Interpretation of Radiographs and Related Standards

V. R. SUBRAMANIAN*

Introduction

Radiography provides a valuable non-destructive method for determining the internal soundness of welds and castings. It is applied extensively now-a-days for weld and castings in both ferrous and non-ferrous materials.

It is used quite widely both in development and production line inspection work. In so far as development work in the field of welding is concerned, it is used as an aid in establishing the proper welding procedure and techniques and also for qualifying welding operators and procedures. In the foundry industry, it is used as an aid in developing proper casting design and foundry technique. For this purpose, pilot castings are examined by radiography to develop proper risering, coring and chilling and to study and control the internal shrinkage.

When used as a production inspection tool, the specifications or standards under which the product is fabricated by welding usually determine the extent of non-destructive inspection testing. In some cases, the entire weldment is subjected to radiographic inspection while in others only certain highly stressed welds are subjected to radiographic inspection and in some other cases, a certain percentage of the total weldment selected at random is inspected. When used as an inspection tool for controlling quality of production in foundry, the method reveals sub-surface defects, thus enabling rejection of unacceptable castings before costly machining operations are performed, and also helps detection of defects otherwise not laid bare by machining which might cause service failure and thus helps to control the quality of the castings. In foundry industry again, the amount of radiographic inspection required depends on the standards and specifications to which the castings are manufactured their design and the usage which they will be put to. For example, in the case of castings which are subjected to low stresses in service, the aid of radiography may be taken only for development of proper foundry technique whereas in the case of castings that will be highly stressed and whose design does not cover adequate safety factor, it may be required to radiographically inspect cent percent. In certain huge castings, only certain areas which are considered critical from the point of view of service stresses or technology of foundering are subjected to inspection by radiographic methods.

One method common in determining the number of castings to be inspected is to arrive at this figure based on the percentage of defective castings detected by applying cent percent non-destructive inspection over a certain period. Another method is to select arbitrarily or inspect on a percentage basis depending on the severity of the service stresses.

For the most effective utilisation of this non-destructive testing method, a proper knowledge of interpreting the radiograph is necessary. Admittedly,

Mr. Subramanian is Development Manager, Welding Consumables, Indian Oxygen Ltd., Calcutta.

no amount of description of appearance of various defects in the radiographs is going to make anyone a good interpreter of radiographs. There is no substitute for experience in this particular field.

Identification of Defects in Weldments

A radiograph is a shadow picture of a material more or less transparent to radiation. The X-rays and Y-rays darken the film so that the regions of lower density which readily permit penetration appear dark on the negative in comparison to the areas of higher density which absorb more of the radiation. Thus voids and cavities in metals are recorded as darker areas whereas heavy inclusions such as iron scale or copper segregation in an aluminium alloy, register as a corresponding lighter region on the radiograph. The film therefore discloses the conditions within the metal of different density or X-ray absorption which may be more or less than the surrounding material. The sensitivity values indicate the smallest variation in absorption that can be registered in the film.

In general, defects in welds are either a void in the weld metal or an inclusion of lesser density than the metal surrounding it. These defects, therefore, show on the radiograph as darkened areas. When interpreting weld radiographs, it is necessary to have all data concerning welding procedure and technique and joint design. This information helps to orient the configuration on the radiograph. Further, certain joint designs and welding procedures are prone to certain weld defects ; some procedures tend to produce porosities or slag inclusions. In welded castings, shrinkage in the castings must be distinguished from weld defects. Defects in welds can be grouped for the purpose of radiographic interpretation in the following manner :—

(1) *Cracks*

- (a) Longitudinal weld cracks
- (b) Transverse weld cracks
- (c) Crater cracks
- (d) Parent metal cracks

(2) *Incomplete Penetration*

(3) *Lack of fusion*

(4) *Porosity*

- (a) Scattered porosity
- (b) Linear porosity

(5) *Slag inclusions*

- (a) Scattered and cluster slag inclusions
- (b) Linear slag inclusions

(6) *Surface defects and irregularities*

- (a) Undercuts

(1) *Cracks :* These are the most serious type of weld defects. Their appearance and clarity on the radiograph is determined by the direction of the X-ray beam in relation to the crack. When a beam direction is parallel to the plane of the crack, the image is distinguished best.

(a) *Longitudinal weld cracks :* These appear on the radiograph as dark and usually well defined lines. They run in the direction of the weld and are usually wavy but in some instances, are sharp and straight. When the plane of the crack does not coincide with the direction of the X-ray beam, the crack will appear as a broad poorly defined band. If the deviation is considerable, the crack may show up as a light shadowy area difficult to detect.

(b) *Transverse weld cracks :* These are not as common as longitudinal cracks. They usually appear on the surface of the welds. Their appearance on the radiographs is similar to the longitudinal cracks except that they are transverse to the direction of the weld.

(c) *Crater Cracks :* These appear either as short or fine straight lines or as several fine tails extending outward from a centre. These are usually formed by the interruption of the welding arc.

(d) *Parent metal cracks :* These originate in the base metal. These may be parallel to the weld joint or transverse to it in the heat affected zones. Another type of base metal cracking is called underbead cracking. Base metal cracking is often very difficult to detect because of the high film density at the edge of the welds with reinforcement.

(2) *Incomplete Penetration :* This defect always occurs at the root of the weld joint and is caused by the failure of the root pass and back pass to fuse properly with each other or with base metal at the root. In the radiograph, incomplete penetration is a straight dark line along the centre of the weld and depending upon the width of the defect, the line will vary from a thin sharp line similar in appearance to that of the

crack to a broad diffused one. When, however, slag occurs with this defect, the line usually appears broad and irregular depending upon the root gap.

(3) *Lack of Fusion :* Lack of fusion is a defect which occurs at the weld-interfaces. It is caused by failure of the weld metal to fuse properly with the parent metal. On a radiograph, this defect appears as a straight line and of varying widths. Very often slag is present in the imperfect fusion void and the image is of an irregular outline not unlike a slag inclusion. If imperfect fusion is not accompanied by slag, it is difficult to detect its presence because the plane of the void seldom is parallel with the usual direction of the X-ray beam. When lack of fusion is suspected, it is necessary, therefore, to take additional shots and imperfect fusion generally appears as a band straight on one side and irregular on the other.

(4) *Porosity :* The term is used to describe gas inclusions which occur in the weld as globular cavities. They are formed by gases that fail to escape as the weld metal cools. On a radiograph, they appear as round spots of varying sizes and densities. A special kind of gas inclusion often referred to as worm holes, is a tube like defect. If the major axis of the worm hole is normal to the weld surface, its image on the radiograph appears as two concentric circles, one of which is darker than the other. If the worm hole is inclined or parallel to the weld surface, it appears as a rectangular shape. Porosities may occur singly, in clusters or randomly scattered throughout the weld. Although linear porosity is actually a form of porosity, it often occurs along with incomplete penetration. On the radiograph, it is recorded as a series of round dark spots distributed in a line lengthwise along the weld. When it occurs with incomplete penetration, the cavities are superimposed on the penetration line.

(5) *Slag inclusion :* It appears on the radiograph in a variety of irregular shapes. These can also occur singly, in cluster, in a linear distribution or scattered randomly throughout the weld. Slag inclusion can occur with incomplete penetration and imperfect fusion. The principal difference between other forms of slag and that which occurs in association with these defects is that the latter is present as a linear condition as compared to the random pattern of scattered slag.

(6) *Surface Irregularities :* Whenever it is practical, it is best to have the weld reinforcement removed before radiography. This will help better interpretation of the radiograph. Since this procedure may not be practicable or possible in many applications, the weld contour and surface irregularities that will be shown on the radiograph must be given due consideration during interpretation to avoid these surface irregularities from being interpreted as internal weld defects. In any case, it is a recommended practice, whether the weld reinforcement is removed or not, to visually inspect the weld surface for surface irregularities that might show up on the radiograph.

One of the common surface defects is under cutting where an abrupt reduction in base metal thickness takes place. On a radiograph these appear as dark lines at the edge of the weld. Chipping or grinding marks that run parallel along the length of the weld are revealed as dark lines which can be confused for cracks, imperfect fusion or incomplete penetration. Other surface irregularities are surface pitting, varying width of cover layer, variation in height of reinforcement and non-uniformity of weld ripples.

Identification of defects in ferrous castings :

The internal discontinuities occuring in various castings which can be detected by radiograph are as follows :—

Gas holes and porosity	Unfused chills
Inclusions	Unfused chaplets
Shrinkage	Cold shuts, misruns, Internal scabs, core rods
Cracks	
Tear or hot cracks.	

Of these, the first five occur most frequently while shrinkage is the most common of all. All these defects are either voids in the casting or an inclusion of lesser density than the surrounding metal. Their images on a radiograph are darker than the immediate area surrounding the defects.

Gas holes : Gas cavities are caused either by gas evolving from the metal or from the mould. They can occur individually, in clusters or distributed throughout the casting. Gas cavities appear as dark, round or nearly round spots of varying densities depending

upon their depth. Often a small tail spreads out from the gas cavity.

Inclusions : Inclusion is a general term applied to sand, slag, oxide or dross trapped in the casting. In most cases, these defects occur near the surface. In some instances, however, it can occur inside the body of the casting. On the radiograph, inclusions are often of relatively lower density than the gas cavities and appear more diffused. They tend to be irregular in shape not spherical or oval in shape.

Shrinkage : These defects are known by a variety of terms such as pipes, capillary piping or shrinkage, primary and secondary shrinkage and spongy metal. All these refer to the unsoundness occurring in that portion of the metal which solidifies last. Shrinkage pipe and shrinkage porosity are represented by filamentary or dendritic dark regions of irregular dimensions and indistinct outlines.

Cracks and Tears : Cracks and tears, sometimes called hot cracks, are similar ; the main difference between them being the time at which they are formed as the hot metal cools. Ruptures which occur just before solidification is complete are known as tears, while those resulting after the metal is relatively cold are termed cracks. They may originate at the surface or more often internally. Cracks are almost always straight and sharply defined, whereas tears are more filamentary and ragged, which are diffused and are of varying density. Cracks are represented by darkened lines of variable width and are filamentary when derived from insufficient feeding or contraction on cooling from the melt. Cracks originating from the internal stress in the weld metal are either angular or straight and are of more constant width.

Unfused chaplets and chills : Chaplets and chill rods which have not been fused completely by the molten pool, are represented on the radiograph by a dark outline, in many cases an exact reproduction of the chill or chaplet. Often the adhering dirt is a source of gas and blow holes are formed by the escaping gas. Misruns and cold shuts appear as very prominent darkened areas of variable dimensions with definite, smooth outlines where the metal failed to fill or unite completely before solidification.

Surface irregularities : Surface roughness appears as white or dark irregular areas with a smooth contour. The colouration depends on whether the surface protrudes or is depressed. The surface irregularities of a rough casting must be compared carefully with the radiograph and identified before an attempt is made to interpret the internal discontinuities.

Identification of defects in castings in light metals :

The internal discontinuities in the light metal castings that can be detected by radiographs are very similar to those described under ferrous castings and their appearance on the radiographs is also similar. While discussing internal discontinuity in light metal castings, special mention requires to be made of gas porosity (hydrogen porosity), which is pecualiar to aluminium castings. On the radiograph, however, these porosities appear as round irregular or elongated dark spots that occur over large areas, if not over the entire castings. Mention should also be made about the microshrinkage or micro-porosity which, is peculiar to magnesium castings. In a radiograph, it appears in relatively large areas as fuzzy wavy lines that tend to have a definite pattern. Mottling is a defect again peculiar to light metal castings which is the usual characteristic of a coarse grained casting and appears as alternate light and dark areas. Segregation is another defect which is a complex phenomenon that results when one or more alloying elements are not properly diffused and tend to concentrate in certain areas. Segregations show up in a radiograph as variation in film density. Often they occur as light or white streaky areas of irregular shape.

Reference Radiographs : Subjecting weldments or castings to radiographic tests and interpreting the result record of internal discontinuities on the film is one thing and accepting a weldment or a casting based on an evaluation of the radiograph is another. For the application of radiography as a quality control aid in production, the evaluation of the radiographs as acceptable or not is very important. So far, the acceptance levels for various categories of internal discontinuities in weldments and castings have been aribitrary and have been based on experience. Admittedly the acceptance levels for the various categories and degrees of severity of internal discontinuities in weldments and castings will necessarily be related to service stresses, safety factors, importance of the components, degree of reliability level required of the components for the particular application, design consideration, such as pressure, temperature, thickness, fabrication, resistance to corrosion, involvement of penetrating radiation or radiation products and the involvement of dangerous gases or liquids. In view of the complicated nature of the problem, acceptance standards have not been formulated so far any where in the world.

American Society for Testing Materials has published the following standard reference radiographs :—

E 155-64	Aluminium and magnesium castings. Inspection of
E 280-68	Heavy walled (4½ to 12 in) steel castings
E 272-67	High strength copper base and Ni-copper alloy castings
E 192-64	Investment steel castings for Aerospace application
E 186-67	Steel castings, heavy-walled (2 to 4½ in)
E 71-74	Steel castings upto 2 in. in thickness
E 99-63	Steel welds
E 310-66T	Tin Bronze castings

These reference radiographs are meant for establishing the categories and severity levels of discontinuities. These are produced under standard conditions and divided into different categories of defects and in each category, there are a number of "usually about 5" severity levels. The above reference radiographs are made use of by purchasers for acceptance purposes by stipulating the severity levels for each category of discontinuity in the formal specification or drawing. The specifications of the purchasers also designate the sampling plan for radiographic tests as well as the extent of radiographic coverage for the samples. The radiographs for acceptance inspection are evaluated in comparison with the reference radiographs as applicable from the list above and to the source and conditions and technique of radiography as applicable. When a particular severity for different categories of discontinuities are called for and if the radiograph under inspection is equal to or better than the reference radiograph, the weldment or casting in question is accepted. If however, severity is more than in the reference radiograph, the weldment or the casting is rejected. These however, could be satisfactorily repaired and put up for reinspection. In the case of welds, the standard reference radiographs cover the types and degrees of discontinuities occuring in steel welds and detectable by radiographic methods. The reference radiographs are intended to serve as a guide for interpretation. No attempt has been made to establish any acceptable limits for internal discontinuity. The types of weld discontinuities illustrated in the reference radiographs and the different degrees of severity covered are given in Table I. In this table, for identification purposes, each type of discontinuity is designated by a number. The degree of severity, in increasing order, is denoted by alphabetical letters A to E. Details of plate thickness of radiograph method employed, and welding procedures are given. From the reference radiographs for welds again, the purchaser for the particular job concerned will have to specify clearly for each type of discontinuity, the acceptable degrees of severities, taking into consideration all the relevant factors similar to those discussed in the case of castings.

Collection of Reference Radiographs by International Institute of Welding

The International Institute of welding has also brought out a collection of reference radiographs. The collection consists of radiographs showing typical weld imperfections of different degrees of severity and it is intended to serve as a guide for the interpretation of radiographs, for unifying interpretation in different countries and for educational purposes, such as training of welders and instruction to radiologists, inspectors and other concerned personnel. It is in its present form not recommended as an acceptance standard for welds but rather as a basis for comparison of radiographs, the type and degree of internal weld imperfections. A number of organisations in the country use these reference radiographs in the same manner as recommended for the ASTM reference radiographs by ASTM.

Indian Standards : The Non-destructive Testing Sectional Committee of Indian Standards Institution has also formed a special panel for collecting a set of reference radiographs for welds and castings. This work is being coordinated by CMERI. The work has progressed to a considerable extent and it is expected in the very near future there will be a set of reference radiographs available in the country from Indian Standards Institution.

Conclusion

In our country, there is a tendency on the part of the inspectors called upon to inspect radiographs to aim at radiographic standards much higher than what might really be required for the particular components and for the service application. This arises essentially because of non-specifying by the designer in clear terms of the different categories of defects and the acceptable severity levels in terms of any set of reference radiographs in drawings and specifications. To derive real benefit from nondestructive testing applied as a tool in production, it is necessary to devote a considerable amount of attention to determining and specifying the category and the degree of severity of defects acceptable for particular castings or for any particular locations in castings or for weldments or for particular location of weldments in a fabrication.

TABLE 1

Types of Weld Discontinuities :

Class	*Term*	*Degree*	*Definition*	*Radiographic appearance*
1.	Porosity (gas) fine	B, C, D, E	Gas pockets or voids in metal	Rounded shadows of varying sizes and densities occuring singly, in clusters, or scattered randomly throughout the weld.
2.	Porosity (gas) coarse	A, B, C, D		
3.	Slag inclusions	A, B, C, D	Non-metallic solid material entrapped in weld metal and base metal	Shadows of elongated or irregular contour occuring singly, in a linear distribution or scattered randomly throughout the weld.
4.	Incomplete fusion	D, E	Fusion which is less than complete. Failure of weld metal to fuse completely with the base metal or preceding beads.	A dark shadow, usually of elongated shape.
5.	Incomplete penetration	B, C, D, E	Root penetration which is less than complete, or failure of a root pass and a backing pass to fuse with each other.	A straight dark continuous or intermittent linear indication, often as a straight line in center of weld.
6.	Cracks, welds, transverse.	A, B, C	Discontinuity resulting from very narrow separation of metal.	Fine dark line, straight or wandering in direction
7.	Cracks, welds, longitudinal	B, D, E		
8.	Cracks, base metal (outside of weld)	D		
9.	Undercutting	B, C, D, E	A groove melted into the base metal adjacent to the toe of a weld and left unfilled by weld metal.	A dark linear shadow of wavy contour occuring adjacent to the edge of the weld, that may be seen visually.
10.	Icicles and burn-through	A, B, C, E	A coalescence of metal beyond the root of the weld or a melting of metal away from the root of the weld ; also through backing strip or ring.	Individual light circular indications or individual or continuous darkened areas of elongated or rounded contours that may be surrounded by light rings.
11.	Slugging (stubbing)	D. E	The addition of a separate piece or pieces of material in a joint before or during welding.	Darkened indications usually outlining the contour of the piece or pieces of material added.