Bobbin Tool FSW - A Moving Geometry Model

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Abstract: Based on the example of a bobbin tool Friction Stir Welding process model a technique to model thermal processes with a moving geometry in COMSOL is introduced. The described approach allows to model the transient temperature fields in setups that are governed by a large relative movement of different parts of the geometry. The movement of the tool is realized in a sequence of discrete time steps. Between any two time steps there is an intermediate step in which automatic geometry regeneration, remeshing and mapping is performed. The mapping of the results is done using two temporary meshes. One represents the static part of the model and the other one the dynamic part to be moved. Custom built Matlab scripts are used to control the mapping as well as the geometry and mesh generation.

Keywords: FSW, Moving Geometry

1 Introduction

Friction Stir Welding (FSW) is a solid state welding process able to join alloys considered not weldable by conventional fusion processes. It was invented in 1991 at TWI by Thomas et al. [21]. The solid state process with its low temperatures yields many advantages over conventional fusion welding techniques. It is a robust process with high reproducibility [18, 22], good surface finish [18] requiring no post-weld treatments [22] that results in little distortion [22, 2, 5, 19, 6, 18, 23] with little residual stresses [19]. High ductility welds can be achieved [18]. Excellent mechanical properties [5] including good fatigue properties [9] are reported. The process can join a variety of metals including Al, Pb, Mg, Ti, Cu, Zn, steels [22, 20] especially hard to weld alloys [24, 19, 6] including ODS Aluminum alloys [4]. No filler material is needed [22, 6] and any welding position is possible with no fumes and virtually no noise [6, 22].

Thermal modeling is a central part of modeling FSW. Many of the properties of a weld can be derived directly from the thermal history of the work piece [17]. Every process model in the field of FSW, be it micro-structural, CFD [5, 1, 13, 12, 25, 10] or thermo-mechanical [14, 26, 27, 8, 11], incorporates a thermal model or uses input data generated by one.

Bobbin tools (two shoulder tools, Fig. 1) can weld closed profiles and require less machine stiffness as compared to standard FSW tools. The process forces act between the two tool shoulders. The thermal cycle during the process is crucial for the material properties of the weld. Therefore a consistent thermal process model is a valuable tool for parameter development and optimization. Especially the transient parts of the weld, the beginning and the end, should be accurately captured in such a model. Therefore a fully transient model featuring the complete moving geometry of an actual welding setup has been developed using COMSOL.

Figure 1: Bobbin Tool.

2 Moving Geometry Model

There are three existing ways to model temperature fields in FSW using Comsol. First of all there is a steady state approach in an Eulerian frame [16]. No transient features can be captured and the results always correspond to long welds. The second way is to use a moving prescribed heat source on a fixed Lagrangian mesh [15]. As the pure Lagrangian model is limited to static mesh and therefore static geometry, it is impossible to include the complete tool. The memory and computational cost is also a limiting factor, as the whole welding line has to be meshed sufficiently fine to deal with the large gradients that occur in the close vicinity of the tool. These are temperature gradients, convective heat flux gradients from tool rotation and heat source gradients defined by regular expressions. The most advanced way is to use a moving heat source on a time dependent geometry in discrete steps with intermediate remeshing and mapping, which was first demonstrated by Carbone et. al. [3]. Up to now this has been demonstrated only for a in-plane motion of a unmeshed tool. What has been missing was a moving enmeshed tool. Including the tool in the enmeshed model yields the great benefit of capturing the rotating convective heat flux which is necessary for a correct prediction of the temperature fields asymmetry.

Based on Matlab scripting and COMSOL a Moving Geometry model has been implemented using an ALE style approach. This means that the geometry of the tool is regenerated at the correct position for a number of discrete time steps. The mesh is regenerated with respect to the new geometry and the temperature field is transferred from the last time step using mapping and interpolation to the new mesh. The mesh is only refined in the vicinity of the tool and coarse in the more remote regions of the model, thus saving memory and computational cost.

The movement and mapping behavior can be implemented using Matlab scripting. Comsol offers predefined functions for mesh generation and mapping but they were not designed for a moving geometry model. Therefore there are some serious challenges in developing a consistent model.

As the tool is moving through empty space, temperature field mapping of the last time step results yields problems on the leading and trailing side. The leading side is moved into a region where there was void space with no temperature information in the last time step, but which is the source for the temperature field mapping. A cross-section of the tool in a simple model with plain step to step mapping reveals this (Fig.(2)).

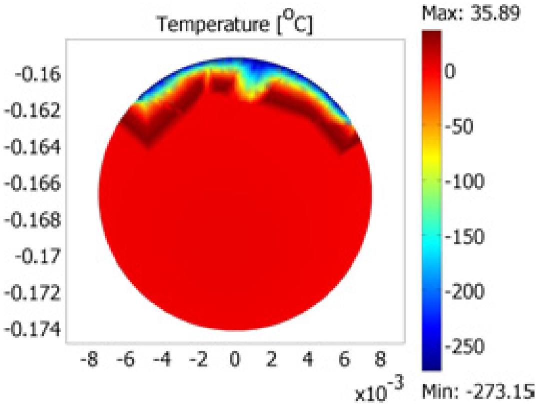

Figure 2: Tool Cross-section - Insufficient Mapping at the Leading Side

The elements at the leading side are assigned a temperature of 0K by the default Comsol interpolation algorithm if they are moved into the void by more than the extrapolation tolerance of the Comsol mapping algorithm. This would correspond to a very large effective convective heat flux out of the leading side of the tool, which is of course not correct. The resulting erroneous thermal field is plotted in Fig.(3).

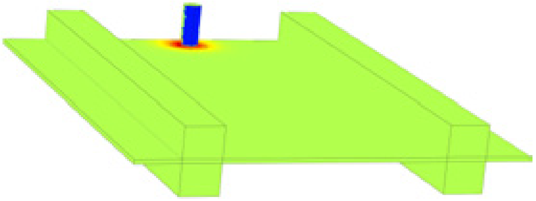

Figure 3: Global Temperature Field - Insufficient Mapping at the Leading Side

In the same way there would be a effective convective heat flux out of the tool on the trailing side, as parts of the thermal field of the tool from the last step get mapped to void and thereby disappear.

These problems must be solved in order to be able to use the moving geometry approach.

The solution used in the present work includes an intermediate mapping step between any two time steps. The latest results are mapped to a model of the tool and a model of the static geometry independently. The model of the tool is then translated to the new position for the next time step by changing the mesh coordinates. Then the model setup for the new time step is generated and the initial values are taken from the two partial intermediate models. This way the mapping can be done without losses due to the nonphysical heat fluxes described above. Additionally the default Comsol interpolation and mapping algorithms are replaced by customized Matlab code. This allows for more control over the extrapolation behavior and robust code dealing with any NaN or 0K mapping values that may result from varying element shape and size in time. A schematic overview over the procedure for an single time step is provided in Fig.(4).

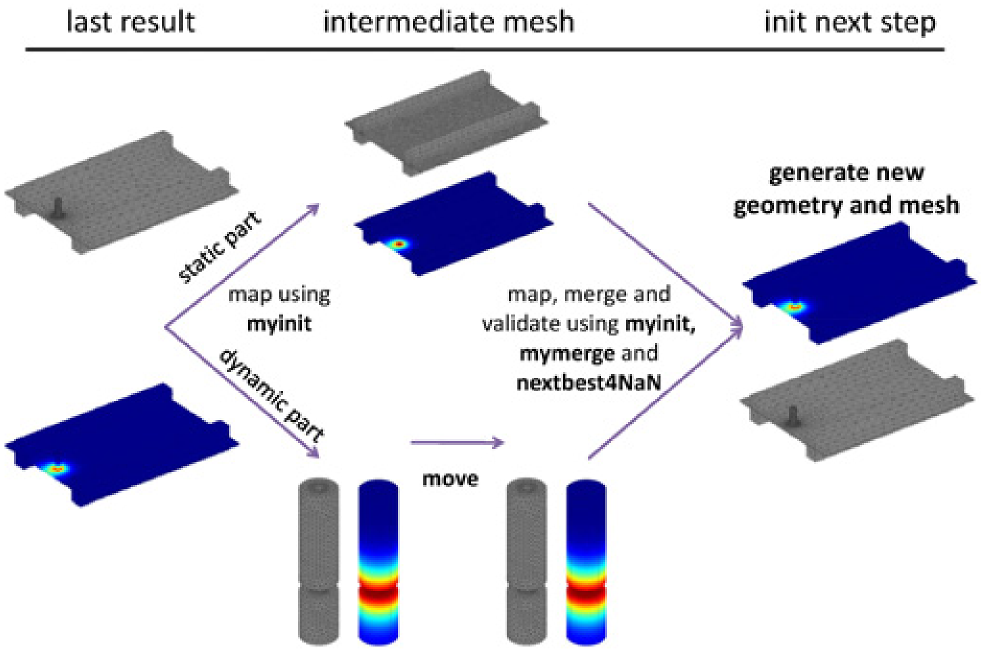

Figure 4: Diagram of a Time Step with Intermediate Mapping

A graphical user interface based on the Java programming language has been developed to interact with Matlab and provide information on the progress of the solution process.

3 Results and Discussion

An exemplary weld has been simulated using a welding speed of $u_{weld} = 800\frac{mm}{min}$ and a tool rotational speed of $\omega = 400RPM$. Five seconds of dwelling are used at the beginning of the weld. The thermal field prediction at a time of 8 seconds is plotted in Fig.(5). The corresponding temperature profile along the weld line in the center of the plates' depth is provided in Fig.(6).

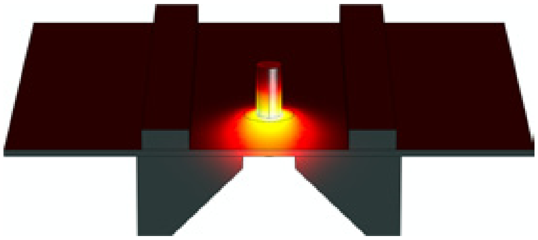

Figure 5: Thermal Field Predicted by Moving Geometry Model

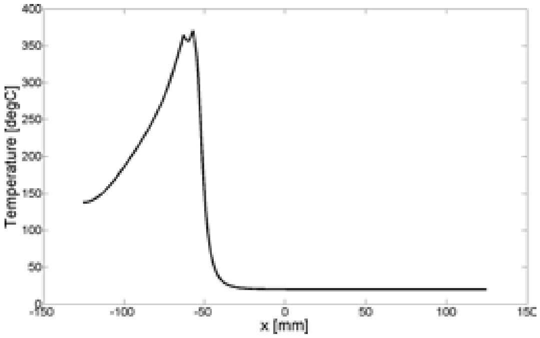

Figure 6: Temperature Profile Along the Weld Line

In order to validate the Moving Geometry approach the predictions are compared to the predictions of an Eulerian steady state model that has been experimentally validated before [7]. Both models describe the same welding setup. The dimensions of the plate is sufficiently large and the welding speed is sufficiently slow to achieve a steady state in the center of the plate. This way it is possible to predict the thermal history of a point with both models and compare the predictions (Fig. 7). The point used for the plot is located half way along the weld line 10mm to the retreating side of the tool.

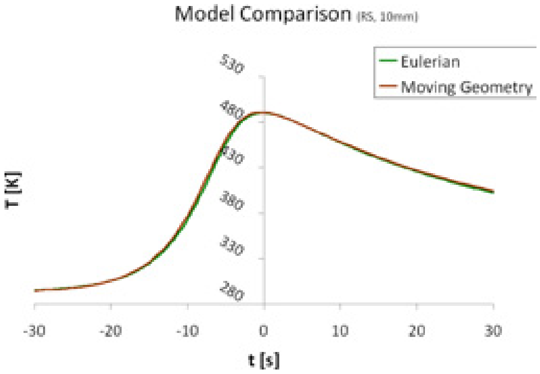

Figure 7: Comparison between Eulerian and Moving Geometry Predictions

It can be stated that the Moving Geometry approach correctly predicts the steady state. It can therefore be assumed that the transient results are correct, too.

4 Conclusion

Valid transient temperature predictions can be obtained from Moving Geometry models implemented in COMSOL using Matlab scripting. When using adequate mapping techniques parts of the enmeshed model can be moved through void space without losing physical integrity of the model.

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