Journal of Engineering Research and Applied Science
Available at www.journaleras.com
Volume 6 (2), December 2017, pp 698-702
ISSN 2147-3471 © 2017

Determination of The Heating Homogeneity of Infrared Cured Carbon Fiber Reinforced Plastics(CFRPs)

Y. O. Alpay[1,a], M. Kilincel[1], R. Ongun[1],O. Erol[2]

[1]Duzce University, Mechanical Engineering, Duzce, Turkey.
[2]Duzce University, Mechatronics Engineering, Duzce, Turkey.

Accepted 28 October 2017

Abstract
Elevated temperature is a crucial step of thermoset and thermoplastic curing of fiber reinforced plastics(FRPs). Heating is conventionally applied by convection which is based on heating a gas by using electric resistances. In this study the homogeneity of the infrared heating was investigated. Twill style CFRP pre-pregs were stacked and the temperature was elevated with infrared heater at different distances and powers. The temperature profile was monitored by thermal camera and the homogeneity of the temperatures on the product was determined by a previously proposed heating profile index (HPI). Results showed that infrared curing performance ad homogeneity strongly depends on distance and power.

Keywords: Temperature uniformity; infrared heating; CFRP.

1. Introduction

Carbon fiber reinforced plastics(CFRPs) are widely used in aerospace, automotive and sports industry due to its lightweight, higher strength to weight ratio and enable to customize the product according to the desired functionality and physical properties. Curing plays a vital role to obtain the desired product. Curing is the process at which the resin completes the cross linking and convert into a hard solid from a liquid form. Most advanced CFRP manufacturing technique is autoclave curing. However, autoclave curing has some drawbacks such as high cost and production time. Hence, new manufacturing methods or manipulations on the existing methods have been densely studied.

Kinsey et al. proposed a new thermal model for FRPs cured in autoclave.[1]. They used finite difference technique to mathematically model the curing state in complex geometries. Roşu et al. [2] researched the cure kinetics of different epoxy resins by using non-isothermal DSC data at different heating rates. Besides the experimental studies, curing simulations is a hot topic in curing of CFRPs. Blest et al [3] deals with the simulation of resin flow, heat transfer and the curing of multilayer thermoset composite materials. Yi et al. [4] developed a finite element procedure monitoring the curing process of polymeric composites considering the exothermic reactions. Joshi et al. [5] present a numerical approach for resin cure system. Their package carry out transient heat transfer and two user programs.

Out-of-Autoclave (OOA) manufacturing methods are trying to be developed to eliminate the capital of autoclave. Kim et al. [6] investigates the out-time on gelation, vitrification and viscosity. The dielectric properties of OOA pre-pregs aged from 0 to 7 weeks were monitored. Chen et al. [7] developed a finite element (FE) simulation program for double diaphragm thermoforming of composites to be able to identify the potential defects of 3D preforms from 2D biaxial from non-crimp fabrics. Sorrentini et al. [8] simulated the hot drape forming (HDF) process for unsymmetrical L-shaped carbon/epoxy composites and optimized the process parameters.

Manufacturing methods using electromagnetic radiation is still a less worked field. Adanur et al. [9] carried out ultraviolet (UV) curing experiments of composites. They studied the optimization of photo initiator concentration on the UV curable formulation. Bajpai et al. [10] investigated the heat resistant UV curable epoxy coatings. The thermal stability and heat resistance parameters of different

[a] Corresponding author;
Phone: +90-380-542-1100, Email: yakupalpay@duzce.edu.tr

additives were studied. The process differences of infrared (IR) drying and curing systems were studied by Casso Solar corporation.[11]. They noted that IR curing has advantages like fast curing times, precise control, contaminant free environment, low maintenance costs and floor- space savings. Kumar et al. [12]studied the optimization of IR curing process parameters like distance from IR, curing schedule and volume of the material on glass fiber reinforced plastics.

In this study, heating homogeneity of an IR heated CFRP was studied. An homogeneity index was proposed to compare the temperature distribution over the specimens. Five different IR lamp power and three different distances from the heat source was considered.

2. Material and method

Twill type pre-impregnated carbon/epoxy composite materials were used in this study. These specimens were bought from Kord-Sa Company. Specimens were identically cut and stacked. All of them were arranged as six layers and 30 mm x 140 mm dimensions. The thickness of plies were 0,3 mm. Three different distances from the IR source and 5 different IR powers were monitored.

Distance (mm)	Power (W)					
	15	150	382	538	728	828
	20	150	382	538	728	828
	30	150	382	538	728	828

Duration of all experiments was limited with 5 minutes. Because, within 5 minutes, the maximum temperature level have been reached in all experiments. Within the scope of the study, it is enough to observe the maximum temperature reached and the heating homogeneity. Heating Homogeneity concept was defined as Heating Uniformity Index(HUI) and the formulation is as follows:

$$HUI = \frac{T_{avg}}{T_{max} - T_{min}} \quad (1)$$

Where, Tavg, Tmax and Tmin represent average, maximum and minimum temperature values, respectively. Higher HUI values mean that the higher temperature distribution homogeneity.

The thermal images were taken per 10 seconds for each experiment. FLIR E6 thermal camera was used for thermal imaging and post processing of images. Ceramicx medium wave-length infrared heater is used as infrared heater. The infrared heater was halogen type and 1 kW power. An ampermeter and voltmeter was attached to the system for the sake of measuring the exact values of voltage and current so as to know the exact power given to the infrared heater. A potentiometer was installed to the circuit to alter the power and the voltage and current was monitored. The power value was calculated using voltage and current values. It was noticed that when the system is working in full power, 1kW power can be generated. The reason behind this is thought that the decrease of efficiency which is frequently encountered in this type of infrared heaters.

3. Findings

It can be seen in Figure. 1 that the lowest heating uniformity for 150 W IR power was evaluated in 20 cm distance. However, homogeneity is more stable at this distance comparing the others, especially at 30 cm. At 30 cm distance, although the homogeneity does not seem to be stable, the average value of homogeneity is higher than the others.

In Figure 2, most significant conclusion is that the homogeneities of all distances at 382 W are very close after about 220 seconds. Before that time, average index values of 20 cm distance is highest, while the 15 cm distance shows the lowest value.

In Figure 3, 20 cm distance at 538 W shows explicitly the highest HUI stability and HUI value. The experiments with 15 cm distance shows the lowest homogeneity although the stability is seem to be better than the previous power levels.

In Figure 4 at 728 W, 30 cm distance exhibits the highest HUI. Besides, the HUI values of three experiments, the HUI values are not getting closer like in the case in 538 W.

In Figure 5, Specimens in all distances at 828 W seem to be more stable than at the other powers. However, the values of HUI are lower. 30 cm distance shows the highest HUI as expected.

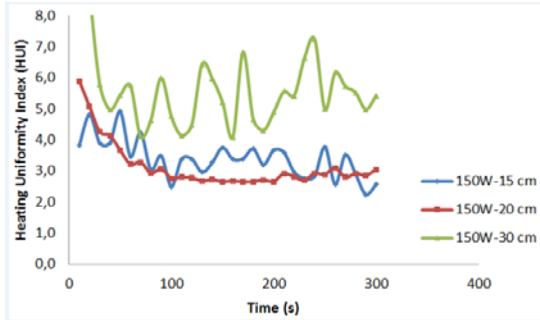

Figure 1. The change of the heating uniformity with regards to time for 150 W IR power

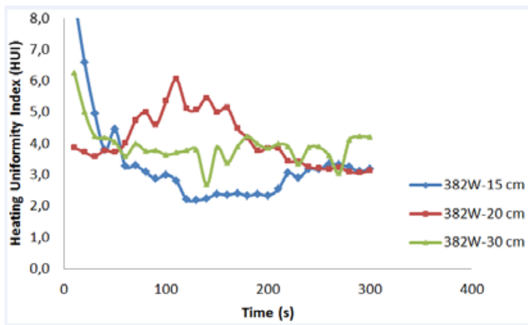

Figure 2. The change of the heating uniformity with regards to time for 382 W IR power.

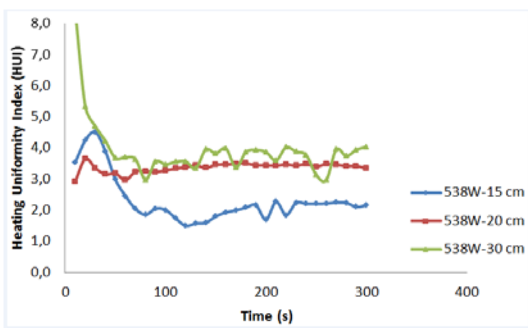

Figure 3. The change of the heating uniformity with regards to time for 538 W IR power.

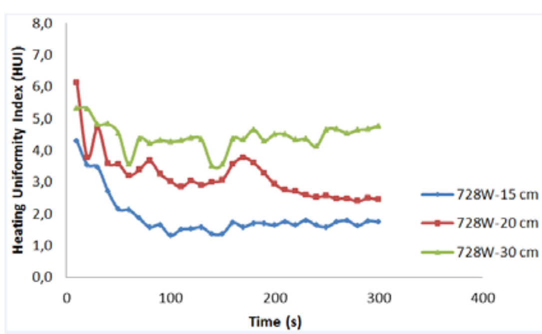

Figure 4. The change of the heating uniformity with regards to time for 728 W IR power.

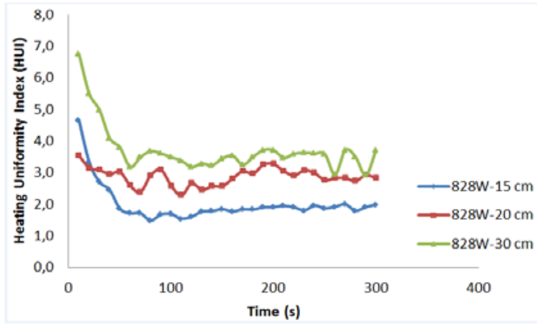

Figure 5. The change of the heating uniformity with regards to time for 828 W IR power.

4. Conclusions

Manufacturing of fiber reinforced composite materials generally handles the curing of the resin. Therefore, newly developed manufacturing methods should concern the curing process of the resin. Infrared curing of FRP composites has been started to be studied recently, hence, the process parameters of this method need to be determined. This study proposes an homogeneity index with regard to distance of IR source from the specimen and the power of IR source. Results showed that different power levels results different temperature distribution. The most effective distance in the aspect of the temperature uniformity seems about 20 cm. Because looking to the all graphs, this distance exhibits the most stable Homogeneity and the highest HUI value, in general. 728 W seems to return the highest HUI values for all distances. Evaluating the all results together, 728 W IR power with 20 cm distance is concluded to be used in an IR cure cycle. Further researches can be held for determining the optimum values of distances and IR power. Besides, different power and distance values can be used in a full scale IR curing cycle. For this purpose, a PLC program should be employed to alter the power and distance according to the output values of temperature.

References

[1] S. P. Kinsey, a. Haji-Sheikh, and D. Y. S. Lou, “A thermal model for cure of thermoset composites,” J. Mater. Process. Technol., vol. 63, no. 1–3, pp. 442–449, 1997.

[2] D. Roçu, C. N. Caçcaval, F. Mustaça, and C. Ciobanu, “Cure kinetics of epoxy resins studied by non isothermal DSC data,” Thermochim. Acta, vol. 383, no. 1–2, pp. 119–127, 2002.

[3] D. C. Blest, B. R. Duffy, S. McKee, and A. K. Zulkifle, “Curing simulation of thermoset composites,” Compos. Part A Appl. Sci. Manuf., vol. 30, no. 11, pp. 1289–1309, 1999.

[4] S. Yi, H. H. Hilton, and M. F. Ahmad, “A finite element approach for cure simulation of thermosetting matrix composites,” Comput. Struct., vol. 64, no. 1–4, pp. 383–388, 1997.

[5] S. C. Joshi, X. L. Liu, and Y. C. Lam, “A numerical approach to the modeling of polymer curing in fibre-reinforced composites,” Compos. Sci. Technol., vol. 59, no. 7, pp. 1003–1013, 1999.

[6] D. Kim, T. Centea, and S. R. Nutt, “In-situ cure monitoring of an out-of-autoclave prepreg: Effects of out-time on viscosity, gelation and vitrification,” Compos. Sci. Technol., vol. 102, pp. 132–138, 2014.

[7] S. Chen, O. P. L. McGregor, A. Endruweit, M. T. Elsmore, D. S. A. De Focatiis, L. T. Harper, and N. A. Warrior, “Double diaphragm forming simulation for complex composite structures,” Compos. Part A Appl. Sci. Manuf., vol. 95, pp. 346–358, 2017.

[8] L. Sorrentino and C. Bellini, “Potentiality of Hot Drape Forming to produce complex shape parts in composite material,” Int. J. Adv. Manuf. Technol., vol. 85, no. 5–8, pp. 945–954, 2016.

[9] S. Adanur and Y. Arumugham, “Characteristics of Ultraviolet Cured Glass-Epoxy Textile Composites: Part 1: Experimental Procedures and Testing,” J. Ind. Text., vol. 32, no. 2, pp. 93–106, 2002.

[10] M. Bajpai, V. Shukla, and F. Habib, “Development of a heat resistant UV-curable epoxy coating,” Prog. Org. Coatings, vol. 53, no. 4, pp. 239–245, 2005.

[11] C. Corp, “Infrared drying and curing

systems," Met. Finish., vol. 108, no. 11–12, pp. 275–279, 2010.

[12] P. K. Kumar, N. V. Raghavendra, and B. K. Sridhara, "Optimization of infrared radiation cure process parameters for glass fiber reinforced polymer composites," Mater. Des., vol. 32, no. 3, pp. 1129–1137, 2011.