Detonator stepping stress acceleration life test

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Abstract: Through the failure mechanism analysis and simulation test of a certain kind of detonator, this paper confirms the stress level of the stepping stress acceleration life test of the detonator, and then establishes the data processing mathematical model and storage life forecasting method. At last, according to the result of the stepping stress acceleration life test of the detonator, this paper forecasts the reliable storage life of the detonator under the normal stress level.

Key words: detonator; stepping stress acceleration life test; storage life forecast

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0 Introduction

Some detonators are long-term stored but disposable products, such as ammunition, food, medicine, etc. In the process of storage, due to the influence of the environmental stress, their function will certainly change. Can the detonators be used effectively after a period of storage? How is the reliability? How long is the storage life? These are the questions that people concern. For years, the methods of long natural storage test or storage reliability test have been adopted to make certain the failure distribution of the detonator and storage life. Though the relatively real storage life can be got by this method, it takes long time. For some detonators, they will fall into disuse even before an entire life test is completed. So this method is not suitable for the swiftly developing science and technology nowadays. Obviously, it is very important to adopt the acceleration life test method of strengthening the stress level and quickening the detonator failure to make clear the quality change rule of the detonators, especially the new detonators under normal storage condition and forecast their storage life in the short time cycle.

Several years ago, we achieved the good effect to forecast the storage life of a certain kind of detonator with the temperature stepping stress acceleration life test method. This paper will introduce the concerned principle of acceleration life test, stress level, mathematical model and storage life forecast of this test in the following.

1 Test principle

To carry out the stepping stress acceleration life test, first of all it is necessary to choose a group of stress levels T_1, T_2, ..., T_l that are higher than the stress level T_0 under the normal storage condition. At the beginning of the test, the test sample will be tested under the stress level T_1. And after a period of time, for example t_1 hour, increase the stress level to T_2, ..., and continue this way until a certain quantity of samples have failure.

The test principle is shown in Fig. 1.

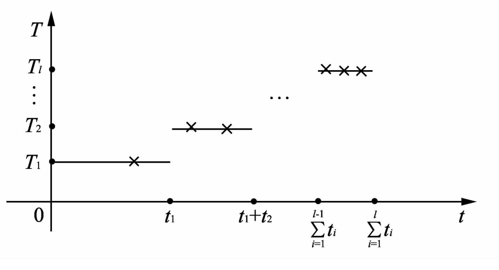

Fig. 1 **Principle figure of the acceleration life test**

2 Stress level

After the test stress is ascertained, how to ascertain the test stress level is a key to the success or failure of the whole acceleration life test. The principle of acceleration stress level can be determined,

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namely, the failure mechanism of the detonator under various stress levels is the same as that under normal stress level. Because if the failure mechanism has change, the whole acceleration test will be meaningless. Through a lot of trial tests and failure mechanism analyses[1], the highest stress level of the detonator in the acceleration life test is known as temperature 353 K(80 ℃), other stress levels can be set according to the principle of temperature value equivalent interval. The detailed distribution is as follows. The temperature stress levels are 338 K (65 ℃), 343 K (70 ℃), 348 K (75 ℃) and 353 K (80 ℃).

3 Test results

Years ago, we carried out the stepping stress acceleration life test of the detonator at the abovementioned four stress levels for 240 days. During the procedure, the samples were tested for many times. The original test results are shown in Table 1.

Table 1 Original acceleration life test result

Stress level	338 K(65 ℃)				343 K(70 ℃)				348 K(75 ℃)				353 K(80 ℃)			
Test time (day)	20	40	60	80	100	120	140	160	170	180	190	200	210	220	230	240
Sample volume (round)	100	100	100	99	99	98	98	97	95	94	91	90	87	81	76	64
Failure quantity (round)	0	0	1	0	1	0	1	2	1	2	1	3	6	5	12	17

4 Mathematical model

4.1 Basic hypothesis

According to the engineering theory and practical experience, the following hypotheses can be put forward.

Hypotheses 1: Under the stress level T_i, the storage life of a certain kind of equipment is subordinate to Weibull distribution, namely,

$$F_i(t) = 1 - e^{-\left(\frac{t}{\eta_i}\right)^{m_i}},$$
$$t \geqslant 0, \ i = 0,1,\ldots,4, \tag{1}$$

where m_i is shape parameter and η_i is characteristic life.

Hypothesis 2: The failure mechanism will not change with the test under various temperature stress levels. From the mathematical angle, it is that the shape parameter keeps unchanged, that is

$$m_0 = m_1 = \ldots = m_4. \tag{2}$$

Hypothesis 3: Under different stress level T_i, there is different characteristic life η_i. Furthermore, η_i and T_i fit the Arrhenius model, that is

$$\eta_i = e^{a+b/T_i}, \tag{3}$$

where a and b are the parameters to be evaluated, and T_i is the absolute temperature (unit: K).

Hypothesis 4: In the course of stepping stress acceleration life test, when the detonator is in the test at high stress level T_{i+1}, it has been test for a period of time at the stress level T_i.

According to Nelson theory[2], the remaining storage life of the detonator only depends on the accumulated failure and stress level at that time, and it has nothing to do with the accumulation method.

4.2 Evaluation of parameters

4.2.1 Evaluation of transitional parameter[3]

From the basic hypothesis, the "converted" distribution of the storage life of a certain kind of equipment can be deduced under the condition of stepping acceleration test.

The test of the sample firstly can be carried out at T_1 with the time t_1; and then increase the temperature to T_2 with the test time $t_2 - t_1$; subsequently $t_3 - t_2$ at T_3, test $t_4 - t_3$ at T_4; Finally the test stops at the moment t_4. According to the basic hypothesis, in the time duration $[0, t_1]$, the sample life distribution is

$$F(t) = F_1(t) = 1 - e^{-\left(\frac{t}{\eta_1}\right)^{m}},$$
$$0 \leqslant t \leqslant t_1. \tag{4}$$

In time duration $(t_1, t_2]$, when test at T_2, it can not be neglected that the sample has been tested for a period time at T_1. Therefore it is necessary to convert this period into an equivalent period of time at T_2. Setting the equivalent time as S_1, so the sample life distribution in $(t_1, t_2]$ is

$$F(t) = F_2(S_1 + (t - t_1)),$$
$$t_1 < t \leqslant t_2. \tag{5}$$

From the basic hypothesis 4, there is

$$F_1(t_1) = F_2(S_1). \tag{6}$$

From Eq. (6), S_1 is solved and substituted in Eq. (5), it can be got as

$$F(t) = F_2(t) = 1 - e^{-\left(\frac{t_1}{\eta_1}+\frac{t-t_1}{\eta_2}\right)^{m}},$$
$$t_1 < t \leqslant t_2. \tag{7}$$

By the same token, there is S_2 satisfying

$$F_3(S_2) = F_2(S_1 + (t_2 - t_1)). \tag{8}$$

Meanwhile there is

$$F(t) = F_3(S_2 + (t - t_2)), \quad t_2 < t \leqslant t_3. \tag{9}$$

That is

$$F(t) = 1 - e^{-\left(\frac{t-t_2}{\eta_3}+\frac{t_2-t_1}{\eta_2}+\frac{t_1}{\eta_1}\right)^m}, \quad t_2 < t \leqslant t_3. \tag{10}$$

Through analogous calculation, it can be got as

$$F(t) = 1 - e^{-\left(\frac{t-t_3}{\eta_4}+\frac{t_3-t_2}{\eta_3}+\frac{t_2-t_1}{\eta_2}+\frac{t_1}{\eta_1}\right)^m}, \quad t_3 < t \leqslant t_4. \tag{11}$$

Expressing the above results integrally with a formula, there is

$$F(t) = 1 - e^{-\left(\frac{t-t_{i-1}}{\eta_i}+\sum_{k=1}^{i-1}\frac{t_k-t_{k-1}}{\eta_k}\right)^m},$$

$$t \geqslant 0, \; t_{i-1} < t < t_i, \; i = 1,2,...,4. \tag{12}$$

Eq. (12) is the failure disuribution function of corresponding temperature stepping acceleration test gainee through convert.

From Eq. (12), it is not hard to get the likelihood function of the sample as

$$L(a,b,m) = \prod_{i=1}^{4}\left(F\left(\sum_{k=1}^{i} t_k\right)\right)^{r_i} \times \left(1 - F\left(\sum_{k=1}^{i} t_k\right)\right)^{m_i - r_i}. \tag{13}$$

Among them, η_i in $F(t)$ should be substituted with relation $\eta_i = e^{a+b/T_i}$, and make $F(t)$ the function of (a,b,m). By numerical value solution, the maximum likelihood evaluation $\hat{a}$, $\hat{b}$, $\hat{m}$ of a, b, m can be solved, respectively.

4.2.2 Evaluation of characteristic life

From acceleration Eq. (3), the evaluation value $\hat{\eta}_0$ of characteristic life η_0 can be obtained at the normal temperature stress level T_0 as

$$\hat{\eta}_0 = e^{\hat{a}+b/T_0}. \tag{14}$$

5 Forecast of reliable storage life

Under the normal storage environmental condition, the reliability distribution function[4-5] is

$$R(t) = 1 - F(t) = e^{-\left(\frac{t}{\eta_0}\right)^{m_0}}. \tag{15}$$

Assuming that R_L is the given lower limit of storage reliability degree, and γ is the confidence level, which is the required storage life T_s, and make

$$P\{R(T_s) \geqslant R_L\} = \gamma. \tag{16}$$

Due to the large quantity of the samples, it is allowable to consider that $\hat{R}(t)$ is approximately subordinate to the normal distribution with the mean $R(t)$ and variance $D(\hat{R}(t))$. From Eq. (16), it can be got by inference

$$P\left\{\frac{\hat{R}(T_s) - R(T_s)}{\sqrt{D(\hat{R}(T_s))}} \leqslant \frac{(\hat{R}(T_s) - R_L}{\sqrt{D(\hat{R}(T_s))}}\right\} = \gamma. \tag{17}$$

Setting μ_γ the underside quintile on γ of standard normal distribution, so T_s satisfies

$$\hat{R}(T_s) - \mu_\gamma \sqrt{D(\hat{R}(T_s))} = R_L. \tag{18}$$

Substituting it by $\hat{M}$, $\hat{\eta}_0$, R_L, γ, μ_γ the storage life under normal storage environmental condition can be calculated by numerical value iteration method.

6 Conclusion

In accordance with the test result, set $\gamma = 0.90$, $R_L = 0.95$, from the above-mentioned data process method, calculate out the storage life of this kind of equipment $T_s = 25.67$ years. This means that under the condition of 90% of confidence level the detonator can be stored for 25 years under normal stress level with the storage reliability degree not lower than 0.95.

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