Jurnal Ilmiah Aplikasi Isotop dan Radiasi
A Scientific Journal for The Applications of Isotopes and Radiation
Vol. 19 No.1, November 2023

p ISSN 1907-0322
e ISSN 2527-6433

Observation of Schrinkage Indications in Excavator's Bracket Casting Using Film Based Radiography

Observasi Indikasi Penyusutan pada Coran Braket Eskavator Menggunakan Radiografi Berbasis Film.

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ABSTRACT

Experimental study has been conducted to examine the casting quality of the excavator's bracket sample using film-based conventional radiography. Referenced standards are ASME Section V Article 2 and/or ASME E94 about radiographic examination. The bracket sample with the thickness of 16 mm was exposured using Co-60 gamma ray radiation source with activity of 80 Ci. The exposure was performed from the distance of 360 mm for 27 second. The D7 medium speed radiographic film was used to record the latent image of the exposured sample. The exposured film was then developed in chemical solutions to convert the latent image into permanent image or radiograph. The radiograph is evaluated using a light viewer to see whether there are any defects or indications in the sample being examined. Under viewing, indications of distributed shrinkage in the casting body were apparently observed. These indications are fall into category of C4 according to the radiograph album of ASME E446 standard for steel casting with thickness up to 2 in. (50.8 mm). The defects of C4 are categorized as worse. The experiment concludes that the casting quality of the excavator's bracket is poor and it is recommended that the bracket should be repaired and re-tested radiographically. Otherwise, the bracket sample is prohibited to use for services because of unsafe reason.

Keywords: Excavator's bracket, film based radiography, shrinkage, indications

ABSTRAK

Penelitian eksperimental telah dilakukan untuk menguji kualitas pengecoran sampel braket eskavator menggunakan radiografi konvensional berbasis film. Standar yang diacu adalah ASME Section V Article 2 dan/atau ASME E94 tentang pemeriksaan radiografi. Sampel braket yang mempunyai tebal 16 mm disinari menggunakan sumber radiasi sinar gamma Co-60 dengan aktivitas 80 Ci. Penyinaran dilakukan pada jarak 360 mm selama 27 detik. Film radiografi D7 kecepatan sedang digunakan untuk merekam bayangan laten dari sampel yang disinari. Film yang telah disinari kemudian dikembangkan menggunakan larutan kimia untuk mengubah bayangan laten menjadi bayangan permanen atau radiograf. Radiograf dievaluasi menggunakan *viewer* cahaya untuk melihat ada tidaknya cacat atau indikasi apa saja pada sampel yang diperiksa. Dalam pengamatan, indikasi penyusutan yang terdistribusi pada badan coran tampak terlihat. Indikasi-indikasi ini tergolong dalam kategori C4 (cacat penyusutan level 4) menurut album radiograf standar ASME E446 untuk ketebalan coran logam hingga 2 inci (50,8 mm). Cacat C4 tergolong kategori buruk. Penelitian menyimpulkan bahwa kualitas coran braket eskavator adalah buruk dan disarankan braket untuk diperbaiki dan di uji ulang secara radiografi. Jika tidak, sampel braket dilarang digunakan karena alasan tidak aman.

Kata kunci: braket eskavator, radiografi berbasis film, penyusutan, indikasi

INTRODUCTION

Casting process is basically simple. It is one of the earliest metal shaping techniques that has been known to human being, even since 3600 B.C [1], [2]. In the earlier centuries, this method was mainly used to make weapons like arrow head,

p ISSN 1907-0322
e ISSN 2527-6433

swords, etc., [2]. Casting is carried out simply by pouring the metal liquid into the prepared mold and allowing it to solidify to form a fixed shape. Among the series of casting processes, solidification may probably be the most important step that needs to be controlled, otherwise the product quality is poor beyond of expectation. Solidification involves a change of metal phase which is potential to generate defects. Any other properties and characteristic of the casting product are established after completed solidification [3], [4].

Bracket is a part of heavy duty excavator. Its function is as a connecting point between the fixed part of the rare-arm and the moving part of the fore-arm. Bracket is a cylindrical form with hollow in it's center, as shown in Fig. 1. Bracket is made of metal through sand casting process. Compared to the other casting processes, sand casting is one of the oldest metal forming and it mostly widely used in any engineering sectors. The concept of all castings processes are basically the same but the sand casting is the easiest ones. In sand casting, the pattern which is the replica of the end product, is created first with help of machining. The sand mixture is then created using different materials like clay, lime, etc.,. The mixture composition determines the quality of the sand casting product. The pattern is dipped in the mould. When the cavity made by pattern in the mould is ready, molten metal is poured and wait for solidification. The solidified metal is then taken out from the mould. Finally the casting product is machined for cleaning and removing any kind of foreign materials on the surface [1], [4], [5].

Structural defects such as porosity, sand and slag inclusions, shrinkage, crack and hot tear are possible to occur in casting. These defects definitively can reduce the strength of the casting products. If such defects are undetected, they can initiate failures during services. It is therefore that a necessary action should be taken during the manufacturing phase so that defect free casting can be obtained [3], [6] – [9].

Radiography has long been recognized as an effective non-destructive tool for examination internal structure of materials, especially metals. It uses radiation source of x-ray or gamma ray for exposuring object and radiographic film to record the radiation ray after passing through the exposured object. So far, radiography is mostly used to inspect metal welding whereas the examination to metal casting are relatively rare. It is purpose of the current study to examine the casting quality of the excavator's bracket using film-based radiography. The experiment was carried out based on ASME Section V Article 2 and ASME E94 standards for radiographic examination. All possible defects in the examined casting sample is evaluated using the radiograph album of the ASTM E446 standard for steel casting up to 2 in (50,8 mm) in thickness [5], [10] - [14].

MATERIAL AND METHOD

The object of experiment is an excavator's bracket. This metal bracket was produced in a foundry located in industrial complex of Cikarang, West Java. The bracket is a cylindrical shape with thickness of 16 mm.

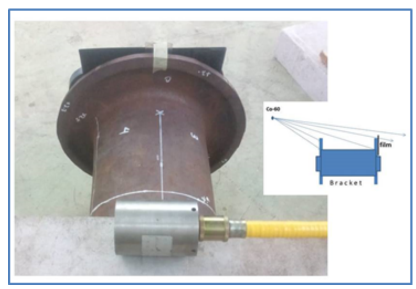


Figure 1. Experimental set up for radiographic examintion to excavator's bracket.

A radiographic technique so called single wall single image (SWSI) has been implemented to exposure the excavator's bracket in the mode of source side exposure. The experiment was prepared based on ASME Section V Article 2 and ASME E94 about radiographic examination in which the SWSI technique is mentioned in these standards [12], [13]. The detail experiment based on SWSI technique was conducted in the following steps. The film was attached at the back side of the bracket such a way that it's position is opposite to the direction of radiation source. The 1B ASTM image quality indicator (IQI) wire has been chosen for the thickness of 16 mm. Medium speed of radiographic film, D7, with the size of 4 in x 10 in was used to record image permanently. The distance from the radiation source to the radiographic film (SFD) was 360 mm. Time required for exposuring the object was 27 second

p ISSN 1907-0322
e ISSN 2527-6433

to produce an adequate quality of radiograph. Gamma radiation emitted from Cobatl-60 radiation source with activity of 80 Ci was used to exposure to the bracket sample. After exposure, the film are processed chemically using solutions of developer and fixer to convert latent images into permanent radiograph. The process was carried out in a darkroom to avoid the effect of environmental visible light. The radiograph is then evaluated under light viewer to check the formed images, as shown in Fig. 2. The density (darkness level) values on material and on IQI are measured using densitometer. Visible indications or defects are observed on viewer. The radiograph is allowed to be scanned, Fig. 3(a) and 3(b) or duplicated on the blank white paper using pencil or permanent ink, as shown in Fig. 3(c). The permanent radiograph and its duplications are saved as permanent record. The experimental set up is presented in Fig. 1, whereas the exposure parameters are summarized in Table 1.

Table 1. Exposure parameters for radiographic excavator's casting.

Material	Carbon steel
Material Thickness	16 mm
SFD	360 mm
Exposure time	27 s
IQI	ASTM 1B, wire
Exposure technique	SWSI
IQI placement	Source side
Film speed	Medium, D7
Fim size	4 in x 10 in
Film processing	manual
Radiation source	Co-60, 80 Ci

RESULTS AND DISCUSSION

Film based radiography has become a mature non-destructive tool for examination internal structure of material especially to inspect discontinuities and/or defects in metals. Standard or procedure for radiographic examination and evaluation of radiograph are available and they are adopted almost by all inspection companies and research institutions worldwide [12], [13]. Here we will discuss two the most important standards for evaluation of permanent radiograph obtained from the current experiment. First is the use of ASME Section V, Article 2 and the second is the reference radiograph album of ASTM E446 standard for evaluation of metal casting with the thickness up to 2 inch (50,8 mm) [12], [14].

ASME Section V, Article 2 in accordance to ASME E94 have been referred as two standards for radiographic examination in the current study. These standards state that radiographic examination shall be performed using single wall single image (SWSI) technique if possible. If it not, double wall single image technique could be performed [12], [13]. In the current study SWSI technique was applied to detect any discontinuities or defects in the exposured excavator's bracket and all recommended parameters of exposure are followed.

The reference radiograph album of ASTM E446 standard is used to evaluate discontinuities or defects or indications in the permanent radiograph. Permanent radiograph is radiograph that has been processed using developing solution in a darkroom, meanwhile discontinuities, defects and indications are the terms that have the same meaning which indicate imperfectness of the object being examined. Permanent radiograph is accepted if the density and the appearence of IQI in permanent radiograph are accepted according to the ASME Section V, Article 2. When these two requirements are fulfilled, the radiograph can be used to detect defects in casting.

Radiograph obtained from exposuring the excavator's bracket using gamma rays from Cobalt source is presented in Fig. 2. Medium speed of radiographic film, D7, produced by Agfa Gavaert® was able to show the appearance of radiograph image in analog format. Density of the permanent radiograph is 2.24. The density measurement were taken at the points on parts of casting material and on IQI as well. Although the density values on these points are different but it's difference is small and insignificant, therefore it can be ignored and the radiographer may choose one density value freely either on the material or on the IQI areas.

10.17146/jair.2023.19.1.6975
p ISSN 1907-0322
e ISSN 2527-6433

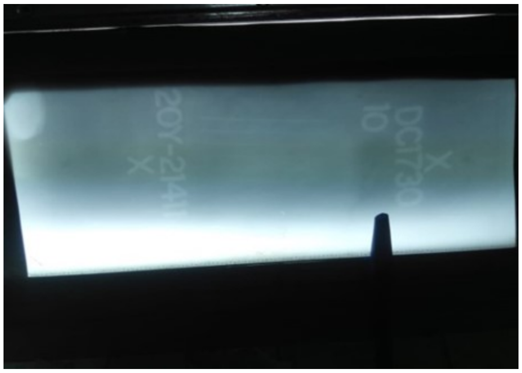


Figure 2. Radiograph evaluated under light viewer

The sensitivity of radiograph is measured based on appearance of the smallest diameter of IQI wire. Observation under light viewer showed that four of six wires of 1B ASTM IQI are apparently observed on the permanent radiograph. This 1B ASTM IQI contains six arrayed wires with different diameter of the wires. The largest and the smallest wire diameters for 1B IQI are 0.813 and 0.254 mm respectively. The diameter of the fourth wire is 0.406 mm and this is the smallest diameter among the four of the six wires that appear in the radiograph. The radiographic sensitivity is calculated based on the ratio of the smallest wire diameter to the material thickness. For the thickness of 16 mm, the radiographic sensitivity is around 1.3 %. In other words, the defect with minimum size of 0.406 mm can be detected in this study.

Interpretation of casting defects is not an easy task, because appearance of the defects are mostly just similar and are not the same with that documented in the album. This is true, especially for the defects that are caused by trapping gas, mostly hydrogen and nitrogen, during solidification process [4]. In this category, the trapped gas can be appeared in the form of porosity, shrinkage and pipe depend on it's shape and orientation [9].

Fortunately, the American Society of Testing and Material (ASTM) has produced a huge numbers of standards, one of which is the ASTM E446 standard about the types and distribution of defects caused by casting processes. This standard is equipped with the album of reference radiographs for steel casting with thickness up to 2 in [14]. Once the defect types have been recognized distinctively, they have to be compared with the reference radiograph in the album. In most cases, the defect shapes that are visible in the permanent radiograph are not exactly the same to that in the album. In such situation radiographer is allowed to choose the one that is 'the most similar' available in the album. In this study, the most similar defect in the bracket casting is the defect in category of shrinkage. Shrinkage is occurred due to material contraction during solidification in which the material density change from liquid to solid [9], [15], [16].

In the ASTM E446 standard, the reference radiographs are grouped by defect categories. There are seven categories of defects in the album. Category A is assigned to gas porosity, category B is sand and slag inclusion defects, category C is shrinkage, category D is crack, category E is hot tear, category F and G are insert and mottling defects respectively. Category C is further subdivided into types of CA (linear shrinkage), CB (featherly shrinkage), CC (sponge shrinkage) and CD (combination of linear, featherly and sponge shrinkage). Category types of CA-CD are all divided into five severity levels. Severity level increases as the level number increases and for each severity level there is always a corresponding reference radiograph that is similar. Categories D-G, however, are not divided into severity level [14], [17].

The defect is also characterized by it's quantity, size and distribution. Under viewing, the defects observed in the permanent radiograph are the most similar to the defect with category C4 (shrinkage with severity level 4). The C4 is in the category of worse defect and the bracket is not recommended to be used in service because unsafe. The authority is requested to repair the bracket and re-examined radiographically afterward.

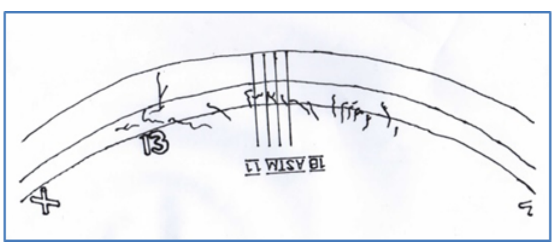
Radiograph is permanent record and it is reported as it is and saved for years. However, the record in other forms are also allowed provided that the information are not change or break. The common alternative record is by mapping the radiograph on a blank white paper on which number, size and distribution of the discontinuities or defects are duplicated exactly the same with the original ones using pencil or permanent ink. Film code, radiographic density and number of visible wire of IQI are also duplicated exactly the same on the white blank paper. The purpose of the duplication of radiograph on paper is to make easier in interpretation without using light viewer.

p ISSN 1907-0322
e ISSN 2527-6433

Moreover, conversion of analog radiograph to digital records are sometimes also allowed, depend on the agreement. The common tool to convert the analog radiograph to digital record is using common and dedicated digital scanners. In addition to Fig. 1, presentation of radiograph in digital form and in form of duplication on paper are shown in Fig. 3.a-c. The result of radiograhic examination of the current study is summarized in Table. 2.

(a)

(b)



(c)

Figure. 3. Alternative presentation of permanent radiograph in (a) digital format using common scanner, (b) digital format using dedicated scanner, and (c) duplication on the paper.

Lesson learned from this study showing that radiography may be considered as a primary tool for material testing and it can serve as quality assurance tool to guarantee the safe use of the tested materials. Based on evaluation, the C4 (shrinkage with severity level 4) fall in the category of worse defect. It is therefore that the examined bracket is not recommend to be used because of unsafe reason. The excavator's bracket shall be repaired to remove all defects in it and re-examined radiographically afterward.

Table 2. Summary of radiographic examintion result

Sample	:	Excavator's bracket
Density	:	2.24
Appearance of IQI	:	4
Radiographic sensitivity	:	1.3 %, high
Defects	:	C4, Shrinkage level 4, worse category

CONCLUSION

Film based radiography has been implemented to examined excavator's bracket. Both density and IQI are accepted according to ASME Section V, Article 2. The sensitivity of measurement is 1,3 % calculated based on the diameter of the fourth wires of the 1B ASTM IQI. It means that the current radiographic system is able to detect a defect with the minimum size of 0,406 mm which is corresponding to the diameter of the fourth IQI wire. The detected defects type in the bracket is in the category C4 (shrinkage with severity level 4) according to the reference radiograph album of ASME E446 standard. Because the C4 falls into category of worse defect, it is concluded that the casting quality of the excavator;s bracket is poor and it not recommended to be used for service because of unsafe reason. The bracket shall be repaired to remove the defects and it is recommended to be re-examined radiographically after repairing.

ACKNOWLEDGEMENT

The authors thank to PT. Komatsu Indonesia for providing us the excavator's bracket casting sample to be evaluated radiographically and encourage us to publish this article to public. This work is also intended as a participation of the authors in scientific society to disseminate recent study in the field of radiography.

AUTHORS' STATEMENT

Sugiharto is the main contributor and there is no conflict of interest among the authors.

p ISSN 1907-0322
e ISSN 2527-6433

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