ADVANCES IN COMPOSITE MATERIALS - ECODESIGN AND ANALYSIS

Edited by **Brahim Attaf**

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Preface

Studies and research activities conducted in the field of high-technology materials show that advanced composite materials are successfully used in key components for many fields of applications, from aerospace & automobile industries, marine construction, renewable energy, modern medicine to micro-/nano-material technologies, including other more complex civil and mechanical engineering assemblies. In addition to this variety of applications, the considerable increase in demand of these smart materials will open up many opportunities to design and manufacture new products for the future. However, these products have to satisfy sustainable development requirements, which can be achieved by a balanced equation that simultaneously guarantees economic growth and environmental protection.

According to these ecological considerations, researchers and industrials involved with high-technology composite materials are strongly encouraged to integrate ecodesign aspects into the composite product lifecycle, providing then a better assessment of environmental and health performances. Furthermore, "going green" can also contribute to the world's socio-economic well-being and living conditions for present and future generations.

By adopting these principles of sustainable design, I am pleased to have this opportunity to edit this new book, which opens a new challenge in the world of composite materials and explores the achieved advancements of specialists in their respective areas of research and innovation.

The scientific and technological research contributions coming from both spaces of academia and industry were so diversified that the 28 chapters composing the book have been grouped into the following main parts:

- *Sustainable materials and ecodesign aspects*: research was focused on the integration of environmental aspects in the different stages of the design process, development of eco-friendly, non-asbestos and fully biodegradable macro-/micro-/nano-composite materials exhibiting less pollution and waste.

- *Composite materials and curing processes*: investigations were undertaken on some technologies of fabrication and on the simulation of the curing process with a reduction of VOC emissions and energy consumption.

- *Modelling and testing of composites*: studies were conducted on mechanical characterization, tolerance analysis, fluid-structure interaction, buckling phenomenon, delamination growth and stress analysis using in one hand numerical approaches, such as finite element method and on the other hand experimental investigations.

- *Stress-strength analysis of adhesive joints*: experimental testing, design formulas and FE codes were used to predict the failure strength of the joint and evaluate the structural behaviour of the damaged elements that were repaired and reinforced with adhesive layers.

- *Characterization and thermal behaviour:* properties of composite material devices for high demanding applications were investigated experimentally and numerically.

The results achieved from theoretical, numerical and experimental investigations can help designers, manufacturers and suppliers involved with high-tech composite materials to boost competitiveness and innovation productivity. Specific recommendations are to give much more focus and attention to (i) the chemical substances used in the manufacturing process, (ii) the amount of VOC emissions, (iii) the enhancement of quality-health-environment performance, (iv) the amount of waste produced, expired materials and ways of recycling, (v) the classification of companies and firms with regard to the new regulations and eco-standards, and more...

The editor would like to thank all Chapter Authors for their remarkable contributions coming from all around the world and appreciate the resulting synergy between academia and industry. Without this rich variety of contributions, the existence of the Book *"Advances in Composite Materials- Ecodesign and Analysis"* would not have been possible.

I also wish to acknowledge the help given by InTech Open Access Publisher staff, in particular Ivana Lorković for her assistance and support.

January 2011

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Part 1

Sustainable Materials and Ecodesign Aspects

1

Generation of New Eco-friendly Composite Materials via the Integration of Ecodesign Coefficients

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1. Introduction

Thanks to their excellent formability, their mass-saving advantage, their high stiffness-to-density and strength-to-density ratios, *i.e.,* E/ρ and σ/ρ and the greater freedom to tailor these high properties in the desired orientation and position, fibre-reinforced polymer (FRP) composites are used in many fields of engineering, from architectural structures, ship superstructures, automobiles, bridge decks, machine parts, dams and reservoirs, to the high technology of the modern aerospace industries (Attaf & Hollaway, 1990a,b). Furthermore, these lightweight materials have some precise objectives, which cannot be reached with some other conventional materials. These attractive advantages coupled with economic design have lead to open up many opportunities to design and manufacture new composite materials and structures for future applications. However, these materials have to satisfy ecodesign requirements, which are based on new standards for designing environmentally-friendly composite products. Within this context, the industrial designers, manufacturers and suppliers who work in the field of composites are having to factor in the impacts of their products on the environment and find new feasible alternatives. Typically, these alternatives are based on a set of equations, called "ecodesign function" (Attaf, 2007). This function must guarantee quality assurance, health protection and environmental preservation all at the same time, making it necessary to come up with ecodesign strategies that include cleaner production, so as to be in compliance with new regulations and still make the product more competitive in the worldwide market.

With this approach as an objective, codes and standards for future composite materials and structures should integrate, at each stage of the designing process, three balanced key criteria characterised mainly by quality assurance (Q for short), health protection (H for short) and environmental preservation (E for short). To achieve these requirements, we have defined and developed new criteria in the form of coefficients. Taking into account the previously specified ecological considerations, these coefficients are now called "eco-coefficients". To assess these eco-coefficients, probability approach (Attaf, 2009) and optimisation procedures based on additive colours technique are undertaken in this analysis. And once these eco-coefficients are determined and approved by ecodesign standards, they can then be integrated into the formulations of design and analysis, in characterisation tests; they can also be implemented into future finite-element computer

programs, etc. In addition, by simply undertaking a comparison of eco-results with classical ones, which do not take into account eco-coefficients, designers and analysts can make better use of ecodesign aspects to assess environmental and health performances.
The aim of this investigation is regarded as: (i) a stimulation for innovation, sustainability and research activities within the field of ecodesign of composite materials and structures; and (ii) an encouragement for designers and engineers involved with high-technology composite materials to have more motivation towards the integration of *Q-H-E* aspects into the development process of FRP products.

2. Ecodesign of composite materials and structures

2.1 Position of ecodesign approach within sustainable development concept

According to most scientific results related to the protection of biodiversity, global warming and climate change may have severe effects on human health and the environment. To improve the well-being and living conditions of present and future generations, it is important that the negative impacts generated from human and industrial activities should be seriously considered in all design phases of a new development. To this end, the sustainable development concept is a strong key issue aiming to achieve the previously discussed objective, which is obviously based on three main criteria or "pillars"; these are: (i) environmental sustainability, (ii) economic sustainability and (iii) social sustainability. As the concept of sustainable design or simply ecodesign is inseparable from the sustainable development concept, it is therefore an undissociable part of it, where quality assurance, health protection and environmental preservation aspects are considered to be important branches belonging to the previously described main pillars. Figure 1 illustrates the specific ecodesign situation in relation to the sustainable development concept.

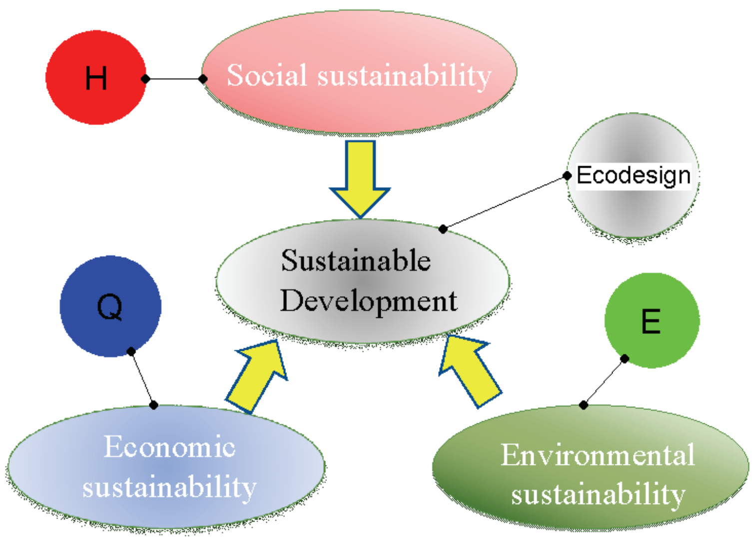
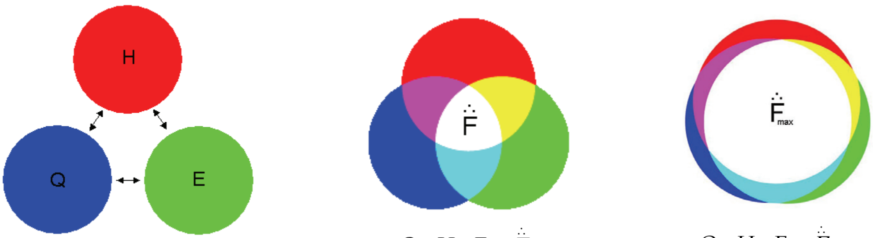


Fig. 1. Ecodesign approach *vs.* sustainable development concept

2.2 Evolution of the interaction between Q-H-E aspects

The main condition of ecodesign can be reached when the interaction between *Q*, *H*, *E* aspects yields a common area of intersection between these aspects, *i.e.*, $Q \cap H \cap E$. The original diagram (Figure 2a) shows health, quality and environment as three separate aspects that operate independently from each other. Joining the *Q*, *H*, *E* aspects gives rise to a new diagram fulfilling the ecodesign condition (Attaf, 2007) that is characterised by the subset $\overset{\therefore}{F}$ resulting from this intersection (Figure 2b). The three dots (∴) above the character *F* are only a brief description of the diagram illustrated in Figure 2a, showing interaction between health, quality and environment aspects. In other terms, the three dots represent the three pillars that characterise the basic elements of the sustainable development concept, as discussed above (Figure 1).

Depending on the resultant area of interaction, an optimisation process can be applied to subset $\overset{\therefore}{F}$ to maximise this area. If optimisation is highly improved ($\overset{\therefore}{F} = \overset{\therefore}{F}_{max}$), then the future diagram illustrated in Figure 1c is achieved and the searched objective is reached, however.



$Q \cap H \cap E = \varnothing$ $\qquad$ $Q \cap H \cap E = \overset{\therefore}{F}$ $\qquad$ $Q \cap H \cap E = \overset{\therefore}{F}_{max}$

(a) original diagram **(b) actual diagram** **(c) future diagram**

Fig. 2. Evolution of the interaction between *Q*, *H*, and *E* aspects

2.3 Ecodesign model and sample space

As it was shown in Figure 2c, the interaction between the three *Q-H-E* aspects yields the apparition of a certain number of events, which are illustrated in Figure 3. Each event is assumed to accomplish one or several functions that are defined by the following subsets (Attaf, 2007)

- Subset *A* (■): characterized by an assured quality, a non-protected health and a non-preserved environment.
- Subset *B* (■): characterized by an assured quality, a protected health and a non-preserved environment.
- Subset *C* (■): characterized by a non-assured quality, a protected health and a non-preserved environment.
- Subset *D* (■): characterized by a non-assured quality, a protected health and a preserved environment.
- Subset *S* (■): characterized by an assured quality, a non-protected health and a preserved environment.
- Subset $\overset{\therefore}{F}$ (□): characterized by an assured quality, a protected health and a preserved environment.

- Subset G (■): characterized by an assured quality, a non-protected health and a preserved environment.

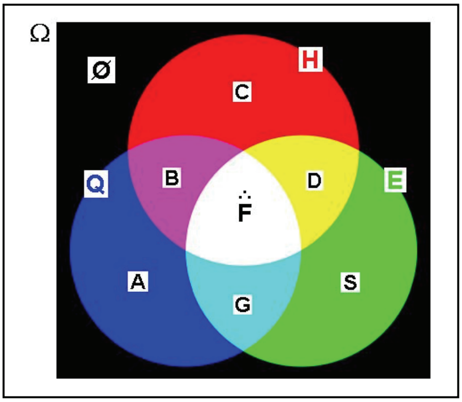


Fig. 3. Diagram showing the ecodesign model and the outcome subsets

The possible outcome sets and subsets can be expressed by the universal sample space as (Attaf, 2007)

$$\Omega = \{ Q, H, E, A, B, C, D, S, G, \dddot{F}, \varnothing \} \quad (1)$$

in which,

$A = Q \cap \overline{H} \cap \overline{E}$ $\quad B = Q \cap H \cap \overline{E}$ $\quad C = \overline{Q} \cap H \cap \overline{E}$

$D = \overline{Q} \cap H \cap E$ $\quad S = \overline{Q} \cap \overline{H} \cap E$ $\quad G = Q \cap \overline{H} \cap E$

$\dddot{F} = Q \cap H \cap E$ $\quad \varnothing = \overline{Q} \cap \overline{H} \cap \overline{E}$

where, $\cap$ denotes intersection symbol, and $\overline{Q}$, $\overline{H}$, $\overline{E}$ are the complement of Q, H, E and indicate that ''*Quality non-realizable*'', ''*Health non-realizable*'' and ''*Environment non-realizable*'', respectively.

The subsequent analysis will concentrate only on the subset $\dddot{F}$, a unique searched subset that characterises the event: "intersection between Q, H and E does exist all the time".

3. Application of probability principles to ecodesign function

3.1 Probability approach

To illustrate the model-set probability, let us consider the sample space Ω that contains all the possible subsets (events) defined by Equation (1) and illustrated in Figure 3. Since the three key sets Q, H and E are composed of several variable elements associated to the different stages involved in the design process where each key set is assumed to fulfil a specific function; it can therefore be written that (Attaf, 2007):

$$\begin{aligned} Q &= \{ x_1, x_2, x_3, \ldots\ldots, x_m \} \\ H &= \{ y_1, y_2, y_3, \ldots\ldots, y_n \} \\ E &= \{ z_1, z_2, z_3, \ldots\ldots, z_p \} \end{aligned} \quad (2)$$

For better visualisation of different issues and calculation of the possible outcome probabilities, it is convenient to construct the probability tree diagram providing simple probabilistic measure. Figure 4 illustrates the different branches representing the possible events (Attaf, 2009).

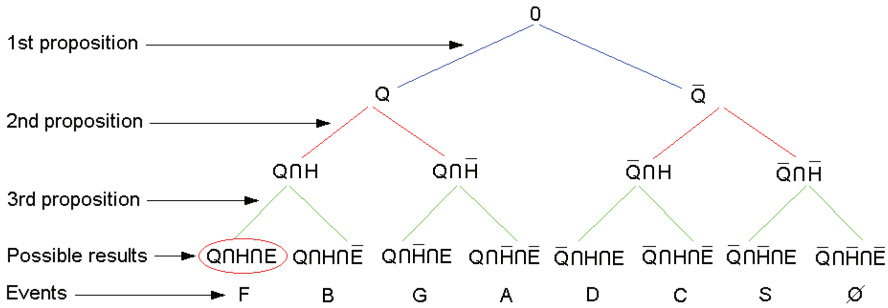


Fig. 4. Probability tree diagram and possible events

The probability theory will be applied to investigate the behaviour of the subset $\overset{\therefore}{F}$, identified by the encircled area in Figure 4. As a result, the corresponding event and its associated probability can respectively be written as (Attaf, 2007 & 2009)

$$\overset{\therefore}{F} = Q \cap H \cap E \tag{3}$$

$$P(\overset{\therefore}{F}) = P(Q \cap H \cap E) \tag{4}$$

3.2 Ecodesign function

The probability $P(\overset{\therefore}{F})$ represents the searched ecodesign function; a function that has multiple variables and lies between the values of 0 and 1, and is defined by $f(Q=x_i, H=y_i, E=z_i)$. However, according to the nature of sets Q, H and E (independent or dependent) and the rules of multiplication in the probability theory, two possible cases (Figures 2a and 2b) may be presented; these are:

a. The sets Q, H, E are independent (Figure 2a): a condition which does not satisfy the searched objective because the probability of the intersection is an empty set. Thus, it may be expressed by the following equation:

$$f(Q=x_i, H=y_i, E=z_i) = P(\overset{\therefore}{F}) = P(\varnothing) = 0 \tag{5}$$

b. The sets Q, H, E are dependent (Figure 2b and/or 2c): a condition that does satisfy the searched objective. Thus, the probability of the occurred intersection can be written as:

$$f(Q=x_i, H=y_i, E=z_i) = P(\overset{\therefore}{F}) = P(Q) \times P_Q(H) \times P_{Q \cap H}(E) \tag{6}$$

where, $P(Q)$ represents the probability of an achievable quality;

$P_Q(H)$ represents the probability of an achievable health, knowing that quality has been achieved; and

$P_{Q \cap H}(E)$ represents the probability of an achievable environment, knowing that quality and health have been achieved.

The following probability notations may be of some use in a certain literature reviews:

$$P_Q (H) = P(H | Q) = P(Q \cap H) / P(Q) \tag{7a}$$

$$P_{Q \cap H} (E) = P(E | Q \cap H) = P(Q \cap H \cap E) / P(Q \cap H) \tag{7b}$$

Equations (7a) and (7b) are only valid when $P(Q)$ and $P(Q \cap H)$ are strictly greater than zero. On the other hand and according to the probability analysis, the realization of the event $\ddot{F}$ can take several values as a final result. This latter can be recapitulated by the following possible events (Attaf, 2007):

- If probability value is null ($P(\ddot{F}) = 0$), then the event is impossible.
- If probability value is equal to 1 ($P(\ddot{F}) = 1$), then the event is certain.
- If probability value is located between the two extreme values ($0 < P(\ddot{F}) < 1$), then it does exist a series of probable events.

3.3 Practical descriptions of the variable probability elements

To be familiar with the probability variable elements expressed by Equation (2), let us consider for example the statement "*quality-assurance aspect is achievable and sustainable for the mould polymerisation process*" and we let the letter "x" denotes the property named "*quality-assurance aspect is achievable and sustainable*" and the subscript "k" refers to the stage number involved in the design process, which corresponds here to "*mould polymerisation process*", we can then characterise the above statement as "x_k". For instance, if the subscript k=4, then the statement can be represented as "x_4". The circular limit line labelled "Q" shown in Figure 3 encompasses the region that contains all the members that have the same property "*quality-assurance aspect is achievable and sustainable*" ($x_1 , x_2 , \ldots.., x_m$).
Proceeding in the same manner as previously, we may characterise the statement "*environment-protection aspect is achievable and sustainable for resin type*" as "z_k", where the letter "z" denotes the property named "*environment-protection aspect is achievable and sustainable*" and the subscript "k" denotes the stage number involved in the design process which corresponds here to "*resin type*". For instance, if the subscript k=2, then the previous statement will be symbolised as "z_2". The circular limit line called "H" shown in Figure 3 encompasses the region that contains all the members that have the same property "*environment-protection aspect is achievable and sustainable*" ($z_1 , z_2 , \ldots., z_p$).
According to this representation for modelling, the property is always symbolised with a letter x, y or z associated to quality, health or environment, respectively. Whereas the stage number involved in the design process is symbolised with a subscript k ($k=1,2,\ldots, N$). The statement is denoted by "x_k", "y_k" or "z_k".

4. Ecodesign coefficients

4.1 Identification of the eco-coefficients

As there are N successive stages in the design process, we found it convenient to assign to each of Q, H and E aspects a specific coefficient representing the probability of approval. When ecological considerations are taken into account, these coefficients are now called "eco-coefficients". From this standpoint, it may for stage (k) be assumed that:

- $\alpha = P(Q = x_k)$ is an eco-coefficient representing the probability of approval in terms of quality assurance,