THE WAY TO DECREASE THE CURING TIME BY 50% IN THE MANUFACTURING OF STRUCTURAL COMPONENTS USING THE EXAMPLE OF FML FUSELAGE PANELS

Philipp Zapp[1], Nikos Pantelelis[2], Hakan Ucan[1]
[1]DLR e.V.; Institute of Composite Structures and Adaptive Systems, Stade, Germany
E-Mail: philipp.zapp@dlr.de / hakan.ucan@dlr.de
[2]Synthesites SNC, Avenue du Lycèe Français 5B, Uccle, Belgium
E-MAIL:BE@SYNTHESITES.COM

1. ABSTRACT

Based on the missing cure monitoring in the manufacturing of structural components, the degree of automation and thus the increase in production cannot be improved. Since much more airplanes per month have to be produced promptly, a higher degree of automation is indispensable.

Especially in the field of Fibre Metal Laminates (FML), there is a high potential. The development of a new production line that will allow automated fuselage production is the focus of the studies within the joint project AUTOGLARE. In order to ensure the optimal processing of the reinforced adhesive, a process monitoring system has been developed for the in-situ process monitoring of the manufacturing process within an autoclave. The simultaneous measurement of the resin's temperature and electrical resistance allows for the real-time prediction of the viscosity, the degree of cure and the glass transition temperature (T_g). The curing of the polymer adhesive was modelled in the lab and its electrical properties were correlated to its T_g. Finally, the cure monitoring system was installed in the autoclave and several trials and an entire fuselage were executed. The continuous measurement of the temperature and resistance in all sensors was quite smooth and accurate while the ORS system provided successfully the evolution of the T_g at four critical locations.

The present scientific publication shows that the use of a process monitoring system can provide a reliable means to achieve online and accurate T_g estimation during the FML manufacturing in an autoclave with a potential to decrease the curing time by 50%.

2. INTRODUCTION

Increasing globalization requires global mobility and keeps air traffic moving to grow. Weight reduction in new aircraft structures will be considered as the basis for ecological and economical flying in the future. This results in requirements for the development of future commercial aircrafts. They should not only have a high proportion of lightweight materials in the primary structure, but at the same time also bring better performance. [1][2][3]

The use of glass fiber reinforced aluminum such as GLARE© achieves the requirements of the aviation industry due the low density, very high damage tolerance behavior and no demand for scheduled fatigue inspections. That means that in case of damage FML structures have the ability to withstand the loads occurring in flight without overall component failure over a defined time interval. On the other hand the damage tolerance capability of such structures brings the advantage of flexibility in manufacturing concessions and also service repairs. [2][3]

The Airbus A380 uses monolithic aluminum materials, carbon fiber reinforced plastics (CFRP) and GLARE in the primary structure. Especially the upper shells of the fuselage are dominant tensile stressed and thus are a challenge for the material used. For this reason, the Airbus A380 uses GLARE as the material for these components with a total area size of 469 m^2. This is almost equal to the surface of the A320 pressurized fuselage. These fuselages are made by the Tier-1-Suppliers of Airbus SE Premium Aerotec GmbH (PAG) in Nordenham / Germany and Fokker Technologies in Pappendrecht / Netherlands (see Figure 1). Both have manual process lines for the annual production of 50 aircrafts with time-consuming and costly process steps. [4][5]

Figure 1: GLARE fuselage panels made by Tier-1-Supplier PAG in Nordenham /Germany [4]

To make FML a real alternative to aluminum, low cost alloys, thermoset and thermoplastic fuselage structures in the short-haul aircraft of the next generation, the production rate has to be increased for 60 aircrafts per month. It corresponds to a production volume of 10,000 m^2 of FML. With the current manual production process this goal can only be achieved through a costly parallelization of production lines. For this reason, new methods and technologies for automated and quality-assured production need to be developed [5] [6].

In the center of the joint project AUTOGLARE is the development of an automated and quality-assured production line. With its partners Airbus Operations, PAG and the Fraunhofer Gesellschaft (FhG), the German Aerospace Center (DLR) is working on time-efficient processes. One point of focus is the development of concepts and technologies for a quality assured and shortened autoclave curing process as will be presented in the present paper.

3. STATE OF THE ART

The manufacturing of components, especially for aviation, is subject to high safety requirements. Due to the complex plant environment and the available measuring systems on the market, quality assurance of the component during the curing process is hardly possible. However, the properties of a CFRP component only become established during the process and can vary from component to component [7]. Due to the complex components, systems and processes, inhomogeneous temperature distributions can occur during manufacturing which may affect the component either being not fully cured or with different properties. To ensure a robust and reliable production, process parameters and cycle times are always dimensioned with high safety factors and processes have lasted much longer than necessary. Therefore it is desirable to have precise knowledge about the condition of a component. To detect the required parameters, the measurement results of several measuring systems such as dielectric, ultrasonic and thermal sensors were analyzed and evaluated. The investigations showed that state-of-the-art dielectric curing analysis is a suitable and reliable method of measurement. It offers the reliable detection of the curing progress of a fibre metal laminate (FML) component during processing. Thus, as shown in Figure 2, the dielectric sensors are integrated in direct contact with the matrix material providing the electrical resistance and temperature of the resin. As extensively demonstrated, the electrical resistance of the resin is directly related to its viscosity and curing state. So based on these measurements the online viscosity and Glass transition Temperature (Tg) can be estimated drawing conclusions on the curing process.

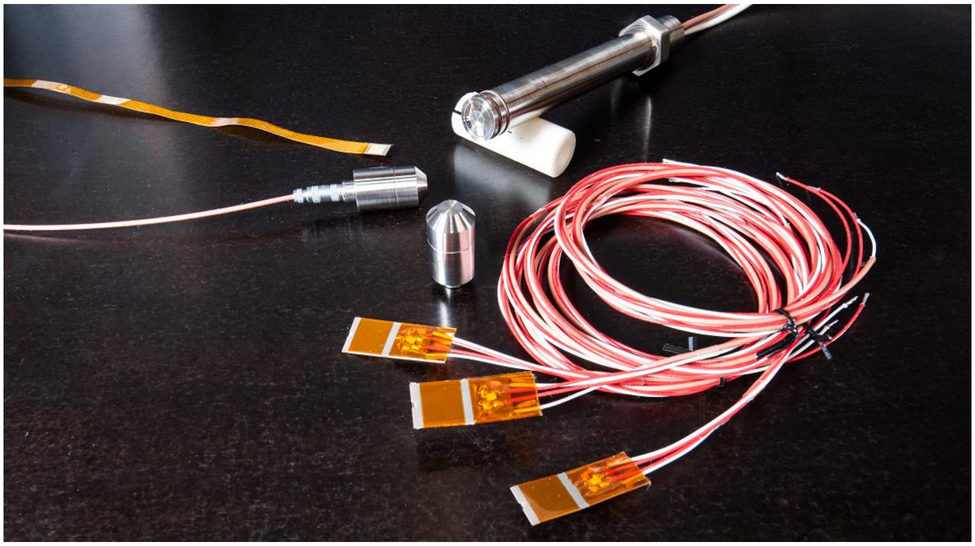

Figure 2 - Dielectric Sensors

To date these sensors cannot be used in production as they require direct contact with the matrix material which is incompatible with industrial regulations but as it has been shown in other applications it is always feasible to develop special non-intrusive durable sensors or place sensors in areas that will not affect the quality of the end product.

4. EXPERIMENTATION

For the upcoming experiments the autoclave of the DLR in Stade was used. With a loading length of 20 meters and a diameter of 5.8 meters, it is capable to cure full-scale components and thus representing the industry standard. The infrastructure of the autoclave is designed in such a way that the cable position of the sensor systems can be guided into the autoclave through flange connections. The evaluation hardware was stored in an air-conditioned server cabinet outside the

autoclave. A special feedthrough for the sensors wiring (approx. 10m long) through the autoclave wall was developed and implemented in order to ensure the safety and the accuracy through-out the whole length of the sensors wiring from the server cabinet up to the component. The investigations should show the added value of sensor systems during the curing process and the potential for increasing the efficiency of the processes. For this purpose, several experiments were carried out in the autoclave.
In order to test the functionality of the system in the autoclave environment, small plates were produced in the preliminary tests. The structure was realized as shown in Figure 3, comprising 3 aluminum sheets and 4 glass fiber layers which is a typical lay-up of a GLARE laminate used in aircrafts [8].

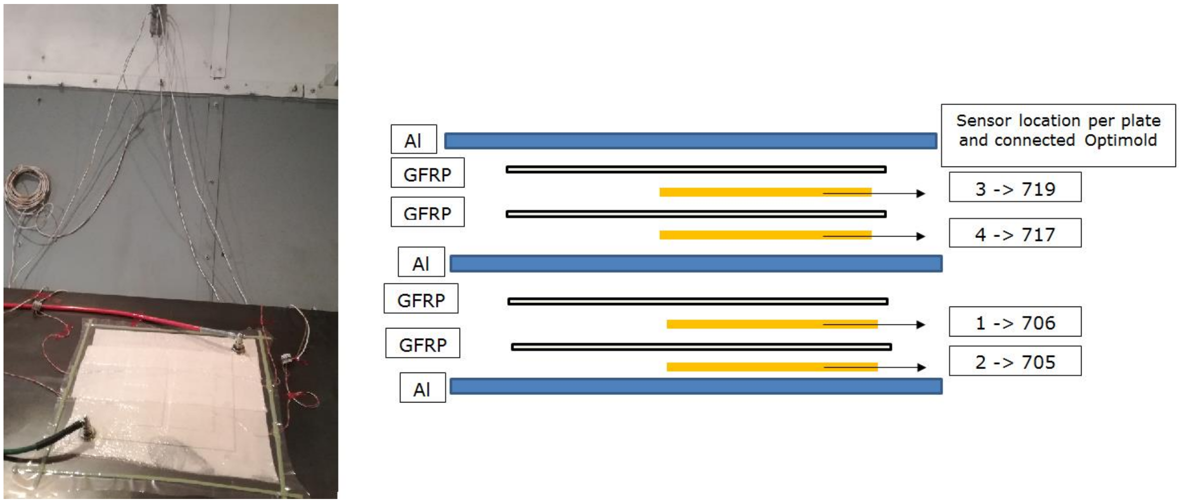

Figure 3 - Preliminary test in the autoclave: (left) component and wiring in the autoclave. (Right) FML layup and sensor location

With the system it is possible to use four sensors to monitor four distinct locations in the structure. Accordingly, four FML plates were manufactured. In order to verify a potential difference between the individual layers, the sensors were integrated in different areas (Figure 3). The process run for about 120 minutes, 60 minutes for heating and 60 minutes for the holding phase before the autoclave is cooled down. As shown in Figure 4, relatively similar temperatures could be measured between the individual layers. Furthermore, the electrical resistance of the four sensors exhibits an initial drop during heating corresponding to the resin’s viscosity decrease. Upon reaching the curing temperature level in the autoclave the electrical resistance increases rapidly until reaching the complete curing.
The system is also capable to determine online the glass transition temperature (Tg) of the resin, which is crucial for the mechanical properties of the component. In this case, the development of the Tg proves to be quite homogeneous and based on these results the curing of FML components in the autoclave appears to be faster than the recommended cycle. As can be seen in fig. 4 the resistance does not increase after half of the cure cycle, indicating that the resin at all four sensors has reached its final Tg.

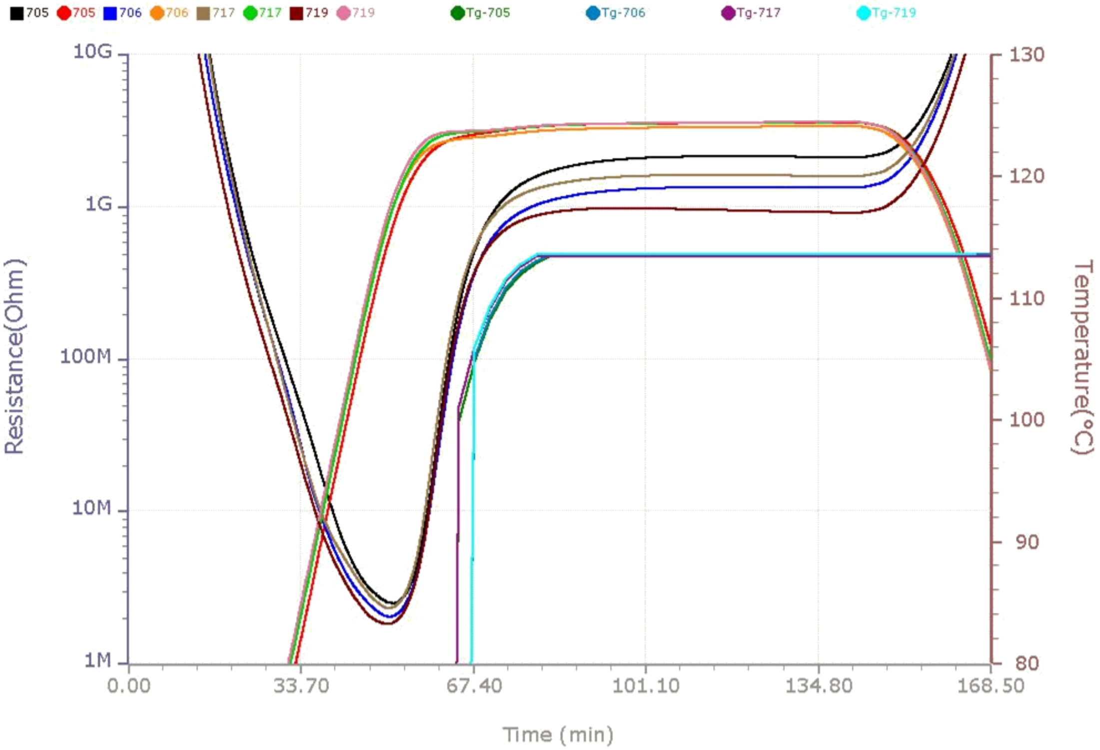

Figure 4 - Evaluation of the sensors after the preliminary test

Following this first successful trial the final demonstrator of the project was arranged. Based on the findings from the preliminary tests, the disposable sensors were placed under the first glass fibre prepreg layer, as shown in Figure 5. From the evaluation data of the preliminary test it appears that the most reliable signals could be detected here. The sensors were aligned with the contacts facing up and placed on the first aluminum layer. With the help of temperature-resistant and aviation-certified adhesive tape, the sensors and the cables were secured accordingly. The cable layer of the sensor consists of several wires, which were led individually through the vacuum structure eliminating any vacuum leakage. Ensuring zero vacuum leakage in such a large structure was crucial for the success of the manufacturing stage.

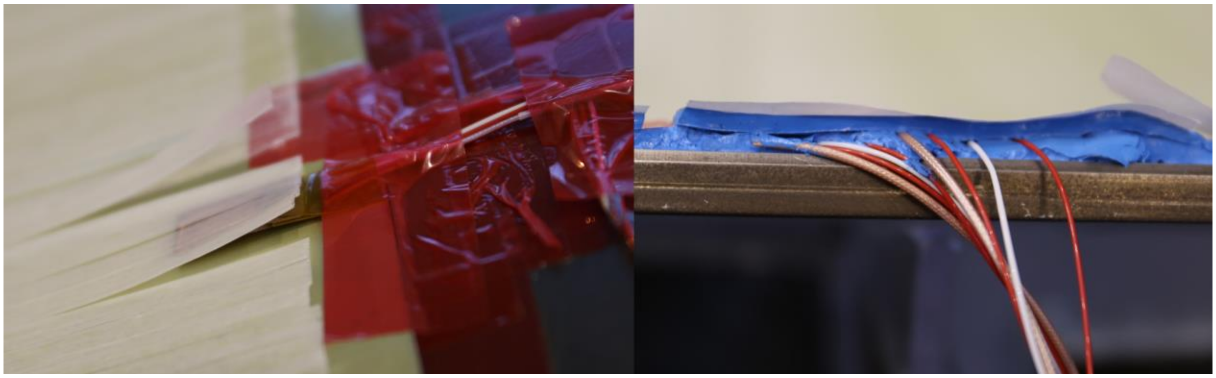

Figure 5 - Sensor integration during production

By using a CFD simulation the complete temperature distribution on the component inside the autoclave was calculated and the hot and cold spots were identified. So two sensors were placed at the areas with the extreme temperatures while the rest were placed in the middle temperature range locations as can be seen in Figure 6 where the exact location of each sensor is illustrated.

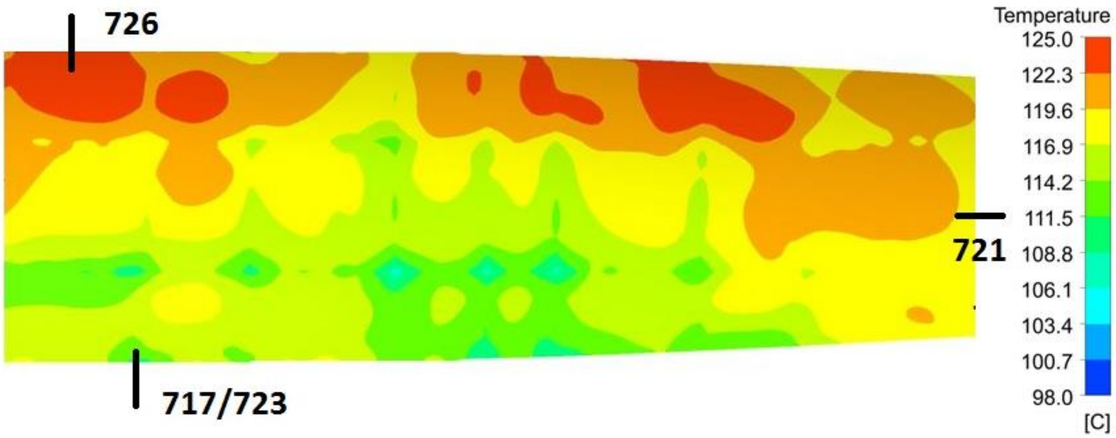

Figure 6 - CFD simulation of the expected temperatures

The connection of the cable layer was solved as in the preliminary test in Figure 3 on the existing connectors in the autoclave. Since the final demonstrator has a much larger thermal mass and provides more turbulence within the autoclave, it was expected that the dielectric sensor readings would be rather irregular. This was confirmed after evaluation of the experiment, as shown in Figure 7.

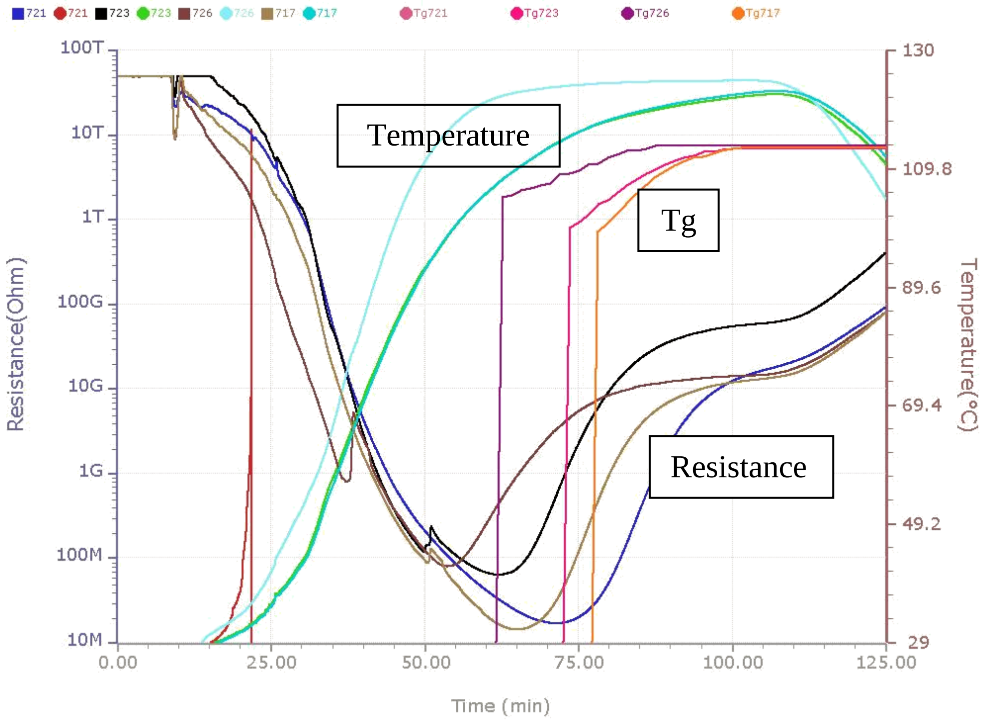

Figure 7 – History of temperature, resistance and online Tg of the 4 sensors at the final test

Based on the temperature measurements it was obvious that the temperature distribution was quite different from the expected pattern due to the larger thermal mass and the curved shape of the tool with respect to the smaller and flat component of the preliminary test. Naturally the difference in temperatures created quite different resistance curves as can be seen in Figure 7. Equally the difference in temperatures, resulted in quite different gelation times of the resin as can be seen in Table 1. This uneven evolution of curing may cause, in the extreme case, significant residual stresses in the component which consequently may deform the part during cooling.

Table 1 - Gelation times of matrix material

Sensor Nr	Approx. Gel time (min)
726	62
723	74
717	78
721	86

Although sensor 726 was in accordance to the simulations the fastest location to gel and cure, sensor 721 was the latest to cure with distinctive delay and without even the temperature stabilizing at this location. So the online Tg estimation was crucial in helping deciding when to switch off the heating of the autoclave and let the component cool down. On the contrary, according to the standard practices of the autoclave curing, the recommended one hour curing cycle of the prepreg manufacturer should actually have started when the temperature reached the recommended temperature level at the lagging thermocouple i.e. when the cooling was actually started in our case. This has led to at least 50% cycle time savings ensuring the quality of the component.

5. CONCLUSIONS

In conclusion, the use of the dielectric sensor technology has been able to provide a deep insight into the process parameters and component properties during the process. The results of the measurement data analysis show that the process time could be shortened by up to 50% without endangering the quality of the component. The diagrams show that it was always possible to detect the required Tg after half of the curing cycle. As a result of this project, the sensors of the dielectric curing analysis were able to reveal an enormous potential for improvement for this process which can be also extended in the serial production of these FML structures.

6. OUTLOOK

Curing inside an autoclave has been always an expensive means of producing composite parts and which also is not a trouble-free process. As it was shown in this study the introduction of intelligent sensors can significantly shorten the processing time, ensuring the quality of the parts and offering an indispensable way to part production traceability.

7. ACKNOWELEDGEMENTS

The authors would like to thank the German Federal Ministry of Economic Affairs and Energy (BMWi) and the DLR Project Management Agency, who provided funding for this project, under the auspices of the second call for the fifth German Aeronautical Research Programme. They would also like to thank all the partners—Airbus Operations GmbH, Premium Aerotech GmbH, Fokker Technologies, Stelia Aerospace, Hexcel and 3M—for the smooth collaboration.

8. REFERENCES

1. Beumler, T. 2004. ”Flying GLARE – A contribution to aircraft certification issues on strength properties in nondamaged and fatigue damaged GLARE structures”, PhD Thesis, Delft University of Technology, Netherlands
2. Alderliesten, R., C. 2017. “Fatigue and Fracture of Fibre Metal Laminates”, Springer International Publishing
3. Hombergsmeyer, E. 2006. “Development of advanced laminates for aircraft structures” presented at the ICAS Conference 2016, 3 - 8 September 2006, Hamburg, Germany
4. Apmann, H. 2016 "Automated FML Manufacturing for Aircraft Fuselages," SAE Int. J. Aerosp. 9(2):214-216
5. Ucan, H. et al. 2018. “Production technologies for lightweight structures made from fibre–metal laminates in aircraft fuselages” in *CEAS Aeronautical Journal* (330), 1-11
6. Beumler, T., 2014. “Development of thin-walled FML structures” presented at the AEROMAT Conference, 16 - 19. June 2014, Orlando, USA
7. Ehrenstein, G. W., 2006. “Faserverbundkunststoffe. Werkstoffe – Verarbeitung – Eigenschaften” München, Wien. Hanser 2007
8. Vlot, A. and Willem, J. „Fibre Metal Laminates an introduction“ Springer 2001