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Original Research Article

A comparative study of transverse shrinkage stresses and residual stresses in P91 welded pipe including plasticity error

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ABSTRACT

The paper deals with the measurement of the residual stresses in P91 welded pipe using the blind hole drilling technique. The P91 pipe weld joints were prepared using gas tungsten arc welding process. The residual stress measurement was carried out using the strain gauge rosette that was associated with the plastic deformation of material and stress concentration effect of multi-point cutting tool. Strain gauge response was estimated experimentally using the tensile testing for the uniaxial loading while finite element analysis was performed for biaxial loading. Gas tungsten arc welds joint was prepared for conventional V-groove and narrow groove design. The corrective formulation was developed for calculating the corrected value of residual stresses from the experimentally obtained strain value. The corrected and experimental induced residual stresses values as per ASTM E837-13 were calculated for both V-groove and narrow groove design. Post weld heat treatment (PWHT) of P91 welded pipe was also conducted to study their effect on residual stresses.

1. Introduction

To overcome the CO_2 emission and lead to endeavors to improve the thermal efficiency of power plants, creep strength enhanced ferritic (CSEF) steels are selected as the candidate material for high temperature operating power plant components [1,2]. CSEF steels have been considered as superior material over austenitic stainless steel due to its attractive thermo-physical and mechanical properties [3–5]. The commonly used CSEF steels are P9, P91, and P92.

However, for long-term creep exposure the lower creep rupture life of P91 welds joint as compared to 'as-received' base metal is a serious issue [6]. The residual stresses, weld microstructure and diffusible hydrogen present in deposited metal are the main parameters which affect the weldability of

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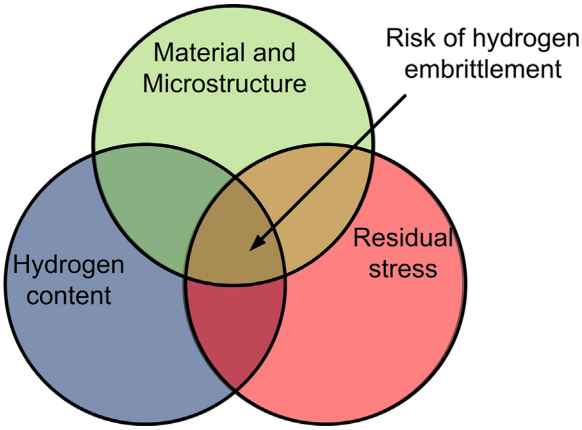

Fig. 1 – Schematic evolution of essential condition that affects weldability.

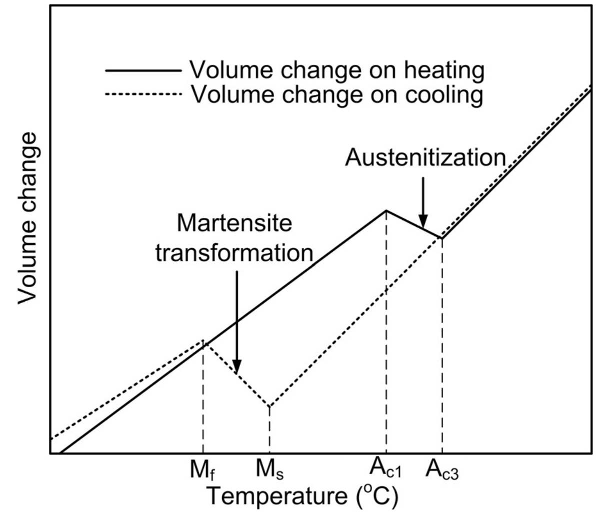

Fig. 2 – Schematic diagram of volume change during heating and cooling cycle of P91 weldments.

P91 steel. The residual stress and microstructure of P91 steel weldment can be controlled by using the proper PWHT as suggested by the researchers [2,7], but the hydrogen induced cracking (HIC) in P91 steel weld is a serious problem [8]. A combined effect of sensitive microstructure, high residual stress and sufficient level of hydrogen on HIC is shown in Fig. 1. Joining of structural component, piping and pressure vessels used in nuclear, thermal fertilizer and chemical power industries are generally carried out by the welding process that results in residual stress, shrinkage stress and distortion at remarkable level [9,10]. In welding process, the localized heating and cooling leads to the formation of complex residual stress and distortion may result in catastrophic failure of welded joint. Localized heating and cooling of base, solidification shrinkage of weld, internal constraint, external constraint like tacking, and phase transformation result in formation of residual stresses and distortion [11,12]. Compared to the weld structure, size of weld pool is very small and expansion and contraction of the weld during the weld thermal cycle is prevented by the adjacent base metal. During the heating cycle, expansion of heated zone leads to the formation of compressive residual stress and cooling cycle results in shrinkage which is prevented by the base metal. After the cooling, shrinkage resistance cause the formation of tensile residual stress in weld zone which is balanced with compressive residual stress of base metal [12].

2. Literature survey

Cottam et al. [11] studied the effect of both type of phase transformation on stress formation. They had reported that the martensitic transformation is more complex and help to reduce the magnitude of residual stress in transformed zone. During cooling process, transformation of austenite to martensite results in BCT structure formation that leads to increase in volume, as shown in Fig. 2 [13]. It has been reported that the precipitation process can reduce residual stress through load sharing. The effect of the martensite transformation is slightly more complex and acts to reduce the residual stress level in the transformed region. The inflection in the residual stress level just beyond the processing interface was attributed to point at which the martensitic transformation ceases resulting in an increase in the observed stress levels in the adjacent untransformed region. The increase the volume of transformed martensite reduces tensile residual stress levels and moves the location of the peak residual stress deeper into the substrate, which may be beneficial to the service life of a component.

A lot of work have been performed related to study of effect of welding process, groove geometry, welding parameters, and number of welding passes on shrinkage and shrinkage stress in pipe and plate weldments. Ghosh et al. [14] performed an analytical study on shrinkage stress mode, magnitude and distribution in different quadrants of GMAW and pulse GMAW welded pipe for different weld groove designs. The mode and magnitude of shrinkage stress in different quadrant was observed to be non-uniform and varied as a function of welding process, parameters and groove geometry. Pulse GMAW process has resulted in lower magnitude and uniform distribution of transverse shrinkage stress compared to GMAW. Higher the heat input during the welding process has resulted in higher magnitude of transverse shrinkage stress. For constant heat input, narrow groove design produced the lower shrinkage stress compared to conventional groove design. The multi-pass welding, the weld metal is subjected to localized solidification shrinkage [15]. The repetitive influence of thermal cycle from subsequent weld passes affects the development of stress in weld groove upto certain extent, and finally it causes a continuous change in groove design and groove area with every weld passes [16]. The change in groove size with subsequent pass results in groove angle variation and it will not be uniform at all location in each quadrant of pipe. The change in groove size and groove area was observed to be more in the case of V-groove weld design than narrow-groove [22] and this occurred due to less weld metal deposition in narrow groove. Ghosh et al. [17] studied the effect of Pulse GMAW and GMAW process on transverse shrinkage stress and distortion of thick butt welded plate.