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Sustainable Design of Automotive Components through Jute Fiber Composites: An Integrated Approach

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1. Introduction

Nowadays, the world faces unprecedented challenges in the social, environmental and economic dimensions. Industrial design has an important contribution shown in all of these dimensions with solutions that provide positive answers. In particular, due to its relevance, the automotive industry confronts a moment of crisis, and based on the ecodesign of products it has been transforming the challenges in opportunities.

In the broad sense of Bertalanffy's (1969) theory, earth and its inhabitants form a single live body in constant evolutive dynamics, in which the human activity influences and is influenced by the environment. Since natural and artificial systems work in holistic relationship, synergy between and self-organization of living organisms maintains the global equilibrium of the systems.

According to Uexküll (1982) there are different and tangible environments which depend on the environmental perception of each species. Thus, the activity and influence of each species in nature are directly related to biological scope. In this sense, the human being developed the ability to create goods and tools to ensure its survival in a hostile and unknown world, beginning a new age based, exclusively, on material consumption from local environment, in which societies perceived and recognized themselves as an integral part of nature. Thus, the consumption rate was consistent with the capacity of the natural systems to absorb waste and generate new natural resources. It did not imply large changes in the environment since it was constrained by biological limits of societies to reach so far lands.

After the industrial revolution, landmark of human domain over nature, this equilibrium between natural and human (artificial) systems was changed drastically. The industrialized society expanded its natural limits, accelerating the consumption of natural resources hence the environmental impacts, unprecedented in human history.

The human activity has reached a scale that resulted in severe perturbation of the nature (Schumacher, 1989) and as a consequence environmental issues constitute a central theme in international policy debates since the 60s. In this context, a group of researchers founded the Rome Club, which pointed out the limits for population and economic growth based on the finiteness of natural resources, through the well-known report "The limits to growth" (Meadows et al., 1972). From that moment, policy changes were perceived in some countries and sustainability became a central point among policy makers, managers, environmental

movements and scientific debates. In the 70s sustainable development emerged as a concept, providing a new view point for environmental issues from purely qualitative to quantitative approaches, recognizing technological, economic and environmental constraints for that growth.

In the 80s, environmental impacts were assigned to the industrial systems and their technological determinism. Nature was considered as a development constraint and costly to global production, reducing the competitiveness of companies. Then, to emphasize the natural resources finitude and the necessity to reduce the consumption, the United Nations established the World Commission on Environment and Development (WCED), which produced the so called Brundtland Report "Our common future" (United Nations, 1987). In the 90s, the globalization brought a new perspective on environmental issues, recognizing them as a global as well as the common interest of nations to establish policies for sustainable development.

At the global conference Rio-92, sustainable development was defined as "the model of development which aims the environmental sustainability through the rational use of natural resources in order to meet the current generation needs without compromise future generation needs". It was established the "Agenda 21" (United Nations, 1992), suggesting targets for sustainable policies of nations, and after that societies have noted that the environmental depletion implies direct impacts on global economic development, as demonstrated by the results in recent decades. In order to foster the evaluation of the Rio-92 proposals, by 2002, the UN organized the World Summit on Sustainable Development - Johannesburg (Rio+10), and it confirmed the poor advance until then. Indeed, only 40 countries had achieved their environmental targets, 24% of the forests around the world had disappeared only in the 90s, and fossil fuel consumption (and CO₂ emissions) had increased about 10% from 1992 to 2002 (United Nations, 2002). It was made clear that the current development model emphasis economic activities as more important than environment, leading to the depletion of natural resources that are essential to satisfy society's needs, even to maintain the current economic system.

According to the UN - Commission for Sustainable Development (United Nations, 1996), sustainability has four dimensions: social, economic, environmental and institutional. It is concerned with the reduction of raw materials usage, and should focus on quality instead of quantity, promoting a better quality of life for everyone, even for future generations and also improving economic and social standards. Therefore, it is necessary to develop a new relationship between society and environment, in which the limits of natural ecosystems in support human activities are taken into account.

This new approach requires deep mentality and behaviour changes to develop the environmental consciousness of societies. In fact, in a world with limited resources and many environmental impacts, it is obvious that environmental damage requires the integration of environmental factors in company budgets, promoting sustainable management strategies (Alves, 2006). In recent years, due to the growing global awareness and societal concern related to environmental issues, people perceive industrial products besides their look and performance. There are increasing concerns on the whole life-cycle of products, e.g. how they are made, used and disposed off. Therefore, in many countries, the environmental approach is becoming a relevant strategy to increase the market share of companies through sustainable products and processes.

In this context, during the last decades several companies have been introducing sustainable concepts in their management and processes through the development of tools and methods

to introduce fully environmental concerns in their activities related to product design. Since the design phase receives and manages information from other phases, it influences the whole company, determining activities such as production, marketing, sales, styling etc (Jeswiet & Hauschild, 2005).

Many authors have pointed out the importance of design for company's success, linking it to the global product development (Fig. 1). It makes decisions during planning, which influence the efficiency of products and processes in their whole life-cycle, also leading the definition of the best way to meet customer needs (Goedkoop et al., 1999). In the 90s, researchers stressed the design phase as essential to define the success of products and companies, pointing out that only among 5% - 15% of the launched products were profitable for companies (Baxter, 1999). Moreover, according to Bettina (Stamm, 2003) a British survey found that in 2002, about 75% of the SMEs (Small and Medium Enterprises) recognized the design phase as a significant strategic phase. Compared to other product life-cycle phases, different studies indicate that design can anticipate new business opportunities and that about 70% of the product costs are decided in design phase (Deng, & Edwards, 2007).

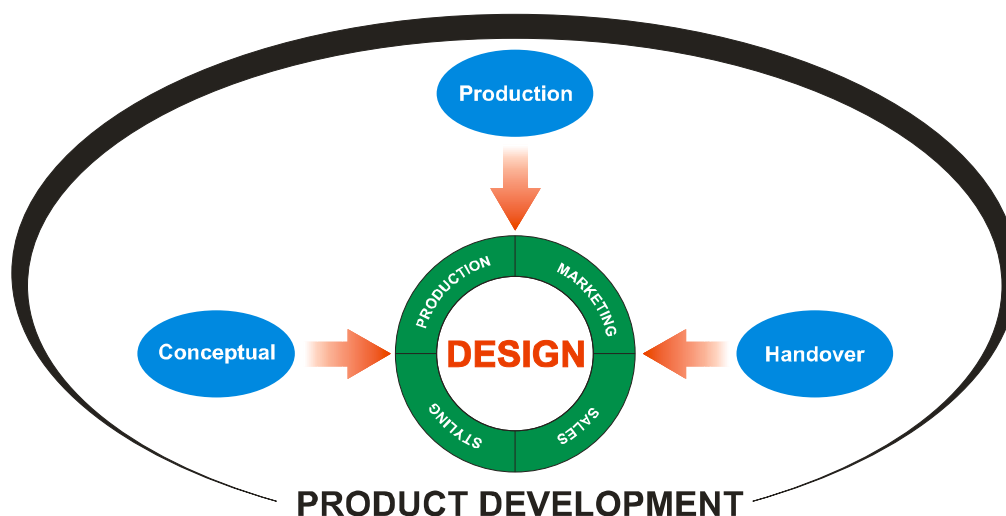


Fig. 1. Phases of the product development process

Therefore, the earlier the improvements are taken into account, the higher the potential for cost savings. However, the large set of different functions and activities of the design process highlighted that a single method or even more a single tool is not enough to address all issues. Many design methods and tools have been developed and mixed to overcome those differences. For example, Chan and Tong (2007) have developed a specific method for a materials selection stage within a design phase based on a life-cycle approach.

In this context, through the multidisciplinary nature of product design, companies can catalyze innovation and prevent pollution, since environmental issues need to be considered in the design phase. Moreover, design also represents an interface between people and companies that pressure and respond to it. Due to this, a collaborative design approach can better fulfill at the same time economic, social and environmental requirements. On the other hand, as discussed by Papanek (1992), among others, design has been used as an instrument to motivate consumption. It has indirectly focused on profitable outcomes, driven by economic performance of products, in which such approach illustrates the predominance of economic rationality at the expense of environmental issues. Then, since

the design phase is presented as the core of the product development, in the last years environmental design has been widely studied to ensure that efforts toward increased environmental rationality and the sustainability of industrial systems are made.

2. Ecodesign into the life-cycle thinking approach

Over the last two decades the interest in environmental issues has grown significantly. Ever increasing attention has been paid to the environmental impacts emerged from design activities, hence from manufacture, usage, and disposal of industrial products. Since the 70s one of the authors, Victor Papanek (1971), also has been discussing the relationship between projectual professions and the environmental impacts raised by their activities.

Twenty years later, Fiksel (1998) published one of the most famous works on the relationship between environmental and projectual issues. The book, illustrated with successful examples, states that projects can meet their environmental requirements without a decrease in other performances. He considers that designers must take into account environmental aspects in a broad life-cycle approach. In recent years, Manzini and Vezzoli (2002) also discussed about life-cycle thinking and the environmental effects from design.

Environmental issues are vital for modern societies, besides the obvious survival problem, because natural resources depletion also implies the drastic decline of the current industrial and economic systems. However, only in recent years people have perceived industrial products besides their look and performance, mainly due to the growth of global awareness and societal concern about environmental impacts. People are increasingly concerned with the whole product life-cycle, for instance how products are made and how they are disposed of. In a world with limited resources and many environmental impacts, sustainable societal and industrial styles have become essential, requiring the integration of the environmental issues in public and private budgets. Consequently, nowadays several companies have been considering the environment as a powerful factor and a business opportunity.

Recent surveys show that environmental issues now seem to be taken seriously by most business agendas. In the past, the majority of companies perceived environment as external or peripheral to their business activities, solving environmental issues by a "curative approach", pollutant emissions were found and cleaned up (end of pipe). Afterwards, a preventive approach was developed to prevent pollution, it showed better results saving costs and resources, and it also motivated life-cycle thinking, hence the ecodesign concepts. Ecodesign also lead designers to take into account environmental aspects, besides traditional aspects currently considered. It implies a holistic outlook (life-cycle thinking) on all phases of a product or system, well known as cradle-to-grave approach, by measuring environmental outcomes that form the basis of ecodesign. The basic idea of ecodesign is to find the source of impacts, increasing the products eco-efficiency still in the design phase. Due to its preventive life-cycle nature, ecodesign represents the best set of strategies to improve companies' market performance whereas it can be applied to develop "greener" projects for any industrial sector. Ecodesign has been recognized as an enabler of companies' transformation, it can lead to behaviour changes that are urgently needed to improve our future, addressing environmental issues and problems behind problems.

Although the design phase itself is a "clean phase", most environmental impacts are defined there, and once a project moves from design to production, its environmental performance is largely defined/fixed. Thus, when potential environmental loads are made explicit even in that phase, strategies may be developed to prevent them. In the Netherlands, a research

suggested that the design process can reduce the current levels of pollution and resource consumption by about 25% to 50% per person (Hilton, 2008).

Many terminologies of ecodesign have emerged during the last years, such as Design for Environment (DfE), Sustainable Design (SD) and Design for Sustainability (DfS) etc. They represent just an evolution of the perspectives on how the subject is perceived and also to some extent an increasingly critical perspective on ecology and design in theory and practice. (Baumann et al., 2002). Despite many definitions, ecodesign emerges as a conciliatory proposal between sustainability and design concepts, also influencing potential life and behaviours of communities when facing the environment in which they live.

Unlike current design, used to stimulate consumption by creating desire for ownership and possession, ecodesign aims at a balance between tools and beliefs to establish a new ethic. Its concepts have potential to change consumer behaviours and ideas about satisfaction and quality of life. Moreover, ecodesign must be thought as a synergy towards a new aesthetical, technical and environmental reasoning, hence, toward new society beliefs.

The main advantage of ecodesign is taking into consideration the environment at the earlier phases, in which constraints are more flexible, once in latter stages despite the project knowledge is large, few changes are feasible since most critical decisions have been taken, decreasing the creativeness, hence reducing the innovation level.

3. Materials and ecodesign

The control, extraction and use of materials have always been closely linked to the human history. For instance, the evolutionary ages are represented by materials such as Stone Age, Iron Age etc, and currently it is possible to state that modern societies have been living in the Plastic and Silicon age, despite the significant introduction of new materials in market.

Nowadays, there are probably over 100.000 commercial materials on the market with different types of impacts on environment (Ljungberg, 2007). This long list demonstrates the problem related to the depletion of natural resources worldwide. Despite the increasing awareness of environmental problems in industrialized societies, society still depends on conventional materials to produce goods. The inability of the environment to support the constant abuse of human activities is becoming clear through various forms of pollution and natural resources depletion that threaten the survival of the planet. Due to this, some studies have demonstrated the depletion and scarcity of resources, even considering that the per capita consumption of natural resources in developing countries is about 1/6 of the consumption in developed countries (Tukker et al., 2000). For instance, the European waste generation is expected to increase about 43% by 2020, while its energy and resources intensity will decline (OECD, 2001).

In this sense, the discussion about the preservation of natural resources has led to the renewed interest concerning materials, motivating changes in product design to address this environmental issue (Papanek, 1995). Collaborative R&D efforts among material scientists and engineers, research institutions and government have been stimulated to find commercial application for renewable natural raw materials, employing them in technical products and/or structural parts. Thus, ecodesign is not just a newly coined buzzword, but it has guided the development of a new generation of natural materials. It shows the important role played by ecodesign related to the natural resource depletion, since it dictates the type and quantity of raw materials and energy that is required to produce and dispose products. Hence, it also shows how important materials are also in product design

(Deng & Edwards, 2007). Despite being generally regarded for their functional attributes, they have become fundamental in a sustainability context. It explains why most eco-methods are implicitly related to material and/or energy management, directly linked with resource scarcity. Then, designers must find materials that can address environmental issues related to the natural resources depletion, besides other requirements, since earth has a limited capacity to cope with the current wide level of impacts raised by human activities.

3.1 Natural resource consumption (depletion)

Halog (2004) defined sustainability as the optimization of the human activity level within both the limit of renewable resources supply and the capacity of the environment to absorb waste. Although this is not the unique dimension of sustainability, it is clear that in the last decades the unsustainable human activities have exceeded the threshold of recovery of the planet, which threatens the welfare of future generations. Even religions, which are traditionally pro-natal, perceive the human being as conqueror of living things on earth, neglecting the environment and its limits (Ljungberg, 2007)

According to WWF (Hails et al., 2006), 40% of natural resources have been consumed since 80s and under the current consumption rate two planets like Earth would be needed to sustain the current patterns (Fig. 2). This was also quantified by the global Ecological Footprint (EF) which in 2003 was already about 2.2 global hectares per person. In other words, each person needs at least 2.2 hectares of productive land to support its activities.

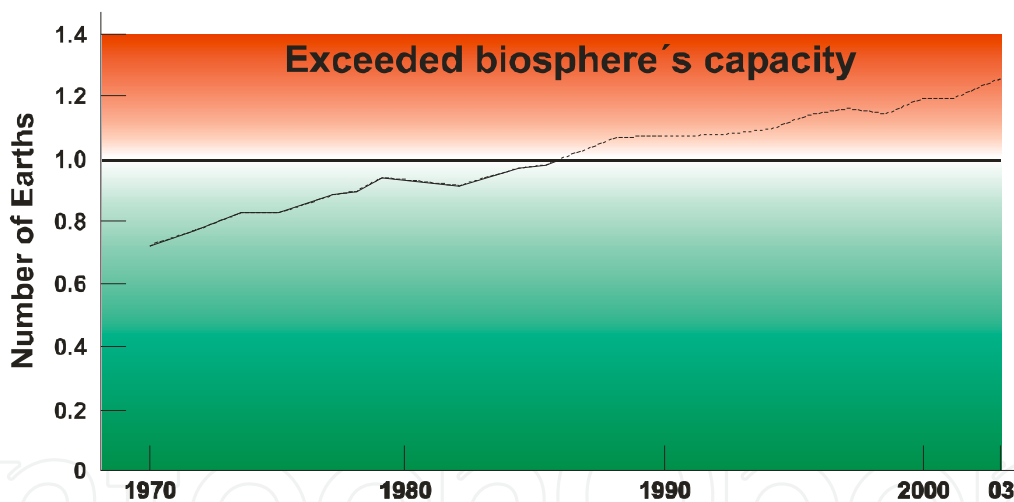


Fig. 2. Global Ecological Footprint. Adapted from (Hails et al., 2006, 2008)

Baudrillard (2005) states that nowadays the social and satisfaction values are fake, they are based on consumption and due to the eternal creation of new products and social needs they become an eternal dissatisfaction motivating more consumption ad infinitum. Easterlin (2006) explained the "eternal dissatisfaction" stating that there is no relationship between the increase of individual income (purchasing power) and the happiness increase. He presented surveys carried out in US and Japan that pointed out the limitation of income growth to produce satisfaction, it means that money and happiness are not directly related. Nevertheless, consumption has been growing worldwide, motivating the development of the global environmental policy related to sustainable consumption that also considers the existence of a maximum consumption to provide individual well-being, beyond a minimum threshold.

Facing this grim context, in which societies can neither give up development nor maintain the current environmental depletion, the last decades have been thought to be hard to replicate. The achievement of a sustainable state depends at least on three key factors: the population, the demand for human welfare and eco-efficiency of applied technologies. The eco-efficiency factor stands out to reach the condition toward sustainability, with a constant growth of population worldwide.

It is a fact that the world population is growing, according to the UN (2004) and the OECD report (2008), it is expected that the world will have about 8.2 billion and 10 billion of inhabitants by 2030 and 2050, respectively (Fig. 3). In Western Europe (WEU) and in South-Eastern Europe (SEE), the population will grow about 1.1% and 16%, respectively, from 2005 to 2030, while in North American countries it will increase about 21%. Moreover, Asian countries will continue increasing their already remarkable population. India with a population of about 1.3 billion inhabitants (growth of about 31%) tends to achieve China's population by 2030 (OECD, 2008). This constant increase has become a constraint for global economy and social development. It will put more pressure on environment through increased consumption, and hence more search for natural resources to provide greater welfare for developing countries.

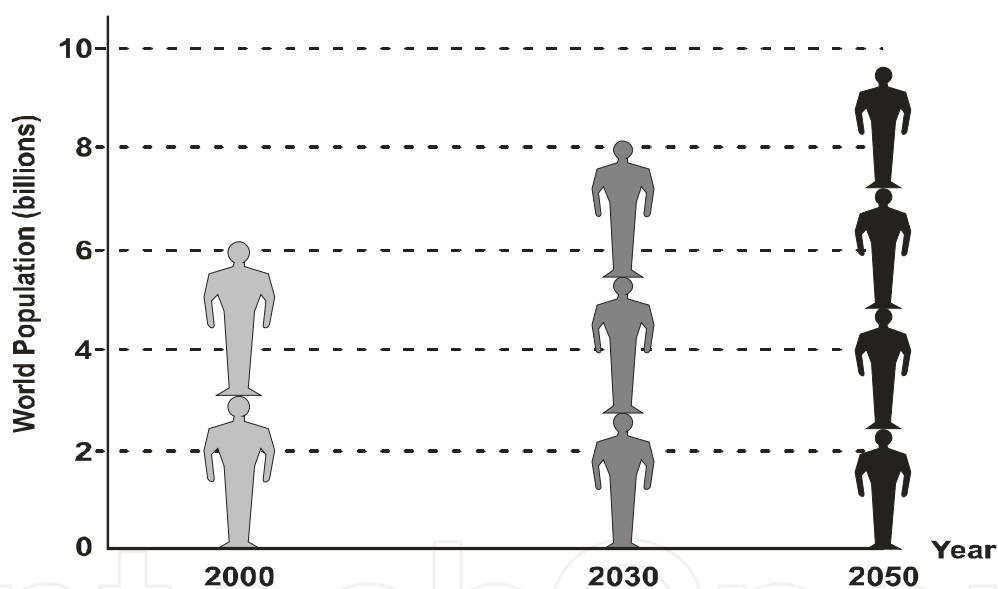


Fig. 3. Forecast of the global population growth. Adapted from (United Nations, 2004)

The situation is dramatized by the forecast of the global increase of the Gross Domestic Product (GDP) by 2030 (European Environment Agency, 2007). According to Field III et al (2001), at a GDP global growth rate of 3% per year, societies will produce and dispose of more objects in the next 25 years than in the whole history of the human being. However, nature will not be able to sustain such growth rates of up to 3% per year expected for the next years by 2030. Indeed, the GDP per capita of Central Europe (CEU) will grow about 141%, while India's will grow about 169%. China will present the highest increase of about 200% by 2030, even though the USA and Canada will still have the highest GDP per capita (European Environment Agency, 2007).

The expected growth of the incomes is heavily dependent on natural resource use, so the demand for resources will increase, mainly for fossil fuels that are used to produce energy and products in many industrialized countries. Although they are essentially non-renewable

and limited resources, their usage has increased at least 20-fold per capita since the end of the 19th century, highlighting the necessity to reduce their consumption (Ljungberg, 2007). Indeed, about 40% of the global energy is derived from petroleum and recently, European studies (OECD, 2008; EEA, 2007) identified that food and beverage, as well as transport and housing account for 70% to 80% of the environmental impacts and 60% of the natural resource consumption. Also, the global resource extraction is expected to increase about 50% from 2002 to 2020 and almost 50% of it is related to non-metallic minerals. However, sustainability can be achieved e.g. by reducing the over-population and/or the consumption, even by eco-efficiency of industrial systems, using less energy or material per unit product. Whereas the expected population growth and therefore the larger consumption of natural resources, for ecodesign the eco-efficiency stands out as the best condition toward sustainability.

In this sense, to minimize environmental loads the ecodesign strategies focus on eco-efficiency, maximizing material productivity. Eco-efficiency measures have shown significant savings in most circumstances, using natural resources in a consistent manner combining environmental and economic performance. To embrace eco-efficiency some publications envisage a reduction in the material flows by Factor 4 or Factor 10 concepts (Schmidt-Bleek, 2008; Weizsäcker et al., 2009). They are based on the dematerialization idea of production and consumption in which all needed products and services as well as energy demands are to be met with less resources.

Figure 4 illustrates levels of eco-efficiency for a given innovation applied on a product against a sustainability degree. Accordingly, environmental improvements are classified into four categories in regards to different levels of eco-efficiency. A potential sustainable level can be achieved by systemic innovations, where new scenarios are proposed to meet sustainable lifestyles (Factor X). It focuses on cultural activities and new standards for quality of life, altering the industrial and social structure of behaviours.

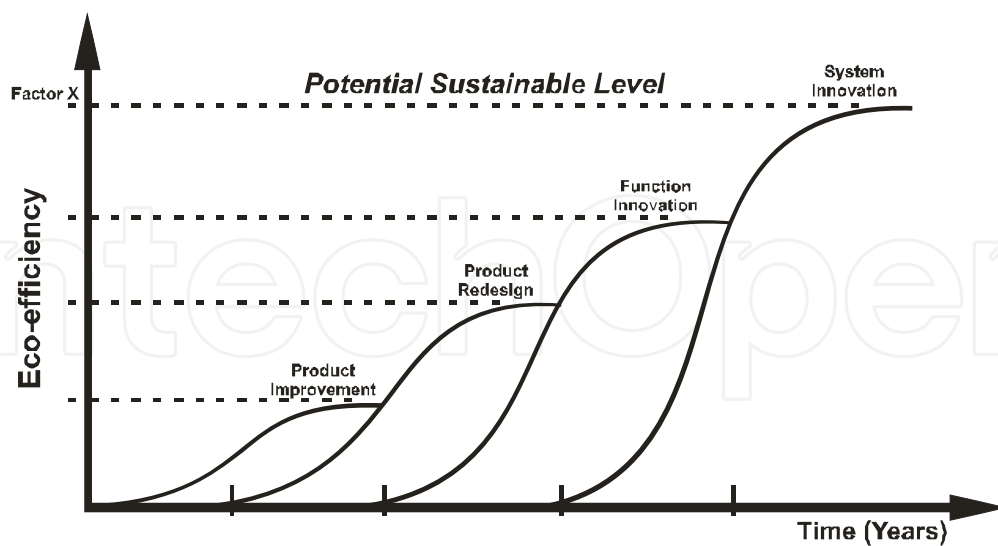


Fig. 4. The Brezet Model for environmental innovations.

Due to the over-consumption and the irreversibility of resource exhaustion, the scarcity of natural resources tends to reach permanent degradation. Renewable resources such as plants, air, water, have a short natural growth of few months, maybe years and can be replenished in a useful time. In contrast, non-renewable resources such as fossil fuel and ore

have a long natural formation cycle. It is important to note that a renewable resource can become non-renewable if its replenishment rate is smaller than its consumption rate, exceeding its biological growth. Many empirical projects that use renewable sources have reduced environmental loads from resource depletion, keeping the quality of life (Figure 5).

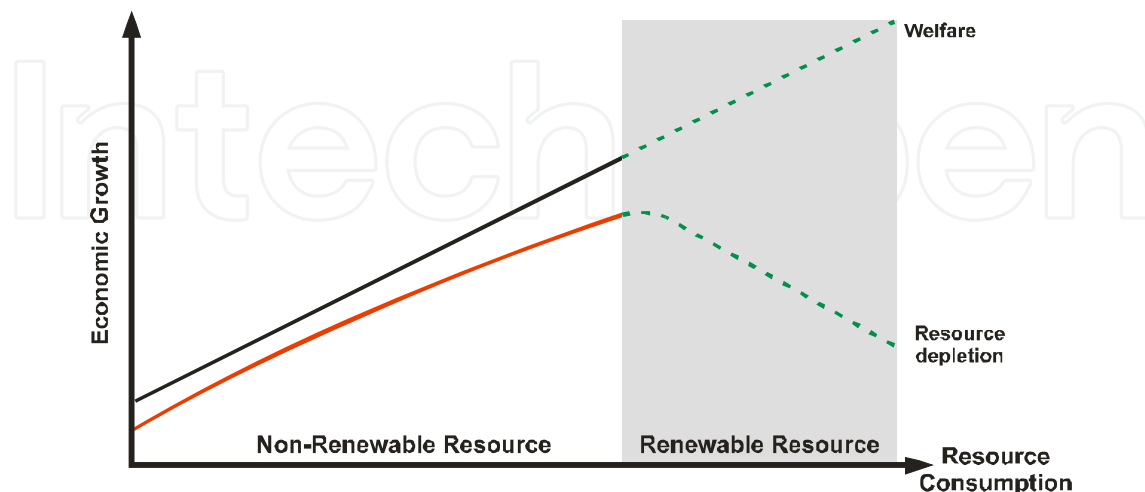


Fig. 5. Potential of renewable resources to reduce depletion. Adapted from (Community and Information Society Technology Programme, 2003)

Several researches (Datschefski, 2001; EEA, 2007) have pointed out Europe as the leading continent in investments related to the use of renewable sources in two important sectors: energy and transport. It has helped to reach targets established in Kyoto's protocol related to the reduction of the greenhouse gases (GHG).

3.2 Sustainable mobility through ecodesign of renewable materials

Nowadays, substantial environmental impacts are induced mainly by four economic sectors: energy, transport, agriculture and tourism. Among them, transport is considered to be the largest pollutant sector with pervasive negative impacts. It is the largest source of greenhouse gases (GHG) due to the rapid growth rate of the global fleet, compared with its progress in energy efficiency. The transport sector requires the introduction of new technologies, which can promote more eco-efficiency in the whole transport system, even changing consumer behavior to achieve a satisfactory reduction of environmental impacts (EEA, 2007).

In recent years, despite the adoption of national programs to reduce emissions, the global indices have shown that GHG concentration grew about 30% from 1980 to 2000 and it is projected to increase about 37% and 52% until 2030 and 2050 respectively compared to levels in 2005 (United Nations, 2009). It will engrave the impact load on environment (e.g. increasing the global warming), since transport sector is the second largest (about 24%) and the second fastest growing source of GHG and CO₂ emissions after the energy sector (about 45%) (Fig. 6). Global emissions of CO₂ from the transport sector are expected to double between 2005 and 2050, from 6.1 GtCO₂ to 12.2 GtCO₂. In OECD countries the transport's share represents 30% of CO₂ emissions, in which road transport accounts for almost 80% of them (EEA, 2007; OECD, 2007).

This is why the transport sector is a greatest concern to the EU member states, specifically regarding to climate changes. Then, it is important the development of cleaner vehicles

combining lower environmental impacts with affordable cost, or even to develop new concepts of transport systems based on eco-efficiency levels that a given innovation project aims to achieve.

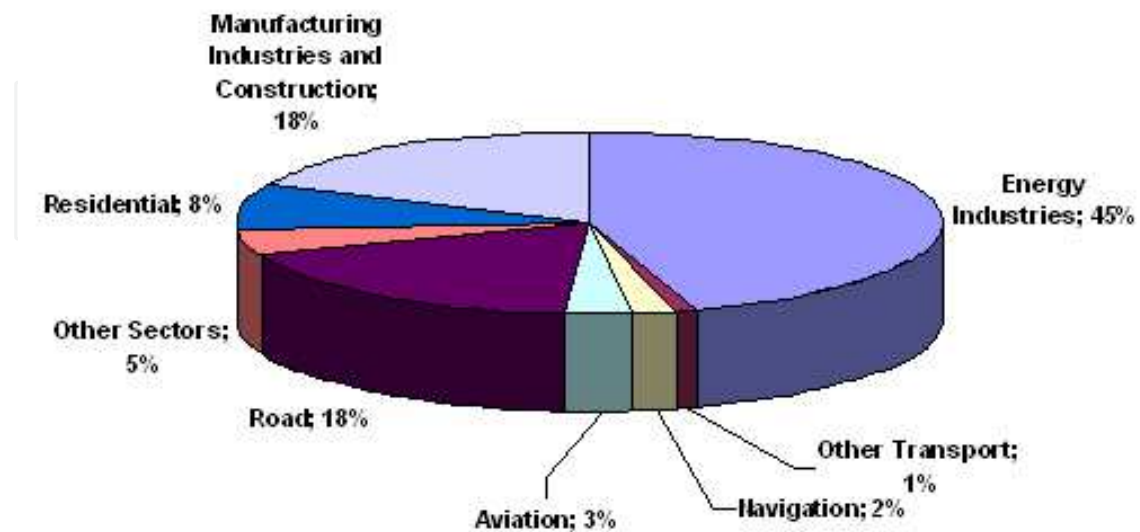


Fig. 6. CO2 emissions related to combustions. (OECD, 2007)

In this specific context, in which automotive companies are undergoing several environmental pressures, ecodesign and renewable materials converge to develop eco-friendly vehicles and/or components, achieving tighter environmental targets towards sustainable mobility. Among a wide range of materials made of renewable sources, there are the composites materials reinforced with vegetable fibers, which show a great potential for automotive usage.

They offer many advantages compared to synthetic fibers, reducing the dependence of non-renewable resources and the greenhouse emissions, they also present light weight, high specific strength and are biodegradable, which is crucial in their disposal phase. They corroborate with the questions and hypothesis of this research since they are a great candidate to replace synthetic fibers as reinforcement of polymeric matrices for industrial/structural automotive components.

3.3 Greener composite materials: vegetable reinforcements

The wide usage of glass fibers with thermoset matrices are considered critically. They have caused several environmental impacts mainly in their disposal phase related to the landfill and incineration control, besides the natural resources depletion, since glass fibers are made of non-renewable sources (e.g. silica and lime).

In this context, many researchers (Puglia et al, 2005; Suddell et al., 2002) have been studying natural fibers as replacement of glass fibers, improving the environmental performance of composites and products made of them. Products are classified based on their source: vegetable, animal or mineral, and they are commonly used as reinforcement of thermoplastic and thermosetting polymeric matrices.

Among them, vegetable fibers have emerged as realistic alternative and they are the most commercially used natural fibers, pointing out a great possibility for industrial application

in composite materials. Furthermore, they are an important source of income for agricultural societies implying positive social impacts. For example, in Brazil there are many types of fibers such as jute, sisal, coir and curauá, all of them already with commercial applications. Brazil has a large potential to produce vegetable fibers that can be found natively or cultivated, becoming a source of income for several local communities (Alves, 2006).

Currently, automotive industry is the most avid and significant in terms of vegetable fibers usage in composite materials. They demand a shift of vehicle design from oil-derived polymers and synthetic reinforcements to natural materials, focusing on the environmental requirements of vehicles. Joshi et al (2004), shows that vegetable composites present better environmental performance than glass composites, e.g. their incineration consume lesser energy (about 45%), resulting in lower GHG emissions.

In Europe, automotive companies have developed components made of vegetable composites motivated mainly by regulations that have played an important role toward sustainable mobility. A good regulation example is the European Directive 2000/53/EC, in which vehicles have to be partially decomposable or recyclable (95%) by 2015 (Suddell et al., 2002). In USA, about 1.5 million vehicles are already using vegetable fibers as reinforcement of thermoplastic and thermosetting polymers (Faruk, 2009).

In Brazil some automotive initiatives are concerned with the selection of "greener" materials from renewable sources. For instance, in 1992 Mercedes-Benz of Brazil agreed to make an initial investment of US\$1.4 million to research the vegetable fibers usage in its vehicles. This initiative translates into new jobs in the coconut fiber production including agricultural producers, and processing plant workers (Alves_a et al., 2009). It is expected that the use of natural fibers in automotive components will grow about 54 % per year, since European and American car makers have been already using them [194]. Projections point out an increase of the European demand for vegetable fibers in automotive industry from 70,000 tones in 2005 to 100,000 tones by 2010, which means a potential European market at about €100 millions (Faruk, 2009).

In Europe the use of natural fibers in the automotive sector increased from virtually "0" in 1994 to more than 28,000 tones in 2000, and in 2002 the global market share of vegetable composites reached 685,000 tones (US\$775 million) mainly motivated by their low cost and density (Margets, 2002). In 2003 the automotive industry consumed about 45,000 tones of natural fibers, in which about 18,000 tones (40%) was accounted for German automotive industry with a linear consumption growth of about 30% (Karus et al., 2003). Indeed, Germany is the most significant customer of vegetable fibers (about 3.5kg per vehicle, excluding wood and cotton) it means about 2/3 of the total European consumption. Predominantly, using vegetable fibers results in lighter internal components (about 25% eu) with comparable properties to glass fibers composites. It reduces the fossil fuel consumption and then the GHG emissions of vehicles (Miller, et al, 2000), which comply with Environmental Directives and Kyoto's Protocol (Rouison, D. et al., 2006; Dietrich, A.B, 2005). Undoubtedly, vegetable or 'green' composites have played a major role in the product design process, presenting many environmental advantages compared to synthetic composites, and offering a possibility for developing countries to use their own natural resources in a wide range of industries. Among various vegetable fibers available to the automotive sector one of the most used is jute fiber, which grows in sub-tropical countries

such as Bangladesh, India and Brazil. Table 1 shows properties of some natural and conventional synthetic fibers.

Fiber	Density (g/cm ³)	Elastic Modulus (GPa)	Specific Elastic Modulus (E/ρ)	Tensile Strength (GPa)	Specific Tensile Strength (σ/ρ)	Elongation at break (%)	Cost(\$/kg) (1€=2.5R\$)
E-Glass	2.6	73	28.07	1.8 - 2.7	0.69 - 1.04	2.5	6
Carbon (PAN)	1.8	260	144.44	3.5 - 5.0	1.94 - 2.78	1.4 - 1.8	60
Aramid	1.45	130	89.66	2.7 - 4.5	1.86 - 3.10	3.3 - 3.7	30
Jute	1.45	10 - 32	6.89 - 22.07	0.45 - 0.55	0.31 - 0.38	1.1 - 1.5	0.8
Sisal	1.45	26 - 32	17.93 - 22.07	0.58 - 0.61	0.40 - 0.42	3 - 7	0.8
Coir	1.33	4 - 6	3.01 - 4.51	0.14 - 0.15	0.11	15 - 40	0.8

Table 1. Mechanical properties of some fibers. (Alves_b et al., 2009)

Extracted from the stem of the jute plant (*Corchorus capsularis* and *Corchorus olitorius*), jute fibers grow mainly in India and Bangladesh, the largest global producers. They also grow natively in China, Nepal, Thailand and Brazil, and together all of these countries represent about 95% of the global jute fiber production (Alves_b et al., 2009). The global production of jute fibers have increased since last century reaching 1 million tones per year in 1900 and about 3,292 millions tones in 2004. In the last years, the jute production growth occurred mainly due to their production and consumption in India. India has a set of policies that have motivated the production and export of jute fibers and their derived products (Anderson et al., 2004).

Jute fibers have irregular cross-sections and their micro-cellular structure is composed of micro fibrils. They have an average length of about 0.5 - 6.0mm with fiber diameter varying from 0.01 to 0.04mm. Their chemical composition varies according to the plant age and the maceration, presenting as main constituents: lignin 12.5% - 13.5%, cellulose from 59% to 61%, fats and waxes 0.9% - 1.4%, minerals 0.5% - 0.79%, nitrogenous matter 1.56% - 1.87% (Alves, 2006).

4. Ecodesign parameters of the case study: The buggy

This work presents the Buggy vehicle as the case study (Fig. 7), defining its frontal bonnet, made of composite material, as the Functional Unit (FU) for technical and environmental analysis. Through the Buggy case study (CS-Buggy) this research intends to evaluate the feasibility of the jute fibers to replace glass fibers as the reinforcement of composite materials, also evaluating the social and environmental performance of the Buggy's enclosures made of jute composites. This work also presents the Sustainable Design Procedure (SDP), a systematic method to introduce environmental concerns in small and medium size companies (SMEs) through their materials knowledge expertise.

Since the design phase dictates most of inputs and environmental loads of a product or a process, composite materials are the innovation focus of the CS-Buggy, also introducing environmental concerns into SMEs planning, this work developed a Sustainable Design Procedure (SDP), for more details see Alves_a et al (2009). SDP is a systematic procedure that aims an “integration” of environmental concepts into the materials selection stage within the design phase. Since materials and their processes are the core business of SMEs, SDP can act as a strategic ecodesign procedure extending environmental awareness for the whole company from design to company policies.



Fig. 7. CS-Buggy vehicle.

SDP intends to influence different decision levels of companies beyond product development, providing a comprehensive and long term approach to achieve the potential sustainable level of eco-efficiency as discussed before. In this sense, a significant attention must be paid to the educational aspects of designers since SDP is based on the philosophy in which to do “sustainable design”. One first needs to breed “sustainable designers”. Subsequently, the environmental knowledge is expected, otherwise it becomes difficult to do any environmental improvement and/or innovation.

SDP aims to optimize the CS-Buggy regarding to the following factors: user needs, design requirements, production process, cost and environmental factors. The SDP structure is composed by qualitative and quantitative stages and it is presented as a sequential procedure in Figure 8. Even though it is a concurrent design approach, in which all stages are defined by traditional and environmental inputs, they can be combined in a simultaneous and interactive way.

Through a filter step, SDP can have as multiple feedback loops as required to re-evaluate previous decisions that have been made, ensuring a collaborative system in which all goals were reached. It is important to note that, to increase the innovation, environmental inputs must be taken into account from the beginning of the design process, and not as a final appendix. According to Manzini and Vezzoli (2002), environmental factors, besides their technical and economic advantages, change the professional perspective, creating an innovative environment.

In fact, environmental inputs improve the innovation as a new variable combined with traditional inputs, generating new ideas (environmental proposals) from a new environmental point of view. The qualitative phases Design Goals and Design Requirements

are detailed in Alves_a et al (2009), in which the following total performances were obtained based on the five parameters (Table 2):

Parameters						
	Environmental	Aesthetical	Technical	Economic	Process	Total
FC	12	8	25	2	17	64.32
FK	13	6	23	5	17	64.31
FJ	23	17	14	15	13	80.39
FC	23	17	13	17	13	81.93
FS	23	17	14	15	13	80.50

Table 2. Total performance (I) of the fibers reinforcement.

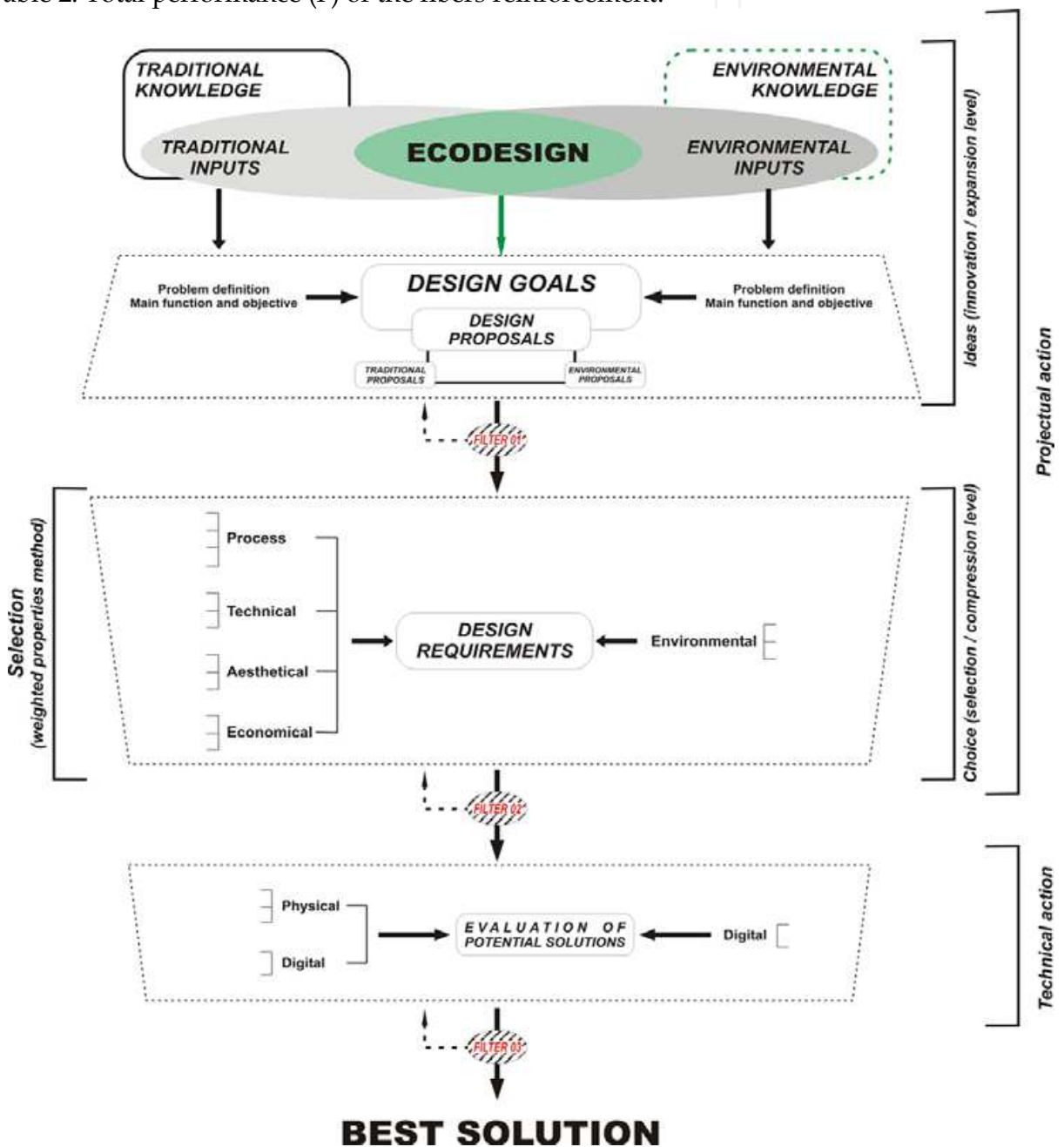


Fig. 8. Structure of the Sustainable Design Procedure.

Finally, it is important to note that the design requirements point out a possible solution. Therefore, after this stage it is necessary to carry out a quantitative analysis to evaluate the feasibility of the best choice and to ensure the success of the whole project, mainly when the best choice is a new and unknown material like in this case study (vegetable fibers). Thus, the remainder discussions are exclusively dedicated to the final SDP stage: evaluation and validation of the choice, due to its crucial influence on the final decision making.

5. Enclosures of the CS-Buggy: from sustainability to the use of vegetable fibers in vehicles

In the previous analysis, the total performance has shown vegetable fibers (sisal, jute and coir) as a potential replacement of glass fiber reinforcements usually used to produce the enclosures of concurrent buggies. Among selected vegetable fibers, jute fiber presents the lowest total performance (see Table 2), even though it was defined as the best potential choice to be evaluated due to the following aspects:

- No significant difference among all vegetable fibers performance;
- Among selected vegetable fibers, only jute fiber allows an useful production of bi-axial and multi-axial fabrics.

5.1 Materials

The fiber reinforcements (Jute and Glass-E) used in this research to manufacture the reinforced polyester composites have two different fabric arrangements (bi-axial and multi-axial) (Fig. 9). The jute fibers were supplied by Castanhã Têxtil Inc from Amazonas State, Brazil. The glass fibers, used as the control material, were supplied by Matexplas Ltda. (Lisbon, Portugal). The standard thermosetting liquid resin used as matrix was the orthophthalic Unsaturated Polyester (UP) Quires 406 PA, and the peroxide methyl ethyl ketone (PMEK) used as the curing agent, was also obtained from Matexplas Ltda. (Lisbon, Portugal). Acetone (technical grade) was used as bleaching solvent to the superface treatment of the jute fibers.

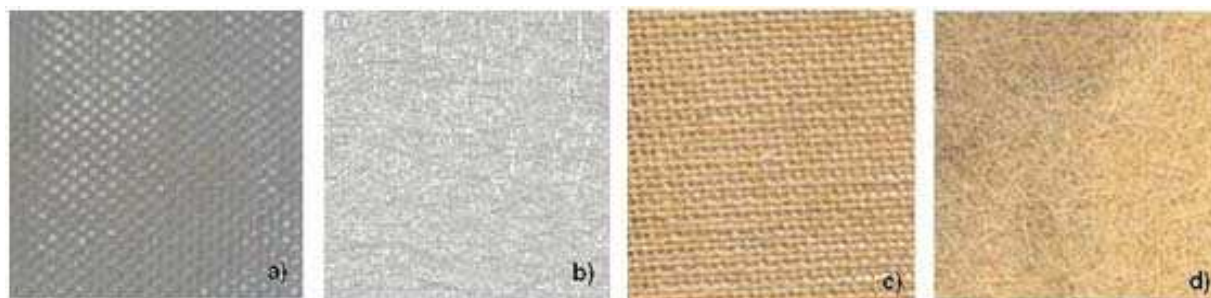


Fig. 9. Fiber's fabrics. (a) Bi-axial glass fibers; (b) Multi-axial glass fibers; (c) Bi-axial jute fibers; (d) Multi-axial jute fibers.

5.2 Characterization and treatments of the jute fibers

Despite the good properties of the vegetable fibers, they are often considered only for applications that require low mechanical performance, due to their hydrophilic nature related to the presence of hydroxy groups in their cellulose structure, besides their natural oleines on the surface, raising their inadequate interface adhesion with polymeric matrices that present a hydrophobic character (Westerlind, & Berg, 1998; Belgacem & Gandini, 2005). These opposite features obstruct the contact between the vegetable fiber and polymeric matrix, resulting in a

poor efficiency to transfer loads across the composite. It implies the failure of the interface between matrix and fibers and accelerates the degradation of the composite. To obtain the percentage of the moisture content and other volatile compounds (mostly oleines) of the jute fibers as well as their thermal stability, a thermogravimetry analysis was performed (TG - weight loss versus temperature). The TG analysis was carried out under He flow (2.0 NL/h) from room temperature to 500°C with a heating rate of 10°C/min. All the tests used 50-60 mg of jute fibers placed in an alumina crucible (100 μ L), using a TG-DTA-DSC LabSys equipment. For the analysis three replicas were obtained. The thermogram for the jute fibers (Fig. 10) shows a small weight loss (about 8.7%) in the range 30°C-125°C. This weight loss can be ascribable to the loss of fiber moisture, and for temperatures higher than 240°C the drastic weight loss can be ascribable to the jute fiber thermal degradation (Joseph et al., 2003).

In this context, in order to increase the wetting behavior of the jute fibers with apolar polyester, and thus improving the interface bonding fibers/matrix, jute fibers were subjected to two treatments to remove their moisture content and the oleines. In the first drying treatment, focused on moisture content in jute fibers, some bi-axial and multi-axial samples of jute fabrics were dried overnight (12h) at 140°C (temperature based on TG analysis), using an universal oven. In the second bleaching/drying treatment, focused on oleines and waxes on the jute fiber surfaces, other samples were previously soaked in acetone (technical grade) during 24h, and were then dried according to the first treatment. The treated jute fabrics were designated as Jute Fibers Dried (JFD) and Jute Fibers Bleached/Dried (JFB/D), while untreated jute fibers were assigned as Jute Fibers Control (JFC) and glass fiber was assigned as Glass Fibers Control (GFC).

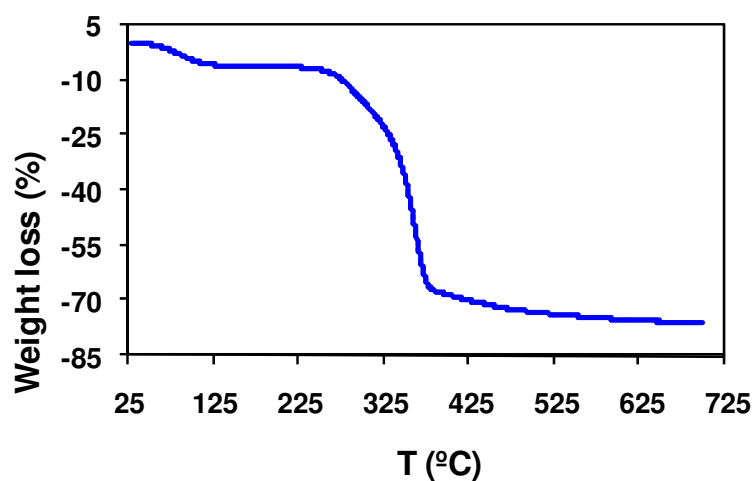
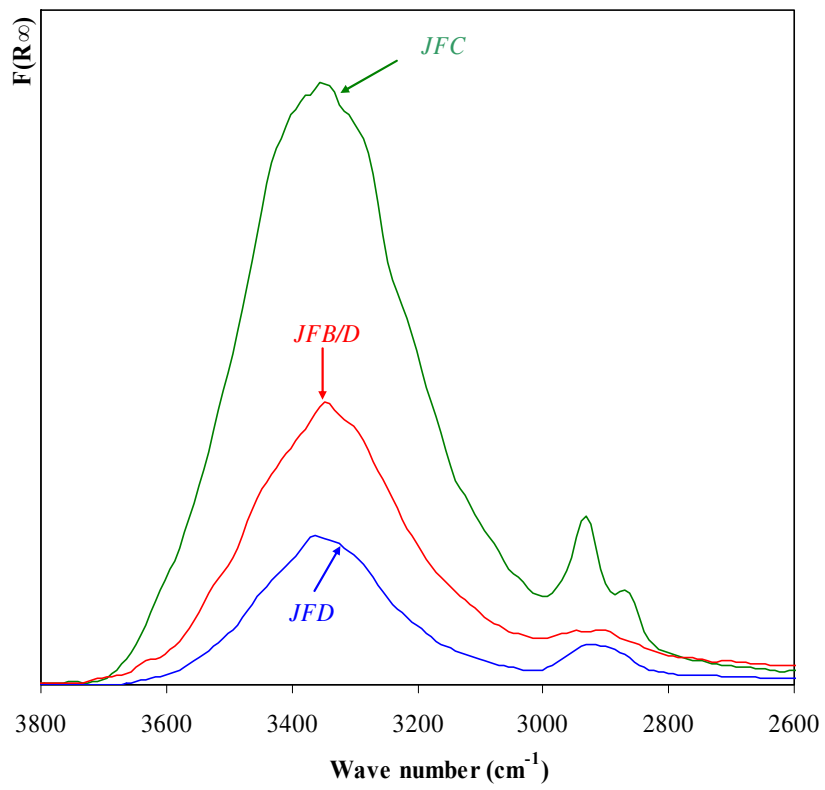


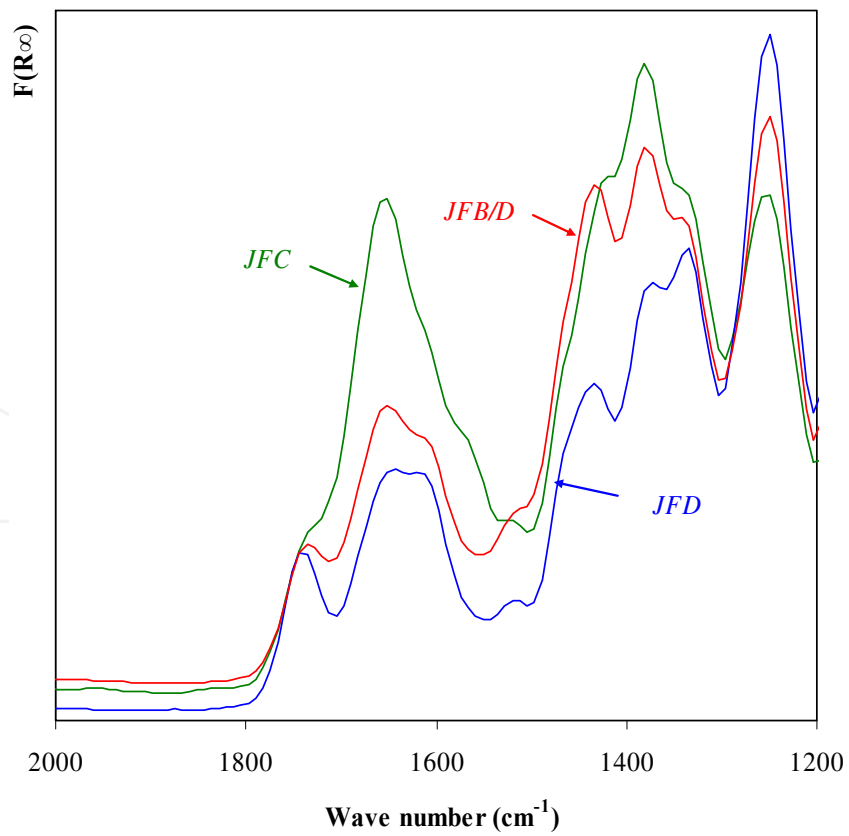
Fig. 10. Thermogram of the untreated jute fiber.

To understand the effects of the treatments on the surface of the jute fibers, an infrared spectra was carried out with a resolution of 16 cm^{-1} . It was performed using a Horizontal Attenuated Total Reflectance Infrared Spectroscopy (FTIR-HATR). Sixty-four scans were accumulated for each spectrum to obtain an acceptable signal-to-noise ratio. During spectra acquisition samples were pressed with 408 PSI. The absorbance of each spectrum was corrected with the Kubelka-Munk transform (Kruse & Yang, 2004).

Figure 11 presents the collected spectra from untreated and treated jute fibers. Several bands were obtained, in which the vibration modes were assigned according to the previously published researches (Ray & Sarkar, 2001).



a)



b)

Fig. 11. FTIR-HATR of untreated and treated jute fibers: (a) 3800 – 2600; (b) 2000 – 1200.

For the analyzed sample the major spectral differences were observed for the regions related to the -OH vibrations. Figure 11 (a and b) shows that for the JFD the O-H stretching band (3720-3000 cm^{-1}) and the vibration of the adsorbed water (1640 cm^{-1}) are significantly less intense than the respective bands for JFC and JFB/D. It can be concluded that the drying treatment was effective to decrease surface moisture content, contributing to improve the compatibility between jute fibers and unsaturated polyester matrix. On the other hand, it is possible to note that the bleaching/drying treatment reduced the efficacy of the drying treatment, since acetone removes waxes and oils from the jute fibers surface, which provide a protective layer for vegetable fibers. Thus, the removal of this natural protection exposes fibers surfaces, which increases their hydrophilic behavior.

Another thermogravimetry analysis was performed to investigate the effects of the treatments on the jute fibers, using the same set up of the first thermogravimetry, in which three replicas were obtained for each sample (JFC, JFD and JFB/D).

Figure 12 shows the main results from thermal analysis of JFC, JFD and JFB/D. The differentiated curves of weight loss are presented (DTG). The thermal decomposition profile was similar for all the analyzed samples. A small weight was observed in the range 30-200°C corresponding to dehydration of fibers. The JFC presents a moisture content of about 8.7% while JFD presented about 6.8%. It also points out the efficacy of the drying treatment, since it removed more than 20% of the fibers moisture content. On the other hand, JFB/D treatment as explained before, removed the protective layer made of waxes and oils from the jute fibers surface. In this sense, it presents fiber moisture content of about 7.6%, which means 11.7% higher than the moisture content found for JFD, pointing out its effect to decrease the efficacy of the drying treatment.

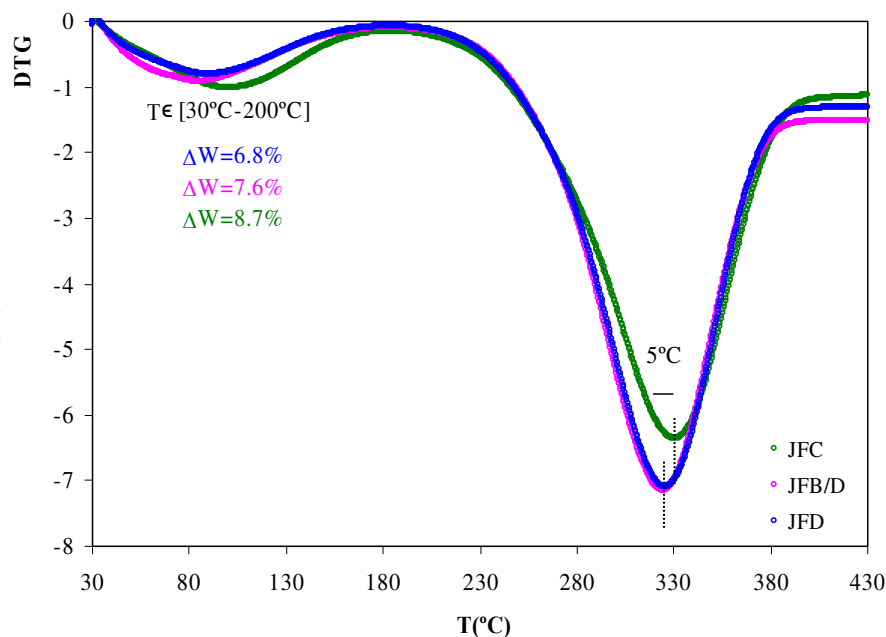


Fig. 12. Thermogravimetry analysis of untreated and treated jute fibers.

Thermogravimetry results are in accordance with FTIR data. In fact, the FTIR bands related to the -OH species are more intense for JFC and JFB/D samples. The thermal stability of the jute fibers was slightly affected by both treatments. For treated jute samples, the maximum

temperature of the thermal decomposition process is 5°C lower than the maximum temperature observed for the untreated jute samples.

After the chemical/physical characterization of the jute fibers and the effects of their respective treatments, composites were manufactured with untreated and treated jute fibers (JFC, JFD and JFB/D) and glass fibers (GFC), and then specimens were obtained from composites and tested under tensile and bending tests, according to ASTM standard (D-3039 and D-790), and Dynamic Mechanical Analysis (DMA). The specimens were cut from composite plates, produced with both bi-axial and multi-axial fiber arrangements. They were produced by Resin Transfer Molding (RTM) process using a RTM UNIT obtained from ISOJET Equipments (France). Composites were prepared varying the fiber content (V_f) from 20% to 30% to reach the maximum volume fraction (V_f) of reinforcement that was used to balance RTM processability and the mechanical properties of the composites. Each V_f was obtained based on jute fibers as volume control, due to their larger filament's diameter (40 μm) compared with the glass fibers (14 μm).

Multi-axial plates were manufactured with one layer of fabrics, while bi-axial plates were manufactured with six layers according to the following stacking sequence [(0/90), (45/-45), (0/90)]_S. Polyester matrix was then mixed with PMEK (0.25 % in volume) and the resin mixture was degassed under a vacuum of 10 mm Hg for 10 min before the impregnation of the fabrics. After that, it was allowed to pass through the mold under different pressures, which were optimized for each fabric arrangement. After the complete filling of the mold, the plates kept 1h curing inside the mold, and were then extracted from the mold and allowed to post cure at room temperature (about 300 h).

5.3 Mechanical behavior of the composites

Figure 13 and Table 3 present the results of the mechanical behavior of the composites, in which the data given for each property are the average of five specimens. For all specimens, the composite materials displayed nearly linear elastic behavior up to the fracture. In the bi-axial samples, GFC presents higher tensile strength (about 100%) than the JFC. It is not associated with the fiber content of the composites (V_f), since the GFC has a lower volume fraction (about 33%) compared to the maximum V_f reached for JFC, produced by RTM process. In fact, it is related to the nature of the fibers used to reinforce the polyester matrix. For multi-axial composites, the specimens have roughly equivalent strengths around 26 MPa. Like in the bi-axial composites, for multi-axial arrangement the tensile strength is not associated with the fiber content, since for GFC the V_f of the glass fiber is much lower (about 50%) than the maximum V_f achieved for JFC, produced by RTM process. Moreover, the V_f of the multi-axial GFC was of about 50% of the maximum volume fraction in which would be possible to produce it, implying a significant decrease of the mechanical properties of the multi-axial GFC composite.

Results also revealed that both treatments brought a significant increase on the stiffness of the jute composites, moving their elastic modulus from about 1.83 GPa for JFC to 5.29 GPa (about 189%) and 4.91 GPa (about 168%) for JFD and JFB/D, respectively. Both treatments provided a significant improvement on the interface bonding of bi-axial jute composites, decreasing significantly their strain (average 55%), in fact their strain became lower even than the strain of glass fiber composites (about 16%). Moreover, the coefficient of variation (CV) for bi-axial jute composites presents a very significant decrease, from 14.70% for JFC to 4.10% and 3.59% for JFD and JFB/D, respectively.

Despite treated composites still presenting lower elastic modulus (about 26%) than that obtained from Classical Theory of Laminated - CTL (6.89 GPa), the results make clear that both treatments provided really great effects related to the interface bonding of bi-axial jute composites. Nevertheless, results also point out an unsuitability of the CTL to predict the mechanical properties of the bi-axial vegetable composites. Unlike for the stiffness, the treatments did not bring a significant increase for the strength of treated composites (average 18%). Indeed it increased from 27.76 MPa (JFC) to 30.38 MPa and 35.33 MPa for JFD and JFB/D, respectively (Table 3). Thus, based on the fact that the elastic modulus is determined from the slope of the stress versus strain curves, its large increase after the treatments can be explained by the improvement of the interface jute/polyester, due to the significant decrease in the maximum strain of the composites.

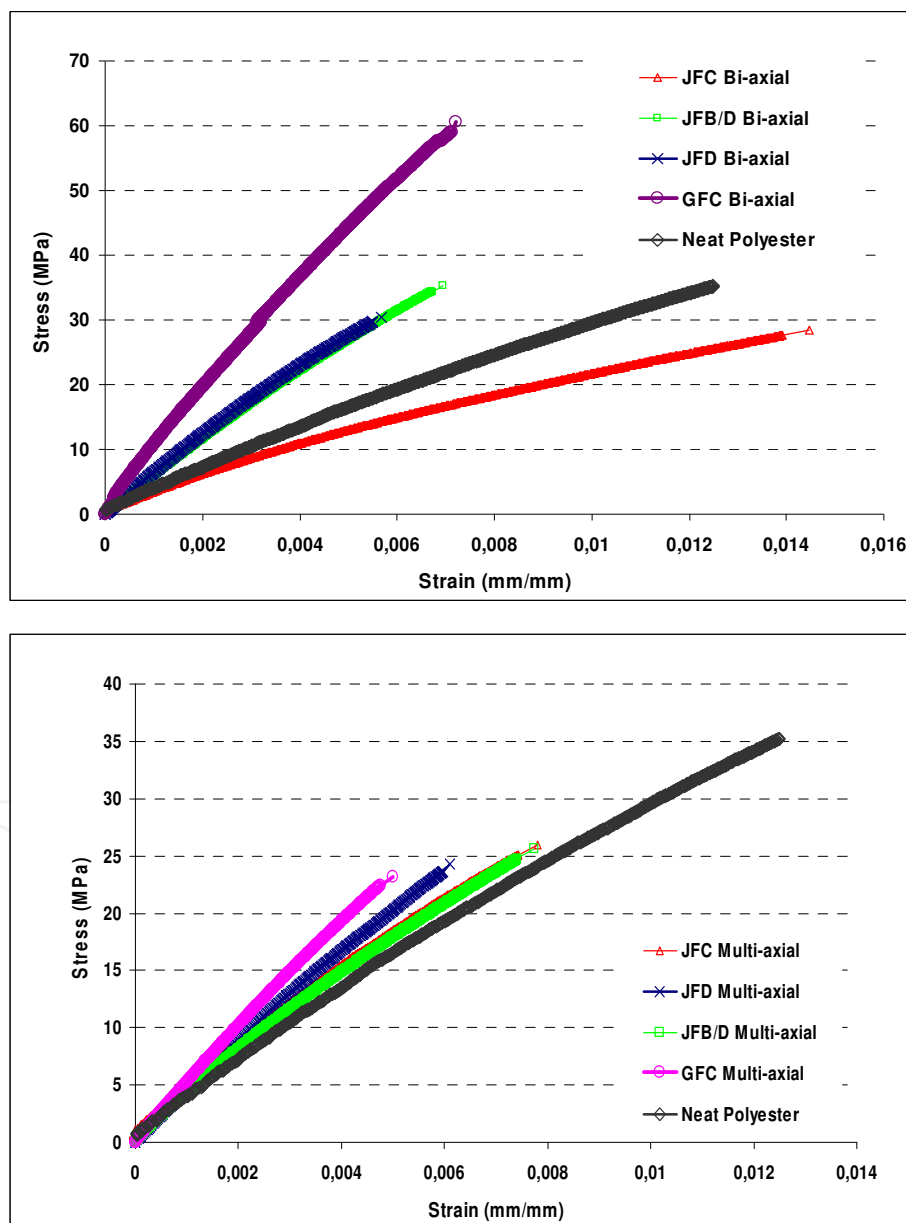


Fig. 13. Evolution on tension of the composites (Bi-axial and Multi-axial, each curve is a plot of a particular specimen whose behavior is representative of its group).

Composites	Fiber Arrangement	V_f (%)	Maximum Stress (MPa)	Maximum Strain (%)	Elastic modulus (GPa)	Coefficient of Variation for modulus (%)
GFC	Bi-axial	21	60.52	0.69	8.81	6.02
	Multi-axial	9	23.21	0.51	4.69	4.81
JFC	Bi-axial	31	27.76	1.49	1.83	14.70
	Multi-axial	14	26.41	0.83	3.19	5.34
JFD	Bi-axial	28	30.38	0.58	5.29	4.10
	Multi-axial	11	24.39	0.60	4.23	5.14
JFBD	Bi-axial	23	35.33	0.72	4.91	3.59
	Multi-axial	9	25.58	0.80	3.55	3.91

Table 3. Mechanical properties of the composites.

On the contrary, for multi-axial fiber composites, both treatments did not imply significant improvements on their mechanical properties. Unlike the bi-axial jute composites, treatments implied no significant change in the elastic modulus of the multi-axial composites (average 22%), moving it from about 3.19 GPa (JFC) to 4.23 GPa and 3.55 GPa for JFD and JFB/D, respectively. Since this fabric's arrangement does not require fibers in tow form, their wettability is much more efficient than the wettability found for bi-axial arrangement, confirming that the arrangement of jute fabrics has large influence on the fiber impregnation. Related to the maximum stress, again treatments did not imply significant changes on it, decreasing from 26.41 MPa (JFC) to 24.39 MPa (JFD) and 25.58 MPa (JFB/D) (about 6%).

Figure 14 emphasizes the fracture cross section of the JFC specimens using a Scanning Electron Microscope (SEM). The rupture was accompanied by a clear withdrawal of the fibers from matrix (pull-out effect), leaving holes that indicate the very poor interface bond (Fig. 14 b). Besides the weak interface, Figure 14 (a and b) also shows that the fibers in the bi-axial JFC composite are not completely involved by matrix, indeed it makes clear the poor wettability in the center of the jute tow.

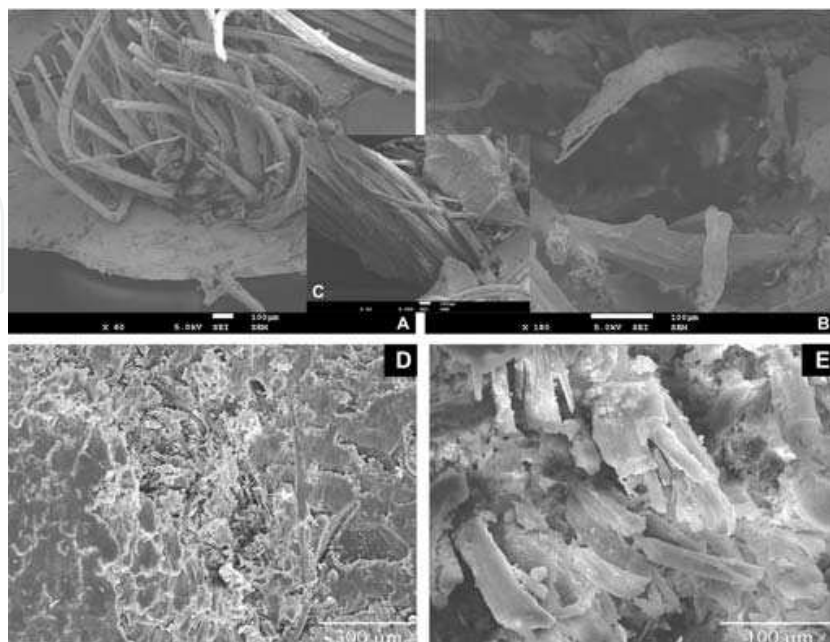


Fig. 14. SEM of the bi-axial jute composites. (a, b and c) untreated; (d and e) treated.

Table 3 also shows that the treatments brought an increase of the matrix volume fraction (V_m) of the jute composites. It is important to remark that JFD and JFB/D present higher elastic moduli than JFC, even with a decrease in their fiber content (V_f). This effect is associated with the better impregnation of the jute fibers by matrix, emphasized by Figure 14 (d and e) that shows the cross section surfaces of the treated bi-axial JFD and JFB/D specimens. After both treatments and on the absence of the moisture content, the tows of the jute fibers are completely impregnated by polyester matrix even into their center, unlike the bi-axial JFC composites. Sydenstricker et al (2003) analyzed sisal fibers after treatments and also found an effective improvement in interfacial adhesion, decreasing the pull-out effect. Since the results of the mechanical properties of both treated jute composites showed no significant difference between the effects raised by both treatments, drying treatment was assigned as the best choice due to its lower costs and environmental impacts. Thus, DMA tests were performed on JFD composites to refine the effects of the drying treatment. The DMA shows that for both fiber arrangements the activation energies present an increase for both JFD composites compared with their respective JFC composites (44% and 21% for multi-axial and bi-axial), which confirms the better interaction between jute/polyester, requiring more activation energy to flow the matrix (Table 4).

The activation energy observed for both treated jute composites is higher than for untreated jute composites, by about 22% and 45% for bi-axial and multi-axial, respectively (Table 4). Compared to the neat polyester matrix, the activation energies of the treated jute composites are higher by about 57% and 22% for multi-axial and bi-axial respectively. In this sense, it is clear that the drying treatment improved the interface bonding, and increased the interaction jute/polyester. All of these results corroborate the previous results, as discussed before. Finally, all results show that both treatments were responsible for a significant improvement on the mechanical behaviors of the jute composites by extraction of moisture and other compounds from jute fiber. In fact, the treatments improved the wetting behavior of the twisted tow of the bi-axial jute fibers, improving the interface bonding jute/polyester.

Composite		$T_g \text{ em } E'' \text{ (}^\circ\text{C)}$			$E_a \text{ (kJ.mol}^{-1}\text{)}$	$E' \text{ (MPa)}$
		1 Hz	5 Hz	10 Hz		
Polyester Matrix		51.75	57.24	60.00	252.72	2,456 (23°C) 2,538 (10°C)
Multi - axial	JFC	34.73	39.16	41.54	274.75	1,971 (23°C)
	JFD	65.06	69.50	70.32	398.04	2,987 (23°C)
Bi - axial	JFC	41.5	46.8	49.2	252.52	1,322 (10°C)
	JFD	60.65	66.11	67.45	307.64	2,754 (10°C)

Table 4. Activation energy of the neat polyester and the composite materials.

5.4 Numerical analysis of the jute composites: design optimizations

In the experimental evaluation of the composites (quantitative analysis), results have shown vegetable fibers as the potential solution, corroborating with qualitative analysis of SDP. Given the bi and multi-axial JFD composite as the best choice, they were carried out through numerical evaluation using ABAQUS 6.7 software. The frontal bonnet of the CS-Buggy with thickness at 4 mm was assigned as the Functional Unit (FU) to predict the behavior of the glass and jute composites during their usage, investigating the suitability of jute fibers to manufacture technical parts. The control bonnet was defined based on the current glass

composite used to produce a concurrent buggy. It is made of multi-axial glass fiber composite with about 23% of fiber volume fraction (Vf) and about 4 mm of thickness, and was assigned as Glass Bonnet Control (GBC). The candidate bonnet made of JFD composites was assigned as Jute Bonnet Composite (JBC).

The boundary conditions of the model can be seen on Figure 15, in which the pressure load was about 800 N (80 kg). The pressure area was assumed as circular with the diameter of about 200 mm placed at the center of the bonnet.

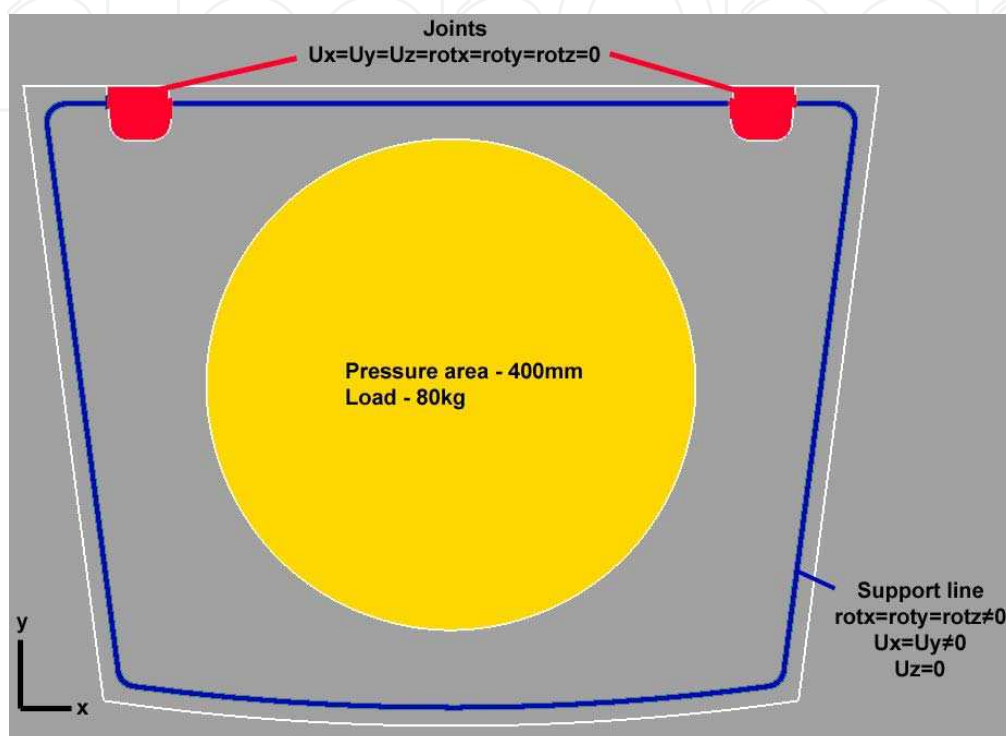


Fig. 15. Boundary conditions of the FEA of the frontal bonnet of the CS-Buggy.

Although the lower mechanical properties of the jute fiber composites comparing with glass fiber composites, and despite their current applications being somewhat limited to non-structural components, the experimental and numerical results pointed out jute fibers as a useful possibility to replace glass fibers in automotive components, satisfying the needs of the end customer. The results of the optimization of the bi-axial JBC show that the bi-axial arrangement of the jute fibers supports the load pressure of the project without implies any change in the design (dimensions and styling) of the bi-axial JBC, besides the change in its layers stacking sequence from $[(0^\circ/90^\circ), (45^\circ/-45^\circ), (0^\circ/90^\circ)]_s$ to $[(0^\circ/90^\circ), (0^\circ/90^\circ), (45^\circ/-45^\circ)]_s$.

6. Environmental performance of the jute composites

The main goal of this work, based on the Triple Bottom Line concepts (Alves, 2006), is to obtain the equilibrium among social, environmental and economic performance of the jute fiber composites to produce technical automotive components. In the previous paragraphs it was possible to evaluate and confirm, through numerical and experimental analysis of the composites, the technical and economic feasibility of the jute fibers in replacing of the traditional glass fibers as reinforcement of composite materials. Thus, to ensure the sustainability and ecodesign concepts based on the Triple Bottom Line, a Life Cycle

Assessment (LCA) was performed to assess the environmental impact of using jute fiber composites and their required treatments for automotive design applications to manufacture the enclosures of the CS-Buggy. The results were compared with the impacts raised by current enclosures made of glass fiber composites over the entire life cycle of the CS-Buggy, assessing the consequences of replacing glass fibers for untreated and treated jute fibers on the overall sustainability of this specific and important automobile sector in Brazil (leisure and tourism).

Like the previous numerical analysis, in the LCA evaluation the frontal bonnet of the CS-Buggy was also assigned as functional unit of the analysis, or in other words, the functional unit can be stated as “the engine cover of 0.35 m² which achieves the required mechanical and structural performance”. Since the LCA was performed to achieve environmental impacts related to the composite materials used to produce the frontal bonnet of the CS-Buggy, its boundary conditions is the entire life cycle of the bonnets made of composite materials and their influence for whole CS-Buggy vehicle, from the extraction of raw materials, over production processes and the use phase to the end-of-life of the vehicle. It includes all the needed transportations as well as the infrastructure to apply the treatments to the jute fibers and to produce the bonnets and to dispose of them.

The inputs regarding the jute fibers cultivation and production were provided by the supplier Castanhã Têxtil Inc, nevertheless they can also be estimated based on the literature. Inputs related to the polyester matrix, glass fibers and vehicles used for transportation were based on SimaPro 7.0 database in its IDEMAT and Ecoinvent libraries. Inputs related to the production of all bonnets were based on the production of the composites (Table 5). The journey logistic inputs were based on the supplier’s database, while electric energy inputs were obtained from Coltro et al (2003) and they are related to the Brazilian electric energy system. Finally, the landfill and incineration scenarios of the end of life of the bonnets were based on Brazilian government reports (Alves_b et al., 2009), the recycling scenario was based on experimental results of the mechanical recycling. Figure 16 shows the schematic diagram of the assumed life-cycle to the functional unit, in which green colored inputs were obtained by the authors and black colored inputs were obtained in the SimaPro database.

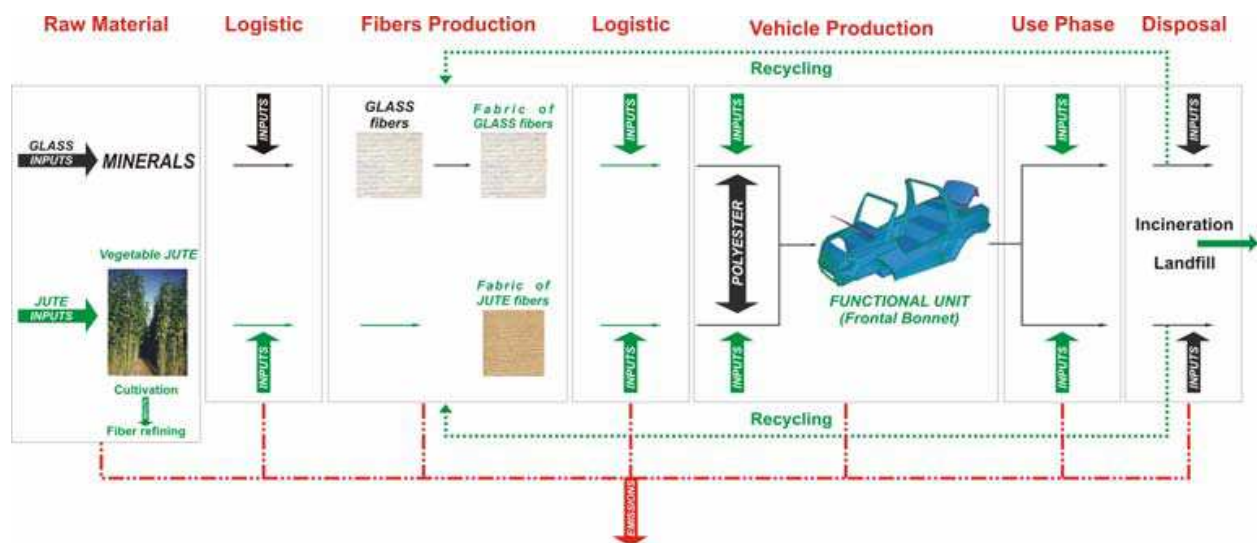


Fig. 16. Boundaries assumed in the LCA.

Bonnet	Injection flow (cc/min)	Volume of the fiber (%)	Mass of the bonnet (kg)	Mass of the fiber (kg)	Injection time (seg)	Total energy consumption (kW.h)
Jute Fibers (untreated and treated)	45	31	1.77	0.65	353	18.5
Glass Fibers	50	21	2.02	0.74	364	17.9

Table 5. Inputs of the bonnet’s production.

For the use phase the fuel consumption was taken into account to identify how influential is the replacement of the glass composites for the lighter jute fiber composites. Through the lower density of the jute fibers in comparison to glass fiber, it was possible to calculate the percentage of reduced weight of the bonnet made of jute fibers (about 15 %) and of whole vehicle (0.048%). In this sense, based on literature (Ljungberg, L.Y, 2007; Miller, et al., 2000), the decreasing fuel consumption of the CS-Buggy due to the use of the jute bonnet was estimated at about 0.029 %, which means about 7.71 L (5.55 kg) for an expected life of 265,500 km. This expected use phase life is based on Sindipeças reports in which is established the average life of a Brazilian vehicle at about 20 years and its average annual use of about 13,275 km/year (Alves_b et al., 2009). It was estimated a current fuel consumption of about 10 km/L for a total weight of the CS-Buggy of about 600 kg. In this sense, the fuel consumption assigned to the bonnets made of glass and jute fibers was respectively about 64.36 kg and 58.81 kg taking into account the density of the petrol at 0.72 kg/L. Regarding the scenario of the final disposal of the enclosures, it will be explained later.

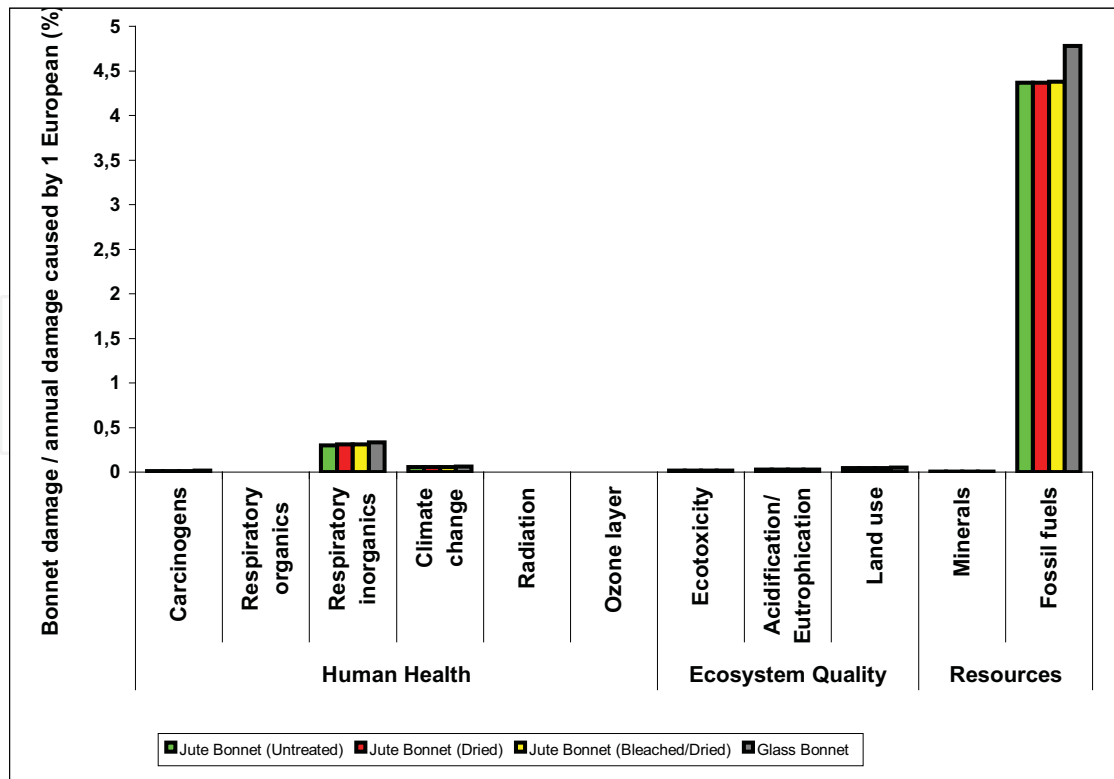


Fig. 17. Impact categories of the bonnets (Total Life-Cycle).

Regarding to the total life-cycle of the bonnets, Figure 17 and Table 6 show the total damage caused by the environmental impacts in their total life-cycles. Overall, it is clear that the use phase is significantly more pollutant than production and disposal phases (about 1,000%), in fact disposal phase represents just about 3% of the total damage, being raised by energy consumption of the recycling scenario. The significant impacts are raised by the use phase (about 97%), since its values are very close of total life cycle and most of impacts are related to the resources damage category due to the consumption of fossil fuel, while 3% are related to the production phase and its energy consumption, which raises respiratory inorganics impacts. In the whole life cycle, glass bonnet presents larger environmental damage (average 9%) comparing with damage raised by all jute bonnets, due to its higher weight and fuel consumption. About the treatments, Table 6 shows that comparing to the untreated jute bonnets, both drying and bleaching/drying treatments decrease the environmental performance of bonnets at about 1% and 2% respectively. In other words, both treatments are high pollutant until the production phase, in which dried and bleached/dried jute bonnets have 18% and 42% more environmental impacts than untreated jute bonnets. After the use phase, the consumption of the fossil fuel (more pollutant) becomes the treatments no significant to the total damage. Finally, results show that in spite the high importance of the production and disposal phases for the life cycle of vehicles, in this CS-Buggy the use phase is more pollutant and more important to focus the design improvements. It confirms researches (Ashby & Johnson 2002) in which the use phase is the most pollutant phase of a vehicle.

Damage category		Production Phase - Use Phase	Disposal Phase
Human Health	UJB	0.36529	0.01012
	DJB	0.37383	0.01012
	B/DJB	0.37572	0.01015
	GB	0.39440	0.01797
Ecosystem Quality	UJB	0.08450	0.00161
	DJB	0.08589	0.00161
	B/DJB	0.08604	0.00161
	GB	0.09179	0.00281
Resources	UJB	4.38789	-0.01428
	DJB	4.38789	-0.01428
	B/DJB	4.39931	-0.01428
	GB	4.80267	-0.01483

Table 6. Damage categories of the bonnets (Total life-cycle).

Related to the total enclosures of the CS-Buggy, results show that the replacement of all glass fibers for jute fibers improves the environmental performance of the vehicle at about 15%, while the frontal bonnet means an improvement of about 9%. Thus, a much more significant effect could be reached by switching to light-weight design of vehicles by design of composite materials. About treatments, unlike the treated jute bonnets in which treatments decreased in the environmental performance of them (about 1% and 2%), for

total enclosures, the treatments implied lower differences among their environmental performance. It proves that treatments of jute fibers are a great choice, improving the mechanical performance of the jute composites without imply environmental impacts.

6.1 Social and economic analysis

In regards to the social requirements, jute fiber plays an important role from fiber cultivation of the plant to the production of the bonnet. In its cultivation phase jute is an important income source to the local farmer communities contributing to the sustainability of the region, avoiding the rural exodus hence its social problem in industrial cities. In the production phase, jute fiber causes fewer health risks and skin irritation than glass fibers for the employees that are directly involved in the production of the components. In the use phase, the social advantage of the jute fibers is related to the human health since jute fibers imply lower fuel consumption than glass fibers, and then raising lower GHG emissions and their environmental impacts. The social advantages of the disposal of jute fibers are also related to the human health, since they are biodegradable for landfill scenarios, while for the recycling scenario they require less energy compared with glass composites (about 50%).

Related to the economic advantages, in Brazil, jute fibers cost about seven times less than glass fibers, while production costs are almost the same, since it is possible to produce either jute or glass composites with almost the same setup and production processes. Using jute fibers also implies lower fuel consumption, so it means an economic advantage for owners of the vehicle. Still, the potential global market for natural fibers in the automobile industry is expected to increase. Nowadays in the USA more than 1.5 million vehicles are the substrate of choice of bio-fibers such as kenaf, jute, flax, hemp and sisal and thermoplastic polymers such as polypropylene and polyester (Faruk, 2009; Margets, 2002).

Finally, this LCA analysis presents the consequences of the replacement of the glass fibers by the jute fibers as reinforcement of composite materials to produce automotive structural components. In regards to the composite materials, CS-Buggy demonstrated that jute fiber composite presents the best solution enhancing the environmental performance of the CS-Buggy's enclosures, hence improving the environmental performance of the whole vehicle. However, it is important to remark that, despite jute fibers being well known as natural, and hence expected to present lower environmental impacts than glass fibers, the LCA showed that until the production phase of the composites, jute fibers imply higher environmental impacts, since they require more energy for manufacturing the composites. Indeed, only from the use phase of the CS-Buggy jute fibers present lower impacts than glass fibers, in which the fuel consumption becomes lower due to the weight reduction of the vehicle.

LCA also pointed out some unknown impacts in production and disposal phases of the bonnets, specifically related to the logistic transports of the jute fibers and the recycling scenario of the composites. It provides to designers an overview scenario of the whole issue that help to make decisions, besides those traditional inputs usually used in the product design, working in partnership with suppliers to improve the logistic of the jute fibers and focusing on the most pollutant phases to prevent potential environmental effects.

7. Conclusions

This work presented a comprehensive and integrated approach of the ecodesign and sustainability concepts through using friendly eco-composite materials, reinforced with jute

fibers. As explained at the beginning, the life-cycle approach used here provided a larger point of view of ecodesign. Through the Sustainable Design Procedure, as a strategic ecodesign method, it was possible to show how the integration of the environmental inputs really improve the level of innovation of the current product design, by interconnecting them with traditional inputs such as the properties of materials and economic factors. In fact, the environmental inputs denoted a new approach of the problem, motivating the inclusion of vegetable fibers and hence jute fibers as candidate to replace glass fibers as reinforcement of composite materials.

The results show that jute fibers need some treatment to improve the mechanical behaviour of the composites, since they present significant moisture content. On the other hand, unlike several chemical treatments of fibers obtained in the literature, in this research two treatments were performed and showed that a simple and inexpensive drying of the fibers is enough to improve the composite properties. In fact, the treatments improved the wetting behaviour of the twisted tow of the bi-axial jute fibers, and then, they improve the interface bonding jute/polyester. After the treatments the volume fraction of matrix into the composite shows an increase due to the completely impregnation of jute fiber tows by matrix, also pointing out the improvement of the interface bonding due to the increase of the interface area.

Related to the environmental performance of the jute composites, the case study confirmed them as the best solution enhancing the environmental performance of the buggy's enclosures and hence improving the environmental performance of the whole vehicle, inspite of their respective treatments. Despite the higher energy consumption to dry the jute fibers, their lighter weight characteristic ensures their better environmental performance compared to the glass fibers. Since the use phase of vehicles was shown to be the most pollutant phase, the lighter weight of jute fibers implied a decrease of the fuel consumption of the vehicle used as case study. Also, LCA pointed out some unknown impacts in production and disposal phases of the bonnets, specifically related to the logistic transports of the jute fibers and the recycling scenario of the bonnets. It is important to remark that results show that automotive components made of vegetable composites need to be lighter than glass composites to present better environmental performance. Otherwise, they do not present environmental advantages, raising more impacts than glass composites.

Finally, this work can be considered a first step towards the sustainability of the Brazilian industry of buggies, since it can be a motivation for other companies to produce more sustainable vehicles, toward the sustainability of this mobility market. It can even drive users awareness for more environmentally friendly consumption behaviour.

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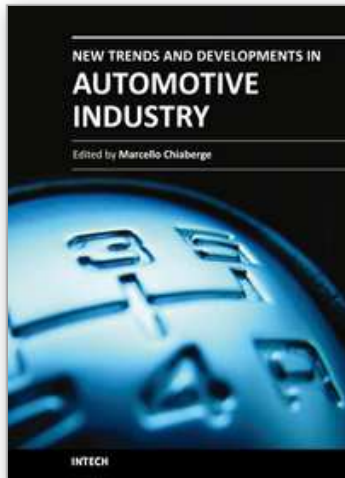
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