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FAST AND ROBUST JOINING PROCESS FOR AEROSPACE COMPONENTS BY LOCAL HEATING OF PASTE ADHESIVES

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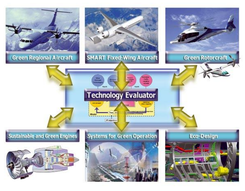
CLEAN SKY

The Clean Sky JTI is one of the largest European research projects ever, carried out over the period 2008–2013 with the following environmental goals:

- 50% reduction of CO2 emissions through drastic reduction of fuel consumption.
- 80% reduction of NOx emissions.
- 50% reduction of external noise.

The project is divided in 6 technology domains including eco-design, the frame of this research, which focuses on green design, production and optimal use of materials thus improving environmental impact.



GOAL

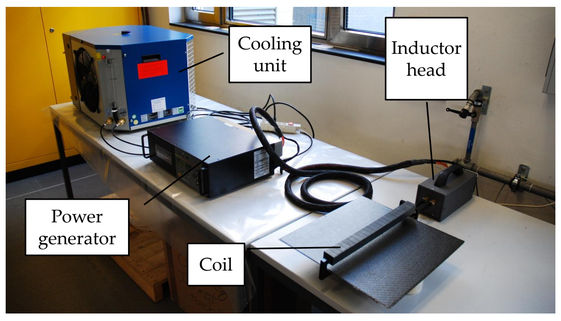
The goal of this research project is to optimize the process parameters for a robust fast joining of aerospace components by paste adhesives. The research approach is considering a number of challenging topics including:

- The investigation of induction heating for selective heating of paste adhesives.
- The acceleration of the curing process of paste adhesives with the use of high temperatures.
- The investigation of the impact of high temperatures on the mechanical performance of the joint.
- The development of a multi-physics design environment.
- The experimental validation of models and technology to:
  - Verify the methodology on an appropriate demonstrator.
  - Optimize bonding process considering ecological and economical impact.
  - Provide design guidelines.

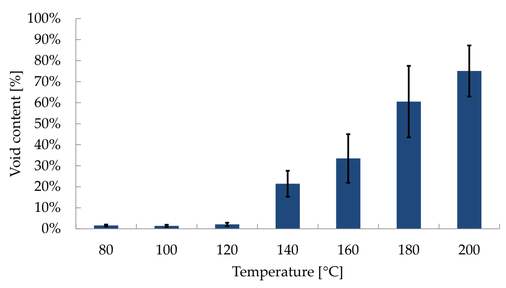
APPROACH

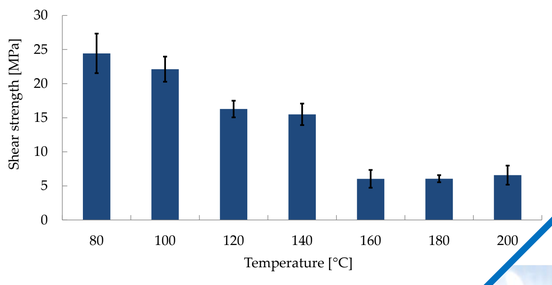
The bonding system selected is the bi-component paste adhesive LMB 6687-2 / LME 10049-4 from Huntsman Advanced Materials. This systems cures at 80 °C for 4 hours, allowing an acceleration of the curing process by a temperature increase.

The heating method considered is induction heating, being flexible and efficient. The dominating effect to generate energy is based on the induction of Eddy currents on CFRP. Then, the energy is conducted to the adhesive. The energy generated depends on the magnetic field, controlled at the equipment by tuning the electrical current, the size of the area and the electrical conductivity of the susceptor.



The main approach to optimize the curing process consists on accelerating the process by increasing the curing temperature. However, this increase is limited by the void formation in the paste adhesive, which decreases the mechanical performance of the joint.





To deal with this limitation, the main hypothesis in this project considers that the degradation of the paste adhesive due to high temperatures is dependent on the degree of cure.

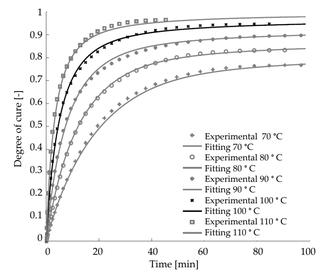
Under this consideration, the paste adhesive would be more sensitive to high temperatures at the beginning of the curing process , where low temperatures should ideally be used.

CURE KINETICS AND THERMAL DEGRADATION MODELING

The cure kinetics of the paste adhesive models the relation between temperature, time and degree of cure. Typically, the characterization of the cure kinetics is carried out through the analysis of the adhesive by Dynamic Scanning Calorimetry (DSC) analysis.

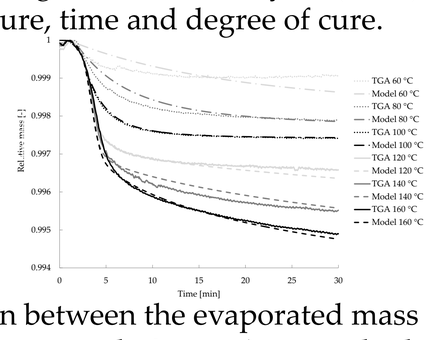
The model considered is based on an n-th order reaction, using chemical and diffusion control parameters:

$$\frac{d\alpha}{dt} = k \cdot (1-\alpha)^n = \frac{1}{\frac{1}{k_T} + \frac{1}{k_D}} \cdot (1-\alpha)^n$$

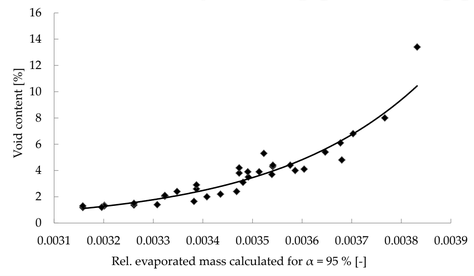


The thermal degradation kinetics is modeled by Thermogravimetric Analysis (TGA), obtaining the relation between evaporated mass, temperature, time and degree of cure.

$$\frac{dm}{dt} = -k_1 \cdot (1-\alpha)^n \cdot (m - m_{max}(T))^p - k_2 \cdot m^q \cdot (T > T_g)$$



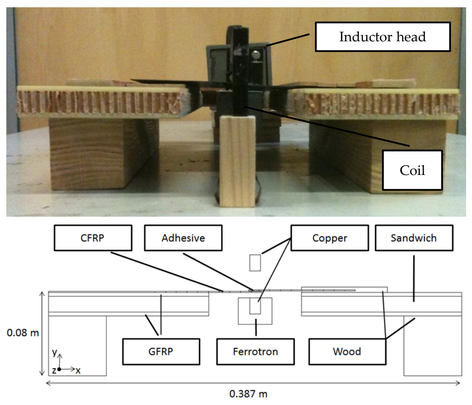
The model is completed with the relation between the evaporated mass and the void content, defined by microscopy techniques. As a result, the void formation can be calculated for any curing process applied.

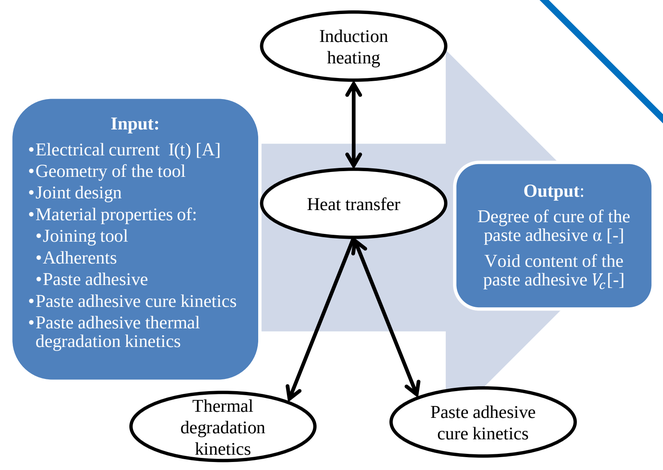


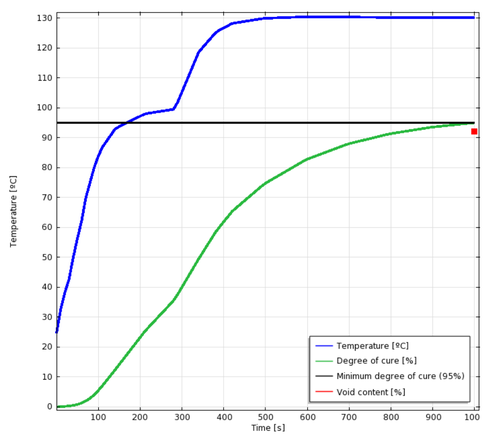
SIMULATION TOOL

COMSOL Multiphysics is the software used to simulate the behavior of the induction equipment. This tool allows calculating the theoretical degree of cure and void content of the adhesive after applying certain electrical current *I (t)* [A].

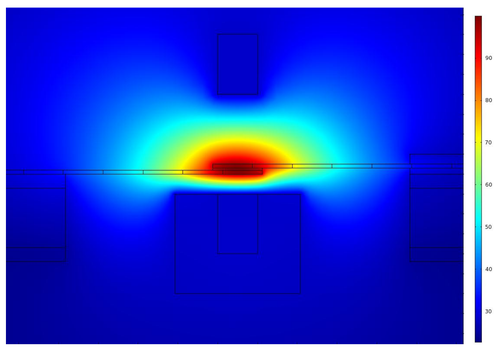
The program is divided in in four modules: magnetic fields, heat transfer, kinetics of the chemical reaction and kinetics of the thermal degradation of the paste adhesive.







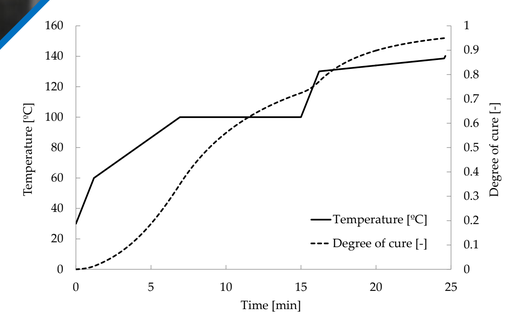
This program can be used to adjust the process to the different conditions and to assess the quality of the curing process applied.

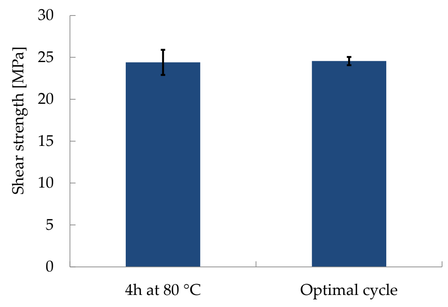


PROCESS OPTIMIZATION

The process is optimized respecting to the time, considering a minimum degree of cure of 95 % and a maximum void formation of 2 %.

The result is a dynamic cycle with a processing time of less than 25 minutes. It is validated by microscopy and SLS test.





The void formation measured on 26 samples is 1.48 ± 0.47 %, always with a degree of cure over 95 %.

DEMONSTRATOR

Finally, the process is applied to a real aircraft part, the aileron of the Dornier 228. The parts are bonded with the optimal curing process and the bondlines are validated by microscopy. The results show that all 21 bondlines have a void formation lower than 2 % and a degree of cure higher than 95 %.