5th International Conference
″Computational Mechanics and Virtual Engineering ″
COMEC 2013
24- 25 October 2013, Braşov, Romania

RELIABILITY AND ENVIRONMENTAL DEGRADATION OF COMPOSITE MATERIALS USING ACCELERATED METHODS

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Abstract: *This paper presents research about accelerated degradation data and a simulation of composite materials using Monte Carlo method. The statistical processing was realized using the ALTA 7 software. The goal of this work is to produce information, which can be subsequently used to determine the indicators of reliability (reliability function, unreliability function, probability density function, mean time to failure, failure rate and acceleration factor), methods of suitable protection and necessary maintenance intervals for composite materials (CFRP carbon-fiber-reinforced polymer). The case study is represented by a set of data from accelerated tests with one environmental stress - temperature.*

Keywords: *reliability, CFRP, accelerated tests, degradation*

1. INTRODUCTION

A composite material is defined as a material which is composed of two or more materials at a microscopic scale and has chemically distinct phases. Thus, a composite material is heterogeneous at a microscopic scale but statistically homogeneous at macroscopic scale. The materials which form the composite are also called as constituents or constituent materials. The constituent materials of a composite have significantly different properties. Further, it should be noted that the properties of the composite formed may not be obtained from these constituents. However, a combination of two or more materials with significant properties will not suffice to be called as a composite material. In general, the following conditions must be satisfied to be called as a composite material [4]:

- The combination of materials should result in significant property changes. One can see significant changes when one of the constituent material is in platelet or fibrous from;
- The content of the constituents is generally more than 10% (by volume);
- In general, property of one constituent is much greater (≥5) than the corresponding property of the other constituent;

There are three important kinds of composites as shown in figure 1.

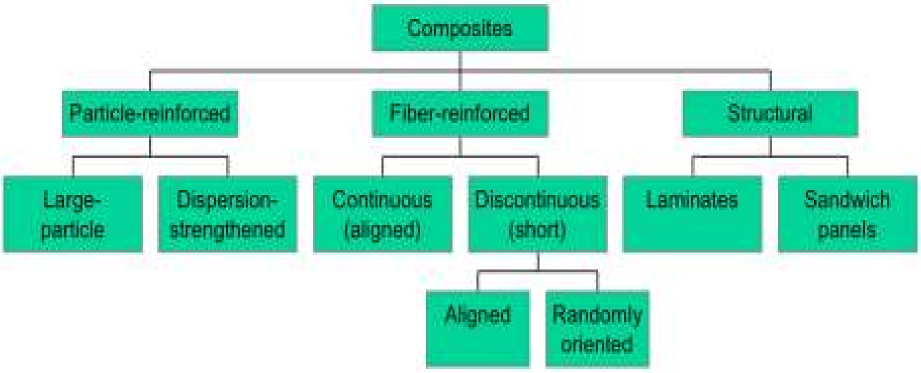

Figure 1: Classification of Composites [4]

In this paper will present the information about CFRP composites testing and durability, description of the simulation tests, mechanical properties and general areas of application. Carbon Fiber Reinforced Polymers (CFRP) is characterized by the following properties (figure 2).

Figure 2: CFRP properties

Carbon Fiber Reinforced Polymers (CFRP) are used for manufacturing: automotive marine and aerospace parts, sport goods (golf clubs, skis, tennis racquets, fishing rods), bicycle frames.

2. RELIABILITY AND DEGRADATION OF COMPOSITE MATERIALS

Given the fact that materials today are often designed with high reliability, even accelerated life testing may not yield enough failures to estimate material reliability in a short period of time. Degradation analysis is an effective reliability analysis tool for materials that are associated with a measurable performance characteristic, such as the wear of brake pads, increase in vibration or the propagation of crack size. Many failure mechanisms can be directly or indirectly linked to the degradation of materials. Failure occurs when the degradation value reaches a predefined critical level. Degradation analysis allows users to extrapolate failure times based on the measured degradation data during the degradation test. To reduce testing time even further, degradation tests can be conducted at elevated stresses. Material reliability at the use stress level can then be estimated using the accelerated degradation test data. In this article, we will show an example of degradation model analysis using ALTA 7 [7].

The analysis of degradation data is one way to overcome these obstacles to obtain the information required to make effective business decisions regarding warranty periods and/or to demonstrate that the material meets the reliability specifications of the customer. Degradation analysis involves the measurement of the degradation of a material, where the degradation can be directly related to the expected failure of the material. This information is then used to estimate the eventual failure time for the material.

Degradation analyses can be performed on data obtained under normal use conditions or under accelerated stress conditions. ReliaSoft's Weibull++ 7 software allows you to extrapolate time-to-failure information from degradation data obtained under use conditions and ALTA 7 allows you to take accelerated stress levels into account. This article presents the methodology behind degradation analysis and example (CFRP composites) of its application under both normal and accelerated conditions.

In order to use degradation data to estimate times-to-failure for the material, the degradation factor that is being measured must be directly related to a failure mechanism for the material and there must be a definite level of degradation at which a failure is said to have occurred. In some cases, it is possible to directly measure the degradation over time, as with the wear of brake pads or with the propagation of crack size. In other cases, it may not be possible to directly measure the degradation without invasive or destructive measurement techniques that would directly affect the subsequent performance of the material. In such cases, the degradation can be estimated through the measurement of certain performance characteristics, such as using resistance to gauge the degradation of a dielectric material. Performance and degradation data are analyzed in a similar manner [5].

Once you have determined the degradation factor that eventually results in material failure, devised a method to measure the degradation and defined the level of degradation at which the material is considered to be "failed," the next step is to measure the degradation for multiple units over time and record the results. As with conventional reliability data, the amount of certainty in the results is directly related to the number of units being tested. With this information, it is a relatively simple matter to use basic mathematical models to extrapolate the degradation measurements over time to the point at which the material is expected to fail. You can then analyze these estimated failure times with standard life data analysis techniques and obtain standard reliability results, like mean time, warranty time and B(X) life [7].

3. CASE STUDY

3.1. Methods and materials

Accelerated reliability/durability testing is experiments in which: the physics (or chemistry) of degradation mechanism (or failure mechanism) is similar to the mechanism in the real operation using a given criteria; the measurement of reliability and durability parameters (time to failure, degradation and service life) have a high correlation with these respective measurements in the real operation a given criteria. Durability is the ability of a product (material, component) to perform a given function under given condition of use and maintenance until reaching a limiting state [1].

Accelerated reliability/durability testing has the same basis – an accurate simulation of the field situation, and then there is no ART and ADT. The only difference is in the parameters of these types of test and the length of testing. For reliability, it is usually the mean time to failure (MTTF), time between failures (TBF). For durability, it is length of time (hours, months or year) or volume out of service [3].

ART and ADT is used with metals, including test coupons and actual parts, as well as composites, welds, bonds, and other joints. Performance included fatigue life, creep, creep-rupture, crack initiation and propagation, wear, corrosion, oxidation. Accelerated stresses include the mechanical stress, temperature, specimen geometry and surface finish. Chemical acceleration factors include humidity, salt, corrosives, and acids. Most metals deteriorate by chemically reaction with oxygen (oxidation) acids, fluorine, alkalis, salt and water

The test specimens (figure 3) were stressed and inspected every 100.000 cycles for crack length. Failure is defined as a crack of length 1,5 mm or greater.

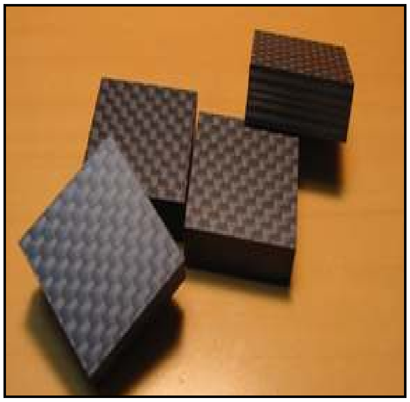

Figure 3: CFRP specimens [6]

In general, the accelerated reliability testing can be divided into two categories: qualitative ALT and quantitative ALT. Qualitative ALT, such as Highly Accelerated Life Testing (HALT), Highly Accelerated Stress Screening (HASS), torture tests, shake and bake tests, are used primarily to reveal probable failure modes for the product so that product engineers can improve the product design. Quantitative ALT consists of tests designed to quantify the life characteristics of the product, component or system under normal use conditions and thereby provide reliability information [2].

When properly implemented, highly accelerated life testing (HALT) and highly accelerated stress screening (HASS) quickly uncover problems associated with product design and production. Both rely on techniques that shorten the time required to identify potential causes of failure. This is done by applying much higher stresses than exist in actual product use, which forces failures to occur in significantly less time than under normal conditions.

In HALT, temperature and vibration stress conditions are used during product development to find weak spots in the product design and its planned fabrication processes. Other test stimuli may include humidity, thermal cycling, burn-in for a specified period of time, over-voltage, voltage cycling, and anything else that could logically expose defects.

This requires only a few units and a short testing period to identify the fundamental limits of the technology being used. Generally, every weak point must be identified and fixed (redesigned) if it does not meet the product's specified limits. In production, HASS employs high stress, frequently well beyond the qualification level, but not at the extreme stress levels conducted in HALT tests. Appropriate proof-ofscreen1 techniques must be used to protect good product, and HASS usually is not possible unless comprehensive HALT was done earlier (because fundamental design limitations will tend to restrict HASS stress levels). The stresses used in HALT and HASS require unique test equipment (Figure 4).

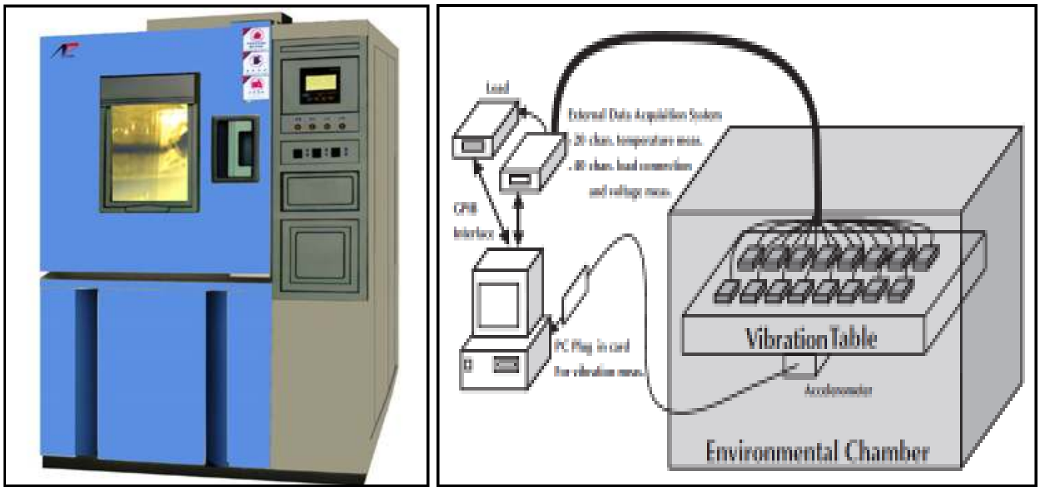

Figure 4: HALT/HASS Chamber with Temperature and Vibration Cycling [2]

3.2. Accelerated Degradation Analysis

The specimens were cyclically stressed and inspected every 100,000 cycles for crack length. Failure is defined as a crack of length 15mm or greater. The test results are presented in Table 1.

Table 1: Degradation Data

Cycles [min]	Temperature [°C]	Unit A [mm]	Unit B [mm]	Unit C [mm]	Unit D [mm]	Unit E [mm]
100000	150	10	10	17	12	10
200000	250	13	15	25	16	15
300000	300	16	20	26	17	20
400000	400	17	25	27	20	26
500000	500	19	29	33	26	33

Can be use degradation analysis with an exponential model for failure extrapolation to determine reliability indicators for the CFRP specimens. The first step is to solve the equation,

$$y = \mathrm{b} \cdot \mathrm{e}^{\mathrm{a} \cdot \mathrm{x}}, \tag{1}$$

or a and b for each of the test specimens. Using regression analysis, ALTA 7 calculates these values for each of the test specimens. These values can then be substituted into the underlying exponential model, solved for x or:

$$\mathrm{x} = \frac{\ln(\mathrm{y}) - \ln(b)}{a} \tag{2}$$

Using the values of a and b with y = 15, can be calculate the point at which the length is expected to reach 15mm for each test specimens. A plot of the degradation analysis is presented in figure 5.a and the extrapolated cycles-to-failure are shown in the ALTA 7 Degradation Analysis utility in figure 5.b.

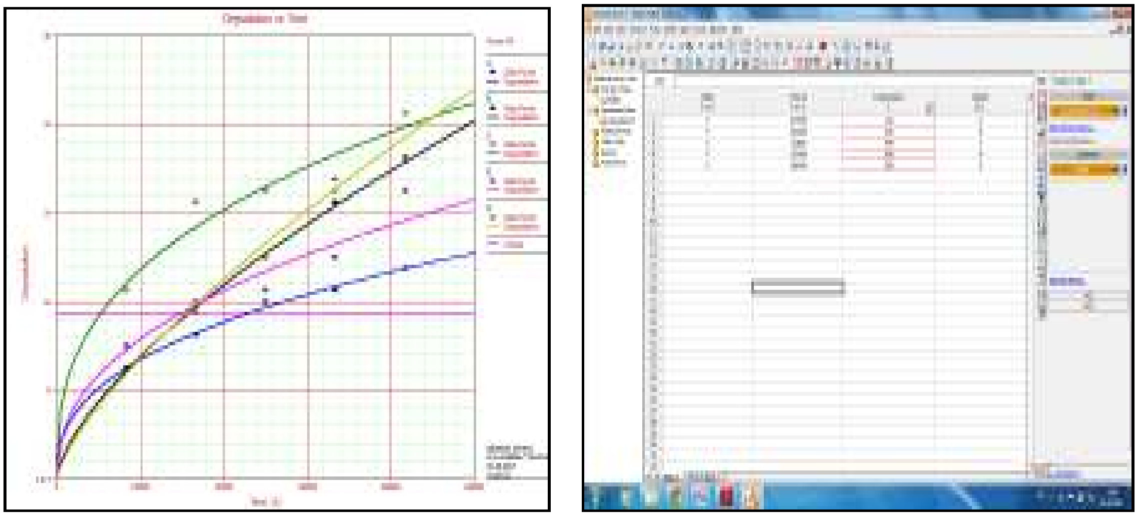

Figure 5: Plot degradation
a) Plot of degradation results from ALTA 7 b) Extrapolated cycles-to-failure data

Can be use ALTA 7 Degradation Analysis utility to extrapolate times-to-failure data points at each accelerated stress level, based on the accelerated degradation data and the exponential degradation model. When the extrapolated data points are transferred to an ALTA Data Folio, we obtain reliability indicators and other plots.

The reliability function represents an essential quantitative measure of reliability and has an important practical utility in the study of accelerated reliability tests. The unreliability function shows out the lack of reliability of the ball bearings. The reliability and the unreliability depending on the number of hours until failure and on the stress level in normal testing regime (50°C). The values of the reliability function and of the unreliability function are plotted in figures 6 a ,b.

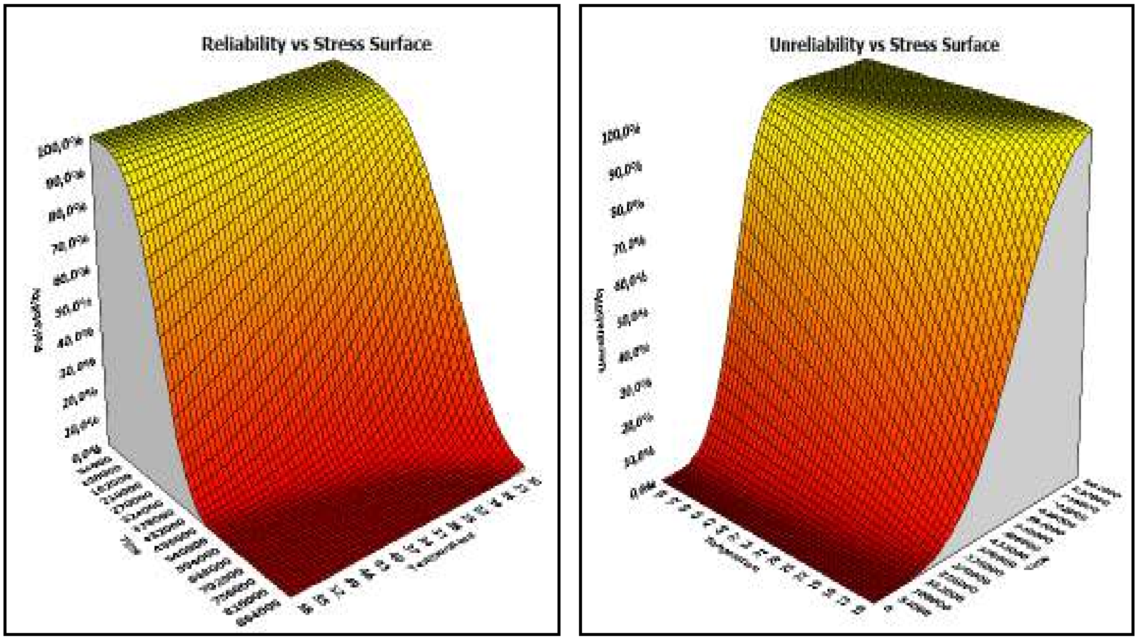

Figure 6: Plot of reliability indicators
a) Reliability function b) Unreliability function

A pdf plot represents the relative frequency of failures as a function of time and stress. The pdf plot is important in most reliability applications than the other plots available in ALTA, it provides a good way of visualizing the distribution and its characteristics such as its shape, mode, etc. The pdf is a function of time and stress (figure 7,a). The failure rate function enables the determination of the number of failures occurring per unit time. This gives the instantaneous failure rate, also known as the hazard function. It is useful in characterizing the failure behavior of composite materials, determining maintenance crew allocation, planning for spares provisioning, etc. Failure rate (figure 7,b) is denoted as failures per unit time.

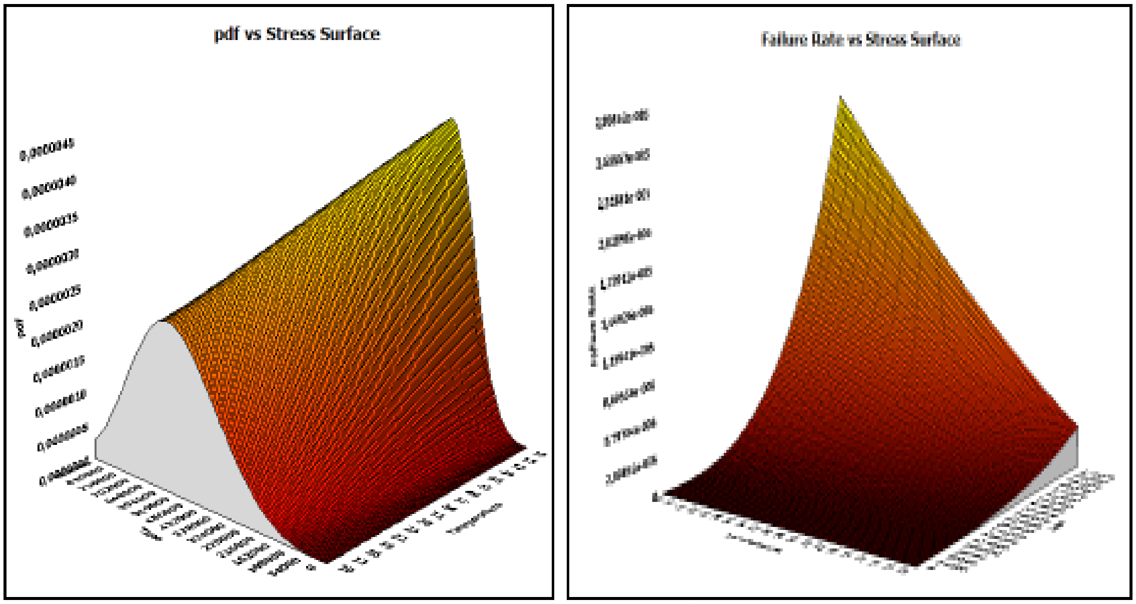

Figure 7: Plot of reliability indicators

a) Probability density function b) Failure Rate

3. CONCLUSION

At some industrial materials (from the aviation, nuclear and electronic fields), for which a high reliability is estimated, the determination of the life time and of the reliability parameters, under normal stress conditions, implies a long testing period. For this reason we opted for the accelerated reliability testing methods. We can observe that, by using the accelerated reliability tests, the testing time has been reduced by 9 times. These are tests being performed at more intense stress conditions, compared to the normal stress conditions, with the purpose of intensifying the degradation processes and, as an economic result, the shortening of the period and costs related to the testing, while preserving the same failure modes and mechanisms. In conclusion, ART is commonly practiced in product life testing and analysis. ART is used to shorten the period between product design and release time and to improve the product performance and reliability. The determination of the warranty period for minimizing the warranty costs, increasing customer satisfaction, and maintaining scheduling are among the objectives of ART.

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