Wave Soldering Structure Optimization Simulation of Multi-layer Ceramic Capacitors

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Abstract. In this paper, the thermal analysis and structural analysis of MLCC are carried out by using the commercial finite element software ANSYS. By comparing the thermal-mechanical analysis results of the structural optimization models of different schemes, the optimal optimization scheme is found. The model calculated the time required for MLCC to reach temperature stability considering thermal convection and heat conduction, and obtained the thermal deformation and thermal stress distribution of MLCC element. Based on the analysis results of MLCC original model, the thermal analysis under different wave soldering temperatures was carried out. Based on the simulated transient results, the structure and materials of MLCC key components were optimized. The results provide a basis for the optimal design of MLCC.

1. Introduction
MLCC (Multi-Layer Ceramic Ceramic) is one of the most widely used and fastest growing Ceramic Ceramic components in the world. As one of the key components in the circuit application, MLCC’s performance requirements and failure phenomena are an urgent problem to be solved [1]. Thermal analysis is becoming increasingly important for the reliability and safety of MLCC structural design [2]. The process of MLCC wave soldering involves complex temperature fluctuation and contact problems, so it is necessary to study the thermal deformation and thermal stress of MLCC to improve the reliability of MLCC components [3]. Further research and analysis on structural optimization of MLCC, improve the structural design of MLCC, and provide products with excellent performance for market application.

2. Finite Element Model and Thermal Analysis Governing Equation of MLCC

2.1. Finite Element Model.
MLCC’s finite element model adopts a three-dimensional solid model and divides a hexahedral mesh (to ensure the calculation accuracy and speed up the convergence time) [4], as shown in Fig. 1. The thermal
analysis and structural analysis are carried out by the finite element method of thermal-mechanical coupling [5]. The high temperature (245) in MLCC wave soldering process is mainly concentrated on the bottom, and the heat flow rate is defined as the surface load to simulate the current temperature rise. Thermal convection boundary conditions are applied to the remaining surfaces. The top temperature of MLCC is low, and heat transfer is mainly conducted through heat conduction. Internal heat transfer is defined as heat conduction. 20-node hexahedral thermal analysis entity unit SOLDID90 was used for thermal analysis, and then thermal analysis unit SOLID90 was converted to structural analysis unit SOLID95 [6]. Material property of elastic modulus, poisson's ratio and coefficient of thermal expansion were added for structural analysis, and fixed constraints were applied to the bottom surface of the terminal electrode.

![Meshing model](image1)

![Boundary conditions for structural analysis](image2)

**Fig. 1.** M Finite element model of MLCC.

2.2. The Governing Equation of Thermal Analysis.

The field variables of the three-dimensional transient temperature field should satisfy the differential Equation Eq. 1 [7]. The heat balance equation Eq. 1 indicates that the heat required to heat the body is balanced with the heat entering the body and the heat generated inside the body. The solution equation of finite element transient thermal analysis is Eq. 2.

\[
\rho c \frac{\partial T}{\partial t} - \frac{\partial}{\partial x} \left( \kappa_x \frac{\partial T}{\partial x} \right) - \frac{\partial}{\partial y} \left( \kappa_y \frac{\partial T}{\partial y} \right) - \frac{\partial}{\partial z} \left( \kappa_z \frac{\partial T}{\partial z} \right) - \rho Q = 0
\]  

(1)
\[
[C]\{\dot{T}\} + [K_T]\{T\} = \{Q\}
\]  
\(\text{(2)}\)

If the boundary conditions and the heat source density do not change with time, that is, the transient heat balance equation is reduced to the steady-state heat balance equation Eq. 3, and the finite element transient solution equation Eq. 2 is reduced to the steady-state solution equation Eq. 4.

\[
\frac{\partial}{\partial x}\left[\kappa_x \frac{\partial T}{\partial x}\right] - \frac{\partial}{\partial y}\left[\kappa_y \frac{\partial T}{\partial y}\right] - \frac{\partial}{\partial z}\left[\kappa_z \frac{\partial T}{\partial z}\right] + \rho Q = 0
\]  
\(\text{(3)}\)

\[
[K_T]\{T\} = \{Q\}
\]  
\(\text{(4)}\)

2.3. Thermal-Mechanical Analysis Results.
After thermal stabilization (200s), the temperature field distribution and thermal stress-strain distribution of MLCC are shown in Fig. 2.

(a) Temperature distribution

(b) Thermal stress distribution
3. Comparative Analysis of Different Wave Soldering Temperatures.

The temperature range of wave peak welding is 245°C-270°C. In order to analyze the difference of wave peak welding temperature under different conditions, finite element analysis is carried out under the condition of wave peak welding temperature is 260°C. The thermal-mechanical analysis results are shown in Fig. 3, and the comparison results of different wave soldering temperatures are shown in Table 1. It can be seen that the temperature field changes little under the two conditions, while the thermal stress-strain under 260°C is slightly larger than that under 245°C.
FIG 3. Thermal-mechanical analysis results of MLCC at wave soldering temperature 260.

**Table 1.** Comparative analysis results of different wave soldering temperatures

| Wave Soldering Temperature (℃) | Max Temperature (MPa) | Max Stress (MPa) |
|--------------------------------|------------------------|------------------|
| 245                            | 25.28                  | 5.93             |
| 260                            | 25.30                  | 6.37             |
| Differences                    | 0.08%                  | 7.42%            |
4. Structural Optimization Analysis.
Through the analysis and calculation of thermal-mechanical coupling of the original model of MLCC wave soldering, the weak spot of MLCC wave soldering and the weak spot in the assembly, namely the tip corner of the terminal electrode, were found out. Therefore, the structure of the terminal electrode assembly is optimized, and the scheme design is shown in Table 2.

| Model design | Inner layer thickness | Middle layer thickness | Outer layer thickness |
|--------------|-----------------------|------------------------|----------------------|
| Model 1      | Double                | Unchanged              | Unchanged            |
| Model 2      | Unchanged             | Double                 | Unchanged            |
| Model 3      | Unchanged             | Unchanged              | Double               |

Structure optimization model of thermal-mechanical analysis results as shown in Fig. 4 to 6, and compared with the original structure model of the results as shown in Table 3. Visible, Model 1 greatly enhances the weak spot of the structure, followed by Model 3. However, Model 2 has little impact. Therefore, the structure optimization design of Model 1 and Model 3 has certain reference significance.

(a) Temperature distribution
(b) Thermal stress distribution
Fig 4. Structural optimization analysis results of Model 1

(a) Temperature distribution

(b) Thermal stress distribution

(c) Thermal strain distribution
Fig 5. Structural optimization analysis results of Model 2

(c) Thermal strain distribution

(a) Temperature distribution

(b) Thermal stress distribution
5. Summary

In this paper, ANSYS finite element software is used to analyze and calculate the reliability of thermal-mechanical coupling for MLCC. The simulation analysis assumes that all contact surfaces are closely connected and ignores the thermal resistance of contact surfaces. The results show that the stress is mainly concentrated at the tip angle of the terminal electrode, and the deformation is also the same. Therefore, the terminal electrode assembly can be identified as the weak part of the model. Then, the process improvement and structural optimization design is targeted, and three optimization schemes are designed. Through the finite element analysis and research on the structural optimization model, it is found that Model 1 is the best structural optimization design scheme, which provides strong support for the structural design of MLCC.

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