X-ray Radiographic Study of Simulated Voids –like Defects in Al -Castings and Welded Joints in Steel

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Abstract

The detection and evaluation of imperfections in internal structures of castings and welded joints by x-ray radiography were studied. Optimum radiography conditions that improved the radiographic detection were attempted.

Mathematical equations for radiography were used to calculate the size and depth of defects in castings were tested for validity to a wide range of parameters commonly used in radiography and for variable density and shape of the defects with respect to surrounding.

Two kinds of samples are prepared. The first is aluminum casting through which two different sizes of a regular steel spheres are included and then radiographed from two opposite sides to estimate their dimensional information from the radiographs. The second sample is steel plates which are welded and then radiographed by x-rays. Imperfections such as incomplete root penetration, undercut and porosity were detected in the radiographs.

Keywords: X-ray radiography, imperfections, castings, welded joint.

Introduction

Not all industrial components that are manufactured meet the required specification. Many types and sizes of defects may be introduced to a component either in casting or welding part during manufacture and may influence the subsequent performance of the component. Consequently, reliable means for detection and quantification at the manufacturing stage and during the performance must be applied. Nondestructive testing NDT systems using well-established physical principles have been developed which will not damage the components or assemblies [1]. The benefits of inspecting manufactured component can be divided into three categories [2]: Increased productivity, increased serviceability and safety. Abnormalities in industrial component may be caused from one or more of the following: Inherent defects, processing defects and service defects [3]. Development in radiography and fluoroscopy in industrial field up to 1982 have been discussed by stewart [4]. Segal and Trichter [5] used radiography as a tool to estimate the width and depth of cracks. In 2010, Mahrok et.al. [6] found that it is necessary to estimate the effect of the reradiated fluorescent radiation as this was found to contribute significantly to the total transmitted intensity when the radiographed sample is too thin.

In this work, it is believed that mathematical equations are needed to calculate the size and depth of defects incorporated in certain radiographed block, tested by a particular radiography system. This fact is previously observed by Mahrok et. al. [7]. The validity of these equations with respect to variable radiography conditions ought to be verified.

Theoretical Part

Two equations derived earlier [7] are used for finding the radius R and depth Y of the spheres inside the aluminum block by radiographed. These equations are

$R = R_L\ R_R\ (2L+X) / ((L+X)\ (R_L+R_R))$...........(1)

$Y = (R_R\ (L+X) – R_L L) / (R_R+R_L)$...................(2)

Where Y and R are the depth and radius of the defect in the radiographed block (test object). The meaning of other symbols in these equations are shown in the Fig.(1). Geometrical relations between x-ray source, radiographed block, size of the defect in the block and on the x-ray films are considered in the formation of equations 1 and 2. These equations are tested for 35 cm and 70 cm focal- object distance (F.O.D) and when density of the introduced object is higher or lower than that of the surrounding aluminum medium, and found to be valid. When the steel sphere is in the middle of the radiographed block, then $R_R=L_L$ and equation 1 will be,

$Y= X/2$

Also equation 2 will be,

$R=R_L(2L+X)/(2(L+X)$ ....(3)

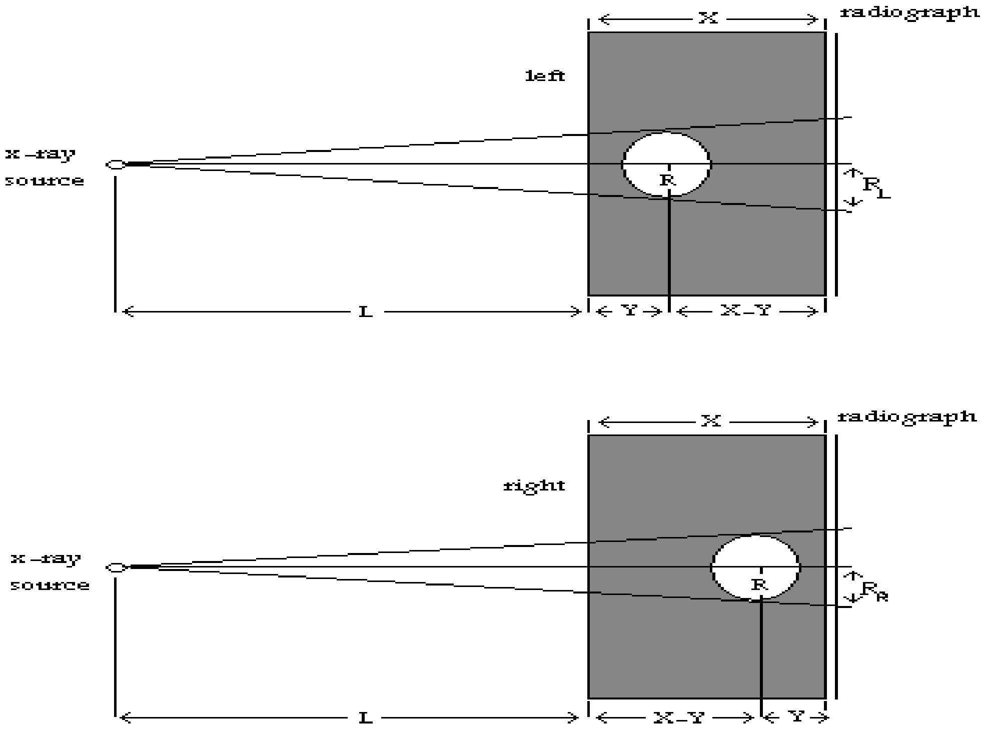


Fig.(1) Experimental set-up for radiography of the test object from two opposite sides, showing the symbols used in equations 1 and 2.

Experimental

X-ray radiography is a well established NDT testing allowing one to realize the industrial defects in internal structure and possible imperfection in the radiographed object.

In order to deduce the size and depth of imperfections in casting an aluminum alloy block was prepared that incorporates two steel spheres of different diameters 2.84 cm and 1.89 cm. The spheres were incorporated in aluminum liquid during pouring inside a rectangular mould of 16.2 cm × 10.2 cm × 6.1 cm. The density of steel and aluminum alloy were 7.8 g/cm^3 and 4.3 g/cm^3 respectively. So a reasonable contrast on the radiographs was to be expected. RADIOFLEX x-ray equipment (japan made) is used for radiography. The x-ray tube in this equipment has tungsten anode with focal spot size of 1.5 mm. The depth of the defect Y and its radius R should have experimentally measured. In order to find Y and R, the test object required to be radiographed from two opposite sides, say right and left sides. Then the radius R and depth Y of the imperfection (assumed spherical in shape) may be found by measuring the symbols appeared in Fig.(1). And substituting them in equations 1 and 2. The steel plates were cut in dimension 20 cm × 20 cm × 0.5 cm and their edges were tapered before welding in a butt weld design. The later may take various geometrical forms as (V) or (K) or (X) shape according to the requirement [8]. The two plates are adequately cleaned then arc welding was used from the side of the prepared edges as illustrated in Fig.(2).

Fig.(2) A photograph illustrates steel welded sample.

Results and Discussion

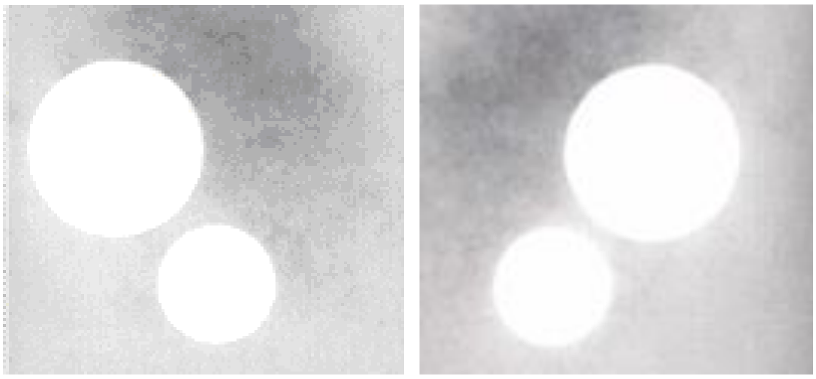
Radiographic measurement at the shadows of foreign materials or defects and the measurement of the geometrical parameters of the experimental system enabled to calculate the actual size of these materials and their depth inside the casting. Fig.(3). Typical radiographs for casting sample at two sides a: for left side b: for right side. Table (1). consist of the actual values of both depth Y and radius of defect R and their measured values based on the radiographs and equations 1 and 2.

The actual values of both Y and R were obtained by cutting the aluminum cast vertically at the region beside the sphere, while the measured values of Y and R where obtained mathematically using an equations mentioned previously and depending on radiography films .

From these calculations one can see that good.

Agreement was obtained between the actual values of the radius of steel spheres and those calculated from radiographes using the appropriate equations, similar agreement was also obtained for the depth of the steel spheres.

Welded sample of carbon-steel alloy was used for evaluation the weld defects that may occurred in the welding process. Typical picture of the radiograph is shown in Fig.(4). Welding defects such as incomplete root penetration (IP), porosity (P) and undercut (UC) are noticed in the radiograph. Table (2). describes these defects with their radiographic appearance. The latent image formed in the pattern of x-rays just after being transmitted through the radiographed object depends on the selection of suitable x-ray voltage, further to the dependence on the structure of the radiographed object.



(a) **(b)**

Fig.(3) Typical radiographs for casting sample at two sides a: for left side b: for right side.

Table (1)
Comparison of the actual and measured values of sphere radius R and sphere depth Y for the two spheres.

Focal Object Distance (F.O.D) in (mm)	*Sphere Radius (R) in (mm)*		*Sphere Depth (Y) in (mm) from left Side*	
	Actual	*Calculated from radiographs*	*Actual*	*Calculated from radiographs*
700	14.2	14.1±0.4	18	18.1±0.4
350	14.2	13.8±0.4	18	17.8±0.4
700	9.45	9.3±0.4	11.9	11.7±0.4
350	9.45	9.2±0.4	11.9	11.4±0.4

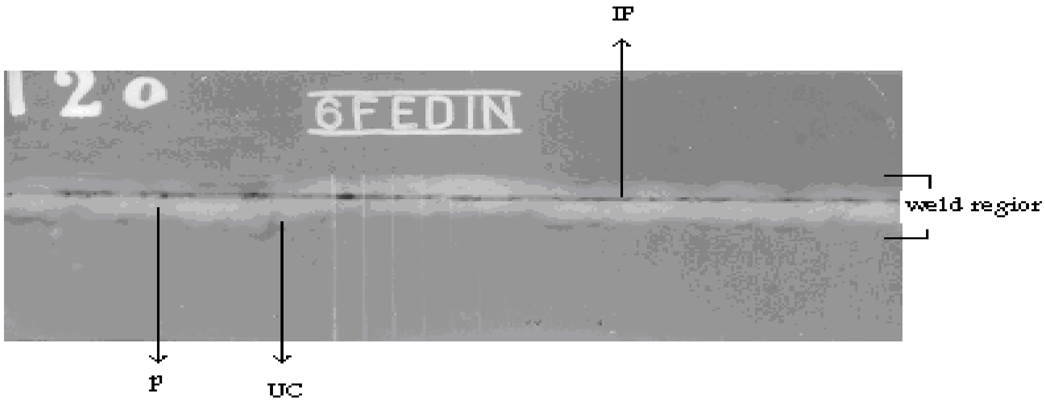


Fig.(4) Typical radiograph of the welded sample.

Table (2)
A summary of the observed defects in welded sample.

N	*Imperfection*	*Imperfection code*	*Description*	*Radiographic Appearance*
1	Incomplete root penetration	IP	Failure of the weld metal to extend into the root area of a joint	Dark intermitted bond with mostly straight edges
2	Porosity	P	A group of gas pores confined to a small area of a weld	As a cluster of small dark round indication
3	Undercut	UC	An irregular groove at the top edge (toe) of a weld	As a dark irregular band along the top edge (toe) of the weld metal

Conclusions

The equations for finding the size and depth of defects are valid under different geometrical factors usually used in radiography and whether these defects are higher or lower in density than the surrounding medium. However there is no reason why these equations should not be applied for other (F.O.D) values used in radiography.

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الخلاصة

تم دراسة وتقييم العيوب الصناعية في التركيب الداخلي لكل من المصبوبات المعدنية ومفاصل اللحام بواسطة تقنية التصوير الشعاعي بالاشعة السينية. تم اختبار افضل الظروف التشغيلية للتصوير الشعاعي والتي من خلالها يتم كشف العيوب بشكل واضح باستخدام تقنية التصوير الشعاعي. لغرض حساب حجم وعمق العيوب الصناعية في المصبوبات المعدنية تم استخدام معادلات مشتقة مسبقا لاثبات مدى ملائمتها للمعلمات الشائعة الاستخدام في التصوير الشعاعي و كذالك للمتغيرات مثل كثافة وشكل العيوب مع اخذ الظروف المحيطة بنظر الاعتبار. تم تحضير نوعين من النماذج احدهما هي مصبوبة المنيوم وغمرت بداخلها كرتين من الفولاذ منتظمتي الشكل ومعلومتي الابعاد وتم تصوير المصبوبة المعدنية من جهتين متعاكستين بواسطة تقنية التصوير الشعاعي. اما النموذج الثاني فهو عبارة عن صفائح من الفولاذ تم لحامها بالقوس الكهربائي وبعدئذ صور المفصل اللحامي بالاشعة السينية وقد بينت الصوره الماخوذة عدة عيوب منها عدم نفاذية مادة اللحام والحزوز الناتجة عن عدم اكتمال عملية اللحام والمسامية.