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CHARACTERIZATION OF BRAZING DEFECTS IN OXYGEN FREE HIGH THERMAL CONDUCTIVITY COPPER USING NON DESTRUCTIVE TESTING TECHNIQUES

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Abstract

All metal joining processes can give rise to defects that will weaken the joint and can lead to failure of the structure. Common brazing defects include, lack of fill (voids porosity) flux entrapment, non continuous fillets, base metal erosion, unsatisfactory surface appearance, Cracks .Any of these defects are potentially disastrous as they can all give rise to high stress intensities which may result in sudden unexpected failure below the design load or in the case of cyclic loading, failure after fewer load cycles than predicted. Because of this, Non-Destructive Testing of brazed joints have become increasingly important to ensure the structural integrity when the material becomes thinner and stronger and brazed joints become smaller; all to reduce weight in order to save material. There are many Non Destructive testing techniques/methods used, depending on Material Type, Defect Type, Defect Size and Defect Location. In this Paper set of Oxygen Free High Thermal Conductivity Copper of 6MM brazed plates are tested by different Non Destructive testing techniques for location and sizing of the abnormalities. The defects and the geometries are then discussed in detail to elaborate the differences and its causes. The brazing conditions are then interpreted which is expected to arrive to a conclusion on selection of Non Destructive Testing methods for location of Non Destructive Testing defects. Non Destructive Testing can also be used to ensure the quality right from raw material stage through fabrication and processing to pre-service and in-service inspection. After the completion of this project it is expected to understand the complete application of the Non Destructive Testing techniques and its utility.

Key words: NDT, VI, LPT, UT, RT

1. Introduction

The Non Destructive Testing is an interdisciplinary field dealing with non-invasive inspection of component and product structure and integrity. It plays a critical role in assuring that structural components and systems perform their function in a reliable and cost effective fashion. Non Destructive Testing methods aim to locate and characterize material conditions and flaws that might otherwise cause planes to crash, reactors to fail, trains to derail, pipelines to burst, and a variety of less visible, but equally troubling events. These tests are performed in a manner that does not affect the future usefulness of the object or material. Non Destructive Testing allows parts and materials to be inspected and measured without damaging them. Because it allows inspection without interfering with a product's final use, Non Destructive Testing provides an excellent balance between quality control and cost-effectiveness. Non Destructive Testing applies to all kind of industrial inspections, including metallic and non metallic structures. Non Destructive Evaluation is a term that is often used interchangeably with Non Destructive Testing. Non Destructive Evaluation is used to describe measurements that are more quantitative in nature. Non Destructive Evaluation method would not only locate a defect, but it would also be used to measure the defects such as its size, shape, and orientation, as well as its effect to the remaining life of structures and components. Non Destructive Evaluation may be used to determine material properties such as fracture toughness, formability, and other physical characteristics [1].

1.2 The Need for Non Destructive Testing

It is actually very difficult to weld or mold a solid object that has no risk of breaking in service, so testing at manufacture and during use is often essential. During the process of molding a metal object, the metal may shrink as it cools, and crack or introduce voids inside the structure. Even the best welders don't make 100% perfect welds. Some typical weld defects that need to be found and repaired are lack of fusion of the weld to the metal and porous bubbles inside the weld, both of which could cause a structure to break or a pipeline to rupture.

Modern Non Destructive Tests are used by manufacturers

- To ensure product integrity, and in turn, reliability
- To avoid failures, prevent accidents and save human life
- To make a profit for the user
- To ensure customer satisfaction and maintain the manufacturer's reputation
- To aid in better product design
- To control manufacturing processes
- To lower manufacturing costs
- To maintain uniform quality level

During their service lives, many industrial components need regular Non Destructive Tests to detect damage that may be difficult or expensive to find by everyday methods. Aircraft skins need regular checking to detect cracks, underground pipelines are subject to corrosion and cracking, Pipes in industrial plants may be subject to erosion and corrosion from the products they carry, Concrete structures may be weakened if the inner reinforcing steel is corroded, Pressure may develop cracks in welds.

1.3Kinds of Non Destructive Testing

There are many kinds of Non-destructive Testing methods and they are into the following two classes

- Methods for detecting surface and subsurface flaws,
- Methods for detecting internal flaws.

The methods for detecting surface and sub-surface flaws include visual testing, magnetic testing, penetrate testing, pressure and leak testing, Magnetic particle testing, electrical and electrostatic testing and thermal testing. The methods for detecting internal flaws include radiographic testing and ultrasonic testing. Each Non-destructive Testing method has its strong point and weak point. The more important point is that sometimes cannot detect a flaw even if we apply a proper Non-destructive Testing method. Because of this NDT techniques are rapidly advancing and all inspectors are making their efforts not to miss a flaw as possible [2].

1.4 Benefits of Non Destructive Testing

By detecting faulty material and thus preventing loss of material, manpower, and shop time Non Destructive tests will increase productively, and with the increased productively will come economic gains. Non Destructive Tests can be used as an aid in new process and manufacturing techniques. Preventative maintenance tells if parts are still satisfactory for use it pays off in dependable predictable production, fewer repairs, less accidents, and lower over-all operating costs. Increased serviceability of equipment and material will result through the application of Non Destructive Testing methods and techniques, by finding and locating defects which may cause malfunctioning or breakdown of equipment. In the field of safety proper use of Non Destructive Tests will aid in the prevention of accidents, with their possible loss of life, property, and vital equipment. The identification of materials differing in metallurgical, physical, or chemical properties can often be done by using Non Destructive Testing methods [3].

1.4 Application of Non Destructive Testing

Non Destructive Testing is used in a variety of settings that covers a wide range of industrial activity. Non Destructive Testing is applied not only in engineering but also in medical fields. The various industries in which Non Destructive Testing used are:

- Automotive industry- for testing engine parts and frame.
- Aerospace industry - for testing air frames, rocket engine parts.
- Power plant industry- for testing propellers, reciprocating engines, gas turbine engines, boilers, heat exchangers.
- Manufacturing industry- for testing of cast products, forged products, welded joints.
- Petroleum and Gas industry- for testing of pipelines, oil storage tanks, pressure vessels.

The objective is to find defects in the material being tested, and the successful application of the test is largely dependent upon the skill of the operator and the equipment used. The objective of each test method is to provide information about, Discontinuities and flaw, Nomenclature of the material, Dimensions and methodology

2. Welding/Brazing Defects

The performance of welded structure in service depends on presence or absence of defects in weld joints. Weld defects impair the strength of welded joints and may results in the failure of a complete assembly / structure in service. In a general, the term weld defect refers to any departure in welded structure or welded joints from the specified requirements. According to the International Institute of Welding, the weld defects are classified into six groups as follows(a) Cracks, (b) Cavities (blowholes, porosity, shrinkage, etc.), (c) Solid Inclusion, (d) Incomplete fusion, (e) Imperfect Shape, (f) Miscellaneous defects.

(a)Cracks

Cracks are the most dangerous amongst all types of defects as it reduce the performance of a welded joint drastically and can also cause catastrophic failure. Depending on the position, location and orientation these can be categorized as longitudinal cracks, transverse cracks, crater cracks, under-bead cracks, and toe cracks [4].

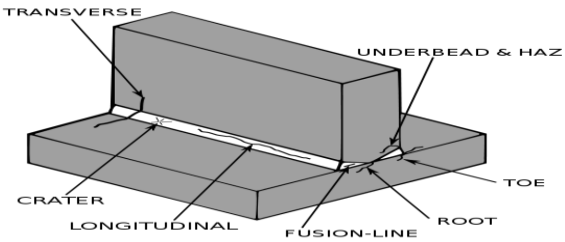
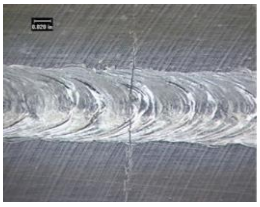
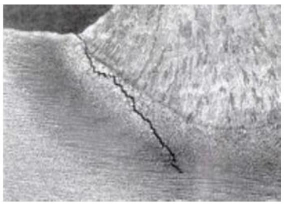


Figure 1: Cracks

(a) **(b)**

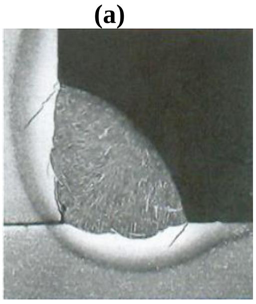
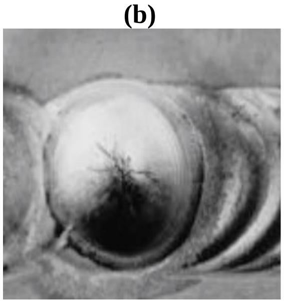



Figure 2(c) **(d)**

(a)Transverse cracks (b) Heat affected zone cracks (c) Toe cracks (d) Crater cracks

(b)Blowholes and Porosities

These are usually subsurface defects in weld joints and are actually voids, holes or cavities formed by the entrapped gases by the solidified weld metal. The source of the trapped gas may be uncleaned rust, dirt, paint, on the parent metal or electrode, damp flux (in shielded metal or submerged arc welding), impurities and moisture in the shielding gas. Normally, porosity is not considered as serious a defect as cracks since the porosity cavities usually have rounded ends which are not expected to propagate as cracks. However, Porosities in weld joints are usually not permitted for pressurized containers intended for storage and transportation of liquid, gaseous or inflammable liquids. The best way to avoid porosity or blowhole in weld joints is to use perfectly clean base materials and baked electrodes.

Figure 3: Porosity

(c) Undercut

Undercutting is when the weld reduces the cross-sectional thickness of the base metal, which reduces the strength of the weld and work pieces. One reason for this type of defect is excessive current, causing the edges of the joint to melt and drain into the weld, this leaves a drain-like impression along the length of the weld.

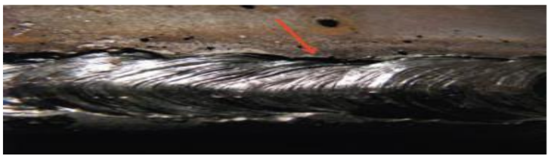


Figure 4: Undercut

(d) Slag Inclusion

The slag inclusion refers to the solidified flux comprising of oxides, phosphorous compounds and nitrides, which fail to float out to the surface and get entrapped in the weld. When gas tungsten arc welding is carried out with direct current electrode positive polarity and at high current, tungsten inclusion from the tungsten electrode into the weld can occur. Such inclusions can be continuous, intermittent or very randomly paced. Slag inclusions reduce the mechanical strength, in particular, the ductility, of the welds.

Figure 5: Slag Inclusion

(e) Imperfect Shape

Dimensional deviations, undercut, under fill, overlap, excessive reinforcement, excessive penetration, bead shape are the examples of Imperfect shape. Under fills and Suck backs refer to uneven depression (such as a concave contour) respectively, on the face or on the root surface of the weld extending below the surface of the adjacent base metal. Both of these defects reduce the cross-sectional area of the weld below the designed amount and thus, a point of weakness and or stress raiser where failure may occur.

(f) Incomplete Fusion and Penetration

Incomplete fusion can occur due to inadequate welding current, offset of electrode from the axis of the weld, too high a weld speed, improper joint preparation and fit-up. It occurs between the parent metal and the weld metal and also between intermediate layers in multi-pass welding reducing the weld strength. Lack of penetration or inadequate penetration usually occurs at the root of the weld and also becomes a built-in crack, which can run through the base metal or weld metal or heat affected zone in actual service condition.

Figure 6: Incomplete fusion

(g) Excessive penetration and / or Reinforcement

Excessive penetration and / or reinforcement are also undesirable in weld joints. Both are usually caused by poor fit-up, too wide a root gap or too small a root face, improper welding technique and excessive welding current. Excessive reinforcement tends to stiffen the weld section and make notches that would create stress concentration.

Figure7: Excessive penetration and / or Reinforcement

2. Methodology

This paper focuses on Evaluation of defects in Oxygen free high thermal conductivity copper materials. Detecting defects in material is one of the most important applications of the Non Destructive Testing. In this paper **Oxygen free high thermal conductivity copper** brazed plates were used to evaluate for flaws using various Non Destructive Testing methods.

The methods involved were such as follows:-

- Positive material identification **(PMI)**
- Visual Inspection **(VT)**
- Dye Penetrant Testing **(DPT)**
- Radio-graphic Test **(RT)**
- Ultra-Sonic Test **(UT)**

Salient findings of studies

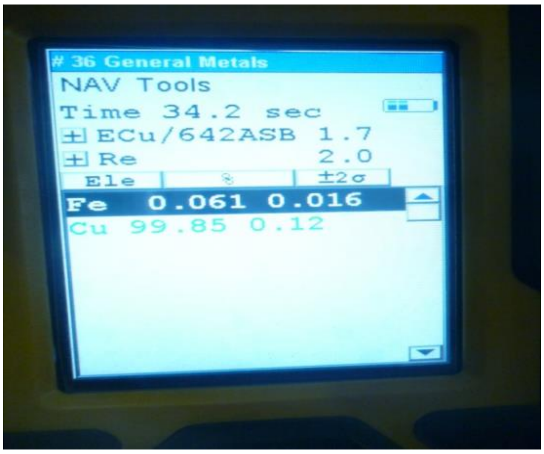
- The material used is Oxygen free high thermal conductivity copper with width and length 40x80mm, thickness 6mm and because copper is non-ferrous material, Bronze Brazing was the method suitable for Oxygen free high thermal conductivity copper.
- After selecting the material, next step is Positive Material Identification .The use of Positive Material Identification gives material identification, grade of the material and detecting elements. Positive Material Identification gives accurate results within seconds as per the standards.
- After Positive Material Identification next method is Visual Inspection. Visual Inspection involves using inspector's eyes to locate for defects.
- Next method is Dye Penetrant Testing was used to find defects only to the open surface.
- Ultrasonic flaw detection test were used to test the internal defects of brazing.
- To validate whether defects is relevant in the above mentioned methods, Radiography test was used. Radiography test is used to ensure the internal flaws.

3. Experimental Results and Discussion

3.1 Positive Material Identification

Positive Material Identification (PMI) is one of the more specialised Non Destructive Testing methods. With positive material identification the alloy composition of materials can be determined. If a material certificate is missing or it is not clear what the composition of a material is, then Positive Material Identification offers the solution. Because specifications for materials used in industry are increasingly more specific, the need for Positive Material Identification testing has been on an increase for the past several years. Periodic plant maintenance shutdowns are less frequent and consequently the materials used in the plant are in use longer. A wider variety of alloys that are indistinguishable to the eye are being used in process plants. When facility and inspection staff replace components, they must be able to guarantee that the new part matches required specifications. Recent industrial accidents have cost the lives of workers and heightened the awareness of the need for accurate and comprehensive Positive Material Identification inspections [5].

3.12Result of OFHC Copper



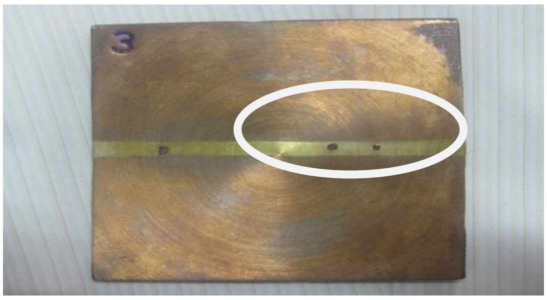
Time: **34.2sec**
Material Identification: **Ecu/642ASB**
Detected elements: **Fe 0.061% and Cu 99.85%**

3.2 Visual Inspection –VT (Surface Examination Method)

Visual Inspection is by far the most common Non Destructive Testing technique. When attempting to determine the soundness of any part or specimen for its intended application, Visual Inspection is normally the first step in the examination process. Almost any specimen can be visually examined to determine the accuracy of its fabrication. Visual Inspection can be used to determine whether the part was fabricated to the correct size, whether the part is complete, or [22] whether all the parts have been appropriately incorporated into the device [6].

3.21Results of Visual Inspection

(i) Test Plate one reveals are free from Visual Defects



(ii) Test Plate two reveals Isolated Blow Holes

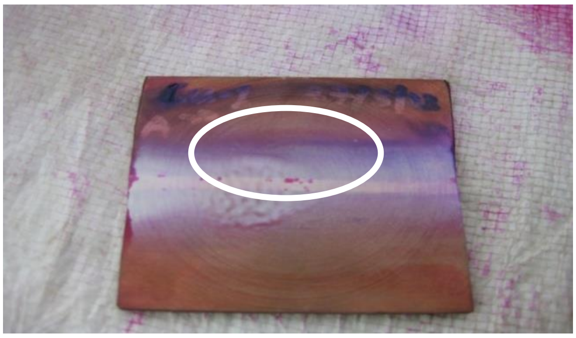
(iii) Test Plate three reveals Shrinkage and Burn Through

3.3 LIQUID PENETRANT TESTING – PT (SURFACE INSPECTION)

Liquid Penetration Inspection is a method that is used to reveal surface breaking flaws by bleed out of a colored or fluorescent dye from the flaw. The technique is based on the ability of a liquid to be drawn into a "clean" surface breaking flaw by **capillary action.** After a period of time called the "dwell," excess surface Penetrant is removed and a developer is applied. This acts as a "blotter." It draws the Penetrant from the flaw to reveal its presence. Colored (contrast) Penetrant require good white light while fluorescent Penetrant need to be viewed in darkened conditions with an ultraviolet "black light". A very early surface inspection technique involved the rubbing of carbon black on glazed pottery, whereby the carbon black would settle in surface cracks rendering them visible. Later it became the practice in railway workshops to examine iron and steel components by the "oil and whiting" method [7[.

3.31Results of Liquid Penetrant Inspection

Plate 1

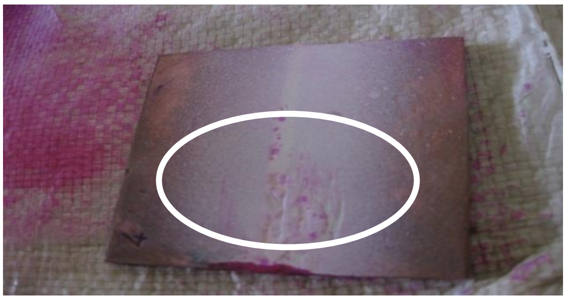


The Test Piece Reveals Cluster Pin Indication which is not acceptable.

Plate 3

The Test Piece Reveals Heat Affected Zone Cracks which is not acceptable

Plate 4



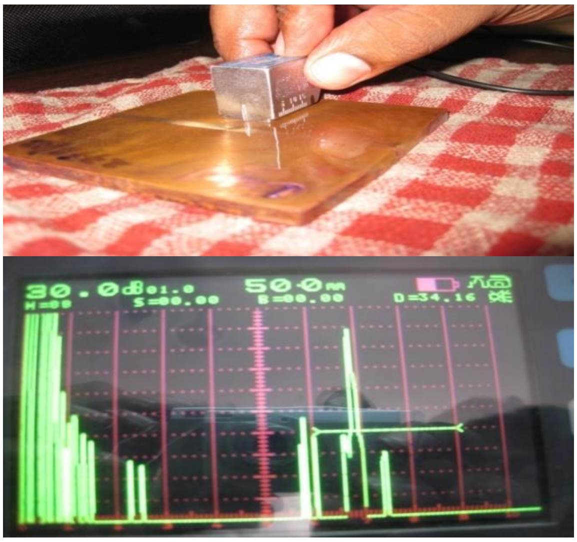
The Test Piece Reveals Blow Holes which is not acceptable

3.4 ULTRASONIC TESTING–UT (VOLUMETRIC EXAMINATION METHOD)

Ultrasonic Testing (UT) uses high frequency sound waves (typically in the range between 0.5 and 15 MHz) to conduct examinations and make measurements. Besides its wide use in engineering applications (such as flaw detection/evaluation, dimensional measurements, material characterization), ultrasonic are also used in the medical field such as sonography, therapeutic ultrasound. Ultrasonic Testing is based on the capture and quantification of either the reflected waves (pulse-echo) or the transmitted waves (through-transmission). Each of the two types is used in certain applications, but generally, pulse echo systems are more useful since they require one-sided access to the object being inspected [8, 9].

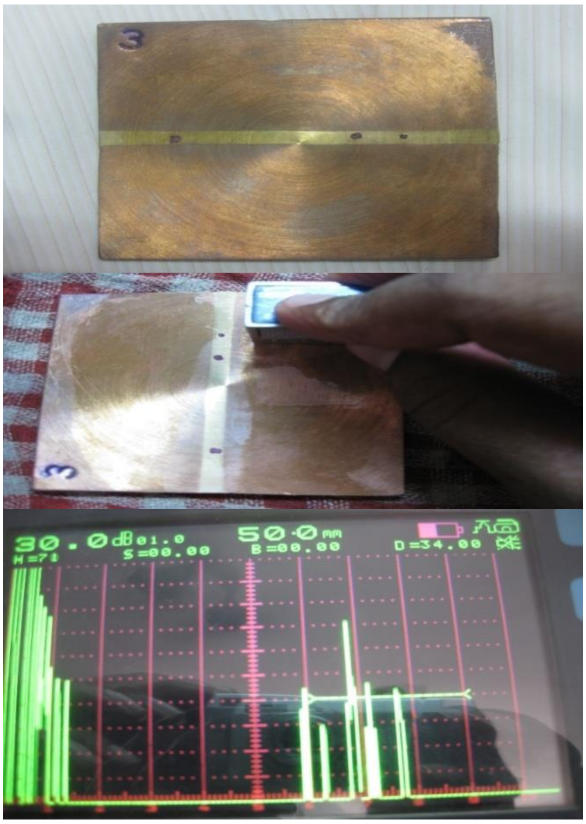
3.41 Results of Ultrasonic Testing

Plate 1



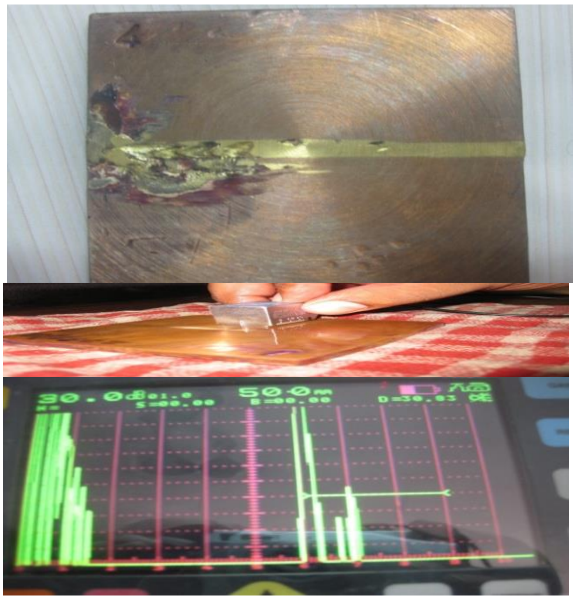
The entire area of brazing was scanned axially using 45° degree ideal probe, the area sound were half skip and full skip distance to ensure 100% scanning is done. The results reveal that the test plate **Lack of Side Wall Fusion, Lack of Porosity,** is detected by Ultrasonic testing. Hence this test plate cannot be put into use.

Plate3



The entire area of brazing was scanned axially using 45° degree ideal probe, the area sound were half skip and full skip distance to ensure 100% scanning is done. The result reveals that the test plate **Lack of Penetration, Lack of side Wall Fusion, Cluster Porosity,** is detected by Ultrasonic testing. Hence this test plate cannot be put into use

Plate 4



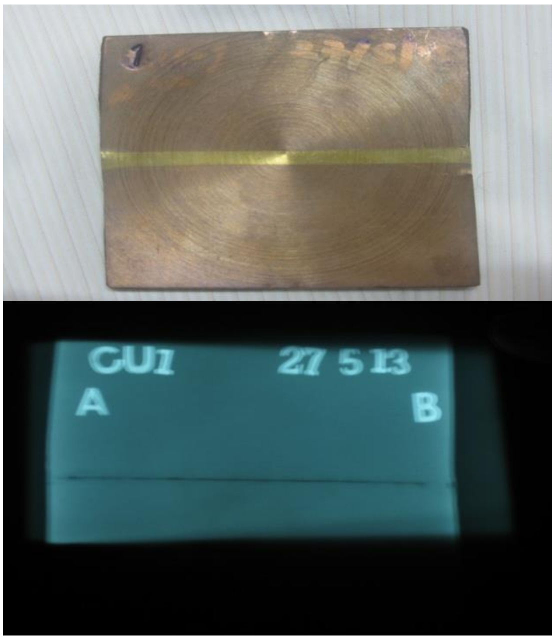
The entire area of brazing was scanned axially using 45° degree ideal probe, the area sound were half skip and full skip distance to ensure 100% scanning is done. The results reveals that the test plate **Lack of Penetration ,Lack of side Wall Fusion,Tungesten Inclusion, Burn through Porosity,** is detected by Ultrasonic testing. Hence this test plate cannot be put into use.

3.5 RADIOGRAPHY TESTING –RT (VOLUMETRIC EXAMINATION METHOD)

Radiographic testing is method of inspecting materials for hidden flaws by using the ability of short wavelength electromagnetic radiation (high energy photons) to penetrate various materials. The intensity of the radiation that penetrates and passes through the material is either captured by a radiation sensitive film (Film Radiography) or by a planer array of radiation sensitive sensors (Real-time Radiography). Film radiography is the oldest approach, yet it is still the most widely used in Non Destructive Testing. Radiographic testing offers a number of advantages over other Non Destructive Testing methods, one of its major disadvantages is the health risk associated with the radiation [10, 11, 12, 13].

3.51 Results of Radiography Testing

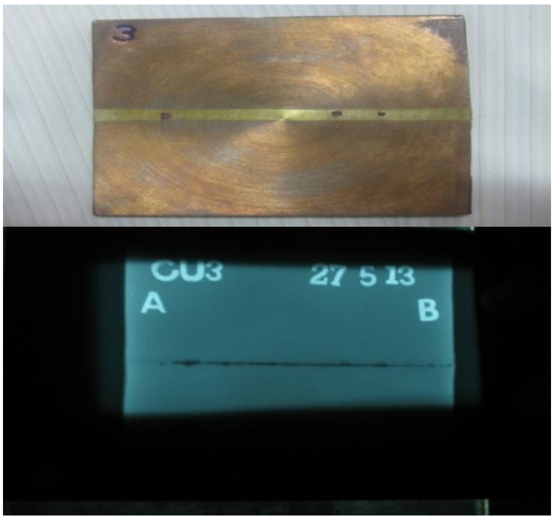
Plate one



The film size used 4x8 with plate thickness 6mm and segment A-B. The test plate one reveals **Lack of Penetration, Lack of side Wall Fusion and**

porosities. Hence this test plate cannot be put into use.

Plate three



The film size used 4x8 with plate thickness 6mm and segment A-B. The test plate three reveals **mismatch**, **Lack of Penetration, Lack of side Wall Fusion and cluster porosities.** Hence this test plate cannot be put into use.

Plate four

The film size used 4x8 with plate thickness 6mm and segment A-B. The test plate four reveals **mismatch**, **Lack of Penetration, Lack of side Wall Fusion Tungsten inclusion and porosities.** Hence this test plate cannot be put into use.

4. CONCLUSION

Methods used in this Evaluation proves that the tools used to evaluate gives an accurate results which proves that the significant defects that are revealed in the samples are evaluated with the help of Non-Destructive Testing and they are strictly not under the permissible limit which henceforth cannot be put into use at any circumstances. The Conclusion gives us a clear picture that the selected material Oxygen free high thermal conductivity copper can be evaluated using the Non-Destructive Testing and the results revealed in this Evaluation can also be used in various manufacturing industries also, this study gives a clear picture that all types of advanced materials can be inspected with these powerful tools. The future will focus on partially or fully automate Non Destructive Testing equipment.

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