NANOFIBERS FOR DAMAGE RESISTANT COMPOSITE MATERIALS

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ABSTRACT

Fiber reinforced polymer composites are the go-to material for designing applications that require a high strength and stiffness at minimal weight such as aerospace structures, wind turbines or ultralight vehicles. However, delamination between the reinforcing plies remains a major occurring failure type. Interleaving electrospun nanofibres between the reinforcing plies has proven to be a viable interlaminar toughening method which significantly limits the occurrence of delamination failure in composites. This contributions gives an overview into the relationship between the electrospun nanofibre properties and the resulting toughened composites.

Key Words: COMPOSITES, FRACTURE TOUGHNESS, ELECTROSPINNING, NANOFIBERS, CRACK GROWTH

1. INTRODUCTION

The poor impact tolerance of laminated fibre reinforced polymer composites is often stated to be one of the main drawbacks of these materials. The reduced load bearing capability of impacted composites is of major concern as even relatively small impact events such as tool drops or runway debris can already cause an important degradation of the mechanical properties of the composite structure without causing visible damage [1]. The poor impact tolerance is a result of the typical laminated nature of many composites. This results in good in-plane properties, but due to the lack of reinforcement in the out-of-plane direction, delamination between the reinforcing plies occurs frequently.

Recently, the use of thermoplastic nanofibres has been proposed to toughen composites [2,3]. They can be easily placed in the resin rich interlayer between two reinforcing plies prior to composite production. Hence, there is no need to disperse them into the resin. Their nanoscale diameter (50-500 nm) offers the possibility of very thin interlayers of only a few micrometers, while their macroscopic length poses no health hazards. Furthermore, the large surface area to volume ratio and superior mechanical performance only add to the advantages of using thermoplastic nanofibres. Electrospinning is the most suited method to produce this kind of fibres. Although there are many expected obvious benefits, the research on composites enhanced with (electrospun) thermoplastic nanofibres is limited compared to other toughening techniques such as carbon nanotubes or phase-separation resins. A thorough understanding of the toughening mechanism is needed.

2. TOUGHENING COMPOSITES WITH NANOFIBRES

2.1 The interleaving concept

During electrospinning, nanofibres are formed as a self-supporting non-woven membrane which can be handled in a similar way as regular fabrics, or be deposited directly on reinforcement fabrics by guiding dry fabric through an electrospinning set-up. Hence, the non-wovens can easily be placed in between the primary textile reinforcements either as standalone membranes or as nanofibre deposited fabrics prior to composite production. No changes to the composite manufacturing process are required. The nanoscale diameter of the nanofibres offers relatively thin interlayers without any weight increase, while their macroscopic length (continuous fibres) poses no health hazards in comparison with other nanomaterials (no risk of small airborne particles). The electrospinning process itself is upscalable, making it a cost-effective nanofibre production method, and allows many polymers to be spun into nanofibres.

The interleaved composites can be thought to have three different levels at which the nanofibres affect the properties (Figure 1). These levels coincide with the hierarchical nature of the laminate itself: (i) the nanotoughened epoxy resin, (ii) the nanotoughened interlayer and (iii) the nanotoughened laminate [4].

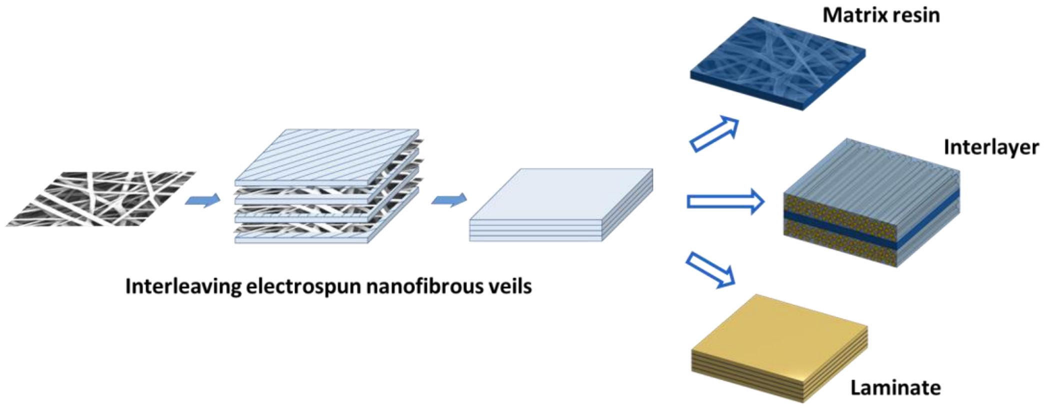

Figure 1. Illustration of the interleaving technique and the multilevel nature of nanofibre interleaved composite laminates.

2.2 A multi-scale analysis of the toughening effect

The effect of the nanofibres was analyzed on each level separately (Figure 2) [4–10]. This multilevel analysis led to a significant advancement of the understanding of these materials in a more structured and general sense, a step that is crucial to be able to design better damage resistant composite structures. Nanofibre interleaved composites with excellent delamination resistance were designed, while obtaining a lot more fundamental knowledge about the prerequisites for effective nanofibre toughening. The improvements were in-line with and often even better than those obtained with traditional toughening methods.

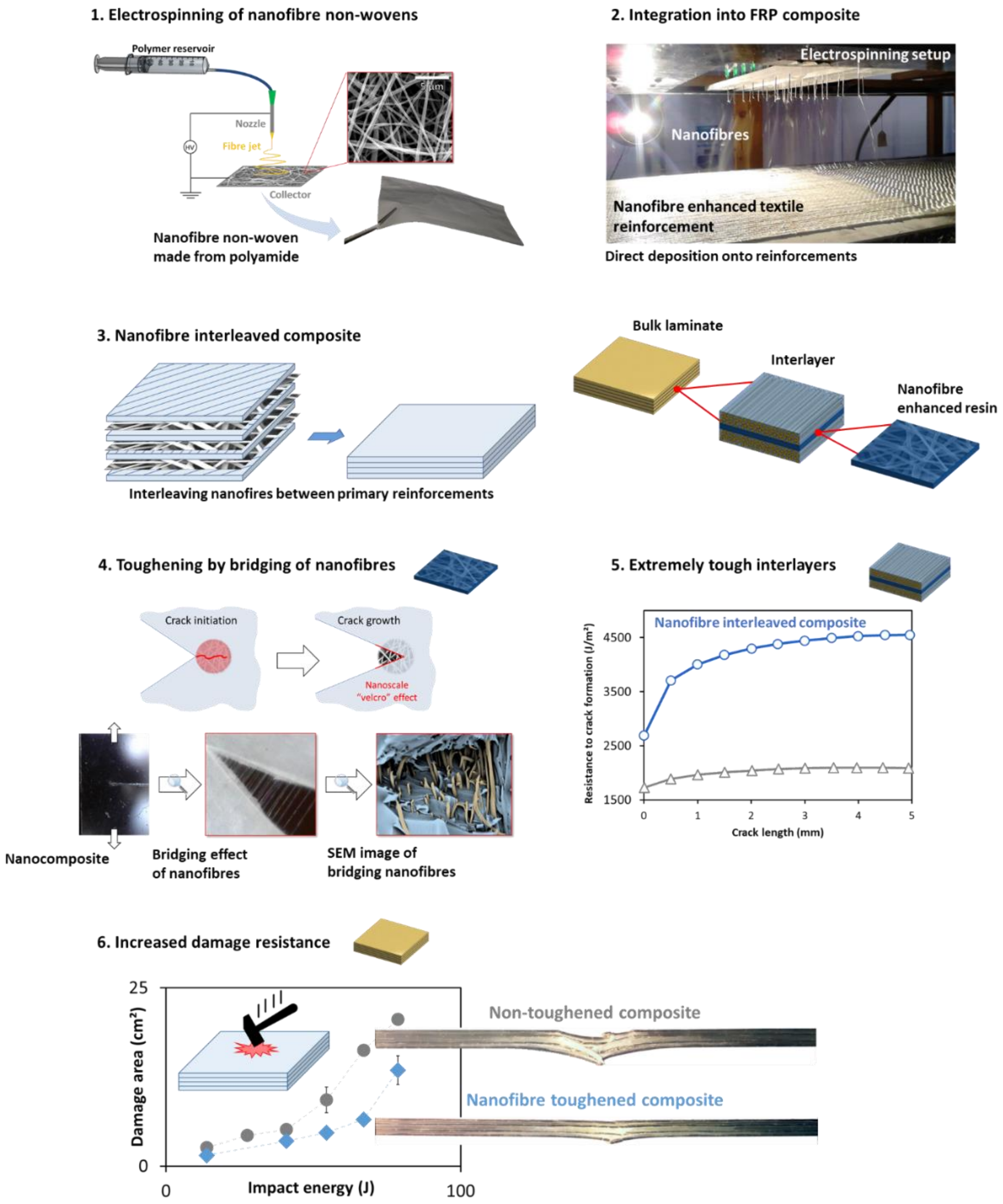

Figure 2. Overview of the research into nanofibre interleaved composites. Starting with the electrospinning of nanofibres (1) as standalone membranes or directly deposited on reinforcing plies (2). Integration of the nanofibres in the interlayers of the composite results in a nanofibre interleaved laminate (3). At the smallest scale, the nanofibres toughen the matrix resin by a nanofibre bridging mechanism (4). This mechanism is the main factor to increase the delamination resistance (interlayer property) substantially (5). The composites with toughened interlayers, and thus a better delamination resistance, in turn have a better macroscopic damage tolerance, for example under impact loading (6).

2.3 Design of general-use nanofibre systems

Much of our earliest work has been performed on either polyamide or polycaprolactone based nanofibres. While polycaprolactone nanofibres resulted in the highest increases in delamination resistance, it had the disadvantage of a very low melting temperature of 55°C, limiting their use for resins that require a curing cycle at higher temperature. Polyamides, with their melting temperature typically above 200°C, can withstand such curing cycles but do not perform well under Mode I delamination growth due to a lack of adhesion with the matrix resin. Therefore, we designed a new system based on coaxial nanofibres with a polyamide core and a polycaprolactone shell [11]. These nanofibres provide good adhesion with the matrix due to a diffusion mechanism of polycaprolactone polymer chains also above its melting temperature [12]. Furthermore, the core is temperature-stable and retains its nanofibrous morphology. Both effects result in a synergistic effect on the delamination resistance. The concept is general in nature and can thus be applied for other core polymers as well, while allowing an industrial relevant and wide working window for curing of the matrix resin.

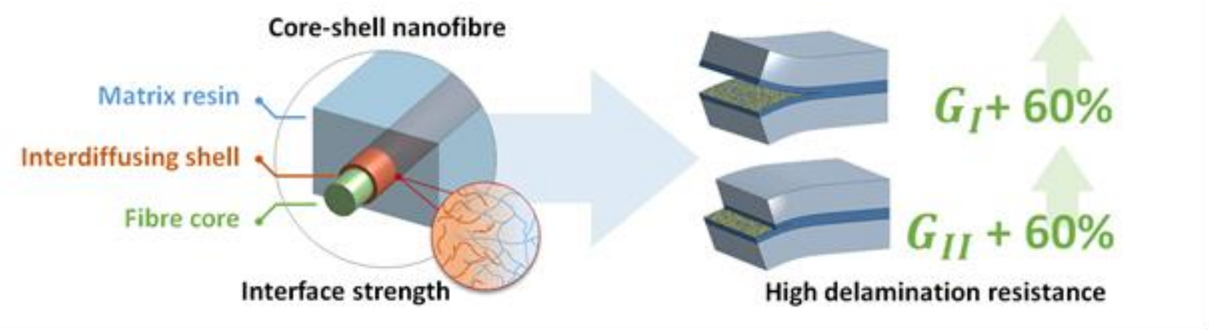

Figure 3. Concept of interdiffusing core-shell structured coaxial nanofibres. The (polycaprolactone) shell will dissolve/diffuse into the matrix resin forming a strong bond between the matrix resin and the nanofibre cores. This leads to a simultaneous increase in Mode I and Mode II delamination resistance.

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