Modelling Solder Joint Formation and Surface Tension-Marangoni Phenomena *

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Abstract

A computational model of solder joint formation and the subsequent cooling behaviour is described. Given the rapid changes in the technology of printed circuit boards, there is a requirement for comprehensive models of solder joint formation which permit detailed analysis of design and optimisation options. Solder joint formation is complex, involving a range of interacting phenomena. This paper describes a model implementation (as part of a more comprehensive framework) to describe the shape formation (conditioned by surface tension), heat transfer, phase change, and the development of elasto-visco-plastic stress. The computational modelling framework is based upon mixed finite element and finite volume procedures, and uses unstructured meshes enabling arbitrarily complex geometries to be analysed. Initial results for both through hole and surface mount geometries are presented.

To facilitate the computational model Marangoni flow with a free and deforming interface has been implemented in the code. The domain may consist of diffrent elements arranged in an unstructured manner in 3D space for steady and unsteady cases. A free surface algorithm with mesh adaption utilising a stress code has also been implemented. The numerical work has been tested against several closed form solutions and free surface shapes have been compared with other numerical predictions. The technique has been used to model the wetting balance in solder using a range of multi-physics capabilities in PHYSICA [1] [2].

1 Introduction

During the Wave and Re-flow soldering processes solder bonds electronic components to circuit boards. Designers of printed circuit boards are continually investigating ways in which to minimise joint defects such as bridging and joint cracking[3]. In the soldering process three distinct phases have been identified, melting and fluxing, flow and shape formation, cooling/solidification and solid deformation[4]. The final geometry of the solder material is determined by the surface tension which is temperature dependent. Temperature and convection effects may alter this final shape slightly. It has been determined that solder joint shapes are largely governed by surface tension just above

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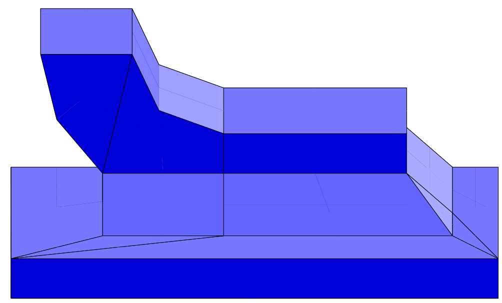

Figure 1: Gull wing initial geometry.

the solidus temperature[5][6]. In principle computational mechanics based software tools can help designers investigate how potential designs (i.e. materials used and volume of solder) affect the final integrity of solder joints.

Modelling to improve our understanding of the soldering process has become an important issue due to the increasing density of solder interconnects on circuit boards. A fully comprehensive computational model needs to address the following interacting physical phenomena,

1. Heating and melting of solder material.
2. Residual convection of the liquid solder.
3. Formation of solder joint geometry.
4. Cooling and solidification of the solder material.
5. Residual stress build up in the joint, lead and board.

The model discussed in this paper is concerned with stages 3 and 4. Previous attempts at predicting solder joint formation have concentrated on predicting the shape that a given volume of solder takes subject to differing surface tensions. Two-dimensional numerical models, based on finite element methods have shown good comparison with experimental data for simple shapes[5]. Three dimensional simulations have been undertaken by a number of researchers using the SURFACE EVOLVER[7] code which calculates complex equilibrium shapes. This code has been used to predict solder joint shapes and defects such as bridging[6].

The vast majority of modelling work on solder joints has concentrated on predicting thermal stress during in-service operation and resulting fatigue analysis [8] [9]. Predicting the flow, solidification and resulting stress profiles during the formation of a solder joint has, until now, been neglected.

In this paper, a framework for a computational model of solder joint formation is described. This is a novel approach in terms of integrating the shape prediction with the subsequent continuum

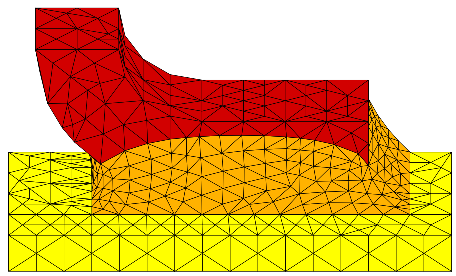

Figure 2: Gull wing solder interface shape prediction.

mechanics of solder cooling. An implementation of a model, with many of the key interacting phenomena using state of the art multi-physics software tools, is presented and some results are shown for through-hole and surface mount geometries. Figure 1 shows the initial pre-processor geometry for a gull wing solder joint. This geometry is used to find the equilibrium shape for the solder interface, figure 2. Multi-physics simulations can then be used to predict such phenomena as visco-plastic strain, figure 3.

To facilitate this implementation Marangoni and surface tension phenomena have been implemented within the code. The wetting balance test for solder is an area in which Marangoni flow has been used to predict a number of discrepancies that have occurred [10]. Laser melted pools in conjunction with Marangoni phenomena have also received attention [11].

Using calculus of variations to find an interface shape(SURFACE EVOLVER) is equivalent to using the Marangoni boundary condition coupled with fluid flow equations and a deforming interface. This has been attempted by solving the flow equations on a fixed mesh and then using the velocity vectors to update the mesh with Finite Elements however this was only for stokes flow. Re-meshing was also used. The coupling for the surface mesh update can either be closely coupled (at the sweep stage) or loosely coupled (at the time-step stage). The loose coupling tends to be more robust but to a lower order of convergence. Closed form solutions exist for selected domains and can be used to test numerical schemes

Generally between two fluids there exists an interface or film which may have a surface tension associated with it. Normal and tangential forces will act on this interface due to the surface tension. A tangential force will be present if the surface tension differs across the interface. This is the force which acts as a boundary condition to induce Marangoni flow. The surface tension differences may be caused by a number of factors including temperature or chemical species. The surface tension γ may be a function of these quantities,

$$\gamma = \gamma(T(\underline{r}), S_i(\underline{r})), \tag{1}$$

where $T(\underline{r})$ is temperature as a function of position, $S_i(\underline{r})$ is a proportion of chemical species which can also be a function of position. A normal force will be present wherever there is surface tension unless the curvature of the surface vanishes.

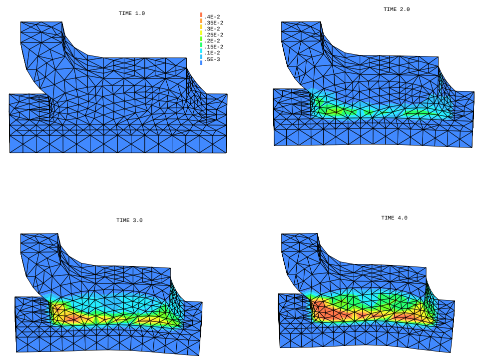

Figure 3: Gull wing visco-plastic strain contours.

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