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Healing potential of hybrid materials for structural composites

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ABSTRACT

The healing potential of light-weight hybrid composites consisting of S-glass and polypropylene fibres in an Araldite LY564 epoxy resin has been investigated. This paper describes a co-mingling process for creating glass–polypropylene hybrid yarns. Cross-ply laminates consisting of hybrid yarns in an epoxy matrix have been tested under low energy impact as well as compression after impact (CAI) loading conditions. The study examines the potential for healing the damage cracks developed during impact, with polypropylene fibres. Key part of this investigation is to evaluate the healing potential of polypropylene fibres through local heating. The study shows that with a simple heat treatment process, significant reduction in the impact induced damage area and a corresponding increase in the compression after impact strength can be achieved; a 65% strength improvement has been measured for the healed specimens when compared to unhealed specimen.

1. Introduction

Structural composites made from continuous/long fibres in a polymer matrix offer great potential in transportation and civil engineering sectors for reduced weight as well as reduced life-time maintenance costs, due to better corrosion and fatigue resistance. However, polymer composites can be expensive, relatively slow to manufacture and difficult to repair when subjected to impact damage. Hence, there is a drive to reduce costs and cycle times in high-volume automotive applications as well as in airframes due to recent surge in the use of composites in civil aircraft programmes [1].

Further weight and cost reductions are possible through selective insertion or hybridisation with cheaper and light-weight materials. For example, sandwich construction with lightweight core and strong/stiff skins offer significant improvement to specific strength and stiffness in the case of bending loads [2,3].

Present work is focussed on improving the structural performance through selective hybridisation with thermoplastic fibres for improving the composite damage resistance and damage tolerance. Hosur et al. [4] investigated the impact response of carbon–glass hybrid composites; Thanomsilp and Hogg [5] studied glass thermoplastic fibre blends in an effort to improve interlaminar fracture toughness. Traditionally, composites have superior specific strength and stiffness but poor impact damage resistance; they easily crack and delaminate [6–8]. As a consequence, several resin toughening solutions based on incorporating rubber or thermoplastic particles were developed primarily for aerospace applications. These toughened epoxy resins are not ideal for resin infusion processes due to their high viscosity that leads to many defects. In an attempt to resolve this issue, Cytec developed the Priform technology [9] through dissolvable fibres in dry fabrics; this is a relatively expensive technology. Present work is based on the incorporation of non-dissolvable thermoplastic fibres that are inexpensive commodity fibres such as polypropylene. In addition to investigating the impact damage resistance, this paper explores the healing potential of hybrid glass–PP composites for ease of repair and better compressive strength retention, improved CAI strength, currently a critical design parameter in aircraft design [1,7].

1.1. Structural repair

Despite having superior in-plane strength and stiffness properties, composites are susceptible to impact damage. When laminates are subjected to low velocity impacts, clearly visible or barely visible through the thickness impact damage occurs. This type of damage results in matrix cracks, delamination, fibre–matrix debonding and fibre fracture which lead to reduction in mechanical properties, especially compressive strength [10]. Maintaining or repairing steps are very common, these can be of

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Fig. 1. Different healing concepts in composite structures: (a) insertion of microcapsules in a thermoset resin system [20] and (b) using hollow fibres filled with a healing agent [29].

high cost in aerospace applications as the first solution before replacing the damaged part [11–14]. Repairs are made in order to restore the structural integrity [15]. There are different composite repair methods available according to structure type: cosmetic, temporary and structural repairs [16].

Table 1
Geometric yarn material properties, density and cost.

	Polypropylene (PP)	S-glass
Yarn number (T)	17 Tex	33 Tex
Filament diameter (d)	24 µm	9 µm
Number of filaments (n)	40	207
Yarn cost per kg (Cm)	2–3$	20–25$
Density (ρ)	900 kg/m^3	2500 kg/m^3

Traditionally, structural repair is conducted by removing the damaged part and performing a scarf patch repair. Healing or self-healing is an alternative method of retaining the structural integrity without making extensive repair work [17,18]. According to the literature, there are different techniques to heal damage in a composite laminate autonomously or applying heat and/or pressure [19]. The use of a healing agent is one of the methods to create composite self-healing systems. Those healing agents can be inserted in the composite structure by different methods [20–24] as shown in Fig. 1(a). For example, micro-encapsulated healing agents and catalytic chemical triggers are diffused inside the polymeric matrix. When cracks reach these locations, healing agents are released in order to bond the damaged regions [25]. Kessler et al. [26] used dicyclopentadiene (DCPD) and bis(tricyclohexylphosphine) benzylidine ruthenium (IV) dichloride as a healing agent and catalyst respectively to create a healing effect in

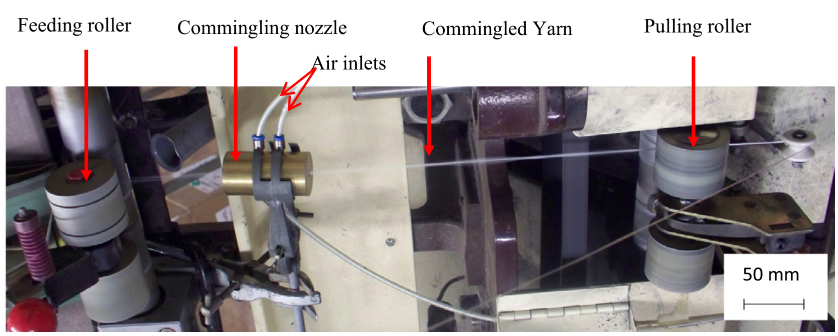

Fig. 2. Commingling yarn processing line in Composite Centre of The University of Manchester.

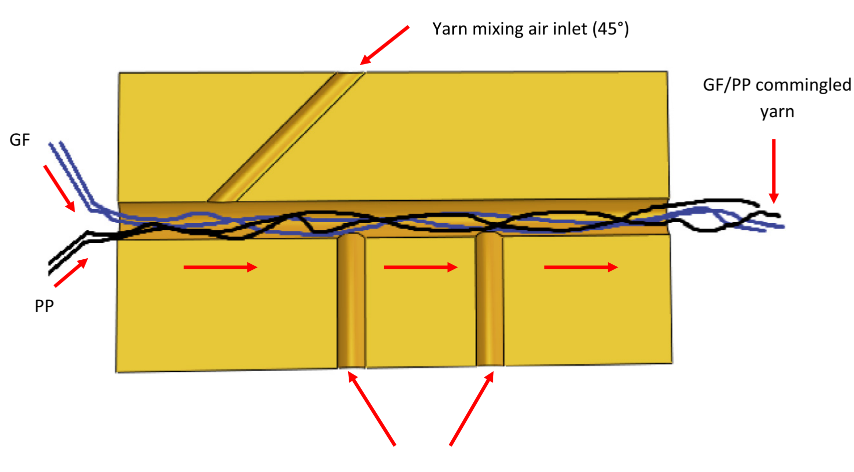

Fig. 3. Commingling nozzle cross-section.