B. Issues Related To Specifying Post Weld Heat Treatments For 9Cr-1Mo-V Steels

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Introduction

Often, there is a desire to post weld heat treat 9Cr-1Mo-V (P91) steels at the highest possible temperature either to maximize tempering for a given hold time or to minimize the hold time. The upper limit of post weld heat treating temperatures for these steels is the lower ferrite-austenite equilibrium transformation temperature, A_1. The equilibrium A_1 temperature is often estimated from experiments that involve heating specimens through the transformation temperature. Transformation temperatures determined this way are referred to as A_{C1}. Whereas A_1 is uniquely defined by chemical composition, A_{C1} depends on experimental measurement techniques. Differences between these temperatures will be addressed.

Technical Approach

A Gleeble™ 3500 thermomechanical simulator was used to measure ferrite-austenite transformation temperatures by monitoring variations of the specimen diameters during heating and cooling with an LVDT strain gauge. Transformation temperatures were determined by curve fitting procedures at points of significant discontinuity on dilation-versus-temperature data plots. Thermodynamic analysis with ThermoCalc™ software was used to estimate both the influence of alloying elements on transformation behavior and the microsegregation of alloying elements in weld deposits. Neural net analysis of the ThermoCalc™ results was used to produce a simple application program to estimate ferrite-austenite transformation temperatures based on P91 bulk chemical compositions.

Results and Discussion

Experimental measurements of specimen dilations were used to show that A_{C1} temperatures increased with heating rate. For instance, A_{C1} varied from about 830°C to about 880°C for heating rates of 2°C/min to 2000°C/min, respectively. Experimental measurements were also compared to published data that show similar trends. Additional experiments showed that nickel additions to P91 decrease both the ferrite-austenite transformation temperature and the kinetics of transformation. The effects on the A_1 of all major alloying elements in P91 were assessed using thermodynamic calculations. The austenite stabilizing elements carbon, manganese, nickel and nitrogen all reduced A_1. The effects of nickel and manganese were virtually identical within their normal ranges for P91 steels. The ferrite stabilizing elements chromium, molybdenum, niobium, silicon, and vanadium increased A_1. Diffraction data are used to show that the transformation of weld deposits may be different than base metal. This behavior is attributed to microsegregation. The microsegregation patterns expected in P91 steels were also evaluated using thermodynamic calculations. These calculations indicate that important elements such as carbon, chromium, manganese, and nickel partition to the liquid during solidification, accumulating preferentially in interdendritic regions. The resulting chemical microsegregation means that transformation temperatures in the weld deposit will vary with the local chemical composition. In particular, A_1 temperatures and martensite-start temperatures will be lowered in the interdendritic regions where concentrations of manganese and nickel are relatively high.

The analysis of microsegregation is consistent with the transformation behavior found by diffraction.

Conclusions

The temperature that is most relevant to post weld heat treatment of P91 (and all carbon steels) is A_1, the equilibrium lower ferrite-austenite transformation temperature. In homogenized wrought material, A_1 is uniquely defined by alloy chemistry. Transformation temperatures measured by heating experiments, A_{C1}'s, are not unique, but vary with heat rate. Using A_{C1} data to specify post weld heat treatment temperature without knowing the effect of heat rate increases the probability of exceeding the real ferrite-austenite transformation temperature. Microsegregation prevents weld deposits from having unique A_1 temperatures. Consequently, weld deposits will require extra care to avoid local reaustenitization during post weld heat treatment.