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Assessment of Integrity and Reliability of Weld Joints in Steel Structure to Attain Sustainability in Infrastructure Manufacturing

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Abstract— The quality of weld is dependent on various parameters including welding method, amount and concentration of energy input, weldability of the base material, filler and flux material, design of the joint and the interactions between all these factors. Different types of welding defects e.g., cracks, slag inclusion, gas inclusions (porosity), non-metallic inclusions, lack of fusion, incomplete penetration, lamellar tearing, overlap and undercut may be induced during welding process. These defects may promote the failure of the component and lead to unexpected incidents and accidents. To ensure the quality of weld, nondestructive testing (NDT) methods are commonly used. The entire volume of the weld joints was scanned using ultrasonic shear wave transducer to assess the integrity of the weld as well as the quality of steel structure. In this study, 84 butt weld joints of carbon steel made from varying thickness sheets were investigated and among them 13 joints were rejected. Total examined weld length was 19.6 m and the amount of defects in this tested length was 907 mm. In this work, it was found that 15.5% of the total number of joints contains defect and in terms of length the amount of defect was approximately 4.6% of the total inspected length. The aim of this study is to improve reliability of Ultrasonic Testing method to identify discontinuities and defects in weld joints in steel structure to reduce the risk of structural incidents and accidents. This will help to attain sustainability in both the steel structure manufacturing industry and infrastructure manufactured from steel.

***Keywords*—** Weldability, Weld defects, Nondestructive testing, Steel structure, Ultrasonic testing

I. INTRODUCTION

Welding technology has been used in different branches of manufacturing like building construction, bridges, ships, rail-road equipment, boilers, pressure vessels, pipelines, automobiles, aircraft and power plants etc. The constructional steel structures consist of beams, channels, angles and plates which are subsequently joined to each other by bolts, welded joints or rivets [1]. These structures are subsequently subjected to variable loads with environmental factors and service factors and can undergo fatigue failures from the weld. The quality and strength of welded joints are dependent on various factors such as the steel type, the design, dimensioning, welding process and the geometry of the structure [1].

Various types of discontinuities such as Porosity, Pipe or wormholes, Non-metallic inclusions, Tungsten inclusions, Lack of fusion, Incomplete root penetration, Cracks, Transverse cracks, Underbead cracks, undercut, excess penetration, Burn through, Root pass oxidation [2,3] may occur during the welding process. Metallurgical discontinuities may also alter the local stress distribution, and in addition, may affect the mechanical or chemical (corrosion resistance) properties of the weld and heat affected zone [2].

The quality and strength of structural welded materials depend on its internal defects. Different types of internal weld defects such as gas voids (porosity), slags and weld discontinuities are the constant problems of welded joints [4]. These defects can lead to component failure and to unwanted incidents and accidents. To reduce the probability of structural incident and accident, the quality of welds must be ensured. Various common non-destructive testing (NDT) methods e.g., Liquid Penetrant Testing (LPT), Magnetic Particle Testing (MPT), Ultrasonic Testing (UT), Radiographic Testing (RT) and Eddy Current Testing (ET) are used for the evaluation of materials and welds [2,5].

II. METHODS

In this study EPOCH 600 UT flaw detector and 70^0 angle beam transducer was used. The test was conducted as per guideline of AWS D 1.1/D1.1M:2015; Structural Welding Code-Steel, to produce acceptable result. Ultrasonic testing is a non-destructive method by which high frequency sound waves are introduced into the object being inspected. Generally, ultrasonic waves having frequency range 0.5 MHz to 20 MHz are used for the testing of materials. On the basis of the mode of vibration of the particles of the medium with respect to the direction of propagation of the waves, ultrasonic waves are classified into longitudinal, transverse, surface and lamb waves. When ultrasonic waves incident a boundary at an oblique angle, the reflection and transmission of the waves become more complicated than that with normal incidence. At oblique incidence the phenomena of mode conversion (change in the nature of the wave motion) and refraction (a change in the direction of wave propagation) occur. The incident longitudinal wave splits up into two components, one longitudinal and the other transverse and this happens for both the reflected as well as refracted parts. The refracted transverse component will disappear if the propagating medium is not a solid. For weld inspection refracted transverse ultrasonic waves are used. Transverse waves propagate through the material with a velocity which is about half that of the longitudinal wave velocity [3].

The sound waves travel through the material with some loss of energy due to material properties. The intensity of sound waves is either measured, after reflection (pulse echo) at interfaces (or flaw) or is measured at the opposite surface of the specimen (pulse transmission). The reflected beam is analyzed to find out the defect. By analyzing the signal, the location and size of the defect can be measured [3].

An angle beam probe transmits longitudinal waves at a definite angle of incidence to the surface of the test specimen. Refraction and conversion of wave modes of beam are used to transmit ultrasound into the test specimen at various angles. The angle of incidence chosen is greater than the first critical angle so that only transverse waves enter that specimen. The angle of refraction for steel specimen and the beam exit point called probe index is marked on the metal case of the probe. For assessing the weld quality and the vicinity of weld material i.e., heat affected zone, ultrasonic transducers of various angles 45^0, 60^0, 70^0 etc., are used to scan different position of weld volume.

III. MEASUREMENT TECHNIQUE

When a test piece is scanned with angle beam probe, reflected echo will be obtained in the scope display of UT flaw detector if properly oriented discontinuity or defect or reflector comes into the beam path. When the reflection occurs before the sound wave reaches the back wall, the reflection is usually called the first leg reflection. If the reflection occurs from a reflector where the sound reaches after the beam reflected from the back wall, the reflection is usually called the second leg reflection.

Then the path propagating by sound is calculated by the following formula:

$$\text{Sound Path} = \frac{V_T\, t}{2}$$

Where, V_T is the velocity of the shear wave of sound in the material and t is the time.

$$\text{SurfaceDistance} = \text{Sound path} \times \sin\theta_R$$

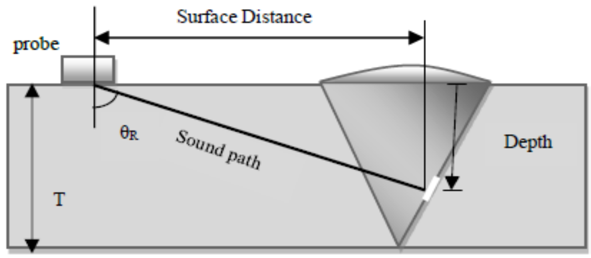

Figure 1. Reflector in first leg

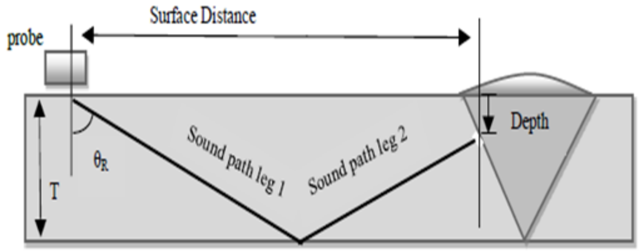

Figure 2. Reflector in second leg

Depth (1^{st} leg) = sound path × $\cos\theta_R$

Depth (2nd leg) =2T- (sound path ×$\cos\theta_R$)

Where, θ_R is the angle of refraction of the transducer/probe and T is the material thickness.

To determine the proper scanning area for both sides of the weld, skip distance of the sound beam must be calculated using the refracted angle of the sound beam and material thickness [6].

$$\text{Skip Distance} = 2T \tan\theta_R$$

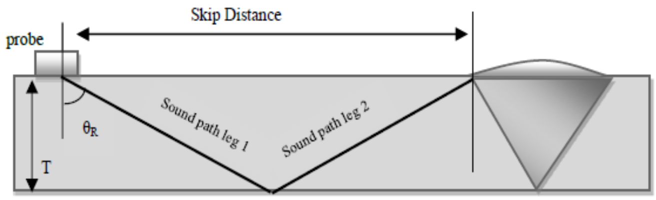

Figure 3. Skip distance

IV. RESULTS AND DISCUSSION

For this study, 84 single-v butt welded plates having different thickness (10 - 14 mm) were inspected and evaluated. Total inspected length of the weld joint was 19.6 m and the amount of defect was 907 mm which is 4.6% of the total tested length. The sample weld joints were taken from different types and shapes of steel beam manufactured for structure of a building. The indication and defects were characterized, assessed and evaluated by code AWS D1.1/D1.1M:2015. American Welding Society (AWS) prepared this code specially for structural welding of steel. Among the 84 weld joints 13 joints were rejected as per evaluation criteria of the code which is 15.5% of the total number of tested joints.

Table 1. Measured data of each indication required for evaluation according to the code “AWS D1.1/D1.1M:2015”.

Weld ID	Sound path ‘w’ (mm)	Indication level ‘a’ (dB)	Reference level ‘b’ (dB)	Attenuation factor ‘c’ (dB)
RW01	23.41	65.0	62.8	0
RW02	28.79	65.8	62.8	0
RW03	38.70	60.7	62.8	1
RW04	41.49	68.7	62.8	1
RW-05	41.67	67.6	62.8	1
RW06	25.75	65.2	62.8	0
RW07	44.08	66.4	62.8	2
RW08	40.09	62.7	62.8	1
RW09	28.07	64.8	62.8	0
RW10	45.70	66.7	62.8	2
RW11	44.65	60.3	62.8	2
RW12	42.77	65.1	62.8	1
RW13	25.74	60.1	62.8	0

Table 2. Evaluation of rejected joints according to the code “AWS D1.1/D1.1M:2015”.

Weld ID	Indication rating ‘d’ (dB)	Severity class	Length of defect (mm)	Depth from test surface (mm)	Result
RW01	+2.2	A	12	8.01	Reject
RW02	+3.0	A	30	9.85	Reject
RW03	-3.1	A	110	6.76	Reject
RW04	+4.9	A	10	5.81	Reject
RW05	+3.8	A	100	5.75	Reject
RW06	+2.4	A	10	8.91	Reject
RW07	+1.6	A	10	4.93	Reject
RW08	-1.1	A	90	6.31	Reject
RW09	+2.0	A	110	9.60	Reject
RW10	+1.9	A	30	4.37	Reject
RW11	-4.5	A	65	4.75	Reject
RW12	+1.3	A	250	5.37	Reject
RW13	-2.7	A	80	8.8	Reject

The indication rating ‘d’ is calculated by [7]:

$$d = a-b-c$$

Where, a is the indication level gain (dB required to bring the reflected pulse amplitude to the reference level and in this case, reflector is indication)

b is the reference level gain (dB required to set the pulse amplitude to the reference level i.e., 50% of the full screen height of the detector and in this case, reflector is 1.5 mm side drill hole of the V1 block)

c is the attenuation factor calculated by the equation, $c = (w-25) \times 0.08$ and

w is the angular distance (sound path travelled inside the material)

Discontinuity severity classes [7]:

i. Class A (large discontinuities): Any indication in this category shall be rejected (regardless of length).
ii. Class B (medium discontinuities): Any indication in this category having a length greater than 20 mm shall be rejected.
iii. Class C (small discontinuities): Any indication in this category having a length greater than 50 mm shall be rejected.
iv. Class D (minor discontinuities): Any indication in this category shall be accepted regardless of length or location in the weld.

Location of the defects were marked on the object and then grinded to expose them. It was observed that grinding of the weld metals reveals the defects and most of them were slag inclusions and porosity. Slug inclusions are inserted in the weld metal due to lack of proper chipping before starting new pass of the weld. Besides, porosity occurs due to use of moisture electrode. Both of these defects may lead to catastrophic failure in its service life. The welders were informed and welding procedures were improved. Moreover, defects were removed totally, re-welded and tested again to assess the integrity. Finally, UT of these weld produced acceptable result.

V. Conclusion

Nowadays, to escalate the socio economic condition of the country the government has taken many national development projects which includes infrastructures made from steel. Besides, steel structures based buildings are becoming popular and this is one of the promising industrial sector which can contribute remarkably to strengthen the socio economic condition of the country. For a building structure, it is very important to ensure the quality of the whole structure. The components made from steel contain a lot of weld joints and the condition of these weld joints determines the strength as well as safety of the infrastructure. There are number of reasons to inspect a weld, the most fundamental of which is to determine whether its quality is good enough for its intended application. The result of this study establish that to become self-reliant in this industrial sector for producing reliable and quality products and to attain sustainability it should be mandatory to examine the structural weld by means of NDT methods as per Codes and Standards during fabrication and prior installation.

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