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DEVELOPMENT OF ARTIFICIAL SUB-SURFACE CRACKS IN WELDED PLATE AND THEIR NON-DESTRUCTIVE TESTING

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ABSTRACT
This work has been carried out to study the optimum condition of generating cracks in welded structures. A sample welded test plate was designed for fabrication of artificial cracks in plate. The test plate was fabricated from mild steel by applying manual metal arc welding technique. Two test pieces of (304 × 152 × 13) mm have been fabricated. Sub-surface cracks were generated. During the welding non-destructive testing was applied to control the quality of weld as well as the size and location of the crack. After finishing the welding, magnetic particle and ultrasonic testing techniques were applied to evaluate the cracks generated. Finally, a comparative study was done to assess the appropriateness of the geometry and location of the crack generated with respect to the design intended. This method is verified to be a useful and effective method to generate artificial cracks in welded samples.

Keywords: Welded plate, sub-surface crack, non-destructive testing.

1. INTRODUCTION
There are inherent flaws in materials due to crystal lattice imperfections and dislocations however microscopic they may be. Manufacturing processes such as welding, casting, forging, surface treatment, etc. may cause further flaws or defects. Materials are used under various conditions of stress, fatigue and undesirable environment, which may create additional defects or aggravate present ones. It has been established that most material failures occur because these defects reach dangerous proportions such that remaining parts of the materials could not withstand the stress they are subjected to, thus become ductile or brittle.

Defects are found in several types and in different location and orientation in the steel materials and equipments that are used in different industries. Especially cracks in welding are very crucial variable for catastrophic failure of an industrial component. Therefore unwanted shutdown of an industrial plant can be occurred. Besides shutdown, human life and equipments of an industrial plant are to be in risk always. Periodic maintenance and checking of the boiler, pressure vessel, pipelines, welded joints of an industrial plant is necessary. In periodic maintenance and integrity assessment of industrial components and welding joints, non-destructive testing (NDT) can play an important role. Non-destructive testing has come into stable practice in assessing product quality and predicting of the cause and time of failures associated with the components of producing equipment [1, 2, 3]. Therefore, appropriate training and certification on NDT is essential for checking integrity of materials.

NDT test specimens constitute a very important part of training and certification of NDT personnel and also important for carrying out actual inspection, and for achieving international recognition of NDT practices [4]. Therefore, there is a need to pay greater attention to this subject.

The present work has been carried out to study the optimum condition of generating artificial crack in welded plate of steel material. Two-test piece have been developed with artificial sub-surface defects. Defects have been evaluated in different stages of the development using non-destructive testing techniques. Later in this paper, a comparison has also been made between the theoretical knowledge and the experimental work of generating artificial defects in welded steel plate.

2. METHODOLOGY AND DEVELOPMENT PROCEDURE

2.1 Mechanism of Crack Formation
Weld cracks are seldom encountered in mild steel welding when the sections are less than 10 mm thick. In thicker sections, cracks may appear in the welds due to one or more of the following factors: (a) rapid cooling of the deposit, (b) heavy restraint in the joint, (c) excessive dilution of the weld with the parent material, resulting in pick-up of carbon and other alloying elements and consequent hardening, (d) excessive hydrogen in the arc derived from moisture, grease, oil, etc. In butt welds, abnormal bead shape is often the cause of cracking.

In the present work, artificial cracks have been fabricated using rapid cooling of the deposit technique. By applying this technique, longitudinal cracks of designed length and location have been generated in the welded steel plate. The fabrication of artificial crack has been performed using manual metal arc welding.

2.2 Design of Welding Plate

Two test pieces having the dimension of 304 mm × 152 mm has been designed for generating artificial cracks of 10 mm length at different depth. The thickness of the welded plate is considered 13 mm. The cap width is considered 14 mm, bevel angle or weld preparation angle 60°, root face and root gap 2 to 5 mm. Longitudinal cracks are intended to generate in the welded plate in defined location.

2.3 Manual Metal Arc Welding

Manual metal arc welding (MMAW) is an electric arc welding process where the heat for welding is generated by an electric arc between a flux covered metal electrode and the work. The filler metal is deposited from the electrode and the electrode covering provides shielding. Other names for this process include the North American term “Shielded metal arc welding” (SMAW), “stick welding” or “stick electrode welding”.

This process is used predominantly to weld ferrous metals and it can weld thickness above about 2 mm in all positions. The arc is under the control of the welder and is visible. The welding process leaves a slag on the surface of the weld bead that must be removed. The most popular use for this process is for the welding of structural steel including low alloy and other higher strength steels [5]. The process is flexible, as the welder only needs to take the electrode holder and work lead to the point of welding. The equipment for the MMAW process consists of a power source, welding cable, electrode, electrode holder, and work clamp or attachment.

2.4 Procedure

Mild steel plates of 162 mm × 162 mm × 15 mm were taken and machined to 152 mm × 152 mm square by using shaper machine. The thickness then reduced from 15 mm to 13 mm by machining. The two plates of having size 152 mm × 152 mm × 13 mm were perfectly aligned with the help of T-scale maintaining 3 mm root gap. Then the two plates were tack welded at two ends.

For welding a backing strip was used to prevent burn-through caused by excessive penetration, which was difficult to avoid even with a 1.6 mm diameter electrode used at 30 amps. If the backing strip were mild steel, it would got welded to the joint by the penetrated weld bead. The strip was retained as an integral part of the joint or removed by machining. The backing strip can be of copper, which does not fuse with the penetrated weld metal and can easily be detached later. Thin sheets would better welded by the oxy-acetylene or argon-arc process, if use of backing strip is to be avoided, because with these processes the welder has better control on weld penetration. Two back strips were welded below the plates in order to avoid deformation.

The down hand or flat welding position is defined as a position in which the weld slope does not exceed 10° and the weld rotation does not exceed 10°. In this present work, the welding has been performed in flat or down hand position.

The sequence of weld passes with specified electrode sizes and currents for 13 mm thickness is described below. In this case, after the V has been filled up, the joint has been turned over and the root has been machined or gouged out by an oxy-acetylene gouging torch, or by a carbon electrode using the air-arc process, till sound metal has reached. The root has then been covered with a sealing pass deposited with a 4 mm electrode at 180 amps. The first weld pass has been performed with a 3.15 mm electrode at 110 amps. The welding metal has been covered with a sealing pass deposited in the second pass with a 4 mm electrode at 180 amps. Then third pass has been performed using a 5 mm electrode at 210 amps to get deeper penetration and a better guarantee that slag inclusions were completely dissolved out. Finally, a 6.3 mm electrode at 290 amps has been used for the fourth and fifth pass to complete the welding. These procedures have been carried out with selected electrodes at specified location.

3. NON DESTRUCTIVE TESTING OF WELDED PLATE

Different Non Destructive Testing (NDT) method has been applied during and after completion of the development of the artificial weld specimens to reveal cracks.

3.1 Ultrasonic Testing Method

Ultrasonic testing has been one of the most indispensable techniques in metal industries for detection and characterization of defects by analyzing variation in amplitude and frequency of the scattered ultrasonic waves [6,7,8]. In the present work, ultrasonic testing has been performed using pulse-echo technique to find cracks in the welded test plate. The pulse-echo technique is the simplest of all the ultrasonic testing methods and also most commonly used methods in industries. It consists basically of measuring the time taken for a short train of sound waves to move through a given distance. This distance can be determined if the speed of sound in the material is known or, if the distance were known; the speed of sound can be readily calculated. By measuring the relative amplitudes of pulses, which have traveled different distances, one can determine attenuation coefficients. Observing the patterns of the received pulses can provide valuable information about the nature of a defect at which the pulses have been reflected and, perhaps, of the structure of the material being tested. With the pulse-echo method, the time taken for sound pulses, generated at regular intervals, to pass through the object being tested and to return is measured. The returned pulses may be received either after a single reflection at a discontinuity of characteristic impedance (i.e. a boundary or a defect) or multiple reflections between the discontinuity and the front surface of the object [9].

After producing cracks to the desired location and depth, the welded plate was machined and polished to remove the dust or spatter. Then the specimen was ready for ultrasonic testing. All the testing have been performed at room temperature. A pulse-echo transducer (Krautkramer) of diameter, d = 10 mm, transmitting a longitudinal wave of nominal frequency 5 MHz has been used for both generating and detecting the elastic waves for checking lamination. The space between the transducer and top surface of the specimen has been filled with motor oil used as a medium for ultrasonic wave propagation. After checking the lamination, an angle beam of 70° probe transmitting compression wave of frequency 4 MHz has been used for detecting cracks in the welding. All the signal from the oscilloscope has been recorded and then determined the location, length and depth of the crack.

3.2 Magnetic Particle Testing Method

Magnetic particle testing method has been used to evaluate the welding quality during the welding process and finally after completion of the welding. Yoke magnetization method has been applied to evaluate the cracks of the welded test plate up to 5 mm from the top of the surface being tested [10]. When any form of electromagnetic or permanent magnet is used, a magnetic field is induced in the test component or work piece in a direction between the poles. The distribution of the field is such that the area of the surface, which is magnetized sufficiently for magnetic particle inspection to be carried out, is bounded by convex curves joining the poles of the magnet.

Before applying the yoke method, the iron particle settlement test has been performed for checking the concentration of particles. Pie gauge has been used for showing the existence and direction of magnetic fields above the surface of magnetized welded test plate. Yoke has been applied to the test plate and the cracks were revealed under ultraviolet light in the dark environment. Finally, after completion of the inspection, demagnetization has been done with an a.c. yoke magnet.

4. RESULTS AND DISCUSSION

In this present work, longitudinal cracks of designed size & location have been fabricated by applying rapid cooling of the deposit technique. The welded test specimens of mild steel have been developed using manual metal arc welding technique. The two test specimen A1 and A2 that were developed are shown in Figure 1.

(a) Specimen A1

(b) Specimen A2

Fig 1. Welded test plates (a) Specimen A1 (b) Specimen A2

4.1 Specimen A1

Test piece A1 was fabricated with a sub-surface longitudinal crack during the sixth pass of the welding process. The crack has been fabricated using rapid cooling technique. The developed crack after sixth pass is shown in Figure 2. The depth is approximately 4 mm from the top of the surface. After development of the crack final passes have been performed with special care so that no unwanted cracks or defects would be formed. After completion of the welding, magnetic particle testing technique has been applied to find the location and size of the crack. The crack has been found successfully using magnetic particle testing technique. The dimension measured is 7 mm. Photograph of the crack developed in Specimen A1 after applying magnetic particle testing technique and UV light is shown in Figure 3.

Fig 2. Photograph of the cracked welded plate (Specimen A1).

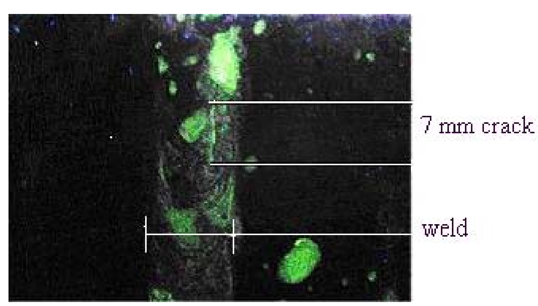

Fig 3. Photograph of the crack developed in Specimen A1 under magnetic particle testing and UV light.

4.2 Specimen A2

Test piece A2 has been fabricated with a sub-surface longitudinal crack during the third pass of the welding process. The developed crack, after third pass, is shown in Figure 4. After development of the crack, final passes have been performed with special care so that no unwanted cracks or defects would be formed. After completion of the welding, magnetic particle testing technique has applied to find the crack but failed. Then ultrasonic method has been applied to find the location, size and depth of the crack. The crack has been found using ultrasonic testing method perfectly. The fabricated test plate, A2 was inspected using ultrasonic flaw detector with compression wave and 8 mm length crack has been detected. In Figure 5, ultrasonic crack signal is shown in the welded plate, A2.

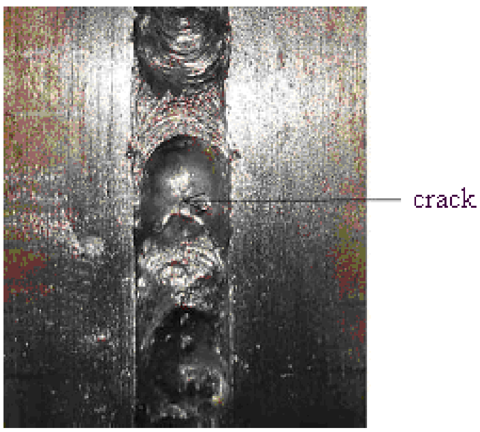

Fig 4. Photograph of the crack formed after third welding pass in Specimen A2.

Fig 5. Observation of crack signal in the welded plate, A2 under ultrasonic testing.

Some other defects were observed during the different welding passes. But finally, those defects were eliminated or fused during the next welding passes. Some unwanted cracks were formed at the edges or heat affected zones of the welding.

5. CONCLUSIONS

The following conclusions can be drawn from the present study:

(i) Two welded test specimen have been developed with artificial cracks as the design intended although there were some unavoided defects developed at the edges of welding.

(ii) In welded test plate A1, a seven (7) mm length crack was developed where in its intended design length was 10 mm.

(iii) In welded test plate A2, the fabricated crack length is 8 mm while the design length was 10 mm.

(iv) The generated crack was verified and studied applying different non-destructive testing methods, i.e., ultrasonic and magnetic particle testing techniques.

(v) The crack of Specimen A1 is revealed by magnetic particle testing method. In case of Specimen A2, magnetic particle testing method was applied, but no crack was found. Then ultrasonic testing method with shear wave was applied and a crack of 8 mm length was found.

(vi) Thus it can be concluded from the present study that this rapid cooling technique is effective method for generating artificial sub-surface cracks in mild steel welded plates.

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