Recent Trends in Non-Destructive Testing of Weldments

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ABSTRACT

Recent trends and advances in of NDT weldments are summarised. Applications of NDT techniques such as magnetic particle inspection, liquid penetration inspection, eddy current inspection, radiographic and ultrasonic inspection have been critically reviewed.

1. INTRODUCTION

A number of situations are encountered in day to day industrial practice where it becomes necessary to study the flaws in metallic components without destroying them. Under such circumstances, we take recourse to nondestructive testing (NDT) techniques. This technique makes the use of the component more reliable, safe and economical.

Welding is one of the prime methods of joining metallic components. It is as much important to takc stock of defects in welded portion as in the main body of the component. Hence there is a great significance of application of NDT techniques for testing of weldments.

A finished weld is not always as good or as bad as it appears by visual observation of the surface. It is only by the help of NDT that it is possible to decide about usefulness of the finished product. Since it is not always possible to carry out the process of welding under strictly controlled and reproducible conditions in industrial practice, it is expected that a number of defects will creep into the weldments and in turn, adversely affect the performance under service conditions. [1]

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NDT has two important roles to play in the context of testing of weldments. Firstly, from these investigations, the presence of defects is established. Secondly, it is also useful to estimate the nature and extent of defects and arrive at a conclusion whether or not the product can be accepted for service. Further, it is also possible to identify and select the components which when repaired become acceptable. For example, small amounts of slag inclusions and porosity generally do not affect the service performance but large amounts of volumetric defects must be repaired.

NDT techniques also help in measuring the defect size and distribution, which plays crucial role in taking final decision of accepting or rejecting the component. A number of NDT techniques have been developed in recent times to detect the flaws in weldments.

2. NON-DESTRUCTIVE TEST TECHNIQUES

Some of the important methods of NDT of weldments, which are used extensively include magnetic particle inspection, liquid penetration inspection, radiographic inspection, ultrasonic inspection and eddy current inspection.[2]

The first two methods, namely magnetic particle and liquid penetration inspection are used to detect only surface defects. On the other hand, radiographic and ultrasonic inspection techniques are useful for study of both the surface as well as internal defects. These four testing techniques are common ones used in industrial practice, while eddy current inspection is not a very popular technique. These methods have basic differences in their principles, applications and limitations. Each of these have a varying scope for advancement.

2.1 Magnetic Particle Inspection

This method is used to study surface or near-surface weld flaws. The only problem associated with this method is that its use is limited to ferromagnetic materials. [3] A liquid solution containing very tiny magnetic particles is sprayed on the surface being checked and the sample is then subjected to a strong magnetic field. Any lack of continuity at or near the surface of the metal when magnetized creates free poles, and attracts the magnetic particles in the solution used. When the magnetic field is removed magnetic particles are left behind concentrated at those sites revealing the defects.

The magnetic field is set-up in the test piece either by passing a current through it by means of test prods or by using a powerful electromagnet against the object to allow the magnetic field to pass through the material being inspected. Fig. 1, shows magnetic powder being used to detect flaws in a weld which has been magnetized by electric test prods.

Both AC and DC fields can be used. AC field has the advantage of high sensitivity at the surface, brought about by skin effect ; DC field has a better chance of sub-surface defects.

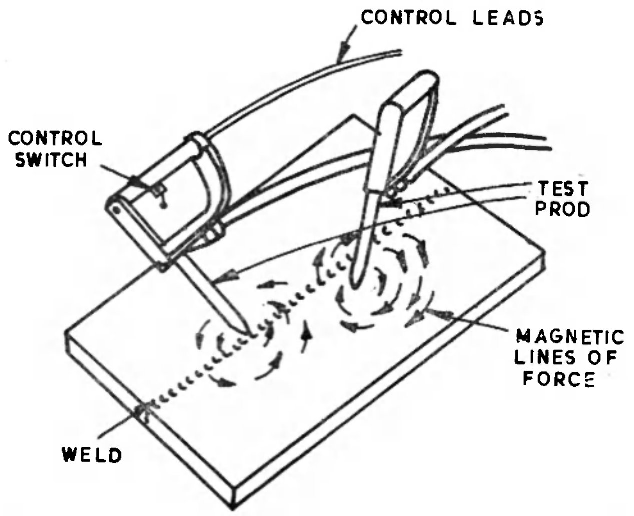

Fig. 1. Creation of magnetic field around a weld with the passage of current through the weld between two test prods.

In the inspection of complex joints such as tubular intersections, loop conductor technique is very popular, as it gives a more consistent field. In this method, the test piece is encircled by current carrying conductor. In turn, a magnetic field is generated in the test piece.

The magnetic field flux lines should be approximately at 90° to crack for maximum reliability. The test piece should be magnetized twice, successively in two mutually perpendicular directions to take care of any random orientation of the crack. The material to be tested should be as clean and bright as possible prior to the test.

Recent advancement in this method is introduction of magnetic tape techniques.

2.2 Liquid Penetration Inspection

This method uses coloured liquid dyes (normally red) and fluorescent liquid penetrants (ZYGLO) to detect large cracks or openings, cold shut, fatigue cracks, partial weld or lap, pits and porosity in welded joints.

The liquid dye penetrant is sprayed on to the clean surface of test piece. Excess amount of dye is removed with a cleaner and the surface is washed with water and throughly dried. Then developer is sprayed on the surface which brings out the colour in the dye penetrant that has penetrated into cracks or pin holes.

Similarly, fluorescent liquid is used and is applied to the surface being inspected. After sometime, the excess fluorescent liquid is removed with cleaner and

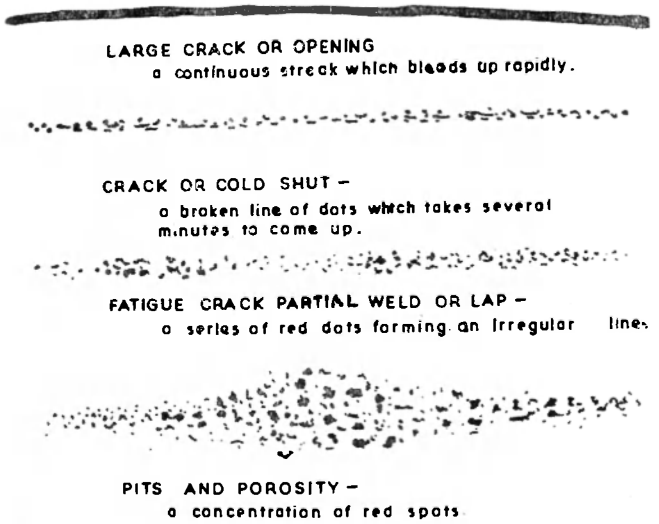

Fig. 2. Detection of surface flaws by liquid dye or fluorescent penetrant method of inspection.

the surface is washed and dried. Then the test surface is viewed under black light (wave length= 3650 Angstrom, which is between the visible and ultraviolet region in the spectrum). Black light causes penetrant to glow clearly in the dark, [2] as shown in Fig. 2. Some solvents used in the cleaners and developers contain high percentage of chlorine to make the liquid non-flammable. Great care is required while using such cleaners and developers in view of health hazard associated with chlorine. Penetrant testing has the advantage that it can be used for all types of materials.

No spectacular advancement has taken place in this technique in the recent past.

2.3 Eddy Current Inspection

Eddy current testing is also one of the methods of finding discontinuities and flaws in welded joints but it is not a very popular technique, because of a number of variables, like metallurgical structure and surface profile.

The method is based on the following principle. When an a.c. coil is brought up close to a conductive metal (ferrous or non-ferrous), it will induce eddy currents in the test piece. These eddy currents produce their own magnetic field which opposes the field of a.c. coil, increasing its impedance (resistance). Coil impedance can be measured. Whenever any flaw comes under the a.c. coil, the eddy current varies in the test piece. This, in turn, changes the impedance of the coil which actuates a flash light and position of the flaw can be detected.

Eddy current systems are being used increasingly in the air-craft industry. Efforts are afoot for calibration for crack depth extension.

2.4 Radiographic Inspection

This is one of the most important techniques of NDT for detecting defects such as blow holes and cracks in the material. The technique is also used in estimation of the type, location and size of defects. This method is excellent because volumetric defects are easily detected and identified. But planar defects are difficult to detect since such defects are thin. However, if the direction of electromagnetic beam is parallel to the plane of defect, identification may be possible as, in this position, it offers maximum thickness to the beam.

A radiograph gives us a permanent record of welded area made on critical constructions such as pipe line, ships, aircrafts etc. The disadvantages of this technique are that special safety precautions are to be taken in view of health hazards associated with radiations. [4, 5] Also the technique is expensive.

2.4.1 *X-Ray Radiography*

It is based on the principle of absorption of x-rays by a body as a function of absorption coefficient 'μ' and thickness 't'. If I_0 is the intensity of the incident beam and I is the intensity of the transmitted beam, then the two are related by the equation

$$I = I_0 \, e^{-\mu t}$$

The greater the thickness of the body, lesser will be the intensity of transmitted beam. When the beam passes through blow holes, cracks or similar defects, then it has to pass through effectively thinner section. Accordingly, the transmitted x-rays are of greater intensity in comparison to other area of test piece. Thus on positive print, defects are marked by light areas. [6]

The accelerating voltage needed varies from 50 Kv to 24,000 Kv in the X-ray tube. For 5 cm thick steel section, 1400 Kv is required and for 50 cm thick steel

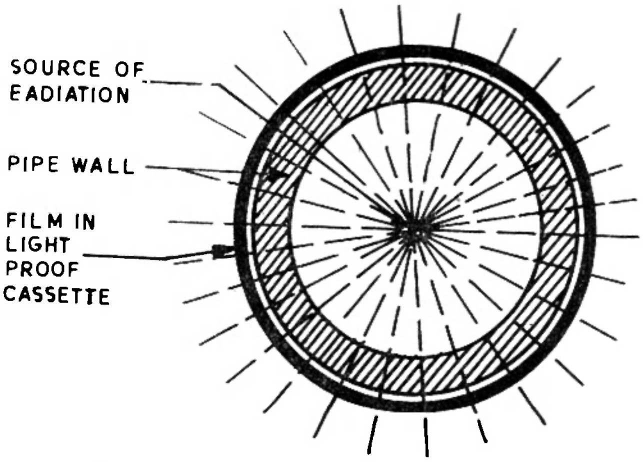

Fig. 3(a). Diagrammatic representation of an X-ray examination of a pipe weld.

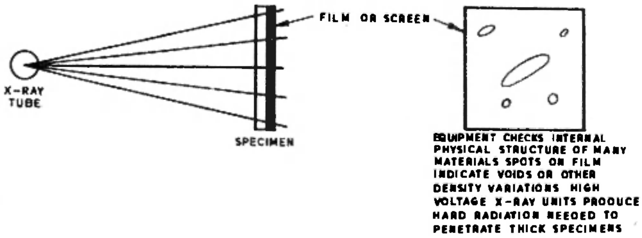

Fig. 3(b). Diagrammatic representation of X-ray photograph of a weld.

section, 24000 Kv is required. Fig. 3 (a & b) shows diagramatically the principle of examining a test piece by this technique.

In recent years, great advances have taken place in radiographic techniques. Now it is possible to obtain sharp radiographic images of defects which the help of microfocus X-ray tubes. It is used at such plates where sensitivity and resolution of radiograph is of paramount importance. Microfocus X-ray tubes are available with spot size as low as 10 μm (compared to spot size of 2 to 4 mm in conventional techniques).

Oak Ridge National Laboratory (ORNL) has developed the small diameter rod anode X-ray system for the examination and inspection of tube-to-tube sheet (TTS) weldments in steam generator and heat exchanger components. Closeness of adjacent TTS welds necessitates the use of miniature X-ray source in the bore of the tubing with film on the outside. Thus, it becomes possible to detect porosity and otherflaws not detectable by conventional X-ray technique.[7]

Image processing is also a significant achievement in this field. In this technique which is also known as X-ray television fluoroscopy, the image is viewed on fluoroscopic screen via closed circuit television camera (CCTV). This technique is advantageous at such places where high accuracy is not necessary and permanent record is not needed generally. Its major application is in inspection of longitudinal submerged arc welds in line pipe.

One of the other major achievements in this field is the development of digital image storage processing. By this technique, it is possible to store the images of defects in the test piece, and produce them whenever required. This technique makes it easier for inspector to interpret the radiographs. This technique gives good contrast and sharpness of the image. The major advantage is of splitting the image in to 256 grey levels (as compared to human eye, which splits the same range into about 60 grey levels between density 1 and density 3).

Now it is also possible to measure the crack height by radiography. Crack dimensions play crucial role in deciding the suitability of the test piece for given service conditions. It is the crack dimensions which affect the performance of welded joint in service. Microdensitometry helps in this direction. This measures the density of parts of image and by comparison and calculations, crack height can be measured. Yokota ([9]) has measured the cracks in 0.06 to 0.2 mm width range and Morikawa ([10]) has shown that error was not more than 4% for 6 to 100 mm specimens.

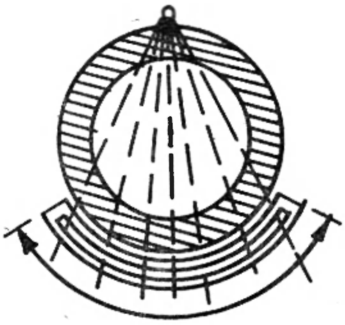

Fig. 4 : Gamma ray inspection method for pipeline.

2.4.2 *Gamma-ray Radiography*

This technique makes use of certain radioactive isotopes namely cesium 137, cobalt 60, Iridium 142, Samarium 153, Thulium 170, and Ytterbium 169. These isotopes give off γ-ray which are about 6 mm in size. γ ray equipment is more flexible in use than standard X-ray equipment. Ytterbium 169 has been found to be well suited for taking radiographs on steel in the 5 to 10 mm thickness range, and has been popular for testing small diameter circumferential welds (e.g. 50 mm in diameter with a 5 mm wall thickness). Fig. 4 shows Gamma ray inspection of pipe line.

2.5 Ultrasonic Inspection

This technique is also very important in detecting flaws and discontinuities in welded joints. Such defects which can not be detected by X-rays or gamma rays can be successfully detected by means of ultrasonic flaw detection. In this method, the thickest welded joints can also be treated.

In this method, an electronic oscillator sends out a.c. to piezoelectric transducer, which converts the electrical energy to acoustic energy with same frequency. A frequency of 2.25 mega cycle is commonly used. This acoustic wave is then sent to the test piece using suitable liquid couplant. If there is a flaw such as crack within the test piece, the acoustic wave bounces back from the crack and returns to the same transducer as an echo. The returning echo cyclically strains the crystal, which then responds by generating a.c. in the same frequency that it receives from the echo pulse. This a.c. voltage generated by the crystal is then amplified and applied to the horizontal plates of cathode ray tube. A small defect returns a small echo, which appears as a short vertical pip on CRO screen, whereas a large vertical

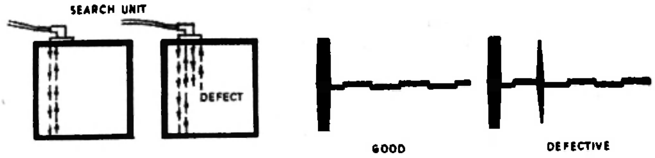

Fig. 5. Ultrasonic test unit in operation and the display of resulting wave on the cathode ray tube.

defect will appear as a large pip. [1] Fig. 5 shows the principle of ultrasonic inspection.

Couplant plays an important role in this technique. If ultrasonic probe is simply put on the surface of test piece, it is possible that no response will appear on CRO screen. This is due to the fact that virtually all the supplied energy is reflected off and no energy enters the test piece to reveal defects. If however the surface of test piece is coated with a layer of water or oil which acts as a couplant, the flaw will appear on CRO screen. In the presence of couplant, sound pulse can pass into the test piece with sufficient power to return as an echo.

This method is very useful in finding defects in electrically slagged welded parts of high power hydraulic presses, the rotors of gas turbines and boiler drums. The various type of defects of electrically slagged welds are : fissures, non fusion spots, slag inclusions, porosity etc. The main difficulty in checking electrically slagged welds lies in their structural non-uniformity. The major non-uniformity is found in multi layer welds made from austenitic steels. These welds prior to heat treatment have dendritic structure and this structure absorbs ultrasonic waves. For example, the ultrasonic absorption coefficient in an austenitic weld is about 0.5 at 2.5 mega cycle frequency of acoustic waves, while in the base metal the ultrasonic absorption coefficient is about 0.04. In such welded joints, flaw detection becomes difficult. To overcome this problem, it is necessary to apply low frequency ultrasonic oscillations. For example, in the inspection of austenitic welds with thickness ranging up to 30 mm, it is necessary to apply a frequency of the order of 1.5 mega cycle. [11]

Generally, most of the defects are detected and positioned by conventional technique. However, measurement of size and identification of the defect poses certain problems. This difficulty arises due to the indirect nature of finding defects by conventional amplitude/time base technique.

To overcome this problem, B-scan system has been used. The defect is surveyed in its correct position in relation to the weld in this method. Conventional flaw detector and probe is employed in the B-scan display. The position of the defect is derived from echo and probe position data. The photographs obtained in this technique can be stored to provide a permanent record. However the technique is time consuming.

Many problems associated with B-scan technique can be solved by use of computors. In such cases, both the ultrasonic and positional information are stored in digital format in the computor from which plots of locations of indications from different views may be produced. Pulse rise time or amplitude can also be utilized for storing the data. Examples of test systems which include computor generated displays are the ultra-image developed by General Dynamics, [12] the P-scan [13] produced by the Danish Welding Institute, the Rotoscan pipe scanning device produced by RTD, and the Accuscan display system, based on a Pantratron systems electronics package used by the U.K.

The output from these systems reveal many details of defects. For example, C-scan plots generated by the Accuscan device reveal two defects—lack of fusion and HAZ (Heat-affected zone) cracking.

A different type of display is generated by the P-scan (projection scan) which is suitable both on site and in the laboratory. By this system, the size of the flaw can be determined as well as a diagnosis of the defect type.

3. CONCLUSION

Developments in recent years have made NDT more reliable for finding flaws and defects in welded structures. Digital techniques and use of computors in NDT have made this technique more advanced and practical. Further advances are expected in radiography and ultrasonic testing for measuring defect dimensions. Although NDT technique is not the ultimate answer to all problems, it can forewarn that possible service failure is likely to take place in component either due to welded structure or due to hazardous environments.

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Welding Spatter

"The railway industry in the UK employs, within its vehicle and track maintenance departments, one of the largest integral NDT organisations. There are some 400 operators within both the mechanical and civil engineering departments, for the application of ultrasonic testing in the course of routine maintenance and the acceptance of new materials and welded structures. Whilst the major effort is directed towards vehicle wheelpairs and the rail, a wide range of components is subjected to routine testing as insurance against costly and often embarrassing failures in service".

—Metal Construction, March '83