Using X-Ray radiographic technique to determine the depth of internal defects in castings and calculation to obtain the optimum radiographic resolution

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Revised on:11/2/2014 & Accepted on: 2/4/2015

Abstract

This paper presents modification method to calculate the depth and cross section area of defects in internal structure of castings by X-Ray radiography technique. Aluminum block incorporate simulated defects which represented by three steel spheres of different sizes and depths, were prepared. Typical radiographs were taken at optimum conditions from two opposite sides of the aluminum alloy block. Then typical radiographs were taken from top side of the aluminum alloy block accomplished by moving the x-ray source at measured interval distances for depth determination. Image J program were used to analysis of the X-Ray films, getting information about the cross section area of the shadow of defects on radiographs and required distance measurement on radiograph, whatever their shape, regular or irregular. Equations derived earlier were adapted to calculate the depth of defects in term of their shadows on radiograph. By compensation the optimum data which got from the Image J program in these equations, the ultimate goal in high accuracy detection of the depth of defects were achieved. The effect of the x-ray fluorescence on the quality of the x-ray image due to use of unsuitable x-ray voltage was also studied. This was achieved by using of different kV to radiograph a test object of (0.1) mm in thickness of Cu and Ag samples.

Keywords :- (X-ray radiography, Castings defects, Image J program, defects depth).

استخدام تقنية التصوير الشعاعي لتحديد عمق العيوب الداخلية للمصبوبات وإجراء الحسابات اللازمة للحصول على أفضل وضوح للصورة الشعاعية

الخلاصة

يعرض هذا البحث طريقة معدلة لحساب عمق ومساحة المقطع العرضي للعيوب في البنية الداخلية للمصبوبات بواسطة التصوير الشعاعي بالاشعة السينية. تم تحضير مصبوبة المنيوم تحتوي على عيوب مصنعة تتمثل بثلاث كرات معدنية مختلفة الاحجام وضعت داخل مصبوبة الالمنيوم وعلى اعماق مختلفه. وقد أخذت الصور الشعاعية

https://doi.org/10.30684/etj.33.4B.10
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النموذجية في الظروف القياسية من جانبين متقابلين من مصبوبة الالمنيوم. ثم أخذت صورتين شعاعيتين نموذجيتين من الجانب العلوي من مصبوبة الالمنيوم, الاولى بصورة موازية للجانب العلوي, والثانية عن طريق تحريك مصدر الأشعة السينية على مسافة فاصلة لغرض تحديد عمق العيوب. واستخدم برنامج (image J) لتحليل افلام الأشعة السينية، والحصول على المعلومات المطلوبة لحساب مساحة المقطع العرضي لظل العيوب في الصور الشعاعية و قياس المسافات المطلوبة على الصورة الشعاعية، مهما كان شكلها منتظمة أو غير منتظمة. تم استخدام معادلات مشتقة سابقا لحساب عمق العيوب داخل مصبوبة الالمنيوم، من خلال تعويض البيانات التي تم استحصالها من برنامج (image J) في هذه المعادلات وتحقيق الهدف النهائي وهو حساب عمق العيوب بدقة عالية. وقد درس أيضا تأثير الأشعة السينية المتفلورة على جودة الصورة الشعاعية بسبب الاستخدام غير المناسب لجهد الأشعة السينية، وقد تحقق ذلك من خلال استخدام فروق جهد مختلفة للتصوير الشعاعي لاختبار نماذج نحاس وفضة ذات سمك (0.1) ملم.

INTRODUCTION

X-Ray was discovered by Rontegen in 1895. The establishment of the radiography after the discovery added a unique dimension to man search for knowledge[1]. In 1920 the nondestructive testing (NDT) has developed from a laboratory curiosity to non destructive tool of production [1].

The effect of radiography in the engineering world has been tremendous where used us an inspection tool heralded a new era in (NDT) [2]. Development in radiography and fluoroscopy in industrial field up to 1982 have been discussed by Steweart [3]. In 1988 Segal and Trichter estimate the width and depth of crack by radiography by using accurate information about the angle of exposure, that radiography is essential part of (NDT) [4].

In 2001 Jedran discussed the non- destructive evaluation of ceramic\ metal joint system by using x-ray radiography technique [5]. In the same year Mahrok and Azeez found a practical method to calculate the size and depth of simulated clay sphere in aluminum casting by analysis of x-ray films and derivation of the equations suitable for the experimental set up used [6].

On the other side, computer software programs science in continues development and one of the most important fields is image processing programs. The development took place in both medical and industrial x-ray radiography fields.

In 2003 Daniel et. al studied the sophistical image analysis of digital radiographies using adaptive threshold a wavelet-based multi-resolution image representation[7] .

In 2009 Sikora et. al proved that the method of non- destructive testing using digital radiograph analysis by(image J) program can be used with full success in evaluation of the propagation rate of fatigue cracks in metallic materials[8] .

In 2010 Mazin and Thamir discussed the ability of equations derived earlier for radiography to calculate the size and depth of spherical shape defects like voids in casting were tested for validity to a wide range of parameters commonly used in radiography [9].

We noticed from the viewed researches that all the experiments ends at specific lines which determine the size and depth of regular defects and the non accurate in the analyzes the x-ray films due to use of manual methods in the analysis.

The aim of this paper is combination between the Image J program to analysis of the x-ray films, cross section area of defects determinations, and equations had been adapted to calculate the depth of internal defects in casting, whatever their shapes and areas on radiographs. Also experiments proves of the effect of the x-ray fluorescence on the quality of the x-ray image was studied

Experimental

For this study Aluminum cast Alloy has dimension of (162×102×61 mm^3) was prepared that incorporate three steel spheres of different sizes. The steel spheres were immersed in the aluminum molten during poring it inside the mold. . Fig. (1) Illustrates the casting of aluminum alloy including the steel spheres.

Then the block was radiographed from two opposite sides using (RADIOFLEX) x-ray equipment of Japan made. Other radiographs were taken from top side accomplished by moving the x-ray source at measured interval distance. Fig. (2) Illustrates this x-ray system. The first radiograph was taken from the right side (R) of the casting and the second radiograph was taken from the left side (L) of the casting. The process was repeated by taking radiograph from right side (R) and moving the x-ray source for measured distance aligned to the its original position, and turned for angle to take the second radiograph. Side radiograph was also taken in order to determine the depth of spheres inside the aluminum cast alloy. The process was repeated at two different focal object distance (F. O. D), the selection of kilo voltage (kV), exposure time, and (F. O .D) was achieved according to the (ASTM-section 5. 1985) [10], in order to obtain acceptable contrast and unsharpness.

By using (canon) scanner (MP250) type, of Japan made, the x-ray radiographs digitalized as (JPEG) image into the computer.

Software image J program was used to analyzes the radiographs, by this way sensitive measurement of defects shadows area was obtained, whatever their types or shapes on radiograph.

After setting the scale of the X-ray radiography image in the program, the steps of the area measurement in brief, was threshold the image and auto selection for the required shadows, follows by area measurements and data saving. After that the required analysis for the depth of defects determination was achieved by selection of the required defects and measuring the distance from the center from the shadows to the image boundary. These steps are shown in fig. (3) and fig (4).

Equations derived earlier were adapted for finding the depth of defects inside the aluminum alloy block.

Equation (1) originally used to find the depth, of regular shape of defects [6]. Figure (5) shows the parameters required to be measured in order to find the depth (Y) of the defect inside the object according to the first method [6].The equation as following

$$Y = (R_R\,(L+X) - R_L L)/\,(R_R+R_L) \qquad \dots (1)$$

Figure (6) shows the parameters required to be measured in order to find the depth (Y_2) of the defect inside the object according to the second method mentioned above [11].

The second method used to determine depth of defect inside the aluminum cast alloy as mentioned above was achieved using the following equation.

$$Y_2 = (X_2)\,(Y_1)\,/\,(X_1+X_2) \qquad \dots (2)$$

By compensation the values, which obtained from the shadows on the radiographs using image J program in the above equations, depths (Y) and (Y_2) were achieved. After that the cross section area (A) of the defects, will also achieved using Image J program.

In order to study the effects of XRF on the quality of the x-ray image , different bremsstrahlung spectra from tungsten anode X-Ray tube generated at (8 , 15 , 30) KV have been examined theoretically and experimentally for attempt to find more suitable spectrum to radiograph a test object of (0. 1 mm) thickness of Cu and Ag. The purity of test samples were examined using XRF technique and found (100%, 96.8339%) respectively, the radiographs of test object at different voltage shown in fig (7).

The ultimate contract UC on the X-Ray films was measured by optical densitometer. The optical density OD of the X-Ray films at a point is a measure of the degree of blackness in that point. Optical density is expressed by:-

$$OD = \log (Io / I_t) \qquad \text{….. (3)}$$

Where

Io is the density of visible light incident on small area of the film and (I_t) is the intensity of the light transmitted by same area of the film.

Results and Discussions

Radiographic measurement of the shadows of the simulated defects using image j program and the measurements of the geometrical parameters of the experimental system enabled as to calculate the actual cross section area of these defects and their depth inside the casting. Table (1) represents the calculated values of the depth of defects on radiographs using two opposites sides technique and the radiograph analyzed using Image J program. Table (2) represents the calculated values of the depth (Y) of the defects using one side technique according to their numbers in figure (3).

From the results shown in table (1), the ultimate goal in measuring the depth and cross section area of simulated defects was achieved using tow opposite sides technique, with required sensitivity of the shadows selection on radiograph.

From the results shown in table (2), the ultimate goal in measuring the depth and cross section area of simulated defects was achieved using one side technique, with required sensitivity of the shadows selection on radiograph. Also one can notice from the above results that every radiograph must have high image quality, which achieve by determining the operating condition such as, tube voltage, exposure time, and geometrical parameters of the x-ray radiographic system in order to achieve all required steps in the program. From the above information reinforces the importance of the use of this program in the sensitive measurement of the cross section areas of the shadows and required distance for equation applications on the radiograph at the differing ways that are difficult to measure habitual.

The limitations of the two opposite sides technique in depth determination of defects which represented in minimum size defects and irregular shape of defects were reduced by using one side technique that in this technique, it is not require to determine the radius of defects on radiograph which solve the problems mentioned above.

The results of cross section area determination are shown in tables (1) and (2) which calculated directly from radiograph using image J program.

The ultimate contrast UC measured on the X-Ray film fig (7) is shown in table (3).UC is the difference in OD between two points on the x-ray film.

In contrast calculation, the fluorescent radiation emitted from Cu is considered to be emitted as Kab_1 as this line is the most intense line in K series of Cu. The same consideration was applied for Ag.

The shaded part of the x-ray spectrum generated at 8 kV in fig. (7) Is small compared to those generated at 15 kV and 30 kV. Larger number of photons in the shaded area means more fluorescence radiation from Ag foil because these photons are higher in energy than the K_{ab} (K-edge describes a sudden increase in the attenuation coefficient of photons occurring at a photon energy just above the binding energy of the K shell electron of the atoms interacting with the photons) of Ag. However, this fluorescence radiation has negative effect on contrast of the test object used as it obvious in table (3). Calculated values of UC as shown in table (1) demonstrated that there is marked improvement in contrast when radiograph Cu and Ag test object with x-ray spectrum (15 and 30 kV in this case) chosen to have the majority of its energy under the absorption edge of the two elements involved. From these results one can introduce its important to consider the effect of the x-ray fluorescence on the quality of the x-ray film and this effects can be avoid using kV under the K_{ab} of the test object.

Conclusions

1- Radiography proved themselves as successful method in detecting the depth and cross section area of defects.

2- Image J program measure the areas of shadows of defects on radiographs whatever their shapes on radiographs.

3- High image quality (which achieved by selection of suitable kilo voltage (kV), exposure time, and (F. O .D)) of the x-ray film is essential point to achieve all required steps in the image J program in order to measure the shadows area with optimum accuracy.

4- The tow adapted equations gives acceptable results in determination of depth of the three types of simulated defects.

5- One side technique solve all the problems in two opposite sides technique which represented by irregular shape of defects and minimum size defect.

6- When considering incident radiation of energy above (K_{ab}) of an element to be radiograph, it is necessary to consider the effect of the re-radiation fluorescent radiation as this was found to contribute significantly to the total transmitted intensity.

Figure (1) A photograph illustrates casting sample of aluminum alloy

Figure(2) A photograph illustrates the x-ray system

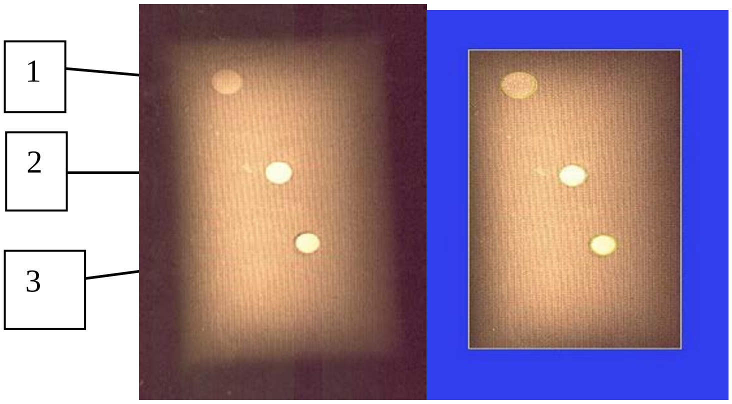
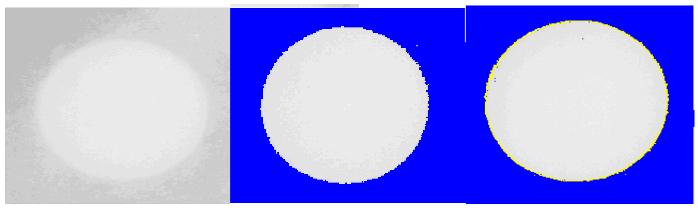
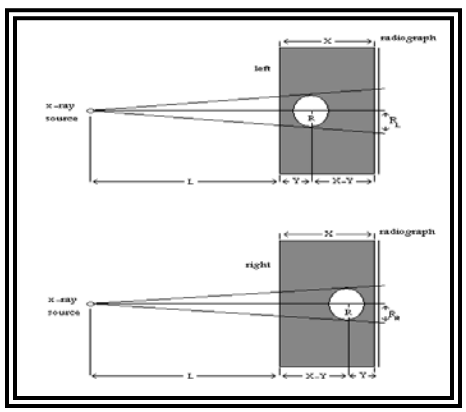


Figure (3) Illustrates the radiograph and the shadow of the defects with numberings



(a) (b) (c)

Figure(4) a- Typical radiograph for casting shows the steel spheres, b- The image after thresholding, c- Selection of area



Figure(5) Experimental set-up for radiography showing the parameters used in equation (1) to calculate depth (Y)

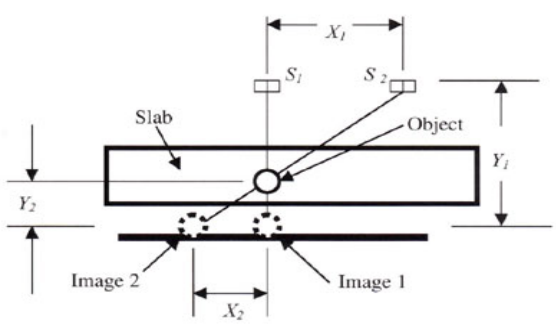
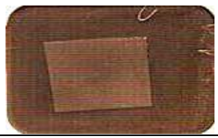
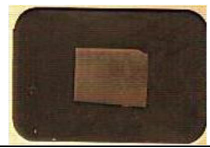
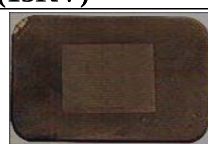


Figure (6) Experimental set-up for radiography showing the parameters used in equation (2) to calculate (Y_2)

	
Ag test object at (8 KV)	**Cu test object at(8KV)**
	
Ag test object at(15KV)	**Cu test object at (15KV)**
	
Ag test object at(30KV)	**Cu test object at (30KV)**

Figure(7) radiographs of Cu and Ag test object taken with X-Ray tube operated at (8, 15, 30) KV

Table (1) Represents the calculated values of cross section area (A) and depth (Y) of the simulated defects according to their numbers in figure (3)

Defect No.	**Focal Object Distance (F.O.D) (mm)**	**Cross Section Area (A)(mm^2)**	**Actual depth(mm)**	**Calculated Depth (Y)(mm)**
1	500	200.96	30	26.49
2		153.86	40	40.56
3		132.665	23	23.51

Table (2) represents the calculated values of cross section area (A) and depth (Y) of the simulated defects according to their numbers in figure (3)

Defect No.	**FocalObjectDistance (F.O.D) (mm)**	**Cross Section Area (A)(mm2)**	**Actual depth (mm)**	**Calculated Depth(Y)(mm)**
1		200.96	30	30.5

2	500	153.86	40	40.46
3		132.665	23	23.48

Table (3) shows the optical density OD and ultimate contrast UC of the x-ray film fig (7)

Voltage (kV)	Optical density		Ultimate contrast (UC) = (D_{Cu} – D_{Ag})
	D_{Ag}	D_{Cu}	
8	0.91	1.22	0.31
15	1.1	2.3	1.2
30	1.72	2.87	1.15

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