This thesis is dedicated
to my mother, *Sree Devi Lalam*

PREFACE

This dissertation is submitted for the degree of Doctor of Philosophy at the University of Cambridge. The research described herein was conducted under the supervision of Professor H. K. D. H. Bhadeshia in the Department of Materials Science and Metallurgy, University of Cambridge, between October 1997 and September 2000.

Except where acknowledgement and reference is specifically made to the contrary, this work is, to the best of my knowledge, original and has been carried out without collaboration. Neither this thesis, nor any substantially similar dissertation has been or is being submitted for any degree, diploma or other qualification at any other university. Part of this work has been presented in the following publications;

Lalam, S. H., Bhadeshia, H. K. D. H. and MacKay, D. J. C .,*Estimation of mechanical properties of ferritic steel welds. Part 1: Yield and tensile strength*, Science and Technology of Welding and Joining, **5(3)**, 135–147, 2000.

Lalam, S. H., Bhadeshia, H. K. D. H. and MacKay, D. J. C ., *Estimation of mechanical properties of ferritic steel welds. Part 2: Elongation and Charpy toughness*, Science and Technology of Welding and Joining, **5(3)**, 149–160, 2000.

Lalam, S. H., Bhadeshia, H. K. D. H. and MacKay, D. J. C ., *Short communication: The Bruscato factor in the temper embrittlement of welds*, Science and Technology of Welding and Joining, accepted and to be published in volume **5**, 2000.

Lalam, S. H., Bhadeshia, H. K. D. H. and MacKay, D. J. C ., *The Charpy impact transition temperature for some ferritic steel welds*, Australasian Welding Journal, **45**, 33–37, 2000.

Sree Harsha Lalam
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ABSTRACT

Welding is a key technology in the manufacture of engineering components and is of particular importance in the context of steels. The complexity of welding alloys has in the past prevented the development of generalised models capable of giving quantitative estimates of anything other than the most simple mechanical properties. It has been possible in the present work, using a neural network technique within a Bayesian framework in combination with physical properties, to develop a set of models dealing with the yield strength, ultimate tensile strength, the ductility and impact toughness of weld metals as a function of the chemical composition and heat treatment. The models are based on a vast quantity of published experimental data which were all digitised and assessed for model development.

Neural networks are used in circumstances where the complexity is difficult to deal with using only scientific principles. For this same reason, the trained networks cannot ever be fully tested since it is hard to imagine how multi–fold interactions between the inputs can affect the outcome. Nevertheless, an attempt was made to assess whether the networks reproduce the known physical metallurgy. For example, the effect of carbon and manganese on the yield strength of low–alloy weld deposits. In almost all cases considered, the networks could be shown to recognise known trends, taking into account the error estimates. Where possible, the network predictions were compared against physical models. For example, the yield strength of carbon–manganese welds can be estimated using deformation theory; this was shown to compare well against predictions using the neural network models. However, in some cases, such as when considering the effect of tungsten on the strength of low–alloy steel welds, it was evident that the models lacked knowledge to such an extent as to make the predictions unphysical. The situation was corrected by adapting steel data to represent welds, and the resulting model was demonstrated to behave properly. This example illustrates that the networks should not be used blindly but rather as an aid to design.

The combined set of models, together with experience from physical metallurgy, were then used to propose a new tungsten–containing welding alloy for use in circumstances where post–weld heat treatments are not practical. This proved to be successful at the first attempt; subsequently, the models have been used successfully by others in a similar way, to invent welding alloys without doing experiments.

The tempering resistance of the tungsten–containing weld has been studied experimentally and compared against a number of alloys. This work indicates that the replacement of molybdenum by tungsten in creep–resistant alloys leads to a lower as–deposited hardness which can be exploited to eliminate post–weld heat treatments. The creep strength can nevertheless (probably) be maintained by the use of vanadium.