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Procedural influences on non-linear distortions in welded thin-plate fabrication

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Abstract

Fusion welding is the most common and convenient method used for the fabrication of large, thin-plate welded structures. However, the resulting tendency to out-of-plane distortion exacts severe design and fabrication penalties in terms of poorer buckling performance, lack of fairness in external appearance, poor fit-up and frequent requirements for expensive rework. This study forms part of a long-term project that has the aim of modelling welding and related fabrication processes computationally with particular emphasis on the out-of-plane distortion outcomes. Throughout the present work the computational models have been cross-referenced to realistic experimental test cases. A repeated finding of the trials was that minor variations in fabrication procedures, were found to have significant effects on distortion. In particular, the pre-fabrication procedures, including spot and tack welding, have a significant effect on the initial out-of-plane distortion leading to differences in distortion of the post-welded structures. The support and clamping conditions during welding and cooling of welded thin-plate structures were also found to have a considerable influence on the final predicted out-of-plane distortion. The outcomes often result in different buckling instability behaviour. This paper concentrates on these aspects and draws on studies of buttwelding between plates of thicknesses 3–8 mm.

Keywords: Welding distortion; Out-of-plane deformation; Computational models; Experimental tests; Pre-fabrication procedures; Support and clamping conditions

1. Introduction

Fusion welding is one of the most versatile manufacturing processes available for the fabrication of large, complex structures from stock plate, sheet and section. However, the process relies on an intensely localised thermal input, which tends to generate undesirable permanent distortions in the finished product. This is especially the case for thin-walled, lightweight construction, where mechanical fasteners and adhesives are very often preferred in order to minimise such difficulties. Certain low heat-input processes such as laser and friction stir welding are beginning to make an impact on this class of structure, but even then, there will be some element of thermal distortion for the fabricator to contend with.

One of the factors which causes the application of welding to be problematic is that the result is difficult to predict as far as final shape accuracy is concerned, and often has considerably different outcomes within what are thought to be identical fabrication procedures. Not all of the variation is necessarily caused by welding as such, but has been found to be due to inadequate quality control of associated operations, such as material handling, cutting and fitting [1]. A recent comprehensive study of stiffened plate construction in shipbuilding, where typical design plate thicknesses are reducing [2] showed that substantial improvements to established procedures and operations previously used for thicker plate were necessary to avoid inordinate rectification costs. A significant factor is that thermal cutting and welding procedures induce compressive residual stress fields in the component and there is therefore a strong potential for non-linear, out-of-plane movements when design thickness is reduced. The degree of out-of-plane distortion, regarded as significant, varies from application to application and may be partly subjective when the appearance lacks 'fairness', as in shipbuilding. Significance can of course be quantified in compression

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buckling situations, where a specific out-of-plane profile will have definite consequences.

The studies discussed in this paper derive from a long-term project that has the aim of modelling welding and related fabrication processes computationally, so that out-of-plane distortion outcomes, in particular, might be predicted. The obvious advantage of computational modelling is that many more variations in design configuration, process and procedure can be explored than would be feasible if investigations were to be carried out through welding trials alone. It is also possible to separate out different influences in a virtual experiment, for example, the effects of gravity and positioning of supports can be explored by assuming that the thin plate to be welded begins its fabrication journey as ideally flat and stress free. Examples of virtual welding experiments will be given in this paper.

However, studies based entirely on computational modelling also embody a risk that important factors in the real world of fabrication may be overlooked. Full-scale welding trials were therefore incorporated in the present work to validate the predictions and to expose influences that might need to be included as inputs to the models. The experimental and computational strands of the present work were developed in parallel and Refs. [3] and [4] provide overviews of the interactions between the welding trials and development of the various models. A repeated finding of the trials was that minor variations in fabrication procedures, at a level that might be regarded by a fabricator as trivial, were found to have significant effects on distortion. This paper concentrates on these aspects and draws on studies of butt welding between plates. Nearly all of the experimental work has been carried out to date on carbon-manganese steels in the 3–8 mm thickness range, although the modelling strategies are generic in terms of potential application to other metals and thicknesses.

2. Modelling strategies

Weld modelling could be extremely complex in principle, given the many physical phenomena involved and the physical interactions between them. Most modelling strategies published in the literature neglect many of the interactions, on the grounds that they are weak. Parameters are represented more simply in terms of lumped inputs and simplified material properties. In the case of welding distortions, the major concern is with effects on the global structure and, therefore, the complex behaviour local to the welding arc and molten weld pool is represented, as shown schematically in Fig. 1, by an electrical/thermal conversion and a transient thermal input to a specified region. The thermal input represents the heat that is delivered to the workpiece by conduction and is specified as a proportion of the electrical energy input to the welding system, allowing for radiation and other losses. The electrical/thermal-conducted energy conversion 'efficiency' is determined by experimental calibration and the shape and size of the weld fusion zone is also determined experimentally through the results of weld trials (see Fig. 7)

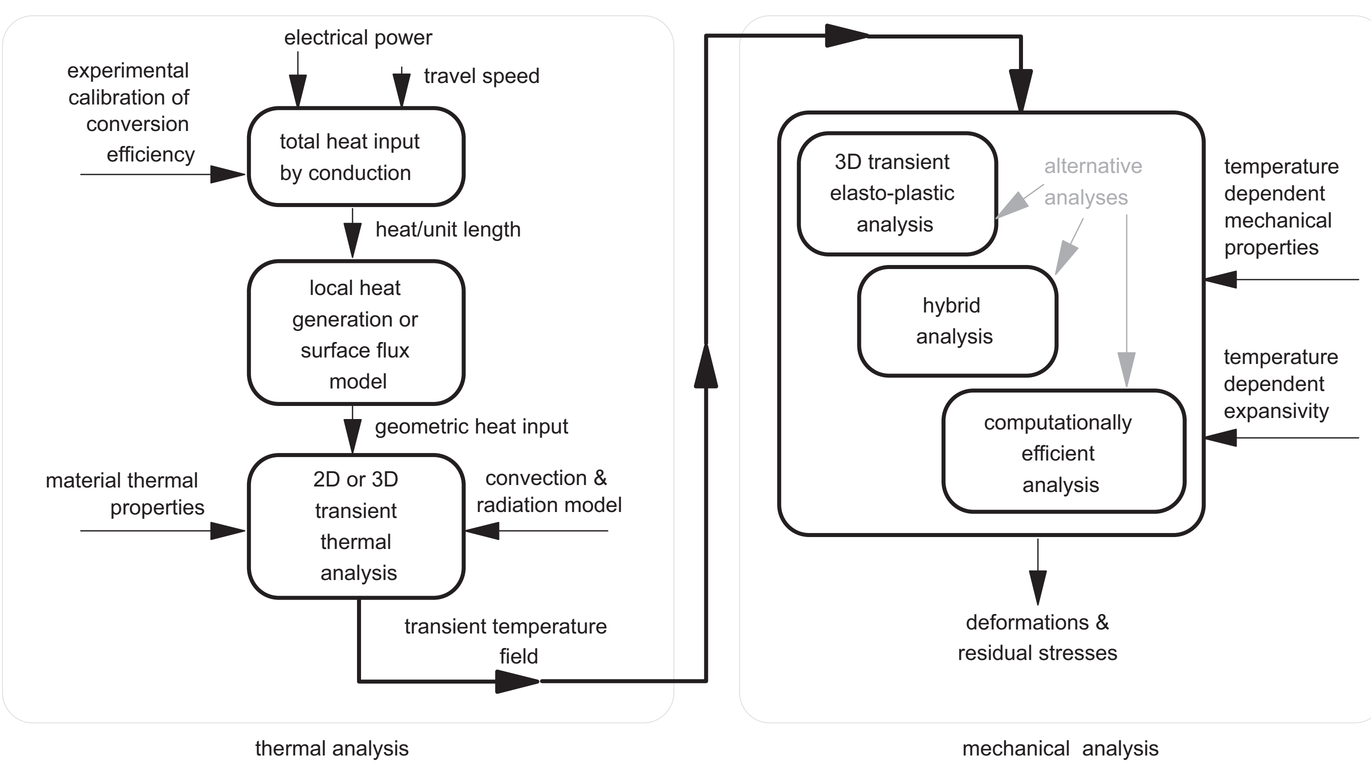

Fig. 1. Uncoupled computational strategy.