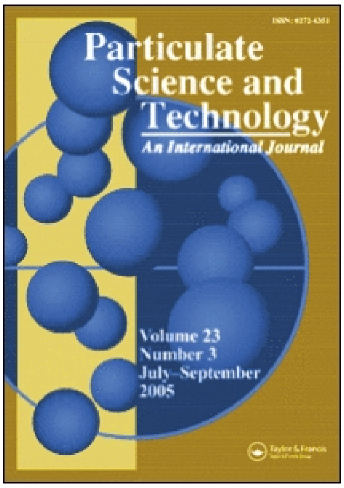

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An Asbestos Fiber Detection Technique Utilizing Image Processing Based on Dispersion Color

Kuniaki Kawabata [a]; Yuta Komori [b]; Taketoshi Mishima [b]; Hajime Asama [c]
[a] Kawabata Intelligent System Research Unit, Advanced Science Institute, RIKEN (The Institute of Physical and Chemical Research), Saitama, Japan [b] Department of Information and Computer Sciences, School of Engineering, Saitama University, Saitama, Japan [c] Research into Artifacts, Center for Engineering, The University of Tokyo, Tokyo, Japan

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An Asbestos Fiber Detection Technique Utilizing Image Processing Based on Dispersion Color

KUNIAKI KAWABATA[1], YUTA KOMORI[2], TAKETOSHI MISHIMA[2], AND HAJIME ASAMA[3]

[1]Kawabata Intelligent System Research Unit, Advanced Science Institute, RIKEN (The Institute of Physical and Chemical Research), Saitama, Japan
[2]Department of Information and Computer Sciences, School of Engineering, Saitama University, Saitama, Japan
[3]Research into Artifacts, Center for Engineering, The University of Tokyo, Tokyo, Japan

In an asbestos qualitative analysis, the major methods are X-ray diffraction analysis and visual observation by operators using a microscope. In particular, a major method of visual evaluation is dispersion staining. In the usual visual observation process, the operators check the asbestos fibers in the view of the microscope and count the number of asbestos fibers. The method presented here attempts to detect asbestos fibers in the images taken by a microscope. The dispersion staining method identifies asbestos fibers with color dispersion from an immersion liquid combined with polarization. The presented method employs color changes of asbestos fibers associated with polarization. Specifically, candidate asbestos fibers are identified using the changes of dispersion colors and also position-matching between two images. The performance of the method has been evaluated by comparing its results with the results obtained by a human expert.

Keywords asbestos, dispersion color, image processing, qualitative analysis

Introduction

Asbestos is a natural ore that is used in great quantities due to its light weight, tensile strength, heat resistance, chemical resistance, soundproofing ability, electrical insulation, and durability. In the construction of houses, buildings, and schools, asbestos has widely been used as heat insulating materials, mold plates, and other building materials. However, if too much dispersed asbestos is inhaled, the fibers remain in the lungs. This has been found to cause such health problems such as malignant mesothelioma, lung cancer, or asbestosis after a latency period of 20 to 40 years (Furuya et al. 2001).

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Address correspondence to Kuniaki Kawabata, Kawabata Intelligent System Research Unit, Advanced Science Institute, RIKEN (The Institute of Physical and Chemical Research), 2-1, Hirosawa, Wako, Saitama 351-0198, Japan. E-mail: kuniakik@riken.jp

As part of the countermeasures against these drawbacks of using asbestos, asbestos analysis is indispensable for investigating whether materials used in buildings contain enough asbestos to cause health problems. Recently, a simple asbestos detection test (Kuroda et al. 2008) was developed to detect asbestos contained in the air by using a specific combination of proteins. Since this kit is not based on a Japanese Industrial Standard (JIS), however, analysis conforming to the standards is necessary. In addition, only chrysotile is detected and other types of asbestos are not.

Asbestos analyses are both qualitative and quantitative: qualitative analyses check whether building materials contain sufficient asbestos fibers to cause health problems, while quantitative analyses determine the ratio of asbestos components. For qualitative analyses, X-ray diffraction analysis and visual inspection are used in combination. The X-ray diffraction analysis method (Lane & Haartz 1979) has already been automated (e.g., Shimadzu X-ray diffractometer XRD-6100). Visual inspection, however, requires considerable labor and time and decreases work efficiency. With the recent increase in the number of asbestos-related problems, requests for asbestos analysis have been steadily increasing and the need to perform efficient analysis has also increased markedly.

The purpose of this study was therefore to develop image-processing technology (Takagi & Shimoda 1991) that could be used to support evaluations of asbestos by the dispersion staining method, a qualitative method for analyzing asbestos. In particular, this study focuses on the evaluation of asbestos fibers in construction materials because it is a hard task for human experts to extract only asbestos fibers from the many pulverized small particles of the construction materials on the image.

Magiscan (Baron & Shulman 1987; Kenny 1984) was developed as an automatic counting system for sampled asbestos fibers in air. The system evaluated the linear features of the objects in the images. Inoue et al. (1998, 1999) also developed AFACS (asbestos fibers automatic counting system) for visual counting of asbestos fibers in air; it extracted the asbestos fibers in the image by using the process of border tracking, smoothing, thinning, and so on. These systems employ image-processing techniques based on a threshold value to brightness distribution on the image. However, the brightness distribution of asbestos fiber is not constant in each sample. Recently, Inoue et al. (2007) proposed an automated asbestos fiber counting method based on the edge information on the images. In either case, the target is sampled asbestos fibers in air; the image almost always includes a small amount of other particles that are like pulverized construction materials.

The method presented in this article detects only asbestos fibers among many of types of particles by using both dispersion color information and shape information.

Asbestos Qualitative Analysis

Qualitative analysis tests determine whether the sample being examined contains asbestos fibers. This analysis is typically conducted using X-ray diffraction and dispersion staining methods. The presence of asbestos is then assessed using both results.

The X-ray diffraction analysis method acquires an X-ray diffraction peak by irradiating a sample and determines whether the X-ray diffraction peak matches an asbestos-specific peak.

Table 1. Dispersion colors of asbestos

Asbestos type	Refractive index	Dispersion colors
Chrysotile	1.550	Red purple to blue
Amosite	1.680	Pink
	1.700	Blue
Crocidolite	1.680	Orange
	1.700	Blue

The dispersion staining method is a visual inspection method in which color dispersion from an immersion liquid combined with polarization are used to identify asbestos fibers. The JIS standards (JIS A 1481: 2006(J) 2006) prescribe the dispersion staining method using a microscope as follows:

1. Observe a prepared sample on the slide glass under a 10× objective lens of a dispersion microscope to find fibers indicating dispersion colors. If any such fiber is found, change the objective lens to 40×.
2. All droplets, up to 1000 droplets, in the area within view using the 40× objective lens are counted. If the dispersion colors match those of asbestos-specific fibers, then the types and quantities of asbestos are recorded. The droplets include all substances in the view and all droplets in the view are counted, irrespective of the type, size, or shape. The asbestos-specific dispersion colors prescribed by the JIS are shown in Table 1.
3. Perform the above processing using three immersion liquids with different refractive indexes. A total of 3000 droplets are investigated to determine whether there are four or more types of asbestos fibers with aspect ratios of 3.0 or more. To determine whether asbestos fibers are present, this result is compared with the results of the X-ray diffraction analysis method, shown in Table 2.

Using this test, the greatest factor decreasing work efficiency of the dispersion staining method is that asbestos fibers have to be counted visually. These microscopic observations are labor and time intensive. Field interviews revealed that not more than 10 samples can be analyzed daily.

In this study, therefore, the authors developed an image processing technology for enhancing the efficiency of asbestos fiber counting by the dispersion staining method.

Table 2. Evaluation of existence of asbestos

	X-ray diffraction analysis method	
	Diffraction peak	No diffraction peak
Dispersion staining method		
Four or more fibers among 3,000 droplets	Qualitative analysis	Qualitative analysis
Fewer than four fibers among 3,000 droplets	Reanalysis by the dispersion staining method	Sample not containing asbestos

Asbestos Fiber Counting by Image Processing

Asbestos fibers in an image are identified and counted using an image-processing technique. To identify asbestos fibers, the authors used the changes of dispersion colors associated with liquid immersion and polarization. Dispersion staining and polarization are advantageous because they can be used to identify candidate asbestos fibers. The technique also ensures that only asbestos fibers of a fixed or greater aspect ratio, those considered harmful, are counted.

Extraction of Asbestos Fiber Candidate Areas

To enumerate them, the asbestos fibers in an image must first be identified. As mentioned above, the authors employed color changes of asbestos fibers associated with polarization for identification. Specifically, candidate asbestos fibers were identified using the changes of dispersion colors between two images if there was a difference in the polarization qualities of the fibers in the images.

To identify candidate asbestos fibers, it is necessary to compare the color values of pixels corresponding to the same fiber in two original images. Because polarization results in a difference in the color values of the pixels in the two original images, corresponding pixels of the two original images cannot be directly compared. Therefore, the deviation is corrected first, but since the deviation here is very fine, the registration between two pictures can be corrected by comparing with the translational shift (vertical and horizontal direction in parallel).

A general algorithm used for image alignment compares the red-green-blue (RGB) values of a pixel in one image with the corresponding pixel of the other image. The sum of the square error of the positions is minimized to estimate the best matching position. The RGB values cannot be used alone as standards for alignment because the object image has unevenness and the RGB values of the background pixels and droplet pixels are not consistent. Without color information, only the pixel brightness can be used as the standard for alignment. Since information for the standards is reduced from three values (RGBs) to one (brightness), the correction values become consistent.

More specifically, original images are converted into gray scale images. Pixels in each gray scale image with a fixed, or greater, pixel value are then compared; the three pixels adjacent (above, below, and on the right and left) to the specified pixel (x_i, y_i) in the two input images (total of 48 pixels) are compared, and the difference between these pixels is calculated. Then the positional deviation (x_i, y_i) from pixels showing no difference from the specified pixel is calculated. A supervised classification is thus performed on the raster image for all with a specified pixel value or greater to calculate:

$$
\begin{aligned}
S_x &= x_i \quad (i = 1, 2, 3, \ldots, n) \\
S_y &= y_i \quad (i = 1, 2, 3, \ldots, n)
\end{aligned}
\tag{1}
$$

The corrected values of the entire image are determined from the calculated data (S_x, S_y), but the S_x and S_y values tend to fluctuate. This is attributed to a slight difference of pixel values between the corresponding pixels because polarization slightly changes the intensity and direction of reflected light, even for the same droplet between two images. If the data are averaged, therefore, outliers can affect the result, which is why median values are generally used for statistical analysis. A median is the number separating the higher half of the data, which are arranged according to size. In this study, the outliers had very little influence on the medians.

To obtain the medians for calculated data $(S_x x, S_y)$, the S_x and S_y values are sorted by size. The following data string is obtained after sorting:

$$\begin{aligned} S'_x &= x'_i \quad (i = 1, 2, 3, \ldots, n) \\ S'_y &= y'_i \quad (i = 1, 2, 3, \ldots, n) \end{aligned} \tag{2}$$

where the medians (x'_c, y'_c) of S'_x and S'_y can be calculated as follows:

$$x'_c = \begin{cases} x'_{\frac{n+1}{2}} & (n \bmod 2 = 1) \\ \frac{1}{2}\left(x'_{\frac{n}{2}} + x'_{\frac{n}{2}+1}\right) & (n \bmod 2 = 0) \end{cases} \tag{3}$$

$$y'_c = \begin{cases} y'_{\frac{n+1}{2}} & (n \bmod 2 = 1) \\ \frac{1}{2}\left(y'_{\frac{n}{2}} + y'_{\frac{n}{2}+1}\right) & (n \bmod 2 = 0) \end{cases} \tag{4}$$

With the calculated medians (x'_c, y'_c) as correction values, the entire image is moved in parallel by x'_c in the X direction and by y'_c in the Y direction. This is the preprocessing stage for identifying candidate asbestos fibers.

Then, the asbestos fiber candidates are identified. For image processing, various color spaces are used. Here, the most common RGB values are used. The method for identifying candidate asbestos fibers is explained below:

From two aligned images, the sum square of the differences in the RGB values of all corresponding values is calculated. This equals the square of the distance between two points in a color space. A pixel greater than a fixed distance value t_d is binarized as a white pixel, and a pixel below a fixed distance value t_d is binarized as a black pixel (Figure 1). The example shown in Figure 1(c) is larger than the actual size because numerous pixels other than asbestos fibers were detected and the color changes of light emitted from the asbestos fibers were also detected. This is attributed to the distance threshold t_d, which is set as low as 100 to increase the likelihood of finding asbestos. When the distance threshold t_d is set to 1000, although only a few pixels other than asbestos are detected (Figure 1(d)), not as many asbestos droplets can be detected as at $t_d = 100$. In addition, the pixels do not as appear as large as the actual asbestos fibers. According to Figure 2, the fiber on the right side of the image was detected at $t_d = 100$ but not at $t_d = 1000$. This is because the changes of the color tone of the asbestos fibers are small. Thus, if the threshold t_d is increased, asbestos may not be detected and harmful building materials may be judged as asbestos free. To avoid this problem, the threshold t_d should thus be set low, which is why t_d was set to 100 in this study.

The processing described above extracts candidate asbestos fibers.

Detection of Harmful Asbestos Fibers

After identifying candidate asbestos fibers, asbestos fibers of a fixed or greater aspect ratio are extracted. Therefore, it is necessary to calculate the aspect ratios of all candidate asbestos fibers.

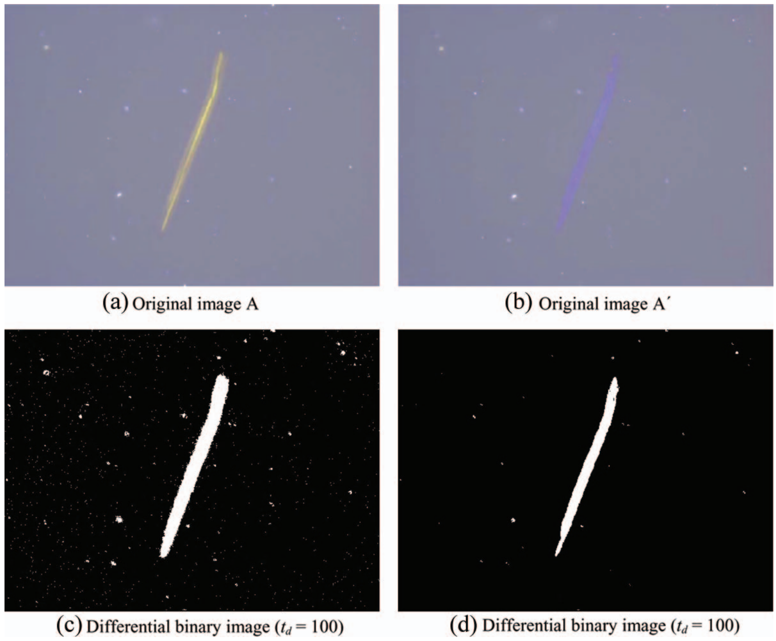

Figure 1. Example of color difference processing (1).

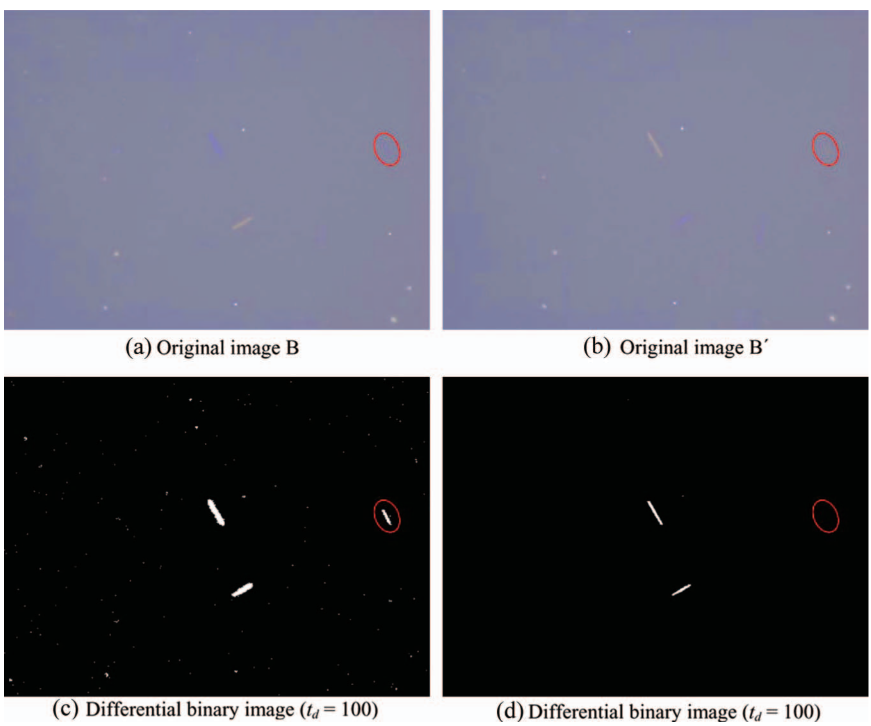

Figure 2. Example of color difference processing (2).

The specific aspect ratio calculation requires that the droplets in the binary image created using the technique described in the previous section be calculated. If the coordinates after rotation are $(\tilde{x}, \tilde{y})$ the formula for rotating a pixel (x, y) around (a, b) by A [*rad*] is:

$$\begin{aligned} \tilde{x} &= (x - a)\cos(-A) - (y - b)\sin(-A) + a \\ \tilde{y} &= (x - a)\sin(-A) - (y - b)\cos(-A) + b \end{aligned} \tag{5}$$

By using this formula, droplets detected by differences in color tone are rotated at iterations of $(\pi/6)$ rad. As shown in Figure 3, after each rotation a droplet is enclosed in a circumscribing rectangle and the aspect ratio is calculated. This process is repeated six times, and the largest value is then taken as the aspect ratio of the droplet.

In the case of Figure 3, for example, the greatest aspect ratio is shown in (c). This processing is performed on all candidate asbestos fibers.

Since some candidate asbestos fibers reflect light from the microscope, and since color changes of reflected light are also detected by color tone differences, the aspect ratios of candidate asbestos fibers in the binary images created in the previous section tend to be smaller than those of asbestos fibers in the original images. If the reference value for an aspect ratio is set to 3.0, asbestos fibers with an aspect ratio of 3.0 or greater cannot be detected in the original images. Therefore, the authors conducted a basic experiment. Sample data for chrysotile, amosite, and crocidolite showed that the aspect ratio varied from 1.5 to 3.0 (as prescribed in the JIS standards). Table 3 summarizes the number of asbestos fibers that could not be detected (detection failures) and the number of droplets without asbestos fibres that were identified as containing asbestos fibers (erroneous detections).

As we can see from Table 3, erroneous detections decrease and detection failures increase when the aspect ratio is set to approximately 3.0. However, when the aspect ratio decreases, detection failures also decrease but erroneous detections increase. Therefore, the aspect ratio needs to be set at an optimum level where the number of detection failures and erroneous detections are both at a minimum. Table 3 shows that the optimal aspect ratio should be 1.8 to 2.0 for chrysotile and 1.9 to 2.0 for amosite and crocidolite. Therefore, a threshold aspect ratio of 2.0 was used for the experiment in this study. In addition to the aspect ratio, large candidate asbestos fiber droplets with aspect ratios of 1.5 or greater were considered to be droplets most likely to contain asbestos fibers. The following conditions were therefore used in a count of asbestos fibers using the supervised classification described above: an

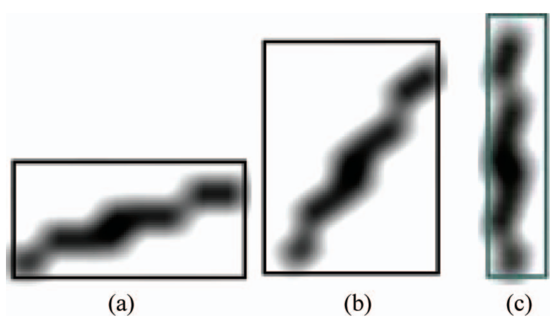

Figure 3. Changes of the aspect ratio by object rotation.

Table 3. Difference between the number of detection failures and the number of erroneous detections

Aspect ratio	Number of detection failures	Number of erroneous detections
(a) Chrysotile		
1.5	0	2
1.6	0	1
1.7	0	1
1.8	0	0
1.9	0	0
2.0	9	0
2.1	1	0
2.2	1	0
2.3	1	0
2.4	2	0
2.5	2	0
2.6	2	0
2.7	3	0
2.8	3	0
2.9	3	0
3.0	3	0
(b) Amosite		
1.5	0	2
1.6	0	2
1.7	0	2
1.8	0	2
1.9	0	0
2.0	0	0
2.1	0	0
2.2	0	0
2.3	0	0
2.4	0	0
2.5	0	0
2.6	0	0
2.7	0	0
2.8	1	0
2.9	1	0
3.0	1	0
(c) Crocidolite		
1.5	0	6
1.6	0	4
1.7	0	2
1.8	0	2
1.9	0	0
2.0	0	0

(Continued)

Table 3. Continued

Aspect ratio	Number of detection failures	Number of erroneous detections
2.1	0	0
2.2	0	0
2.3	0	0
2.4	0	0
2.5	0	0
2.6	0	0
2.7	0	0
2.8	0	0
2.9	0	0
3.0	0	0

image was created by extracting asbestos fibers, after extraction, asbestos fibers were counted by labeling the pixels of the asbestos fibers.

Experiment

Experimental Conditions

For the experiment, commercial chrysotile, amosite, and crocidolite samples, obtained from the Japan Association for Working Environment Measurement, were used. From these standard samples, prepared samples for observation were fabricated. Under a phase-contrast dispersion microscope, the authors took several images of each sample while changing the dispersion colors of the asbestos fibers by polarization. The image types and the numbers of samples are listed in Table 4. As mentioned above, the asbestos fibers were counted using two images with different dispersion colors in one set.

By using the proposed method, it is possible to distinguish between asbestos and other fibrous materials because the method evaluates not only the shape but also the difference of dispersion color of the target. In actuality, there were fibrous materials in the microscopic images for the experiments.

Results

Table 5 shows the asbestos fiber counting results. The actual asbestos and measured asbestos counts of all images used for asbestos fiber counting were summed, and the average number of failure detections and the average number of erroneous

Table 4. Original images used for the experiment

Image type	Asbestos fiber count
Sample containing chrysotile	78 (39 sets)
Sample containing amosite	108 (54 sets)
Sample containing crocidolite	76 (38 sets)

Table 5. Asbestos fiber counting results

	Sample containing chrysotile	Sample containing amosite	Sample containing crocidolite
Actual asbestos count	149	167	72
Measured asbestos count	182	210	214
Average of detected failures	0.37	0.34	0.21
Average of erroneous detections	1.22	1.13	3.95

detections for each group were calculated. For samples containing crocidolite, the average number of detected failures per image was small compared with the other two types for which numerous droplets other than asbestos fibers were erroneously detected.

In the case of one sample of chrysotile (Figure 4), the original images show three asbestos fibers. All of the fibers were detected successfully and no erroneous assignments were made.

In the case of one sample of amosite (Figure 5), the original image shows three amosite fibers. All of the fibers were successfully detected and, other than amosite, no erroneous assignments were made for fiber droplets.

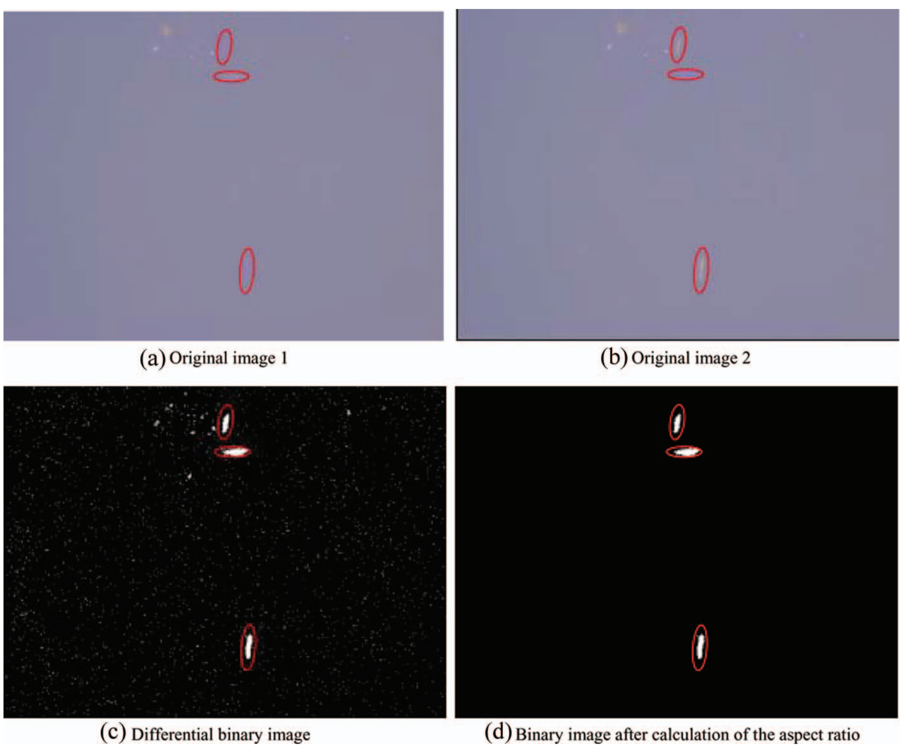

Figure 4. Successful counting of asbestos fibers (chrysotile).

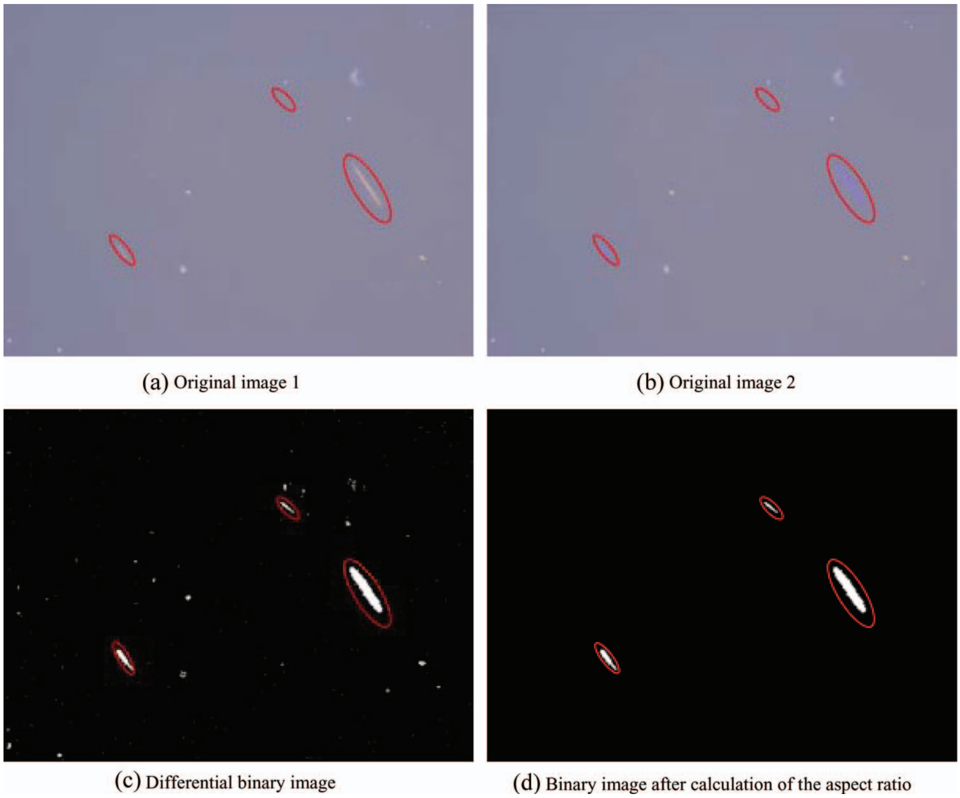

Figure 5. Successful counting of asbestos fibers (amosite).

As shown in Figure 6(c), several droplets other than crocidolite fibers were detected by differences in color tone. When this image is processed using the aspect ratio calculation, only crocidolite droplets were detected (Figure 6(d)). The original images also show a crocidolite fiber with an aspect ratio over 3.0 (circle), which was successfully detected.

Discussion

Asbestos fiber detection failures occur because polarization does not greatly change the color tones and the asbestos fibers cannot be detected by differences in color tone. In addition, when changes in tone are great, the tone of reflected light from the asbestos fibers also changes. The detection of this reflected light is another factor. These factors combine to make the aspect ratio of an asbestos fiber smaller than the actual aspect ratio (Figure 7), causing detection failure. Asbestos fibers exhibiting marked variations in color tone in small areas exhibit this phenomenon.

Numerous droplets other than asbestos fibers are detected by color tone differences if the pixel positions cannot be matched when the two original images are aligned. Since the angle of polarization is changed between two original images, even the pixel values of corresponding pixels often fail to match completely. For alignment, the pixel values of a specified pixel and the 48 neighboring pixels are compared with those of the corresponding image pixels. Since the pixel values of

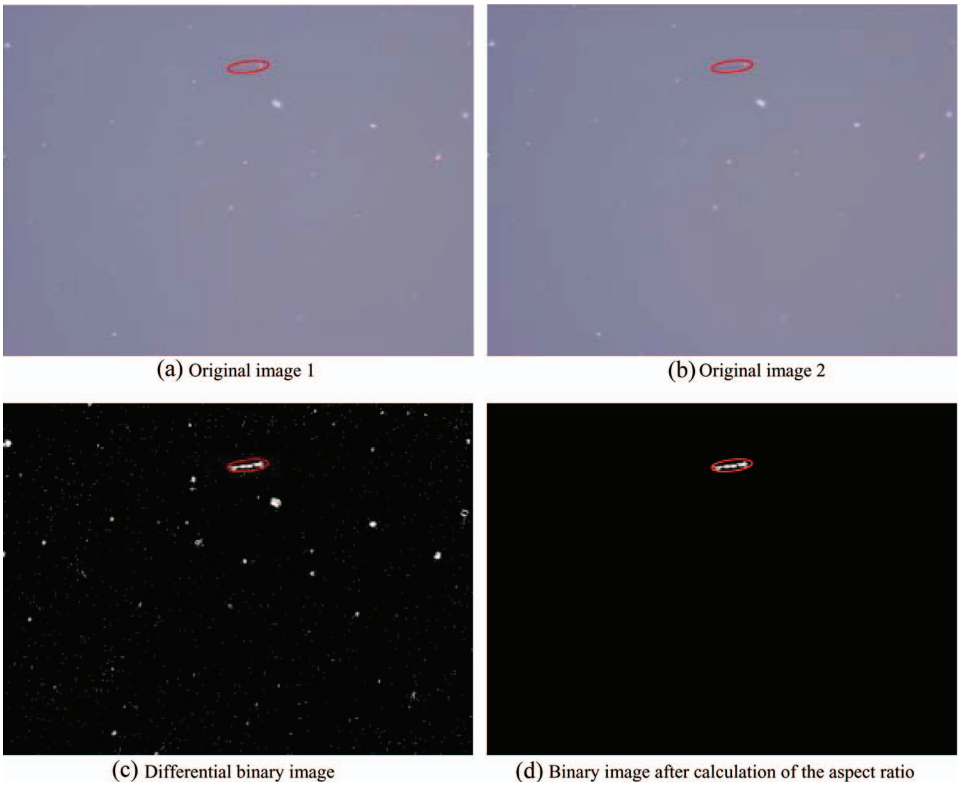

Figure 6. Successful counting of asbestos fibers (crocidolite).

the corresponding pixels differ due to the reason given above, a pixel value may accidentally match that of another pixel among the 48 neighboring pixels. If this problem occurs frequently in images, the positions may be corrected in the wrong directions. If color tone differences are obtained from two original images with alignment failures, droplets and backgrounds may be compared with each other. Since the background colors differ greatly as a matter of course, many droplets other than asbestos fibers could be detected. It is these droplets with aspect ratios of 2 or greater that seem to be detected as candidate asbestos fibers.

All of these failures can be attributed to the influence of the aspect ratio. By varying the aspect ratio from 1.5 to 3.0, the authors averaged and clarified the

Figure 7. Decrease of the aspect ratio by color tone difference.

asbestos fiber detection failures per image and also the number of erroneously identified droplets.

In Figure 8, the average number of asbestos fiber detection failures for all three asbestos types tested increases as the aspect ratio is increased; however, the increase of crocidolite failures is relatively low compared to chrysotile and amosite. In other words, there are many asbestos fibers among chrysotile or amosite with aspect ratios in the rage of 1.5 to 3.0 but not many among crocidolite. Possible factors

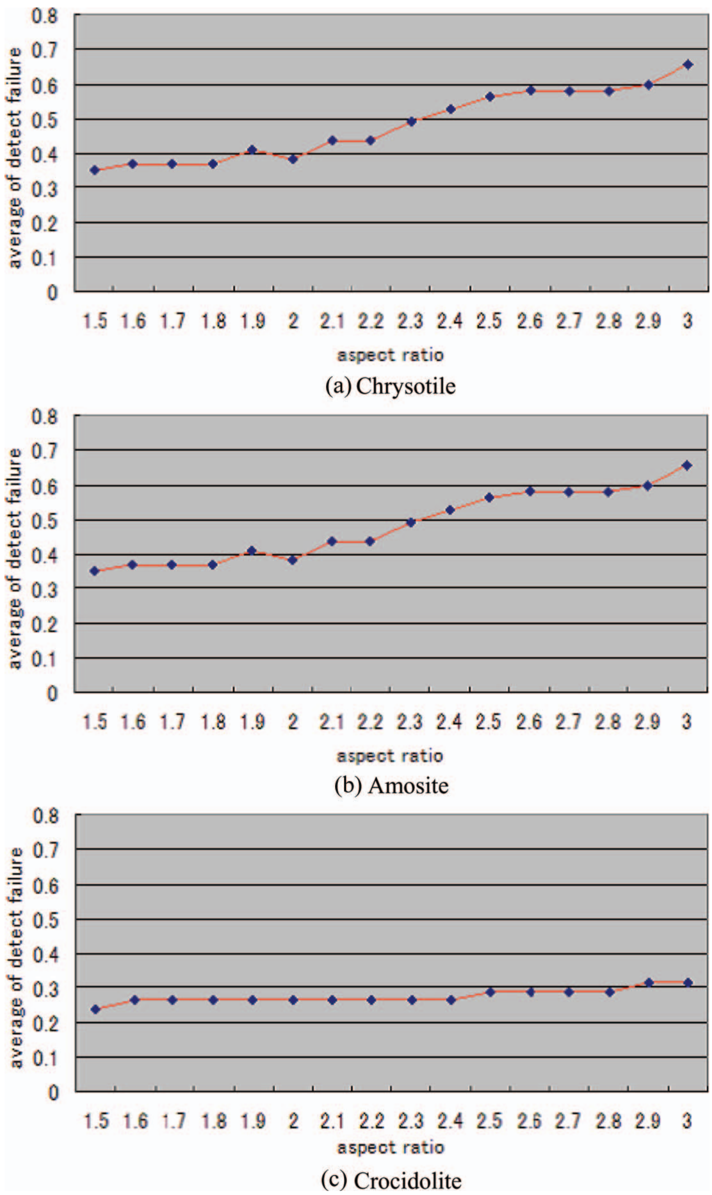

Figure 8. Average number of asbestos fiber detection failures per image according to the aspect ratio.

include dispersion colors and the intensity of reflected light. The reflected light from chrysotile or amosite is strong because the dispersion colors are bright. Since the aspect ratios of asbestos fibers after detection become smaller than the intrinsic aspect ratio, many asbestos fibers are considered to exist in the range of 1.5 to 3.0.

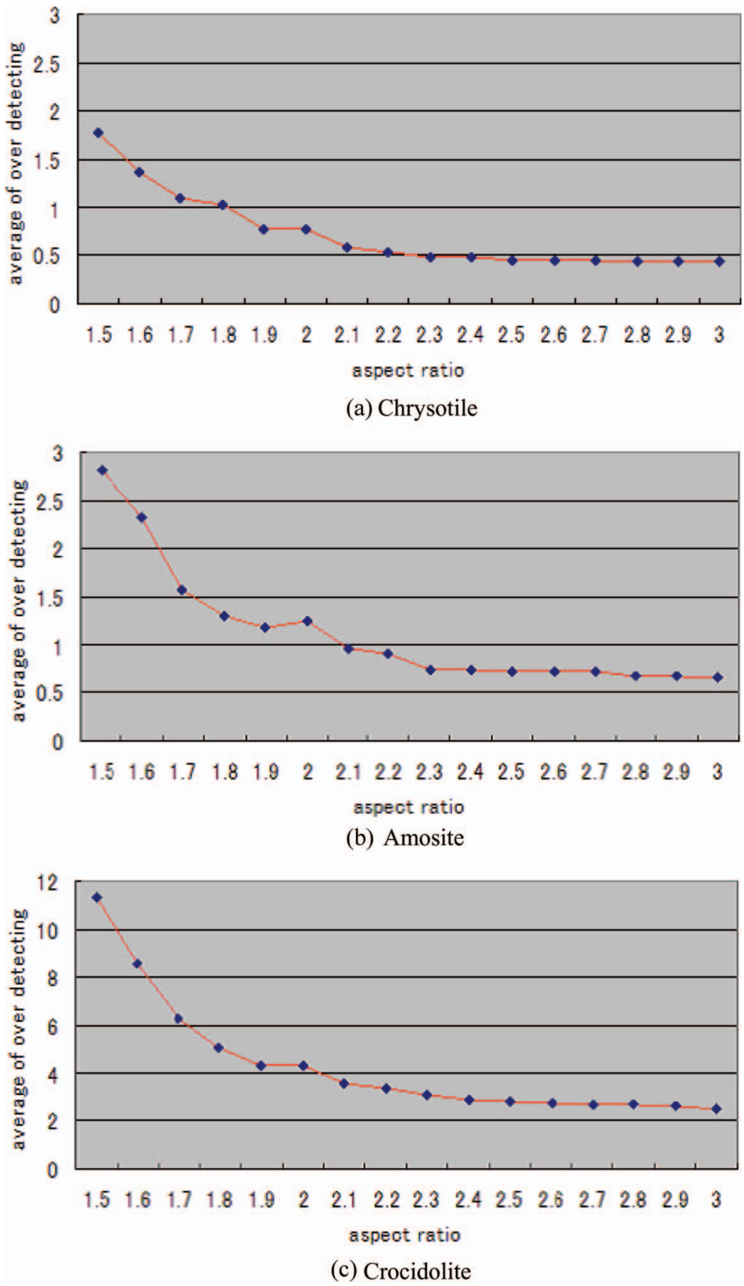

Figure 9. Average number of droplets misidentified as asbestos fibers per image according to the aspect ratio.

Meanwhile, the reflected light from crocidolite is weak because the dispersion color is dark. Therefore, the shapes of asbestos fibers can be detected rather clearly. This may be why the number of crocidolite detection failures was not affected by the aspect ratio, but the detection failures of the asbestos fibers could not be conducted at the stage where color tones are compared.

In Figure 9, as the aspect ratio increases, the average number of erroneous detections of droplets other than asbestos fibers decreases. This result is opposite that of the average number of asbestos fiber detection failures (Figure 8). This means that numerous droplets other than asbestos fibers exist with aspect ratios ranging from 1.5 to 3.0. According to Figure 9, the average number of erroneous detections is especially great for crocidolite, probably because the number of crocidolite droplets per image was greater than the number of chrysotile and amosite droplets per image.

Conclusions

In this study, to reduce the time and effort required for asbestos detection, the authors developed a technique for counting asbestos fibers using an image-processing method based on the dispersion staining method used in asbestos analysis.

Using a phase-contrast dispersion microscope, two original images showing color changes in asbestos fibers in response to liquid immersion and polarization are aligned according to respective pixel locations. Using color tone differences, color-changed pixels are detected. By calculating the aspect ratios, candidate asbestos fibers with aspect ratios of 2 or greater are detected and labeled for counting.

The proposed technique was applied experimentally to images obtained from standard samples of three types of asbestos (chrysotile, amosite, and crocidolite). Statistical analysis of the entire images revealed that the average number of asbestos fiber detection failures per image was approximately 0.4 for chrysotile and amosite and approximately 0.2 for crocidolite. Conversely, the average number of incorrectly identified asbestos fiber droplets as was approximately 1.2 for chrysotile and amosite and approximately 4.0 for crocidolite.

The proposed technique assumes utilizing to static microscopic images. Therefore, some improvements would be required to apply to real-time detection using a video camera; they would be discussed in our future work.

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