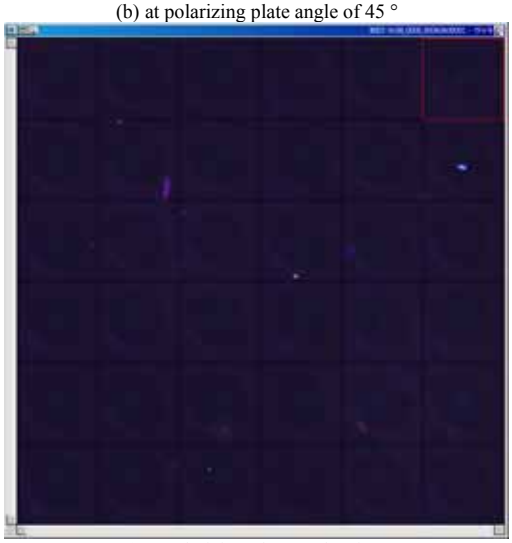
Here, it is known that few specimens can be usually analyzed by a single operator in a day and the inspection of single specimens takes about one hour. From this point of view, developed system can collect the microscopic image data and support to realize more efficient work. By using this system, the operator can observe and judge the microscopic images on the wide monitor. It is considerable that the system provides the effects to reduce physical burdens of the operators relatively. Moreover, captured images are stored and managed by using this system. It is a novel by-effect and is not done in usual dispersion staining method process. It would be important to have such evidences for the analysis result.



(a) at polarizing plate angle of 0 °



(b) at polarizing plate angle of 45 °



(c) at polarizing plate angle of 90 °

Figure 9 Examples of reproduced images (6 x 6 unit images) in a tile pattern based on the position ID

VI. Conclusion

This paper describes the development of an automatic polarized microscopic imaging system to support the dispersion staining method, which is an important technique used to perform qualitative analysis of asbestos particles contained in building materials.

Based on the information set forth in the official procedure, we experimentally created an advanced prototype system that automatically detects target area for imaging and controls the polarizing plate angle, captures images from the microscope, and stores image data.

Our future work is to construct a more advanced supporting system with the asbestos fiber and particle detection techniques based on the image processing methods [13][14] that are currently developing.

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