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Current status of recycling of fibre reinforced polymers: Review of technologies, reuse and resulting properties

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ABSTRACT

A complete review of the different techniques that have been developed to recycle fibre reinforced polymers is presented. The review also focuses on the reuse of valuable products recovered by different techniques, in particular the way that fibres have been reincorporated into new materials or applications and the main technological issues encountered. Recycled glass fibres can replace small amounts of virgin fibres in products but not at high enough concentrations to make their recycling economically and environmentally viable, if for example, thermolysis or solvolysis is used. Reclaimed carbon fibres from high-technology applications cannot be reincorporated in the same applications from which they were recovered, so new appropriate applications have to be developed in order to reuse the fibres. Materials incorporating recycled fibres exhibit specific mechanical properties because of the particular characteristics imparted by the fibres. The development of specific standards is therefore necessary, as well as efforts in the development of solutions that enable reusers to benefit from their reinforcement potential. The recovery and reuse of valuable products from resins are also considered, but also the development of recyclable thermoset resins. Finally, the economic and environmental aspects of recycling composite materials, based on Life Cycle Assessment, are discussed.

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Contents

1. Introduction

Fibre reinforced resins, thermosets as well as thermoplastics, are increasingly used to replace metals in numbers of industrial, sporting and transport applications. One of the biggest challenges posed by fibre reinforced composites is their recycling. Environmental legislation is becoming more and more restrictive, and just the environmental impact of these materials disposed in landfills is accelerating the urgency to reach more industrial scale solutions to the recycling of composites. Landfill is a relatively cheap disposal route but is the least preferred waste management option under the European Union's Waste Framework Directive [1], and opposition to it is expected to increase over the coming years; it is already forbidden in Germany, and other EU countries are expected to follow this route [1]. Many different recycling techniques have been studied for the last two decades: mechanical processes (mainly grinding) [2–18], pyrolysis and other thermal processes [19–39], and solvolysis [40–85]. Some of them, particularly pyrolysis, have even reached an industrial scale, and are commercially exploited: for example, ELG Carbon Fibre Ltd. (ELGCF) in United Kingdom use pyrolysis [32], Adherent Technologies Inc. (ATI) in USA use a wet chemical breakdown of composite matrix resins to recover fibrous reinforcements [81] and, in France, Innoveox [82,83] propose a technology based on supercritical hydrolysis. Pyrolysis is the most widespread technology as it is a proven and heavily used process in the chemical industry. However as the fibres degrade at high temperatures, solvolytic processes have attracted increasing interest, especially over the last decade. Supercritical fluids have received much attention because of their tuneable properties depending on operating conditions (temperature, pressure and volume), however the associated equipment can be very expensive due to the severity of the conditions. Recent investigations have considered less severe conditions, but in detriment to process time [53,56,76,78,79]. Solvents and/or catalysts are used that can be toxic and difficult to dispose or separate. The fibres can also be more damaged by the use of catalysts. If the objective of recycling is to recover fibres, this cannot be done in detriment of environmental aspects (used energy, chemical products, emissions...). A complete evaluation must be carried out in order to compare the different technologies in terms of environmental impact, efficiency and commercial viability. It is also quite clear that the choice of the separation/recycling