World Journal of Nuclear Science and Technology, 2013, 3, 106-108
http://dx.doi.org/10.4236/wjnst.2013.33018 Published Online July 2013 (http://www.scirp.org/journal/wjnst)

Application of Photon-Counting X-Ray Computed Tomography to Aluminum-Casting Inspection*

Koichi Kan[1,2*], Yukino Imura[1,3], Hisashi Morii[3], Koji Kobayashi[2], Teruo Minemura[2], Toru Aoki[1,3]
[1]Graduate School of Science and Technology, Shizuoka University, Hamamatsu, Japan
[2]Hamamatsu TSC, Chuo Hatsumei Institute, Hamamatsu, Japan
[3]Research Institute of Electronics, Shizuoka University, Hamamatsu, Japan
Email: *kan@chuhatsu.co.jp

Received April 25, 2013; revised May 26, 2013; accepted June 4, 2013

ABSTRACT

One of the issues in the aluminum-alloy die casting industry is the space occurring inside the casting, and the improvement of the verification technology is expected. The purpose of this research is to seal holes inside the aluminum metal by resin and verify them by photon-counting X-ray computed tomography (CT) using an energy-discrimination 64-channel cadmium-telluride (CdTe) line detector. Moreover, it is important to estimate the image of the effective atomic number and the electronic density by the energy mapping of the attenuation coefficient utilizing photon-counting X-ray CT to distinguish both the aluminum metal and the resin filler in the aluminum hole. As a result, the energy discrimination of the resin filler in the space of aluminum casting has been attained. We could observe the atomic number image utilizing dual-energy X-ray CT method with the 64-channel CdTe photon-counting detector.

Keywords: X-Ray CT; Photon-Counting; Aluminum-Alloy Die Casting; Impregnation

1. Introduction

In the aluminum-alloy die-casting industry, the impregnation is one of the countermeasures for the space occurring inside the casting. Considering assurance of product quality, it is needed to evaluate whether the impregnation is adequate. However, it is a current state to rely on only the pressure inspection. In the pressure inspection, the sealing of one hole may guarantee the safety of many holes, and it is impossible to evaluate all the holes sealed by fillers. The size of hole is analogized according to the difference of the leak rate by the prior pressure inspecttion in the case of heavy leakage. However, it tends to be excluded from the impregnation processes.

In X-ray computed tomography (CT) image of the metal including aluminum, the deterioration of both the images caused by the Compton scattering and the beam hardening exists. Using the energy-discrimination photon-counting cadmium-telluride (CdTe) detector [1] developed in our laboratory, it was clarified to be able to remove the influence of Compton scattering without using X-ray photons below 40 keV and to suppress the image deterioration by beam hardening using photon-energy information. Mapping of effective atomic number and electron density using energy information had been reported [2]. With the eliminating beam hardening method and the mapping of the effective atomic number and the electron density, an X-ray CT system is expected to have capability for measurement. In this study, we verified both the sealing of hole in the aluminum metal casting goods and the impregnant material using the photon-counting X-ray CT.

2. Experiment

2.1. Impregnation

Using vacuum-dip-pressure method (MIL-1-6968) as the impregnation. Setting the sample in a pressure vessel, and the pressure is decreased to 65 Pa and is held at 65 Pa during 5 min. After immersion of the impregnating solution, the pressure is increased up to 0.4 MPa and is held during 5 min to seal holes. Next, the sample is removed from the pressure vessel after releasing air, unnecessary impregnant is wiped, and then the sample is warmed up to 95˚C using a dryer to during 1 hour. The sealing of the sample is checked before the measurement using the CT. The samples are made from aluminum die-casting alloy of ADC_{12}, and the impregnant material is methacrylate resin ($C_6H_{10}O_3$).

The sample 1 is cut to 10 mm square and has through

*Corresponding author.

holes of 5 and 4, 3, 2, 1 and 0.5 mm in diameter and the sample 2 is made from casting materials. The resin material for sealing is Super Seal P601, mainly consisting of methacrylate ester monomer.

2.2. X-Ray CT

The experiment was executed by scanning samples with a 64-channel CdTe line sensor (Hamamatsu), which consisted of 64 elements aligned side by side at intervals of 0.2 mm [1]. The measurement system is shown in **Figure 1**.

The rotation speed was 90 s for 360˚ (450 steps). Samples were inspected using the X-ray CT with a photon-energy-range from 40 to 150 keV. After sinogram was built, the CT images were reconstructed using the back projection filtered method [3]. With these CT images, the material identification by dual-energy X-ray CT (DXCT) was carried out. Mapping of the effective atomic number and the electron density is led as below [2]. When the two linear attenuation coefficients $\mu(E_1)$ and $\mu(E_2)$ corresponding to the different photon energies E_1 and E_2 are obtained from the CT images, the effective atomic number Z to the 4th power Z^4 is given by the following equation:

$$Z = \frac{\{\mu(E_2)G(E_1,Z) - \mu(E_1)G(E_2,Z)\}}{\{\mu(E_1)F(E_2,Z) - \mu(E_2)F(E_1,Z)\}} \quad (1)$$

where $G(E, Z)$ is the electron cross section according to scattering term, and $F(E, Z)$ is the photo electric effect. The effective atomic number Z is obtained first by iterative algorithm, and then the electron density ρ_e is determined by [4,5]:

$$\rho_e = \frac{\mu(E_1)F(E_2,Z) - \mu(E_2)F(E_1,Z)}{F(E_2,Z)G(E_1,Z) - F(E_1,Z)G(E_2,Z)} \quad (2)$$

3. Results and Discussion

Both the CT image and the effective-atomic-number mapping of aluminum sample 1 are shown in **Figure 2**. In sample 1, the effective atomic numbers of the aluminum-die-cast part and the impregnated part were 12.2 and 7.6, respectively. The error rate of the aluminum was 6%. As the effective atomic number of methacrylate resin (C6H10O3) was 6.58 with an error rate of about 13 %. Given that the effective atomic number obtained by a photon counting X-ray CT system includes error around 1.0 [2], these results indicates that aluminum and methacrylate resin were identified.

The CT image of sample 2 is shown in **Figure 3(a)**, and expanded image is **Figure 3(b)**. In **Figure 3(b)**, a part indicated by arrows is darker than surroundings, and it indicates that the part is of different material from impregnant resin or aluminum. The CT value at the solid line in the image is plotted in **Figure 3(c)**.

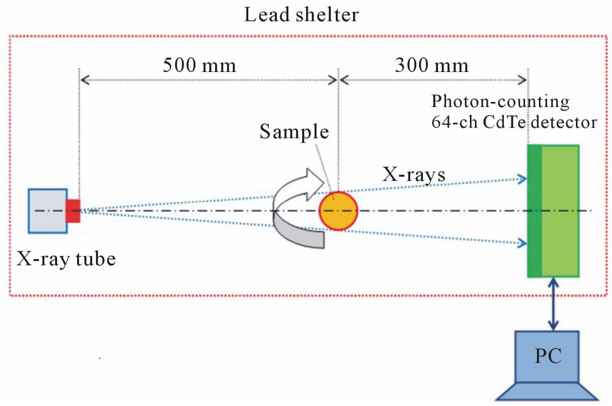

Figure 1. Schematic diagram of experimental system.

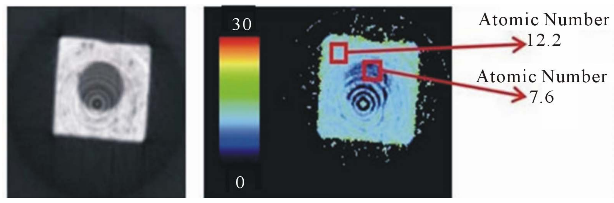

Figure 2. CT image of aluminum sample 1. (left) X-ray CT image and (right) atomic number mapping (material distinguished resin from aluminum) using 64-channel CdTe detector with photon-counting.

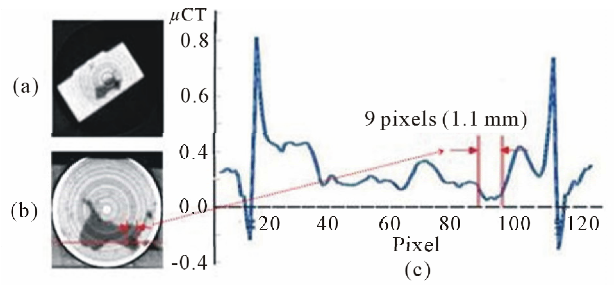

Figure 3. CT image of aluminum sample 2. (a) X-ray CT image, (b) and (c) μ CT-Pixel.

The CT is performed by magnification method shown in **Figure 4**, and the distances between the X-ray tube and the sample are shown in **Figures 4(a)** and **(b)**. The diameter of hole observed in **Figure 3(b)** is derived as 1.1 mm by the number of pixel shown in **Figure 3(c)** and the magnification rate in **Figure 4**.

The leakage quantity Q (ml/min) as a function of the average diameter of the hole in the aluminum die-casting is led by the equal of Hagen-Poiseuille equation:

$$Q = 60\pi D^4 \Delta P / 128\eta L, \quad (3)$$

where D (cm) is the average diameter of hole in the aluminum die-casting, ΔP (Pa) is the pressure difference or the inspective air pressure, η is the viscosity coefficient (1.81×10^{-5} Pa·s at 20˚C), and L (cm) is the length of tube or the hole. As the result of measurement, the Q of sample

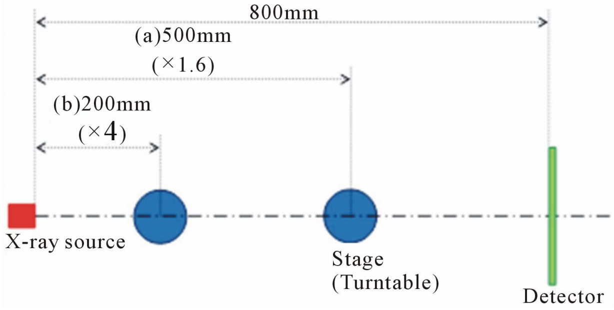

Figure 4. Imaging conditions of sample 2.

2 was 18,000 ml/min, and the average diameter D of the hole of aluminum die-casting was estimated as 0.5 mm.

4. Conclusion

This study has proved that it is possible to distinguish between impregnant and aluminum, through the material identification by DXCT. Without using low-energy photons below 40 keV, and by using the energy information, both the image deterioration by Compton scattering and the effect of beam hardening were reduced successfully, and the void space inside the hole of aluminum die-casting was captured clearly. As the results, the discrimination between the metallic material (aluminum) and the resin was performed from the experiment with sample1, and the hole diameter in sample 2 from X-ray CT image was close to the calculated value from the pressure measurement. It is usually possible to seal the hole by acrylic resin impregnation in near 100% ratio, but this sample 2 is still not sealed completely. The resin impregnation has the centrifuging and the water cleaning (washing) processes. These are being factors that hinder the sealing of holes. In this study with the photon-counting X-ray CT, it is shown that one of the causes concerning the lack of space (hole) sealing is the shape of hole. In the next study, taking CT image in 3D display, it is expected to be able to inspect holes in the aluminum die-casting with more details and precision.

REFERENCES

[1] Y. Tomita, Y. Shirayanagi, S. Matsui, T. Aoki and Y. Hatanaka, "X-Ray Color Scanner with Multiple Energy Discrimination Capability," *Proceedings of the SPIE*, Vol. 5922, No. 3, 2001, pp. 291-293.

[2] W. Zou, T. Nakashima, Y. Onishi, H. Morii, Y. Neo, H. Mimura and T. Aoki, "Soft-Tissue Material Properties under Large Deformation: Strain Rate Effect," *Proceedings of the 26th Annual International Conference of the IEEE EMBS*, San Francisco, 1-5 September 2004, pp. 2758-2761.

[3] R. Brooks and G. Chiro, "Principles of Computer Assisted Tomography (CAT) in Radiographic and Radioisotopic Imaging," *Physics in Medicine and Biology*, Vol. 21, 1976, pp. 689-732.

[4] W. Zou, T. Nakashima, Y. Onishi, A. koike, B. Shinomiya, H. Morii, Y. Neo, H. mimura and T. Aoki, "Atomic Number and Electron Density Measurement Using a Conventional X-Ray Tube and a CdTe Detector," *Japanese Journal of Applied Physics*, Vol. 47, No. 9, 2008, pp. 7313. doi:10.1143/JJAP.47.7317

[5] G. Matsumoto, Y. Imura, H. Morii, A. Miyake and T. Aoki, "Analysis of Artifact with X-Ray CT Using Energy Band by Photon Counting CdTe Detector," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, Vol. 621, No. 1-3, 2010, pp. 292-294. doi:10.1016/j.nima.2010.05.056

