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Nanocomposite matrix for increased fibre composite strength

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Abstract

A new type of three-phase thermoplastic composite has been made, consisting of a main reinforcing phase of woven glass or carbon fibres and a PA6 nanocomposite matrix. Nanocomposites have the potential to improve the matrix dominated flexural and compressive strength by increasing the matrix modulus. Good quality fibre composites have been made with several types of PA6 nanocomposite and unfilled PA6 in combination with glass and carbon fibre reinforcement. Flexural tests on commercial PA6 fibre composites have shown the decrease of the flexural strength upon increasing temperature and this has been compared with the decrease of the matrix modulus. The nanocomposites used in this research have moduli that are much higher than unfilled PA6, also above T_g and in moisture conditioned samples. The strength of glass fibre composites can be increased by more than 40% at elevated temperatures and the temperature range at which a certain minimum strength is present can be increased by 40–50 °C. Carbon fibre composites also show significant improvements at elevated temperatures, although not at room temperature. The advantage of the use of nanocomposites instead of other polymers to improve the fibre composite properties is that the properties can be improved without any change in the processing conditions.

Keywords: Nanocomposite; Fibre composite; Hybrid compound

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1. Introduction

Continuous fibre reinforced thermoplastic composites have been developed as an alternative to thermoset fibre composites with a wide variety of matrix polymers, ranging from cheap commodity plastics to very expensive high performance polymers. Polymer nanocomposites based on exfoliated layered silicate are a different type of composite material, containing extremely small particles with a thickness in the range of 1 nm. The length scales of the reinforcement in fibre composites and nanocomposites are very different; for example, the thickness of an exfoliated silicate sheet is 10,000 times smaller that the diameter of a typical glass fibre. Therefore, the two composites can be combined in a new type of three-phase hybrid composite. In this new three-phase composite the main reinforcing phase are continuous fibres, which are used at a high volume fraction (for example $V_f = 0.5$ in woven fibre composites). The matrix itself is a composite too in the new three-phase composite, containing particles on the nanometer length scale. In Fig. 1 a schematic drawing shows this concept: The fibres are long and continue through the entire length of the sample and the particles in the matrix material fit between the fibres, without reducing the fibre volume fraction. No fibres are replaced by nanoparticles, but the matrix-dominated properties of the fibre composite can benefit from the improved properties of the nanocomposite.

Thermoplastic fibre composites were first developed with high performance polymers such as polyetheretherketone (PEEK) as matrix material, to improve on the mechanical properties of thermoset matrix resins for aerospace applications. Because of the high cost and high processing temperatures of this and other aromatic high performance polymers the applications are limited to fields in which the price is of little importance, such as in military aircrafts and space vehicles. The advantages of thermoplastic composites

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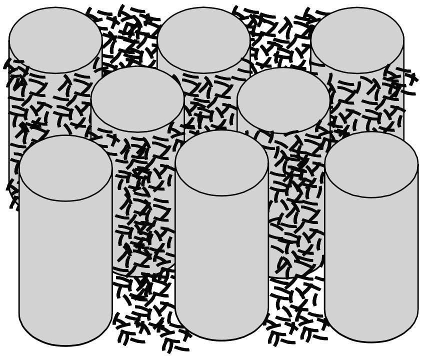

Fig. 1. Nano-particle reinforcement of the matrix in a continuous fibre composite.

in processing, such as the long shelf life of prepregs and zero emissions during processing, have led to the development of thermoplastic fibre composites in many different price- and performance classes. Polyamide 6 (PA6) is an engineering plastic that is positioned between the cheapest commodity plastics and the high performance polymers, both in price, performance and processing temperature. It is an interesting polymer for use as fibre composite matrix material because it has good mechanical properties while being relatively cheap, and it has a low melt viscosity and a relatively low melting point of 220 °C [1]. However, PA6 has a relatively low T_g and its tendency to absorb moisture from the environment lowers the T_g further. The modulus decreases strongly above T_g, and, therefore, the performance at high temperatures and in moist environments could be improved.

Nanocomposites based on PA6 have a much higher modulus [2], they retain a relatively high modulus at temperatures above T_g and in the presence of absorbed moisture [3], and have a strongly reduced creep compliance [4]. Therefore, nanocomposites can eliminate or reduce the disadvantages associated with PA6 as matrix material for fibre composites.

The nanoparticles in the matrix nanocomposites are only intended to improve the matrix-dominated properties of the fibre composite. The fibres dominate the modulus and the tensile strength of the fibre composites, and, therefore, the increased matrix modulus does not provide a significant increase in the composite modulus or tensile strength. The most important improvement that the nanocomposite matrix can provide is an increase in the compressive and flexural strength of the fibre composite. The compressive strength of continuous fibre composites is usually lower than the tensile strength, because the fibres can easily buckle under a compressive load. The compressive strength depends on the modulus of the matrix [5–9], because a higher modulus increases the lateral support of the fibres and, therefore, reduces the tendency for fibre micro buckling or kinking. The flexural strength of a continuous fibre composite is dominated by the compressive strength because failure usually starts at the compressive side due to micro buckling or kinking, as can be seen in the PA6 glass fibre composite sample in Fig. 2.

For this reason, flexural measurements are a good way to measure the effect of nanocomposite matrix materials on the matrix dominated properties of the fibre composites. Bending loads are often encountered in the applications of composite materials, therefore, the flexural strength is also of great practical importance.

Previously published research on the concept of a nanocomposite matrix for fibre composites concerned nanocomposites based on epoxy resins. These nanocomposite matrices did not lead to an improvement of the fibre composite strength [10–12], apparently due to problems with fibre impregnation or because the fibre were damaged in the process.

In this article the results are described for a three-phase thermoplastic composite based on PA6 nanocomposites reinforced with woven glass and carbon fibres. In order to understand the influence of the temperature and absorbed moisture on the flexural strength of the fibre composite, the strength of PA6 composites is first studied over a wide temperature range and after moisture conditioning. Subsequently, the properties of the nanocomposite matrix materials that are important for the impregnation step and for the mechanical properties of the fibre composite are discussed. The improvement of the flexural strength the nanocomposites can provide at various temperatures in both dry and moisture-conditioned samples compared with the composites with an unfilled PA6 matrix shows the potential importance of this new class of composites.

2. Experimental

2.1. Materials

2.1.1. Fibre composite

A commercially available glass (TEPEX® Dynalite 102) and carbon fibre composite (TEPEX® Dynalite 202) based on PA6 as matrix from Bond Laminates, was used to

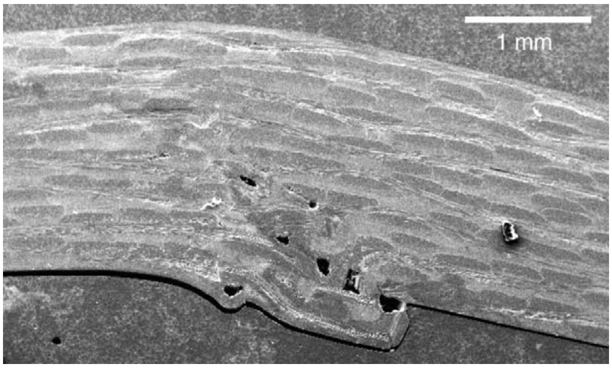

Fig. 2. Compressive failure of a PA6 glass fibre composite sample in a flexural test.