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Optimization of process parameters during carbonization for improved carbon fibre strength

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Abstract. Based on their extraordinary properties, carbon fibres nowadays play a significant role in modern industries. In the last years carbon fibres are increasingly used for lightweight constructions in the energy or the transportation industry. However, a bigger market penetration of carbon fibres is still hindered by high prices (~ 22 $/kg) [3]. One crucial step in carbon fibre production is the process of carbonization of stabilized fibres. However, the cause effect relationships of carbonization are nowadays not fully understood. Therefore, the main goal of this research work is the quantification of the cause-effect relationships of process parameters like temperature and residence time on carbon fibre strength.

1. Introduction

Because of their outstanding mechanical properties combined with low density carbon fibres are in the last years increasingly used for light-weight applications in the transport or the energy industry. Through the use of carbon fibre in wind power plants, an enhanced and more efficient rotor blade design can be achieved. This results in a decreased rotor blade weight, by which the total efficiency is enhanced. Modern airplanes, like the Airbus A350 or the Boing 787 “Dreamliner” consists of more than 50 % carbon fibre reinforced plastics (CFRP). One milestone in the automotive industry was the development of the BMW i3/i8. The passenger cabin of both cars is fully produced of CFRP, by which the weight and therefore the fuel consumption of the whole car are reduced.

The market outlook for carbon fibres is very promising [2]. In 2014 the production capabilities of carbon fibres manufactures exceeded 100.000 tons per year. Currently, a constant annual growth rate of more than 10 % is projected for the carbon fibre market [2]. All in all, the carbon fibre market and its outlook can be described as very promising. However, due to the very energy demanding production process the production costs of carbon fibres are very high (15 – 25 €/kg). Therefore, carbon fibres are nowadays still not used for mass application. One crucial production step during carbon fibre production is the process of carbonization. The mechanical properties (strength, young’s modulus and breaking elongation) of the produced carbon fibres are adjusted in this process step. However, the cause-effect relationships of the different process parameters (e.g. temperature, residence time, fibre tension) are still not fully understood. Therefore the main aim of this research is the investigation of the influence of the process parameters temperature and residence time during carbonization on the mechanical properties of the produced carbon fibres. Final goal is the
development of process parameters, by which the mechanical properties of produced carbon fibres can be adjusted. Furthermore, carbon fibre strength and young’s modulus are maximized.

Figure 1: Carbon fibre manufactures and production capacities in 2013 [2]

2. Materials and Methods
For the investigation of the cause-effect relationships of carbonization a continuous technical scale production line in the technical centre of the “Institut für Textiltechnik der RWTH Aachen” is used. As raw material an industrial 12k precursor from Bluestar Limited GmbH (Grimsby, UK) is used.

Table 1. Properties of the analysed precursor material

| Property               | Unit | Value |
|------------------------|------|-------|
| Strength               | GPa  | 0,5   |
| Young’s modulus        | GPa  | 10    |
| Breaking elongation    | %    | 15    |
| Density                | g/cm³| 1,2   |
| Diameter               | µm   | 12    |

The precursor is stabilized on a continuous technical line with “standardized” process parameters. A 4 Zone temperature profile with a maximum temperature of 260 °C and a total residence time of 100 minutes is used. Next step is the research of the cause-effect relationships during LT carbonization. Final step is the optimization of the process parameters during HT carbonization. The mechanical properties (Strength, Young’s modulus, fineness, breaking strain) are measured by single filament tests in a Favimat+ from Textechno Herbert Stein GmbH & Co. KG (Mönchengladbach, Germany). Figure 2 shows the general approach of this research work.
3. Experimental results

Figure 3 shows the results of temperature variations during carbonization on the evolution of carbon fibre strength. The x-axis shows the maximum temperature during LT and HT carbonization. Residence time in both heating zones was set to 5 minutes.

The figure shows, that carbon fibre strength increases with increasing temperature during LT carbonization. In contrast to this result the same effect can’t be seen in HT carbonization. In general, the standard deviation of the tested single filaments after HT carbonization is very high. The standard deviation increases for lower LT carbonization temperatures. Reason for this could be an inhomogeneous fibre structure due to not finished reactions in LT carbonization. Figure 4 shows the results of temperature variations during carbonization on the evolution of young’s modulus.
The figure shows very clearly, that young’s modulus increases with increasing maximum temperature during HT carbonization. This is in accordance to literature values [1] [3]. The figure also shows that the maximum temperature doesn’t have any influence on young’s modulus during HT carbonization. For a maximum temperature during LT carbonization of 600 °C and 900 °C, the young’s modulus which evolves during HT carbonization is nearly the same. The conclusion is, that young’s modulus only depends on the max. temperature during HT carbonization.

4. Conclusion

The results show, that the maximum temperature in LT carbonization does have only little influence on the resulting carbon fibre properties (strength and young’s modulus). During the experiments it was observed, that the fibre tension during LT and HT carbonization has a bigger influence on the resulting carbon fibre properties. The cause effect relationships of this process parameter on the mechanical properties of carbon fibres will be studies in a future research work.

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