SMWD 2023, KTH Royal Institute of Technology, Stockholm, 23rd – 25th May 2023

Efficient and Sustainable CFRP Manufacturing through Microwave-Based Curing for Advanced Control Exposure Optimization

Y. Alekajbaf* (1), S. Murali (2), and D. Dancila (1, 2, 3)
(1) FREIA, Department of Physics and Astronomy, Uppsala University, Sweden
(2) Percy Roc AB, Uppsala, Sweden
(3) Microwave Group, Department of Electrical Engineering, Uppsala University, Sweden

Summary

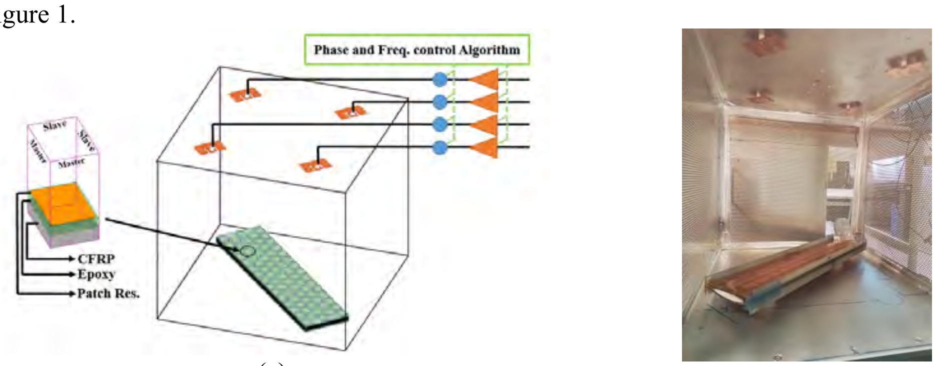
This study presents a new approach for curing carbon fiber reinforced polymers (CFRP) using microwaves. The method utilizes a metallic resonance coating layer that covers the surface of CFRP composite. Then, the coated CFRP is placed into a multimode cavity which is powered by four 250 W solid-state power amplifiers. To ensure that the heating pattern is controlled and the CFRP composite is heated homogeneity, a smart control algorithm is developed which is able to control the phase and frequency of each power amplifier separately. The experimental results demonstrate that the proposed approach is effective in controlling heating process for microwave-based CFRP curing.

1. Introduction

Carbon fiber reinforced polymer (CFRP) composites are widely used in the aerospace, wind blades, automotive, and other industries due to their exceptional mechanical properties, low weight, and corrosion resistance. Recently, conventional methods such as conduction heating and oven curing were commonly used for the CFRP curing process. However, these methods have disadvantages, such as high energy consumption, long processing times, and limited scalability. As a result, many alternative methods have been introduced to overcome these drawbacks [1]. Therefore, Microwave-based curing processes are becoming attractive due to their potential to significantly reduced processing times and energy consumption. However, there are several challenges while applying this method to the curing of carbon fiber reinforced polymer (CFRP) composites, such as uneven heating and the tendency of carbon fibers to absorb microwaves. To overcome these challenges and obtain the full potential of microwave curing for CFRP, this work proposes an efficient solution. The small metallic patches which resonant in a multi-mode microwave cavity could work as an absorber. So, coating CFRP with this absorber layer is an effective solution to overcome the challenges of microwave-based CFRP curing. This paper summarizes our progress and results of applying this idea to achieve homogeneous heating of CFRP using a multimode cavity at 2.45 GHz.

2. Design and physical setup

The main challenges of microwave-based CFRP curing are non-uniform heating and weak microwave absorption issue due to complex interactions between the microwave radiation and the conductive nature of the carbon fiber material. As a result, using multimode microwave cavity can provide a more uniform distribution of the microwave energy and reduce the occurrence of hot spots thus, the overall heating uniformity will be improved. Also, adding microwave susceptors to the CFRP composite which enhance microwave absorption can increase efficiency of the curing process by combining microwave and conduction heating methods. Based on previous research and discussed approaches, we propose an effective hybrid method to achieve homogeneous heating in the CFRP curing. In this method, CFRP composite is coated with dielectric epoxy and small resonator parts are placed on it [2]. Next, the CFRP is placed in a controllable multi-mode cavity. The proposed setup for this solution is shown in Figure 1.



(a) (b)

Figure 1. (a) Designed Physical structure for microwave-based CFRP curing, include the covered CFRP composite with the resonance patches, multimode cavity, and phase and frequency control, (b) Experimental setup photograph.

According to periodically structure of resonators and desired frequency, the rectangular resonance patches are designed and simulated using periodical master/slave boundary conditions in HFSS software at 2.45 GHz. So, the metallic patches' layer are resonated at the frequency of the incident microwaves within a multimode controllable cavity and absorb the electromagnetic field to produce an efficient heating in CFRP. The used multimode cavity, with dimensions 500mm×500mm×500mm, are derived by four 250 Watts solid state power amplifier at 2.4 to 2.7 GHz. Also, to modify electromagnetic field inside the cavity and optimized heating pattern inside the CFRP, the phase and frequency of RF power in each port controlled by a smart digital algorithm. The proposed smart control algorithm use a thermal feedback that obtain the heat distribution of CFRP composite surface by the optical sensors to control independently phase and frequency in each solid state power amplifiers. So, the resonance layer and the controllable multimode cavity which uses a smart control produce an optimized electromagnetic field distribution and absorption for a homogeneous and effective heating in CFRP.

3. Simulation and experimental results

The proposed setup in Figure 1.a is simulated using HFSS and Icepack software to investigate electromagnetic and thermal behavior, respectively. The simulated heat distribution in the CFRP surface is illustrated in Figure 2.a for several different phase and frequency condition in the frequency range 2.4 to 2.7 GHz. Also, the experimental results of the presented system in the same phase and frequency conditions are tested in the experimental condition are shown in Figure 2.b. These results provide a good view of the effect of the proposed approach. Additionally, based on the simulation and experimental results, it can be observed that the development of the control phase and frequency algorithm at each port could be beneficial in achieving a more homogeneous heating in CFRP composites.

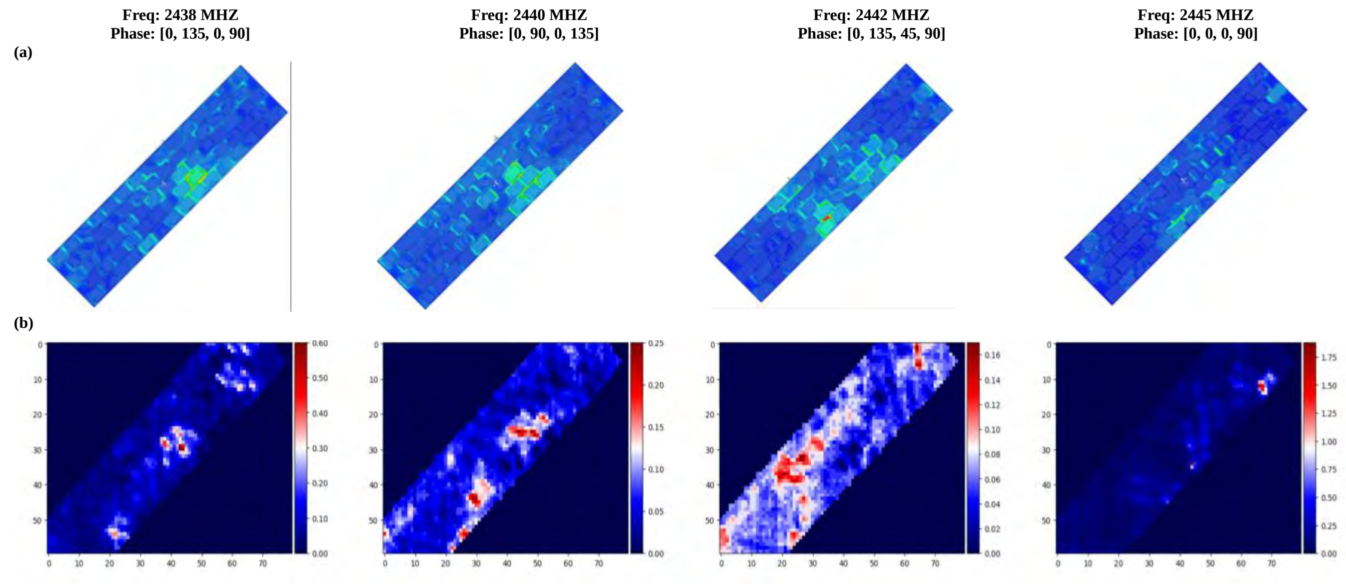


Figure 2. Heat distribution in surface of CFRP, (a) Simulation results (b) Experimental results (Captured using an optical sensor)

6. Acknowledgements

The authors would like to thank their colleagues in the FREIA Laboratory, Uppsala University, Uppsala, Sweden, for their assistance and support.

References

[1]. D. Abliz, Y. Duan, L. Steuernagel, L. Xie, D. Li, G. Ziegmann, "Curing Methods for Advanced Polymer Composites - A Review" *Polymers and Polymer Composites*, 21, 6, 2013, pp. 341-348, doi:10.1177/096739111302100602

[2]. J. Zhou, Y. Li, Z. Zhu, E. Xu, S. Li, and S. Sui, "Microwave heating and curing of metal-like CFRP laminates through ultrathin and flexible resonance structures," *Compos. Sci. Technol.*, vol. 218, no. August 2021, p. 109200, 2022, doi: 10.1016/j.compscitech.2021.109200.