DEVELOPMENT OF PRODUCTION COSTS OF CFRP PARTS

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Abstract

The production cost of CFRP- parts is one of the most decisive decision gates for the usage of CFRP products in industry. Especially for mass production products, such as in the automotive sector, production costs are always important. As a result CFRP parts are often avoided, even though they show a better technical performance than the benchmark materials. Since 2012 the leading edge cluster MAI Carbon works on the topic of cost reduction for CFRP parts. More then 35 R&D projects were carried out. Most of them worked on the field of cost reduction.

This publication summarizes some of the results and gives an overview of the significant developments in the field production costs. Towards the end of the cluster R&D project on one project was initiated to investigate the achieved results and evaluate the effects to the production costs of CFRP parts. The results of this project but also calculation in other projects show that a strong cost reduction of CFRP parts is possible by a reduction of the material prices and new production technologies. It has been demonstrated sound and transparent that costs of well under 20 € / kg part weight are possible and realistic in high volume production.

1. Introduction

Carbon fibre reinforced plastics (CFRP) offers different excellent mechanical properties, but up to now the industrial use is still low compared to other materials, like metals or not reinforced plastics. One important reason why CFRP are mainly used in high-tech products is the high production costs. Another factor is the ability for massproduction. Such techniques are only developed occasionally. Nevertheless, due to the mechanical properties, CFRP are established in different industries like the aerospace industry or racing. Different producs also show that a massproduction with fibre reinforced plastics is possible, even if often a mixture of glas and carbon fibres is used.

In the last 10 years the interest in CFRP increased significantly. Different sectors would like to benefit form the properties of the material. The most important driver was the automotive industry. The requirements regarding costs, cycle times and stability of the processes are very high in the automotive sector, as well as the market volume. Due to this, numerous developments of existing or totally new processes have been started and significant progress was achieved. These context is one important driver for the leading edge Cluster MAI Carbon.

MAI Carbon was founded in 2012 by the Federal Ministry of Education and Research (BMBF). One main objective of the leading-edge cluster is to enhance the technology readiness level of CFRPs for high volume applications. This requires leap innovations throughout the life cycle of a structure, beginning with the fiber and matrix material through manufacturing of components and product systems to coherent recycling approaches. In addition, the research activities in MAI Carbon shall lead to significant reductions regarding the production costs and cycle time (see Table 1).

Motivation for this publication is on the one hand to quantify the economic benefits achieved by the research und development projects in the framework of MAI Carbon. On the other hand, relevant cost drivers in the production chain shall be identified. This includes a study of the State of the Art (SotA) production technologies, innovative process chains and technological improvements. In each case the production related boundary conditions and the weight-specific costs analysed. So this analyses try to give a general overview of the development of costs bu no cost calculation for specific products. Even though different part geometries are taken into account. The influence to and of the hole (hybrid) product design is neglected. At the End this study does not give results for specific products, for these a separate evaluation has to be done and the results may differ.

The here presented results are part of the projects MAI Enviro [1], MAI Enviro 2 [2] and MAI ProCut [3]. A full overview of the projects is given in the project specific reports [1-3].

Table 1. Strategic objectives of the MAI Carbon Cluster

Strategic objectives	Definition	Target values
Cycle time	The time required to complete one cycle of a plant production program from start to finish for a single process step	< 1 minute
Reduction of process costs	Share of production costs per unit costs of one component in series production	- 90%
Efficiency during production processes	Reduction of the number of process steps	+ 60%
Reduction of waste in production process	The proportion of material waste in kg measured by CCmaterial used in total during the production process	- 50%
Recycling rate	Used material, which can be recycled after its end of life	80%
CO2 efficiency	CO2 equivalents will be compared with one another	A positive CO2 balance

2. Approach and evaluation methods

For the cost calculation material and manufacturing costs are taken into account. The manufacturing costs consider machine and labor costs, as well as imputed depreciation, imputed interest rental costs, maintenance costs and energy costs. Since the utilization rate of the equipment is not fixed in this study, this also has an impact on the production costs. The most relevant assumptions can be taken from Table 2. Engineering and development expenses are not considered. A complete overview about the assumptions and approach is given in [2].

Table 2. Main parameters for the base case 2012

Material costs	Non-Crimp-Fabrics	Carbon fiber roving	Epoxy resin
	50 €/kg	25 €/kg	6 €/kg
Part geometry	Part size	Part thickness	
Curved parts	0.5 m² to 1.5 m²	1 mm to 3 mm	
Profiles	Ø35 mm to Ø150 mm		
Production setup	Preforming	Curing process	Cut-offs
Curved	NCF-IR-press forming	RTM 5min	parts 40% preforming| 10% machining
Profiles	Braiding	RTM 5min	5% preforming|10% machining
Plant availability	85%		
No. of shifts per day	3		

3 Results

3.1 Impact of the annual production quantity on the production costs

One important result of the study is the effect of massproduction to the production costs. In Figure 1, the weight-specific costs for the defined scenarios in Table 2 are illustrated as a function of the produced parts per year. As expected, with higher production volumes, the costs decrease. The main reason is the improved utilization rate of the equipment, which results in lower manufacturing costs. However, significant costs reductions are visible up to 50,000 parts per year. Furthermore, at a specific parts quantity, the costs abruptly increase. Here is reached the highest possible utilization rate of the production equipment and a multiplication of the equipment is required. A higher production rate per year does not significantly influence the production costs per weight.
The differences between shell-like parts and profiles are related to the process chain. Whereas for profiles a braiding process with 5% cut-offs is considered, shell-like parts are manufactured with standard textiles resulting in 40% cut-offs.

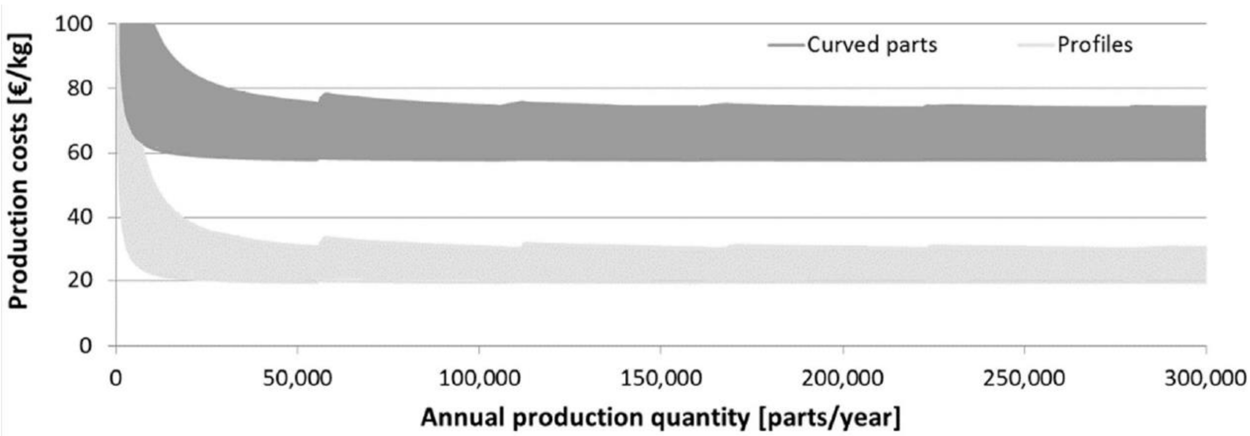

Figure 1. Manufacturing costs [€/kg] depending on the annual production quantity for the base case in 2012

3.2 Influence of part-related parameters

Another interesting aspect is the influcnce of the dimensions of the part to the costs per weight. Due to the fact that the costs are referred to the weight a higher need of materials based on larger parts should have no influence on the calculated costs. Nevertheless could be the production of larger parts more efficient, but also more complicated and more or less expensive. To evaluate this part parameters are varied as defined in Table 3 and cost calculation carried out.

Table 3. Variation of part parameters

Setup Name	Part surface [m²]	Thickness [mm]	Fiber Volume content [%]
Low	1.5	3	45
Medium	1	2	50
High	0.5	1	55

In Figure 2 the weight-specific production costs for shell-like parts for the three setups and different production volumes are shown. The bars are divided into the different cost types, material costs (remaining in the part and cutoffs), machine costs for each process step and labor costs. In addition, the average utilization rate of the equipment is illustrated.
At a small amount of parts per year the dimensions of a part have a high influence on the costs per weight. Smaller parts are much cheapter produced. At a higher number of parts per year this effect is still visible, but much smaller.

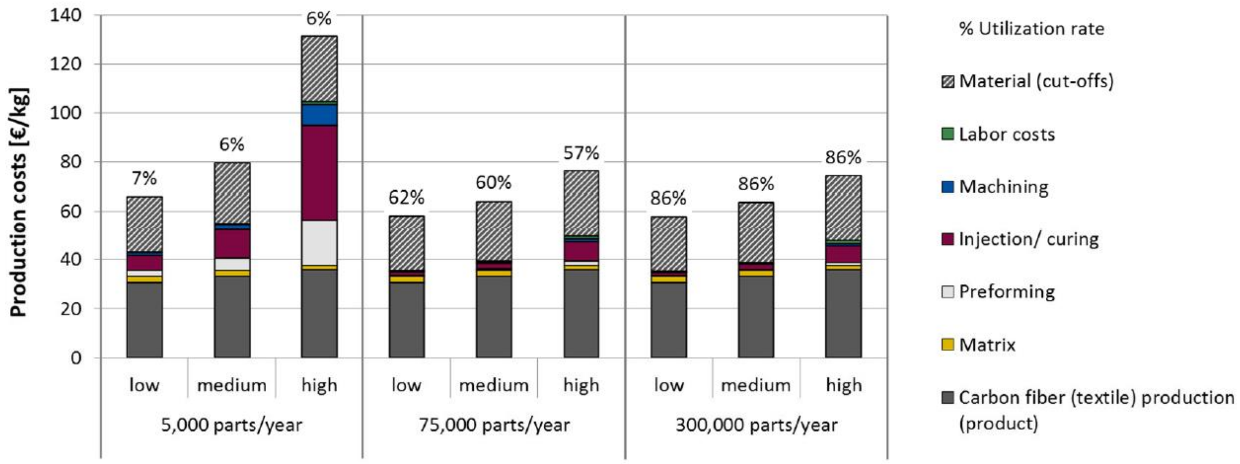

Figure 2. Impact of different production scenarios for curved part; base case in 2012

3.3 Effects of new production technologies and optimized materials to the costs

The main question of this publication is how new production technologies will influence the costs per wight of CFRP parts. At the moment many new optimized processes are under development. At the same time high development efforts are done at the material side. Therefore, much faster matrix system are available and the prices for fibres decrease.
To evaluate the effects the current developments different variants are analysed. In Figure 3 the parameters of these variants are illustrated. V1 correlates with the state of the Art. V2 takes a reduced

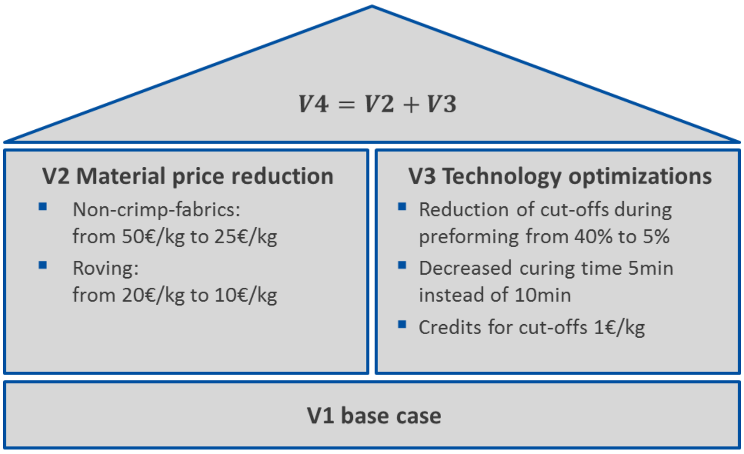

Figure 3. Overview of the investigated assumptions for a cost reduction

fibre price into account. Also the price for semifinished products like NCFs is reduced. V3 investigates the effects of new and optimized production technologies, with shorter cycletimes and less cut-offs. In V4 assumptions of V2 und V3 are combined. The reduction potentials are evaluated for a medium production setup, considering the three defined annual production quantities.

In Figure 4 and Figure 5 the result for shell-like parts and profiled parts is shown. Following will be discussed the different variants.

Material price reduction: Cutting the material prices in half has a significant impact on the production costs. Comparing the base case V1 with V2, a cost reduction between 35 and 55% for shell-like parts can be achieved depending on the quantity per year. Even for profiled parts a cost reduction between 20 to 31% is visible. At the analysed braiding technology for profiled parts the cut-offs are allready today much smaller than for shall-like parts. But in both cases the material costs dominate the production costs in large-scale production, due to the high utilization of the equipment.

Technical optimization: Even higher effects are visible at the technical optimisation. For shell-like parts the reduction of cut-offs is the most important factor. For dry-fibre placement systems a cut-off of only 5% is calculated, compared to 40% for the usage of NCF in V1. Also a roving could be used and not the much more expensive NCF. This results to high cost reduction. In contrast, for profiles the cut-off rates are already very small today. So here nearly no effect is visible.
The reduction of the curing time from 10 min for state of the art to 5 min in the optimized processes had a positive effect for shell-like parts as well as for profiles. Due to the shorter processing time, the labor and equipment costs are reduced. For shell-like parts a cost reduction of 1% (small-scale) and 3% (large-scale) was calculated, for profiles cost reduction of 3.5% (small-scale) to 8.5% (large-scale). Another assumption for this scenario of a technical optimization is a payment for cut-offs. It is expected that cut-off will be recyceled. But the market potential is still difficult to assess, so only a credit of 1 €/kg carbon fibre cut-off is considered. This is only an assumption and at the moment not really viable. However, the effect of this assumption is small to the calculated costs, as the cut-off is under 5%. For shell-like parts and for profiles the cost reduction is under 1 %.
The combination of all these effects results in a significant cost reduction for schell-like parts. For a production rate of 5.000 parts per year the costs reduction is about 43% for 75.000 or 300.000 parts per year it is 64 to 65 %. For profiles the calculated cost saving is much smaller and between 3.5 % to 8.5 %, depending on the production rate. This shows that the used technology is already well developed. This is also visible by a comparison of the costs per kilogram. The costs for profiles in a state of the Art production are on the same level with the costs for shell-like parts, in consideration of all the technical optimizations.

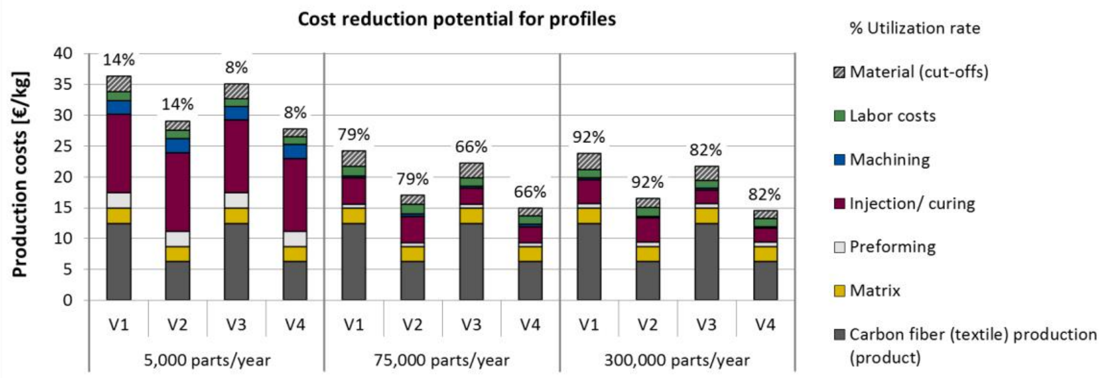

Figure 4. Cost reduction potential for profiled parts

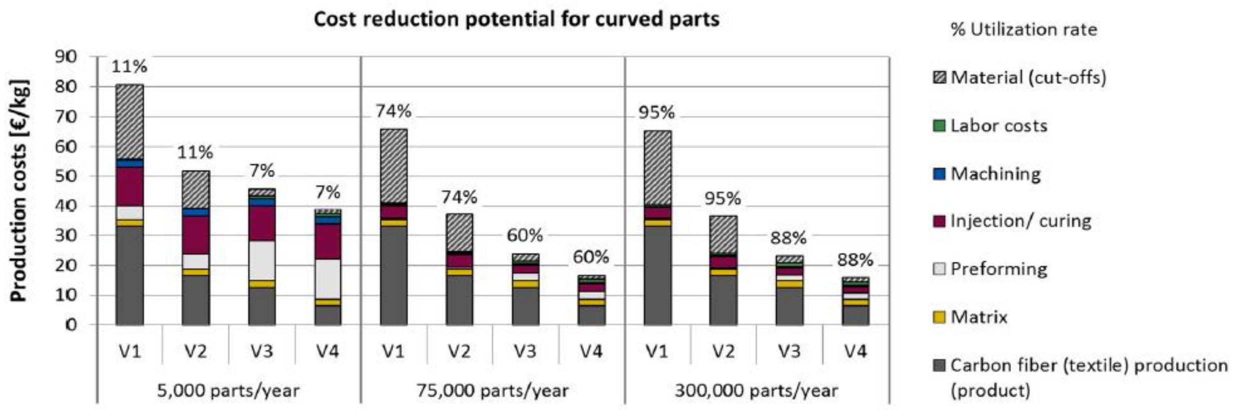

Figure 5. Cost reduction potential for shell-like parts

Combination of technical optimization and material price reduction: The combination of the two calculated variants leads to a strong cost reduction. Table 4 gives an overview about the cost reduction for the different types of parts and the different production rates.

Remarkable is not only the strong cost reduction, but also the cost per kilogram weight. For shell-like parts costs between 40 and 18 €/kg are calculated depending on the number of parts produced per year. For profiles the costs are even less, between 36 and 15 €/kg.

Table 4. Variation of part parameters

Part geometry	5.000 Parts/Year	75.000 Parts/Year	300.000 Parts/Year
Shell-Like	52 %	75 %	76 %
Profile	23.5 %	38.4 %	39.1 %

3.5 Cost Reduction in machining CFRP parts

Beside this general costs analyses out of the project MAI Enviro and MAI Enviro 2, cost calculations for specific production steps have also been done. Here the calculation of the machining process with a new machining tool shall be presented. These are results out of the project MAI ProCut [3]. In this project milling tools with a diamond surface and a defined cutting edge were developed. Due to this and an optimised geometry, the feed rate could be increased. Tests were performed at the production of the lower straps of the A380 and the door surrounding of the A350. With the new milling tools the roughing and the finishing could be done in one step. Due to this the machining time could be reduced by 50 %. At the same time the tool life increases with about 20%. The new milling tools were also evaluated at the benchmark panel according to the “Wiener-Modell”. In comparison to a PCD tool, the feed rate could be 3.5 time higher. But the tool life is only half that long. Due to the new production technology, the costs of the tool are also only half that high compared to a PCD tool. At the end, the costs for machining of the benchmark part are with an PCD tool 1.54 €. With the new developed tools, the costs are 0.58 €. That is a reduction of the costs at 62%.

4. Summary

A significant reduction of of the production costs per weight of CFRP parts occurs by increasing the production rate. This effect is visible for a production rate up to 50.000 parts per year. For more than 50,000 parts per year no significant reduction of the costs is visible anymore. The cause is that at a production rate of about 50,000 parts per year the utilisation of the production machinery is reached , and a multiplication of the equipment is required. Also non-recurring costs like costs for design and engineering are not taken into account. Nevertheless is important to notice that there will be a significant decrease of the costs per weight at a production rate below 50,000 parts per year.

The cost analysis has also shown that the production of smaller components leads to higher weight-specific costs, especially for low volume production. Reasons can be found in the low utilization rate of the equipment and the process times, which are often not affected by the part size and thickness. Thus, with the production of a thicker part results almost the same machine costs, but more mass is produced compared to a smaller component. However, with an increasing production volume, the machine costs and therefore the part size induced fluctuations, decrease.

The most important result of this study is the evaluation of the effects of futher developments on the production costs. By cutting the material prices in half, a cost reduction between 20 to 44% can be achieved, depending on the quantity per year. New production technologies lead to cost reductions of 42% to 65% for shell-like parts. In contrast to curved parts, the achievable cost reduction potentials are lower for the production of profiles. A combination of both, material price reduction and better processes lead to an cost reduction up to 76% compared to the state of the Art in 2012. The same effects are visible at concret examples like the machining of parts. With new technologies, which will come to the market now, a cost reduction of over 60% in also possible.

All these analyses show that strong decrease of the production costs for CFRP parts will occur in the next few years or already occurred. This will make CFRP interesting for new sectors and products.

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