Reliability Verification Method of Aged-Electric Initiator using Closed Bomb Test

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1 Introduction

Electric initiators use high-performance explosives and convert electric energy into thermal energy through a Joule heating wire contacting with the explosive. An electric initiator consist of a primary charge, a secondary charge, a heat bridge wire, and a glass-metal seal, as shown in Figure 1. Applying an electric current through a contact pin, the temperature of the heating wire rises over the auto-ignition temperature of primary charge within milli-seconds. The primary and secondary explosives deflagrate in sequence while generating heat(energy) and pressure to initiate the ignition of ignitor inside the solid rocket motor

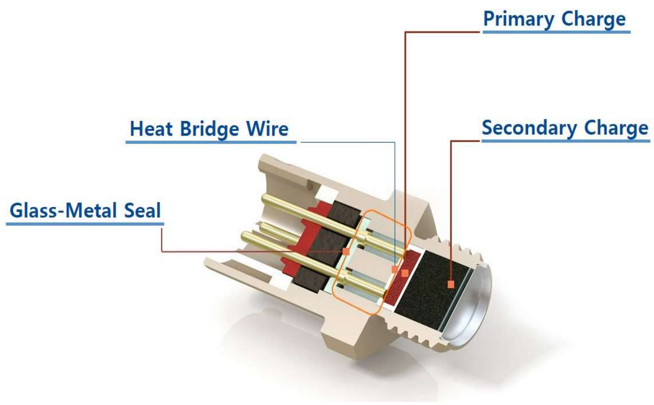

Figure 1: Configuration of Electric Initiator

Qwing to its one-time use character, electric initiator is generally called one-shot devices, and very high reliability is required. According to the related specification, the reliability of initiators for space launch vehicles or guided weapon systems requires over 0.995 (95% confidence level). In military applications, the initiators assembled into the system are stocked. And their readiness-to-use are maintained in the storage condition for a long time. And they are sometimes discarded without being used until the end of

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life. However, regardless of the stock time, the reliability must be maintained and required to guarantee a shelf life of at least 10 years or more.

Research on the shelf life and reliability of initiators has been conducted in two ways. The first is reliability evaluation through the Stockpile Reliability Program (SRP) or Ordnance Assessment (OA) Program. One may check the structural integrity of aged items stored for a certain period of times and the current state of the product through performance tests. And one may prolong the shelf life with the program. In the case of initiator, the inspection and testing are generally conducted according to AIAA Standard or MIL-STD, and if all tests are passed, one may extend the 3 years of shelf life. This method of confirming shelf life through SRP or OA program has the advantage of obtaining accurate information on life time or reliability because of using actual samples.

The second method of evaluating the shelf life is to simulate the aging phenomenon according to an accelerated aging test. In initiator, a influence of temperature aging is dominant because it is stored in a container filled with nitrogen in the storage that maintains a constant temperature. For this reason, a high-temperature accelerated aging test using an environmental chamber is performed to accelerate the aging of the initiator and confirm shelf life. This method is good for predicting shelf life but it cannot be used to calculate reliability. In this study, Bayesian Approach combining an accelerated aging test method is used to research reliability verification method to consider the shelf life and reliability at the same time. Aging components of the initiator are identified and acceleration factor is calculated based on Arrhenius theory since the factor affecting aging is temperature (heat). Also, the life evaluation equation combining Weibull and Binomial distribution is calculated by applying the Bayesian technique. Finally, a reliability over shelf life verification test plan is established and performed, and actual reliability was predicted based on the performance test result.

2 Establishment of Accelerated Aging Test Plan

The accelerated aging test accelerates the aging of components by testing under severe stress (temperature, humidity, voltage, etc.) than normal conditions, and the time point when the aging characteristics are deteriorated to the predefined failure criterion is defined as the failure time. The failure time can be defined as shown in Figure 2 and the user can accurately predict the life under normal conditions by analyzing the failure data obtained due to aging under accelerated conditions. In this accelerated aging test, there is a condition that a rate determining step (aging process due to a physical / chemical reaction affected by a failure time) must exist between samples, and that acceleration according to stress must be established.

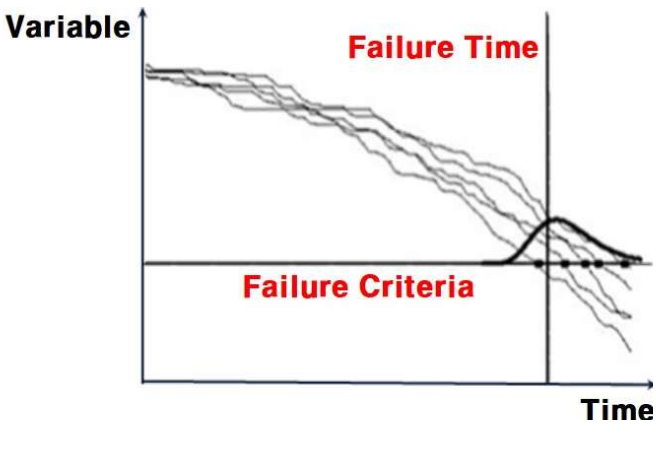

Figure 2: Failure Criteria and Definition

Failure Mechanism means a physical/chemical process leading to failure by stress, and Failure Mode is defined as a phenomenon that appears as a result of the failure mechanism. In order to perform an accelerated aging test, it is most important to first identify the failure mechanism and failure mode, which is identified through the Failure Mode & Effect Analysis (FMEA) presented in MIL-STD-1629A.

FMEA is a technique that qualitatively analysis the effect of failure modes of components constituting the system on other components and the entire system. It is a technique to identify external stresses such as environmental factors. There are two major failure modes of the initiator identified through FMEA: 'O-ring pressure leak' and 'generated pressure below specification'.

In this study, charge is considered to cause the failure mode. As mentioned earlier, initiators are stored for a long period of time before missions, and their power and sensitivity degrade due to aging by temperature. Accordingly, the aging characteristics of the initiator can be defined in two ways: power and sensitivity. The aging characteristics of these initiators can be confirmed through performance tests in three characteristics: maximum pressure, ignition delay time, and maximum pressure time.

The Arrhenius theory is equation between life and stress that models aging failure due to chemical reactions, and is most often used to predict accelerated aging tests by temperature factors. The Arrhenius model representing the life distribution according to temperature is shown in Equation (1).

$$\mathrm{L}(T) = A \cdot exp\left(\frac{E_a}{kT}\right)$$

A is the Arrhenius constant, E_a is the activation energy, k is the Boltzmann constant, and T is the absolute temperature. Based on the Arrhenius theory of Equation (1), the acceleration factor between the normal temperature condition and the accelerated temperature condition is calculated as shown in Equation (2).

$$\mathrm{AF} = \exp\left[\frac{E_a}{k}\left(\frac{1}{T_a} - \frac{1}{T_u}\right)\right]$$

In Equation (2), T_u is the steady state temperature, and T_a is the temperature under accelerated conditions. Through the calculated acceleration factor, the actual aging period compared to the acceleration time is calculated as in Equation (3).

$$t_u = t_a/AF$$

Here, the reliability of the initiator generally has the characteristics of a binomial distribution, and if the distribution for the shelf life of the initiator is an exponential distribution, the time that can guarantee the lifetime reliability R at the (1-a)% confidence level is expressed by the formula (4) can be calculated as follows.

$$t_u = B_{100(1-R)} \frac{\chi^2_\alpha(2r+2)}{2n[-\ln(R)]}$$

In Equation (4), t_u is the life under normal operating conditions, $B_{100(1-R)}$ is the life to be guaranteed, r is the allowable number of failures, and $x^2_{\alpha(2r+2)}$ is the chi-square distribution value with 2r + 2 degrees of freedom, n is the number of samples, and R is the reliability of the target life time. Finally, the accelerated aging test plan was established according to Equation (4), and the target reliability was set to 0.9 and the reliability level was set to 90% to confirm whether reliability was guaranteed during the life span of 20 years. When calculating the acceleration factor, the activation energy uses the results calculated in previous studies, and the number of allowable failures is set to 0.

3 An Example of a Simple Equation

After the establishment of the accelerated aging test plan is completed, the test is performed according to the plan. For this, an accelerated aging test is conducted while maintaining 200 samples at 70℃ in the same chamber as in Figure 3-(a), and after the aging tests are completed, perform a performance test by connecting to a closed bomb to measure three performance characteristics. (Figure 3-(b))

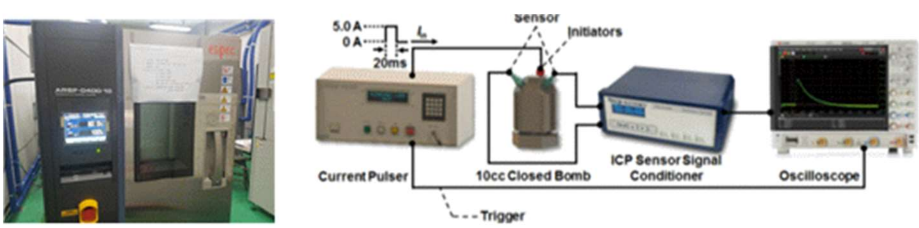

Figure 3: Environmental Chamber(a, left) and closed bomb test(b,right)

An example of performance test results is shown in Fig. 4, and the ignition delay time is the time when 10% of the maximum pressure is generated, and the time when the maximum pressure occurs is defined as the maximum pressure time.

Figure 4: Test result plot

As a result of the test, it was confirmed that all 200 of the 200 shots met the performance standard, and that the reliability of 0.9 (confidence level of 90%) was demonstrated 20 years after the target was set.

4 Conclusion

In this study, a method for verifying the lifespan and reliability of an electric initiator was studied by combining the accelerated aging test based on the Arrhenius theory and the Bayesian theory. To this end, the failure and aging characteristics of the initiator were first defined, and the aging characteristics were identified by performing FMEA according to MIL-STD-1629A. Based on the identified aging characteristics, an accelerated aging test plan was established to prove lifespan and reliability by applying the Arrhenius theory and Bayesian theory, and accordingly, aging tests and performance tests were conducted to confirm whether aging of the initiator performance occurred. did As a result of the test, it was confirmed that all 200 of the 200 samples satisfied the standard, and it was proved that the target reliability was satisfied through the test.

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