Research on solder joint stress damage evaluation method based on discrete SSI model

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Abstract. Based on the discrete SSI(Stress-strength-interference) model, this paper establishes a stress damage evaluation method for the through-hole insertion process. First, based on the Monte Carlo sampling method, the mean value of solder joint stress was clarified, and a stress-strength interference model for through-hole insertion was established. Secondly, after calculating the shape of the solder joints of the through-holes, the simulated load input curve is determined and the stress simulation is performed to obtain the stress and strain simulation results. The stress and strain of the PCB board are measured through experiments. Finally, a random stress model of solder joints was established by Monte Carlo sampling, and a constant strength model of through-hole solder joints was established in combination with material strength. According to the stress strength interference model, the failure probability of process stress damage was calculated, and the stress damage evaluation of solder joints in through-hole insertion process was realized.

1. Introduction

With the rapid development of the electronics manufacturing industry, and the requirements of miniaturization, light weight, and increasing integration of weapons and equipment, the demand for through-hole insertion technology is increasing. The through-hole insertion process is currently the most commonly used component assembly process on the market, and the impact of stress damage introduced during the process on the life and reliability of electronic components can not be ignored, so research on impacts of the electronic component assembly process itself on devices, PCB boards, solder joints, etc. is necessary. [1]Due to the existence of temperature stress in the welding process, certain residual stress may be introduced in the components, solder joints and PCB, causing potential defects such as warpage of the board and micro cracks in the solder joints, leading to cracks in the process of later use. Adversely affect the reliability of the entire product. The failure analysis of the device shows that 70% of the failure of the through-hole device is caused by the failure of the solder joint. Therefore, in order to achieve the high reliability requirements of the through-hole insertion process, it is necessary to characterize and evaluate the stress damage caused by the through-hole insertion process by establishing a stress-damage model of the through-hole insertion joint, providing a basis for the improvement of through-hole insertion process and the evaluation of component process stress damage. Specifically, based on the measurement results of the stress damage of the through-hole insertion, the quantitative characteristics of the process conditions, process deviations, and process defects are obtained. Then establish a stress damage model for manufacturing through-hole plug-in solder joints, and evaluate the process of stress damage research.
At present, the stress-strength interference model has been widely used in the reliability analysis of various structures. The research on stress-strength interference model has also achieved many results. If analyzed from a mathematical point of view, these results are mainly divided into two aspects: on the one hand, strength and stress are used as random variables; on the other hand, strength and stress are used as random processes. When the stress and strength in the model are time-independent random variables or fuzzy variables, they are called static SSI models. The research on static models mainly focuses on how to solve the problem of calculating or estimating the probability value in the model under different conditions.\cite{2}

Based on the mature stress-strength interference model, this paper mainly considers factors such as process deviation, process defects, and process conditions in the manufacturing process. Using strength and stress as random variables, the material parameters, structural dimensions, and process deviations of electronic components are analyzed to establish random distributions of strength and stress respectively. Further evaluate the failure probability of electronic components, characterize the stress damage of the electronic component process, and then analyze the impact of important processes in the electronic component manufacturing process to improve the reliability of the electronic component manufacturing process.

2. Establishing the overall process of stress damage assessment for through-hole insertion process

![Figure 1. Research Flowchart of Stress Damage Evaluation Method for Through Hole Insertion Process](image-url)
The rapid development of microelectronics technology has brought higher and higher requirements for high-density electronic packaging. The reliability of electronic packaging has become an important part of component reliability. Solder joints are necessary mechanical connections to maintain the smooth flow of electrical signals in electronic components. Solder joints, PCB boards, and components are important basic components of electronic components, and together they have an impact on the service life of electronic components. Because the failure of a single solder joint will cause the failure of the component or even the entire electronic system, the reliability of the solder joint is the key to the reliability of the electronic package and even the component. In order to ensure the quality and reliability of electronic products, the evaluation of the stress damage caused by the through-hole insertion process should be specifically implemented to accurately identify the failure mode and failure mechanism of the solder joint. And characterize the stress damage at the solder joint, that is, establish the stress strength interference model of the solder joint. This can quantify the reliability of solder joints under various process modes, and provide a theoretical basis and data support for further research.

Most of the failures of electronic components are caused by process defects in packaging and assembly. The largest proportion of these process defects is the failure of solder joints. For example, the amount of solder paste is too large or too small, the uneven application of pressure causes the solder paste to be inconsistent in height, and the solder paste is wet. Solder joint failure is partly due to welding defects during the process, and partly due to fatigue damage during work.

In order to study the stress damage at the solder joint, the residual stress at the solder joint needs to be measured before the next step of establishing the stress interference model. However, the volume of the solder joint is small and not planar, and the residual stress on the solder joint is extremely difficult to measure. Through simulation analysis and literature investigation, it can be known that the residual stresses of the solder joints are concentrated at the edges in contact with the PCB board, that is, the maximum stress of the solder joints should be approximately parallel to the plane of the PCB board. Therefore, the stress distribution of the solder joints and the surface of the PCB is obtained by performing stress simulation on the solder joints of the through-hole insertion process. Due to the mutual nature of the force, a strain gauge electrical measurement method can be used. That is, after the ±45° strain gauge is pasted on the surface of the PCB board, the change in the strain gauge is measured after the PCB board undergoes a temperature change during the welding process, so that the average stress of the PCB board is measured. Correct the simulation model by referring to the actual stress value obtained from the test. After the model is modified, the corresponding stress average value at the solder joint can be obtained in the ANSYS software. The variance of the PCB board stress can also be obtained through multiple measurements, and this data is used as the stress variance at the solder joint to provide a data basis for the subsequent stress strength interference model.

3. Study on stress-strength interference model of solder joints
3.1. Study on solder joint strength model
The connection of the soldering interface of the electronic component is based on the wetting effect of the solder on the two base metal surfaces. Solder is a connecting material, which is fixed on the metal surface of the base body, thus providing metal continuity. In addition, the solder is also used for the two wetted surfaces connected by the bridge to form the connection between the two base metals. The performance of the solder at this time determines the performance of the entire solder joint. The connection interface is formed by retouching during welding. The lower melting point solder is a good filler metal, which can conduct electricity and heat, and has all metal properties such as ductility and gloss.

The ductility of SnPb solder and the annealing ability of most alloys in the solder at room temperature or near room temperature allows the component to release a large amount of stress in the solder joint when subjected to vibration and heat, thereby avoiding damage to components. If this stress is not released and is transferred to the lower strength components (such as metal-ceramic bonding surface, etc.), it will cause the connection to crack.
When discussing the physical properties of SnPb solder, the mechanical strength requirements of solder joints need to be considered. The strength of a welded joint depends primarily on the design of the material and geometry. In many cases, the strength of the metal interface is usually much higher than the strength of the filler. In this case, the weakest link is the filler itself. The strength of the assembly is a function of the critical area involved under both tensile and shear forces. If the weakest link is known, the joint strength $S_b$ of the assembly can be expressed as:

$$S_b = \sigma_b A_b$$

in which, $S_b$ is the joint strength of the assembly; $A_b$ is the critical area of the base metal; $\sigma_b$ is the yield strength (tensile stress or shear stress) of the base metal.

The strength of the filler metal itself can be expressed in the same way as:

$$S_s = \sigma_s A_s = S_j$$

in which, $S_s$ is the solder strength; $A_s$ is the critical area of the solder; $\sigma_s$ is the yield strength (tensile or shear stress) of the solder; $S_j$ is the strength of the welded joint, that is, the strength of the solder joint.

For wave solder joints here, we think that $A_s$ is the area of the interface between the solder joint and the pad, which can be considered as the pad area:

$$A_s = x \cdot L_{pad}$$

where $x$ is the pad width and $L_{pad}$ is the pad length.

1) Calculation of pad width

The pad width $x$ can be determined according to the component width $W$ and the position accuracy $\delta$:

$$x = W + \delta$$

in which, $x$ is the pad width, $W$ is the component width, and $\delta$ is the component position accuracy. The position accuracy of the component can be obtained according to the dimensional accuracy $\Delta W$ of the width $W$ of the component itself and the placement accuracy $\delta_1$ of the placement machine. The width $x$ of the pad when the component is mounted is determined by the end electrode of the chip component not exceeding the pad. To determine the pad width $x$, the dimensional deviation in the component width $W$ direction must be taken into consideration, that is, the width $W$ dimension accuracy $\Delta W$ and the component placement accuracy $\delta_1$ when the component is actually mounted. Calculate the root mean square value of the statistical data of $\pm 3\sigma$ ($\sigma$ is the standard deviation), that is,

$$\delta = \left(\delta_1^2 + (\Delta W)^2\right)^{1/2}$$

in which, $\delta$ is the component position accuracy, $\delta_1$ is the chip accuracy, and $\Delta W$ is the dimensional accuracy of the chip component width $W$.

2) Calculation of pad length

The pad sizes $L_s$ and $L_k$ can be determined according to the reliability requirements of the joint. For example, in order to ensure the reliability of the joint, the amount of solder at the joint should be kept at more than $1/2$ of the height of the chip stone component. This can form a good welding meniscus on the inside. $1/2$, the formation of the meniscus inside the component is determined by the pad size, as shown in Figure 2.\[3\]
During soldering, assuming that the contact angle between the solder and the pad is 45°, and the floating amount of the pad size is $t = 0.1\, \text{mm}$, the pad sizes $L_s$ and $L_L$ can be obtained by the following formula:

$$L_L = L + S_1 \times 2 + \delta$$ \hspace{1cm} (6)

in which, $L$ is the component length, $S_1 \approx H/2 + t$, and $\delta$ is the component position accuracy.

$$L_s = L - T \times 2 - S_2 \times 2 - \delta$$ \hspace{1cm} (7)

in which, $T$ is the electrode width, $S_1 \approx 0.1\, \text{mm}$ (the floating amount $t$ of the component), and $\delta$ is the component position accuracy.

The position accuracy of the components can be determined by the component dimensional accuracy and the placement accuracy of the placement machine.

Then the pad length $L_{pad}$ can be calculated by the following formula:

$$L_{pad} = \frac{L_L - L_s}{2}$$ \hspace{1cm} (8)

The expression for the pad area $A_s$ can be obtained from the above formula is as follows:

$$A_s = x \cdot L_{pad} = (W + \delta) \times \left(\frac{H}{2} + t + \delta + T + S_2\right)$$ \hspace{1cm} (9)

The expression of solder joint strength $S_j$ is:

$$S_j = S_S = \sigma_s A_s = \sigma_s \times (W + \delta) \times \left(\frac{H}{2} + t + \delta + T + S_2\right)$$ \hspace{1cm} (10)

in which, $\sigma_s$ is the material characteristic, $W$, $H$, and $T$ are the structural dimensions, and $t$, $\delta$, and $S_2$ are the process deviations.

3.2. Determination of mean value of solder joint stress based on Monte Carlo sampling

The mean value of solder joint stress based on Monte Carlo sampling refers to the determination of material characteristics, structural dimensions, process deviations and other parameters of electronic components in a typical manufacturing process in combination with the stress damage measurement results of the entire process of electronic component manufacturing. Then, the finite element analysis
(FEA) simulation method is used to establish a simulation model of the electronic component considering the entire manufacturing process, and the stress, strain and static strength results of the electronic component are analyzed. Based on the process deviation of the entire manufacturing process, Monte Carlo (MC) method is used to obtain the stress simulation data of electronic components. Based on the stress simulation data of electronic components, the probability density function of the mean value of solder joint stress is fitted.

Under actual conditions of use, factors such as process parameters and stresses of the interconnect solder joints fluctuate randomly. Therefore, the influence of parameter randomness should be considered to determine the failure probability of the solder joint. The randomness here includes two aspects: ① the randomness of the interconnect solder joint design and process parameters; ② the randomness of the external stress applied value and time. The research on randomness is divided into three aspects: ① the method of determining and describing randomness; ② the impact of randomness on the failure rate prediction based on the failure physical model; ③ the failure rate calculation method considering randomness.

The basis of the Monte Carlo method is to use a computer to generate a sample of random numbers for a specified distribution. Some methods have been developed statistically to solve this problem. Generally speaking, it is easier to generate samples from uniformly distributed U (0,1), and a series of pseudo-random numbers can be generated by a linear congruence generator. Various statistical indicators of these sequences and the theory of uniformly distributed U (0,1) The calculation results are very close. Such pseudo-random sequences have better statistical properties and can be used as real random numbers. Commonly distributed random numbers can be generated based on uniformly distributed samples.

The basic idea of Monte Carlo method is:
1) Establish a simple probabilistic statistical model for the actual problem, and make the solution of the problem the probability distribution or numerical characteristics of the model, such as the probability of an event or the expected value of a random variable.
2) Establish a sampling method for random variables in the model, and conduct simulation experiments on a computer to obtain sufficient random sampling and statistics on related events.
3) Analyze the test results, and give an estimate of the solution and its accuracy (variance).

Usually, the Monte Carlo method uses the sample average value $\bar{x}_N = \frac{1}{n} \sum_{n=1}^{N} x_n$ of the samples $x_1, x_2, \ldots, x_n$ of $n$ random variables $X$ as the approximate value of the required solution value $I$. Knowing from the law of large numbers, when $E(X) = 1$ is the sample mean $\bar{x}_N$ converges to $I$ with a probability of 1. According to the central limit theorem, for $\forall \lambda > 0$, $P \left( |\bar{x} - 1| < \frac{\lambda}{N} \right) \approx \frac{2}{\sqrt{2\pi}} \int_{0}^{\lambda} e^{-\frac{1}{2}t^2} dt = 1 - \alpha$ indicates that $\left( |\bar{x} - 1| < \frac{\lambda}{\sqrt{N}} \right)$ is approximately true with probability $1 - \alpha$. Usually when $\alpha$ is small, it is called $\alpha$ significant level. $1 - \alpha$ is the confidence level. $\lambda$ is called the standard deviation of $X$. The above shows that $\bar{x}_N$ converges to $I$ at a rate of order $O \left( \frac{1}{N^{1/2}} \right)$.

If $\alpha \neq 0$, the deviation of the Monte Carlo method is:
$$\varepsilon = \frac{\lambda}{\sqrt{N}} \sigma$$

The normal deviation $\lambda_\alpha$ in the above formula corresponds to the significance level $\alpha$.
The characteristics of Monte Carlo are:
1. The Monte Carlo method and program structure are simple.
2. The probability of convergence and the speed of convergence are independent of the dimension of the problem.
3. Strong adaptability.
When using the Monte Carlo method to simulate the problem process, it is necessary to produce random numbers subject to various probability distributions. In reality, a truly random number sequence cannot be obtained, and it is usually replaced by a pseudo-random number sequence that is calculated by a computer using a certain algorithm and is approximately random. In general, in the Monte Carlo method, various random numbers with different distributions are obtained on the basis of the most basic 0 ~ 1 uniformly distributed U (0, 1) random numbers. Commonly used methods for generating non-uniform random numbers are:

1) Inverse change method—when the probability density function f(x) of the variable can be integrated into the distribution function F(x) or when F(x) is an empirical distribution, and F(x) is easy to find the inverse function , inverse transformation method is used to obtain random variables. The inverse transform method can be used to generate random samples of exponential, uniform, Weibull, triangular, and empirical distributions. It is also the basic principle of many discrete distribution samples. The general steps of the inverse transform method are:
   a) Calculate the distribution function F(x) by the probability density function f(x) of the random variable;
   b) Let F(x) = R and x be within its range;
   c) Solve the equation F(x) = R and obtain x = F^{-1}(R)
   d) Generate uniform random sequences R1, R2, R3, ..., Rn, in the range of (0,1) and bring these random sequences into the function x = F^{-1}(R) to obtain the random sequence of the random variables x1, x2, ..., xn.

2) Compound sampling method—The compound sampling method was proposed by Marsaglia in 1961. The core idea is: the probability distribution function F(x) to be extracted can be represented by a linear combination of several other distribution functions F1(x), F2(x) ... Moreover, when the F(x) -compliant random number cannot be directly generated, or if the random number obeying F1(x) is easier to obtain than the random number obeying F(x), you can choose to construct the obedience F(x) random number.

Suppose that for all x, the distribution function F(x) of the random variable ε can be written as F(x) = \sum_i p_iF_i(x). If the probability density function f(x) of the random variable ε can be written as f(x) = \sum_i p_i f_i(x), where p_i \geq 0, \sum_i p_i = 1 and each F_i(x) are distribution functions. The above formula is to meet the sampling formula sampling steps are as follows:
   a) Generate a positive random integer I, such that P{I = i} = p, i = 1,2,...;
   b) Generate a random number X with a distribution function of F_i(x).

Repeat a) and b) to generate a random number sequence with distribution function F(x).

Therefore, in this paper, the Monte Carlo sampling method is used to establish a random stress model of solder joints.

The specific method of establishing the random stress model of the solder joint is as follows:

1) Determine the random stress distribution type of the solder joint. According to the central limit theorem, if the magnitude of a parameter is the result of multiple small independent random factors, then it can be considered that this parameter follows a normal distribution. According to this principle, the stress generated by the solder joint formed after the assembly process should follow a normal distribution. After determining the distribution type, calculate the mean (μ) and variance (σ^2) of a set of values as the distribution parameters.

2) Generate random numbers that conform to the stress distribution of solder joints, count and draw frequency histograms. First, use the ‘normrnd’ function in Matlab to generate a random number that follows the normal distribution obtained in the previous step to expand the test data of the stress of the solder joint. Second, determine a statistical interval number M, use the hist function in Matlab to count the number n of random normal data falling in each interval, and calculate the central value x_{out} of each interval. Finally, use the bar function in Matlab to draw the frequency histogram and frequency histogram after sampling.
(3) Fit the distribution curve of solder joint stress and calculate the distribution parameters after sampling. Use the frequency histogram obtained in the previous step to fit the normal curve, and use the fitting toolbox in Matlab to calculate the mean and variance of the fitted normal distribution. The normal distribution curve obtained after fitting is used as the random stress model of the solder joints of electronic components.

The probability density function \( f(x) \) of the obtained solder joint stress is as follows:

\[
 f(x) = \frac{1}{\sqrt{2\pi\sigma}} \exp\left(\frac{(x - \mu)^2}{2\sigma^2}\right)
\]

where \( x \) is the stress of the solder joint, \( \mu \) is the mean value of the stress of the solder joint, and \( \sigma^2 \) is the variance of the stress of the solder joint. \(^{[4]}\)

3.3. Stress-strength interference model of electronic component solder joints

The stress strength interference model (SSI model) is a commonly used model to evaluate the reliability of electronic products under stress damage. This model is an important type of failure model in product failure analysis. It indicates that the failure of the product is caused by the stress exceeding the withstand strength of the product. It is generally assumed that both strength and stress are random variables that follow a certain distribution. When the distribution functions of strength and stress are independent of time, it is called static SSI model. But in fact, due to the effects of fatigue, erosion, aging and other factors, the resistance strength of many products will gradually degrade under the effect of stress with the increase of use time. Therefore, the stress-strength interference failure model considering the strength degradation under stress is more in line with the changing law of materials. This type of SSI model can be called a dynamic SSI model.

The stress-strength interference model is a commonly used reliability evaluation model in reliability engineering, that is, according to the probability theory method. Under the condition that the probability density function of stress and strength is known, the failure probability and reliability of the product are calculated. The advantage of the stress-strength interference model is that it is simple and easy to use, but it needs to satisfy the assumption that stress and strength are distributed independently, otherwise it cannot be applied. \(^{[5]}\)\(^{[6]}\)

The application of the stress-strength interference model is not limited to calculating the reliability of mechanical structures based on stress and strength distribution. In a broad sense, "stress" refers to any applied load that may cause failure, including stress, torque, torque, pressure, temperature, shock, vibration, stress strength, strain, and deformation; "strength" refers to the component or system subjected to the applied Load capacity, including yield stress, ultimate stress, yield moment, dumping moment, buckling load and allowable deformation, etc. Therefore, some scholars refer to the stress-strength interference model as a load-strength interference model, and can be used in conjunction with various failure modes, such as yield, buckling, fracture, and fatigue.

According to the theory of stress-strength interference, if the stress experienced by a component or system exceeds its own strength, it is considered that a failure has occurred. If the load and strength of the system or component are constant values, and the strength is greater than the load value, no failure will occur, as shown in Figure 3 (a). However, according to the actual situation, the strength of the system or component is usually distributed according to probability. Similarly, the load on the system or component is usually not a constant, but obeys a certain distribution, as shown in Figure 3 (b). When the lowest level of the system or component's own strength is greater than the highest level of the load, no failure will occur at this time. However, as the time of stress application continues to increase, the material may degrade and cause the strength of the system or component to weaken. When the probability distribution function of strength and load overlap, that is, when the load is greater than the strength, it will cause the failure of the product. The failure probability is the probability that the load is greater than the strength. Reliability is the probability of failure. Therefore, the functional expressions of reliability \( R \) and failure probability \( F \) are respectively
where $\sigma$ represents a certain point of stress $X$, and $\delta$ represents a certain point of strength $Y$. That is, when both stress and strength are subject to some random distribution of variables. Suppose the probability density function of stress $X$ is $f(\sigma)$, when the value is taken at $\sigma$ point, $X = f(\sigma)$; the probability density function of strength $Y$ is $g(\delta)$, when the value is taken at $\delta$ point, $Y = g(\delta)$.\(^7\)\(^8\)

According to the above, the reliability can also be calculated using the probabilistic method, that is:

$$R = P(\sigma < \delta) = P[(\delta - \sigma) > 0]$$

$$F = P(\sigma > \delta) = P[(\delta - \sigma) < 0]$$

$$R + F = 1$$

$$(13) \quad (14) \quad (15)$$

In this paper, the stress-strength interference theory in a broad sense is used to establish a random stress-constant strength interference model for solder joints. Calculate the inherent reliability of solder joints formed by the assembly process, and realize the stress damage characterization of electronic components based on the SSI model. The schematic diagram of the random stress-constant strength interference model of the solder joint is shown in Figure 4.
According to the basic expression of the stress strength interference model, the stress strength interference model of the assembly joint can be specifically expressed as

\[ R = \int_{-\infty}^{S_j} f(x) \, dx \]  \hspace{1cm} (17)

4. Stress damage evaluation of through-hole solder joints based on SSI model

Based on the SSI model, the stress damage assessment process of the through-hole insertion process of electronic components is shown in Figure 5.

**Figure 5.** Evaluation process of stress damage of electronic components based on SSI model
(1) Combine the post-weld strength of the solder joint to establish a constant strength model of the solder joint, which is

\[ S_j = \sigma_s \times (W + \delta) \times \left(\frac{H}{2} + t + \delta + T + S_2\right) \]  \hspace{1cm} (18)

Among them, \( \sigma_s \) is the material characteristic, \( W, H, T \) is the structure size, \( t, \delta, S_2 \) is the process deviation.

(2) According to the simulation results and actual measurement parameters, determine the stress distribution type and value of the distribution parameters of the solder joint. Use Monte Carlo sampling to generate random numbers for load parameter distribution and count the distribution of random numbers. Draw a frequency histogram and fit the distribution curve to establish a random stress model of the solder joint.

(3) According to the stress-strength interference model theory, the stress-strength interference model of solder joints as shown in Fig. 4 is established. The curve represents the probability density function of the random stress distribution of the solder joint, and the straight line represents the constant strength model of the solder joint. According to the stress-strength interference model, the reliability and failure probability of solder joints are calculated, so as to characterize the stress damage of electronic components.

Combining the strength model of solder joints and the random stress model of solder joints based on Monte Carlo sampling, the reliability model of process stress damage based on the stress-strength interference model is as follows:

\[ P = 1 - R = 1 - \int_{-\infty}^{S_j} f(x) dx = 1 - \int_{-\infty}^{\sigma_s (W + \delta) \left(\frac{H}{2} + t + \delta + T + S_2\right)} \frac{1}{\sqrt{2\pi\sigma}} \exp \left(-\frac{(x - \mu)^2}{2\sigma^2}\right) dx \]  \hspace{1cm} (19)

in which, \( P \) is the failure probability of process stress damage, \( S_j \) is the strength of the solder joint, \( \mu \) is the mean value of the solder joint stress, \( \sigma_z \) is the variance of the solder joint stress, and the material characteristic parameter \( \sigma_s \) is the solder yield strength. The structural dimension parameter \( W \) is the width of the component, \( H \) is the height of the device, and \( T \) is the width of the device electrode. The process deviation parameter \( t \) is the pad size floating amount, \( \delta \) is the component position accuracy, and \( S_2 \) is the device size floating amount.

First, according to the measured value of the strain gauge electrical measurement method, the probability distribution curve of the stress at the solder joint is fitted by the Monte Carlo sampling method. In this way, a stress strength interference model for characterizing the reliability of solder joints is established. The specific steps of using Monte Carlo sampling to establish the stress strength interference model are:

(1) Determine the random stress distribution type of the solder joint. According to the central limit theorem, if the magnitude of a parameter is the result of multiple small independent random factors, then it can be considered that this parameter follows a normal distribution. According to this principle, the stress generated by the solder joint formed after the assembly process should follow a normal distribution. After determining the distribution type, calculate the mean (\( \mu \)) and variance (\( \sigma^2 \)) of a set of values as the distribution parameters.

(2) Generate random numbers that conform to the stress distribution of solder joints, count and draw frequency histograms. First, use the normrnd function in Matlab to generate a random number that follows the normal distribution obtained in the previous step to expand the test data of the stress of the solder joint. Second, determine a statistical interval number \( M \), use the hist function in Matlab to count the number \( n \) of random normal data falling in each interval, and calculate the central value \( x_{out} \) of each interval. Finally, use the bar function in Matlab to draw the frequency histogram after sampling.
(3) Fit the distribution curve of solder joint stress and calculate the distribution parameters after sampling. Use the frequency histogram obtained in the previous step to fit the normal curve, and use the fitting toolbox in Matlab to calculate the mean and variance of the fitted normal distribution. The normal distribution curve obtained after fitting is used as the random stress model of the solder joints of electronic components.

Secondly, the upper and lower limits of the solder joint failure stress specified in the standard can be directly selected as the fault criterion of the solder joint; if there is no upper and lower limits that can be directly referred to, ±2σ or ±3σ can also be selected as the fault criterion.

Finally, the stress-strength interference model at the solder joint is established according to the stress-strength interference model theory, so as to more accurately characterize the reliability of the solder joint, and provide a reference and theoretical basis for characterizing the stress damage of electronic components.

4.1. PCB board surface stress measurement

The strain gauge electrical measurement method is used to measure the surface stress of the PCB board. That is, after the ±45° strain gauge is pasted on the surface of the PCB board, the PCB board undergoes a temperature change during the soldering process to measure the voltage change of the strain gauge. The stress on the surface of the PCB is obtained through the conversion of voltage-stress formula. The temperature curve of the wave soldering process is obtained through the investigation results as shown in Figure 6. Put the soldered PCB board into the incubator, and take out the PCB board after a wave soldering temperature change process. The surface stress of the PCB board is measured by the strain gauge electrical measurement method. The mounting method of the strain gauge is shown in Figure 7. Repeat the test five times and record the data. The data record is shown in the Table1.

![Wave soldering temperature curve](image_url)

**Figure 6.** Wave soldering temperature curve
4.2. Evaluation of stress damage of through-hole solder joint welding process

The stress distribution data of the surface of the PCB board obtained by each test. The residual stress on the surface of the PCB corresponding to the five tests is calculated, and the results obtained from the five times are averaged. Adjust the simulation model according to the average stress result, and finally adjust the stress at the solder joint obtained with reference to the average stress of the PCB board. The stress at the solder joint is taken as the mean of the SSI model, and the variance of the five-time PCB board stress is taken as the variance of the SSI model. The stress at the corresponding solder joint is shown in Figure 8. The mesh quality is shown in Figure 9.

Table 1. Test record

| Measure times | \( \Delta U_{-45^\circ} \) (mV) | \( \Delta U_0 \) (mV) | \( \Delta U_{45^\circ} \) (mV) | Maximum principal stress \( \sigma_1 \) (MPa) |
|---------------|------------------|----------------|----------------|----------------|
| 1             | 3.3              | 6.0            | 6.3            | 19.607         |
| 2             | 3.6              | 5.5            | 6.7            | 20.458         |
| 3             | 3.8              | 5.4            | 5.9            | 18.000         |
| 4             | 3.2              | 6.3            | 6.5            | 20.378         |
| 5             | 3.9              | 5.6            | 6.2            | 19.904         |

Mean (\( \mu \)) | 3.56 | 5.76 | 6.32 | 19.67214

Variance (\( \sigma \)) | - | - | - | 0.994309

Figure 7. Strain gauge paste method

Figure 8. Stress distribution at the solder joint
From the figure, the stress at the solder joint is 55.70 MPa. Through the mean and variance of solder joints, the probability density distribution function is obtained. Then use MATLAB to sample the data obtained from the experiment by Monte Carlo to get 4000 times of data. Draw the frequency histogram and draw the fitted normal curve to obtain the stress strength interference model graph. Calculate the probability of failure according to the formula 19.

Among them, $\sigma_s$ is the yield strength of Sn63Pb37, taking 21.3MPa, $W$ is device width, $H$ is device height, $T$ is device electrode width, $t$ is the floating amount of pad size, taking 0.1mm. $S_2$ is the floating amount of device size, taking 0.1mm. $\delta$ is the placement accuracy of the patch, calculated according to the above formula. ($\delta_1$ is the placement accuracy, taking 0.4mm, $\Delta W$ is the dimensional accuracy of the chip component width $W$, taking 0.4mm)
Figure 11. Stress strength interference model

The curve represents the random stress model of the stress at the wave solder joint. The straight line represents the constant-strength model of the stress at the solder joint. The upper limit of the strength is the mean stress plus twice the variance. According to the stress-strength interference model, the reliability and failure probability of solder joints under different residual stresses are calculated, so as to characterize the stress damage of the electronic component process. Finally, the failure probability of the plug solder joint is 0.022986951, and the data record of the calculation result is shown in Table 2.

Table 2. Result of stress strength interference model of cartridge solder

| Through hole SSI Model parameters |       |
|----------------------------------|-------|
| Mean                             | 55.69585122 |
| Variance                         | 0.995726129 |
| Failure probability              | 0.022986951 |
| Reliability                      | 0.977013049 |

5. Results

This paper studies the stress damage of electronic components based on discrete stress interference model. The research status of electronic component reliability characterization technology and the research status of stress strength interference model were investigated and analyzed. The solution of the stress interference model for electronic components is determined. Secondly, through the research literature analysis, it is determined that the stress strength interference model of the solder joint is used to characterize the reliability of the entire electronic component. Finally, the stress strength interference model at the solder joint is established based on the test data. The stress-strength...
The interference model is selected as the evaluation model of stress damage of electronic components, based on the stress data measured by the electronic components after undergoing process temperature. Monte Carlo sampling method was used to obtain the distribution curve of residual stress in through-hole insertion process. Combined with the material characteristics, structural dimensions and process deviations of the solder joints, a random stress model is established, and a constant strength model is set according to the standard requirements. Based on the stress-strength interference model, the failure probability of solder joints for through-hole insertion was calculated, and the stress damage characterization of electronic components for through-hole insertion process was completed.

The established stress strength interference model of solder joints is:

\[
P = 1 - R = 1 - \int_{-\infty}^{\infty} f(x) \, dx = 1 - \int_{-\infty}^{\sigma_s + (W+\delta)\left(\frac{H}{2} + t + \delta + T + S_2\right)} \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{(x - \mu)^2}{2\sigma^2}\right) \, dx \quad (20)
\]

Among them, \(\sigma_s\) is the yield strength of Sn63Pb37, taking 21.3MPa, \(W\) is device width, \(H\) is device height, \(T\) is device electrode width, \(t\) is the floating amount of pad size, taking 0.1mm, \(S_2\) is the floating amount of device size, taking 0.1mm, \(\delta\) is the placement accuracy of the patch, calculated according to the above formula. \(\delta_1\) is the placement accuracy, taking 0.4mm, \(\Delta W\) is the dimensional accuracy of the chip component width \(W\), taking 0.4mm.

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