Functionalization of PA6 to increase the interfacial shear strength to unsized recycled carbon fibres

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1. INTRODUCTION

In times when ressource management becomes more relevant which each day, recycling is a very important topic. The most work in the topic of recycling is done in commercial waste. But the recycling of high-performance materials becomes more viable as well, due to the high production costs of these materials. Recycled carbon fibres (rCF) are a great alternative to new carbon fibres, since the mechanical properties are almost identical. Both can be used in composite parts as reinforcing structure. Since the recycled fibres are not endless anymore, they can't be used in the same way that new fibres are used.

1.1 Hybrid-nonwovens

A very efficient way to use the recycled carbon fibres is to process them into a nonwoven. Nonwovens can be used to reinforce semi-structural composite parts. When the matrix of the composite consists of thermoplastic materials (in this case PA6), these materials can get mixed into the recycled carbon fibres, to create a hybrid-nonwoven. In figure 1 a hybrid nonwoven is shown.

Figure 1. Hybrid-nonwoven, consisting of rCF and PA6

Hybrid-nonwovens can be produced via a carding or an airlay process. Both processes have their specific strengths. A nonwoven produced by an airlay process, has no preferential direction of the fibres, the strength of the materials against applied load is the same in any

direction. A carded nonwoven can have a pretty high preferential direction of fibres. The loads that can be applied in the preferential fibre direction is significantly higher than in the other directions. But in return the strength in the other directions is weaker. Hybrid-nonwovens of rCF and PA6 can be hot-pressed into a desired shape. During the Process the thermoplastic fibres melt, infuse the carbon fibre structure and solidify again during cooling.

1.2 Recycled carbon fibres

Recycled carbon fibres get pyrolized to get rid of any unwanted materials. During this process the sizing on the surface of the fibres gets also removed. For a good fibre-matrix-adhesion it is necessary to have some kind of coupling agent between the rCF and the matrix. One way is to reapply a sizing after the pyrolyzing, but this process is quite expensive (up to 25 % of the processing costs of rCF).

2. FUNCTIONALIZATION OF PA6

The target is, to substitute the reapplying of sizing by functionalizing the PA6-matrix-fibres. To achieve this, different coupling agents were selected to functionalize the PA6. To find suitable coupling agents, various experts were contacted, and a selection of promising coupling agents was chosen. The coupling agents were compounded into the PA6 in concentrations from 1 to 5 %. The produced compounds were tested for their spinnability with a micro-extruder. With the model DSM Xplore Micro 15cc Twin Screw Compounder very small amounts of material can be spun. With the results of the spinnability tests and mechanical properties tests, in the cases that a filament could be spun, four coupling agents got selected for further testing. The chosen coupling agents were:

- Delion CBN-004
- Delion CBN-005
- Scona TSPP 1213 GB
- BYK P4102

To investigate the influence of the coupling agents on the interfacial shear strength between the functionalized PA6 and the rCF, micro-droplet-tests were performed.
The principle of the testing method is shown in figure 2:

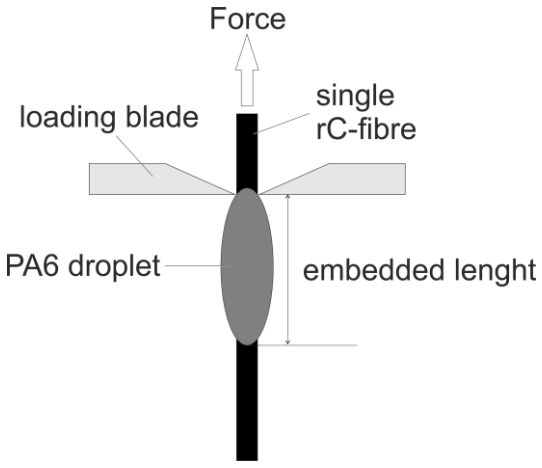

Figure 2. Principle of the micro-droplet testing method

For the test, the PA6 gets melt and is then applied to a single rC-fibre, as a droplet over a specific length (embedded length). With the loading blades the PA6-droplet gets sheared of the rC-fibre. The force required to do that is the interfacial shear strength and gets measured during the process.
To add the coupling agents to the PA6-fibres, two possible ways were chosen. One way was to apply the coupling agents as spin-finish during the spinning process of the PA6-fibres. The other way was to compound the coupling agents into PA6 prior to the spinning, and spin the compound afterwards.

2. INTERFACIAL SHEAR-STRENGTH RESULTS

The results of the micro-droplet tests can be seen in figure 1.

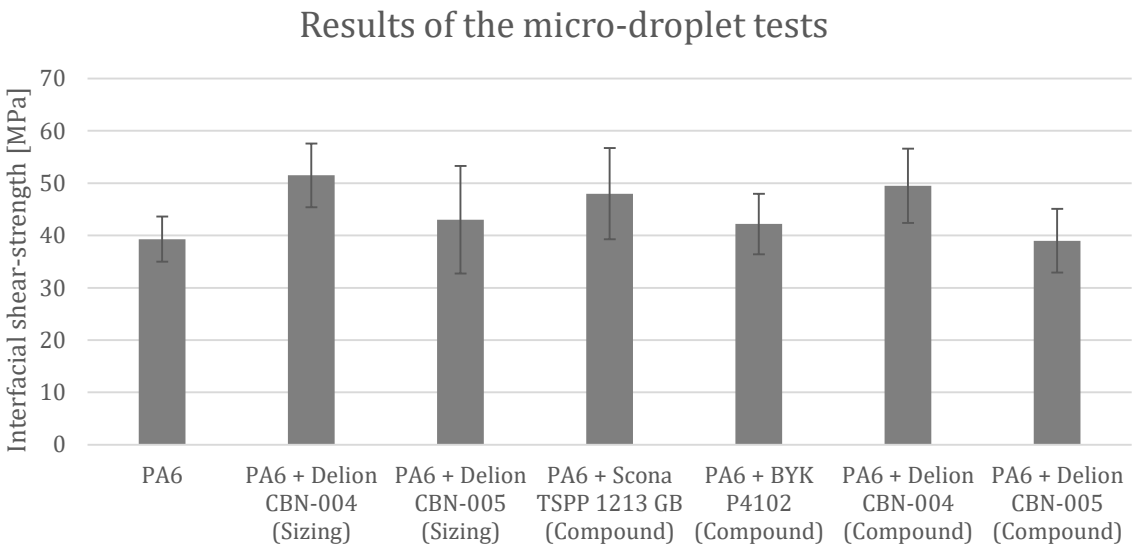

Figure 3. Interfacial shear-strength between rCF and PA6 variations

The results show a significant increase in interfacial shear strength of most of the functionalized PA6 mixtures. The three mixtures with the best results are:

- PA6 + Delion CBN-004 as sizing
- PA6 + Scona TSPP 1213 GB as compound
- PA6 + Delion CBN-004 as compound

For testing under real conditions, 25kg fibres of each of these three functionalized PA6 variants were produced. They get processed into hybrid-nonwovens, consolidated by hot-pressing afterwards and then tested for their mechanical abilities.
The test results are still pending. Which functionalized PA6 mixture performs best in a real composite structure is still to be concluded.

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