International Journal of Pressure Vessels and Piping 88 (2011) 375–383

Contents lists available at ScienceDirect

International Journal of Pressure Vessels and Piping

journal homepage: www.elsevier.com/locate/ijpvp

Tensile properties of modified 9Cr-1Mo steel by shear punch testing and correlation with microstructures

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ARTICLE INFO

Article history:
Received 22 December 2010
Received in revised form
1 July 2011
Accepted 1 July 2011

Keywords:
Modified 9Cr-1Mo steel
Microstructural variation
Shear punch test
Yield strength
Strain hardening exponent
Intercritical heating

ABSTRACT

Modified 9Cr-1Mo ferritic steel (P91) is subjected to a series of heat treatments consisting of soaking for 5 min at the selected temperatures in the range 973 K–1623 K (below Ac_1 to above Ac_4) followed by oil quenching and tempering at 1033 K for 1 h to obtain different microstructural conditions. The tensile properties of the different microstructural conditions are evaluated from small volumes of material by shear punch test technique. A new methodology for evaluating yield strength, ultimate tensile strength and strain hardening exponent from shear punch test by using correlation equations without employing empirical constants is presented and validated. The changes in the tensile properties are related to the microstructural changes of the steel investigated by electron microscopic studies. The steel exhibits minimum strength and hardness when soaked between Ac_1 and Ac_3 (intercritical range) temperatures due to the replacement of original lath martensitic structure with subgrains. The finer martensitic microstructure produced in the steel after soaking at temperatures above Ac_3 leads to a monotonic increase in hardness and strength with decreasing strain hardening exponent. For soaking temperatures above Ac_4, the hardness and strength of the steel increases marginally due to the formation of soft δ ferrite.

1. Introduction

The modified (mod) 9Cr-1Mo ferritic steel is widely used in power plants because of its excellent high temperature creep strength, resistance to stress corrosion cracking, low oxidation rate and good weldability. The steel is a modified version of conventional 9Cr-1Mo steel with the controlled addition of niobium, vanadium and nitrogen. It derives its high temperature strength from tempered martensitic microstructure with high dislocation density and sub-boundaries stabilized with $M_{23}C_6$ type carbides and fine MX types of carbonitrides in the matrix. The martensitic microstructure of the steel and the shape and size/distribution of the precipitates are vulnerable to change on heat treatments associated with and without phase transformations, which affects the mechanical properties of the steel appreciably. The heat affected zone (HAZ) of a fusion welded joint of this steel is a typical example where a variety of microstructures is formed during weld thermal cycle, which control the mechanical behaviour of weld joint especially under creep conditions [1].

The aim of the present work is to study the mechanical behaviour and microstructural changes of mod 9Cr-1Mo steel as it passes through different transformation temperatures Ac_1 ($\alpha \rightarrow \alpha + \gamma$), Ac_3 ($\alpha + \gamma \rightarrow \gamma$) and Ac_4 ($\gamma \rightarrow \gamma + \delta$). The shear punch (ShP) technique is used to evaluate the mechanical properties of the steel with different microstructural conditions. The ShP testing involves axi-symmetric loading of a small disk specimen of 3–8 mm in diameter and 0.3–0.5 mm thick clamped between a set of dies with a flat punch [2,3]. This technique requires very small volume of material compared to the conventional tensile test and hence promising for applications where conventional mechanical tests are practically not possible, as in the HAZ of ferritic steel weld joints [4], coatings, and failed components. Further, the punched out slug can be used as the starting material for microscopic examinations thus facilitating structure–property correlations. This technique is also gaining importance as a useful tool for structural integrity assessment of power plant components using small volumes of scooped out specimens. The important considerations for effective utilization of this technique are that (i) the sampling dimensions shall be sufficient enough to ensure bulk mechanical response of the material being tested. This is taken care by ensuring that sufficient grains in the specimen volume participate in the deformation (ii) material's mechanical response shall be isotropic: so that specimen orientation effects are unimportant.

The methodology developed for evaluating the tensile properties from shear punch testing is briefly described in the next

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0308-0161/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijpvp.2011.07.001