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Natural fibre composites: Comprehensive Ashby-type materials selection charts

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ABSTRACT

To aid design engineers in closing the existing gap between current scientific knowledge and actual market applications of plant fibre reinforced plastics (PFRPs), this article provides comprehensive Ashby-type materials selection charts for PFRPs to facilitate product design and development. General tensile mechanical property profiles are presented for a variety of PFRPs to enable the design for (i) optimal stiffness and strength, (ii) minimal weight (i.e. optimal specific properties), (iii) minimal cost, and (iv) minimal eco-impact. A large database is used to capture the range in properties of different (i) reinforcements forms (short fibres: pellets and nonwovens; long fibres: multiaxials and unidirectionals), (ii) polymer matrices (thermoplastic and thermosetting), and (iii) manufacturing techniques (injection moulding, compression moulding, hand lay-up, vacuum infusion, resin transfer moulding and prepregging). As PFRPs are often viewed as alternatives to glass fibre composites (GFRPs), for demonstrative purposes the tensile properties of the various PFRPs are compared with similar GFRPs. Moreover, highlighting that other mechanical parameters may be critical performance indices for specific products and applications, a materials property chart for a fatigue-limited design is also produced.

1. Introduction

Increasing environmental concerns and awareness amongst consumers, tightened environmental and waste management legislations by government, and a deepening reliance on non-renewable resources by industry despite a commitment to social responsibility are key factors that have driven the increasing interest in the use of bio-based materials as replacements to traditional 'man-made' materials in various applications. To alleviate some of the environmental issues associated with using synthetics in fibre reinforced plastics (FRPs), bio-based, if not fully-green, ingredients are being considered to replace both the typically synthetic fibre reinforcement and the petrochemically-derived matrix [1]. Notably, other than the eco-advantage of using bio-based constituents, their typically lower cost and wide availability, and their promising and competitive technical mechanical properties have strengthened the case for bio-based composites as engineering materials [1].

Despite the tremendous interest and vivid research in natural fibre reinforced composites for over two decades, to date, they have been successfully established only in the automotive industry (for interior components) [1,2], and have to a limited extent penetrated the construction (mainly deckings) and consumer goods markets [2]. Parallel to this, in spite of a threefold growth in the use of plant fibres (excluding wood and cotton) in reinforced plastics over the last decade in the EU, only a small percentage of plant fibres have been utilised as reinforcements in composites [1]. A report by the European Industrial Hemp Association [3] claims that in 2012, while hemp fibres represented 10–20% of the market share of plant fibre reinforced plastics (PFRPs) in the EU, the total allocation of hemp for composites applications was 14%; the two primary applications of hemp fibres were for specialty pulp and paper (55%) and insulation (26%). Flax fibres, on the other hand, accounted for >60% of the EU market share of PFRPs, but even their primary application (>75%) lay in textiles [4].

While it is clear that there is great scope for plant fibres to be exploited as composite reinforcements, it is often suggested [1,5–7] that the critical aspects limiting the wide industrial applications of PFRPs relate to:

(i) the variable and often inferior mechanical properties of plant fibres in comparison to synthetic fibres like E-glass,
(ii) the lack of – or at least limited – empirical data on (a) critical atypical loading conditions such as off-axis, multiaxial, high-strain rate, fatigue and creep loading, and (b) the effects of environmental conditions such as humidity/moisture and temperature/fire, and

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(iii) inadequate understanding of (a) processing requirements of plant fibres for composites applications, and (b) manufacturing processes suitable for plant fibre composites.

In my opinion, however, the key and long-overlooked aspect is the lack of materials selection databases incorporating near-comprehensive data sets on PFRPs. The consequence is that PFRPs may not be on the radar of engineers and product designers in all relevant industries as viable alternative materials.

1.1. Materials selection processes

Materials selection is an integral part of the product design and development process (Fig. 1). To manufacture products which efficiently perform their function in specified operating conditions over their design life, appropriate materials need to be employed. Typically, the selection criteria for materials choice are defined by the component function, objective and constraint. Invariably, the material processability and part manufacturability, dictated by the shape, reproducibility and assembly of the final component, may also affect the materials choice. Due to the large variety of materials (and associated manufacturing processes) available, the selection of materials for a given component may be a challenging task. Indeed, if the selection process is not rigorous, the designer may opt for an inappropriate material or overlook an attractive alternative material. Utilising systematic materials selection processes is therefore essential.

Numerous materials selection techniques have been developed over the years (refer to [8–10]), all of which rely on a large data bank of materials and their properties. The two key steps in materials selection are screening and ranking (Figs. 1 and 2) [8–10]. The former enables to quickly narrow the field of possible materials to a manageable few while the latter narrows the choices further and then evaluates and ranks the choices to identify the optimal material(s).

1.1.1. Ashby's method

One of the most popular techniques for initial screening of materials is Ashby's chart/bubble method. Asbhy [8] compares the relative performance of a variety of materials for a specific constructive function by using performance indices as design criteria. Materials screening, on the basis of these performance indices, is best achieved by plotting the performance indices that are typically a mathematical combination of material properties on each axis of a materials selection chart, also known as an Ashby plot. Individual materials or material sub-classes appear as balloons that define the range of their properties. Ashby plots, such as the one presented in Fig. 3, are very useful for four key reasons

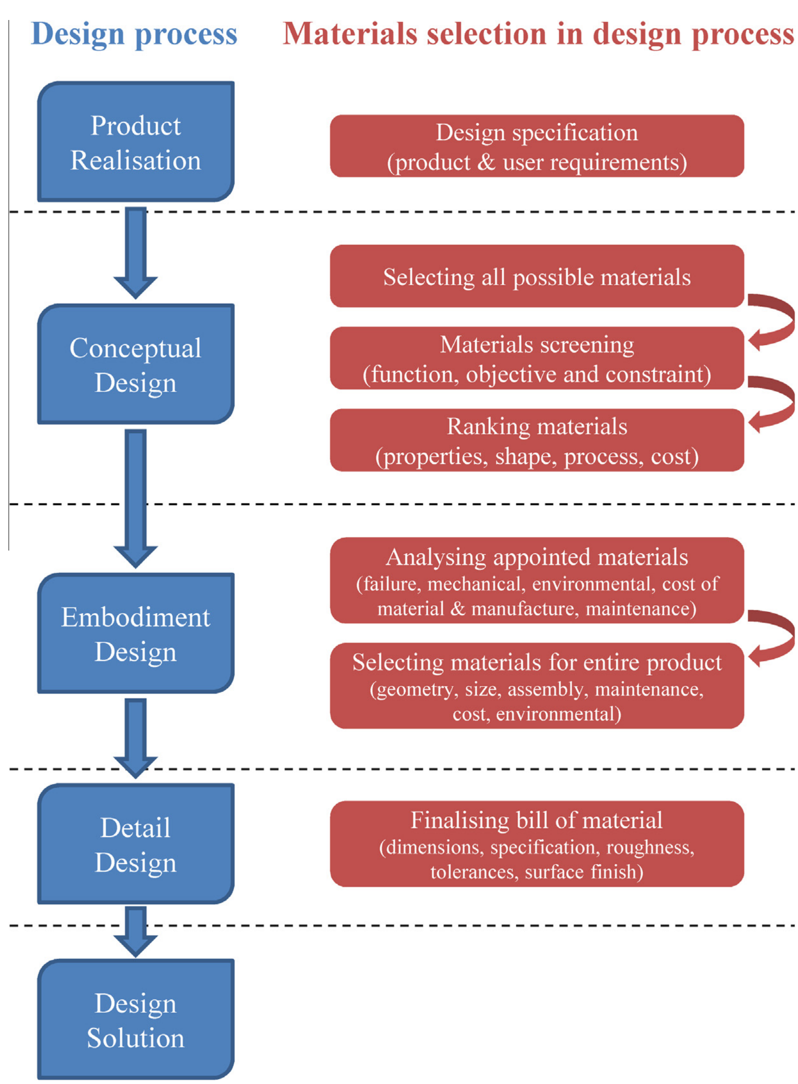

Fig. 1. Key steps in materials selection through various stages of product design.