

Sustainable alternatives to thermoset polymers for aerospace composites: a comparison using LCA

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Keywords: Life Cycle Analysis, Thermoplastic polymers, Vitrimers, EVTOL, Composite materials reshaping.

The path to achieve climate neutrality outlined by the European Green Deal poses a great challenge for the aviation industry, especially looking at ICAO forecasts on the air traffic demand, which will keep on growing in the next years. In addition, also the new market possibilities born with the advancement of the Advanced Air Mobility (AAM) sector presents several opportunities and challenges. Even though most CO₂ emissions is generated during the use phase of an aircraft, with the reduced mission time and the high volumes of production which AAM is likely to bring, it will be necessary to optimize the whole life cycle. In this sense, Fiber Reinforced Polymers (FRPs) will be critical. Thanks to their excellent mechanical performance and low density, they grant a significant reduction of fuel consumption, yet they pose a big problem when it comes to end-of-life scenarios. Thermoset resin is often employed to manufacture primary and large aerospace structures. Since it offers great chemical stability, it is very hard to recycle, up to the point that usually consumed FRPs end up in landfills. The best strategy to address this problem would be to find an alternative polymer which grants the possibility to reshape and repair damaged components, limiting as much as possible resource depletion.

In this study, two alternative matrices will be investigated and compared to traditional epoxy resins. High-performance thermoplastic polymers are already market available, such as the family of ketone-based plastics. They are suitable for aerospace applications but present usually manufacturing cycles with higher temperature with respect to epoxy resins. The most innovative alternative resides in Covalent Adaptive Network polymers (CANs), such as vitrimers. This family of polymers can be processed in the same way of thermoset resins, but, thanks to the exploitation of reversible aromatic disulfide exchange in epoxy networks, it is possible to achieve a plastic behaviour under some trigger conditions, for example exposure to high temperatures. Both these families of polymers give the possibility to reshape the composite material when damage to the structure occurs.

The objective of this analysis is to establish a case study relevant to the comparison of different polymeric matrices for composite materials in the production of aerospace structures. In particular, the global warming potential of three alternatives will be evaluated: traditional thermoset resins, high performance thermoplastic polymers and dynamic covalent bond polymers. Considering the potential growth of the AAM market, an interesting and insightful application is the life cycle of an Electric Vertical Take-off and Landing aircraft (EVTOL). A cradle-to-gate analysis has been performed, with the addition of the end-of-life scenario. The aircraft's use phase, though significant for carbon footprint, is omitted from consideration. This is because the choice of polymeric matrix is not expected to impact the system's performance significantly, as composite material properties are mainly influenced by fiber selection. The study will focus on the same fibers for all models, differing only in polymer choice. The necessary data for the Life Cycle Inventory (LCI) has been found in literature, both on the mass composition of an EVTOL configuration in terms of materials [1] and on the typical processes employed for such materials in the aviation industry [2], [3]. Only the structural and system components will be modelled, neglecting the battery pack and the electric motor, which are outside of the scope of the analysis. The considered material will be aluminium, stainless steel, titanium, carbon fibre reinforced polymers (CFRP) and glass fibre reinforced polymers (GFRP).

To implement the LCA, SimaPro has been used. Three models have been developed, one for each polymeric matrix. The same processes for the metallic materials have been considered for each model, hence the only difference regards the composite materials. The LCA scheme for CFRP is reported in Figure 1 for the three

matrices. The main difference resides in the disposal strategy. Thermoset-based CRFP can be recycled in different ways, yet the most used is by mechanical recycling, the output is then used as a filler to produce new composite materials. On the other hand, thermoplastic and CANs based CFRP can be reshaped in case of structural damage, avoiding the production of new composites.

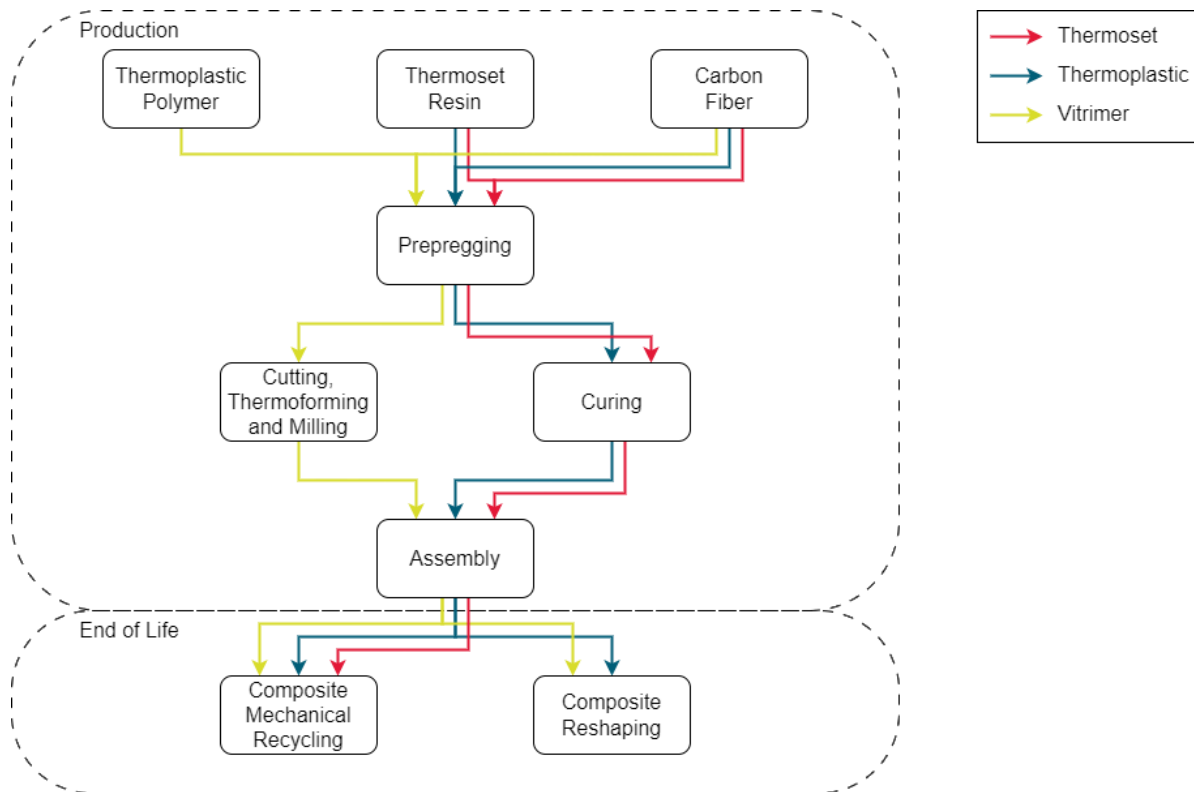


Figure 1 LCA scheme of GFRP for thermoset, thermoplastic and vitrimer matrices.

The Life Cycle Impact Assessment (LCIA) has been carried out using the Recipe 2016 method, which collects 18 midpoint indicators that are representative at a global scale. The most relevant merit parameter is the global warming potential, expressed in equivalent tonnes of CO₂ emissions. Of course, this value strongly depends on the amount of recovered material in the case of thermoplastic based CFRP, hence a sensitivity analysis has been performed. The results are shown in Figure 2. The baseline percentage of reused material is considered to be 70%, the upper limit of the environmental impact is associated to a percentage of reused material of 50%, while the lower limit refers to the case in which 90% of the material is recovered.

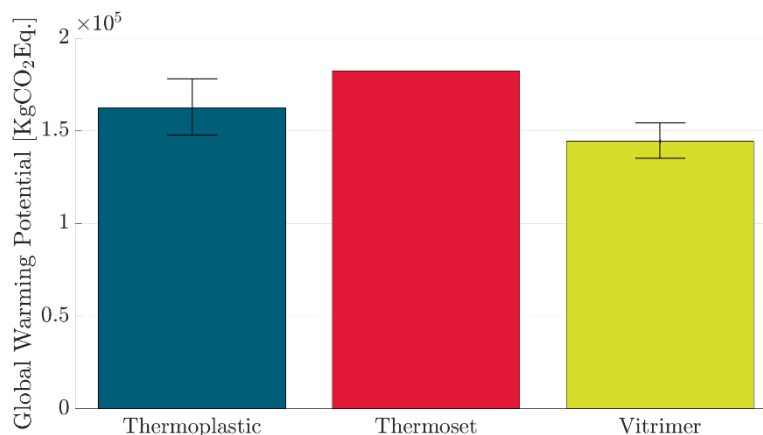


Figure 2 Global warming potential associated to the matrix type and the percentage of reused material.

As expected, the possibility to reshape composite materials can significantly reduce the carbon footprint over an entire life cycle. It must be noted that these are preliminary results, based only on data available from

literature. In addition to this, only one cycle of reuse has been considered for CFRP based on thermoplastic and CANs, but it could be possible to reprocess them more than once. This remains yet to be experimentally established, as well as the long-term performance for what concerns fatigue, crack propagation, creep and resistance to atmospheric agents.

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Acknowledgments

This study was carried out within the MOST – Sustainable Mobility National Research Center and received funding from the European Union Next-Generation EU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.4 – D.D. 1033 17/06/2022, CN00000023). This manuscript reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.