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Determination and Validation of Residual Stresses by X-Ray Diffraction Method of Pipe Girth Weld Joint

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Abstract
During welding the stresses are induced after the cooling and this induced residual stresses affects the life of the weld joint. In this paper we find out the residual stresses induced in the carbon steel pipe and validate the result by experimental analysis and suggest the method of relaxation by post weld heat treatment.
This paper explored the residual stresses in ASTM A53 (Grade B) pipe girth welds, before and after post weld heat treatment by Xray diffraction method which includes full residual stress mapping in the weldment and close to external and internal pipe surface. The induced residual stresses simulated by thermomechanical analysis. The results compared and validated to recommend the PWHT is effective to reduce the residual stresses.
Keywords
Girth Weld, FEA,Residual Stress, Xray diffraction method, Post weld heat treatment.

INTRODUCTION

A weld joint consists of three metallurgical different regions, namely weld metal, heat affected zone (HAZ) and parent metal. Residual stresses are introduced during welding as a result of parent metal restraint on the shrinkage of hot weld metal during cooling due to thermal expansion and contraction and simultaneous microstructural phase transformation [1] in a weldment, residual stresses can possibly be as high as the materials yield strength or even higher at room temperature. In industrial production, one of the reasons for the preference edge preparation for the welding, apart from the advantages of higher productivity rates and reduced weld volume compare to conventional grooves, is the relatively lower heat input during welding, resulting in a smaller heat affected zone. Lower heat input also introduces lower levels of residual stresses [2]. Many experimental and simulation investigations have been carried out for determining the residual stress distribution and magnitude in pipes, both at the surface and through wall thickness [3]. Among the non-destructive techniques like X-ray diffraction and neutron diffraction methods has concrete output [4, 5]. Post weld heat treatment (PWHT) is applied after welding, aiming at reducing residual stresses in thick-walled components and thus improving the structural integrity performance [6]. It is an optional procedure in fabrication practice, and the need for this is largely dependent on the grade of the material, component thickness and the criticality of application. PWHT is commonly conducted in an enclosed furnace for a few hours to remove the hydrogen, improve fracture toughness and relax residual stresses in components when possible. However, in the circumstances that conventional furnace PWHT is not feasible, local PWHT can be considered as an alternative for the application of which equipment availability, geometry of the Structure, fabrication requirements and working environment should be all taken into Consideration [7]. Regarding relief of residual stresses, the PWHT holding temperature has been demonstrated to be more critical than the holding time. Information on the effectiveness of PWHT has been incorporated into industrial standards and codes such as BS 7910 [8], which assumes that in wide grove welds, different levels of stress relief occur in both transverse and longitudinal directions following a conventional furnace PWHT. BS7910 also provides information on the effect of PWHT temperature. However, the guidance provided is not intended to be relevant to narrow-gap welds. In addition, the information regarding the degree of stress relief after local PWHT is still limited; although some practical work with regard to local PWHT has been carried out experimentally and analytically to investigate the effective heating bandwidth for stress relaxation [9,10] and through-thickness temperature gradient criteria [11,12].The induced residual stresses in girth welds in pipe before and after PWHT. Residual stress distributions will identify non-destructively by

Xray diffraction and compared with the recommendations given in two engineering critical assessment procedures BS 7910 and R6 [13]. Welding residual stresses were simulated using the finite element analysis.

EXPERIMENTAL

Sample preparation

The material selected to prepare sample for the weld joint is ASTM A53 Grade. Chemical compositions of the parent metal and mechanical properties are listed in Table 1 and Table 2.The dimensions of the sample are the outside diameter is 63.5mm (2 inch.), the internal diameter is 59.4mm (2.34 inch.) and the length is 140mm.

Table 1. Chemical compositions of the material.

Material	C (%) Carbon	Si(%) Silicon	Mn(%) Manganese	P (%) Phosphorous	S(%) Sulphur	Nb(%) Niobium
Parent Metal	0.30	0.045	1.30	0.05	0.045	0.06
Filler Metal	0.06	0.45	0.90	0.025	0.035	0.15

Mechanical properties as per ASME standard specification consider for specimens to carried out the test and simulation. All weld metal specimens were extracted along the girth weld in the hoop direction. Parent metal samples were extracted parallel to the pipe axis. All tests were conducted according to ISO 6892-1:2016 standard at ambient temperature and the results are presented in Table 2.

Table 2. Mechanical properties of the material.

Material	Tensile strength (Mpa)	Yield strength (Mpa)	Yield ratio	Elongation(%)
Parent Metal	415	240	18	40
Filler Metal	520	425	13	23

Welding Process

Metal inert gas welding process chosen and carried out by using standard manufacturing specification with ER70S-3 wire electrode. Before welding the edge prepared by removing material form the edges of pipe to developed V groove. Then two sample pipe pieces were skin tacked at four locations based. And the root pass and rest passes carried out by specific time interval and allowed to air cool. And minimum inter-pass temperature maintain and recorded.

X-ray Diffraction Measurement

The theory of residual stress measurement by X-ray diffraction method is also based on the Bragg's equation.

$$n\lambda = 2d\sin\theta \qquad (1)$$

The X-ray measurement is carried out on Stress Analyzer 'XSTRESS 3000'. using the interatomic spacing as the ultimate gage length The residual stress is calculated by

$$\sigma = K.M \qquad (2)$$

$$K = \frac{E}{2(1+\mu)}\frac{\pi}{180}\cot\theta o \quad (3)$$

$$M = \partial(2\theta\psi x) / \partial(\sin^2\psi) \qquad (4)$$

Where θo is diffraction angle at stress free state stress free state, Ψ is the angle between the normal of crystal surface and the material surface, K is stress constant. There is a linear relationship between 2θ and $\sin^2\Psi$ and M is the slope between diffraction angle 2θ and $\sin^2\Psi$.M is calculated if more than three points (2θ, $\sin^2\Psi$) are determined.

The test machine is high voltage power supply for X-ray tube continuously variable within 5 to 30 kV and current 0 to 10 mA. Self-contained recirculating water cooling with heat exchanger for X-ray tube and power supply. Before measurement, the surface was cleaned and polished. Four angles Ψ=0deg,15 deg,30deg,45deg used in each measurement.2θ is determine by the full width at half maximum of parabola, and determine the residual stress is calculated by equation (2).

FINITE ELEMENT SIMULATION

FEA Model

This study develops a finite element model of girth welding of two pipes, as shown in Figure 1. The total length of the two pipes is 280 mm. The outer diameter is 63.5 mm. The thickness is 4 mm. Because of anticipated high temperature and stress gradients in and around the fusion zone and heat affected zone, a relatively fine mesh is used within a distance of 10mm on both sides of the weld center line. The material used here is ASTM A53 Grade steel for welding joint. The properties of material such as thermal conductivity, specific heat, and temperature dependent and mechanical properties for the base and filler material taken in account for the Thermomechanical analysis.

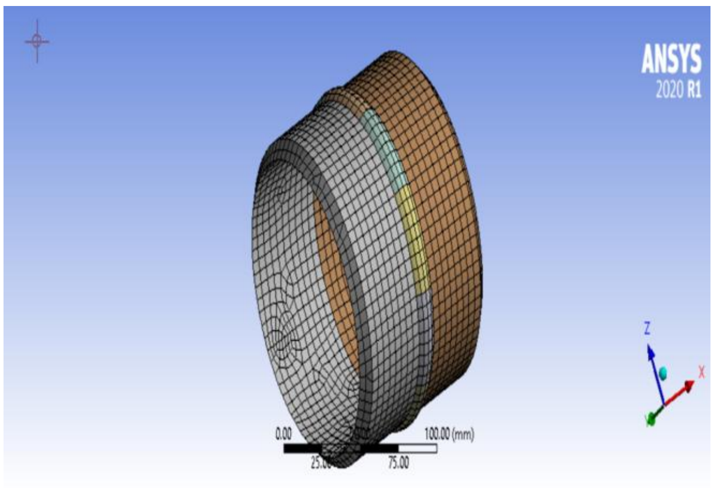

FIGURE 1. FEA Meshing Model

Transient Thermal Analysis

The non-uniform temperature distribution occurred in welding process which induced the residual stresses as shown in figure 2 in the weld joint. And the equation for transient heat transfer analysis is
ρc∂t∂T(x,y,z,t)=−∇·q(x,y,z,t)+Q(x,y,z,t)

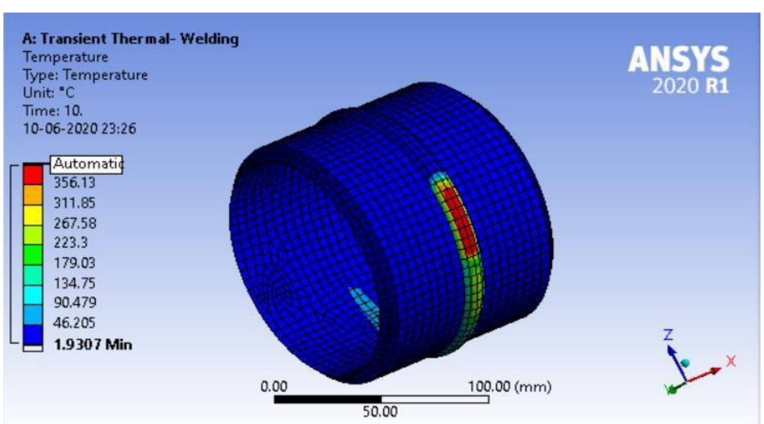

FIGURE 2. Non uniform temperature distribution

Transient Structural Analysis

By considering the temperature past record during welding process and thermal analysis for each interval of time. The total strain found due to phase transformation. And this phase transformation developed the residual stresses in weld joint of carbon steel pipe shown in figure 3.

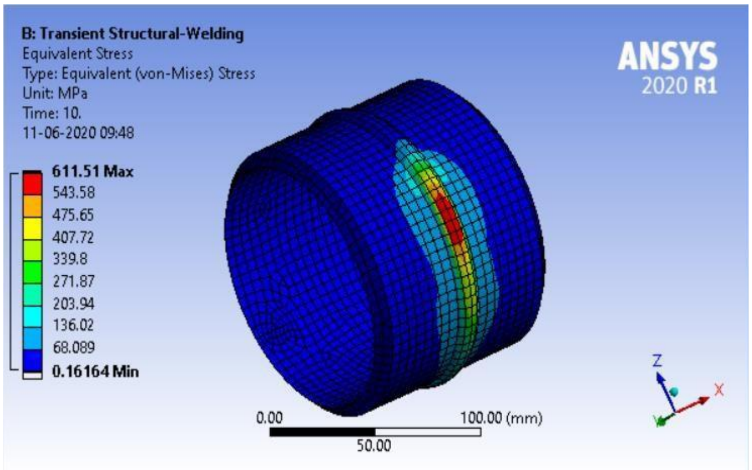

FIGURE 3. Transient Structural Analysis

POST WELD HEAT TREATMENT

After the checking of induced residual stresses in pipe weld joint by Xray diffraction and FEA simulation. The joint taken for heat treatment process in conventional furnace. And heat treatment carried out as per the recommended standard temperature and time. And again, the residual stresses were measured by Xray diffraction method and FEA simulation as per shown in figure 4.

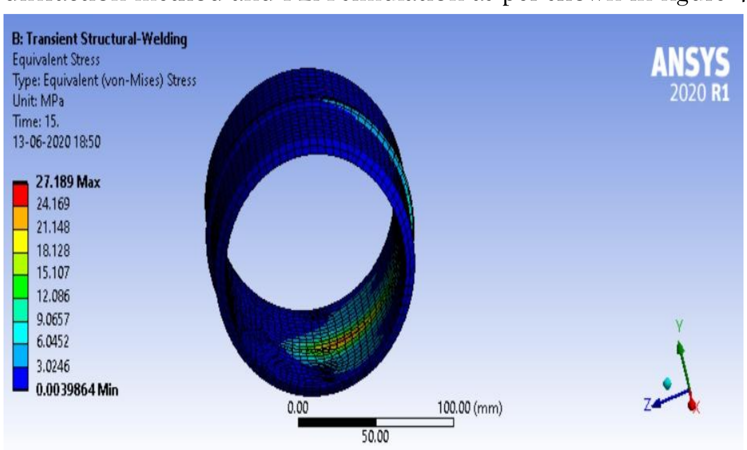

FIGURE 4. Transient Structural Analysis after PWHT

RESULT AND DISCUSSION

The results of finite simulation analysis of finite element of model of girth welding joint of two carbon steel pipe is compare with residual stress measurement by X-ray diffraction method. And found to be very closed to each other as per shown in figure 5. It indicates that the developed FEA model for pipe weld joint is correct and validate to experimental result.

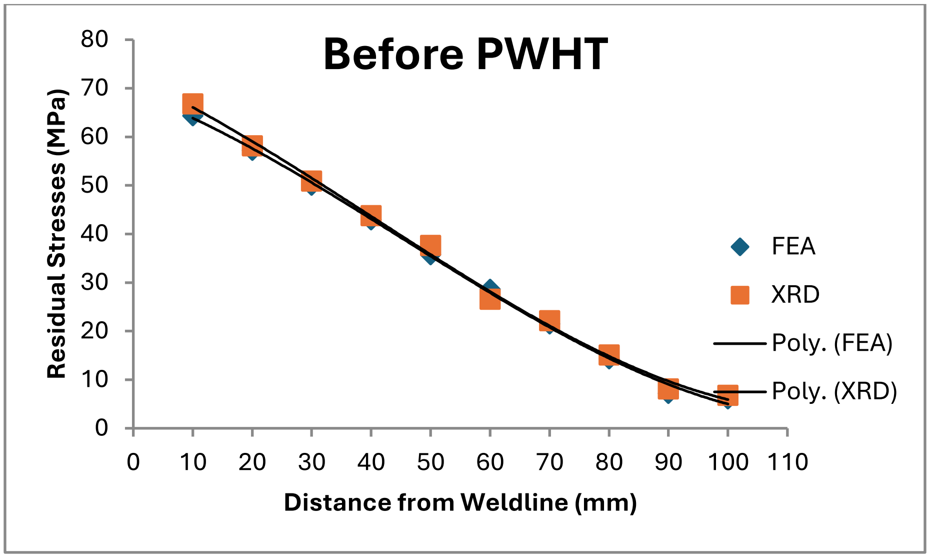

FIGURE5. Result Before Heat Treatment

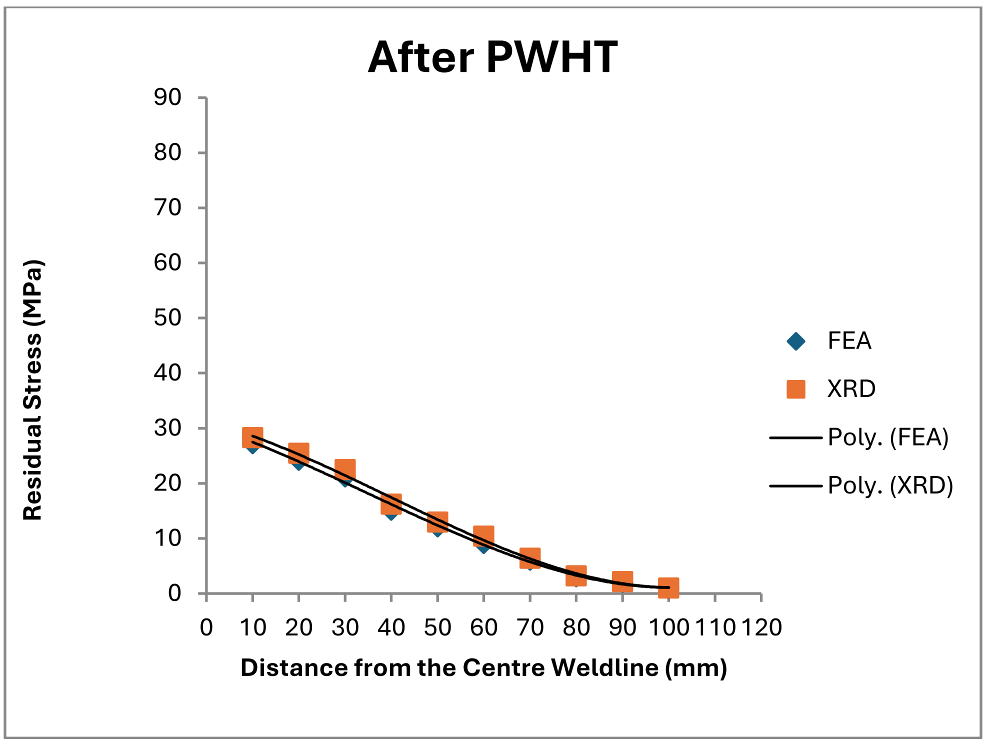

FIGURE6. Result After Heat Treatment

Again, we carried out the computation and non-destructive Xray diffraction test for same specimen after the post weld heat treatment (PWHT). And it proved that the magnitude of induced residual stress is decreases as per shown in figure 6.by heat treatment which help to increase the life of weld joint.

CONCLUSION

The significance of this study that to developed FEA model to check induced residual stresses are correct and validated by Xray diffraction method. And suggested the method of Post weld heat treatment which found very effective to reduce the residual stresses which increase the life of weld joint.

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