Study on Burn-through Prediction of In-service Welding

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Abstract

The pressure of media flowing in the pipe is one of the most important factors that has greatly influence on burn-through during in-service welding. The burn-through phenomenon was studied on the radial displacement with numercial simulation method supplemented by means of actual welding tests under different inner pressure. The results show that the radial displacement of the node beneath the molten pool increases with the increasing temperature of welding. When the temperature is close to the peak temperature, the deformation of the node has a mutation. Futhermore, the mutation degree becomes larger with higher inner pressure. Under a specific temperature field, the radial displacement of the node with maximum temperature at the inner wall changes linearly with the increasing pressure at the first stage, but when the inner pressure is up to a fixed value, the trend cannot be continued, and a mutation appears and indicts that the buru-through should occur if we don't take preventive measures. So the radial displacement can be seen as the burn-through criterion of in-service welding.

KEY WORDS: (in-service welding), (burn-through), (radical displacement), (SYSWELD)

1. Introduction

In-service welding is an advanced technique that is frequently employed in the repair, modification or extension of high-pressure gas pipelines[1]. When replacing the broken pipe caused by corrosion or local damage in order to maintain the safe operation of long-distance gas pipelines, in-service welding repair technology has significant economic and environmental advantages while compared with traditional repair methods[2-4]. One of the primary concerns with welding onto pipelines in active operation is burn-through[5]. Once burn-through occurs, the gas leak is likely to cause pressure bursting in the pipe-wall and even explosion, which will seriously threaten the safety of workers and the continuous operation of high-pressure pipelines.

Domestic and foreign scholars are putting more and more research emphasis on burn-through prediction during in-service welding. Because how to predict and prevent burn-through is the key technique to guarantee the safe in-service welding repair. Previous research by BMI (Battelle Memorial Institute) concluded that burn-through will not occur unless the maximum inner wall temperature exceeds 982 ℃ [6]. However, Bruce et al. did some in-service welding experiments on API X55 pipelines, and proved that burn-through did not occur when the inside surface temperature exceeded 1260℃ which had the safety margin of 278 ℃ while compared with 982 ℃ burn-through limit[7]. Belanger et al. analyzed burn-through conditions by using water as flowing medium. He found that the maximum inner wall temperature does not change with the increase of inner pressure[8]. In addition, through experimental methods, the inside surface temperature is very difficult to measure. Sabapathy et al. studied the effect of internal pressure on burn-through by translating the temperature field into an effective cavity in the pipe-wall[9]. Goldak et al. analyzed circumferential welds during sleeve repair welding and found that the given electrode diameter and the shape of the fillet weld have a signification effect on burn-through[10].

In this paper, three-dimension finite element (FE) models were established to simulate burn-through phenomenon during in-service welding process. The effect of pressure on welding deformation has been studied mainly, aiming at developing a procedure to predict burn-through and providing the theoretical support to the in-service welding repair technique.

2. Numerical Modeling of In-service Welding

The 3-D FEM model and mesh generation are established in Visual Mesh. The diameter and the thickness of the pipe are 75 and 4 mm, respectively. The material of pipe is 16Mn and its thermal physical properties based on temperature are calculated by the formula in [11]. The model adopts eight-node hexahedral elements mesh including 23717 notes and 26934 elements. In order to reduce the calculating time and improve the numerically computational precision, the mesh densification was used in the hardened zone and HAZ which have a high temperature changing gradients. In the place far from melting area, temperature changing gradients is not so obvious and the mesh is sparsely divided.

The 'Double Ellipsoidal Heat Source' (DEHS) is adopted, since the result of this model is at better agreement with the experiment[12]. The double ellipsoid model is based on the work of Goldak[13]. The model uses the following equation to define the volumetric heat flux inside the front half and rear half of the heat source, as shown in Fig. 1.

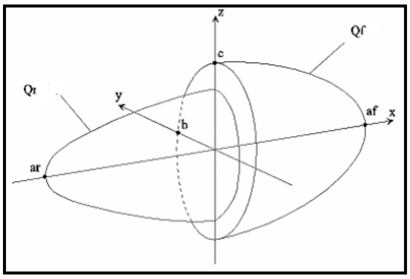


Fig. 1 Double ellipsoidal heat source configuration

The front half of the source is the quadrant of one ellipsoid, determined as following in Eq. (1):

$$q_f = \frac{6\sqrt{3}f_1Q}{\pi^{3/2}abc}\exp\{-3[(\frac{x}{a})^2+(\frac{y}{b})^2+(\frac{z}{c})^2]\} \quad (1)$$

For the rear quadrant of the source, the power density distribution calculated as following in Eq. (2):

$$q_r = \frac{6\sqrt{3}f_2Q}{\pi^{3/2}abc}\exp\{-3[(\frac{x}{a})^2+(\frac{y}{b})^2+(\frac{z}{c})^2]\} \quad (2)$$

In Eq. (1) and (2), Q is the heat input; the parameters a, b, c are the semi-major axis of ellipsoid.

Compared with the traditional welding process, in-service welding is a technique that applies welding onto a pipeline within which there is flowing medium. The internal medium pressure have an important effect on in-service welding safety and burn-through susceptibility. Thus, the numerical simulation on in-service welding process must consider the effect of internal pressure. Software SYSWELD could achieve this research purpose. Fig. 2 shows the way how inner pressure loads on the pipe-wall. The values of inner pressure are 0.3MPa, 0.4MPa, 0.5MPa, 0.6MPa, 0.7MPa, 0.8MPa, 0.9MPa, 1MPa and 1.2MPa, respectively.

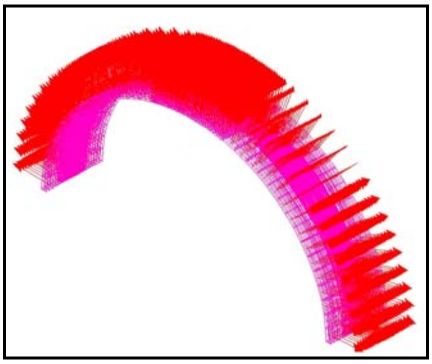


Fig. 2 Internal pressure loads on pipe model

3. Results and Discussion

High temperature makes the material losses strength. When the reduction of pipe-wall strength is too great, burn-through of in-service welding will occur. Thus, this paper studied the welding deformation only when inner wall surface is heated to high temperature. Fig. 3 shows the radial displacement curve at the peak temperature under 0.7MPa at measured inner points across the molten pool. It can be seen that the center point under molten pool has the highest welding deformation. When the deformation reaches to a certain degree and exceeds the plastic limit of pipe-wall, pipe-wall cannot resist the load of internal medium pressure, and then burn-through occurs. So the most danger point is the one just under the molten pool.

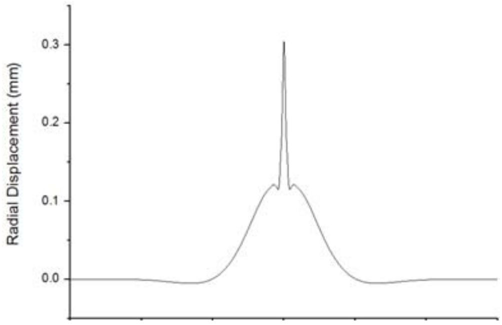


Fig. 3 Welding deformation curve of the inner points under 0.7MPa across the molten pool at high temperature

Fig. 4 is the change curve of radial deflection at different inner pressures. It can be seen that as internal pressure raises, radial deflection increases linearly. At this stage, radial deflection is the function of internal pressure. When medium pressure raises to 0.8MPa, the curve climbs suddenly and the curve slope increases sharply. After this threshold value of internal pressure, radial deflection grows gently again with the increase of internal pressure. Thus, it can be concluded that the sharp growth of radial deflection under inner pressure of 0.8MPa could be regarded as the indication of the occurrence of burn-through.

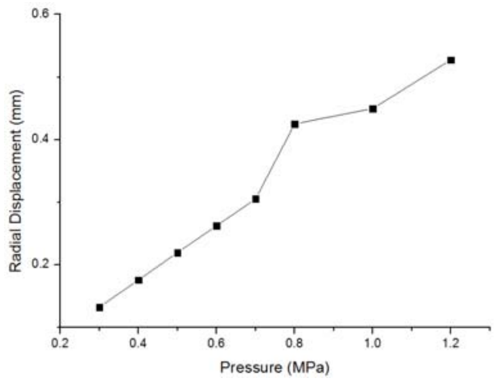
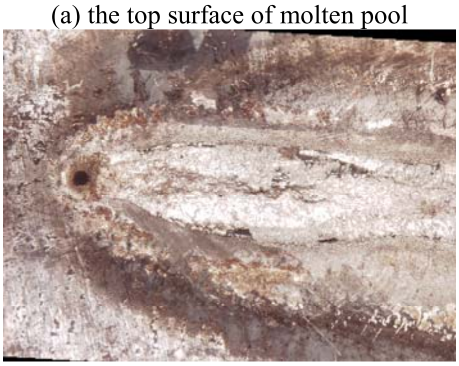


Fig. 4 Curve of radial deflection at different pressures

Burn-through during in-service welding is actually the convex deformation of pipe-wall caused by the combined action of welding stress and internal pressure. The author thought that the latter is even more important for the burn-through susceptibility. While the plastic deformation of pipe-wall exceeds the plastic limit bearing capacity, the deformation grows sharply, metal fails, the flowing medium leaks at the failure position, and then burn-through occurs. Fig. 5 is the macrograph of test specimen of in-service welding. It is clear that burn-through occurs at the high-temperature region just below molten pool, as shown in Fig. 5a and c. Burn-through mainly depends on the local reduction of pipe-wall strength caused by localized heating during in-service welding process. The loss of material strength at the region just below weld pool is the greatest and the effective thickness is the least. When the remaining strength cannot resist the load of internal pressure, destabilization will occur. As shown in Fig. 5b, the inside surface of pipe-wall appears burn-through hole. Around burn-through hole, metal produces plastic deformation, which makes pipe-wall bend outward, as shown in Fig. 5c. Fig. 6 shows the predicted radial deflection of a certain cross-section in the pipe under internal pressure of 0.7MPa. The simulation result is in a good agreement with practical deformation.

According to above analysis, the conclusion can be drawn that as internal pressure increases, the convex deformation at the high-temperature region of pipe-wall will gradually grow. The change curve of radial deformation with internal pressure has a mutation point where the deformation has a sharp growth. At this mutation point, burn-through occurs. Internal pressure of this point is regarded as threshold value of predicting burn-through.

(a) the top surface of molten pool



(b) the back surface of molten pool

(c) the cross-section of molten pool when burn-through occurs

Fig. 5 The morphology of burn-through during in-service welding

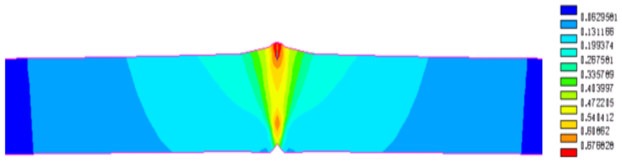


Fig. 6 Pipe-wall deformation profile under 0.7MPa

4. Conclusion

The pressure of flowing medium in the pipe has a significant influence on burn-through during in-service welding. In this paper, the burn-through phenomenon was studied by analyzing radial displacement of pipe-wall using numerical simulation software SYSWELD. The simulation results at different internal pressures are verified through in-service welding tests. It can be concluded that at the measured point just blow molten pool, welding deformation gradually increases as inner wall surface temperature raises. When temperature is close to the peak temperature, radial deformation of the measured point has a sharp growth. Furthermore, the extent of mutation raises with the increase of internal pressure. Under a given temperature field, radial deflection at the region with the maximum inner wall temperature increases linearly with the increasing internal pressure. When internal pressure is up to a fixed value, welding deformation raises sharply and a mutation point appears. The radial displacement at this point can be regarded as the burn-through criterion of in-service welding.

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