Cost analysis of the process chain of rCF staple fiber organic sheet manufacturing

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The recycling of raw materials is gaining more and more importance in politics, industry and the media. According to the composite market report published by the Federation of Reinforced Plastics (AVK), Frankfurt/Germany, the global demand on carbon fibers (CF) will raise to 95,500 tons by 2020 [1]. Up to 40% of these CF will accrue as so-called in-house waste during production of carbon fiber reinforced polymer composite (CFRPC) parts, e.g. due to cut-offs [2]. In this article, the costs of a novel process chain to recycle in-house CF waste will be investigated. The state-of-the-art of semi-finished products made of recycled carbon fibers (rCF) shows that CFRPC plate materials, so-called organic sheets, can be manufactured out of rCF staple fiber yarns which feature superior mechanical properties compared to glass fiber reinforced ones and can be compared to virgin carbon fiber organic sheets [3-5].

In order to evaluate the economical attractiveness of rCF organic sheets, the process chain developed in the project “InTeKS” was investigated according to the overall cost-comparison method. The project “InTeKS” was funded by the Federal Ministry of Economics and Energy on the basis of a resolution of the German Bundestag (funding code VP2088343TA4).

In addition, the single process steps were analyzed separately, including individual machine’s hour rates. Hence, the investigated process chain consists of 3 individual parts: the fiber cutting, the yarn manufacturing and the textile manufacturing (Fig. 1). The actual manufacturing of organic sheets has not been considered since seen cost-wise there is no difference to conventional organic sheets made of virgin fibers.

The total costs TC (formula 1) consist of the summands of single cost types. These cost types represent the depreciations $C_d$, calculated interests $C_i$, calculated rental costs $C_r$, personnel costs $C_p$, material costs $C_m$, energy costs $C_e$, maintenance costs $C_{ma}$, tooling costs $C_t$ and miscellaneous costs $C_{mi}$.

$$TC = \sum_{k=m}^{n} \left[ C_d + C_i + C_p + C_m + C_e + C_{ma} + C_t + C_{mi} \right]$$ (1)

The material costs cumulative to 4.90 $/kg for a fiber volume content in the organic sheet of 50% and a PA 6 matrix by considering the auxiliary materials (crochet yarn) and a CF fiber loss factor $\xi = 1.15$ (formulas 2-4). A price for rCF of 5 $/kg was assumed, which is in line with the declared goal of the market-leading CF recycling companies. The crochet yarn was calculated at 0.021 $/kg, based on the weight of the finished non-crimp fabric (NCF). The energy costs were estimated in the analysis at 0.25 $/kWh.

$$P_{m, total} = \frac{\delta_{ICF}}{\delta_{ICF} + \delta_{PA6}} \cdot P_{ICF} \cdot \xi + \frac{\delta_{PA6}}{\delta_{ICF} + \delta_{PA6}} \cdot P_{PA6} + P_{crochet yarn}$$ (2)

$$P_{m, total} = \frac{1.8}{1.8 + 1.14} \cdot 5 \, €/kg \cdot 1.15 + \frac{1.14}{1.8 + 1.14} \cdot 3.5 \, €/kg + 0.021 \, €/kg$$ (3)

$$P_{m, total} = 4.90 \, €/kg$$ (4)

All further data sets of the individual process steps were provided by the industrial partners, who were asked to fill in a structured questionnaire. A heuristic optimization approach was used to determine a suitable allocation of resources in the process chain.

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Fig. 1
Process chain of rCF staple fiber organic sheets

Fig. 2
Cost trend in dependency of output

Fig. 3
Percentage distribution of the sub-process costs with a production quantity of 350,000 kg/year
To this end, the capacity was increased until a percentage reduction in the machine hour rate was achieved. This takes into account capacity restrictions, all fixed product costs, shifts and the personnel costs of the individual machines.

To display a cost overview depending on the quantity produced, the cost function was divided into several intervals. Each area represents an optimal machine and shift allocation. Fig. 2 shows the cost trend graphically. It can be seen that the increase in the cost function considerably flattens out when a production of 60,000 kg/year is reached. From this point on, the necessary facilities can be used efficiently and staff work to full capacity. The fixed-step development is explained by the one-off acquisition costs of new systems and by the newly hired personnel.

With a planned output quantity of rounded 350,000 kg/year, the pure production costs drop to 3.63 €/kg. If the material costs of 4.90 €/kg are added up, the costs amount to 8.53 € per kg rCF staple fiber fabric. The further course of the curve suggests that marginal costs are almost reached. In this case, further savings can only be achieved by reducing material costs.

Fig. 3 shows the percentage distribution of the sub-process costs at an annual production of 350,000 kg. Material costs are responsible for 58 % of the total costs. This can be seen as both an opportunity as well as a risk, since the analysis is based on the assumption of stable material costs. Moreover, the scale-up of production to a 3-figure annual ton output is a risk, because a planning factor (effective time of machine usage) of 80 % has been employed for this analysis. The coordination of start-up activities of all machines has not been considered. Furthermore, the uncertainty of some values, such as investments in machines as well as other contingencies, can lead to a situation where real costs can exceed those determined in this study.

The cost analysis shows, that organic sheets made of rCF staple fibers with good mechanical properties show an attractive cost structure and thus can be a true alternative to existing fiber reinforced polymer composites.

References