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Effect of fibre configurations on mechanical properties of flax/tannin composites

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ABSTRACT

Flax reinforced tannin-based composites have a potential to be used in vehicle applications due to the environmental advantages and good mechanical properties. In this paper, the effects of fibre configuration on mechanical properties of flax/tannin composites were investigated for nonwoven and woven fabric lay-up angles (UD, $[0^\circ, 90^\circ]_2$ and $[0^\circ, +45^\circ, 90^\circ, -45^\circ]_2$). The tannin/flax composites were prepared by compression moulding. The manufactured specimens were then characterized for quasi-static tensile properties, dynamic mechanical properties and low-energy impact performance. Failure mechanism was further investigated using microscopy and demonstrated the need for further adhesion improvements. The study shows that the UD fabric reinforced composite performs better in tensile strength and modulus whereas $[0^\circ, +45^\circ, 90^\circ, -45^\circ]_2$ composite provides the best impact energy absorption performance.

1. Introduction

Natural fibre-reinforced composites have attracted the interest of many industries (Kalia et al., 2011) due to their comparative mechanical properties and outstanding bio-degradability characteristics. Natural fibres are known to be bio-degradable, CO_2 neutral (remove carbon dioxide from the atmosphere), low density/price and non-toxic, compared to the established synthetic fibres (Bos, 2004; Fan et al., 2011). Flax fibres like other lingnocellulosic fibres are inexpensive, have good recyclability, and are widely investigated for manufacturing composites.

In the area of flax fibre reinforced composites, most of the research (Bos et al., 2006; Van de Velde and Kiekens, 2001; Van Den Oever et al., 2000; Åkesson et al., 2011) focuses on polypropylene (PP)-based, epoxy-based (synthetic and natural) and polylactic acid (PLA)-based composites. Polypropylene (PP) is the most common synthetic thermoplastic matrix for flax fibre reinforcement on account of its low density, low thermal expansion, good resistance to water and recyclability. Garkhail et al. (2000) used maletic-anhydride grafted PP (MA-PP) to prepare the flax composites through two processing methods: film-stacking and paper-making process. The effects of alignment structure of flax fibres in PP based composite was addressed by Van Den Oever et al. (2000). Synthetic thermosets including epoxy, phenolic etc. are also used for the preparation of flax composites. For example, the tensile deformation behaviour of polyester resin/flax thermoset composites was studied by Hughes et al. (2007). In addition to the synthetic polymer matrices, the use of bio-polymers as matrix materials has been increasing rapidly in the recent years. Saiah et al. (2009) reinforced the thermoplastic derived from wheat flour by flax fibres and used X-ray diffraction to analyze the crystallinity of the fibres. The increase in fibre content led to the increase in intensity of peaks at 2θ of 15.1°, 16.8°, 22.7° and 34.4°, corresponding to crystalline structure of flax fibres. Adekunle et al. (2012) manufactured flax/bio-thermoset (methacrylated soybean oil and methyacrylic anhydride modified soybean oil) composites with different fibre stacking sequences and lay-up angles, leading to the maximum tensile strength of 119 MPa and Young's modulus of 14 GPa. Åkesson et al. (2011) fabricated the flax-reinforced PLA composite, which was cured at elevated temperature via compression moulding. They performed DMA analysis and found that the storage modulus of PLA composites reinforced with 70 wt% flax fibres is 9.32 GPa and

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Table 1
Selected examples of mechanical properties of flax fibre reinforced composites.[c]

Fibre/matrix	Processing	Tensile strength	Tensile modulus	Impact strength	Reference
Flax/bio-thermoset (MSO)[a]	Compression moulding	50–120 MPa	6–15 GPa		Adekunle et al. (2012)
Flax/bio-thermoset (MMSO)[b]	Compression moulding	50–120 MPa	7–15 GPa		Adekunle et al. (2012)
Arctic flax/epoxy (50:50)	Resin transfer moulding	280 MPa	40 GPa		Oksman (2001)
Plain woven flax/epoxy	Hand lay-up			17–35 kJ/m^2	Muralidhar et al. (2012)
Plain-woven flax/thermoset	Compression moulding	280 MPa	32 GPa	(Charpy) 15 kJ/m^2	Adekunle et al. (2011)
Flax/lactic acid resins (70:30)	Compression moulding	62 MPa	9 GPa		Åkesson et al. (2011)
Flax/PLA (polyactic acid)	Injection moulding	40–55 MPa	3–6 GPa	(Charpy) 9–11 kJ/m^2	Bax and Müssig (2008)

[a] Methacrylated soybean oil.
[b] Methacrylic anhydride-modified soybean oil.
[c] See in Section 1.

3.29 GPa at 20 °C and 140 °C, respectively. Table 1 exhibits some mechanical properties of selected flax reinforced polymer composites through recent research.

One possible matrix for fully bio-degradable flax composites is tannin resins (bio-resins) from plant sources (e.g. wattle, myrtle, pine etc.). Tannins contain many phenolic rings and have a high molecular range of 500–2000 and are chemically grouped into hydrolysable and condensed tannin. The hydrolysable tannin is capable of hydrolysing in certain conditions (e.g. alkalis, acids and enzymes), whereas the condensed tannin is more stable and suitable to produce resins (Pizzi and Mittal, 2003). Tannin crosslinking by formaldehyde via methylene or methylene ether bridges in a polycondensation reaction is the traditional chemistry for tannins to function as exterior-grade weather-resistant wood adhesives (Pizzi, 1983, 1994; Pizzi and Mittal, 2003). To decrease or completely eliminate formaldehyde emission during processing, the use of hexamethylenetetramine (hexamine) was developed as an effective alternative to traditional hardeners (Fig. 1). Compared to the widely reported tannins for adhesive applications (Bisanda et al., 2003), there are only a small number of

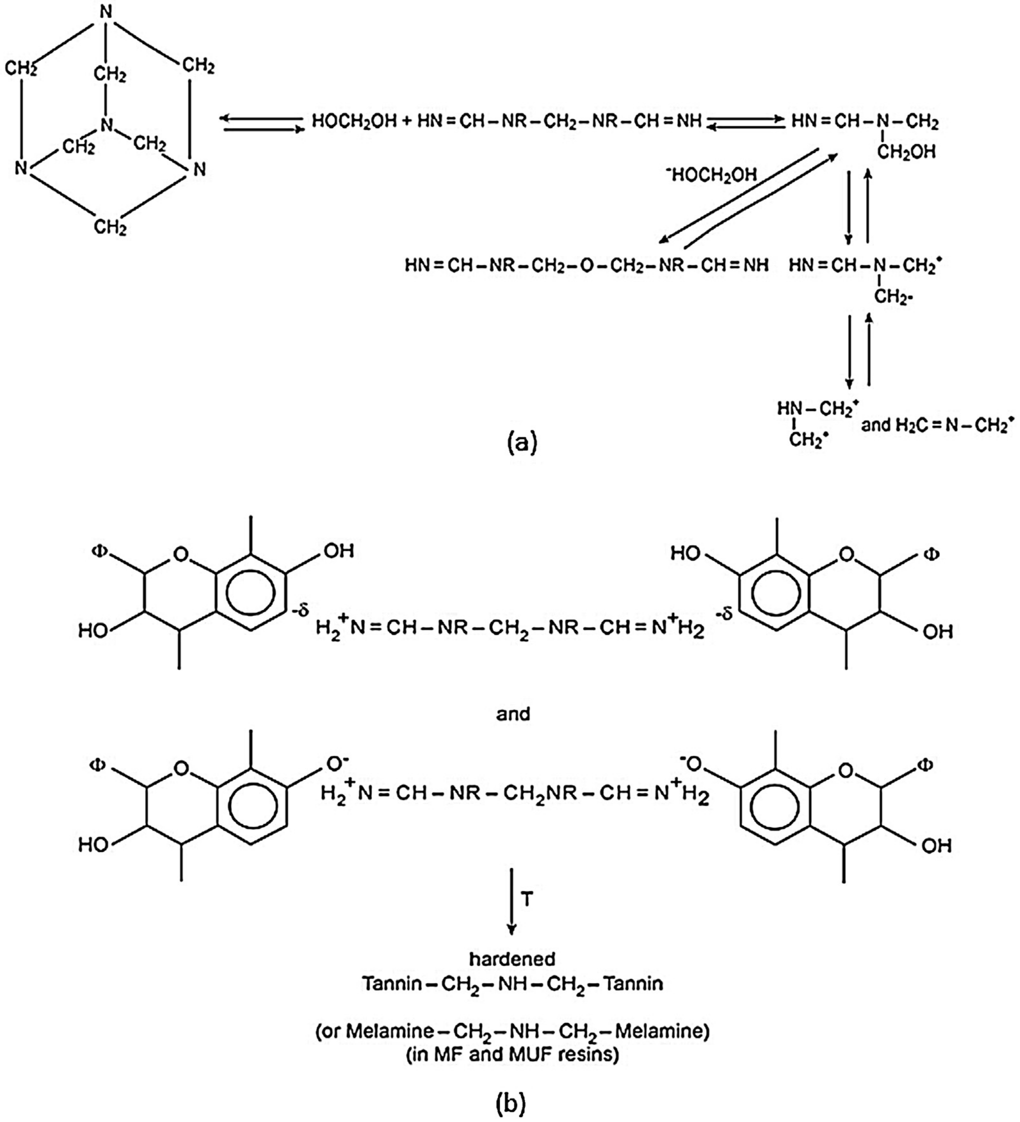

Fig. 1. The chemical reaction between tannin and hexamine: (a) decomposition of hexamine; (b) polycondensation of condensed tannin (Pichelin et al., 1999).