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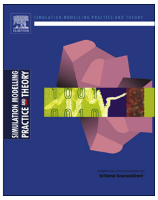

Optimization of pin through hole connector in thermal fluid–structure interaction analysis of wave soldering process using response surface methodology

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ABSTRACT

This paper presents an optimization of pin through hole (PTH) connector in the wave soldering process; the optimization was performed by using response surface methodology. The geometrical and process parameters (i.e., offset position, pin diameter, offset angle, and solder temperature) were optimized by using response surface methodology via central composite design for the wave soldering process. Thermal fluid–structure interaction aspects were considered in the optimization. A mesh-based parallel code-coupling interface was employed to connect both fluid and structural solvers. The interactive relationship between independent variables (i.e., offset position, pin diameter, offset angle, and solder temperature) and the responses (i.e., filling time at 75% volume, von Mises stress, and maximum displacement) were investigated. The generated empirical models were examined and well substantiated by the simulation results. The optimum geometrical and process parameters of the wave soldering process for the PCB and PTH connector were as follows: 0.12 mm of PTH offset position, 0.17 mm of PTH diameter, 0° of offset angle, and 473 K of molten solder temperature.

1. Introduction

Wave soldering is an important process in electronic assembly in which components are soldered onto a printed circuit board (PCB). Pin through hole (PTH) components are soldered onto the PCB when passing through the solder pot. During the process, molten solder fills the PCB hole, which is driven by the capillary effect. The occupied solder material in PCB hole is solidified in the cooling zone and forms the solder joint. Physical design and assembly conditions, such as pin size, PCB hole diameter, pin position, and angle, may influence the flow characteristics of molten solder during wave soldering. A process setting such as solder temperature, conveyor speed, and molten solder fountain may influence the quality of the solder joint. For example, high temperatures could result in overheating of the PCB and the components attached to the PCB, which may result in unintended defects and lower overall reliability. Therefore, optimization of the wave soldering process is important to optimize each independent variable, thereby eliminating defects and maintaining solder joint reliability.

An optimization is a fundamental process that is systematically applied in most engineering applications by using various optimization techniques such as Taguchi method [1,2], response surface methodology (RSM) [3], artificial neural networks

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[4], genetic algorithm [5] and neuro-fuzzy genetic algorithm [6]. Optimization often produces solutions that are better than the conventional solution. In many cases, the conventional method is carried out manually by trial and error method, which is time and cost consuming. Therefore, a systematic technical approach has been introduced to provide a more reliable solution than the conventional solution. Optimization of wave soldering had been experimentally investigated by using Taguchi method [1,2], the neural network approach [4,7], and mixed-level fractional factorial design [8]. In addition, an expert system that uses a self-organizing map [9–11] had been used to diagnose and optimize the process condition in wave soldering. The independent variables that were considered in previous experimental works include atmosphere condition, chip wave, flux type and quantity, board size and thickness, soldering temperature [12], contact time, preheated surface temperature, flux wettability, and PCB properties. However, optimization by using thermal fluid–structure (FSI) simulation analysis has not yet been reported in the wave soldering process. The advantages of using simulation analysis can reduce research cost and time before mass production. It can also provide engineers with a clear visualization of the process such as the physicochemical phenomenon (e.g., flow front advancement, temperature, and stress contour).

In the electronics assembly, several wave-soldering features (e.g., insufficient vertical fill, over heated of the component and solder short of high density PTH) lead to the interconnector/solder joint defects. To eliminate the solder joint defects, the proper control of process setting (e.g., solder temperature, contact time and preheat temperature), physical design of the PTH is significant in the wave soldering process. For example, solder temperature [12] and the PTH diameter [13] crucially influence the vertical fill of the PTH. Besides, PTH offset angle [14] and position [15] induce uneven capillary flow (due to uneven capillary force), which might cause incomplete filing and air traps in the PCB hole. Other factors such as capillary force, surface tension and wetting properties [16] also influence the filling of the vertical fill. In the current study, the thermal-FSI aspects were considered during the wave soldering process. Therefore, the independent variables (i.e., offset position, diameter, offset angle, and solder temperature) were chosen in this study to investigate the interactive relationship of each factor by using RSM. The virtual modeling technique was applied to model the wave soldering process by using fluid (FLUENT) and structural (ABAQUS) solvers [17,18]. Filling time, thermal induced stress, and pin displacement were the responses in RSM optimization during the wave soldering process. The key contribution of the RSM optimization is reducing the number of simulations, which means to reduce the complexity of the design and computing times. Besides, the RSM is adopted to enhance engineering processes and obtain an optimal parameter-setting for design parameters. The key aspect of the RSM application in the electronics assembly is to determine the number of direct problems (FSI-simulations) to be solved in order to achieve a good function approximation. This study and its findings enhance understanding of the interactive relationship between geometry and process parameters in the wave soldering process.

2. Methodology and modeling

2.1. Governing equations and volume of fluid model

Molten solder fills the PCB hole during wave soldering process. Thus, this study focuses on the filling process and the fluid mechanism. The motion of molten solder in the simulation is described by using 3D incompressible transport equations, namely, continuity equation, Navier–Stokes equation, and conservation of energy, and written as [19].

The continuity equation is shown as follows:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \tag{1}$$

where u, v, and w are velocities in the x-, y-, and z-axis, respectively.

The Navier–Stokes equation in the x-direction for incompressible flow is as follows:

$$(x\text{-direction})\quad \rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=-\frac{\partial P}{\partial x}+\eta\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)+\rho g_x \tag{2}$$

where ρ is the density, u is the velocity vector, P is the static pressure, η is the viscosity, and g_x, g_y, and g_z are gravity in the x-, y-, and z-axis, respectively. Similarly, Eq. (2) is applied for the y- and z-directions.

Energy equation is used to express the temperature of molten solder in the filling process

$$\rho c_p\left(\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}\right)=k\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right) \tag{3}$$

At a high temperature, the molten solder has a nearly constant viscosity [20]. Hence, the Newtonian fluid equation is

$$\eta=\frac{\tau}{\dot{\gamma}} \tag{4}$$

where τ is the shear stress, and $\dot{\gamma}$ is the strain rate.

The multiphase volume of fluid model with implicit scheme was applied for flow front tracking during capillary action of molten solder filling. The scheme distributes the liquid phase by assigning a scalar to each cell in the simulation grid. F is the