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Predicting the potential of agro waste fibers for sustainable automotive industry using a decision making model

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ABSTRACT

Developing a sustainable industry requires proper utilization of the available and compatible natural resources. Selecting a proper natural fiber type to form a reinforced polymer composite suitable for sustainable automotive industry is considered as a multi criteria decision making problem. This work (i) ranks different natural fiber types according to their appropriateness for the sustainable automotive industry using a decision making technique for the first time. (ii) Predicts the potential of the date palm fiber (DPF) as a reasonable cheap alternative for the sustainable automotive industry. A combined informative/expert-feedback decision making model utilizing the analytical hierarchy process (AHP) was built to rank and predict the potential of the natural fibers. This model can optimize finding the most appropriate available, cheap, eco-friendly alternative material to enhance not only the sustainability and productivity of the automotive industry but also the environmental performance too. A pilot questionnaire was conducted to ensure the appropriateness of the used model. The natural fiber options considered were: coir, date palm, flax, hemp and sisal. The flax fiber type is the best choice for automotive applications as it ranks highest, followed by the date palm fiber as a reasonable competitive cheap alternative choice. This decision was made based on simultaneous technical and economic standpoints. Date palm fiber was found to be the best choice regarding many criteria like Fiber's Specific Strength to Cost Ratio one. Results demonstrated that the most AHP model priority stack was occupied by both Mechanical Properties and Specific Performance for Automotive Applications criteria. Sensitivity analysis illustrated the reliability of the results and the drawn judgments in this study.

1. Introduction

Proper material selection would not only explore the desired physical and meta-physical properties of products, but also take a vital role in the customer satisfaction attributes. In a scenario where rapid progress in material science has made a wide range of available engineering materials for designers, the proper compatibility of the product's material with its performance and recyclability becomes essential for sustainable engineering products (AL-Oqla and Sapuan, 2014). Thus, exploring new eco-friendly materials and selecting their desired distinctive characteristics and attributes would lead not only to innovation in design but also to expand new sustainable design possibilities suitable for desired concerns (AL-Oqla and Sapuan, 2014). Due to the inveterate relationship between materials attributes and their availability, machinability, cost, recyclability as well as performance in the end used product form, the selection of the most appropriate material type for an innovative particular application becomes a complex matter (AL-Oqla et al., 2015). This selection has a nature of multi-criteria decision making (MCMD) problem where appropriate decisions have to be taken (Dweiri and Al-Oqla, 2006).

1.1. Natural fiber composites and sustainability

Among the available modern materials, bio-based composites, particularly, the natural fiber reinforced polymer composites (NFRPC) or simply (NFCs) have recently higher value for various industrial applications. In such type of materials, natural fibers (such as hemp, jute, flax, kenaf, and sisal) are utilized as reinforcing materials for polymer-based matrices. In light of the growing ecological, and economic awareness, besides the governmental emphasis on the environmental regulations and sustainability concepts, as well as the high petroleum cost (Faruk et al., 2012;

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Kalia et al., 2011; Kastensson, 2014); the optimal usage and utilization of natural resources was emphasized not only to decrease wastes and treat disposal problems (AL-Oqla et al., 2014b; AL-Oqla and Sapuan, 2014; Subramoniam et al., 2013), but also to decrease environmental pollutions and improve the sustainable environmental management systems (Kalia et al., 2011; Leceta et al., 2014; Subramoniam et al., 2013). On the other hand, NFCs as environmentally corroborative materials, have been confirmed and used as an alternative type to the traditional glass/carbon reinforced polymer composites (Faruk et al., 2012; Leceta et al., 2014). The advantages that natural fibers show over traditional glass ones make them suitable for modern industrial applications and very competitive in automotive industry (AL-Oqla and Sapuan, 2014; Alves et al., 2010; Blume and Walther, 2013; Faruk et al., 2012; Kastensson, 2014; Mir et al., 2010). Such advantages include recyclability, good thermal and acoustical insulation properties, bio-degradability, low cost, availability, energy recovery, CO_2 sequestration enhanced, reduced tool wear in machining operations, and reduced dermal and respiratory irritation (AL-Oqla et al., 2014b; AL-Oqla and Sapuan, 2014; Alves et al., 2010; Faruk et al., 2012; Pilla, 2011; Sarikanat, 2010). Moreover, the properties of the NFCs' individual constituents (polymer/filler) in addition to their compatibility and interfacial characteristics can determine the final properties and performance of the NFCs products (Mir et al., 2010; Sarikanat, 2010). Therefore, the possibilities of making many exciting materials with totally new properties can be expanded (AL-Oqla et al., 2014a; AL-Oqla and Sapuan, 2014). Thus, such proper selections and implementations of agro wastes in NFCs can be in advantage of the economic growth, industrial sustainability and environmental performance, where available low cost eco-friendly materials can be integrated with the industry to solve an environmental waste problem issue as plenty of natural fibers are annually accumulated and burnt (AL-Oqla and Sapuan, 2014). This would also lead to achieve low weight products with low energy consumptions and costs (Blume and Walther, 2013; Subramoniam et al., 2013). The availability of the natural fibers worldwide can also enhance the productivity of the industrial sectors, where no shortage of raw materials can be achieved (AL-Oqla et al., 2014b; AL-Oqla and Sapuan, 2014). Moreover, such implementation of NFCs in industry has positive social impacts in both local and international societies through participate creating new jobs, where the supply chain of raw materials is necessary (AL-Oqla and Sapuan, 2014; Alves et al., 2010; Subramoniam et al., 2013). Furthermore, the desired degradability characteristics of the NFCs would improve both the environmental performance and the remanufacturing processes through promoting the end life products' recyclability (Blume and Walther, 2013; Subramoniam et al., 2013). This in order would widen the economic and ecological advantages of such adoption. Consequently, adapting agro wastes in industry has positive environmental, social and economic impacts, which make it one of the most potential solutions for the industrial sustainability at the current time.

On the other hand, the potential, suitability, and capabilities of natural fibers as reinforced fillers in polymeric matrices have been investigated and addressed by several researches. Most of these focused on the NFCs mechanical properties, fiber/polymer compatibility, manufacturing processes, chemical modifications to improve the desired performance, and other technical issues. But few researchers conducted sorts of comparisons between different NFC materials for certain applications (AL-Oqla et al., 2015; AL-Oqla and Sapuan, 2014). Huda et al. (2008) had performed impact tests to investigate the impact strength of the bamboo fiber/PLA composites. According to their study, fibers treatments were able not only to improve the adhesive forces between the matrix and the fillers that lead to an improvement in the impact strength, but also to provide an effective resistance to micro propagation during the impact. On the other hand, the potential of implementing the midribs of date palm for wood-cement composite industry in Saudi Arabia was examined by Nasser and Al-Mefarrej (2011). Moreover, Al-Khanbashi et al. (2005) explored the date palm fibers usage as polymeric matrix reinforcement and discussed the characteristics of the resulted composite. In contrast, little studies were found considering precise decisions for selecting the proper NFC materials for particular application. An AHP model was used by Sapuan et al. (2011) to select proper materials for automotive dashboard panel. They systematically organized a database of 29 types of NFC materials to rank their suitability for the automotive dashboard panel. The properties of materials considered in that study were only density, Young's modulus and tensile strength. In contrast, little studies considered decision models in selecting the quality of cotton fibers for textile applications (Majumdar et al., 2004). On their part, Cheung et al. (2009) expressed the potential of the animal based fiber composites. They highlighted the implementation of both animal and plant base fibers in biomedical engineering and mentioned some factors to be considered during selecting materials suitable for that application.

1.2. Natural fibers for automotive industry

Automotive industry is one of the main sectors taking the societal, environmental, and governmental needs and responsibilities into considerations. Research and development in automobiles field in European countries as well as others are enhanced using natural fibers as filler materials in plastic products (Alves et al., 2010; Blume and Walther, 2013; Chiappetta Jabbour et al., 2013; Kalia et al., 2011; Subramoniam et al., 2013). That is; because of the tremendous need to reduce the weight of the produced vehicles, which is necessary to reduce the fuel consumption in one hand and to achieve better environmental performance by reducing CO_2 emotions on the other. The new bio-based commercial vehicles are more economical and lighter alternatives for consumers. Such vehicles are rich with interior parts that use natural fibers (like coir, jute, sisal, and hemp) as reinforcing agents for biodegradable materials to be composted or recycled when desired (at the end of its life cycle) (Blume and Walther, 2013; Chiappetta Jabbour et al., 2013; Subramoniam et al., 2013). Such implementation of natural fibers as reinforcing agents is considered efficient in automotive applications as they are used in components that does not exposure to heavy loads, but to have a good dimensional stability at low cost (Dittenber and GangaRao, 2011; Kalia et al., 2011).

The suitability of the bio-fiber reinforced composites for automotive sectors was investigated by several researchers (Alves et al., 2010; Mir et al., 2010; Sarikanat, 2010), where several characteristics and properties of different natural fiber/plastics composites were investigated including fiber modification, thermal stability, crystallinity, durability and weathering resistance. Furthermore, other studies were carried out to address the importance of developing the sustainability of automotive sectors utilizing deployment of useful concepts, alternatives and procedures such as: eco-design for industrial applications throughout parametric studies, life cycle assessment procedures, environmental management and operational performance, introducing light weight concepts, conducting comparisons and addressing the high quality characteristics of material alternatives, implementing decision making tools for vehicle developments, strategic planning concepts, designing for remanufacturing processes and others (AL-Oqla and Sapuan, 2014; Alves et al., 2010; Blume and Walther, 2013; Chiappetta Jabbour et al., 2013; Kastensson, 2014; Leceta et al., 2014; Subramoniam et al., 2013).

Although there is an obvious need for implementing decision making tools as well as other beneficial ones in the sustainability theme to enhance achieving better sustainable societies (Bonilla