DEVELOPMENT OF A MICROWAVE INJECTOR FOR RESIN INFILTRATION

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Abstract

A novel microwave (MW) injector at 2.45 GHz for resin infiltration is under development at Institute for Pulsed Power and Microwave Technology (IHM), Research Center Karlsruhe (FZK), Germany. Resin injection is an essential step in production of carbon fibre reinforced plastics (CFRP) for aerospace applications. A compact, low-cost and automated MW injector provides an efficient and safe energy transfer from the MW source to the resin and supports an appropriate electromagnetic field structure for homogeneous infiltration. The system provides a temperature monitoring and an automatized MW power switching, which ensures a fast answer of the MW system to rapid changes in the temperature for high flow rates of the resin. To analyze techniques for adjusting the MW injector to an optimized working point, the developed system has been tested and at first experimentally optimized for a water load. In the low power measurements with a vector network analyzer, the length of the waveguide cavity has been adjusted to provide the lowest reflections and a good efficiency of the system. The MW injector is currently tested and optimized for specific resin infiltration. Preliminary infiltration experiments show a desired increase of the resin temperature.

INTRODUCTION

In recent years it has been reported that microwave processing of composites gives clear advantages over conventional curing, such as: volumetric and selective heating, reduction of cycle time as well as energy savings [1]. By development of large scaled 2.45 GHz modular HEPHAISTOS systems at the Research Center Karlsruhe (FZK), Germany, in combination with a fully automated setup for the curing of CFRP parts, it has been shown that these advantages of MW heating can be realized also for industrial manufacturing, leading to lower processing costs and reducing the overall price of CFRP materials [2]. So, at FZK developed MW systems are superior for production of high performance CFRP components, using advanced materials such as epoxy resins and carbon fibers. The HEPHAISTOS system line is characterized by a very high field homogeneity, rapid control of the process, industrial upscale, automation and reduced hardware costs [3]. The systems are now commercially available at the company of Voetsch, Reiskirchen, Germany (www.v-it.com)

The focus of the research on MW CFRP processing at FZK was the development of stand alone systems for novel pressure-less processes in combination with specific infiltration techniques, such as Vacuum-Assisted Process (VAP) [1]. This process provides a rather simple approach to fabricate designed CFRP parts in relatively low-cost processes using low presure. To inject resin into dry carbon weave, the resin as well as the lay up as to be preheated, to keep the resins viscosity low. The resin assisted by vacum in VAP, moves through the dry lay up of carbon fibre weaves. After the injection phase, the curing cycle can immediately start. After curing at high temperatures, the part is removed from the cold oven.

The complete process can be automated with the HEPHAISTOS systems. A typical process in a HEPHAISTOS-CA system contains the stages: initial heating and tempering phase, resin injection phase according the VAP process, final heating for curing and at last the cooling down phase of the sample [1].

Resin injection is an essential step in production of CFRP for aerospace applications. To increase the flow rate of a resin and to speed up the infiltration, the viscosity of a resin can be decreased by heating. So, to reduce the injection cycle and to enhance the quality of the infiltration of the resin in the dry carbon fiber lay up, the MW heated resin infiltration has been proposed. A MW injector provides an efficient and safe energy transfer from the MW source to the resin and supports an appropriate electromagnetic field structure for homogeneous infiltration. In this way, the resin injection stage in the process will be also performed by means of MW radiation, which completes the MW processing cycle of CFRP parts in the HEPHAISTOS technology.

The MW injector should increase the resin temperature from 80°C at the input of it up to above 120°C at the output of the injector. The resin is preheated in the resin tank and the resin flow is assisted by vacuum. The system provides a temperature monitoring and an automatized MW power switching, by controlling the temperature of the flowing resin at the output of the system. The control ensures a fast answer of the MW system to rapid changes in the temperature for high flow rates of the resin.

A proposed MW injector system consists of the WR340 standard waveguide section, a cylindrical holder of a teflon (PTFE) hose for resin injection , a low-cost kitchen oven magnetron that is directly coupled to the waveguide (without any circulator or tuner) and a control and monitoring unit.

To analyze techniques for adjusting the MW injector to an optimized working point, the developed system has been tested and at first experimentally optimized for a water load. In low power measurements with a vector network analyzer (VNA), the length of the WR340 waveguide cavity has been adjusted to provide the lowest reflections and a good efficiency of the system. In high power experiments, water has been heated up near the boiling point with the MW injector. In the same time, investigations on the flow rate of the water have been undertaken.

The MW injector is currently tested and optimized for specific resin infiltration. A RTM6 resin system of company *Hexcel* is used for these investigations. Preliminary results of experimental low power measurements and of high power infiltration experiments show that a low reflections level and a desired increase of the resin temperature have been achieved. After a full integration of the MW injector to the HEPHAISTOS systems, final experimental verification for the MW CFRP processing will be performed.

DESIGN AND EXPERIMENTAL OPTIMIZATIONS

Design demands like low-cost, compactness, safety, power efficiency and automation require an innovative but rather simple approach in development of a MW injector. The novel MW injector is build in that way that the teflon hose for resin infiltration is positioned parallel to the electric field vector E of the fundamental TE_{10} mode in the WR340 standard rectangular waveguide, centered in the broad waveguide side. The hose is inserted in a larger teflon cylinder that outside the rectangular waveguide totally fills a cylindrical metal holder. So, the MW injector system can be considered as a joint of a rectangular waveguide partially field with two concentrically positioned dielectrics, (PTFE teflon – lossless and resin - lossy) and a circular waveguide totally filled with the same two dielectrics. The joint is normal and centered to the broad rectangular waveguide side. The simpler problem of a circular waveguide concentrically filled with two dielectrics has been already treated in the literature [4], as well as the problem of rectangular-circular waveguide joint [4, 5]. However, the MW system that is proposed here, presents a new concept.

Our approach is an experimental optimization of the presented MW system that avoids uncertainties of simplified analytical and numerical calculations and leads to a reliable device that is aimed to operate under industrial conditions. Parameter which can be considered in the optimization process is the length of the rectangular waveguide cavity. The optimizations are performed in the low power measurements with VNA. At first, the MW injector has been optimized for the water flowing through the system, by adjusting the length of the WR340 waveguide to the value that gives the low reflections level ($|S_{11}|$ parameter < 0.1). In the same time, investigations on the flow rate of the water

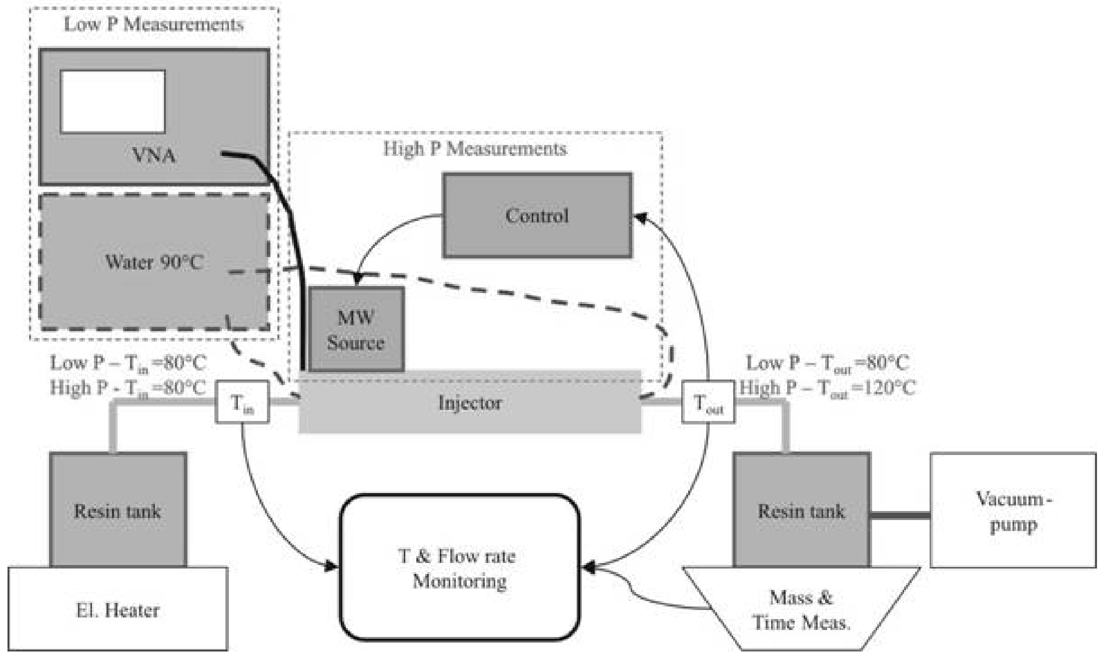

Figure 2. Schematic of the experimental setup for low- and high-power measurements

have been undertaken. In that way, the optimization techniques of MW injector dvelopment have been analyzed and confirmed.

Crucial issue in the design of the MW injector is the required, very fast control of the system. For the flow rates higher than 1 kg/min and for given geometry, a medium needs less than 0.1 s to flow through the MW active zone of the injector. So, very fast and precise temperature sensors for monitoring the output resin temperature and also very fast and reliable magnetron switching control are needed. Control should provide a stable output temperature of the resin, which gives a stable resin flow and a high quality infiltration. After the optimization of the MW injector system, the control and automation will be considered in details as a next step in the design. In Fig. 1 the principal experimental setup for both, low (low P measurements block in Fig. 1) and high (high P measurements block in Fig. 1) power P measurements of MW injector for RTM6 resin system is presented. In low P measurements, the MW injector had to be preheated by hot water at 90°C to avoid cooling down and flow stop of the resin. After this warming up of the MW injector, the VNA, resin at 80°C from tank and vacuum pump are connected to the system and the optimization measurements have been performed. In the high P experiments, a magnetron source and the T control are attached to the system. The magnetron is directly connected to the waveguide and the T control maintains the given output T of the medium.

RESULTS

After setting the waveguide length to the optimized value, very low level of the reflections (|S11| parameters < 0.1) for the water load at 75°C have been measured with VNA. In the high power experiments the water load at flow rate of 0.5 kg/min has been heated to the boiling point.

For the case of the RTM6 working point optimization, minimized $|S_{11}|$ parameter of 0.05 is measured with VNA at 2.45 GHz. A typical T increase, $DT = T_{in} – T_{out}$, in the preliminary experiments, has been depicted in Fig. 2 for T_{in} = 77°C and the flow rates of 0.1 kg/min. DT_{max} = 32°C has been measured in this case and that is an effective temperature increase which includes the thermal losses. The difference of the temperatures at the system output before and after the MW source was switched

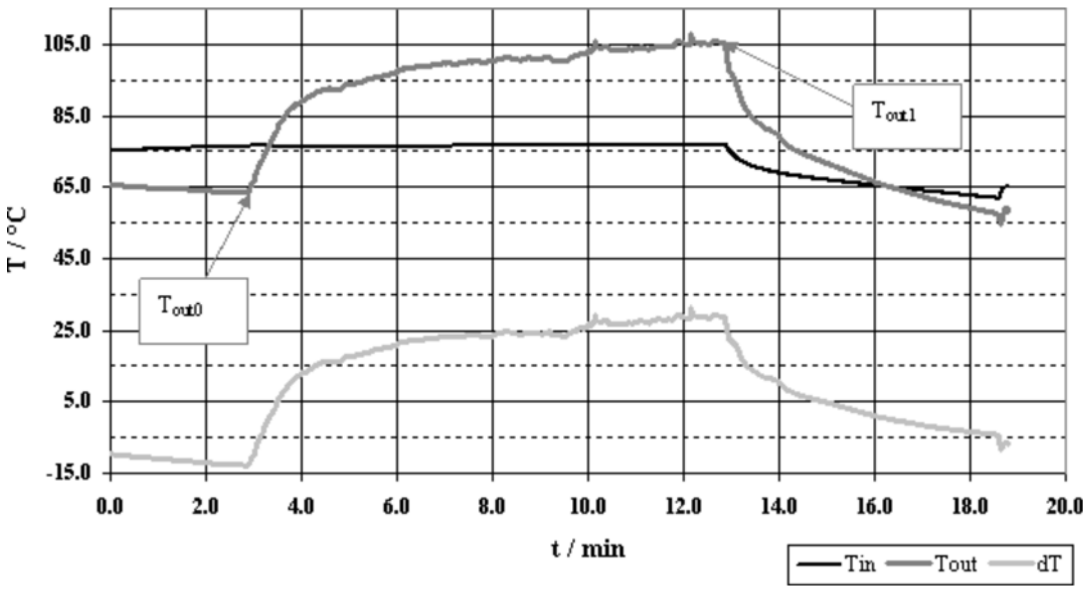

Figure 4. A typical measured temperature increase of a heated and injected RTM6 resin system

on can be defined as a total temperature increase $DT_{tot} = T_{out1} - T_{out0}$ = 43°C, and it shows that the desired temperature increase of 40°C has been achieved.

CONCLUSIONS AND OUTLOOK

Development of the new MW injector for resin infiltration in CFRP fabrication for aerospace applications has been described. The results of the experimental optimization of the novel MW system have been presented. Using a MW injector, the resin can be preheated very fast up to 120°C and then injected in the dry carbon fibre wave, enhancing the quality of infiltration and reducing the injection phase time.

The next step in MW injector development is a design of control and monitoring unit with challenging fast response. In the future MW injector will be fully automated and integrated to the HEPHAISTOS systems and final experimental verifications for the MW CFRP processing will be performed.

REFERENCES

[1] Feher L., M. Thumm and K. Drechsler, (2006). “Gigahertz and Nanotubes – Perspectives for Innovations with Novel Industrial Microwave Processing Technology”, *Advanced Engineering Materials*, 8 (1-2) , pp 26-32.

]2] Feher L, M. Thumm (2004). “Microwave innovation for industrial composite fabrication-the HEPHAISTOS technology,” *IEEE Transactions on Plasma Science*, 32 (1), pp 73-79.

[3] Feher L., K. Drechsler, J. Filsinger and M. Thumm (2005). “Development of the industrial 2.45 GHz HEPHAISTOS CA2 microwave processing system for composite fabrication,” *Proc. of 10th Int. Conf. on Microwave and High Frequency Heating*, pp 56-59.

[3] Marcuvitz N. (1951). *Waveguide Handbook 10*, McGraw-Hill Book Company, pp 393 -396.

[4] Wade J. D. and R. H. MacPhie(1986), “Scattering at Circular-to-Rectangular Waveguide Junctions”, *IEEE Trans. – MTT*, 34(11), pp. 1085-1091.

[5] MacPhie R. H. and K. Wu (1995), “Scattering at the Junction of a Rectangular Waveguide and a Larger Circular Waveguide”, *IEEE Trans. – MTT*, 43(9), pp. 2041-2045.