ENERGY EFFICIENCY AND ECOLOGICAL BENEFITS OF A SELF-HEATED CFRP TOOL DESIGNED FOR RESIN TRANSFER MOULDING

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Abstract

Due to the continuously growing ecological requirements in the aerospace industry in service as well as in the production, solutions for more environmentally friendly product life cycles have to be developed.

The ecological effectiveness of manufacturing helicopter rotor blades out of carbon fibre reinforced plastics (CFRP) using a self-heated CFRP tool for resin transfer moulding (RTM) is investigated. The energy consumption and the resulting ecological impact are compared to the state of the art technology, an aluminium series prodcution tool for the Prepreg technology.

Through a power measurement during the use-phase, the energy consumption is determined for both tools. The ecological benefit is evaluated through a life cycle assessment (LCA), regarding four common impact categories.

The measurements prove that a self-heated CFRP tool can lead to significant energy savings of 87% during the use-phase. Combined with a RTM process also a cycle time reduction of 41% can be achieved. In addition the LCA identifies a saving potential of over 40% in all regarded impact categories.

In summary the investigations demonstrate that curing of composite structures is ecologically worthwhile with a self-heated CFRP tool.

1. Introduction

In the aerospace industry most composite parts are manufactured using the Prepreg technology. Due to the associated material costs the RTM process has been investigated as an alternative method over the past years. Cost reduction due to lower material prices, abandonment of refrigeration, flexible process chains using preforms, shorter cycle times as well as a lower energy demand for curing are some of the most important advantages of the RTM technology.

Prepreg and RTM tools are usually made out of metal (aluminium or steel), resulting in a high energy demand during curing and in a different thermal expansion compared to the CFRP. Furthermore the huge tool masses leads to disadvantages in handling and slow thermal reaction behaviour during

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heating and cooling phases. Therefore new tooling designs and materials as well as innovative heating strategies, promising an improvement for the mentioned aspects, are required.

In this work the energy efficiency and the resulting ecological benefit of a self-heated CFRP tool for manufacturing helicopter rotor blades using the RTM technology is investigated. This tool is compared to a state of the art series production aluminium tool, which is used for the Prepreg technology. Thus not only the tool design and the used materials will be levelled against each other but also the manufacturing technology itself.

2. Set-up and methods

The compared tools of this work are presented in Figure 1. The aluminium tool is the series production tool for the manufacturing of helicopter rotor blades from Airbus Helicopters Deutschland GmbH. It consists out of three main parts: the aluminium cavity itself, the heating panel with an integrated water cooling system and the transportation device, which are both made out of steel.
The self-heated CFRP RTM tool, manufactured by Qpoint Composite GmbH, has an upper and a lower mould. For a sufficient stiffness in longitudinal direction and for transportation, a steel frame is applied on top of each mould. To ensure a proper surface quality of the rotor blade, the inner surface of the tool is made out of a gel coat, the epoxy resin RenGel® SW 5200 / Ren® HY 5212 from Huntsman. The used heating elements, developed by Qpoint Composites GmbH, are out of carbon fibres. They are located near the inner tool surface and supersedes an additional, external heating [1]. Each tool mould has 10 heating circuits, whose location are optimized according to a curing simulation of the rotor blade [2].

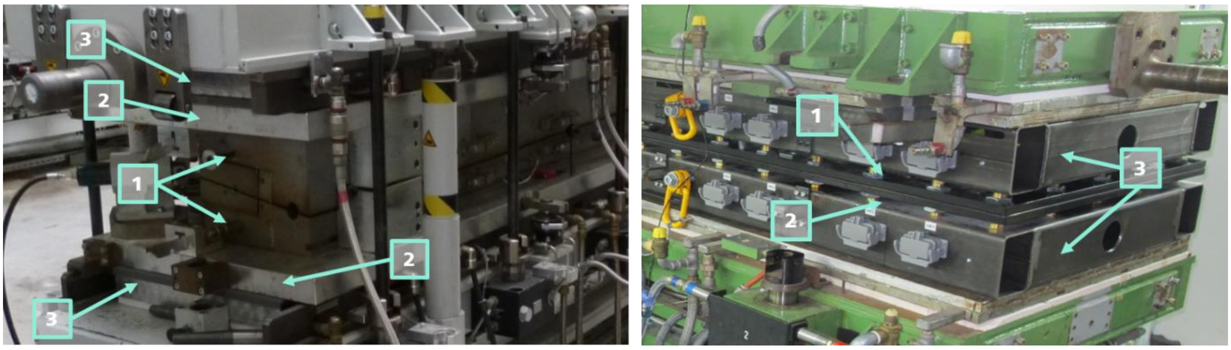

Figure 1. Aluminium tool used for Prepreg technology (1-cavity, 2-heat-/and cooling plate, 3-transportation device) (left); CFRP tool used for RTM technology (1-upper mould, 2-lower mould, 3-steel frame) (right)

The power measurement during the use-phases (manufacturing of one helicopter rotor blade out of fibre reinforced plastics) for both tools is carried out with the measuring instrument Fluke 1730, recording the voltage and amperage of the actual process. Figure 2 shows the different curing cycles for both tools. For the manufacturing of rotor blades with the CFRP tool using RTM, the epoxy 823 RTM Resin from CYCOM and for the aluminium tool the epoxy based Prepreg HexPly®913 from Hexcel is used. To consider the different room temperatures in summer and winter, the evaluation of the measured data starts at 30 °C and ends at the demoulding temperature of 60 °C for the CFRP tool and 45 °C tooling temperature for the aluminium tool. As it can be seen in Figure 2, the curing cycles of both tools not only differ in the number of heating phases, but also in temperature levels and total cycle times due to the different epoxy resins. The curing cycle time of the RTM process using the CFRP tool is up to 5.5 h, whereas the Prepreg cycle for the benchmark aluminium tool takes about 9.4 h.

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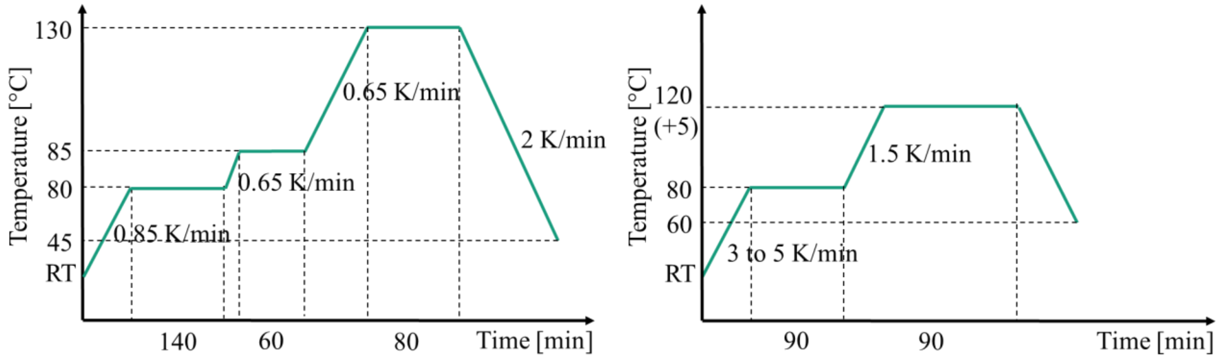

Figure 2. Prepreg curing cycle for the amluminium tool (left) and RTM curing cycle for the CFRP tool (right)

For a holistic ecological evaluation not only the analysis of the energy efficiency during the use-phase is decisive, but also the life cycle of the tools is investigated through a LCA.
Thus the LCA is carried out as a cradle-to-grave analysis using the software tool GaBi 6.0 from Thinkstep. Consequently the investigations include the manufacturing, the use-phase as well as the end of life of the tool. All of the required mass and energy flows are measured during the tool production and in service. Further background data (e.g. energy supply or scrap collecting rates) are taken from the GaBi Database or from literature [4] [5] [6].
For reliable results and due to the uncertainty of some input parameters, a minimum and maximum scenario is conducted for all relevant parameters (e.g. production waste, number of use-phase cycles, energy consumptions of the manufacturing steps). The analysed impact categories in this work are the Primary Energy Demand (PED), the Global Warming Potential (GWP) the Ozone Depletion Potential (ODP) and the Photochemical Ozone Creation Potential (POCP), which are based on the methods by the Centre of Environmental Science at Leiden University (CML) from 2013.

3. Results

3.1. Energy measurement

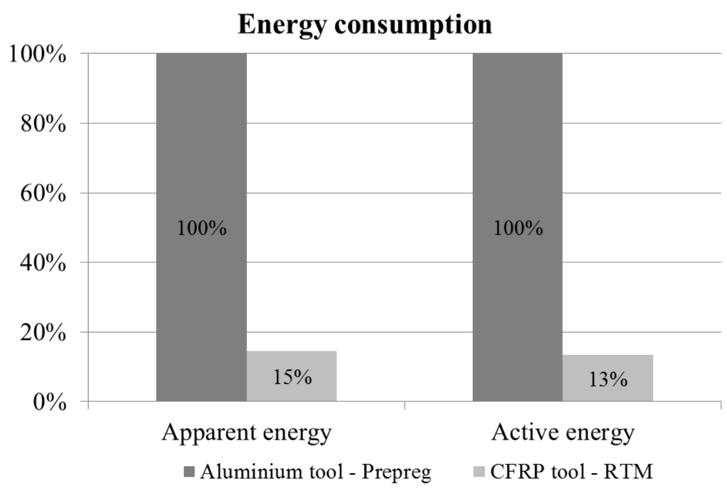

Figure 3. Relative energy consumption of the aluminium and the CFRP tool in comparison for one complete curing cycle.

Figure 3 shows the relative energy consumption for both tools in comparison, each for one curing cycle. As the baseline the energy consumption (apparent and active energy) for the aluminium tool is chosen. The CFRP tool requires 85% less apparent, or rather 87% less active energy than the aluminium tool.

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However the curing cycles of the RTM and Prepreg technology differ from each other in dwell stages, temperature levels and significantly in cycle times (compare Figure 2). Using the curing cycle of the RTM technology in combination with a self-heated CFRP tool leads to a total cycle time reduction of 41% compared to the aluminium tool. Thus the achieved energy savings are not only caused by the new heating system and the tooling material, but also due to the used curing technology and resin system.

For a direct comparison of the energy efficiency of the tooling concepts, the same curing cycles should be conducted and measured for both tools. Indeed it is not possible to interfere and change the cycle of a series production process or to adopt the curing cycle for Prepreg material to the RTM resin. Therefore the energy demand is recalculated theoretically for both tools. As the measured power demand is almost constant within the single cycle stages for both tools, the energy consumption behaves nearly linear over the heating and dwell phases, at least in the regarded temperature area. During the heating stages 100% of the power is needed, whereas in the dwell stages, the power demand depends only on the adjusted temperature level, but is still nearly constant. During the heating stages it is the phase time, which depends on the temperature level. Those temperature-depending backgrounds could get derived through the conducted trials. Thus the cycle phase and temperature dependet power consumption can be multiplied with the dwell time in order to calculate the energy demand for other curing cycles.
At first the Prepreg cycle of the aluminium is adapted, which is visible in Figure 4, in order to summarize it to the same amount of heating stages as the RTM cycle.

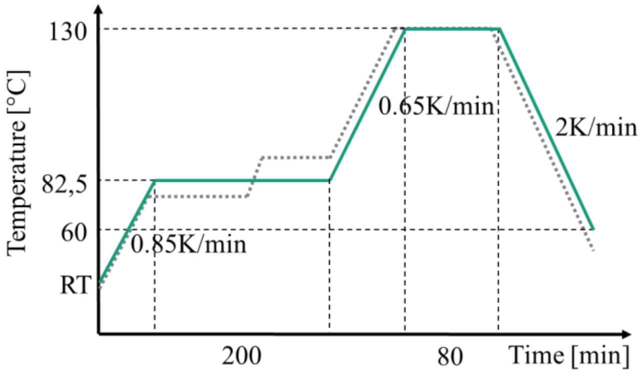

Figure 4. Adapted Prepreg cycle for the aluminium tool

The first and the second cycle stage are summarized to a middle temperature level of 82.5 °C. The power consumption is calculated as the mean value of the measured data for both stages. Additionally the cooling phase is shortened to the CFRP tool's demoulding temperature of 60 °C. In sum the adapted Prepreg cycle takes 8 hours and 22 minutes.

For this adapted Prepreg cycle the energy demand is calculated using the measured power data from the CFRP tool multiplied with the adapted Prepreg cycle phase times. In the same way, the measured power data from the aluminium tool is adapted to the original RTM cycle. Figure 5 shows the results of these calculations, which are based on the active energy consumption of the aluminium tool using the Prepreg technology. The energy demand for the RTM cycle is about 46% lower for both tools, due to the reduced cycle time.

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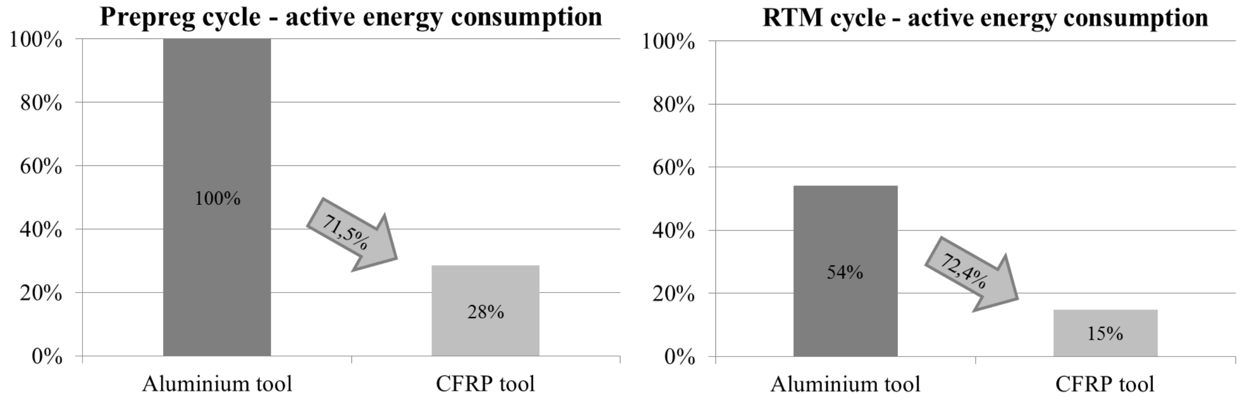

Figure 5. Calculated energy demand of the aluminium tool and the CFRP tool referred to the adapted Prepreg cycle (left) and referred to the RTM cycle (right).

The comparison of both toolings shows that there is a clear energy saving potential of the CFRP tool towards the aluminium tool. In case of the adapted Prepreg cycle the energy reduction is about 71.5% in active energy. Regarding the RTM technology a saving potential of about 72.4% can be achieved.

3.2. Main results of the Life Cycle Assessment

The ecological evaluation through the LCA proves a clear saving potential for the RTM CFRP tool compared to the aluminium tool in all regarded impact categories.
There is a reduction of about 70% in the Primary Energy Demand (PED) and in the Global Warming Potential (GWP), 40 to 50% in the Photochemical Ozone Creation Potential (POCP) and about 93% in the Ozone Depletion Potential (ODP) visible.
Figure 6 shows, representive for all impact categories, the result of the PED for both tool manufacturing phases (equal to zero use-phases) and for two use-phase scenarios, considering 500 and 1000 curing cycles. As the baseline the aluminium tool with 1000 curing cycles is chosen.

Due to the reduced energy demand in the use-phase, the saving potential increases with the number of curing cycles. Although the production of carbon fibres is a very high energy intensive process [2], there is a saving potential in all regarded impact categories even for the manufacturing of the CFRP tool towards the aluminium tool. This is mainly caused by the significant weight reduction achieved through the design of the tool and the high strength / stiffness to weight ratio of CFRPs. The CFRP tool has an overall weight of 630 kg, whereas the aluminium tool, including the heat- and cooling plate as well as the transportations device, weights 7790 kg. Due to this lightweight potential of about 91%, the production of the CFRP tool is ecological worthwhile than the aluminium tool even for low numbers of use-phase cycles.

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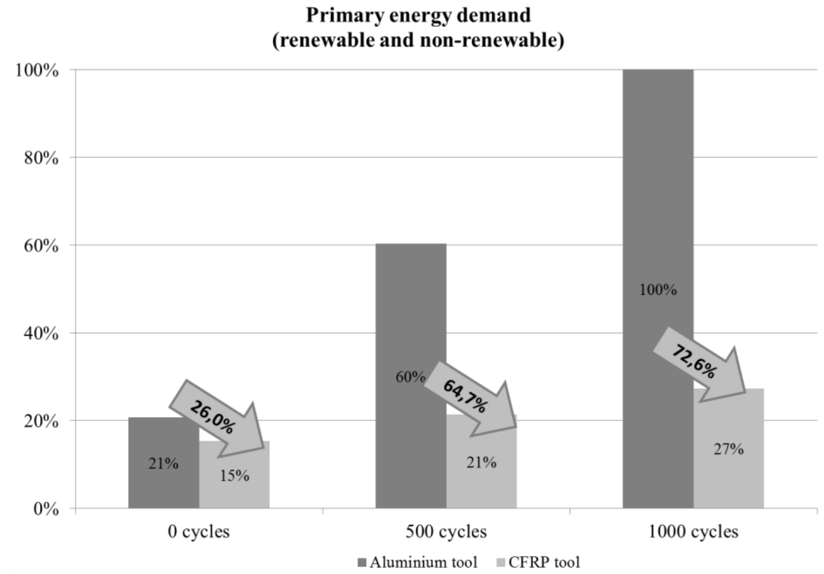

Figure 6. Primary Energy Demand (PED) for the manufacturing of the aluminium tool in comparison to the CFRP tool and with the consideration of 500 and 1000 use-phase cycles.

4. Summary and conclusions

The investigations prove that, besides a better handling due to the achieved weight reduction, a self-heated CFRP tool has a lower power demand, mainly caused by the reduced thermal mass and the use of a energy efficient heating system. This leads to a lower energy demand independent to the used resin or curing technology (RTM or Prepreg).

Due to the shorter cycle time, a self-heated CFRP tool can reduce in combination with an RTM cycle the energy consumption up to 87% during the use-phase and allows in this case a significant cycle time reduction of 41%.

Furthermore the LCA has shown a huge saving potential in all regarded impact categories for the manufacturing of the CFRP tool, which is mainly caused by the achieved weight reduction. The ecological benefit increases even more with the consideration of the use-phase due to the lower energy demand per cycle.

Still it should be mentioned, that the economic benefit strongly depends on the service life of the CFRP tool [7], which is at that point lower towards its metallic counterparts. Additionally an increase of the tool mass is expected because some improvements in stiffness and in longitudinal stability have to be developed.

Acknowledgments

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Figure 7. CFRP RTM tool with integrated heating, developed and manufactured by QPoint Composites GmbH for manufacturing a full size helicopter rotor blade with an approx. length of 5 meters, exhibit at the project partner (LCC Technische Universität München) site.

References

[1] J. S. Weiland, M.P. Hartmann and R.M. Hinterhölzl. Characterization of an RTM cure process with CFRP molds and independent heat patches. *Proceedings of 20th International Conference on Composite Materials Copenhagen*, July 19-24 2015.

[2] J. S. Weiland, M.P. Hartmann and R.M. Hinterhölzl. Cure simulation with resistively in situ heated CFRP molds: Implementation and validation. Elsevier Ltd., 2015.

[3] E. Griffin. Carbon fiber from PAN - contents of factory gate to factory - life cycle inventory summary. 2009.

[4] P. Morgan. Carbon Fibers and their Composites. *Boca Raton: CRC press, Taylor & Francis Group,* 2005.

[5] R. Witik. Economic and environmental assessment of alternative production methods for composite aircraft components. *Elsevier Ltd*., 2012.

[6] H. Stiller. Material Intensity of Advanced Composite Materials. *Wuppertal: Wissenschaftszentrum Nordrhein-Westfalen, Institut für Technik*, 1999.

[7] P. Kammerhofer, K. Drechsler and S. Zaremba. Investigations on the mechanical robustness of CFRP molds. *20th International Conference on Composite Materials Copenhagen,* July 19-24 2015.

Excerpt from ISBN 978-3-00-053387-7