Out-of-Autoclave Processing Development of Aerospace Carbon Fiber Polymer composites

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Project Objectives :

Despite composites autoclave processing being well established, the associated high energy losses can make such processes less efficient than OoA (Out of Autoclave) processing. Aligned with the global quest for carbon footprint reductions and also in response to the increased demand for Fiber Reinforced Composites (FPPs), the industry is looking for alternatives to increase the efficiency of their respective manufacturing process while maintaining the design mechanical properties.

Amongst the OoA processing methods, RTM is a well-established method offering tight dimensional control, repeatability and high Fibre Volume Fraction (FVF). The FVF or RTM processed components can be tailored and typically match or exceed those of prepregs processed in conventional Autoclaves. The direct contact of the mould with the processed material reduces the energy requirements, also enabling faster and more uniform heat up or cool down stages.

In this project, the impact of a wide range of RTM manufacturing parameters and their importance on part quality is being studied. Understanding the most significant parameters could enable the manufacturer to optimize the process for the specifics of each component.

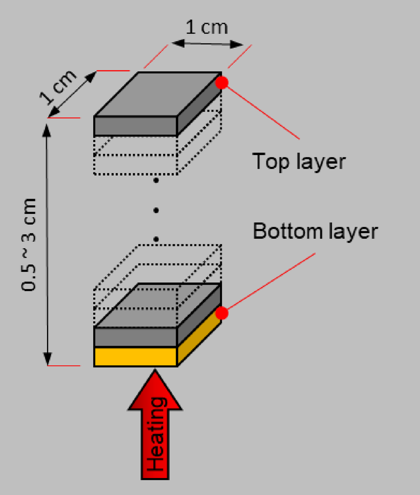
Figure 1. **A giant autoclave for baking CFRPs** (aviation-images.com)

The curing process of epoxy resin is a temperature-dependent chemical reaction and slows down at lower temperatures. To achieve a fully-cured product, the resin needs to be heated up to a certain temperature for a certain period of time. Typically the cure temperature suggested by resin manufacturers is below but close to the glass transition temperature of the epoxy. However, due to the exothermic essence of the cure reaction, it is challenging to control the temperature within the part. To prevent overheating, low heating rates and isothermal steps in between are considered in the heating program.

Finding the optimal value for input parameters to keep the maximum temperature below glass transition (Tg) temperature at the shortest manufacturing time can be the key to optimize the process and avoiding the build-up internal stresses.

Therefore, a numerical model has been developed to simulate the different manufacturing conditions.

Significance of each individual input from the model then will be analysed by Analyse Of Variance (ANOVA). Afterward, the Response Surface Method (RSM) will be employed for optimization purposes. Initially, the main response parameters for optimization are the peak temperature and the temperature difference within the part.

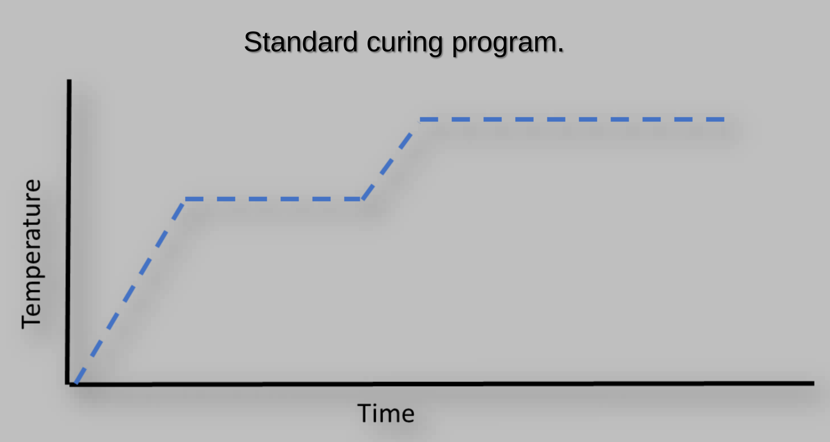


Conditions:

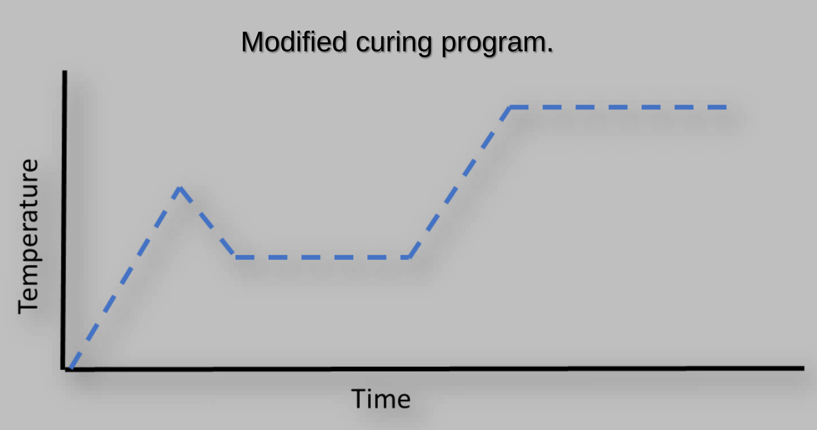
- No heat loss from the system.
- Heating from one side (Bottom layer)
- Maximum temperature at top layer.

Figure 2. **Schematic illustration for the numerical model.**

Analytical results:



Input (controllable) parameters	Low and high values
Part Thickness	5 mm – 30 mm
First heating rate	0.5 ˚C/min – 3 ˚C/min
First dwell temperature	20 ˚C – 40 ˚C
First dwell time	20 min – 40 min
Second heating rate	0.5 ˚C/min – 3 ˚C/min



Input (controllable) parameters	Low and high values
Part thickness	5 mm – 30 mm
First heating rate	0.5 ˚C/min – 3 ˚C/min
Transition temperature	30 ˚C – 50 ˚C
Cool down rate	1 ˚C/min – 3 ˚C/min
First dwell temperature	20 ˚C – 40 ˚C
First dwell time	20 min – 40 min
Second heating rate	0.5 ˚C/min – 3 ˚C/min

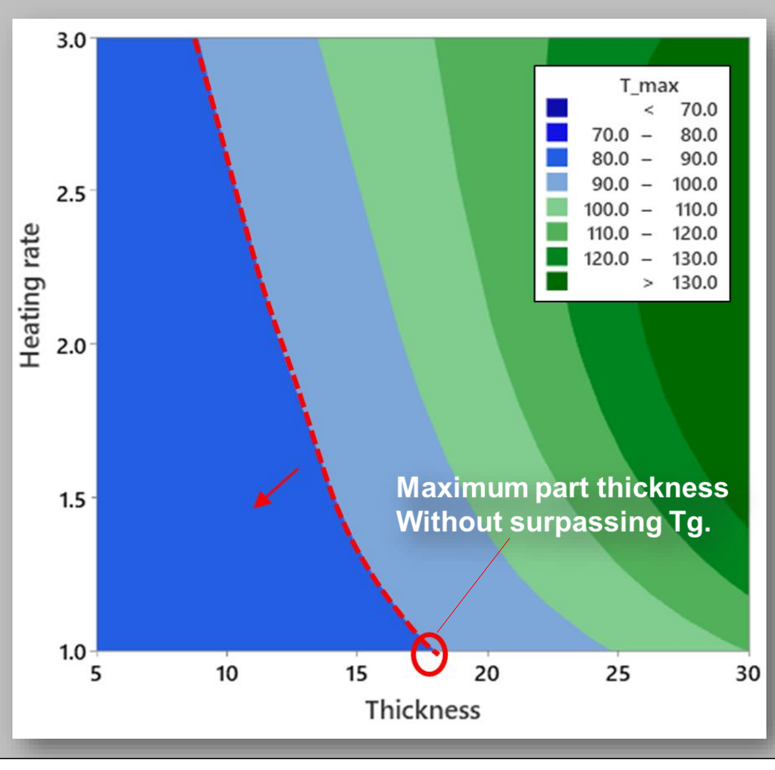


Figure 3. **Peak temperature values for the standard curing program.**

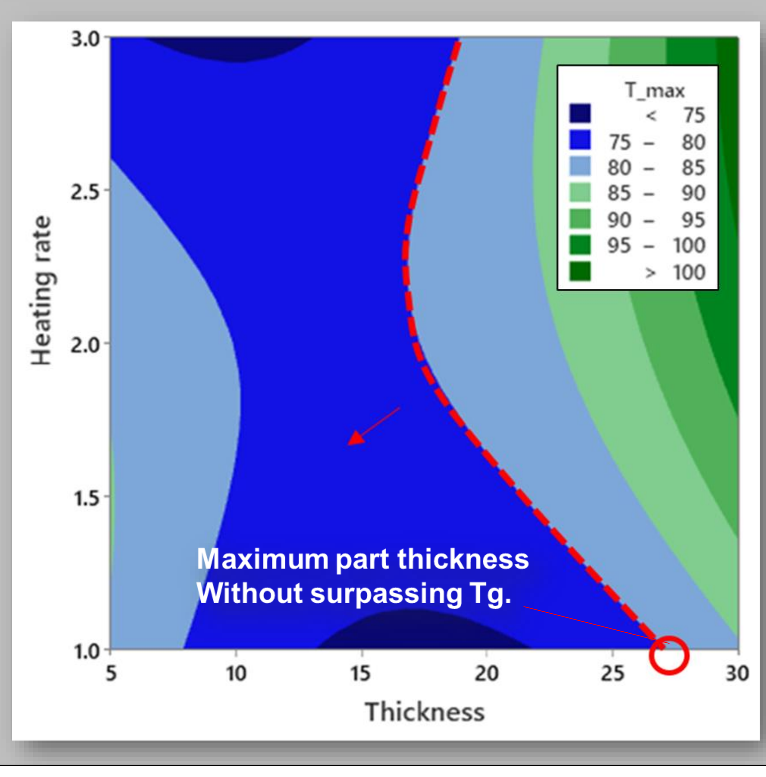


Figure 4. **Peak temperature values for the modified curing program.**

Comparing the results in the figures above illustrate how the method can be used to find the exact value for individual parameter regarding the defined limits. Adding more input parameters and using RSM, the maximum thickness of the part can be increased from 17mm to 27 mm without exceeding the maximum allowed temperature (80 ˚C).

Validation :

The cure equation parameters and performance of the simulation tool were validated by comparing with actual experimental results.

Table 1. **Measured values for epoxy**

The activation energy (Ea)	m	n	Pre-exponential factor (A)
55.34 (kJ/mol)	0.2	1.8	200,000

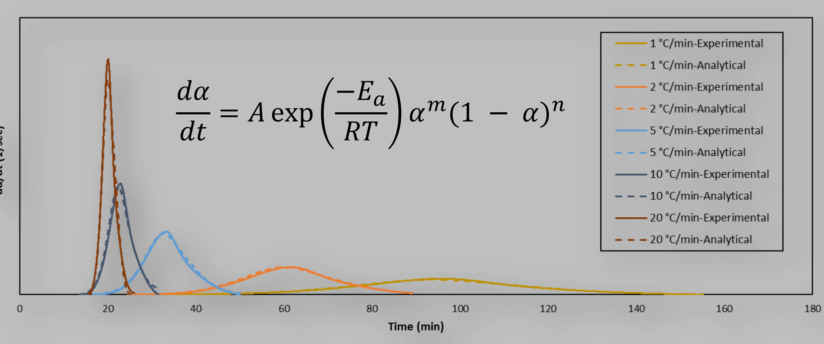


Figure 6. **Measured values for epoxy cure rate versus simulation.**

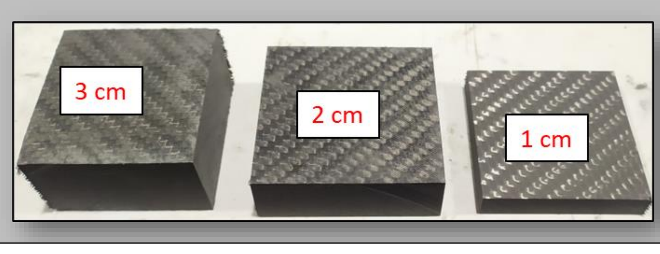


Figure 5. **Manufactured CFRPs with 1, 3,and 3 cm thickness.**

Temperature of the parts with different thicknesses were measured at top and bottom layers and were compared. Vacuum bagging process was used to manufacture samples. The samples were cured my applying constant temperature from the bottom.

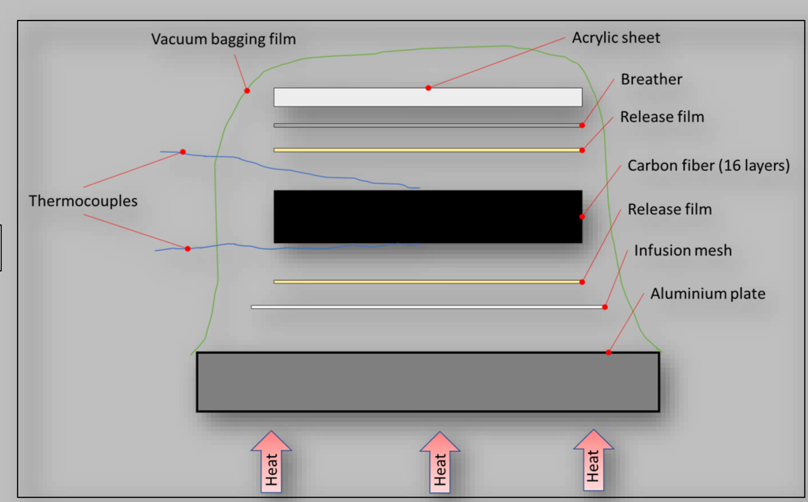


Figure 7. **Schematic illustration of CFRPs manufacturing.**

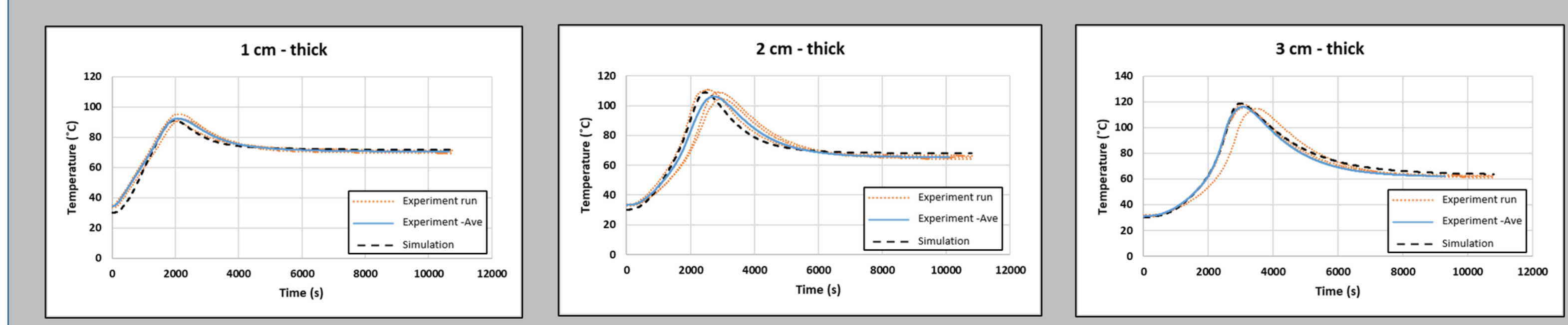


Figure 8. **Comparing the top-layer temperature of the sample .**

Future work :

The Response Surface Method is capable of optimizing multi-parameter situation. This will be used to create a comprehensive model capable of optimizing complicated situation. Some of suggested parameters are as follow:

Input (s)

- Composite thermal conductivity
- Ambient temperature
- Mould material
- Heat loss from the system
- Changes in part thickness (layer-off)
- Fiber fraction

Output (s)

- Formation of residual stress
- Manufacturing time
- Cost
- One-sided and two-sided heating