Industrial Composite Fabrication with the 2.45 GHz HEPHAIS-TOS System

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Abstract

The HEPHAISTOS system integrates advantageously the basic processing steps as tooling, tempering of the resin and lay up, the impregnation of the fibres, pre-forming techniques as well as finally the process curing of the composite structures. Composites for aerospace applications in prepreg and wet technology have been successfully fabricated and investigated for quality and certification issues. Features of the system, as well results on the material investigations are presented. The use of microwaves shows new approaches on the process interaction for the fibre materials, precursors, resin systems, lay-up preparation etc. with direct consequences on the adjustable material properties. The highest potential for cost reduction for CFRP is to be found on the manufacturing process which implies substantial long time and high energy consumption, as well as a low degree of automation. The situation for the developing industrial CFRP processing business has to be carefully considered in view of its realistic market impact, e.g. by analyzing future manufacturing options as well as the weight savings for aircraft fuselage structures. The obtained studies show clearly the need to focus on the single process steps to optimize for future industrial CFRP production. For increasing the penetration of composites on the market, technological progress on several issues is essential. In conclusion, novel autoclave-free systems with innovative microwave heating techniques for CFRP processing are under special consideration of industrial oven system manufacturers and end users.

1 The HEPHAISTOS-System

1.1 System Development

The developed microwave pilot system is named after Hephaistos, who is the builder and craftsman for the Greek gods, being also responsible since the past for oven and transportation technologies. The name HEPHAISTOS (**H**igh **E**lectromagnetic **P**ower **H**eating **A**utoclaveless **I**njected **ST**ructures **O**ven **S**ystem) stands as well for the technological concept of this microwave approach. The current system integrates advantageously the basic processing steps as tooling, tempering and injection of the resin and lay up, the impregnation of the fibres, pre-forming techniques as well as finally the process curing of the high performance laminate.

The most notable effect processing CFRP materials with microwaves is their volumetric heating, offering the opportunity of very high heating rates. In comparison to conventional heating where the heat transfer is diffusive and depends on the thermal conductivity of the material, the microwave field penetrates the material and acts as an instantaneous heat source at each point of the sample. The CFRP can be selectively heated, keeping the oven environment cool.

Fig.l: Hephaistos (Greek God), painting ca. 525 BC. He is also known as Hephaestus and Vulcan (Roman).

Spatial temperature homogeneity is crucial for qualified material properties. The samples must be exposed therefore to excellent homogeneous field distributions. This is essential, as the carbon fibres imply a very high microwave reflectivity and the tendency for arcing and breakdowns at loose ends in areas of inhomogeneous microwave patterns.

This problem is very severe and one of the major phenomena, that made microwaves not applicable yet for CFRP processing. A specific multimode applicator development aims to tackle these problems.
Monomode applicators involve only controllable field properties in small specific applicator regions, whereas multimode ovens promise, especially for frequencies higher than 2.45 GHz, the possibility for low field fluctuations in larger regions. Simulations and experiments have shown, that achieving high quality homogeneous field distributions over most of an applicator volume is not trivial, even at frequencies in the millimetre-wave regime (30 GHz) [2].

Distinctive physical and technological advantages of microwave heating compared to conventional heating are:

- Volumetric heating of composite materials: The microwaves penetrate instantaneously the materials and generate locally a specific heating content.

- Reduction of cycle times: Due to the volumetric Heating, the heating rates with a structure can be strongly increased gaining for a higher throughput of products.

- Selective Heating: Microwaves only heat the composite structure, the oven and components “keeps cool”.

- Energy savings: Only the lightweight structure is directly heated. The oven will not be cooled actively, which results as well in reduction of cycle times.

- Rapid control of the process: Due to the instantaneous and volumetric heating within the composite structure processes can be applied, which are impossible in conventional ovens due to their inertia on temperature changes especially if local overheating occurs for exothermal reactions.

- Upscale: The HEPHAISTOS-technology can be applied for large structures.

- Automation: The fabrication process as well as control and sensoring can be adjusted very advantageously with the HEPHAISTOS-technology, such that overall optimizations of the process chain can be gained.

- Reduced hardware-costs of the heating system: Due to the use of standard industrial 2.45 GHz components, an industrial HEPHAISTOS-system is much more convenient than autoclave systems.

An industrial microwave oven for production needs is successfully designed, if the available processing volume containing uniform field properties is about the size of the whole cavity and reflections are minimized. Conceptions of novel millimetre-wave technology have been transferred by DELFI simulations to 2.45 GHz technology to realize these demands by providing a large part capability for CFRP processing. The main hardware contribution of the system development is realized for a specific modular applicator containment providing an excellent homogeneous electromagnetic field distribution. The fabrication process can be performed pressurized up to 5 bar or at standard conditions. The processes are measured remotely by infrared sensors or shielded low-cost thermocouples.

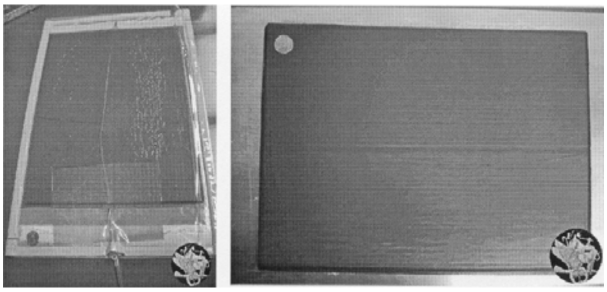

Fig. 2: Process setup: 1 bar vacuum bagged prepreg plate (left) and homogeneously cured sample after the process (HEPHAISTOS-BA System).

CFRP can be distinguished generally in duroplastics and thermoplastics depending on the choice of matrix material, which is used in advanced composites to interconnect the fibrous reinforcements. They are as varied as the reinforcements. Today, epoxy resin is the primary thermoset composite matrix for airframe and aerospace applications. The HEPHAISTOS technology could successfully demonstrate that all commercial resin and fibre systems can be used. The most commonly used materials for industrial composite fabrication are prepreg materials, due to their easy handling and storing issues. The fibres here are impregnated with resin compositions.

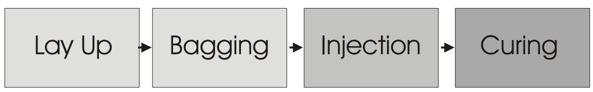

Fig. 3: Injected Composite’s fabrication scheme

The advantages of wet resin systems for infiltration are high service temperatures and the option of rapid processing cycles. A typical manufacturing scheme

showing the basic handling procedures is depicted in the flow chart of Fig. 3. Of all the heating systems the autoclave is today the most popular system for this composite field, as prepregs usually need a high pressure environment along the curing process for forming.
Concerns on this state of the art approach are [3]:

- Long process times
- Inherently energy inefficient system
- Major difficulties caused by large thermal gradients and slow heat up times
- Bag failures
- Complex expensive tooling
- High acquisition costs

The HEPHAISTOS microwave system containment is very compact and can be used as an inset to upgrade at low costs existing conventional autoclave systems. The above cited concerns and disadvantages are reduced. But, because on the very cost-intensive nature for autoclave based composite processing technologies, autoclave-free approaches without pressurizing are most promising for future broadband industrial application.

1.2 Autoclaveless CFRP Synthesis

A preferred approach is the wet or injection technology, where resin is drawn into a dry lay up of carbon fibre weaves. The produced parts show good surface detail and accuracy. The need for shipping and storing refrigerated prepreg is removed as well. The simple set up with a 1 bar vacuum bag reduces drastically the overall technological demands. Infiltration technology can be a very cost-effective non-autoclave process, where high performance CFRP parts can be fabricated in nearly arbitrary shapes using simple process management in a not pressurized environment.

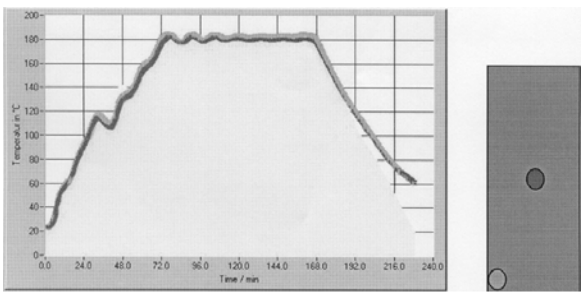

Fig.4: a 15 cm x 30 cm rectangular CFRP test plate processed and injected in an HEPHAISTOS-CA system (left). The temperature measured points are visualized in the right picture.

To inject resin into dry carbon weave, the resin as well as the lay up has to be preheated, to keep the resins viscosity low. After the injection phase, the curing cycle can immediately start. The complete process is automated with the HEPHAISTOS system. A continuous monitoring and control for the cure cycles of composite materials is permitted.

Fig.4 shows such a typical process in an HEPHAISTOS-CA system: the initial heating and tempering phase up to 110°C, resin injection phase, final heating for curing to 180°C and at last the cooling down phase of the sample. On the right picture, the measuring points in the centre and the edge of the sample can be seen. The temperature-time diagram shows clearly, that the temperature is homogenous during the dynamic heating as well in the stationary state, where the curing of the resin takes place.

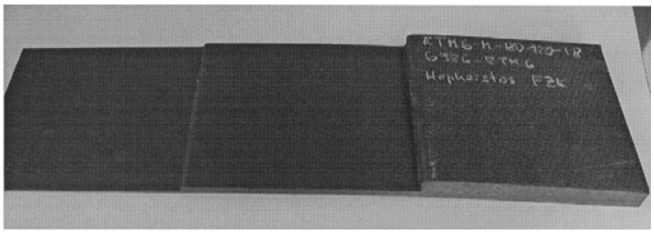

Fig.5: Large RTM6 injected CFRP Plate (60 cm x 20 cm) with integrated steps 2 / 6 / 20 mm.

As a result, Fig.5 shows a large sized CFRP plate (60 x 20 cm) fabricated in the HEPHAISTOS-CA microwave system. The curing was performed at 180°C using a standard RTM6 resin system. Material investigations showed an aviation certified quality.

For the near future, additional potentials concerning the process control (reduction of cycle times) and the material properties of fabricated structures will be opened up due to optimized process steps and resin systems.

The technological demonstration could be finished successfully. Currently the scale up for production facilities and their technical specifications are worked out. A big system HEPHAISTOS-CA2 working under industrial guidelines is under development.

1.3 Literature

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