Proceedings of the 10th Annual World Conference of the
Society for Industrial and Systems Engineering,
2021 SISE Virtual Conference
September 23-24, 2021

An Introduction to the Accelerated Reliability Testing Method: A Literature Review

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Abstract: Accelerated testing is a primary tool in product and / or system design, so reliability can be assessed by applying accelerated life and accelerated degradation tests. This type of test allows obtaining information on the behavior of the life of a product by evaluating certain stress variables (for example, temperature, voltage, humidity, pressure, etc.). The experimentation consists of applying stress levels, in order to shorten the observation time and obtain data quickly. In this type of test, the acceleration variables are generally related to an empirical model, this when there is no complete knowledge of the physical and chemical phenomena of the process or system. Furthermore, with the relationship between the acceleration variables and the acceleration time, it is possible to observe the distribution of the product life. The objective of this work is to observe the generalities of the degradation tests and the applications found in the literature review.

Keywords: Reliability, Accelerated Life Tests, Accelerated Degradation Tests, Life Relationships

1. Introduction

Nelson (2004), comments that seeking to increase their competitiveness, companies design new products, adding new functions, new materials, or making improvements in production processes (Roberto et al., 2005), this generates an effect on their cycle life (Sanchez & Pan, 2011). In addition to this, innovation processes require the development of products that ensure reliability and therefore quality (Meeker & Hamada, 1995), and thus impact productivity. This shows the importance of reliability in processes and products (Meeker, 2010). It is noted that reliability is understood as the probability that a unit survives up to a specified time under normal conditions of use (Meeker, 2010). In turn, Lawless (2000), cited by Escobar, Villa, & Yañez (2003), mentions that "reliability refers to the proper functioning of equipment and systems, and includes software, hardware, human and environmental factors." While Evans & Lindsay (2008), mention that reliability can be defined as the probability that a product, piece of equipment or system offers the performance for which it was designed, during an established period, under the operating conditions that are specified. This implies that, by improving the reliability of the product, you will improve the competitiveness of the company.

Reliability is determined as the performance over the life of a product, this indicates that the search for quality is important but not sufficient since it must last for the time that the product was designed (Escobar et al., 2003). Given its characteristics, reliability can be directly assessed only after a product has been in service during design time. According to Meeker & Escobar (2004), the precise prediction of reliability presents challenges for its determination and analysis.

According to Evans & Lindsay (2008), reliability is determined indirectly, considering the number of failures per unit of time during the considered life period. For the reliability calculation according to Elsayed (2012), a wide variety of methodologies have been developed, which include tests to determine possible failure mechanisms, reliability acceptance tests, reliability prediction tests, accelerated life tests (ALT) among other. Some of the tests are a) Highly Accelerated Life Tests (HALT); b) Reliability Growth Test (RGT); c) High acceleration stress test (HASS); d) Demonstration of Reliability Test (RDT); e) Reliability acceptance test; f) Burning test or burn in; g) Built-in self-test (BIST); h) Accelerated life tests (ALT), and i) Accelerated degradation tests (ADT).

2. Methodology

The methodology followed for the literature review according to Hernandez (2010) implies detecting, consulting and obtaining the bibliography (references) and other materials that are useful for the purposes of the study, from where the relevant information has to be extracted and collected. and necessary to frame our research problem. In this sense, the key words of the research were identified in the first instance, being Reliability; Accelerated life tests; Accelerated degradation tests; Life-effort relationships, which are distinctive of the proposed research. Subsequently, the bibliography was compiled, making use of the databases that the Autonomous University of Ciudad Juárez (UACJ) has, selecting those articles that are most related to the purpose of this work. With the available information, the consultation was carried out in order to identify those that are relevant and discard those that are not. In the referred queries, the objective of the published work is observed, the problem to be solved by the authors, the methodologies used, and the results obtained are identified, in order to obtain relevant information for our study. In order to carry out a review of the literature on reliability and accelerated tests, we worked with 67 primary sources, including articles and books.

3. Accelerated Testing: An Overview

Accelerated tests (ATs) are widely used in reliability studies (Zhang & Meeker, 2006). According to Escobar & Meeker (2007), its use is greater in the manufacturing industry, where it is necessary to evaluate the reliability of the components and the subsystem, as well as to certify components, detect failure modes so that they can be corrected, compare different manufacturers, etc. According to Nelson (2004) the most common types of acceleration of the tests are: high rate of use, overvoltage, censorship, degradation, sample design and stress load.

Accelerated tests consist of experimenting at high levels of stress that shorten the shelf life of the product or accelerate the degradation of its performance (Nelson, 2005). Although exact reliability metrics are obtained using test data under normal operating conditions (Elsayed, 2012), these tests require more time, especially for components and products with long useful lives, therefore, the time necessary to test a sample of such devices tends to be excessive (Shaked & Singpurwalla, 1983), generating high costs; For this, there are techniques that allow to reduce testing time, such as accelerated life tests or accelerated degradation tests (Zhu & Elsayed, 2013). The main objective of accelerated test methods is to induce failure or degradation of components and / or systems in a much shorter time, to obtain the failure data or the degradation observations in accelerated conditions to estimate the reliability in normal conditions of functioning (Elsayed, 2012).

3.1. Accelerated Life Testing

The purpose of accelerated life tests (ALT) is to obtain information on the life distribution of a product, either in the design phase or in some modification (Mohammadian & Ait-Kadi, 2010). In these tests, the product is subjected to high stress levels, presenting failure in a shorter time than under the design conditions (Fard & Li, 2009). The data are analyzed and extrapolated using a model appropriate to the design conditions to estimate the life distribution of the product (Meeker, 2010). According to Zhang & Meeker (2015), levels of effort usually involve temperature, voltage, pressure, or combinations between them (Pascual, 2007). It should be noted that in the determination of guarantees we find an application where it is expected to have accurate predictions of the useful life of the product (Yang, 2010).

In accelerated life tests, according to Chung, Seo, & Yun (2006), different types of stress are applied, one of which is constant, where it is applied during the test period, and another of a staggered type. here the voltage changes, either in a fixed time or due to the appearance of a certain number of determined faults. According to Zhao & Elsayed (2005) constant stress levels are widely used in ALTs for modeling the life distribution of the product.

In this sense, according to Nelson (2005) the analysis is based on models that consist of a theoretical distribution of life whose parameters are functions of the acceleration variables and unknown coefficients to be estimated from the test data. He also points out (Nelson, 2004) that a statistical model for an accelerated life test consists of 1) a distribution of life that represents the dispersion in the life of the product and 2) a relationship, between "life" and stress. The life distributions in common use are: the exponential distribution, normal, lognormal, Weibull and values extremes. Where the relationships express a distribution parameter (such as a mean, percentile, or standard deviation) as a function of acceleration stress and possibly other variables, the most commonly used are 1) the Arrhenius relationship for accelerated temperature tests and 2) the inverse power relationship.

3.2. Accelerated Degradation Test

An accelerated degradation test (ADT) model consists of a performance distribution whose parameters are a function to accelerate the variables and the time of the test (Nelson, 2005). According to Tang et al. (2004) in ADT applications, it is important to identify the degradation characteristic that is correlated with the reliability of the product and, therefore, it will degrade over time (Rodriguez, 2017), resulting in the degradation path of this characteristic is considered as loss of performance. This means that when the performance characteristic exceeds a certain limit, the time of product failure is established (Boulanger & Escobar, 1994). This means that with those of the ADT it is possible to make inferences about the performance of the product under conditions of use and at operating times greater than the duration of the experiment (Boulanger & Escobar, 1994), this implies extrapolation in two dimensions: the stress and time. That is, ADTs provide information about the change (degradation) that is occurring in one or more characteristics of each device in the test long before a failure actually occurs (Boulanger & Escobar, 1994).

According to Wu, Yang, Wang, & Xue (2014), degradation has two main modeling aspects: 1) the stochastic process (Kharoufeh & Cox, 2005; Park & Padgett, 2006), in which degradation is a stochastic process based on two specific methods, one based on the theory of the non-stationary stochastic process or graphical method (Nelson, 1981; Wei & Dietrich, 2005) and the method based on the yield distribution and 2) the general approach of the degradation path (Freitas, Colosimo, Santos, & Pires, 2010), which considers degradation as an independent increase process such as the Wiener or Gamma process (Fan, Ju, & Sun, 2015; Pan & Balakrishnan, 2010), uses two methods 1) Mix of effects (Li & Kececioglu, 2006; Lu & Meeker, 1993) and 2) By approximation or pseudo-failure (Chen & Zheng, 2005).

3.3. Statistical models

According to Meeker & Escobar (2004), probability theory and statistical models and methods play an important role in reliability. Nelson (2004) points out that a statistical model for an accelerated life test consists of 1) a distribution of life that represents the dispersion in the life of the product and 2) a relationship between "life" and stress. Meeker (2001), for his part, mentions that the normal distribution is rarely used as a model and instead the log normal and Weibull distributions are used. However, Condra (2001) points out that there are many statistical probability distribution functions, among which he mentions the normal, log normal, Weibull, exponential, gamma, binomial, Poisson, Chi-square, etc., where the first four they are the most used in reliability. Table 1 shows the main life distributions with the functions used in reliability. On the other hand, models are required that relate the variables of acceleration, temperature, voltage, pressure with the acceleration time and thus interpret the data (Meeker & Escobar, 1998).

Table 1. Most used distributions in reliability (Condra, 2001)

Life distribution	Probability density function $f(t)$	Cumulative probability function $F(t)$	Reliability function $R(t)$	Hazard rate function $\lambda(t)$
Normal	$\frac{1}{\sigma\sqrt{2\pi}} exp\left[\left(-\frac{1}{2}\right)\left(\frac{t-\mu}{\sigma}\right)^2\right.$	$\frac{1}{\sigma\sqrt{2\pi}}\int_0^t exp\left[\left(-\frac{1}{2}\right)\left(\frac{x-\mu}{\sigma}\right)^2\right]dx$	$1-F(t)$	$\frac{exp\left[\left(-\frac{1}{2}\right)\left(\frac{t-\mu}{\sigma}\right)^2\right]}{\int_0^\infty exp\left[\left(-\frac{1}{2}\right)\left(\frac{x-\mu}{\sigma}\right)^2\right]dx}$
Log normal	$\frac{1}{\sigma t\sqrt{2\pi}} exp\left[\left(-\frac{1}{2}\right)\left(\frac{\ln t -}{\sigma}\right.\right.$	$\frac{1}{\sigma\sqrt{2\pi}}\int_0^t \frac{1}{x} exp\left[\left(-\frac{1}{2}\right)\left(\frac{\ln x-\mu}{\sigma}\right)\right.$	$1-F(t)$	$\frac{f(t)}{1-F(t)}$
Weibull	$\frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} exp\left[-\left(\frac{t-}{\eta}\right.\right.$	$1-exp\left[-\left(\frac{t-\gamma}{\eta}\right)^\beta\right]$	$exp\left[-\left(\frac{t-\gamma}{\eta}\right)^\beta\right]$	$\frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1}$
Exponential	$\lambda\exp(-\lambda t)$	$1-\lambda\exp(-\lambda t)$	$exp(-\lambda t)$	Λ

3.4. Models in Accelerated Testing

According to Escobar & Meeker (2007), for the analysis of accelerated test data, it is required to relate acceleration variables, and these are adjusted to a model to describe the effect that the variables have on the processes that cause failures. Condra (2001) mentions that mathematical models are used to relate the behavior of the elements at one level of stress to their behavior at another level. However, when there is little understanding of the chemical or physical processes that lead to failure, the only alternative is to develop an empirical model that provides an excellent fit with the available data (Escobar & Meeker, 2006). The functional relationship according to Proschan & Singpurwalla (1980) is known as the acceleration function or the time transformation function; examples of these are the Law of Power, the Arrhenius Law, and the Eyring Law. The models are also known in the literature as life-effort relationships, the most common are shown in Table 2 related to the acceleration factor (Zhao & Elsayed, 2005).

Table 2. Most common life-stress relationships and their acceleration factor (Zhao & Elsayed, 2005)

Relationship	Model	Acceleration Factor
Arrhenius	$C\exp\left(\frac{B}{V}\right)$	$\exp\left(\frac{B}{V_0}-\frac{B}{V_s}\right)$
Invers Power Law	$\frac{1}{KV^l}$	$\left(\frac{V_s}{V_0}\right)^l$
Eyring	$\frac{1}{V}\exp\left(-\left(a-\frac{B}{V}\right)\right)$	$\frac{V_s}{V_0}\exp\left(B\left(\frac{1}{V_0}-\frac{1}{V_s}\right)\right)$
Temperature - Humidity	$A\exp\left(\frac{\varphi}{V}+\frac{b}{U}\right)$	$\exp\left(\varphi\left(\frac{1}{V_0}-\frac{1}{V_s}\right)+b\left(\frac{1}{U_0}-\frac{1}{U_s}\right)\right)$
Non-Thermal Temperature	$\frac{C\exp\left(\frac{B}{V}\right)}{U^n}$	$\left(\frac{U_s}{U_0}\right)^n\exp\left(B\left(\frac{1}{V_0}-\frac{1}{V_s}\right)\right)$

4. Applications

Some applications are, for example, those reported by: Liu, Li, & Jiang (2017) who propose a new method for accelerated degradation tests, under different types of accelerated stress with dependence, For his part, Peng (2017), applied Bayesian methods to estimate and correct an accelerated life model proposing an evaluation method, while He & Fu (2017) conducted experiments to test whether the electrical fatigue failure in dielectric devices can be adjusted using a function that has the same mathematical expression as the law de Coffin-Manson, Sun, Liu, Li, & Liao (2016a) propose a reliability evaluation method that combines Brownian motion and copulas to model the ADT data obtained from vibration signals, in turn Liu, Li, Sun, & Wang (2016), propose a general ADT model based on the Wiener process to solve the problem of accelerated degradation data analysis, considering the variation from unit to unit and the temporal variation of the degradation process, likewise Rodríguez-Picón, Rodríguez Borbón, Valles-Rosales, & Flores Ochoa (2016), propose two degradation models based on the Arrhenius relation and the inverse power law relation, describing the interaction through the copulate function, and they use the Bayesian method to estimate the model parameters. For their part, Bai & Chung (1989) consider an accelerated life test model in which the units are tested under conditions of constant multiple stress or progressive stress and that obeys the inverse power law.

5. Conclusions

Advances in technology and the need to develop more sophisticated products and equipment, has forced manufacturing companies to comply not only with high quality in their production systems, but also in the search to be more competitive and stay in the markets, they must ensure the reliability and safety of their products. For years, methods for obtaining information have been perfected, being able to experiment with the variables that cause failure more quickly, and extrapolating the information to normal conditions of use. The designed tests, being accelerated life tests or accelerated degradation tests, allow obtaining data to model the life distribution of the product and calculate its reliability, which in turn allows to establish the guarantee limits of the product design. These tests are a useful tool in determining potential applications with the failure data obtained through experimentation. Accelerated tests are thus an excellent tool for evaluating and improving the reliability of products or systems, in order to meet the current demands of customers and users.

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