The Optimization Method of Component Multi-stress Reliability Enhancement Test Based on Fuzzy Theory

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***Abstract*—In the development and production stages of components, the reliability enhancement test (RET) has been used as one of the necessary test methods to identify weak links in product design and production. Due to the diversity and the complex environment of components, how to reduce the cost of RET and stimulate the potential defects of the device products quickly has become the primary research goal. In this paper, a design method of component multi-stress RET based on fuzzy theory is presented. First, we use the FMECA to obtain the sensitive stresses of components. The sensitive stresses order is measured by the fuzzy theory. Second, we use the double-crossed stepwise stress method to verify the sensitive stresses sequence. Third, the stress combination of RET is determined by using the fuzzy matrix calculation results and the data distribution characteristics. Fourth, using the failure physics theory and orthogonal experiment methods to optimize the design of RET. Finally, a case study with A/D converter is carried out to verify the above methods. The optimization method of multi-stress RET is helpful to quantify different factors and quickly excite potential defects of components by using failure physical simulations.**

Keywords*—*fuzzy theory; Multi-stress RET; optimization method

I. Introduction

For the failure of components is the main factor for the failure of equipment-level products and even system-level products, it is particularly important to improve the reliability of components. At present, the multi-stress reliability enhancement test(RET) is an important method to improve the reliability of components [1]. Although there are many studies on multi-stress RET for components. The field of study lacks test specific methods and executable technical basis in the research area. Its difficulties mainly include three aspects. (1)In the process of multi-stress RET, the selection of stress usually depends entirely on judgment and specific use environment [2]. (2)The traditional methods lack quantitative evaluation of different sensitive stresses, and It is difficult to determine the stress type superposition of the multi-stress tests [3]. (3)The setting of test conditions and the selection of test types often depend on the experience, which has great randomness. Therefore, to solve the above problems, this paper establishes a Multi-stress RET method based on fuzzy theory, which includes quantitative evaluation of different sensitive stresses and optimization of multi-stress strengthening test sections [4]. At the end of this paper, a case is used to verify the feasibility of the above reliability assessment.

II. Determining Sensitive Stress of Components

In the multi-stress RET, it is necessary to consider the application of multiple stresses. FMECA (Failure Mode Effects and Criticality Analysis) is an analytical technology based on failure mode and targeting failure effects or consequences [5]. In this paper, we use the FMECA to obtain the sensitive stresses of components. The subjective judgments is quantified into a specific sensitive parameter by the fuzzy comprehensive evaluation [6]. Different levels of fuzzy evaluation are used to describe the membership of evaluation factors. In the calculation it retains the evaluation information the greatest extent and highlights the main factors. The fuzzy evaluation process of sensitive stresses is shown in Fig. 1.

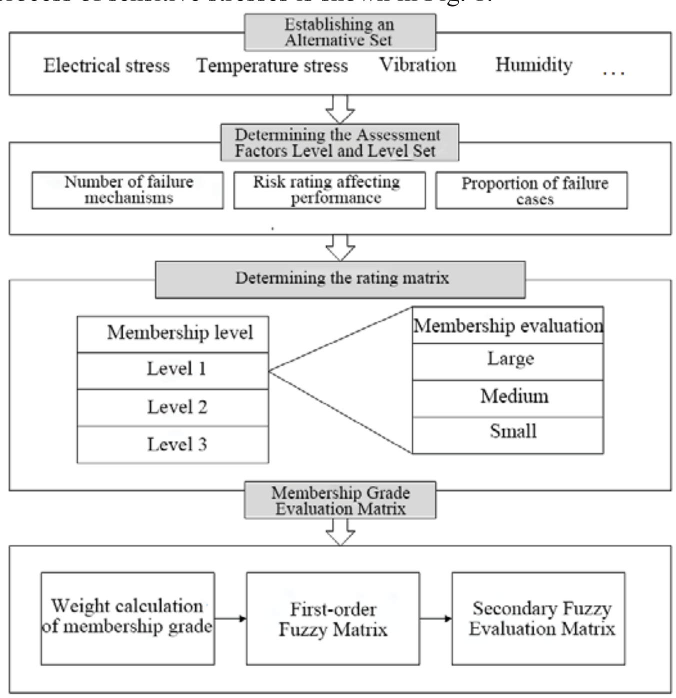

Figure 1. The fuzzy evaluation process of component sensitive stresses

A. *Establishing an Alternative Set*

First we need to determine the evaluation object. According to the application environment of the components, stresses such as temperature, humidity, vibration and electrical are selected as evaluation targets. Define the alternative set as:

$U=\{U_1,U_2,U_3,U_4\ldots U_m\}$.They represent different evaluation objects in turn.

B. Determining the Assessment Factor Levels and Level Set

According to the evaluation results, the factors are selected for the sensitivity of different stresses, and different stresses are evaluated. It is selected according to the stress sensitivity and its excitation efficiency of the failure mechanism [7]. First, stresses affect the risk level for component performance (R_1). Second, stresses affect the number of component fails (R_2). Third, stresses affect the proportion of the component failure causes (R_3). Based on the results of the survey and FMECA, we evaluate the membership of different levels. The three factors are considered to be larger, and the stress excitation efficiency is higher. The factor set is defined as: $q=\{q_1,q_2,q_3\}$ .They represent the above three evaluation factors in turn. The qualitative evaluation results of fuzzy factors are quantified, and the fuzzy levels of different fuzzy factors are divided. They include the first level, the second level and the third level. In the quantification, the most desirable level of each influencing factor in the evaluation should be considered. The fuzzy number represents the value of the linguistic variable. According to the values of high, normal and low linguistic variables, the quantized values of each level are 0.7, 0.5 and 0.3. The hierarchical set matrix is shown in Table I.

TABLE I. FUZZY FACTOR LEVEL TABLE

Fuzzy Factor	**Level**		
q_1	High(0.7)	Normal(0.5)	Low(0.3)
q_2	High(0.7)	Normal(0.5)	Low(0.3)
q_3	High(0.7)	Normal(0.5)	Low(0.3)

C. Determining the Hierarchical Judgment Matrix and Weight Calculation

Establish a membership evaluation matrix for components. Because the method tends to use the higher and lower evaluators of the compromise, the membership metrics are the same as the fuzzy factor level of 0.7, 0.5, and 0.3 [8]. The membership evaluation matrix is to evaluate the membership degree of each evaluation object in turn for the three fuzzy factors q_1, q_2 and q_3. We obtain the membership evaluation matrix R_1, R_2, R_3 of three fuzzy factors. The evaluation results be described in the following expression:

$$R_i=\begin{bmatrix} r_{i11} & r_{i12} & r_{i13}\cdots r_{i1m} \\ r_{i21} & r_{i22} & r_{i23}\cdots r_{i2m} \\ r_{i31} & r_{i32} & r_{i33}\cdots r_{i3m} \end{bmatrix},\quad (i=1,2,3) \tag{1}$$

The element r_{ijk} in the matrix represents the membership of the different objects evaluated at different levels. The subscript i represents the *i-th* evaluation factor, j is the *j-th* fuzzy level, and k is the m different evaluation objects in the alternative set. W is the weight of each fuzzy factor level and expressed as:

$$W_{ij}=q_{ij}\Big/\sum_{j=1}^{3}q_{ij} \tag{2}$$

The subscript represents the *j-th* rank of the *i-th* factor, and the weight set of the *i-th* factor is expressed as:

$$W_i=[W_{i1},W_{i2},W_{i3}],(i=1,2,3) \tag{3}$$

D. Computing Fuzzy Matrix

According to the established hierarchical evaluation matrix, the first-order fuzzy evaluation matrix B is determined by comprehensive calculation. The calculation formula is as follows:

$$B_i=W_i\times R_i=\left[b_{i1},b_{i2}..b_{im}\right] \tag{4}$$

The first order fuzzy matrix is as follows:

$$B=\begin{bmatrix} b_{11} & \cdots & b_{1m} \\ b_{21} & \cdots & b_{2m} \\ b_{31} & \cdots & b_{3m} \end{bmatrix} \tag{5}$$

Through the calculation of the second-order fuzzy matrix, we obtain the sensitive value of the alternative concentrated stresses. We determine the sensitive stresses and sensitive stress orders of the component products. Establish the second-fuzzy matrix A for different stress combinations. Each column value reflects the sensitivity of the different stress conditions to the components. It can be expressed as:

$$A=C\cdot B=(a_1,a_2,\ldots,a_m) \tag{6}$$

$C=(c_1,c_2,c_3)$is the weight matrix of the different factors. In turn. It represents the importance of different factors to the evaluation results, and the sum is 1. The matrix A is finally calculated by stress evaluation. It corresponds to four evaluation objects of temperature, humidity, vibration and electrical stress. Each value in A is the sensitivity parameter of each evaluation object.

E. Verification of Sensitive Stress Sequencing Based on the Double-Crossed Stepwise Stress

After completing the sensitive stress sorting of the components by the fuzzy theory, the sorting results can be verified by the double-crossed stepwise test [9].First, different magnitudes need to be set for different stress levels. The selection of step magnitude should select the appropriate magnitude evenly between the recommended working environment stress and the working limits of components. The magnitude settings should refer to the standard values specified in the component manuals. When the working limit is unknown, it can be determined by referring to the difference of the corresponding stress between different test conditions in GJB548. The double-crossed stepwise test schedule is shown in Table II.

TABLE II. THE DOUBLE-CROSSED STEPWISE STRESS DIAGRAM

Stress1 / Stress2	D_1	D_2	D_3	D_4
U_4				
U_3				
U_2				
U_1				

III. DETERMINING THE STRESS COMBINATION OF MULTI-STRESS RET

In order to improve the cost-effectiveness ratio of the test, save the test time, and expose the defects of the product through fewer tests, it is necessary to select the test stress type according to the calculation results of the sensitive stress fuzzy matrix of components [10]. The data of sensitive values in the fuzzy matrix are fitted. Taking the results of data obeying normal distribution as an example, if the sensitivity parameter is larger than σ , the component is more sensitive to single stress in the selection of stress combination in RET. If the sum of the sensitive parameters is larger than 2σ , the components are more sensitive to double stresses, and the double stress RET should be carried out. In other cases, four kinds of comprehensive stress tests are carried out. The process of determining stress combination in multi-stress RET is shown in Fig.2.

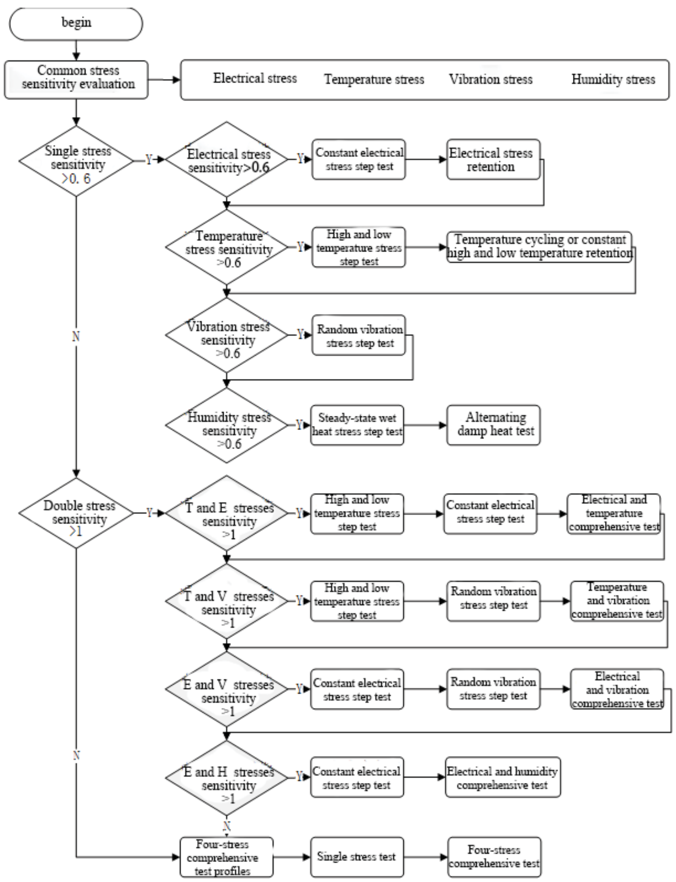

Figure 1. Procedure of multi-stress RET.

After the type of test determined, the test plan requires a single stress step Pre-test for different stresses in the test type. It determines the working and damage limits of components, including high temperature limits, low temperature limits, electrical stress limits related power supply voltage, etc. Therefore, it provides a basis for the determination of the amount of stress applied in the study of the experimental scheme.

IV. OPTIMIZING METHOD OF COMPONENTS RET

We need to determine the stress factors and its levels. For it takes more time and effort to carry out a complete RET, this paper uses orthogonal test design. It uses the method of failure physics simulation to find the optimal reinforcement test profile. We introduce the optimization method by taking the four-stress comprehensive RET as an example. Before the test, the working limit and the damage limit of the product's high and low temperature, electrical stress and vibration stress should be demined through the Pre-test. Based on this, the value of the stress factor is determined. It is shown in Table III.

TABLE III. DIFFERENT STRESS FACTOR LEVELS TABLE

	Factor	Level 1	Level 2
Tem-perature	Maximum temperature	T_H	$(T_H'+T_H)/2$
	Minimum temperature	T_L	$(T_L'+T_L)/2$
	High temperature immersion time	5min	10min
	Low temperature immersion time	5min	10min
	Temperature change rate	15℃/min	30℃/min
Electricity	Power supply voltage value	V_H	$(V_H'+V_H)/2$
	Reference level jitter amplitude	5% V_{REF}	10% V_{REF}
	Input voltage pulse amplitude	Input range	200% Input range
	Input voltage pulse frequency	Input range	200% Input range
Vibration	Vibration frequency range	20-3000 Hz	50-2000Hz
	Acceleration power spectral density(PSD)	40%G_H'	80%G_H'
Humidity	Relative humidity	30%-60%	60%-90%

Explanation of the letter symbol is given here.T_H indicates the rated maximum temperature.T_H' indicates the damage limit obtained by the bottom test.T_L indicates the rated minimum temperature.T_L' indicates the damage limit obtained by the bottom test. V_H indicates the rated working voltage. V_H' indicates the damage limit obtained by the bottom test.G_H' indicates the random vibration damage limit.

The failure physics model is selected according to the type of stresses. The common failure physical models for the components of the mainstream simulation software CALCE are shown Table IV [11].

TABLE IV. FAILURE PHYSICAL MODEL

Temperature correlation model (Including chip and component temperature)		**Electrical stress correlation model**	**Vibration correlation model**	**Humidity correlation model**
Metallization electromigration Model	Gold-aluminum compound failure Model	Metallization electromigration Model	Random vibration fatigue Model	Plastic seal corrosion failure Model
TDDB Model	PTH Failure Model			
Chip bonding fatigue Model	Solder joint thermal fatigue Model	TDDB Model	Interconnect system shock vibration failure Model	Sealed package corrosion failure Model
Bond wire bending fatigue Model	Chip fatigue fracture failure Model			

Temperature correlation model (Including chip and component temperature)		Electrical stress correlation model	Vibration correlation model	Humidity correlation model
Bond pad fatigue Model	-	-	Chip break Model	-

Through the orthogonal arrangement table, the CALCE PWA simulation software carries out life simulation [12]. According to the life simulation results under different failure mechanisms, the Miner linear cumulative damage method performs cumulative calculations [13]. Finally, we get the damage ratio under different test profiles. By comparing the cumulative damage ratios of products under different profiles, the optimal multi-stress RET design profile appeared [14]. Through the evaluation of the cross-section of the orthogonal test, the key factors are found which affect the RET. In the end, we will develop a better experimental program.

Miner cumulative damage is as follow [15]:

$$R_i = \sum \frac{n_i}{N_{ij}} = 1, \qquad i = 1, 2, 3, \cdots 16, \; \text{j=1,2,} \cdots 7 \tag{7}$$

In the formula, n_i represents the application time of the *i-th* group profile; N_{ij} represents the pre-failure time under the *j-th* failure mechanism under the *i-th* section. R_i is the Miner cumulative damage ratio.

V. EXAMPLE VERIFICATION

Taking a domestic A/D converter as an example, this paper illustrates the optimization method of multi-stress RET profile. According to the environment that the product may encounter in practical application, four kinds of stresses (temperature, humidity, vibration and electrical stress) are selected as evaluation objects. The following three conditions are took into account in the evaluation. First, stresses affect the risk level for component performance (R_1). Second, stresses affect the number of component fails (R_2). Third, stresses affect the proportion of the component failure causes (R_3).

1) According to the components use environment, we define temperature, humidity, vibration and electrical stress as evaluation objects. According to formula (1), the alternative set is defined as $U=\{U_1, U_2, U_3, U_4\}$.

2) Evaluate the influence of different stresses on components by fuzzy factor level and establish a membership evaluation matrix. Take the evaluation of the stress risk level of R_1 on component performance as an example. Through the failure investigation and analysis results, the electrical stress has the highest comprehensive risk level of component performance. The temperature stress is second only to the electrical stress. The vibration and humidity are significantly lower than the electrical stress and temperature stress. Therefore, the three membership degrees of 0.7, 0.3, and 0.3 are set in the first column of temperature stress evaluation. For the second and third columns of humidity and vibration stress, the three degrees of membership are set which are significantly lower than the temperature of 0.5, 0.3, and 0.3. Due to the highest electrical stress, three membership degrees of 0.7, 0.5, and 0.3 are selected in the fourth column. In the same way, in R_2, R_3, the membership of different levels are evaluated based on the survey results and the results of FMECA. Finally, the membership evaluation matrices are

$$R_1 = \begin{bmatrix} 0.7 & 0.5 & 0.5 & 0.7 \\ 0.3 & 0.3 & 0.3 & 0.5 \\ 0.3 & 0.3 & 0.3 & 0.3 \end{bmatrix} R_2 = \begin{bmatrix} 0.7 & 0.5 & 0.5 & 0.7 \\ 0.3 & 0.3 & 0.3 & 0.5 \\ 0.5 & 0.3 & 0.3 & 0.3 \end{bmatrix} R_3 = \begin{bmatrix} 0.7 & 0.3 & 0.3 & 0.7 \\ 0.3 & 0.3 & 0.3 & 0.5 \\ 0.3 & 0.3 & 0.3 & 0.5 \end{bmatrix}$$

3) We perform the first order fuzzy matrix calculation. According to the hierarchical weight set calculation formula, the weight set corresponding to the three levels of the three influencing factors is determined as:

$$W_1 = \left[\frac{7}{15}, \frac{1}{3}, \frac{1}{5}\right] W_2 = \left[\frac{7}{15}, \frac{1}{3}, \frac{1}{5}\right] W_3 = \left[\frac{7}{15}, \frac{1}{3}, \frac{1}{5}\right] \tag{8}$$

The first-level evaluation matrix is calculated according to the first-level evaluation matrix formula (4).

$$B = \begin{bmatrix} \frac{73}{150} & \frac{59}{150} & \frac{59}{150} & \frac{83}{150} \\ \frac{79}{150} & \frac{59}{150} & \frac{59}{150} & \frac{83}{150} \\ \frac{73}{150} & \frac{3}{10} & \frac{3}{10} & \frac{89}{150} \end{bmatrix} \tag{9}$$

4) We perform the second order fuzzy matrix calculation and define the weight set for each of the influencing factors. R_1 should be the most important evaluation standard for the selection of sensitive stresses for component strengthening tests. The evaluation standard R_2 has the least weight. R_3 is the evaluation standard after R_1. Therefore, the weight set of the three influencing factors is determined as follow:

$$C = (0.55,\ 0.15,\ 0.3) \tag{10}$$

According to the formula (6), the second evaluation matrix result is as follow:

$$A = [0.493 \quad 0.365 \quad 0.565] \tag{11}$$

We get the results of the second-order fuzzy evaluation matrix. The stress sensitivity is in order temperature, humidity, vibration, electrical stress.

5) We carry out the double-crossed stepwise comprehensive stress tests of temperature and vibration. Perform electrical performance tests after 5 minutes of each level. The cross-step sequence of the test is shown in Table V.

TABLE V. THE DOUBLE-CROSSED STEPWISE TEST

temperature / vibration	75℃	100℃	125℃	150℃
8(m/s²)²/Hz				8
6(m/s²)²/Hz			6	7
4(m/s²)²/Hz		4	5	
2(m/s²)²/Hz	2	3		

The electrical vibration test system is selected to apply random vibration. The temperature was stepped by using a custom heating plate and a temperature controller. Zero error, fullness error, linear error and integral error have no obvious change trend with the test conditions. The test data of the remaining test parameters change within the scope of the specification. The results are shown in Table VI. and Fig. 3. From the results, the test parameters have obvious changes with the change of the cross-test magnitude. Grades 3 and 4, grades 5 and 6, grades 7 and 8 are stepwise rises or falls with temperature. The change in the parameters is reflected by the increase in component temperature. The temperature is greater than the vibration in sensitivity.

TABLE VI. TEMPERATURE AND VIBRATION COMPREHENSIVE TEST PARAMETERS

Test level	Supply current	Output high average	Output low average	Output leakage average (Vo=5.0)	Output leakage average (Vo=0.0)	Input leakage average (IN=5.0)	Input leakage average (IN=0.0)
□-(m/s^2)^2/-Hz	mA	V	V	uA	uA	uA	uA
1-25-0	0.1851	4.859	0.184	0.344	-0.484	0.279	-0.111
2-75-2	0.1679	4.828	0.204	0.434	-0.673	0.393	-0.632
3-100-2	0.1643	4.818	0.228	0.453	-0.629	0.545	-0.868
4-100-4	0.1656	4.819	0.226	0.826	-1.010	0.532	-1.013
5-125-4	0.1302	4.807	0.239	0.893	-1.360	0.666	-1.372
6-125-6	0.1274	4.805	0.242	1.027	-1.628	0.658	-1.627
7-150-6	0.1484	4.798	0.256	1.306	-2.561	0.748	-1.967
8-150-8	0.1505	4.799	0.256	1.289	-2.733	0.865	-2.149

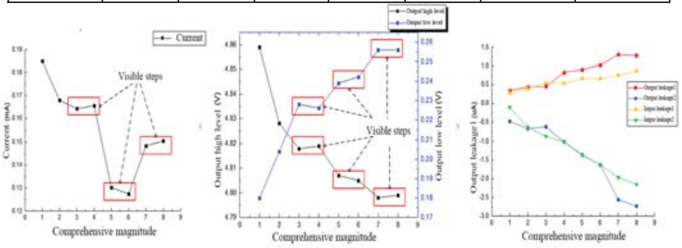

Figure 3. Temperature and vibration comprehensive test parameter analysis

The following tests can be carried out in accordance with the above procedure in sequence: Cross-step test of vibration and electrical stress, Cross-step test of temperature and electrical stress, Comprehensive cross-step test of temperature, vibration and electrical stress. The final order of stress sensitivity is Electrical stress > Temperature stress>Vibration stress. The results of the fuzzy sensitivity evaluation are correct. It is feasible to verify the fuzzy sensitivity evaluation method. It is effectively to analyze the difference in sensitivity of different test stresses effectively analyzed by cross-stepping test.

6) In the test type determination, the evaluation of this case selects three fuzzy magnitudes of 0.7, 0.5, and 0.3. The RET tests for temperature stress and electrical stress are carried out.

7) According to the results of the determined test types, we study the performance of components by orthogonal test methods. There are two levels of values for different parameters. Since the low working temperature limit is not clear, we set the recommended working temperature and equipment limit low temperature. The setting of the high and low levels of temperature parameters and electrical profile parameters is shown in Table VII.

TABLE VII. TEMPERATURE AND ELECTRICAL TEST PROFILE PARAMETERS

Stress	Factor	level 1	level 2
Temperature stress	A Maximum temperature	125℃	150℃
	B Minimum temperature	-50℃	-70℃
	C High temperature immersion time	5min	10min
	D Low temperature immersion time	5min	10min
	E Temperature change rate	15℃/min	30℃/min
Electrical stress	F Power supply voltage value	5V	15V
	G Reference level jitter amplitude	5% V_{REF}	10% V_{REF}
	H Jitter frequency	50Hz	100Hz
	J Input voltage pulse amplitude	5V	10V
	K Input voltage pulse frequency	1KHz	2KHz

8) Through the orthogonal test method, we developed a ten-factor two-level orthogonal test table for the above ten profile parameters. The number of trials is 16 times. The test plan is shown in Table VIII. A, B, C, D, E, F, G, H, J, and K represent the above profile parameters in turn. -1 represents the low level of the factor and 1 represents the high level. Through the analysis of the simulation results of different experimental schemes, we can find a better experimental scheme and identify the main factors affecting the test.

TABLE VIII. ORTHOGONAL TEST SCHEME FOR TEMPERATURE CYCLE AND ELECTRICITY

Test number	A	B	C	D	E	F	G	H	J	K
1	-1	1	1	1	-1	1	-1	1	-1	-1
2	-1	1	1	-1	-1	-1	1	1	1	-1
3	1	1	-1	1	-1	-1	-1	-1	1	1
4	-1	-1	-1	1	-1	1	1	1	1	1
5	1	1	-1	-1	-1	1	1	-1	-1	1
6	1	-1	-1	-1	1	-1	1	1	1	-1
7	-1	-1	1	1	1	-1	-1	-1	1	1
8	-1	-1	1	-1	1	1	1	-1	-1	1
9	1	-1	1	-1	-1	1	-1	-1	1	-1
10	-1	1	-1	-1	1	1	-1	-1	1	-1
11	1	1	1	1	1	1	1	1	1	1
12	-1	-1	-1	-1	-1	-1	-1	1	-1	1
13	-1	1	-1	1	1	-1	1	-1	-1	-1
14	1	1	1	-1	1	-1	-1	1	-1	1
15	1	-1	1	1	-1	-1	1	-1	-1	-1
16	1	-1	-1	1	1	1	-1	1	-1	-1

9) We performed finite element simulations sequentially for the designed orthogonal test. The simulation screenshots are shown in Fig. 4.The parameters of the finite element simulation result puts into the failure physical simulation software to obtain the pre-failure time under different failure mechanisms. The results are shown in Table IX.

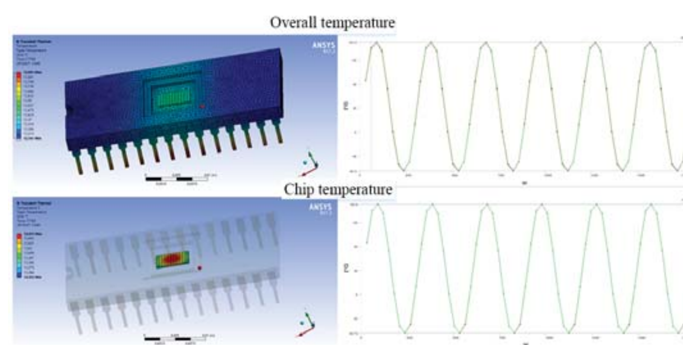

Figure 4. Simulation results for section 5

TABLE IX. FAILURE PHYSICAL SIMULATION CALCULATION RESULTS

Test number	TDDB (h)	Electromigration(h)	Chip break(h)	Bonding layer fatigue (h)	Bond line fatigue (h)	Pad fatigue (h)	Au-Al Compound (h)
1	7.72E+05	2.52E+05	81937.5	26354.17	22520833	174097.2	3.91E+10
2	1.21E+06	3.05E+05	96152778	52708.33	45041667	348194.4	5.72E+10
3	1.37E+05	1.73E+05	19071759	27627.31	17556713	127620.4	9.03E+09
4	1.42E+05	1.22E+05	119849.5	38263.89	43101852	349652.8	9.28E+09
5	9.49E+04	1.48E+05	198703.7	53101.85	33745370	245296.3	6.60E+09
6	2.82E+04	6.09E+04	1E+08	52824.07	42453704	323750	2.36E+09
7	2.08E+05	2.07E+05	15497685	26180.56	29490741	239236.1	1.28E+10
8	1.43E+05	1.76E+05	173634.3	52361.11	58981481	478472.2	9.35E+09
9	1.95E+04	7.49E+04	148449.1	41504.63	33356481	254375	1.73E+09
10	7.89E+05	3.66E+05	144750	41250	35250000	272500	3.99E+10
11	9.38E+04	1.02E+05	129759.3	37314.81	23712963	172370.4	6.54E+09
12	2.12E+05	1.45E+05	60185185	40277.78	45370370	368055.6	1.31E+10
13	1.19E+06	4.36E+05	34145833	37812.5	32312500	249791.7	5.65E+10
14	1.14E+05	1.11E+05	628240.7	42337.96	26905093	195574.1	7.73E+09
15	2.80E+04	8.75E+04	45601852	37731.48	30324074	231250	2.34E+09
16	1.92E+04	5.17E+04	84421.3	26412.04	21226852	161875	1.70E+09

Finally, for the above results, we apply the method of linear cumulative damage for analysis. The results of linear cumulative damage calculations and their orders are shown in Table X.

TABLE X. LINEAR CUMULATIVE DAMAGE RESULTS

Test number	Damage time(h)	Cumulative damage ratio(h/h)	Sequence
1	383.3333	2.35E-02	11
2	766.6667	1.99E-02	14
3	427.7778	2.45E-02	10
4	527.7778	2.78E-02	9
5	822.2222	3.72E-02	5
6	777.7778	5.75E-02	2
7	361.1111	1.88E-02	15
8	722.2222	2.86E-02	11
9	611.1111	6.08E-02	1
10	600	2.33E-02	12
11	577.7778	3.51E-02	6
12	555.5556	2.18E-02	13
13	550	1.85E-02	16
14	655.5556	3.16E-02	7
15	555.5556	4.33E-02	4
16	388.8889	4.95E-02	3

10) Finally, we perform visual analysis and range analysis for the results of the simulation analysis. According to the results of the linear cumulative damage analysis, the cumulative damage ratio of the ninth group is the highest among the current 16 orthogonal test sections. This group of test sections has the best damage effect. This profile is the most efficient in the intensive test and has the strongest ability to stimulate potential defects in the product. Based on the ninth section, a multi-factor comprehensive is designed to enhance test profile. We use an intuitive experimental design to optimize the experimental profile. The result is shown in Fig. 5.

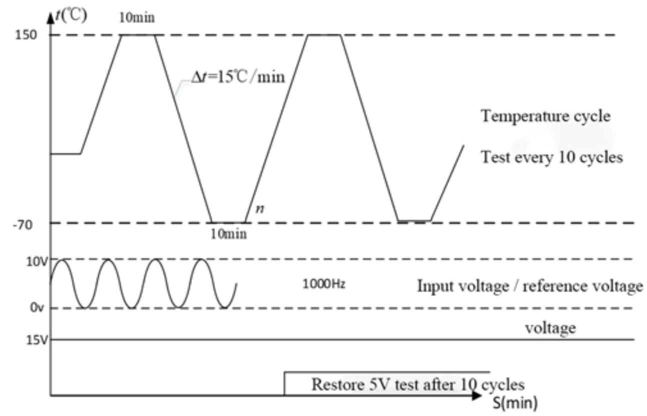

Figure 5. Temperature cycle and electrical RET profile

Using the method of range analysis, we also carry out range analysis for 10 section parameters in the enhanced test section. The range analysis of the failure physics simulation results are shown in Table XI.

TABLE XI. RANGE ANALYSIS RESULTS

Profile parameter	Temperature stress related factors				
	Max temperature	High temperature immersion time	Min temperature	Low temperature immersion time	Temperature change rate
Range	0.1573	-0.0945	0.0015	-0.0397	0.0041
Sequence	1	10	7	8	6
Profile parameter	Electricity stress related factors				
	Power supply voltage value	Input voltage pulse amplitude	Input voltage pulse frequency	Jitter frequency	Reference level jitter amplitude
Range	0.0499	0.0141	0.0117	0.0137	-0.0709
Sequence	2	3	5	4	9

Comparing the extreme values of different test profile parameters, the key factors show how to affect the test results. They are in order: maximum temperature, supply voltage and input voltage pulse amplitude. In the design of the RET section, we obtain the profile parameters that have the greatest influence on the test results through the analysis. The RET profile is designed for the max temperature, supply voltage and input pulse voltage. We design a test profile 2 with the high levels values for these profile parameters. The result is shown in Fig. 6. This is a comprehensive test of high temperature and electrical stress.

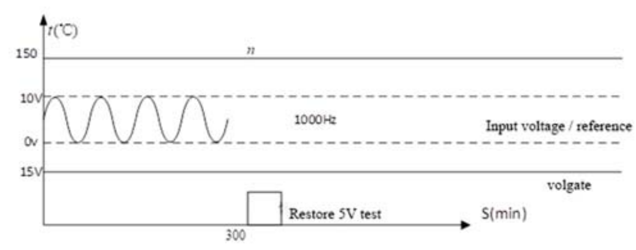

Figure 6. High temperature and electrical strengthening test profile

VI. CONCLUSION

In this paper, a design method of multi-stress hardening test section based on fuzzy theory components is presented. The method combines the fuzzy matrix and two alternate step-stress test to determine the sensitive stress sequence of components. We propose a method for determining the combination of multiple stresses. At the same time, the multi-stress RET profile is optimized by orthogonal test design and failure physical simulation. Using this method can reduce the cost of RET, quickly stimulate the potential defects of the product, and provide a theoretical basis for the optimization of the product pair.

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