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Modelling of metal deposition

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ABSTRACT

Modelling and simulation of metal deposition (MD) poses several challenges to the modeller in addition to the usual challenges in modelling of welding. The aim of the work presented in this paper is to enable simulation of metal deposition for large three-dimensional components. Weld paths that are created in an off-line programming system (OLP) can be used directly to prescribe the movement of the heat source in the model. The addition of filler material is done by activation of elements. Special care must be taken to the positioning of the elements, due to large deformations. Nodes are moved to ensure that the added material has correct volume and shape. A physically based material model is also implemented. This material model is able to describe the material behaviour over a large strain, strain rate and temperature range. Temperature measurements and deformation measurements are done in order to validate the model. The computed thermal history is in very good agreement with measurements. The computed and measured deformations also show quite good agreement. It has been shown that the approach yields correct results, providing that flow stress and heat input models are calibrated with sufficient accuracy. The method reduces the modelling work considerably for metal deposition and multipass welding. It can be used for detailed models but also lumping of welds is possible and often necessary for industrial applications.

1. Introduction

The metal deposition (MD) process is quite similar to multipass welding but with the aim to build up features or even complete components with wanted geometry. This can both reduce weight and increase the flexibility of the manufacturing process. Simulations can assist in developing this manufacturing process. The current work is part of a project where the objective is to simulate the manufacturing chain of aerospace components. Two issues have been in focus. One is the development of a material model that is valid over a large strain, strain rate and temperature range. A physical based material model has been used for this and is described briefly in the paper.

The other issue, which is the main focus of the current paper, is enabling simulation of metal deposition. Simulation of multipass welding and particularly metal deposition poses several challenges to the modeller in addition to the usual challenges in modelling of welding. There are numerical aspects such as, element activation methods and heat sources. There are also practical aspects, how to simplify the description of the weld process for the user. An approach for supporting this in a convenient way is presented in this paper. The method is implemented in a commercial finite element code and applied to a validation case.

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2. Background

2.1. The metal deposition process

The advantage with the metal deposition process is that material is added where it is actually needed instead of making a large component and machining the wanted features. The structural components in an aero-engine are good examples where deployment of the MD process simplifies the production provided the quality can be assured. They are generally slender with more bulky features such as flanges and bosses needed to connect the components that could be produced by the MD process.

The two most common processes for manufacturing of structural components today is forging and casting. Forged components typically need to be largely oversized due to the complexity of the final shape. In many cases the subsequent machining removes more than half of the volume of the component. Since nickel based super alloys and titanium are used, the actual material cost is therefore significant. Machining in these high strength materials is also a time consuming and costly process. Casting produces a component that is much closer to the final shape. However, the material integrity of castings is not as good as for forgings or sheet metal. There are also limitations in the design of the component, transitions of thicknesses must not be too sharp and the ratio between the thickest and thinnest section must not be too large. Metal deposition in combination with e.g. fabrication offers a product with high structural integrity, produced with a minimum of scrap. Clark et al. [1] concluded that the Shape Metal Deposit process (SMD) is a viable method of fabricating local, complex features in aerospace components.

Despite these obvious advantages, MD is not widely used in the aerospace industry as the quality must be assured before it can be adopted. The current work is part of the technology development at Volvo Aero Corporation where simulation of the MD process is an important tool to learn about the process and design it in order to assure the quality. The finite element method is used to predict distortions and residual stresses due to the process. Then different welding sequences, weld speeds, pause times, etc. can be evaluated at a relatively low cost.

In this work the tungsten inert gas (TIG) process is used as the heat source together with a wire feeder system. There are other processes that can be used for MD. The most widely used process is laser cladding, where a laser beam is used as the heat source and the material is added by powder injection. Laser cladding gives a very small heat affected zone, low residual stresses and small distortions. However, difficulties related to powder flow and oxidation may increase the formation of porosity and inclusions [2,3]. The addition of material can be done by wire instead of powder. This gives much higher material usage efficiency. It also lowers the risk to the operators and makes the process more environmental friendly. Metal wires are also more easily available and cheaper than powders [4]. Another combination is electron beam and wire feed. This can give an excellent result regarding defects and microstructure [5]. The electron beam equipment needs to be operated in vacuum and controlling the interaction between the electron beam and a thin wire in the fusion zone requires particular regulation. Clark et al. [1] investigated the metal inert gas (MIG) process for MD and concluded that it is a viable method for fabrication of local, complex features in aerospace components. The MIG welding can offer high deposition rates at a relatively low investment cost. The use of a consumable electrode in MIG welding increases the risk for spatter. This in turn may reduce the productivity and quality of the process.

2.2. Computational welding mechanics

The scope of Computational Welding Mechanics (CWM) 'is to establish methods and models that are usable for control and welding of welding processes to obtain optimal mechanical performance' [6]. The development of this field can be found in the papers by Lindgren [7–10] and the books by Radaj [11], Lindgren [6] and Goldak and Akhlagi [12]. The book by Lindgren [6] describes different modelling options and strategies as well as validation of models. The phenomena that are relevant in welding can be divided in different fields, shown in Fig. 1. It has been found possible in CWM to decouple the modelling from the physics of the welding process and also ignoring fluid flow and still being able to create models fit for purpose. Thus CWM models are thermo-mechanical models where the weld pool details are replaced by a heat input model, see Fig. 2. This simplifies the simulations considerably at the cost of needing to calibrate the heat input model.

Simulation of MD shares the same problems as for multipass welding but in a much larger scale as there may be thousand of weld passes in MD. The problems can be summarised as:

(1) The precise location of each weld pass is not known due to the large deformation that occurs. A cross-section of the weld may reveal their location at the end of the process but the geometry of the joint and exactly where they are laid are not known.
(2) The practical problem of creating the finite element model. The model must be increased by elements corresponding to the filler material and energy must be input at this location. Accounting for large deformation, as is necessary in this context, increases this problem further.

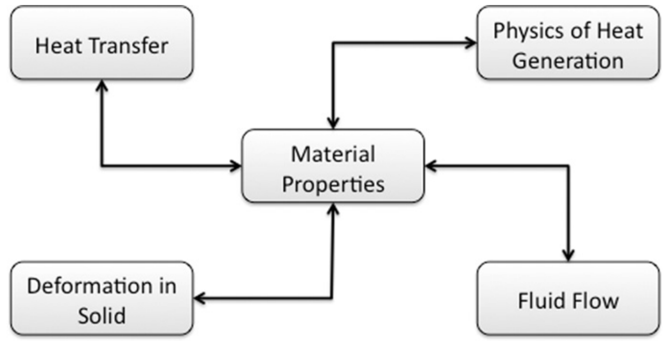

Fig. 1. Fields in CWM modelling together with weld process models, from [6].

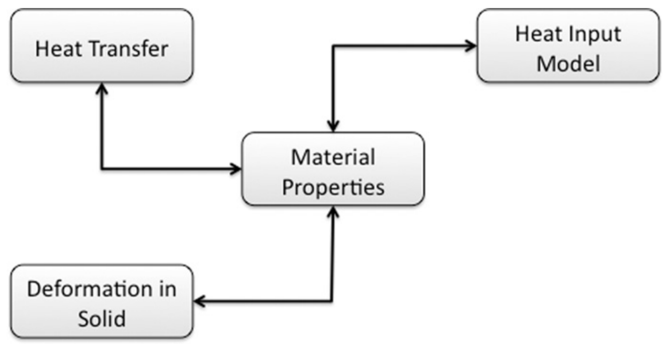

Fig. 2. Fields in classical CWM modelling fusion welding without weld process model and fluid flow model, from [6].

The first multipass welds [13–17] were a few welds and large deformations were ignored. It is not clear how the elements of not laid weld were treated in these first analyses. The first three-dimensional multipass weld simulations were mentioned in [18–22]. Overlay repair and cladding, consisting of several hundred weld passes, has been studied in a simplified manner [23–27].

The techniques for activating elements corresponding to added filler material can be classified into two types, the quiet and inactive approach. The concepts were introduced and compared by Lindgren et al. [28], see also [6,7]. If elements, corresponding to not laid welds, are given fictitious material properties so that they do not affect the rest of the model, then it is called the quiet approach. These elements are given normal material properties when the filler material corresponding to them is added. Thus the elements and their degrees of freedom are part of the system of equations to solve in the finite element procedure. The elements are not a part of this system in the inactive approach. They are brought into the finite element assembly process when they are activated. The quiet approach is simple to implement, it only needs the possibility to switch material properties, whereas the inactive approach requires a reconstruction of the matrix profile and pertaining logic in the finite element code.

The number of experimental studies is far more than the number of numerical simulations of metal deposition presented in the literature. Mughal et al. [29] presented a 2D model for modelling of the TIG layering process together with experiments for validation. They used the quiet element technique and separate thermal and mechanical activation. The shape and position of the deposited material was pre-defined in the modelling step. A 3D model for the laser cladding process, laser in combination with powder, was presented by Toyserkani et al.