# Effects of Degree of Cure, Direction of Heat Flow and Temperature on Thermo-physical Properties of Out-Of-Autoclave Carbon Fiber-Epoxy Prepreg

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**Abstract.** Thermal conductivity is an essential parameter considered by engineers when selecting composite materials for aerospace applications. It mainly is a function of temperature, direction of heat flow and degree of cure (DOC). In this study, thermo-physical properties of 5320-8HS carbon fiber-epoxy prepreg and samples with DOC of 95%, 83%, 67%, 33% and 2% were determined by the Laser flash technique. Measurements were taken along 0, 90 and through-the-thickness (TT) directions and the effects of DOC, temperature and direction of heat flow on thermo-physical properties was studied. Thermal conductivity along t-t direction remained constant regardless of temperature change while it increased in 0 and 90 directions. Conductivity along 0 direction is 4.8 times that of TT direction whereas the diffusivity is 5.5 times that of TT direction. The diffusivity in 0 direction can approximately be equated with 90 direction. Further, thermal conductivity and diffusivity increased with an increase in DOC.

## 1. Introduction

Nowadays, the use of composite materials for aerospace applications is increasing significantly. More than 50% of the primary structures of B787 Dreamliner [1] and A350-XWB [2] are made out of composites. In a recent development, Learjet-85 [3] becomes the first business jet to have all composite structure. The trend in usage and developments in out-of-autoclave (OOA) technology emphasizes the need to characterize thermo-physical properties. In this paper, the anisotropic nature and temperature dependence of the thermo-physical properties of carbon-epoxy prepreg cured at different DOC was discussed.

### *1.1. Thermal diffusivity(α)*

Thermal diffusivity measures how fast heat propagates by conduction under transient conditions. According to Parker[4]:

$$\alpha(t) = 0.1388 d^2 / t_{1/2} \quad (1)$$

where d~thickness; $t_{1/2}$~ Half rise time (time required to reach half of the max temp); $\alpha$ ~diffusivity (mm$^2$/s)

### *1.2. Specific heat Capacity($C_p$)*

Specific heat capacity indicates the amount of heat per unit mass required to raise the temperature by 1 º C.

$$C_p = Q / (m \rho \Delta T) \quad (2)$$

where Q~Heat flow (J); ρ~Density (kg/m$^3$); m~mass (g); ΔT~ Change in temperature (C); $C_p$~ Specific heat capacity (J/gC)

### *1.3. Thermal conductivity(k)*

Thermal conductivity is the rate of heat flow through a unit thickness over a unit area with unit temperature difference . It is expressed by Fourier equation as:

$$k = \left(\frac{Q}{A}\right)\left(\frac{dx}{dT}\right) \quad (3)$$

where, k~thermal conductivity;Q~Heat flux(W);A~area (m$^2$); $dT/dx$ ~Temperature change across the thickness

## 2. Experiment, Results, Discussion, and Significance

### *2.1. Materials*

In this paper, Cycom 5320-8HS prepreg was studied. 5320-8HS is OOA prepreg made out of eight harness satin carbon fibers in epoxy resin.

### 2.2. *Sample preparation*

The panels were manufactured by curing 30 plies with planar dimensions of 101.6 mm× 101.6 mm. The panels were cured inside an oven to DOC of 2%, 33%, 67%, 83% and 95%. The curing of 5320-8HS is discussed elsewhere[6].These panels were machined to average sizes of 10.0mm×10.0mm× 2.0mm along 0,90 and TT directions. 0% DOC (prepreg) samples were made from six 10.0mm×10.0mm plies.

### *2.3. Measuring Instrument*

LFA 447 Nanoflash [4,5] was utilized to study thermo-physical properties. Pyroceram 9606 [7] was used as reference material. Both sample and reference materials were coated with DGF123 graphite powder [8]. In this test, front side of the sample is heated by a short light pulse. Then, the resulting temperature rise on the rear face is measured by infrared detector. By analyzing the temperature as function of time, the thermal diffusivity is determined [5]. Specific heat is determined by comparing the thermal response of the sample with the reference. The thermal conductivity is calculated using

$$k(t) = \alpha(T).C_p.\rho(T) \quad (4)$$

### *2.4. Density measurement*

Small material from edges of each panel were used to determine the density. Mettler Toledo's XS205 dual range scale [9] was utilized for the measurement.

| *DOC (%)* | *95* | *83* | *67* | *33* | *2* | *0* |
|---|---|---|---|---|---|---|
| Density ($g/cm^3$) | 1.621 | 1.521 | 1.534 | 1.537 | 1.573 | 1.377 |

Table 1. Measured density for each panel

### *2.5. Results*

Thermal diffusivity decreased with an increase in temperature whereas it increased with DOC. The diffusivity in 0 direction can approximately be equated with 90 direction and is about 5.5 times that of TT direction. For 2% and 33% DOC, diffusivity behaves differently which probably is due to lower glass transition temperatures followed by further curing.

Specific heat increased with an increase in temperature but is less dependent on DOC and heat flow direction. The above explanation holds true for specific heat for 2% and 33% DOC.

Thermal conductivity along TT direction can be approximated as constant regardless of temperature increase whereas it increased in 0 and 90 directions. In addition, it increased with an increase in DOC. Thermal conductivity along 0 direction was equal with the 90º direction and 4.8 times that of TT direction.

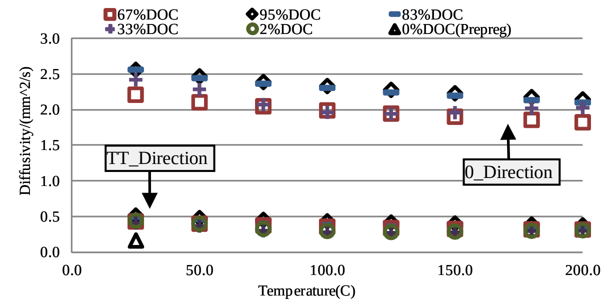


Fig. 1. Thermal diffusivity in 0 and TT directions

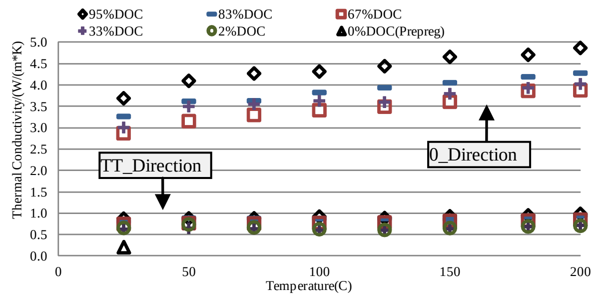


Fig. 2. Thermal conductivity in 0 and TT directions

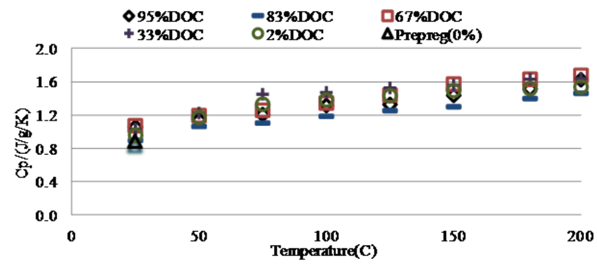


Fig. 3. Specific heat in TT direction

## 3. Conclusion

Thermo-physical properties of Cycom 5320-8HS were experimentally determined along 0, 90, and TT directions for 0%, 2%, 33%, 67%, 83% and 95% DOC samples at temperatures ranging from 25 to 200°C. Generally, thermal conductivity and specific heat increased with an increase in temperature whereas diffusivity decreased. Thermal diffusivity and conductivity along 0 and 90 directions were approximately equal. Both thermal diffusivity and conductivity along TT direction were less dependent on DOC and one-fifth of their respective values along 0 directions.

## 4. Acknowledgement

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