TITLE

Infrared heating of multiwalled composites and polymers

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CERAMICX CENTRE FOR
INFRARED INNOVATION

Contents

Infrared Heating of Composites and Polymers

Infrared heaters are a widely used medium for the heating of various polymers and composites. The heating may be for softening, processing, or as part of a (post) curing process. Surface condition and transmissive properties of the material are of high importance in heating the material effectively. Transparent polymers may often transmit more infrared energy through the material, thus not contributing to heating. Surface roughness is also important, where shiny surfaces reflect infrared radiation; again this reflected energy will not contribute to the heating of the object.

Generally, most processes involve heating of a single surface and in cases of components that require heating of other internal surfaces, infrared heating is often disregarded. This paper will show how the surface qualities of the material affect the heating rate, as well as how the penetrative properties of infrared radiation, when matched to the material being heated can often be utilised to heat a second surface below the first layer.

Materials Tested

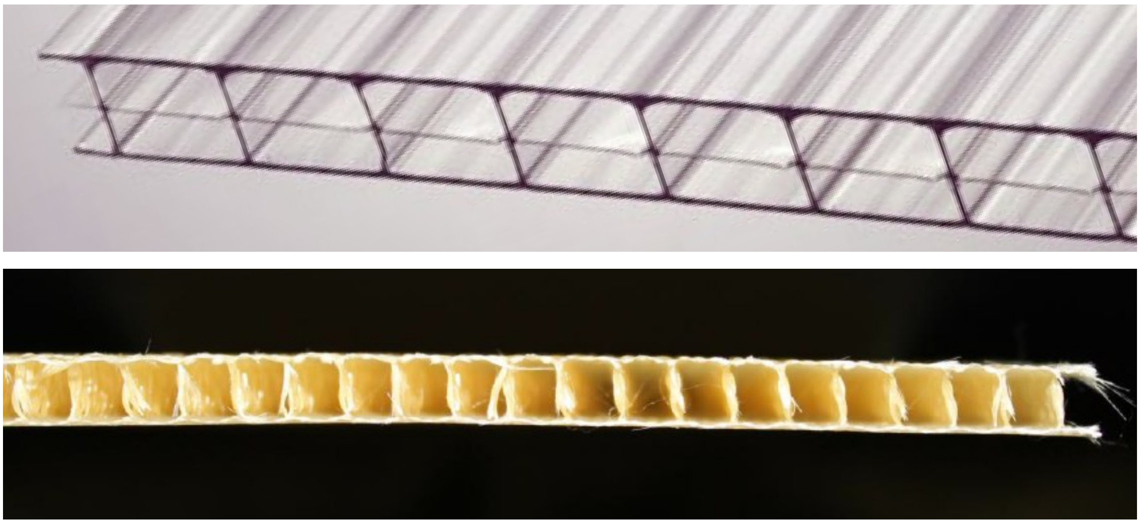

Figure 1: Multi-celled Polycarbonate and Composite sheeting.

Two materials were tested and compared by Ceramicx research engineers: a polycarbonate multi-celled sheet (the type found in greenhouses, patios and transparent roofing) and a proprietary multi-celled composite sheet consisting of glass fibre in an epoxy matrix. Both are shown in Figure 1. The composite sheet had a smooth side and a rough side, both of which are shown in Figure 2.

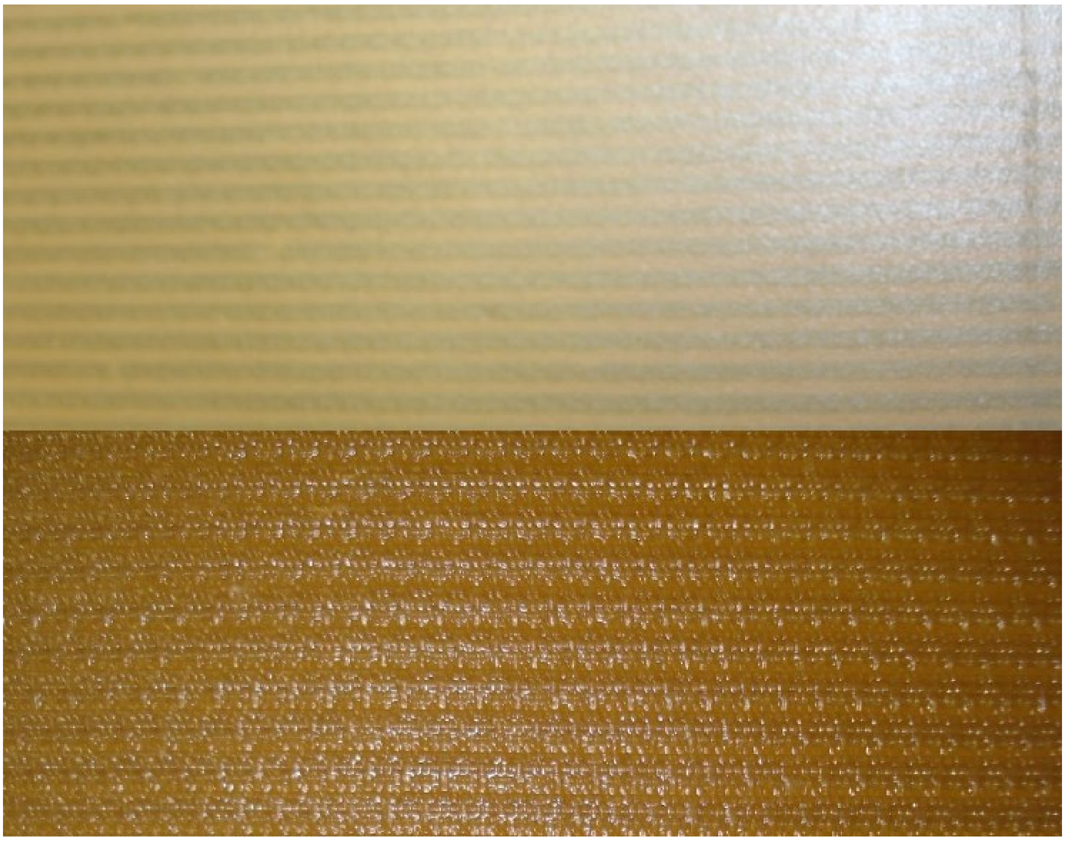

Figure 2: Rough side and smooth side of composite sheet

Ceramicx Experimental Experience

Ceramicx has been using the Herschel testing apparatus for material evaluation since 2013. Over this period, their research engineers have gathered significant data on various materials from standard polymers, filled polymers, fabrics and composites for a wide variety of uses such as packaging, automotive/aviation, clothing/footwear, building and shelter.

To characterise a materials' response to infrared radiation, several heater types covering short, medium and long wave infrared ranges are mounted a fixed distance from the material and the temperature of the top and bottom of the material are then recorded using optical pyrometers.

Table 1: Peak emission wavelength for heaters

Heater	Peak emission wavelength (µm)
QHM	≈ 1.25
QTM	≈ 1.4
FQE	2.1 – 2.4
FFE	3.75 – 5.5

Table 1 shows the typical range of peak wavelengths for the various heaters in the Ceramicx product line. Longer wavelengths tend to be absorbed and converted into thermal energy at the surface whereas shorter wavelengths are usually more penetrating and heat below the surface of the material.

In general, polymeric materials with organic bonds (carbon, hydrogen or oxygen), will absorb very well in the wavelength range of 3.2 – 3.6 µm, however, depending on the exact nature of the bonds, this can be shifted from the long to medium IR regime. [1]

Experimental Setup

The experimental work was completed using the Ceramicx infrared sandwich test setup within the Herschel test machine. Various heaters or infrared emitters can be positioned above and below a specimen and the temperature monitored via non-contact infrared thermocouples. The heaters are fixed in place and allowed to warm up to their operating temperature before the test specimen is brought under them for a period of time. Heating can occur from one or both sides, as shown in Figure 3, however, in this report, all heating was from a single side only in order to establish the transmission properties of the material as a function of incident IR wavelength.

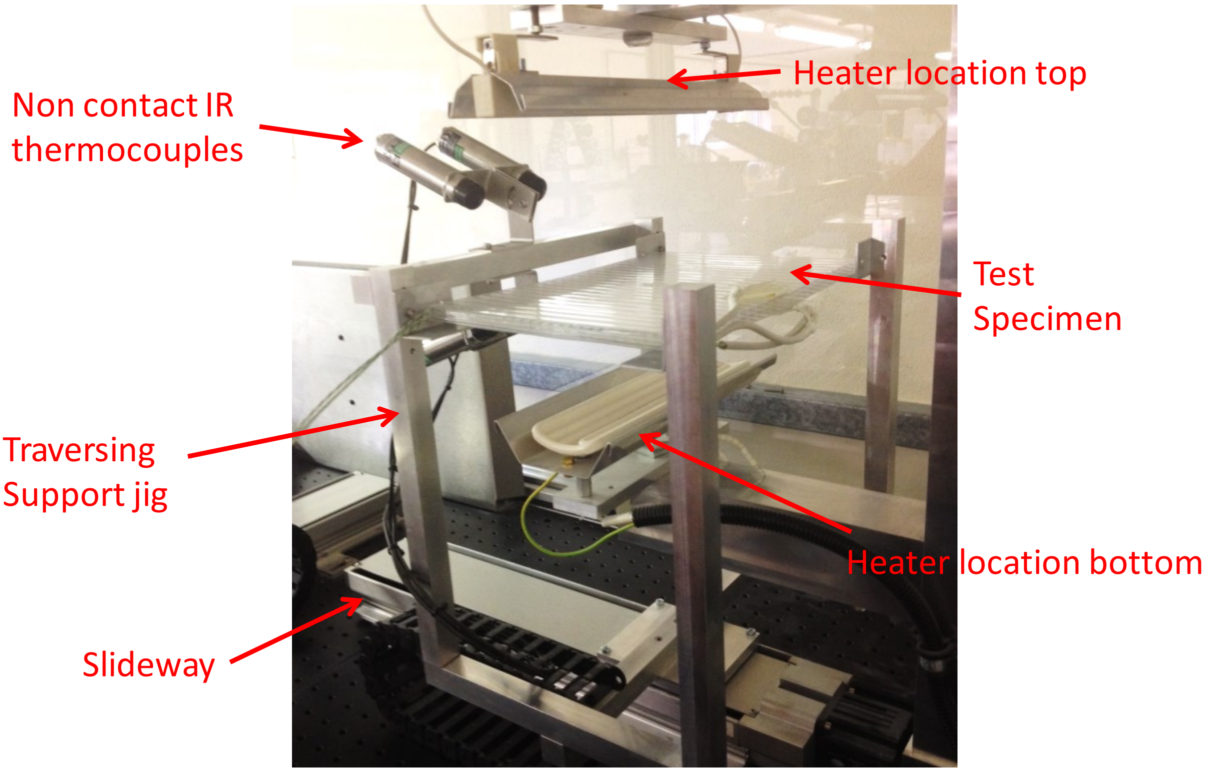

Figure 3: IR sandwich test set up showing two possible heating positions

Results

Halogen Heater (QHM)

The Ceramicx QHM is a halogen tube heater which provides the shortest IR wavelength. Placing this above the surface of the material heats the top surface of all the materials relatively rapidly as shown in Figure 4. The bottom surfaces also heat relatively quickly, indicating a good level of transmission of infrared radiation through the top surface and the air gap, to the bottom surface.

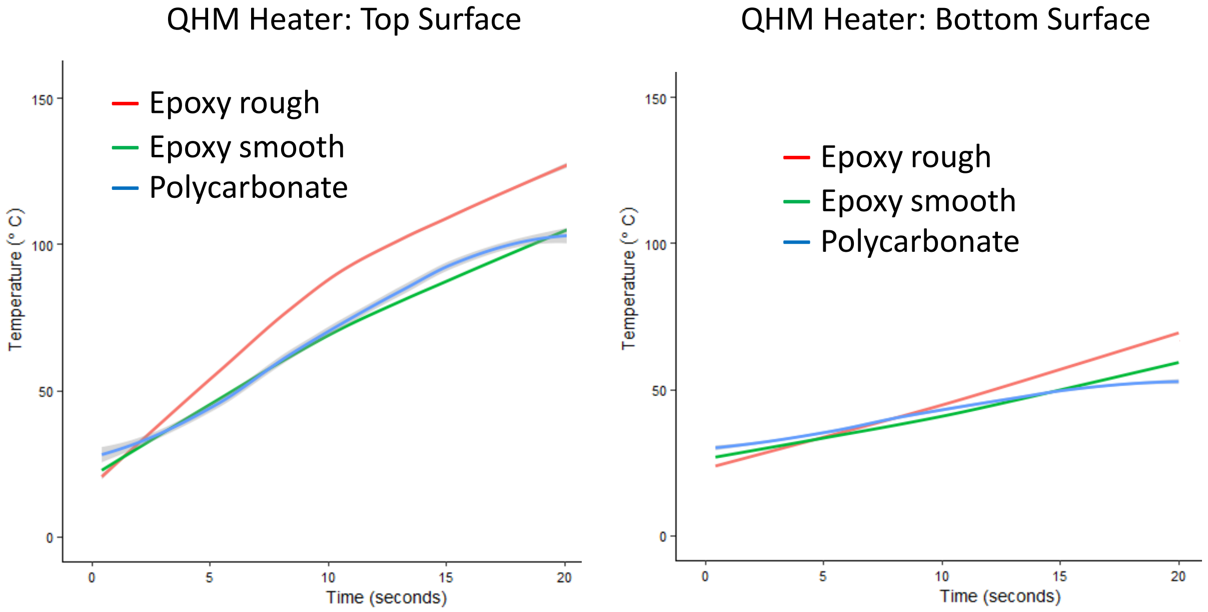

Figure 4: Heating of the three materials with shortwave halogen heater

After 20 seconds under QHM radiation, the bottom surface of polycarbonate showed a 14°C increase in temperature. The heating rates for the epoxy smooth and rough surfaces were more than 5 and 7.5 times that of polycarbonate respectively.

The difference in the heating rates for the rough and smooth surface of the epoxy material clearly shows the influence that surface finish can have on IR heating characteristics. In this instance, the rough surface provides a greater absorption surface area and also less reflectivity from the surface of the material.

Tungsten Heater (QTM)

The Ceramicx QTM heater produces a slightly longer wavelength output than the QHM, as indicated in Table 1. This is because the heater operates at a lower filament temperature, typically around 1500°C. In certain instances, this can be advantageous. Figure 5 shows that during heating of the three materials in question there is much less transmission of infrared for the smooth surface of the epoxy material and the polycarbonate materials, however, the rough surface of the epoxy material heats very quickly. On the bottom surface, the heating rates for the epoxy smooth and polycarbonate materials are similar.

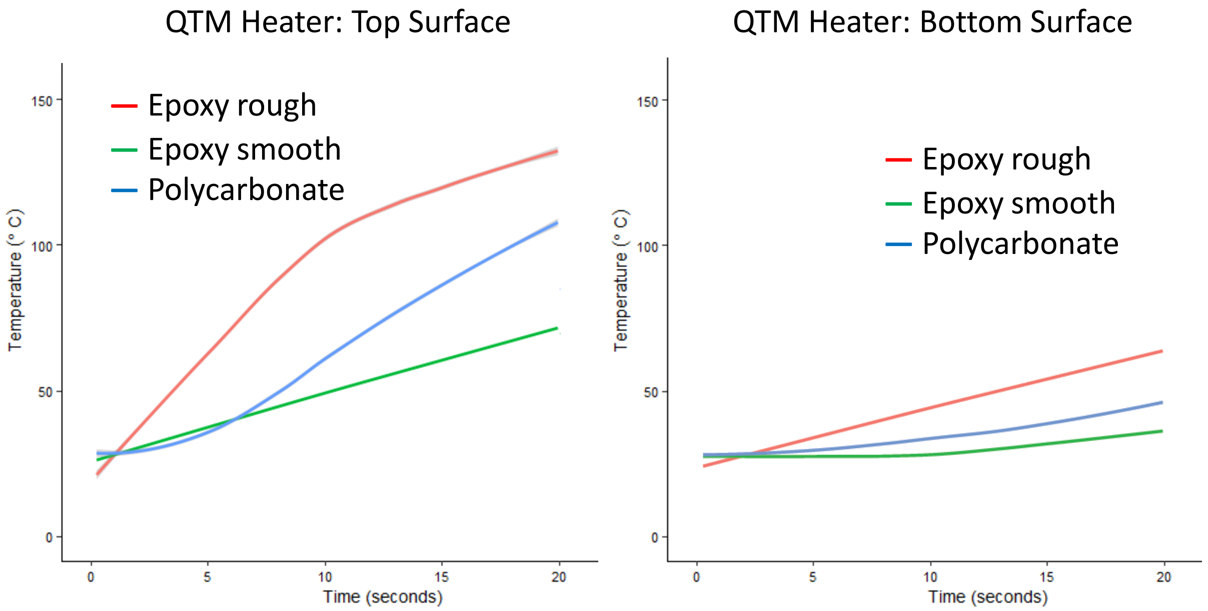

Figure 5: Heating of the three materials with medium wave halogen heater

Quartz Heater (FQE)

Ceramicx FQE heater is a medium wave heater which has an output between that of the QTM and ceramic elements. The FQE heater shows a higher rate of heating for the two composite samples than for the polycarbonate sample. As shown in Figure 6, for the epoxy material, the increase in temperature for the bottom surface is greater than that seen for the shorter wavelength heaters, indicating that more transmission (through the top surface) and therefore absorption at the bottom surface is occurring. It is noticeable that very little heating of the bottom surface of polycarbonate occurs by comparison with the two epoxy materials.

The high heating rates may, in part, be due to the glass fibre reinforcement within the material which absorbs strongly in this medium-long wave regime. It is difficult to say definitively whether the high heating rates which are seen for longer wavelength radiation (quartz medium (FQE) elements in particular) are due to the absorption by the glass fibre or the epoxy in the composite sample. It is known that glass absorbs particularly in the medium to long wavelength band (i.e. $2.8 \leq \lambda \leq 4.5\mu m$) [2].

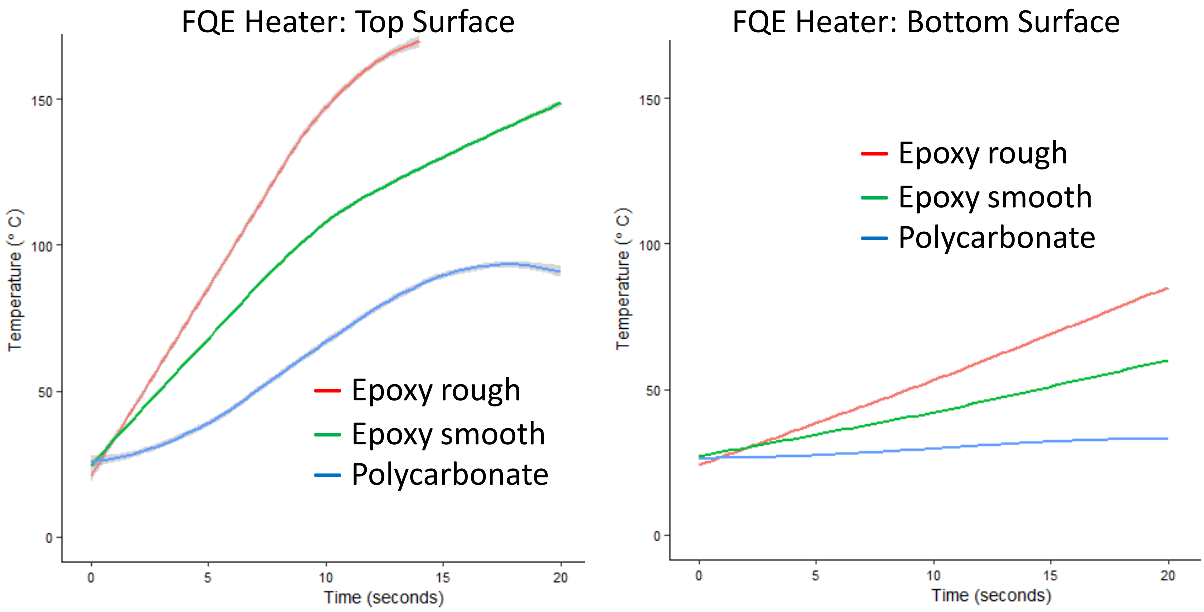

Figure 6: Heating of the three materials with quartz medium heater

Ceramic Heater (FFE)

The ceramic heaters produce the longest wavelength of infrared radiation in Ceramicx current product line. With reference to Figure 7, the long-wave FFE ceramic heater shows a similarly high heating rate for the top surface of the three materials in question; however, the opposite is true for the bottom surface with very little heating occurring for this surface. This indicates that virtually all of the incident radiation is absorbed at the surface and very little transmitted through to the bottom surface. This lower degree of penetration is expected with longer wavelength infrared radiation.

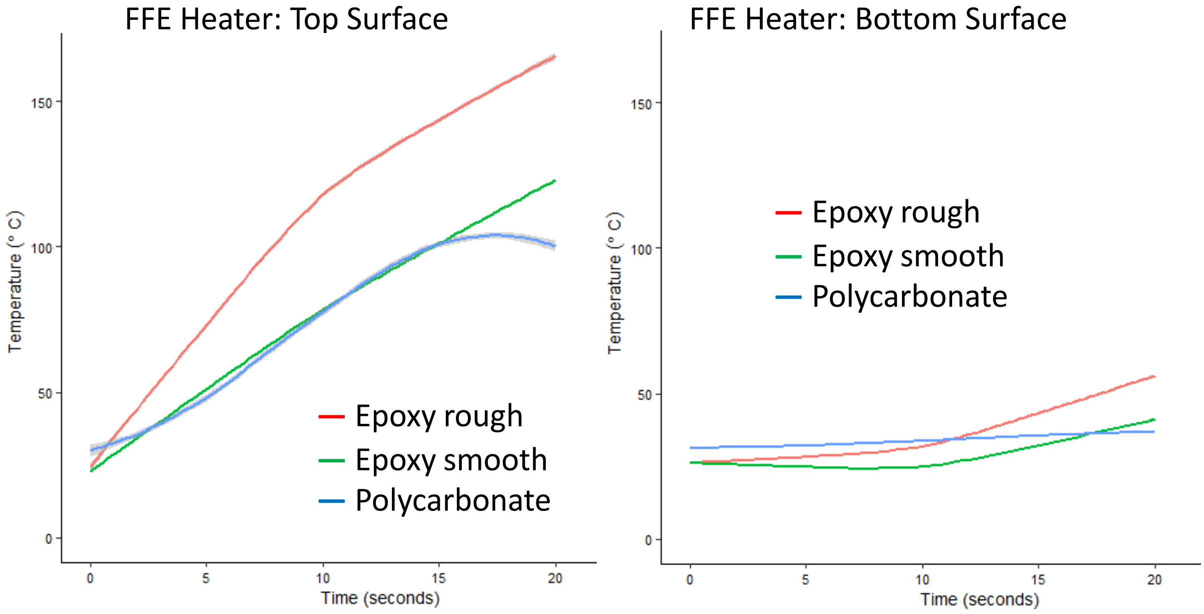

Figure 7: Heating of the three materials with long wave ceramic heater

Discussion on Heating Rates

The average heating rate ($^{o}C.min^{-1}$) over the 20 second test period for the materials is shown below in Table 2.

Table 2 Average heating rates for top and bottoms surfaces over the 20 second heating period

Heater	Peak Wavelength	Material	Heating rate Top surface (^{o}C. min^{-1})	Heating rate Bottom surface (^{o}C. min^{-1})
QHM	≈ 1.25µm	Epoxy smooth	243	96
		Epoxy rough	315	135
		Polycarbonate	140	43
QTM	≈ 1.4µm	Epoxy smooth	133	25
		Epoxy rough	327	117
		Polycarbonate	174	31
FQE	2.1 – 4.0µm	Epoxy smooth	372	99
		Epoxy rough	543	183
		Polycarbonate	192	20
FFE	3.75 – 5.5µm	Epoxy smooth	300	45
		Epoxy rough	423	90
		Polycarbonate	204	16.5

The table shows how the heating rate varies widely between materials, their surface finish and infrared wavelength (heater type). The fastest heating rate was found to occur with the FQE heater on the rough side of the composite material, probably as a result of the glass fibres and epoxy matrix absorbing energy well in this wavelength region. However, despite the materials being identical, the surface finish on the roughened side heats up around 1.5 times faster than the smooth side. The smooth finish actually reflects the infrared radiation away and is not absorbed, while the rough surface increases the surface area available for IR absorption and also reduces the reflectivity of the surface, thereby leading to higher temperatures. When comparing the other heating element types, this difference in the heating rate of the smooth and rough surfaces is easily seen.

If we analyse the bottom surfaces of the composite materials, we see that the heating rates attained are approximately ⅓rd of the top surface heating rate. It is difficult to be precise, but one exception is noticed, a lower heating rate at the bottom surface for the FFE heater which has the longest wavelength and therefore least penetrative ability.

For the polycarbonate, the transparency of the material leads to a higher amount of infrared transmission and therefore less absorption and lower heating rates than for the composite. Looking at the top surface temperatures, the fastest rate of heating was provided by the FFE element. The wavelengths here are long wave (3.75 – 5.5µm) and are well absorbed by most polymers. In addition, shorter wavelengths are seen to be less effective as they simply transmit through the transparent polycarbonate. This is easily understood by observation, where the very short wavelength of visible light actually passes through this clear material.

For QHM and QTM heaters, the difference in the heating rates seen between the bottom and top surfaces of the polycarbonate material shows the difference in penetration. More energy, from the QTM heater, is absorbed at the top surface leaving less available for the bottom surface. The opposite is true for the QHM heater.

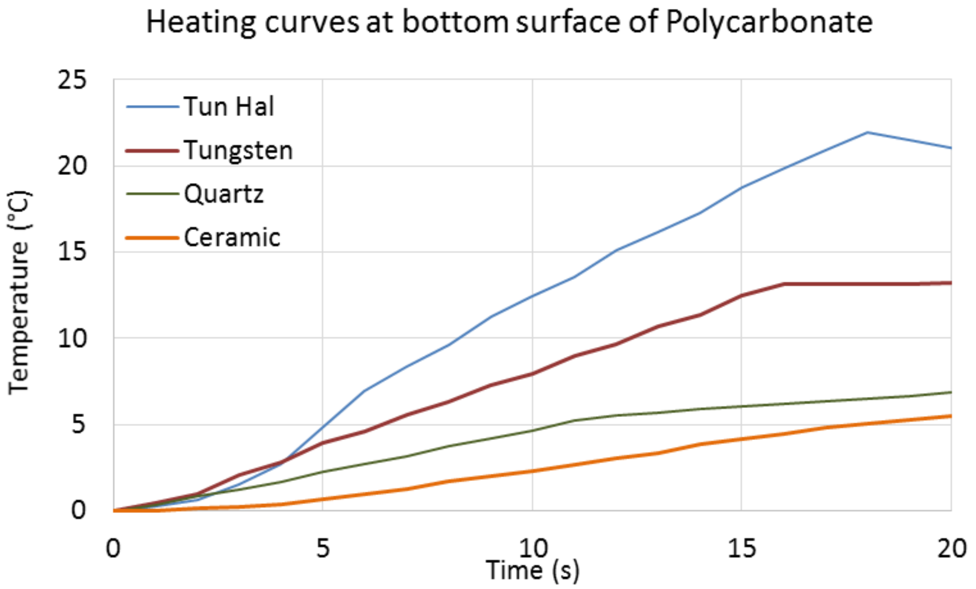

Figure 8: Heating curves of bottom surface of polycarbonate material

One of the more interesting results is the FFE element on the polycarbonate. Despite the FFE giving the best heating rate of 204 ^{o}C.min^{-1} at the top surface, this gave the lowest heating rate of 16.5 ^{o}C.min^{-1} at the bottom side. The heating rates at the bottom surface are shown in Figure 8. Conversely, the shorter wavelength infrared, from halogen and tungsten heaters, passes through the clear polycarbonate top surface but penetrates better to the lower surface, resulting in higher heating rates with increased wavelength at the bottom surface. Therefore if a transparent multi-celled material were to be heated with infrared, care must be taken during heater selection to ensure the desired internal temperatures. This result for polycarbonate and the aforementioned results for epoxy show the importance of prior testing and in the careful selection of the element type for the particular job in hand.

Conclusions

Using different infrared emitters to heat materials can have a dramatic influence on the temperature achieved and the distribution of this temperature through the material. Many polymers absorb well in the medium to long wavebands (ceramic and quartz) rather than short wavelengths (halogen and tungsten). Rougher surfaces tend to heat faster than smooth surfaces. Also, transparent materials can be troublesome to heat as the infrared energy can be transmitted straight through without heating. However, this can also be advantageous should internal walls or surfaces need heating or stress relieving.

- The best infrared emitter for the epoxy-glass fibre was the medium wave Ceramicx FQE 1000W element. This was true for smooth and rough surfaces.
- The best infrared emitter for heating the polycarbonate was the longwave Ceramicx FFE 1000W.
- Shorter wavelengths penetrate deeper into the materials than longer wavelengths. This can be useful in thicker substrates, or in heating deeper layers.
- Infrared penetration through the polycarbonate material decreases with increasing wavelength.

- The rough side of the composite material aids IR absorption compared to the smooth surface resulting in faster heating.

The results presented in this paper are indicative of the surface heating and penetrative capability of infrared. This data shows that simple material variations such as surface finish can cause dramatic changes in the IR heating process. The results also show the importance of actual tests on specific materials which must be taken in conjunction with the material processing steps.

Contact Ceramicx today to discuss using infrared for your polymer or composites process or application.

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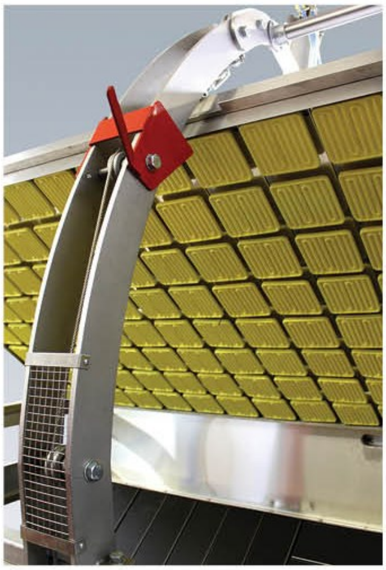
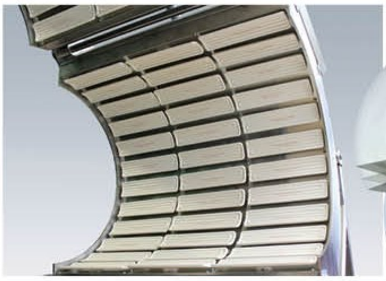
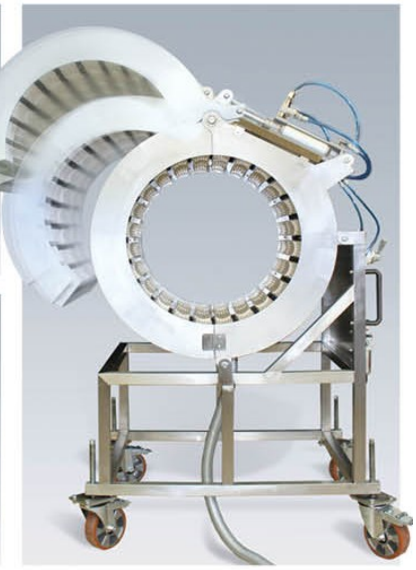
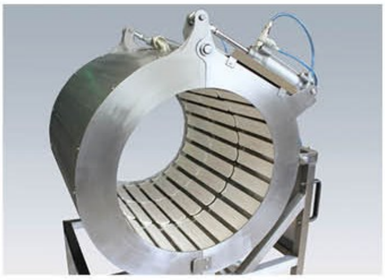
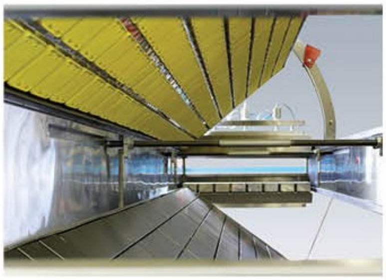
[2] R. Stair and C. A. Faick, “Infrared absorption spectra of some experimental glasses containing rare earth and other oxides,” *Journal of research of the National Bureau of Standards,* vol. 38, pp. 95 - 101, January 1947.

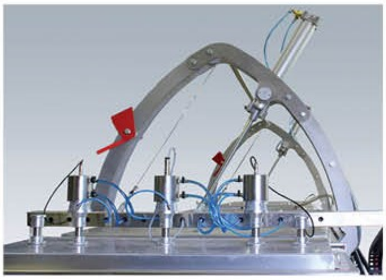


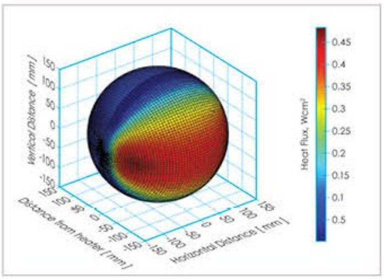











Vertical Distance [mm]
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0
-50
-100
-150
Distance from heater [mm]
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100
50
0
-50
-100
-150
Horizontal Distance [mm]
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-100
-50
0
50
100
150
Heat Flux, Wcm²
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0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.5