A Digital Analysis Approach for Estimating Decarburization Layer Depth of Carbon Steel via a Portable Device

Wesley Huang1,2, Chia-Sui Wang1, Yih-Feng Chang1, and Chia-Mao Yeh3

1 Chia Nan University of Pharmacy & Science, No. 60, Sec 1, Erren Road, Rende District, Tainan City, 717, Taiwan
2 First Optoech Co., Ltd., No. 1, University Rd., Yan Chao Dist., Kaohsiung, 824, Taiwan
3 National Sun Yat-sen University, No. 70, Lienhai Rd., Kaohsiung City, Taiwan
E-mail: box1025@mail.cnu.edu.tw

Abstract. Decarburization layer depth has great influence on the quality of metal forming process. For determining the depth value, the inspector progresses the measurement by manual nearly, which is subjective and inconsistency. This paper presents a digital analysis approach for measuring the decarburization depth automatically. Meanwhile, this analysis can be carried out by a portable device. For the digital analysis approach, the morphology image process is developed by comparing the variation of gray gradient of image from edge to core region. While the histogram of grayscale gradient falling down sharply, the distance from edge to the point was defined as the ferrite decarburization depth. Meanwhile, if the histogram keeps decreasing and stopping the decrease at one point, then the distance from edge to that point was defined as the totally decarburization depth. For the portable device, the analysis software is settled on a cloud-based calculating system. The analyst can capture the metallographic image shown in the monitor by smart glasses. Then, the analysis result is shown in smart glasses directly. All analysis and calculation process are progressed on a cloud-computing system. Finally, a digital metallographic analysis approach for estimating decarburization depth of carbon steel specimen by a portable device can be carried out.

1. Introduction

Decarburization phenomenon refers to that the carbon on steel surfaces reacts with the deoxygenation in heat treatment furnaces due to heat treatment and causes reduction in carbon content on steel surfaces as well as hardness. Decarburization depth refers to the distance from the place where the steel starts to be decarburized to the surface. There are two major approaches to manually measure the decarburization layer depth. One is hardness test, referring to using a micro Vickers hardness meter to gradually knock into the core along the surface, so as to record the hardness changes. It is the beginning of decarburization when the difference between the measured hardness and the core hardness is more than Hv30. The distance from the point to the surface measured with a microscope is defined as the decarburization layer depth, denoted as DHT. Another is to measure with optical microscopes. In this way, an inspector selects the fixed magnification (normally 100 to 200 times) for observation in the view field and determines the start point of decarburization, to measure the distance from the start point to the surface to be the position of the decarburization layer, denoted as DMT [1]. There are two approaches in measuring decarburization layer depth with metallographic images, including manual measurement and digital measurement, and this study used the latter to discriminate automatic measurement.
About material image inspection, the digital metallographic inspection is mostly applied to failure analysis [2-4]; and some applications are in abrasion calculation and spacemen life forecasting [5, 6]. Papa and Albuquerque applied digital image processing to analysis on grey casting iron and nodular casting iron, to distinguish the types of grey casting iron and to globular graphite statistics [7, 8].

Concerning the grain analysis, Hanning and Engelberg tried to compensate the missing grain boundary after corrosion of 304 Austenite stainless steel by the method of image comparison [9]. Vieira and Paciornik [10] calculated the area proportion of pearlite by the method of uncertainty evaluation, but the research only issued the calculation results and the uncertainty of two different materials.

This study carried out an automatic digital algorithm, and used the gray gradient in combination with the way of determining the threshold value through hardness re-correction, to increase the accuracy of automatic calculation results of the decarburization layer depth. In application, the image capture function of smart glasses can be applied to take the image and send back to the cloud to estimate the decarburization layer depth, so as to achieve the inspection efficiency.

2. Digital image analysis

Combining with hardness correction, the main inspection approach applied in this study was optical measurement for automatic decision making. This approach is relatively simple but objective in inspection process. The main steps are as below: (1) measuring hardness, and deciding position and depth used in hardness method and decarburization method; (2) based on this decarburization layer depth, correcting the threshold value measured by optical method, so that the measurement is more consistent with the current status of hardness variation; (3) conducting automatic calculation with the corrected composite software to calculate the optical decarburization layer depth.

The image processing procedure mainly consists of the following steps: (1) gray scaling, (2) sharpening, (3) binarization, (4) analytic statistics and (5) decision making.

Gray scaling refers to, assuming that the color temperature has no effect on optical input, making color images grayscale reference to existing grayscale parameters to avoid calculation errors caused by different colors [11]. Sharpening function is to increase the grayscale gradient of all pixels in grayscale images, so as to improve the accuracy of the following binarization [12]. Binarization is to convert a grayscale image into a black-and-white image based on a threshold value. Assuming that, for an image, the width and high pixels are \( w \) and \( h \), separately. The grayscale is \( G_i \) when the pixel is at the position \( i \), and it is defined black (\( G_i = 0 \)) and white (\( G_i = 255 \)) while \( 0 \leq G_i \leq 255 \). When the binarization threshold value is \( \lambda \), the pixel \( B_i \) after binarization is

\[
B_i = \begin{cases} 
0, & \text{if } G_i \leq \lambda \\
255, & \text{if } G_i > \lambda 
\end{cases}
\]

where the quantity of \( i \) is \( w \times h \). Afterword, a binarization pixel statistics is carried out after binarization, and the analysis method is mainly based on the binarization pixel distribution in the specimen. The major way is to divide the specimen image into ten equal parts (from Area \([1]\) to Area \([10]\)) from the core to the surface, and to calculate the binarized pixel mean values in all areas from \( \bar{G}[1] \) to \( \bar{G}[10] \). In these ten binarized pixel mean values, the first threshold value is determined the location with the maximum gradient of pixel counts. The interval of \( \bar{G}[i] \) (1 ≤ \( i \) ≤ 10) is divided into ten equal parts, so as to calculate the grayscale mean values from \( \bar{G}[1] \) to \( \bar{G}[10] \). Likewise, the second threshold value is determined the location with the maximum binarized pixel gradient. In decision making, to take \( \tilde{G}[j] \) (1 ≤ \( j \) ≤ 10) of the second stage and the median position \((x, y)\) of its interval can be determined as the DMT. As the algorithm issued above, the DMT measurement is the distance from this position to the surface, i.e., the decarburization layer depth. The second threshold value can be regulated through manually correction by hardness method, which is measured by means of optical microscopes. In this study, the threshold value was determined through manually hardness correction method firstly, and then the digital optical measurement is progressed only in actual inspection.
3. Metallographic inspection service system of a portable device

Regarding the cloud metallographic inspection service system used in this study, combining with a portable device and the cloud computing platform. The digital inspection mentioned above was used to establish a cloud-based metallographic inspection platform, and the relevant patent were obtained. In this study, the structures of cloud-computing platform shown in Fig. 1 mainly consist of four modules, including the portable device module, the cloud inspection module, the account management module and the history query module, respectively.

3.1. Portable device module

Connected to the network of the cloud metallographic inspection server, the portable device module used in this study is a pair of smart glasses with an application software (APP). The pair of smart glasses used in this study consists of a pair of portable inner projection glasses and a separate auxiliary controller. The controller runs an APP to use the camera on the smart glasses to capture the images of the decarburization layer displayed on the observation screen of the microscope, and is connected to the cloud inspection server through a module linked by WiFi wireless signals, so as to achieve cloud network connection and data transmission. A display module is used to display the photos obtained by the image capture module or the image transceiver module, and an image transceiver module is used to send the photos obtained by the image capture module or a mobile device operation system is used to receive the images from the cloud inspection server. The auxiliary controller contains an input module for the users to control to input data or instructions, and the display module displays the data or instructions.

![Figure 1. Architecture of cloud-computing platform.](image)

3.2. Cloud inspection module

The cloud inspection module is the core of this study, after logging in, corresponding type of digital metallographic inspection can be selected or other digital problems can be analyzed by using the manual inspection. The users can select inspection types, upload images, server, transmit data to the digital computer, select parameters, call corresponding algorithms and calculate the results of digital decision making.

The results of digital decision will be firstly sent to the reviewers to confirm rationality of the inspection contents. After the rationality of the inspection contents is confirmed, the reports will be sent to the inspectors. In the above way, the original inspection duration of 4 to 5 days for the post metallographic inspection analysis can be shortened to 1 hour, and the inspection time is shortened by above 99%.

3.3. Account management module

For the cloud fastening inspection service system, the user account management can be performed to confirm valid accounts as well as the grade and categories of users, in addition to general user information.

3.4. History query module

The system in this study can be used to inquire the history of inspection results. The major function is that, after inspection, the users can directly inquire on the cloud inspection service system without saving the inspection results on their own. In this method, not only the users’ trouble of data saving
and maintenance at local ends can be eliminated, but also the historical inspection data can be accessed directly and rapidly, so that the metallographic inspection efficiency can be improved.

4. Experimental description
In this study, the optical microscope used was Olympus BX51M, the metallographic camera was Sentech STC-MC152USB, the image capture pixel was 1360 × 1024, RGB was used for image capture, and images were sampled at an optical magnification of 500 times. The captured images were output to a 22" 16:9 screen for display. A pair of Epson smart glasses BT-300 was used for capture, a 5-megapixel CMOS camera was used, the CPU was Intel-based, and the operation system was Android V5.0.

This study decided the decarburization layer depth after spheroidization anneal of AISI 1022 steel. The chemical components composed are: C: 0.18-0.23%; S: 0.1%; Mn: 0.7-1.0%; P: 0.03%; S: 0.035%. The conditions of spheroidization anneal are heating to 700 ℃, cooling the furnace temperature to 500 ℃ after holding the temperature for 10 hours, and taking out to cool in air.

5. Results and discussion
From the hardness test, the core hardness of the specimen was Hv 127. The distance from the position of (Hv -30) to the wire surface was 0.024 mm, which was the total decarburization depth for verification of this study object. By microscopic method, digital metallographic images were captured through smart glasses, and then the calculation was made after returning to the cloud analysis system.

Fig. 2 shows the images and analysis results used for inspection in this study. Fig. 2(a) shows the metallographic images taken digitally before inspection. Fig. 2(b) shows the inspection result which is 0.021 mm analyzed by microscopic method based on the analysis mode in this study with a personal computer. Fig. 2(c) shows the inspection images taken by smart glasses and transmitted to the cloud, and the inspection result is 0.028 mm shown in Fig. 2(d). The errors compared with hardness detection and general cloud analysis are 0.003 and 0.007 mm, respectively, which are able to be acceptable in the metal manufacturing industries.

The difference between personal computer and smart glasses is mainly caused by two conditions. Firstly, the light condition is the main factor very much in demand. The inhomogeneous grey-scale distribution is carried out by environment light with smart glasses. Meanwhile, the reflection of monitor also causes the image distortion, as shown in Fig. 2(c) and 2(d), what we can see is the lower part of image exhibiting relative white than origin image [Fig. 2(a)].

Secondly, the magnification also performs divergence with different distance between smart glasses and monitor. As shown in Fig. 3, the magnification is calculated as: original specimen for 1 time, objective lens for 50 times, eyepiece for 10 times, reduce lens for 0.5 time, capturing camera for 20 times, controlled monitor for 1 time. And the magnifications can be estimated as 1×50×10×0.5×20×1=500 times.

When the smart glasses is obtained in calculation, through the resolution can be adjusted with the same height of captured image of camera on smart glasses and shown image in monitor, the measuring difference is also generated for the difficult to tuning posture of the head mount device. This measuring difference also causes little influence on image recognition.

When the analysis of different magnifications was proceeded as shown in Fig. 4 which can be found that same two conditions happened. Fig. 4(a) and 4(b) show the metallographic images observed under 100 times of magnification, whose decarburization depths are 0.079 and 0.091 mm, respectively. Fig. 4(b) performs a larger image than Fig. 4(a) apparently, though two images are the same one. The inspector could not keep a perfect posture and make the difference. Fig. 4(c) and 4(d) show metallographic images observed under 200 times of magnification, whose decarburization depths are 0.024 and 0.030 mm, respectively. The distance difference between two images is 0.006 mm, which is made from different light distribution.
Figure 2. (a) shows the original metallographic captured by microscope camera; (b) shows the analysis result with original metallographic; (c) shows the metallographic captured by the portable device; (d) shows the analysis result with metallographic captured by the portable device.

Figure 3. Schemia of magnification calculation.
Figure 4. (a) shows the analysis result with original metallographic under 100 times of magnification; (b) shows the analysis result with metallographic captured by the portable device under 100 times; (c) shows the analysis result with original metallographic under 200 times; (d) shows the analysis result with metallographic captured by the portable device under 200 times.

6. Conclusion
This study applied portable devices to develop a cloud computing platform with portable cloud metallographic inspection services for measuring the decarburization layer depth. Combining with the database system of mySQL, this system used the present PHP web language to call the local applications to digitally decide and calculate the uploaded metallographic images, and then the decision results were projected onto the inner projection lens by using the glasses and were transmitted to the users, to complete the service. The conclusion is shown as below:
1. The study results can be used to actually conduct digital cloud decision for metallographic structures with images of decarburization layer depth.
2. The mainly difference is caused by two condition. One is the light factors, which includes environment light and reflection of monitor. The other is change of magnification with distance between smart glasses and monitor.
3. The errors compared with hardness detection and general cloud analysis are 0.003 and 0.007 mm, which can be accepted in industrial use.

7. References
[1] Standard Test Methods for Estimating the Depth of Decarburization of SteelSpecimens. ASTM E1077-01 (2001)
[2] B. Pawłowski, P.Bała, J. Krawczyk, M. Stępień, T. Śleboda, Eng. Failure Anal. 82, 533 (2017)
[3] C.A. Duarte, E. Espejo, J.C. Martinez, Eng. Failure Anal. 79, 704 (2017)
[4] A. Lanzutti, A. Gagliardi, A. Raffaelli, M. Simonato, M. Magnan, F. Andreatta, L. Fedrizzi, Eng. Failure Anal. 79, 634 (2017)
[5] T. Mikołajczyk, K. Nowicki, A. Kłodowski, D.Y. Pimenov, Mech. Sys. Signal Process 88, 100 (2017)
[6] T. Mikołajczyk, K. Nowicki, A. Kłodowski, D.Yu. Pimenov, Mech. Sys. Signal Process. 104, 503 (2018)
[7] J.P. Papa, R. Y.M. Nakamura, V. H. C. Albuquerque, A. X. Falcão; J. M. R. S. Tavares, Expert Sys. Appl. 40, 590 (2013)
[8] V.H.C. Albuquerque, A.R. Alexandria, P.C. Cortez, J. M. R.S. Tavares, NDT&E Int. 42, 644 (2009)
[9] F. Hanning, D.L. Engelberg, Mater. Charact. 94, 111 (2014)
[10] P.R.M. Vieira, S. Paciornik, Mater. Charact. 47, 219 (2001)
[11] M. Grundland, N. A. Dodgson, *Color to Grayscale Conversion* (UCAM-CL-TR-649, University of Cambridge, 2005)
[12] R.C. Gonzalez, R.E. Woods, *Digital Image Processing* (Prentice Hall, Third edition, NJ, USA, 2008)