Non-destructive test of watermark materials quality for art pottery using x-ray digital radiography

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Abstract: In this study, the quality of watermark materials for art pottery were tested using x-ray digital radiography. The embedded watermarks in art pottery were chosen from 3 materials namely wood, and polylactic acid (PLA), and acrylic. Watermarked potteries quality testing were carried out during the making process, namely before and after being burned. Watermarked potteries were tested with 60 kV tube voltage regulation, 16 mA strong current, and 0.16 s exposure time. The radiographic image results obtained were then analyzed using ImageJ software. There are 3 stages of testing, namely visual analysis, image line profile analysis, and linear attenuation coefficients analysis. The results of visual analysis show that there were no crack in the watermarks so that planting the watermark did not damage the pottery. The graph of image line profile analysis results shows that the watermark made from wood was most clearly seen on the radiographic image. The attenuation coefficient value in the watermarked part does not change before and after the burning process while the attenuation coefficient value of the pottery had increased due to the shrinking process of the pottery. Wood has the largest attenuation coefficient value difference with pottery, so making it suitable as a watermark material for art pottery.

1. Introduction

In the marketing process, product counterfeiting often takes place, including the counterfeiting of art products such as clay pottery [1]. To protect the copyright of art pottery products, watermarking techniques are needed that produce markers of a product so that its authenticity is maintained. Watermarking is very popular to hide data in a product because it is invisible and inseparable from products that are given a watermark [2]. To get a good watermark for pottery products, it is necessary to test the quality of the watermark material.

The technique that can be used is Non-destructive test (NDT) because by using this technique, the watermark will be observed properly without splitting the pottery product. The NDT techniques that have been used to identify pottery are optical techniques [3] and imaging techniques using X-ray radiography [4-9]. X-ray digital radiography is better than optical technique because X-rays more easily penetrate thicker objects than visible light. X-ray digital radiography can inspect the contents inside of art pottery without damaging it [8]. Digital X-ray radiography is one of the NDT techniques that can be
used as a tool to describe the internal parts of an invisible material without damaging and splitting the material [10-12].

But until now X-ray digital radiography is only widely used in the medical sector. Utilization of X-ray digital radiography for the industrial sector is still very rare, especially in the art pottery industry. Although some previous studies have shown that X-ray radiography is used for pottery inspections, but most research is focused on historical pottery [4-9]. Whereas, if we use it in the art pottery industry it will be very useful for quality control for craftsmen especially in testing the quality of watermark material.

For some reason above, it is important to conduct research on the quality test of watermark materials using digital X-ray radiography. This research focuses on examining the possibility of physical changes that occur in art pottery during the manufacturing process, starting from the printing process to burning if there is a watermark in it. This study also looks at the possibility of changes in shape that occur in the watermark during the process of making art pottery, so that the ideal material for making watermark is known because it is clearly seen on the radiographs of art pottery. Watermark material suitable for clay will be obtained, so that it can be formed, not causing cracks during the drying and combustion processes.

2. Methods
2.1. Sample Preparation
Material samples that are prepared are art pottery and watermark. Pottery is made of clay with a thickness of 7 mm. Pottery is shaped like a bowl with a diameter of 20 cm. The sample watermark materials that are used comes from wood, acrylic, and polylactic acid (PLA). Watermarks are shaped like a flower frame with a thickness of 2 mm. Watermarks are incorporated into the art pottery during the making process. The sample of the pottery and watermark is shown in figure 1.

![Figure 1. (a) Art pottery (b) watermark; blue (PLA), brown (wood), transparent (acrylic)](image)

2.2. Exposure of X-ray radiation
X-rays exposure process using x-ray digital radiography is intended to obtain radiographic images. X-ray radiation is carried out during dry-watermarked pottery after it is burning at a temperature of 1000 °C. X-rays exposure use optimized exposure factors, namely 60 kV of the tube voltage, 16 mA of the filament current, 0.16 seconds of the exposure time, and 100 cm of the exposure distance. For every watermarked pottery sample, radiographs are taken 3 times and then averaged. Set up of x-ray digital radiography shown in figure 2.
Figure 2. Set up of X-ray digital radiography (a) Monitor screen, (b) CPU, (c) Copper shielding box, (d) X-ray tube, (e) Fluorescent screen, (f) Camera, and (g) Panel control

2.3. Watermark material quality analysis

Quality analysis of watermark materials is divided into 3 stages, namely visual inspection, analysis of image line profile, and analysis of linear attenuation coefficients.

Visual inspection is done by seeing the results of watermarked pottery samples and radiograph results directly after the process of making, drying, and burning. Inspections is done to see if there are any samples that experience cracks on the surface or internal part of the pottery samples which are not seen directly after the drying and burning process.

Line profile analysis is used to determine the gray value of the selected pixel line. Line profile analysis use ImageJ software by drawing a straight line at the position that we want to know the gray value from the radiographic image. The line profile is produced a graph that represents the pixel position on the x-axis, and the average gray value of the pixel on the y-axis.

Figure 3. Selection of ROI data from the radiograph image

The attenuation coefficient analysis is used to determine the value of the attenuation coefficient of art pottery samples and the watermark in it. Retrieval of data use the ROI Manager on the ImageJ software to get the gray value. Data retrieval is done on three part, namely the background image, the image of the pottery section without watermark, and the image of the pottery section with a watermark in it. Linear attenuation coefficients were analyzed according to the Beer-Lambert equation shown in equations 1 and 2.

\[
\mu_g x_g = \ln \left( \frac{I_0}{I_g} \right) \tag{1}
\]

\[
\mu_w x_w + \mu_g (x_g - x_w) = \ln \left( \frac{I_0}{I_w} \right) \tag{2}
\]
Where $I_0$ is the gray value average on the background image, $I_g$ is the gray value average on the image part of the pottery without watermark, $I_w$ is the gray value average on the image part of the pottery with watermark, $x_g$ is the thickness of the pottery, $x_w$ is watermark thickness, $\mu_g$ is the pottery attenuation coefficient, and $\mu_w$ is the watermark attenuation coefficient. Selection of ROI data more clearly is presented in Figure 3.

3. Results and Discussion

3.1. Visual inspection

Visual inspection is done by looking at all the results of the pottery sample and its radiograph directly in each making process. Inspection results showed that there was no major damage to the pottery samples such as cracks on the surface of the pottery. Pottery radiograph results except for the watermark also there are no cracks in the pottery that are not visible from the surface. These show that the watermarked potteries have good quality, and shows that the planting of watermarks using wood, acrylic and PLA as the base material does not damage the pottery during the making process [1,13]. If observed in Figure 4 visually, all types of watermarks appear to have the same contrast so that through this analysis have not been able to find the best watermark.

![PLA watermark after being burned](image1)
![Acrylic watermark after being burned](image2)
![Wood watermark after being burned](image3)

![PLA watermark before being burned](image4)
![Acrylic watermark before being burned](image5)
![Wood watermark before being burned](image6)

Figure 4. Radiograph image of watermarked pottery

In addition, for all types of watermarks, a more contrasting image seen in the condition of the pottery has been burned. This is because after experiencing clay burning the water content is reduced and causes changes in the density of the pottery [13]. Changes in clay density to watermark density produce a more contrast watermark image.
3.2. Analysis of image line profile.

Qualitatively, the watermark in the pottery can be seen clearly, especially after going through the burning process through radiographic images. Quantitatively, a line profile analysis is performed to determine the exact gray value on the radiographic image so that the watermark material that can be seen is most clearly visible in the pottery. An analysis of the watermarked pottery radiograph profile produces a graph with two peaks. The peak indicates that the part is a watermark because it has a different gray value than the pottery section. Line profile analysis was performed on all radiographic images to obtain a profile graph. The graphs are then compared with each other so that the watermark material that is most clearly visible on radiographs can be identified. This analysis presents a graph comparing the line image profiles for watermark variations during conditions before burning (Figure 5) and after burning (Figure 6).

![Figure 5. Line profile of pottery image for watermark variations before burning](image1)

![Figure 6. Line profile of pottery image for watermark variations after burning](image2)

Watermarking aims to provide the characteristics and mark of the authenticity of the pottery, therefore the watermark pattern must be clearly visible after the pottery is finished. Based on Figure 5, it can be observed that the peak gray value for acrylic watermarks shows the lowest results while the wooden watermark obtains the highest gray value peak. Physically, the phenomenon of the difference in gray values between the three types of watermarks can occur due to differences in the density of watermark material. Density of denser material causes the intensity of X-ray radiation that can penetrate smaller objects so that the gray value in the image obtained is lower (dark) [10-12,14]. Wood has the lowest density compared to acrylic and PLA so that the intensity of X-ray radiation that penetrates the
wood and reaches the detectors is higher. Figure 6 displays a graph of gray value after the pottery goes through the final burning process. Figure 6 shows that the top edges of the graph are quite steep, indicating the edge of the watermark clearly looks different from the pottery. Acrylic watermark has the lowest graph peak. This indicates that the acrylic material looks the faintest on radiographic images compared to wood and PLA materials. The watermark in wood shows the highest peak so that it can be said to be the most contrasting [13].

In the pottery condition before and after being burned, wood watermarks consistently have the highest gray value peaks so that based on the results of the line profile analysis graphs, it can be seen that the wood material is best used as a watermark in pottery because it is seen most clearly on radiographic images compared to acrylic and PLA. When compared them, the graph between the line profiles of watermarked pottery before and after being burned shows a higher trend. That is because after the burning process there is a thick shrinkage of the pottery. In accordance with Lambert Beer's Law (Equation 2), the intensity of radiation penetrating an object (transmittance) decreases exponentially regarding the thickness of the material [12]. After burning the pottery, it has thick shrinkage so that the intensity of X-ray radiation that penetrates is higher than before burning. This is what causes the gray value on the line profile which is a representation of the intensity of the transmittance radiation has increased after the pottery is burned.

3.3. Analysis of linear attenuation coefficients

In the stage pottery before being burned, Table 1 shows the average value of the attenuation coefficient on pottery worth 1.011 cm\(^{-1}\) with a maximum error of 0.01 cm\(^{-1}\). These results indicate that the pottery used in this study is homogeneous for each sample. The attenuation coefficient value correlates with the density of a material [14]. The value of the attenuation coefficient is relatively homogeneous in the three samples of pottery before it is burnt, showing that the pottery is made with the same conditions both in terms of clay content and the proportion of water content. In the section contained in the watermark, it is seen that wood has the lowest attenuation coefficient value compared to paraffin and PLA. The low value of the wood attenuation coefficient indicates that the X-ray photons are the easiest to pass through wood compared to paraffin and PLA. The difference in attenuation coefficient values is caused by differences in the particles making up the material and the density of the watermark material particles.

| Process          | Watermark Materials | \(\mu_g\)        | \(\mu_w\)        |
|------------------|---------------------|------------------|------------------|
| Pottery before being burned | PLA                 | 1.014±0.010     | 0.886±0.014     |
|                  | Acrylic             | 1.009±0.008     | 0.987±0.013     |
|                  | Wood                | 1.019±0.009     | 0.850±0.012     |
| Pottery before being burned | PLA                 | 1.093±0.010     | 0.883±0.013     |
|                  | Acrylic             | 1.083±0.011     | 0.993±0.012     |
|                  | Wood                | 1.093±0.010     | 0.847±0.011     |

In the stage pottery after being burned, the average yield of pottery attenuation coefficient values is increasing compared to the stage before being burned. Once burned, the water content in the pottery is reduced, causing the pottery to begin to shrink. Depreciation of the pottery indicates that the particles making up the pottery earth come closer together to fill the void left by the vaporized water particles. The closer the particles making up the pottery, making it harder for X-ray photons to penetrate the pottery, so the potency attenuation coefficient value increases. The average value of the attenuation coefficient in the watermarked section also did not experience a significant change because the watermark material did not experience shrinkage [13]. The results of the attenuation coefficient analysis on the overall watermark show that wood has the lowest attenuation coefficient value compared to paraffin and PLA in each manufacturing process.
Therefore, the watermark made from wood is most clearly seen on the radiograph because it has the greatest attenuation coefficient value difference with pottery.

4. Conclusion
Watermarked potteries have good quality because there are no visible cracks on the surface or inside the earthenware based on radiographic images. In addition, the watermark can be clearly seen on the pottery radiograph until the end of the combustion process. Quality test of watermark materials show that wood is an ideal watermark material compared to paraffin and PLA. That is because the difference in the gray value and the attenuation coefficient value between wood and pottery shows the highest value.

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