Characterization of Weldments Defects through Non Destructive Evaluation Techniques

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Abstract

Background/Object: Non-destructive Testing (NDT) methods are valuable tools in quality assurance of weldments in engineering and technology. The objective of this paper is to evaluate the structural health monitoring of the weldments through NDT methods. Methods/Analysis: The samples taken for these studies are extensively used in Aerospace and industrial applications. The dimensions of fabricated samples of stainless steel and mild steel is 300 mm x 180 mm x 10 mm, D3 tool steel is 180 mm x 150 mm x 25 mm, Aluminum is 150 mm x 120 mm x 10 mm and Titanium is 160 mm x 60 mm x 2 mm. These samples are subjected to Gas Tungsten Arc welding (GTAW) during welding artificial defects are incorporation by altering the weld parameters. The profile of weld defects is studied by using basic Non-Destructive Testing techniques. Findings: Defects which are open to surface and subsurface defects up to 6 mm depth are detected by Visual Inspection (VI), Liquid Penetrant Test (LP) and Magnetic Particle Inspection (MPI) techniques. Ultrasonic – B scan NDT technique is adapted for study of thickness profile of weld region of weldments found distinct result in aluminum weldments. Orientation and Internal of defects of the weldments were detected by Gamma ray Radiography and Ultrasonic Testing methods found forging material inclusion in SS material, Aluminum weldments. Application/Improvements: These evaluation studies through Nondestructive Testing techniques are much useful for structural health monitoring of the weldments.

Keywords: Characterization, Evaluation, Non Destructive Testing, Weldments, Defects

1. Introduction

Assembly of components involving welding process extensively to produce sound weldments and to maintain the integrity of quality control weldments need to defect free. Understanding the various defects, their causes and remedies will help us to ensure high quality and long lasting welds. Weldability is the capacity of a material to be welded under the imposed fabrication conditions into specific suitable designed structure and to perform satisfactorily in the intended service. Because of its strength, welding is used in ship building, automobile manufacturing, aerospace applications, and thousands of other manufacturing activities. The gas shielded, tungsten arc process enables these metals and a wide range of ferrous alloys to be welded without the use of flux.
ties, or flaws but there is no completely acceptable system of comparison, because the results are highly dependent on the application.

2. Material and Method

In the normal engineering practice the engineer selects the best properties of materials to make alloys which especially offer most desirable package of properties strengthening of engineering materials are done by allowing and heat treatment to maintain good strength at high and low temperatures. Also it needs to have sufficient ductility which is important to have extensive utility in structural application in the engineering materials. The professional engineer should know how to select materials which best fit the demands of the design - economic and aesthetic demands, as well as demands of strength and durability. SS 316 L is the standard molybdenum-bearing grade which gives better overall corrosion resistant properties, particularly higher resistance to pitting and crevice corrosion in chloride environment which made it as a nuclear grade material to use in structural application of nuclear power plant and have good Weldability. The most common steel material is mild steel which occupies 85% of steel utility directly for further processing, quality assessment of this larger quantity is necessary. D3 tool steel is a high carbon, oil hardening and high chromium tool steel. It is characterized by highly attainable hardness and numerous large chromium rich alloy carbides in the microstructure. Aerospace material Aluminum Alloy HE-15 (2014 A) is a copper based alloy with very high strength together with excellent machining characteristics. Alloy 2014 is commonly used in many aerospace structural applications due to its high strength. Titanium alloy are metals that contains a mixture of titanium and other chemical elements. These are tough, light in weight, extraordinarily corrosion resistant, ability to withstand extreme temperature and have high tensile strength. A flaw that has been evaluated as rejectable is usually termed a defect. Every non-destructive test method has limitations. Through examination in most of the cases requires a minimum of two methods one for conditions that would exist internally and another that would be more sensitive to conditions that exist at surface of the part. The limitations of each method need to know prior to its use and also the threshold of detectability is a major variable that must be addressed and understand for each method. A prerequisite to perform non-destructive test includes through understanding of important attributes such as the processes that the part undergone, intend used for the part, applied codes and standards. This paper will illustrate various defects in engineering materials and how the engineer can select appropriate NDT technique leading to more effective results.

In the industry, various NDT techniques are used for defect detection applications. Visual Inspection, Liquid Penetrant Examination, Magnetic Particle Testing, X-ray radiography and Ultrasonic Inspection tests are the major techniques for weld quality inspection and detailed in various publications. The nature of the discontinuities that are anticipated for the particular test object should also be well known and understood for this a correlation is established between in Table 1 type of defects and best suitable NDT methods to be practiced according to American Society for Metal Hand book, this correlation saves time in real operation condition for quality control.

2.1 Sample Preparation

All the sample are Joined using Gas Tungsten Arc Welding (GTAW) according to the type of material and thickness filler material, weld passes, current and other welding

| Defect Type          | V.I | PT | M.P.T | U.T | R.T | A.E |
|----------------------|-----|----|-------|-----|-----|-----|
| Micro-crack          | P   | E  | G     | G   | P   | E   |
| Macro-crack          | E   | E  | E     | E   | O'  | E   |
| Porosity             | G   | G  | E     |     |     |     |
| Surface Imperfections| G   | E  | E     | G   | P   | E   |
| Internal Imperfections| ×  | ×  | G     | E   | E   | E   |
| Brazing/bonding      | G   | G  | G     | E   | E   | E   |
| Inclusion            | ×   | ×  | P     | E   | E   | E   |

P = Poor; G = Good; E=Excellent; O’ = Orientation dependent; ×= Not Applicable.
parameters are changed as shown in Table 2. Deliberately defects are introduced into weld region and Heat Effect Zone region (HAZ) by Altering weld parameters majorly current.

### 2.2 Experimental Setup

#### 2.2.1 Visual Inspection

Defects origin at surface which can be detected by careful direct visual inspection. All the weldments under sufficient illumination of the test surface are undergone direct visual inspection thoroughly to check the weld discontinuities.

#### 2.2.2 Liquid Penetrant Testing (LPT)

Liquid Penetrant Inspection is one of the straight forward Techniques. The steps involve in this technique are given below according to ASTM SE-165Standard\textsuperscript{8}.

**Penetrant Application and Dwell Time**: The penetrant is applied effectively by brushing within the specified temperature range. The penetrant is left on the surface for a sufficient time to allow as much penetrant as possible to be drawn from or to seep into a defect. The total time in which the penetrant is in contact with the surface is called the dwell time which depends on various factors like penetrant material, application, materials used, nature (size, shape, surface condition etc.) of the part under examination and type of discontinuities expected\textsuperscript{7}.

**Developer Application**: To draw the penetrant trapped in flaw back to the surface where it will be visible, a thin even layer of developer is applied to the sample. Non aqueous wet developers at a distance of 15 cm away from specimen in atomized coated on the surface of the part, allowed to dry for 5 min as developing time.

**Process Inspection**: As the penetrant is of type III it is examined under direct light of illumination of 100 lux and under Ultraviolet light (black light) in dark room.

### Table 2. Welding parameter of metals

| Material       | Filler material | Current Ampere | Number of Passes | Dimensions Before weld | Dimensions after weld | Image |
|----------------|-----------------|----------------|------------------|------------------------|-----------------------|-------|
| SS 316L        | ER:316L         | 200-230        | 4                | 75*305*10 mm           | 150*305*10 mm         | ![Image](image1) |
| MS -08         | ER:308 L        | 180-220        | 4                | 75*250*10 mm           | 150*250*10 mm         | ![Image](image2) |
| D3 Tool Steel  | ER:308          | 200-230        | 8                | 75*180*10 mm           | 150*180*20 mm         | ![Image](image3) |
| Aluminum HE-15 | ER:4043         | 200-230        | 3                | 60*150*10 mm           | 120*150*10 mm         | ![Image](image4) |
| Titanium Alloy | ER:Ti-20        | 180-220        | 1                | 30*165*2 mm            | 60*165*2 mm           | ![Image](image5) |
2.2.3 Magnetic Particle Inspection (MPI)
Potential technique used to inspect the sub surface defects like laps, cracks, seams, micro cracks and discontinuities on or near the surface up to 6 mm depth in material is Magnetic Particle Inspection. For better inspection, a white background film is placed over the inspection area over mild steel and D3 Tool steel.

_Calibration of Magnetic Partial Equipment (Yoke):_ Best sensitivity of flaw is attained by calibration of the yoke according to ASTM 1444E—01 and ASTM E-709-01. Yoke needs to lift a weight of 10 lb in Alternative Current (AC) and 40-50 lb in Direct Current (DC) that indicates the magnetic field strength and depth of penetration as shown in Figure 1. It is also examined under ASTM test block and six lines are clearly observed as shown in Figure 2.

![Figure 1. Calibration of yoke in AC (A) and DC (B) mode.](image)

Introducing Magnetic Field: Yoke (Make: SIMS, Model: Y-A/D) is preferred to introduce indirect magnetic field into material. Longitudinal magnetic field is induced in the specimen and these lines will pass through the material. Direct current is preferred for deep possible penetration. If any gap or interruption occurs, the magnetic flux leak will take place in that area. The magnetic flux at this point is relatively high when compared to other areas.

Magnetic Particle Application: On the white background inspection area, dry magnetic particles are dispersed. Due to the magnetic flux leak, magnetic particles accumulate over the defects.

Inspection Procedure: Examined under sufficient light intensity of 100 ft (1000 Lx).

2.2.4 Ultrasonic Investigation
Ultrasonic technique is the potential tool for probing the defects through the weld joint. As the inspection area is weld region we cannot directly place probe over so 45° angle probe with shears wave and Pulse echo technique procedure is adapted for investigation. Calibration of the ultrasonic flaw detector (Make: Modsonic; Model: Da-Vinci-alpha) is done according to ASTM E 164 standards by using V2 blocks for angle probe sensitivity adjustments are carried out using zero key, range, material velocity, angle, measurements, which are set to one and other parameters given to device for inspection conditional sensitive level of ultrasonic flaw detector with angle beam probe 45°, X off is found to be 10 mm and given feed to equipment by considering tolerances as +1 or -1 on Sound path.

_Generating distance-amplitude curve:_ The use of electronic methods to compensate for attenuation losses as a function of ultrasonic metal travel distance may be employed by DAC curve. Specimen reference DAC block is prepared with same grade material of that need to inspected having dimensions 40 mm thickness and hole drilled subsequently at ¼ t = 10, ½ t = 20, ¾ t = 30 on the BAC block of stainless steel and dimensions of 50 mm thickness and holes drilled subsequent at 10 mm, 20 mm, 30 mm, 40 mm depths on aluminum DAC block. By considering the thickness of the DAC block sound path, surface distance is calculated. Actual sound path and surface distance are extracted from the device by amplitude response from the DAC block. Capture the amplitude of first hole by placing the probe at a surface distance of 10 mm and sound path 14.14 mm is equal to and not greater than 80% sweep-to-peak, adjust the instrument gain to attain 80%, enter this reading in DAC menu by using...
enter key as first point, similarly carry this procedure. Without changing the sensitivity control, obtain maximum amplitudes from for second and third hole without altering gain. Due sound attenuation and hole diameter the actual values are differed from calculated values. Amplitude in stainless steel DAC for first each in block is 80% and second echo is less than the 1st i.e., 34% and the third echo is less than 2nd i.e., 26% as plotted in Table 2. In aluminum DAC curve first each in block is 80%, second echo is less than the 1st i.e., 72%, the third echo is less than 2nd i.e., 47% and fourth echo is increased up to 57% as plotted in Table 3 and Table 4. Indication of echo are feed into DAC menu by using ENTER key on the screen by entering 2 and 3 points. Connected the screen marks by pressing DAC ON to provide the distance amplitude curve for the side-drilled hole as in Figure 3 and Figure 4. The line in DAC curve represent that if an echo crosses upper line implies reject second one for repair and bottom line for acceptance.

Table 3. Table of data to draw ferrous DAC curve

| S. No | Thickness T=40 | Actual surface distance | Actual Beam path | Ref Db |
|-------|----------------|-------------------------|------------------|-------|
| 1     | ¼ t = 10       | 9.39                    | 13.29            | 56.0% |
| 2     | ½ t = 20       | 19.07                   | 26.98            | 54.9% |
| 3     | ¾ t = 30       | 31.07                   | 43.95            | 63.3% |

Table 4. Table of data to draw ferrous DAC curve

| S.No  | Thickness T=40 | Actual surface distance | Actual Beam path | Ref Db |
|-------|----------------|-------------------------|------------------|-------|
| 1     | t = 10         | 8.99                    | 12.72            | 80%   |
| 2     | t = 20         | 19.14                   | 27.07            | 72%   |
| 3     | t = 30         | 29.69                   | 41.49            | 47%   |
| 4     | t=40           | 39.79                   | 56.20            | 57%   |

Inspection procedure: Inspection is carried over the work piece by applying 2T oil as couplant over weld and HEZ (Heat Effect Zone) sound velocity of material is changed and recalibrated while performing over aluminum Weldment. A scan in thoroughly carried over entire specimen and B Scan is also executed where continuous discontinuity of defects observed.

2.2.5 Industrial Radiography Testing

Radiography involves exposing a test sample to penetrating radiation (with high energy) so that the radiation passes through the object being inspected and they are recording medium placed against the opposite side of that object. The part is placed between the radiation source and a piece of film will stop some of the radiation. Thicker and denser areas will stop more radiation. The film darkness will vary with the amount of radiation that reaches the film through the test object. The minimum recommended thickness limitation may be reduced when the radiography techniques are used to demonstrate that the required radiography testing sensitivity has been obtained. Radiography test is conducted on the sample. Wire type and hole type pentameters are taken for test accuracy.

3. Results and Discussion

3.1 Visual Inspection

This provides detecting and examining a variety of surface flaws, such as contamination, surface finish, and
surface discontinuities over MS EN-08, aluminum HE-15, Titanium weld joints. Examining surface cracks at the bottom of D3 tool steel it is important particularly because of its relationship to structural failure during load conditions. Stainless steel 316 L material is free from surface imperfections.

3.2 Industrial Radiography

All the films are examined in ideal dark room and interpreted that cluster porosity in the middle of weld observed in EN-08 mild steel, incomplete or lack penetration of penetrant is noticed in D3 Tool steel, SS 316 L material is packed with crack, slag and forging material inclusion, In aluminum He-15 x-ray film slag inclusion and porosity is observed which are vividly shown in Figure 5.

Figure 5. Radiography films of. (a) Mild steel EN-08. (b) D3 Tool Steel. (c) SS316L. (d) AL HE-15.

3.3 Liquid Penetrant Test

Observed surface cracks in Titanium weldments in both good and defect region, small scale of porosity is noticed in HAZ as shown in Figure 6(a). In AL-HE 15 cluster porosity in weld region and porosity in HAZ region observed as shown in Figure 6(b). Pin hole are identified in mid face of weld and crack in weld toe region as shown in Figure 6(c). No surface defects are identified in SS316 L and D3 tool steel but identified crack at back side of D3 tool steel as shown in Figure 6 (d) (e).

3.4 Magnetic Partial Inspection

Only Ferrous materials D3 Tool Steel and Mild steel EN-08 are undergone magnetic partial inspection, high flux leak taken place at entire toe region of weld bed, small scale of porosity is also observed on weld region of D3 tool steel as shown in Figure 7(a). Small cracks are identified in the region of weld and cluster porosity on weld region as shown in Figure 7(b) no defects is found in HAZ region in mild steel.

3.5 Ultrasonic Investigation

Ferrous material having velocity with 3250 ms and ranging 60 mm are investigated over single DAC curve. In

Figure 7. (a) M.P.I results of D3 tool Steel. (b) Mild steel EN-08.
Figure 8. Ultrasonic echo of SS316 L.

Figure 9. Ultrasonic echo crossing D3 tool steel.

Figure 10. Ultrasonic echo crossing mild steel EN-08.
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SS316L material acoustic impedance mismatch is noticed at a depth of 9.11 mm with an echo amplitude 47% and another defect cluster porosity is investigated in B-Scan at a depth of 8.40 with an amplitude of 58 percentage is depicted in Figure 8.

B-Scan profile of Lack of penetrant defect is observed at a depth of 19.80 mm with sound echo amplitude of 45% and Small scale of porosity is also observed at a depth of 15.62 mm with a sound echo of 34% in D3 Tool steel as shown in Figure 9.

Mild steel EN-08 is investigated over A-Scan, B-Scan and identified sound echoes which are crossing reject line at the depth of 3.54 and 2.72 with a sound amplitude 58 and 67 percentage as shown in Figure 10.

Aluminum HE-15 alloy is investigated over aluminum DAC curve and found distinct changes in sound attenuation echo of at 51 percentage at a depth of 2.15mm which is crossing reject line of DAC. Another small echo is notice at weld region with an echo of 37% just crossing repair line at a depth of 1.87 mm as shown in Figure 11.

Figure 11. Ultrasonic echo crossing DAC Curve of HE-15.

4. Conclusion

The effects of various parameters such as accuracy, precision and sensitivity guide line that influence the selection of NDT technique were determined. Radiography test vividly shows that orientation and magnitude of defects influence for further methods. Liquid Penetrant Test identifies surface discontinuities in all the weldments; SS316 L is free from surface defects. Ferrous materials are investigated with magnetic particle inspection and found distinctly lack of penetrant, porosity in D3 tool steel and Porosity in weld region of Mild steel E-08. Ultrasonic A, B-scan is carried out for subsurface discontinuities with personal material DAC curve; various defects are identified and quantified with respective sound attenuation echoes. Selecting appropriate NDT technique can improve efficiency and reduce the time and cost.

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