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Environmental impacts of recycling carbon fibre reinforced high-performance thermoplastics for aerospace composite structures and uncertainty from modelling choices

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Introduction

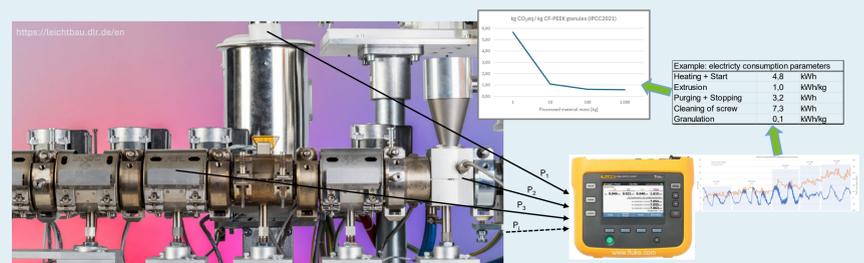
- Additive manufacturing (AM) of thermoplastic composites offers new opportunities and areas of application for specialised high performance lightweight structures.
- Typical aircraft materials are virgin carbon fibres (vCF) embedded in high temperature thermoplastics like the Polyaryletherketone (PAEK) material family.
- In addition to their design freedom, thermoplastic composites offer a potentially improved recyclability compared to classic thermoset based material combinations.
- The degradation of material properties, e.g. by shredding end-of-life parts makes a 100% substitution of virgin (v) materials with recycled (r) materials currently impossible. A refreshment with virgin materials is necessary in a potential cascading use of recycled materials in a future circular economy scenario for aircraft components.
- Comprehensive Life Cycle Assessment (LCA) is important to support answering the question of using recycling versus virgin materials or other competing materials.
- Data gaps, confidentiality or low-TRL are still major challenges in the aviation sector.
- Here, for a simplified cradle-to-gate model, the parameterisation of a granulation process and the results on uncertainty based on different sources of material LCI data are demonstrated in the GWP100 category.



Potential circular pathway of high performance thermoplastic composites. CF-TPC waste (upper left) and regrinds ready for compounding (upper right). Direct extrusion nozzle (lower right) under development at DLR and a potential use case in the DLR Innovation Lab Empower AX, individual overprinted functional layers on a conventionally produced monolithic CFRP laminate (lower left).

Methodology

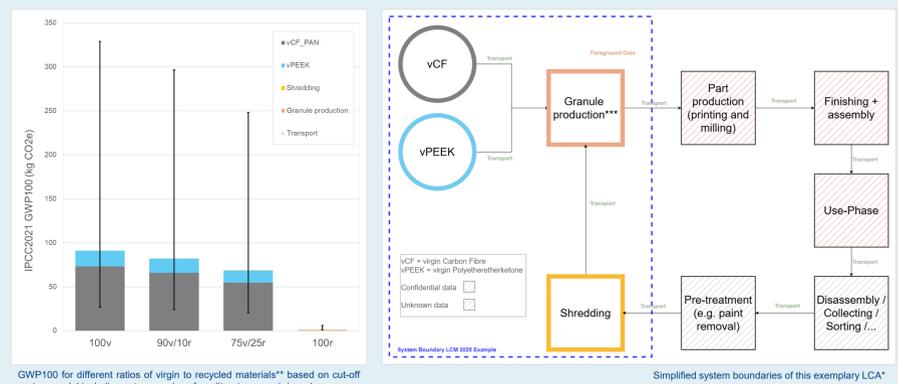
- Composite production processes are complex and generalisation into a universal simple dataset may lead to under- or overestimations of environmental impacts.
- A descriptive parameterised modelling is necessary to improve accuracy and precision and hence reduce uncertainties.
- This example is followed to a twin-screw extruder as part of the thermoplastic composite recycling process chain under investigation in the DLR laboratory.
- Fixed values such as electricity consumption for the starting phase (heating), purging and screw cleaning are combined with parameters for extrusion and granulation phase energy consumption depending on material type and throughput.
- Other factors are water consumption (cooling) and emissions.



Twin-screw extrusion line at DLR SY laboratory (left) and exemplary energy measurements for different screw currents as one parameter for the final parameterized unit process with an preliminary set of fixed and variable parameters (right). A realistic assumption for material throughput is necessary to reduce the overestimation from typical laboratory data.

Results

- Data quality for granule production step can be improved by parameterised unit processes based on industrial scale laboratory measurements.
- Typical material recycling steps for thermoplastic composites, such as shredding and granulation, have a minor relative impact on LCA results.
- High refreshment rates are necessary for fulfilment of requirements in a closed-loop recycling of scrap and EoL waste for aircraft components.
- Open-loop recycling offers high potential for optimal cascading use in non-aviation applications with less demanding material requirements.
- Overall results of this simplified LCA are overshadowed by high uncertainty for production of virgin materials such as vPEEK and vCF because of limited data availability. Some published datasets influence the results by an order of magnitude and can potentially be misused for biased comparisons.



GWP100 for different ratios of virgin to recycled materials** based on cut-off system model including extreme values from literature as min/max bar.

Simplified system boundaries of this exemplary LCA*

*Software: Umberto LCA Version 11.15.1 (Rev 0) / Database: Ecoinvent 3.11 Cut-Off / Background data: RER > GLO market datasets / LGIA: IPCC2021 Global Warming Potential 100 years [CO₂e] **Declared Unit = kg of CF-PEEK granules ***Granule production includes production and waste treatment of purging and cleaning materials

Conclusion

- Parameterised LCI to model complex composite production processes and increase data quality versus existing background data.
- Improvement of data quality for many lightweight materials necessary for better transparency in comparative LCA.
- Outlook: Individual data for recycled materials to account for degradation effects and their influence on modelling (e.g. as part of DPP)
- Publication of FAIR parameterised LCI data for composite production processes that can be used in LCA databases and PEF/CR Aircraft



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