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Observation of the heating behavior of infrared cured carbon fiber reinforced plastics

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Abstract
Carbon Fiber reinforced plastics (CFRPs) are widely used in automotive, aerospace, sports and leisure sector as light and high strength materials. Most advanced CFRPs are manufactured via autoclave ovens which apply temperature and pressure. But the usage of this material is still limited because of its limitations such as high costs and mass production difficulties. Therefore, new manufacturing methods are trying to be developed. In this study, the possibility of infrared curing method was inspected. For this purpose, an infrared heating system was installed to cure the CFRP. Medium wave-length infrared was used. The heating system allows altering the distance to change the distance effect on heating. Results showed that infrared heating is viable for controlled-heating when the autoclave cure cycle is to be applied as long as the distance of the lamp and material and the wattage of the infrared lamp are adjusted.

Keywords: Infrared heating; curing mechanism

1. Introduction

Carbon fiber reinforced plastics (CFRPs) in which a thermosetting resin used are manufactured by arranging the uncured fiber-resin mixture into the desired shape and then curing the material under pre-determined temperature and pressure. The resin is cured and undergoes a chemical reaction to create the cross-links so as to gain its strength. The elevated temperatures should be higher than the resin's glass transition temperature.[1] They are used in many industries like aerospace, automotive, sports, marine etc. because of their high strength to weight ratio.

Usages of these composite parts are still limited because the long curing times, expensive material costs and intensive labor costs. These drawbacks make the researchers to develop manufacturing solutions which reduce the costs without sacrificing the quality. The main disadvantages of autoclave curing are initial investment cost and operating costs. A large volume considering the product is heated up to 220 oC for 6-7 hours. This makes autoclave process to be very expensive [2]. Efforts to reduce the manufacturing costs of this material can be classified into 2 groups: Efforts to develop fast curing resins and efforts to reduce the operating costs. Curing behavior of fiber reinforced plastics has been extensively studied. Kinsey et al. proposed a new thermal model for FRPs cured in autoclave.[3]. They used finite difference technique to mathematically model the curing state in complex geometries. Roşu et al. [4] 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 [5] deals with the simulation of resin flow, heat transfer and the curing of multilayer thermoset composite materials. Yi et al. [6] developed a finite element procedure monitoring the curing process of polymeric composites considering the exothermic reactions. Joshi et al. [7] 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. [8] 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. [9] developed a finite

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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. [10] 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. [11] carried out ultraviolet (UV) curing experiments of composites. They studied the optimization of photo initiator concentration on the UV curable formulation. Bajpai et al. [12] investigated the heat resistant UV curable epoxy coatings. The thermal stability and heat resistance parameters of different additives were studied. The process differences of infrared (IR) drying and curing systems were studied by Casso Solar corporation.[13]. 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. 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, infrared curing possibilities are investigated for an autoclave cure cycle in the view of heating rate and distance dependence of heating rate of the material. This study aims to provide information about the heating behavior of infrared heating so as to explore the possibilities of replacing the conventional resistance heating system of the autoclave with infrared radiation heating. This would reduce the operational costs of the autoclave curing. In this point of view, infrared curing proposes not an OOA system, but a modified autoclave system.

2. Material and Method

In this study, twill type pre impregnated carbon fibers (Pre-preg) supplied from Kord-Sa was used. They are cut as 30 mm x 140 mm plies and 6 layers are stacked. An infrared heating system was installed which allows to change the distance to the material. Experiments were conducted at 5 different wattage of infrared and 3 different distances as tabulated below.

Table 1. The voltage and distance parameters that experiments are held

Distance (mm)	Voltage (V)				
15	80	140	170	200	214
20	80	140	170	200	214
30	80	140	170	200	214

As seen in the Table 1, 15 different experiments were conducted. The thermal images were taken during the experiments one per 10 seconds. All experiments are limited with 5 minutes. Because in pre-experiments, it is seen that the maximum curing temperatures needed in autoclave cure cycles are reached at about maximum 5 minutes. The longer experiments would not serve a valuable information as we consider the heating rates up to the maximum curing temperatures, which is considered about 220 ^{o}C .

FLIR E6 model thermal camera was employed to take the thermal 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

The graphs in the figures 1, 2 and 3 represent the heating patterns of pre pregs in different powers and distances. When the maximum temperatures are considered, a temperature drop can be noticed above 120 ^{0}C. This is attributed to the exothermic reaction initiation above this temperature value. While adjusting the cure cycle parameters in the manufacturing system, this phenomenon should be considered because temperature drops may deteriorate the cross linking process in such cure cycle that accurate heating rates are desired.

The second important deduction from the heating patterns is that in all experiments both maximum temperature values and average temperature values converge on a certain value. This information is important because while the control unit is designed, i.e. in a certain distance, it provides the information about the temperature value of a certain power, or voltage, so the programming of the control unit will be easier and give the more accurate results. Besides, the plateau regions of the cure cycles, the temperature values that should be held at the same value in a certain time, can be accurately determined by this information which leads to reduce the programming effort.

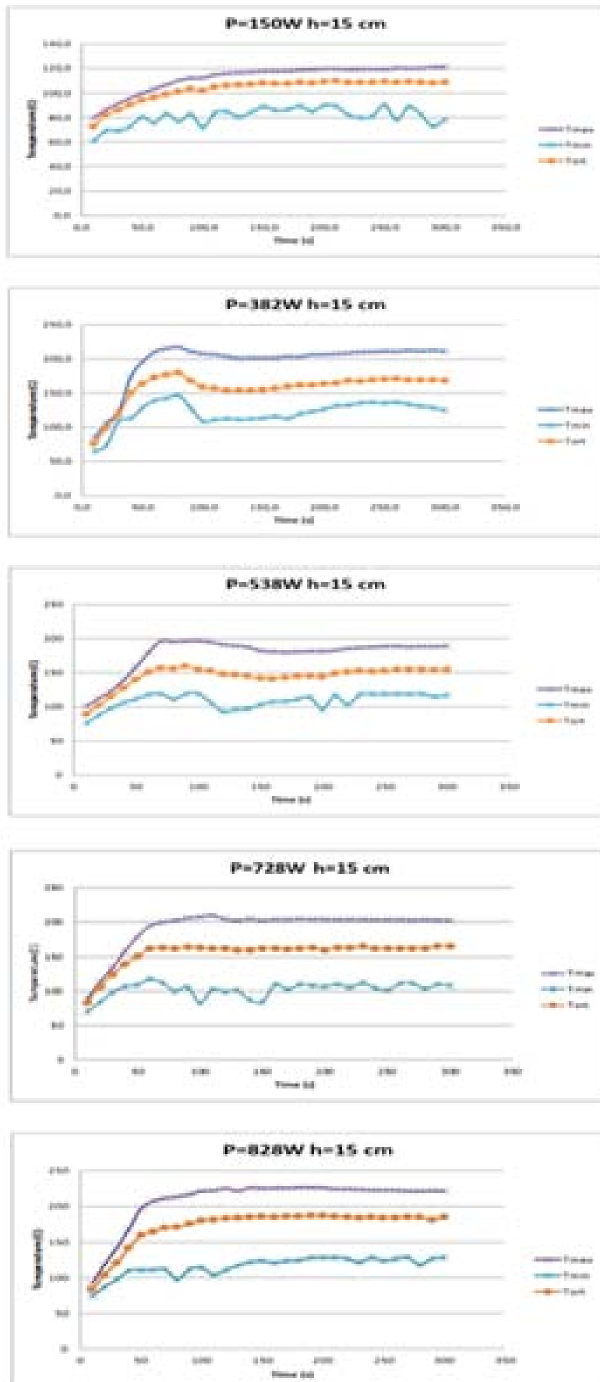

Figure 1. Heating behavior of the specimens at the 15 cm distance at different power values.

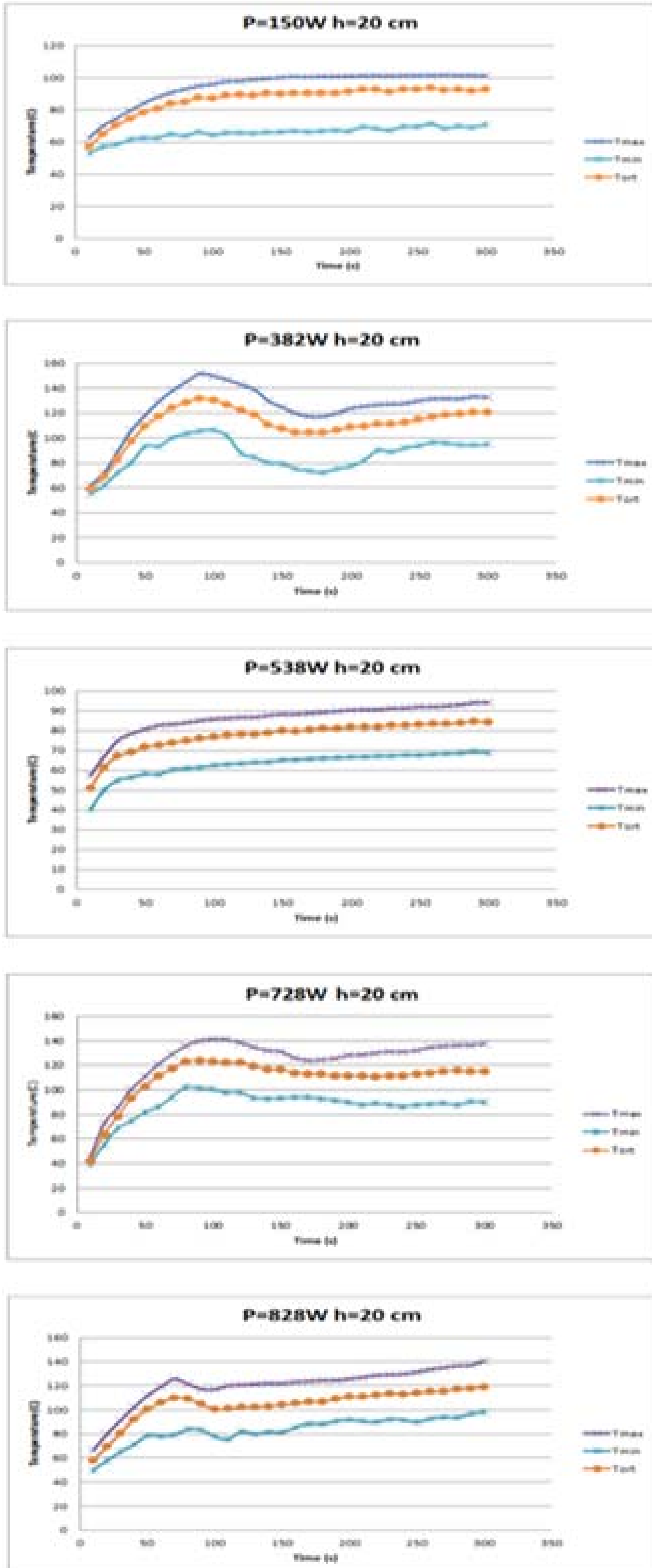

Figure 2**.** Heating behavior of the specimens at the 20 cm distance at different power values.

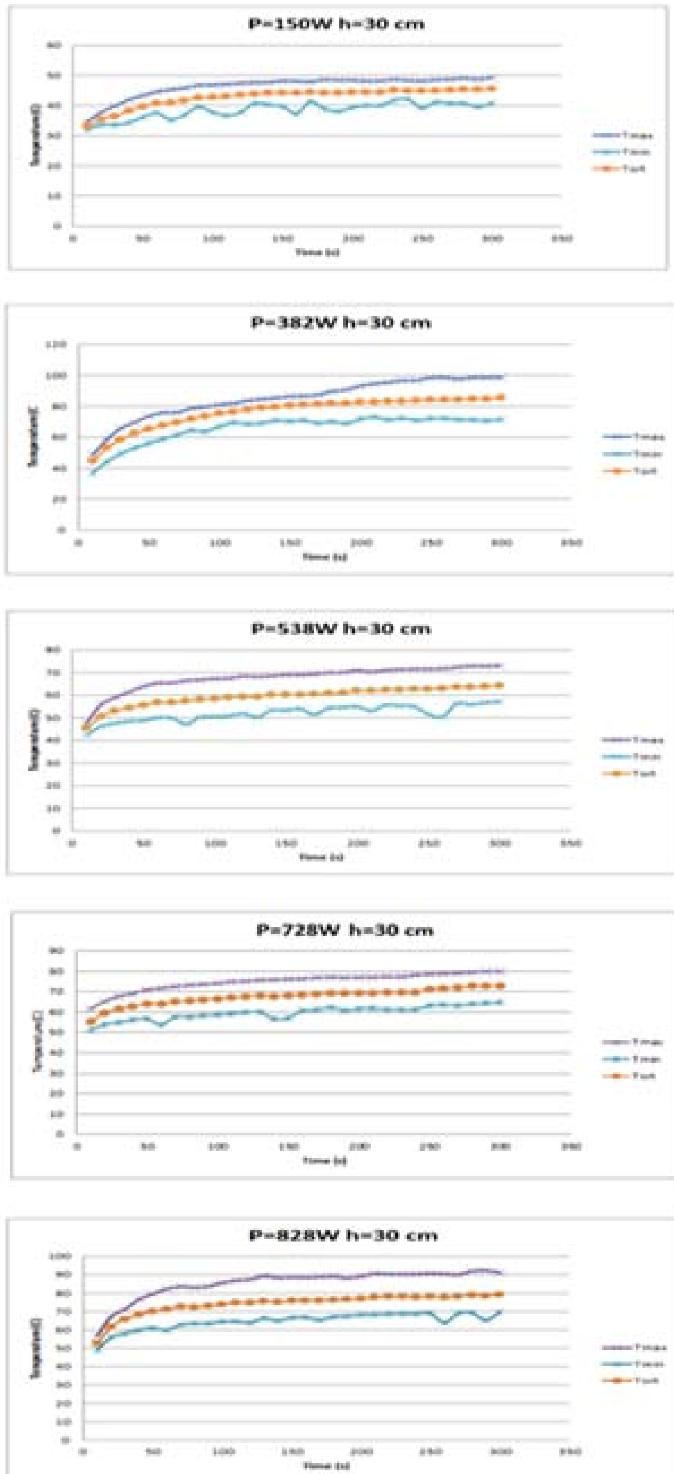

Figure 3. Heating behavior of the specimens at the 30 cm distance at different power values.

4. Conclusions

New manufacturing methods which reduce the composite material's costs is a hot topic in industry as well as in academy. This study examined the heating patterns in a new heating mechanism, i.e.

infrared radiation heating mechanism, so as to provide information for a power, or voltage controlled programming. The study showed that the temperature of the material converges to a value at certain power and distance parameters. This may enables the program to more accurately adjust the heating rates as well as the power values at plateau regions of the cure cycles. In addition to this, the capacity of the heating system is determined at the chosen parameters. This allows selecting the optimum parameters according to the cure cycle parameters to be applied. In this field, further analysis can be conducted by adapting PLC system to the mechanism. Hence, more precise voltage-temperature information can be gathered.

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