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Natural fiber reinforced polymer composites in industrial applications: feasibility of date palm fibers for sustainable automotive industry

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ABSTRACT

Proper utilization of the available natural resources and wastes became crucial for developing sustainability in industry. In this work, the feasibility of using the date palm fibers in the natural fiber reinforced polymer composites (NFC) for automotive industry was reported. Moreover, this work identifies a gap in the way of evaluating NFC relative to comprehensive desired criteria. This gap leads to disregard potential natural fiber types in industrial applications and keep it no more than an environmental waste problem. Here, criteria that affect the NFC were categorized and classified into levels. Governing criteria were suggested, collected and tabulated according to each level. To ensure the potential and competitiveness of the date palm fiber (DPF) in developing sustainability of the automotive industry, several comparisons between DPF and other fiber types commonly used in this industry were carried out. In most comparisons, DPF was the best selected fiber among all other types. DPF was the best regarding specific Young's modulus to cost ratio criterion. Technical properties and performance, environmental, economical, and societal aspects strongly contribute toward adopting DPF into the automotive sector to improve its sustainability and productivity. Furthermore, this adoption has a significant environmental influence throughout achieving an efficient sustainable waste management practice.

1. Introduction

Material selection is a vital process in engineering design for a successful sustainable product. Materials are not only important for mechanical properties but also can explore both physical and metaphysical properties of products and play a corner stone role in the customer satisfaction attributes. It is of paramount importance for any design to achieve success at low cost. Taking into consideration the tremendous need and awareness of environmental impact, the proper compatibility of the product's material with its performance and recyclability has recently higher priority in engineering product design. Several factors, constrains, and limitations affect the usage of a specific type of material in a particular application (Ashby and Cebon, 1992). This makes the optimizing of these constrains and the selection of proper material type is a complex matter where proper decisions have to be taken (Dweiri and AL-Oqla, 2006). Due to the inherent relationship between the materials and their availability, machinability, product design, cost, recyclability and performance in the final product form (Dweiri and AL-Oqla, 2006), modern techniques like optimizations, informative decisions, and expert systems are utilized to end up with proper material selections (Dieter, 1997; Dweiri and AL-Oqla, 2006; Jahan et al., 2010).

The natural fiber reinforced polymer composites (NFRPC), (simply natural fiber composites (NFC)), became recently highly valuable materials. In this type of materials, natural fibers (such as hemp, sisal, jute, kenaf, flax, etc.) are used as reinforcing material (fillers) for polymer-based matrices. In light of the governmental emphasis on the new environmental regulations and sustainability concepts besides the growing of ecological, social, and economical awareness, as well as the high cost of petroleum resources (Faruk et al., 2012; Kalia et al., 2011a,b); the optimal utilization of natural resources was enhanced (Kalia et al., 2011a). Utilizing natural fibers in particular, will not only decrease waste disposal problems, but also will reduce environmental pollution (Kalia et al., 2011a). Natural fiber composites as environmentally attractive materials, have been proven and emerged as an alternative to the glass-reinforced or carbon reinforced polymer composites (Faruk et al., 2012; Kalia et al., 2011a,b). Natural fibers have major advantages over traditional glass fibers that make them very competitive in

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modern industrial applications and particularly in automotive ones (Alves et al., 2010; Faruk et al., 2012; Kalia et al., 2011a,b; MIR et al., 2010; Pickering et al., 2007). Such advantages include low cost, good thermal and acoustical insulation properties, availability, CO_2 sequestration enhanced, energy recovery, reduced dermal and respiratory irritation, and reduced tool wear in machining operations (Alves et al., 2010; Faruk et al., 2012; Kalia et al., 2011a,b; MIR et al., 2010; Pickering et al., 2007; Sarikanat, 2010). The properties and performance of engineering products made from NFC depend not only on the properties of their individual components but also on their compatibility and interfacial (polymer/filler) characteristics (Kalia et al., 2011b; Pickering et al., 2007; Sarikanat, 2010), which expand the possibilities of producing many exciting new materials with totally new properties (Kalia et al., 2011b).

Many researches have investigated and addressed the competitiveness, capabilities and suitability of natural fibers as reinforced fillers in polymeric matrices. Most of the researches focused on the mechanical properties, chemical modifications to improve fiber/polymer compatibility, manufacturing processes and other technical issues. Some researchers compared between different NFC in order to show their suitability for certain purposes and applications. Pickering et al. (2007) extensively investigated Polypropylene composites reinforced with hemp fibers throughout the injection molding process. The authors studied fibers treatments, modifications, in addition to the optimization of the hemp fiber quality. Earlier investigations studied the properties of jute/plastic composites, where several characteristics were investigated including crystallinity, fiber modification, thermal stability, weathering resistance, durability, in addition to its suitability to the automotive industry throughout eco-design components (Alves et al., 2010; MIR et al., 2010; Sarikanat, 2010). In contrast, Al-Khanbashi et al. (2005) explored the usage of the date palm fibers as polymeric matrix reinforcement and discussed the characteristics of that composite. Moreover, Nasser and Al-Mefarrej (2011) examined the potential of implementing the midribs of date palm as a raw material for wood–cement composite industry in Saudi Arabia while Shen et al. (2009) investigated and compared bio-based plastics with petrochemical plastics with emphasis on their technical and market potentials. They raised limitations that should be taken into considerations in the interpretation phase, and presented recommended types of actions which can lead to a better understanding of the potentials of bio-based plastics with petrochemical plastics. In addition, analyses and conclusions for policy makers have been derived.

Based on our literature search, only very few studies were found regarding precise decisions for selecting the proper natural fiber composites (NFC) for a particular application (Cheung et al., 2009; Sapuan et al., 2011). Sapuan et al. (2011) have used the Analytical Hierarchy Process (AHP) method to select the proper NFC material for automotive dashboard panel, where a database of properties for natural fiber composite materials was systematically organized. The properties of materials considered in that study were only the density, the Young's modulus and the tensile strength. They considered 29 types of natural fiber composite materials to rank their suitability for the automotive dashboard panel. On their part, Cheung et al. (2009) discussed the potential of natural fiber composites and focused on both mechanical and thermal properties of the NFC, particularly, the animal based fiber composites. They highlighted the potential of both plant and animal base in biomedical engineering and introduced some factors to be considered in selecting general material suitable for biomedical applications. They also classified characteristics of the selected materials according to the compatibility with such applications like being, bio-inert, bi-functional, bio-active, in addition to the characteristics of the host such as tissue, age, sex, race, etc.

Our extensive literature search indicated that there is a lack of information regarding selecting the proper natural fiber composite materials for many applications. This is due to the large possibilities of generating new natural fiber composite materials with novel properties (Kalia et al., 2011b). Therefore, there is still a need for pair-wise comparisons of the natural fiber composite materials among wide range of desired criteria that affect the selection of the particular applications to end up with informative selection decisions. This, in order, will help designers and decision makers to reach the best choice of NFC materials according to their design criteria and limitations. According to the literature and the researchers' best knowledge; there were very few studies that have considered the ranking of different types of natural fiber composites with respect to desired criteria. These comparisons were conducted according to narrow wide criteria, mainly mechanical, technical and cost, but not in a comprehensive manner. Moreover, there was a lack of a clear systematic classification of the factors and criteria affecting the selection process of the natural fiber composites. That is, there is an insufficient collective database of selection criteria for the natural fiber composites to be used as a primary selection tool for designers and decision makers in this area.

Consequently, the objectives of this work are to: categorize the considerable factors and criteria affecting the selection process of the natural fiber composite materials for different applications (automotive industry as an example); address the potential and capabilities of the date palm fibers compared to other types used in automotive industry (particularly, coir, hemp, and sisal) among certain selective criteria from those categorized in this study; address the lack of information in comparing natural fiber composites relative to comprehensive criteria and emphasize the establishment of overall natural fiber composite material guidelines and database to assist designers in NFC material selection process.

2. Methods

In order to compare between different types of NFC, criteria that affect the selection of NFC materials were categorized into levels. In each level, proper criteria, characteristics and properties were suggested, collected from published literature and tabulated. To demonstrate the effectiveness of such classification and criteria for proper evaluation of NFC, the competitiveness of date palm fibers in the sustainability of the automotive industry was investigated utilizing selective criteria. Many comparisons between different types of natural fibers commonly used in the automotive sector in addition to the date palm were conducted. These comparisons were performed regarding various factors like technical properties and performance, environmental, economical, and social ones that distinguish the feasibility of the date palm fibers in enhancing the sustainability and productivity of the automotive industry. A comparison with respect to each single criterion was conducted and illustrated in a separate figure.

3. Results and discussion

3.1. Criteria affecting the selection process of the NFC materials

Unlike isotropic materials, components made of composite materials are to be created by designers based on the functional requirements. This implies the best chosen of the reinforcement, the matrix, the process for curing in addition to other aspects that should be performed in an optimized manner. Development of materials database, where properties, characteristics, and performance of different materials can be utilized, not only serves the