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Improving the bond strength at hybrid-yarn textile thermoplastic composites for high-technology applications by laser radiation

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ABSTRACT

This article examines the development of a laser pretreatment method for glass fibre reinforced polypropylene surfaces for industrial applications. This work aims to create a reproducible surface for bonding low-energy polypropylene which adheres very poorly to most adhesives and forms to the matrix material for plastic composites. The combination of glass fibres with polypropylene in the form of hybrid yarns is intended to produce a low-cost and powerful engineered fibre composite with applications in high-technology industries. The key process is bonding the engineered fibre composite without modifying the material properties. This is done by adhesive bonding. For this purpose, various pretreatment processes were examined and compared, for example, surface degreasing, plasma pretreatment for final cleaning and activation, the use of peel ply and laser pretreatment. The laser pretreatment serves two purposes: the defined generation of different surface structures and the exposure of glass fibres to be able to exploit the adhesive properties of glass surfaces. Moreover, two processes of artificial aging were performed to simulate potential boundary conditions during future use thus ensuring well-founded assessment of the pretreatments. Possible maximum initial adhesive strength is not the only key factor in favour of a decision to use adhesive bonding. Rather is the resistance to aging in real ambient conditions relevant for the long-term usage and stable bonding behaviour. Finally, the surface pretreatment methods are compared with each other, assessed and critical issues of surface pretreatment and material are validated.

1. Introduction

At present, due to stricter requirements in many high-technology industries it has become imperative to use lightweight construction materials, such as engineered fibre composites in automobile and aerospace engineering. Modified or even new joining techniques are required when these new materials are used and optimum performance is a key consideration.

The Collaborative Research Centre SFB 639 *'Textile-reinforced composite components for function-integrating multi-material design in complex lightweight applications'* examine relevant material joints. These adhesive bonding tests were performed with engineered fibre composites that were manufactured from a hybrid yarn structure that consists of glass and polypropylene fibres. The main aim is to create a reproducible and high-strength adhesive bond of the hybrid-yarn textile thermoplastic composite (HYTT) with like and unlike joining elements. For this purpose it is necessary to improve the bonding properties of polypropylene, which is not unexpected due to its low-energy surface [1–9]. Several approaches to increase the adherence have been considered.

The potentially feasible alternatives include the pretreatment of the HYTT to ensure optimisation of adhesion between the polypropylene surface and the adhesive [1–5,8–12]. Another method is the application of a prime coating to the joining area, to improve adhesion of the adhesive agent [1]. Another feasible approach is the modification of polypropylene in terms of the joining technology adhesive bonding or the modification of the adhesive to improve adhesion [1,6,13–15]. The research done and explained below focuses on the pretreatment of the joining partners to ensure the necessary preconditions and properties for the joining method adhesive bonding. Conventional pretreatment methods, such as peel ply, atmospheric-pressure plasma (AP plasma) and flame impingement for low-energy plastics of low

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adhesive strength have become noticeable on the market [1,7,10,16]. For a couple of years, researchers have also been studying alternative laser procedures [1,17], thereby focussing in particular on the excimer laser with its high-energy UV radiation [8,18–21]. Two different goals are linked to the examined laser pretreatment. One goal is the selective modification of the topography in the joining area to enlarge the bonding area and to provide for mechanical anchoring of the adhesive. On the other hand, it is necessary that the glass fibres of the HYTT are exposed to be able to exploit the thus improved bonding properties of the glass fibres.

2. Experimental

2.1. Materials selection

The fibre composite is a hybrid-yarn textile thermoplastic material that consists of glass and polypropylene fibres which form a fabric with a 2/2-twill weave in the original state. Fig. 1 shows a fabric weave of this type. This weave type has the advantage of higher strength and stiffness in comparison with other weaves, such as plain weave, and at the same time allows the fabric to be pliable and easy to process [22–24]. The test material was delivered by Saint-Gobain Vetrotex GmbH as Twintex® (T PP 60 745 BF 90) with a content of 60% by weight glass and a theoretical density of 1.5 g/cm^3 and 1870 tex [25,26].

The glass fibres of the hybrid yarn are continuous electric-glass filaments that act as reinforcing fibres. These filaments combine very good mechanical properties, water resistance, good corrosion resistance and good chemical stability with low cost. For this reason, electric-glass is the most widely used glass fibre with a market share of approximately 90% [22]. The polypropylene fibres of the hybrid yarn correspond to the thermoplastic matrix of the engineered fibre composite. This material combines numerous advantages, such as good recyclability, absence of volatile matter, elimination of limited storage times with good ductility and flexibility [22,27]. Since the glass and polypropylene fibres are both contained in the hybrid yarn, the consolidation process of the fabric layers is much more efficient than in the injection process. This is enabled by the fact that the reinforcing fibres and the matrix are in close contact, and that the matrix is exactly where it is needed for consolidation. Thus we obtain very high process speeds and efficient material utilisation. The engineered fibre composite owes its good mechanical properties, excellent impact strength and good fatigue strength to the good ductility and flexibility of the thermoplastic polypropylene matrix. Moreover, this material has a good repeatability and reproducibility [22,27].

The adhesive system is chosen according to the application envisaged. For the purpose of choosing an adhesive system it is necessary to distinguish between structural and semi-structural adhesives and to know the resulting adhesive properties, such as ductility or gap-bridging capability. Other decisive factors are the attainable adhesive-bond strengths and the parameter fields for the making and curing of the adhesive bonding, for example, the number of adhesive components, the mixture ratio of the components, pot life and the curing temperature and time.

The adhesive screening was performed with different adhesive systems with the rather different characteristics. It showed the most promising results for a two-part epoxy resin system and was therefore chosen as the adhesive system for structural adhesive bonds of the HYTT. The used adhesive was a Scotch-Weld™ DP 490 from 3 M, which was a visco-plastic construction adhesive.

2.2. Analytical techniques

At the Fourier transformation infrared spectroscopy (FTIR) an IRspecXL was used. The light was p-polarised and in a wavelength from 24 μm up to 0.3 μm and was emitted with a grazing incidence angle ($\theta = 73°$). The measurement dot size was 0.8 mm × 1.5 mm. The spectra were recorded in reflecting mode with a DTGS-detector and measured the reflection R. An Au-mirror was used for the reference signal. The analysis was occurred to the Kubelka–Munk theory to determine the absorption coefficient A of the material. The Kubelka–Munk theory required an endless thick sample which causes that the transmission T of the radiation is insignificant. This requirement reduce the equation of the absorption to $A = 1 - R$ [28,29].

For the laser triangulation a Cyberscan Ventage was used. It is a non-contact surface measurement system for determine the surface topography as profile or 3D-contour. This system is based on laser radiation which reflection is detected from different optical sensors. The used laser source is working at a wavelength of 670 nm. As optical sensor was a DRS500 used which has a measurement range up to 500 μm at z-direction and provides a spot size of approximately 16 μm up to 23 μm. The analysis of the measurement was performed with special software.

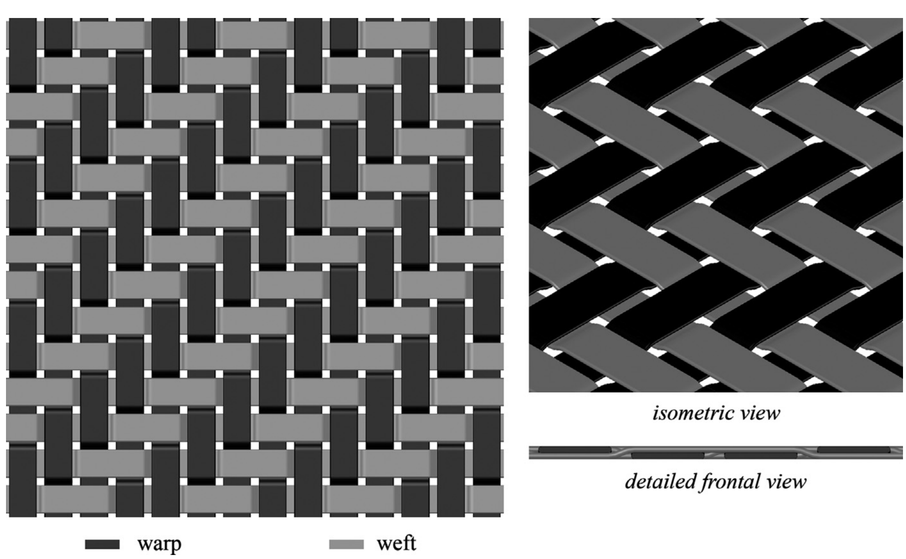

Fig. 1. Model of 2/2-twill weave of the glass-polypropylene hybrid yarn.