CHAPTER 3

ULTRASONIC NON-DESTRUCTIVE TESTING FOR WELDING DEFECTS CLASSIFICATION

3.1 WELDING DEFECTS

Structural discontinuities that occurs in the welding process are called welding defects. A weld defect is any physical characteristic in the completed weld that reduces the strength and/or affects the appearance of the weld. In the weld, there is change in metallographic structure at certain points which is not homogenous. The defects normally occurs in weldments are crack, porosity, lack of fusion, lack of penetration, tungsten inclusion, slag inclusions, oxide inclusions and undercutting. These defects are explained briefly as follows.

3.1.1 Crack

The thermal cycle during welding has a significance effect on the quality, properties of the complete joint and metallurgical changes that result, the parameters being the highest temperature reached during the cycle and the rate of cooling. In the welding processes the joint is heated to melting point of the metal and then cooled rapidly, mainly by conduction of heat into mass of the work. After the welding cools, cracks may appear if the weld metal is hard and brittle and the joint is rigid. Weldment with crack and its radiography is shown in Figure 3.1.
Figure 3.1 Weldment with crack and its radiography

Cooling of the weld depends upon rate of heat input, parent metal thickness, its thermal conductivity, its temperature before welding, chilling agents like draught and low temperature condition, increase in number of members to form a joint and the geometry of the welding joint. If the welding arc is suddenly extinguished and the welding heat withdrawn, a more severe quenching effect results than due to continuous welding when heat is constantly supplied.

Crack formation can be prevented by preheating the weldment before work on it and post-weld slow cooling after finished often are specified for thicker sections or for base metal. The preheating and post-weld heating and stress relieve heat treatment help reduce residual stresses so that the crack formation is prevented in weldments.

Cracks can be detected in a radiograph only when they are propagating in a direction that produces a change in thickness that is parallel to the x-ray beam. Cracks will appear as jagged and often very faint irregular lines. Cracks can sometimes appear as ‘tails’ on inclusions or porosity.

3.1.2 Porosity

Porosity is the result of gas entrapment in the solidifying metal. Porosity can take many shapes on a radiograph but often appears as dark round or irregular spots or specks appearing singularly, in clusters or rows.
Sometimes porosity is elongated and may have the appearance of having a tail. This is the result of gas attempting to escape while the metal is still in a liquid state and is called wormhole porosity. All porosity is a void in the material it will have a radiographic density more than the surrounding area. Weldment with porosity and its radiography is shown in Figure 3.2.

![Figure 3.2 Weldment with porosity and its radiography](image)

The low welding current, arc lengths either too short or too long, or any other factor which encourage the rapid solidification of the weld metal will tend to cause porosity. Too high welding speed may not permit gases to escape due to which porosity may be formed. Excessive high current may over heat the electrodes and excessive drying of the flux covering may contribute to porosity.

The best way to avoid porosity is to use perfectly clean, dry welding equipment and electrodes. Excessive current and arc lengths that are too long should be avoided.

Cluster porosity is caused when flux coated electrodes are contaminated with moisture. The moisture turns into gases when heated and becomes trapped in the weld during the welding process. Cluster porosity appear just like regular porosity in the radiograph but the indications will be grouped close together.
3.1.3 Lack of fusion

Lack of fusion (Cold Lap) is a condition where the weld filler metal does not properly fuse with the base metal or the previous weld pass material (inter pass cold lap). The arc does not melt the base metal sufficiently and causes the slightly molten puddle to flow into base material without bonding.

Lack of fusion is a term applied when there is a discontinuity between the weld metal and base metal or the layers of weld metal. Lack of fusion may be caused when the base metal temperature or previously deposited weld metal is not raised to the melting point. This defect is also caused when oxides or any other foreign matter adhering on the surfaces are not dissolved by the aid of suitable flux, so that the metal may fuse properly on the joint surfaces. In order to secure proper fusion, it is not necessary to melt an appreciable portion of walls of the joint, but it is only required to bring the surface of the base metal to fusion temperature to obtain the structural continuity of the base and weld metal. Weldment with lack of fusion and its radiograph is shown in Figure 3.3.

![Figure 3.3 Weldment with lack of fusion and its radiography](image)

To avoid lack of fusion, foreign and non-metallic substances which prevent underlying metal from reaching fusion temperature must be removed and the joint cleaned properly. After depositing each pass careful attention
must be given to deslagging of welds between the depositions of successive runs. When the surfaces are rough, they should be chipped or ground properly before further metal is deposited.

### 3.1.4 Lack of Penetration

Incomplete penetration or lack of penetration occurs when the weld metal fails to penetrate the joint. It is one of the most objectionable weld discontinuities. Lack of penetration allows a natural stress riser from which a crack may propagate. The appearance on a radiograph is a dark area with well-defined, straight edges that follows the land or root face down the center of the weldments. Weldments with lack of penetration and its radiograph is shown in Figure 3.4.

**Figure 3.4 Weldment with lack of penetration and its radiography**

Penetration depends upon the use of correct electrode size in relation to the geometry of the joint, the correct welding current and manipulation of the electrode in relation to the weld groove. Accuracy of the joint preparation is most important and must be in accordance with the drawing approved by inspecting authority. Low welding current may result in a large void being formed by the weld metal by merely bridging the fusion faces. Wrong polarity with D.C. machine may cause lack of penetration. Too large or too small in relation to the joint can cause lack of penetration.
When automatic welding is used, the machine must be set accurately to follow the line of the joint and the defect is prevented. It is also prevented by controlling the rate of travel and providing adequate welding current.

3.1.5 Tungsten Inclusion

Tungsten is a brittle and inherently dense material used in the electrode in tungsten inert gas welding. If improper welding procedures are used, tungsten may be entrapped in the weld.

Tungsten inclusion may be caused when contact of electrode with weld pool. This defect is also caused by Contamination of the electrode tip by spatter from the weld pool. Extension of electrode beyond the normal distance from the collet, resulting in overheating of the electrode will tend to cause tungsten inclusion. Inadequate shielding gas flow rate or excessive wind drafts resulting in oxidation of the electrode tip can cause tungsten inclusion. Radiographically, tungsten is denser than aluminum or steel; therefore, it shows as a lighter area with a distinct outline on the radiograph. Weldment with tungsten inclusion and its radiograph is shown in Figure 3.5.

![Figure 3.5 Weldment with tungsten inclusion and its radiography](image)
Tungsten inclusion can be prevented by avoiding contact between electrode and filler metal. To avoid tungsten inclusion is to reduce welding current and adjust shielding gas flow rate. By avoiding larger diameter of electrode also prevent the tungsten inclusion.

3.1.6 Slag Inclusion

Slag refers to non metallic inclusions which are described as oxides and other solids or foreign matter entrapped in weld. Slag may be formed and forced below the surface of the molten metal by the stirring action of the arc. Slag may flow in front of the arc causing the metal to be deposited over it. Also with some types of electrodes, slag in crevices of previously deposited weld metal will not remelt and will be trapped in the weld. Weldment with slag inclusion is shown in Figure 3.6.

![Slag Inclusion Diagram](image)

**Figure 3.6 Weldment with slag inclusion**

The most common cause of slag inclusion is inadequate cleaning of weld metal between passes. Slag also can be present in the molten weld metal for other reactions such as high-viscosity (stiff) weld metal that is too cool to flow properly, rapid solidification, or too low a preheat temperature that prevents the slag from floating to the top of the weld before the weld metal turns solid.
The slag inclusion may be avoided by proper cleaning and preparation of the groove before each head is deposited. Scale, rust, dirt etc., must be removed from joint prior to welding. Care must be taken to prepare the joint surfaces smooth and free from irregularities. Slag can be removed by wire brushing, light chipping or grinding.

3.1.7 Oxide Inclusions

Oxides trapped during welding. The imperfection is of an irregular shape and thus differs in appearance from a gas pore. Weldment with oxide inclusion is shown in Figure 3.7.

![Figure 3.7 Weldment with oxide inclusion](image)

A special type of oxide inclusion is puckering. This type of defect occurs especially in the case of aluminium alloys. Gross oxide film enfoldment can occur due to a combination of unsatisfactory protection from atmospheric contamination and turbulence in the weld pool.

The oxide inclusion may be prevented by proper cleaning and grind the surface prior to weld.
3.1.8 **Undercutting**

Undercutting is a term used to describe a groove or channel in the parent metal along a toe of the weld. The fault generally appears as a groove either continuous or intermittent reducing the base metal thickness. This may either occur on the surface of the base metal, at the toes of the weld, or in the fusion faces of the multi-run.

Undercutting is caused when excessive welding current is used and when the operator uses an inaccurate technique, such as too rapid welding speed, excessive side manipulation or improper angle of electrode. The different characteristic of the electrode is also responsible for undercutting. Mill scale on the surface of parent metal along with rust and surface irregularities, damp electrodes and magnetic arc blow are the causative factors. Weldment with undercutting is shown in Figure 3.8.

![Internal Undercut](image)

**Figure 3.8 Weldment with undercutting**

In case of static loading, presence of small and intermittent undercutting may generally be ignored. Deep undercutting should be chipped out before rewelding.
3.2 NON-DESTRUCTIVE TESTING (NDT)

NDT is basically an examination that is performed on an object of any type, size, shape or material to determine the presence or absence of discontinuities, or to evaluate other material characteristics without affecting the physical properties and causing no structural damage to it.

Inherent flaws in the work piece of a machine such as cracks, pores and micro cavities may result is a fatal failure of the machine, thus affecting the production. Hence it is very important to detect the flaws in the part. Destructive method of testing may not help for machine parts due to structural damage occurring with it. Thus, Non Destructive Testing is a method used to test a part for the flaws without affecting the physical properties and causing no structural damage to it (Huang et al 2001). There are many methods of NDT techniques available for testing. Common NDT methods include

1. Ultrasonic Test
2. Liquid Penetration Test
3. Eddy Current Test
4. Magnetic Particle Test
5. X-ray and Gamma ray Radiography Test

Uses of NDT

- Flaw Detection and Evaluation
- Leak Detection, Location Determination
- Dimensional Measurements
- Structure and Microstructure Characterization
- Estimation of Mechanical and Physical Properties
- Stress (Strain) and Dynamic Response Measurements
- Material Sorting and Chemical Composition Determination
Ultrasonic testing is one of the widely used and powerful techniques for nondestructive testing of materials. One of the largest applications of Ultrasonic testing in NDT is weld inspection.

### 3.3 ULTRASONIC TESTING

Ultrasonic testing uses high frequency sound energy to conduct examinations and make measurements. Ultrasonic inspection can be used for flaw detection/evaluation, dimensional measurements, material characterization, and more.

#### 3.3.1 Ultrasonic Testing Principle

Ultrasonics are the sound waves whose frequency is greater than 20kHz. Due to the high frequency they have a very good penetrating power. When sound waves propagate from one medium to another, a part of the sound energy is reflected and the rest is transmitted at the interface separating the two media as shown in Figure 3.9. This property is made use to detect flaws because not only interfaces also the flaws can reflect the ultrasonic sound energy (Silk 1997).

![Figure 3.9 Propagation of sound energy](image)

Figure 3.9 Propagation of sound energy
The interaction of the sound energy is stronger for higher frequencies. Hence high frequency ultrasound in the frequency range 0.5 MHz to 25MHz is found suitable for the testing. The waves are generated by using either a Piezo-electric energised crystal cut in a particular fashion to generate the desired wave mode or an Electromagnetic acoustoic transducer. The relation among the intensities of the incident and reflected sound energy is given in equation (3.1).

\[
I_2 = I_1 \left( \frac{\rho_1 - \rho_2}{\rho_1 + \rho_2} \right)^2
\]  

(3.1)

The intensity of the sound wave reflected from the interface generally depends upon the difference in the densities of the pair of media \((\rho_1 - \rho_2)\) for the given incident wave intensity. Here \(\rho_1\) and \(\rho_2\) are the densities of the two media 1 and 2 respectively through which the sound wave is propagating. Thus, if the ultrasonic wave propagates from a medium of higher density into a medium of lower density then maximum reflection of intensity takes place at the interface separating the two media. The flaw in the medium results in the reflection of sound energy due to the variation of density and hence their detection is made possible. Reflections are analysed electrically and the reflection is called echo.

### 3.3.2 Ultrasonic Inspection System

Figure 3.10 shows that the typical ultrasonic testing system. It consists of several functional units, such as the pulser/receiver, transducer and display devices.
A pulser/receiver is an electronic device that can produce high voltage electrical pulses. Driven by the pulser, the transducer generates high frequency ultrasonic energy. The sound energy is introduced and propagates through the materials in the form of waves. When there is a discontinuity (such as a crack) in the wave path, part of the energy will be reflected back from the flaw surface. The reflected wave signal is transformed into an electrical signal by the transducer and is displayed on a screen.

The longitudinal ultrasonic pulses are generated using the probe. For each generated pulse the echoes are observed on the oscilloscope as shown in the Figure 3.10. The first echo corresponds to the reflection from the upper surface of the part. If there exists a flaw, a second echo is observed with a lower pulse height due to smaller reflection intensity. A third echo is observed due to the reflection from the back surface. The intensity of the echo from the back surface reflection is less due to attenuation of sound energy in the medium (Erhard and Ewert 1991).
3.3.3 Advantages and Limitations

Ultrasonic Inspection is a very useful and versatile NDT method. Some of the advantages of ultrasonic inspection that are often cited include:

- It is sensitive to both surface and subsurface discontinuities.
- The depth of penetration for flaw detection or measurement is superior to other NDT methods.
- Only single-sided access is needed when the pulse-echo technique is used.
- It is highly accurate in determining reflector position and estimating size and shape.
- Minimal part preparation is required.
- Electronic equipment provides instantaneous results.
- Detailed images can be produced with automated systems.
- It has other uses, such as thickness measurement, in addition to flaw detection.

As with all NDT methods, ultrasonic inspection also has its limitations, which include:

- Surface must be accessible to transmit ultrasound.
- Skill and training is more extensive than with some other methods.
- It normally requires a coupling medium to promote the transfer of sound energy into the test specimen.
- Materials that are rough, irregular in shape, very small, exceptionally thin or not homogeneous are difficult to inspect.

- Cast iron and other coarse grained materials are difficult to inspect due to low sound transmission and high signal noise.

- Linear defects oriented parallel to the sound beam may go undetected.

- Reference standards are required for both equipment calibration and the characterization of flaws.

### 3.4 SUMMARY

In this chapter various welding defects are discussed with causes and remedies. Non Destructive Testing and ultrasonic Testing in defects classification are explained in detail. The basic principle of Ultrasonic testing is also explained elaborately with the advantages and limitations at the end.