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Predicting weld cooling rates and the onset of failure during in-service welding

Prakash N. Sabapathy

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The University of Adelaide

Department of Mechanical Engineering

South Australia 5005

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ABSTRACT

A comprehensive numerical simulation of the in-service welding of high pressure gas pipelines has been developed. A system has been established for predicting the safe, suitable welding conditions at which in-service manual metal arc welding using low-hydrogen electrodes can be achieved on thin, high-strength pipes with flowing pressurised natural gas. The two main concerns of in-service welding are: the possibility of excessively hard heat affected zone microstructure due to fast cooling rates, and the possibility of failure of the pipe wall due to localised heating from the welding arc.

The finite element method was applied to calculate the cooling rates from circumferential fillet welds and branch on pipe welds. Initial development considered approximating the process in two dimensions, but was quickly rejected in favour of three-dimensional conduction only models which included temperature dependent material properties. The welding arc was approximated as a three-dimensional heat flux distribution function. Numerical simulations were validated using both laboratory and field trials. The experiments involved welding on a water cooled device which simulated in-service welding cooling conditions in a laboratory, while a second experiment involved welding onto a flow-loop attached to an actual operating pipeline. The results from the experiments were used to define the heat source distribution, to account for weld weaving, and shallow penetration welding. Weld pool flow was not calculated, but the effects of weld pool convection were included in the heat source.

An investigation was made to calculate the limits at which in-service welding can produce safe, mechanically sound welds under a combination of low wall thickness pipe and high pressure. Initial development consisted of calculating pipe wall deflection using three-dimensional thermal elastic-plastic models. Such models are very expensive computationally, which led to the development of a new model to calculate the limits of in-service

welding. This 'equivalent cavity' model primarily used a thermal field, as calculated from the thermal models, to calculate the maximum pressure at which a weld can be deposited. The accuracy and feasibility of the equivalent cavity model was determined by comparing its predictions with published data relating to pipe wall failure, and numerical simulations of pipe wall failure using thermal elastic-plastic finite element models.

In combination, the thermal and pipe wall failure models offer valuable savings during the design stage of in-service welding. While the models form an accurate system to predict weld cooling rate and the possibility of pipe wall failure, they avoid the cost of traditional trial and error experimentation, often chosen for the testing phase of in-service welding.

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