Performance Characteristics of Weld Defect Inspection by Magnetic Particle Testing

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ABSTRACT: ***The industrial product like nozzle consist of magnetic nano-particles for the Ferro fluid black plays an important role under the domain of mechanical engineering applications. In this research work, Non-Destructive Testing (NDT) technique based on deposition of a Ferro fluid Black 140CM, Grey 249 and 147-A/2 is used for the defect testing of the boiler nozzle's surface. Magnetic Particle Testing (MPT)is one of the widely used method for Ferromagnetic material because it is fast and relatively easy to apply as compared to other NDT method. The only requirement from an inspect ability stand point is that the component being inspected must be made from ferromagnetic material (iron, nickel, cobalt or some of their alloy). This method uses magnetic field and small magnetic particles to detect flow in component & obtained defects (linear or rounded indication) of the welded part must be machined with diamond cutter grinding machine till the defects removed.***

Keywords: Non-Destructive Testing (NDT), American Society of Testing Materials (ASTM), Direct Current (DC) & Alternating Current (AC).

I. INTRODUCTION

Quality development and the risk management of the industrial products require lot of expertise and knowledge for the inspection weld surface by Non-Destructive Testing (NDT) during manufacturing. Detection and evaluation of the weld parts is the assessment methods & tends to reduce as the critical defect size. NDT processing has attracted international attention for the proper development of the engineering society and the development of the industrial life with reducing the risk in the services. Methods of NDT depends upon the services of the equipment's. All the defects which may occurs during inspection is not detected by a single NDT methods, so table 1 represents the NDT method selection for different defect position or flow type.

NDT methods use no. 0, 1, 2, & 3 for following purpose as;

(0) will not detect
(1) Not Well Suited
(2) Fairly well suited
(3) Ideal application

Table-1: NDT method Selection

S.N.	Defect position	Visual	Liquid Penetrant	Magnetic Particle Testing (for Ferromagnetic material)	Ultrasonic		Eddy Current (for Conductive Material)	X-Ray
					Straight Beam	Angle Beam		
1	Surface breaking inner	1	3	3	1	2	3	1
2	Surface breaking volumetric defect	3	3	3	3	3	3	3
3	surface Linear &normal to surface	0	0	2	1	2	3	1
4	Near-surface Linear & Parallel to surface	0	0	0	3	3	0	0
5	Near surface Volumetric	0	0	2	3	3	3	3
6	Surface linear & Normal to surface	0	0	0	1	2	0	1
7	Subsurface Linear & parallel to surface	0	0	0	3	3	0	1
8	Subsurface Volumetric	0	0	0	3	3	0	3
9	Thickness measurement of Thin Material	0	0	0	3	3	3	3
10	Thickness measurement of Thick Material	0	0	0	3	3	0	3
11	Non-Conductive coating thickness measurement	0	0	0	2	2	3	1

NDT nowadays used for the critical services with high temperature & pressure services like Furnaces, heat exchanger, boiler, radiators, chillers etc. on the fracture of mechanics calculations. Non Destructive Testing (NDT) is considered few key factors to complete the process of defect identification are below mentioned as:

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a) *Mediums* to interpret the results to detect the cause.
b) *Radiographic signals* to detect the cause of welding defects.
c) *Test object* must be under the penetrate testing for indicating or recording signals.
d) Basis for interpreting the Test piece results which have *energy source* or *medium* used.

Fig. 1 is showing the visibility of cracks in nozzle at different view angles as at the each angle defects are not visible. Therefore view angle is also important to locate the defect.

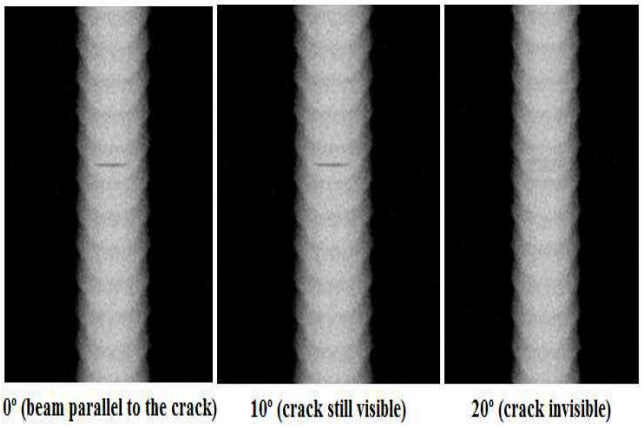

Fig. 1: Detection of the welding cracks by radiography testing.

The present research is based on Magnetic Particle testing to detect the defect on the surface of the boiler nozzle.

2.1 Basic principle of Magnetic Particle Testing

Magnetic Particle testing has relatively simple concept based on magnet and shows all the basic principles of magnet as:

1. Magnet has two pole (North Pole & South Pole).
2. Magnetic flux traveling form South Pole to North Pole inside the magnet and North Pole to South Pole from outside the magnet.
3. The magnetic flux have a definite loop and never cross each other.
4. Flux strength will be maximum at pole and decreases as distance between pole increases.
5. When the magnet is broken into the two pieces then each pieces shows the same properties.

A.MAGNETISM

Since all matters are made by atom and affected by magnetic field, however it doesn't react with each other. When a material is placed in range of magnetic field the magnetic force of the material's electron is affected. This effect is known as Faraday's Laws of magnetic induction. When this force is removed then the atoms of material is randomly arranged it is called as unmagnetized material (as shown in Fig. 2). When the magnetic force is applied on a ferromagnetic materials then the atoms are aligned in a straight line, it is called as magnetized material (as shown in Fig.2

Fig. 2: Atoms of Unmagnetized material

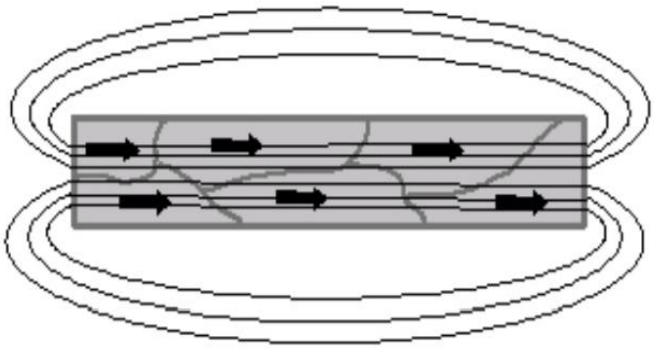

Fig. 3: Atoms of Magnetized material

Magnetic Particle testing is a combination of two basic NDT methods:

a) Magnetic flux leakage testing and
b) Visual testing.

Magnetic flux leakage testing is the discontinuity of magnetic field produced by the magnet, as shown in Fig. 4 & 5.

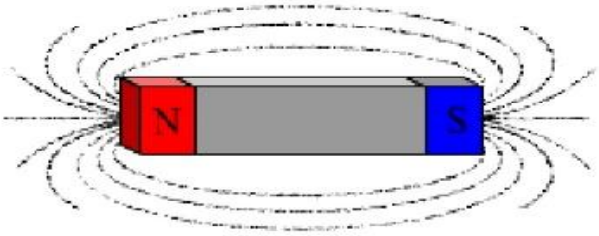

Fig. 4: magnetic field lines

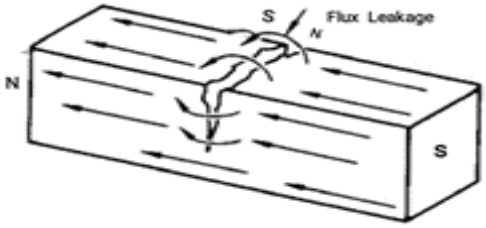

Fig. 5: Flux leakage

B. Components used in magnetic particle testing are.

a) Pie Gauge

The pie gauge is circular octagonal highly permeable material divided into eight sections made by non-ferromagnetic materials.

These sections are bronzed furnace and copper plated. The gauge is placed on the test piece copper side up and the test piece is magnetized. After that the magnetic materials are applied and excess magnetic material is removed with air blower and the indication provided shows the strength of magnetic field shown in Fig. 6. & 7.

Fig. 6: pie gauge

[*Source*: *Thermax Sez Unit, Mundra, Gujrat*]

Fig. 7: pie gauge shows the magnetic strength

[*Source*: *Thermax Sez Unit, Mundra, Gujrat*]

b). Electromagnetic yoke

Electromagnetic yoke is an equipment used to establish magnetic field in magnetic materials. It is an electrically operated solenoid based machine. It can be operated on both AC & DC mode with strong magnetic force and having a tendency to lift 7.5kg at AC mode and 17.9 kg at DC mode, as shown in Fig. 8.

Fig. 8: Electromagnetic yokes

[*Source*: *Thermax Sez Unit, Mundra, Gujrat*]

c). Ferro fluid (Magnetic material, Medium)

Magnetic material are fine crystals of magnetic materials (iron, nickel, cobalt). Ferro fluids are colloidal particles which undergo an enormous viscosity for fine surface particles. It is prepared for the magnetic nanoparticles and suspensions of larger (μm-scale). It is having application to react with the magnetic field inside the surface of the materials.

It is available in two state:

i. Dry medium

ii. Wet medium

Both dry and wet medium are available in different color with different grade. Such as FC 247 black (dry), FC 249 gray (dry), FC 147 –A/2 black (wet), FC 131 A/2 yellow (wet). Chemical precipitation is a more efficient method to prepare magnetic nanoparticles and magneto rheological fluids. There are essentially two methods to produce Ferro fluids.

a) Size Reduction and,

b) Chemical Precipitation

The application include their use in heat dissipation and damping problems, dynamic sealing, lubricating and waste sorting. In this experiment 249 grey is used shown in Fig. 9. Chemical reaction under the precipitation are recorded below:

$2Fe_3+Fe_2+8OH \rightarrow FeOFe_2\ O_3+4H_2O$

Fig. 9: Non-fluorescent dry method magnetic powder-Ferrochem Grey 249, ASTM E-709

[*Source*: *Thermax Sez Unit, Mundra, Gujrat*]

d). Workpiece Material

Workpiece material is made of P91 (combination of 9% chromium and 1% molybdenum) alloy steel made for high temperature work range 570℃ to 600℃ with pressure ranging from 170 bar to 230 bar. Welding is the process used during construction and it affects microstructures. So preheating and post heating to maintain the inter-pass temperature of microstructure. Preheating and post is done with P91 material to save it from catastrophic failures. For better control an ideal and uniformly heating system should be used for inter-pass the temperature between job material surface and welding material. This is worker friendly heating process.

P91 material has a wicked effect with water. The use of material without heated has a great affinity to hydrogen as it causes stress corrosion cracking. Pre-heating is done properly to remove moisture and post heating is to be done as soon as to avoid the moisture.

The welding stud must be used having stud material similar to p91 otherwise after post heating the material of stud may react with material of p91 and its composition may change which results to change in properties of p91 material at the joint.

II. LITERATURE REVIEW

In this research work, literature survey around the effect of different parameters of non-destructive test that defines the characterize elements and also explains about the properties of materials, qualification of processing treatments during fabrication and assessment of damage to the elemental background of the overall scenarios.

P.P. Nanekar and B. K. Shah (2004) described for the development of NDT widely moved towards the ultrasonic testing for the microstructural behavior and mechanical properties of the materials with their certain elements. Author describes their achievements in their own laboratory for the investigation of the element behavior over the materials characteristics. Degradation mechanism for the fabrication of processing services are engaged in the whole area of the industries.

Peter Thorpe (2004) directly focused on the wearer gear and their useable service to benefit the fire services. A non-destructive test that indicates the optimization of the gear that performs the firefighting in the quality and compromised to degrade. It was found that the fire fighter wearing the gear at unnecessary risk to turnout the gear inevitable.

G. Riegert (2006) focused on the special area to needs of the various methods that used as high-specific-strength materials. The industrial and sensitive respond lightweight structures and to provide reliable results in a short time.

Dr R Halmshaw MBE (2006) discussed about the methodological detail and mention the most important results in the area of the NDT. Also explain the useable benefits for the background thesis and details the whole report in the graph developed for the collected data.

J. Hola, K. Schabowiz (2010) identified trends for the development of the NDT techniques particularly in the field of the concrete or reinforced materials. It had assessing the elements strength or their integrity of structural formation in the field are indicated. Paper defined for the technique used and focus on the depths of the cracks, defect detecting, and detecting the dimensions of the surface with 2D and 3D image of the elements.

Valmet (2010) analyzed & inspected the casting, wall thickness of the material and also their weldments. All the accurate manner is critical for several years but comprehensive technique makes is easy to all source. Issues were identified and resolve for the weldments and their casting issued through the NDT processes.

Zahirian (2011) used the NDT techniques on offshore facilities for more accurate and reliable results in the inspection of the flow lines of the offshore production facilities. Matrix for the data formed for the inspection of the parameters. Each particular NDT methods recorded and analyzed on this investigation of the thesis.

Mohamad Pauzi Ismail (2017) had analyzed the quality of concrete for their water leakage and cracking to the wall surfaces internal and external. It evaluate the structural building integrity with the methods of NDT. Based on the recorded data, monitoring of the building is done to make this more important subject in the area of projects. NDT methods are used in internal and external surfaces for the better integrity of the life cycle analysis to cover parameters required in the inspection.

Presented literature study helps the industries to stay away from their unwanted catastrophic consequences by effective maintenance management. Inspection is periodically required for the remarkable advantages such as high quality, accuracy, flexibility and betterment of the equipment's.

III. OBJECTIVES

a) To define the discontinuity of the magnetic material based on deposition of a Ferro fluid Black 140CM, 147-A/2 and Grey 249 consisting of magnetic nanoparticles in the test-piece surface for the development of an innovative NDT concept.

b) To identify visual inspection method of NDT for reducing of welding cost.

c) To use magnetic materials (Ferro Fluid Black 140 CM, 147-A/2 & Grey 249) for fill crack gap by using electrode material as workpiece material(P91).

IV. EXPERIMENT SETUP

Present work used magnetic Particle Testing based on deposition of a Ferro fluid Black 140CM, Grey 249 and 147-A/2. Conducted experiment used magnetic field and small magnetic particles to detect flow in component as shown in Fig. -10. Experimental set up comprise of many equipment's like Electromagnetic yoke machine, Pie Gauge, test specimen, Air blower, Magnetic material 249 grey & Calibration plate

The only requirement from an inspect ability stand point is that the component being inspected must be made from ferromagnetic material (iron, nickel, cobalt or some of their alloy).

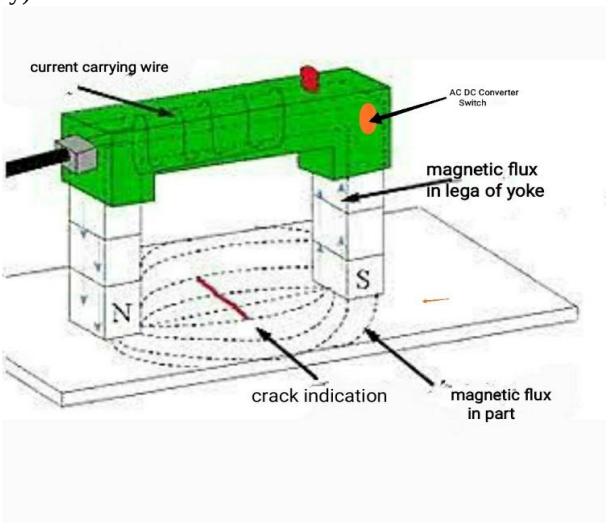

Fig. 10; Experimental setup for magnetic particle testing

A. Methodology of Experiment

Test Specimen of material P 91 opted for defect identification. It may be of welded or machined with wire type FF2 grinding machine. Surface that is being examined within 25.4 mm should be dry, smooth and free from all the contaminants which that could interfere with examination such as dirt, welding flux, spatters, oil, greese slag, paint and arc strike. Methodology of conducted experiment was adopted as below mentioned;

a) Only AC current should be used only otherwise specified. The full magnetic field intensity equipment should be used.

b) Examination should be done by continuous method, i.e. the magnetic remains the same till the magnetic powder (medium) is being applied and excess of medium is being removed With a light air blower.

c) The particle medium shall be applied and removed on the surface of specimen uniformly with air blower as shown in Fig. No 11 & 12 respectively.

Fig. 11: Magnetic medium is applied on specimen with air blower

[*Source: Thermax Sez Unit, Mundra, Gujrat*].

Fig. 12: Excess of medium removed from specimen with air blower.

[Source: Thermax Sez Unit, Mundra, Gujrat]

d) The temperature of the job should not be more than 315 ℃ or as per limitation range set by medium manufacturer.

e) Light with minimum intensity of 1000lux should be maintained during the examination.

f) All area to be examined in two perpendicular direction with minimum overlap of 10%.

g) The pole spacing of electromagnetic yoke machine shall not more than that used during calibration with calibration plate. If there is need to change the pole distance then one should calibrate again at specified distance.

B. Examine and Evaluation of Indications

i. The indications having any dimension greater than 1.5mm should be considered.

ii. A linear indication is one having length greater than 3 times its width

iii. A rounded indication is one with circular or rounded shape with a length less than 3 times its width.

iv. If there is doubt regarding any point then re- examined for confirmation.

C. Acceptance criteria

The examines surface should not be accepted for the following conditions as;

(i) Linear cracks (Fig. 13, a)

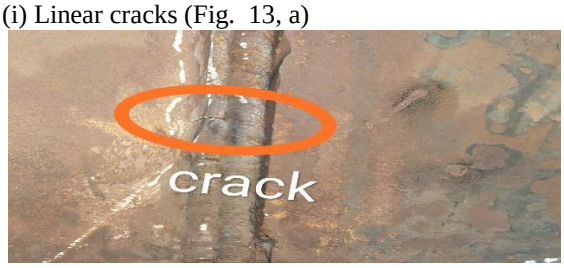

Fig. 13, a: linear cracks located on specimen surface.
[*Source: Thermax Sez Unit, Mundra, Gujrat*]

(ii) Rounded crack greater then 5mm.

(iii) Three or more rounded indications separated by 5mm (Fig. 13, b)

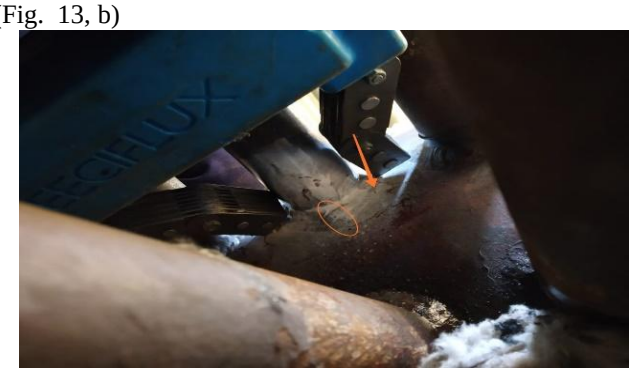

Fig. 13, b: rounded indication located on specimen

[*Source: Thermax Sez Unit, Mundra, Gujrat*]

D. Simulation Analysis of detected Cracks

The length of detected cracks is around 40 mm and the width of the crack is in between 5 mm and 5.2 mm gradients. It is found that the crack is having shape of rectangular (linear) approximately.

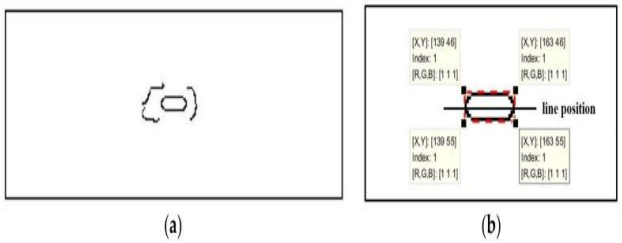

Fig. 14: Cracks and their slope curve for edge

detection

Detected crack should be corrected by following few consideration as below mentioned;

i. To remove the obtained defects (linear or rounded indication) of the welded part must be machined with diamond cutter grinding machine till the defects removed.

ii. Reweld the defected points and again go through the magnetic particle testing again.

iii. Sometime the unwanted material such as dust & slag also shows the false indication so need to remove them in order to maintain surface evenness.

iv. Sometime the welder tested there welding torch by making an strike on the job surface known as arc strike which should not be there as it reduces the thickness of material by burning it.

Time is considered for the variations inside the slope curve for the temperature length graph, which is maximum and minimum as found in Fig. 15. It is easier to found that time curve is identified in this variations. Also, for the quantitative evaluation of the cracks the slope curve theoretical basis are exactly the same. Slope curve over the analysis to the model was not affected by the temperature gradients until the pressure is applied.

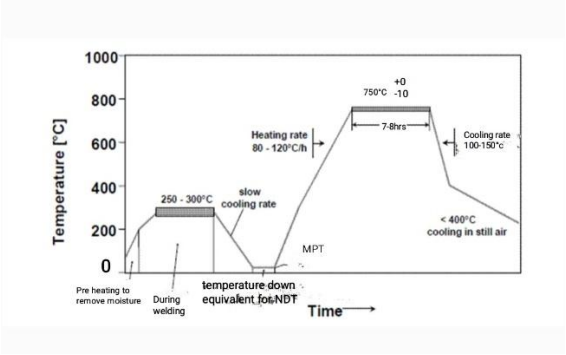

Fig. 15: Analysis of the Temperature distribution and slope of first derivation at different times for analysis.

E. Impact of Defect in NDT

Defects are the unwanted parameter which reduce the quality as well as life of the material.

i. Ignorance of defect during inspection of high pressure vessel may reduce the life of object and if the defect is major the tubes or other important part of the boiler or pressure vessels may burst which is equal to the explosion of a nuclear reactor, as very hot steam is released from the boiler.

ii. The rounded defect may be ignored at some extent, but the linear defects is directly proportional to the pressure and never be ignored, as it results directly to crack the specimen or surface.

V. RESULT AND DISCUSSION

Crack was found as shown in figure 13 (a & b) by Magnetic Particle Testing and after that these crack was removed through machining by diamond cutter grinding machine.

Finally, Magnetic Particle Testing was carried out again as per ASME Section V, Article 1, and Para T-150 and it's tested result is showing in Table-2.

Table-2: Magnetic Particle Testing Report of test specimen.

[*Source*: *Thermax Sez Unit, Mundra, Gujrat*]

S.No	component/part no.	Joint No.	Dimention	Result
1	Superheater Coil Root	IMC - 42, J1-49	50.80 OD ×5.6 thk	No recordable indication observed.The welded part is ideal for further process

VI. CONCLUSION AND FUTURE WORK

It is concluded that conducted study was to assess the feasibility of the testing through Non-Destructive Testing (NDT) technique "Magnetic Particle Testing" based on deposition of a Ferro fluid Black 140CM, Grey 249 and 147-A/2. The detection of surface cracks in non-ferromagnetic materials (P91) has been studied experimentally and mentioned concluded important points are as;

a) Small linear indication should not be ignored if it is in range of acceptance limit consider its dimensions along with actual position.

b) If rounded indications are ignored then focus on its both the acceptance parameter as if there is a single rounded indications with larger dimensions is called as pin hole, and if it is under the limitation then simply note down for further maintenance.

c) In terms of visual inspection need to focus on surface smoothness as during welding slag formation is a major issue which restrict the visibility of defects.

d) A types of defect also appear in terms of rounded indications which is a combination of rounded indication with lack of fusion and air bubbles.

Future Work

NDT is really important consideration to achieve the ultimate objectives when reviewing potential NDT techniques. To develop the proposed technique it is a need of the industrial society to meet the safety & accuracy, reliability requirements of NDT applications in the various sectors of the todays engineering life. Also, to reduce the inspection costs, NDT employed for the time being products robust delivered in the actual time period sets for the achievements. While in mean time the engineering effort and expenses to the overall society of the engineering in the detailed mode to convert them from laboratory systems into robust, reliable field units is considerable.

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