A COMPARISON OF INFRARED AND XENON FLASHLAMP HEATING FOR THERMOSET AUTOMATED FIBRE PLACEMENT

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Abstract: *Xenon flashlamp heating has shown significant promise as an alternative to laser and infrared heating in Automated Fibre Placement (AFP). Although research has primarily been focused on high-power heating of thermoplastic composites, there is still a pressing need to improve automated processing of thermoset composites for current aerospace applications. This paper focusses on a comparison of infrared heating (the state-of-the-art on many AFP systems) and flashlamp heating applied to AFP of thermoset materials.*

Three aspects of the AFP process are investigated: the maximum achievable lay-up speed; the homogeneity and extent of the heating across the material width (perpendicular to the lay-up direction); and the ability of the heating systems to achieve fast heat-up and cool-down rates.

Keywords: Flashlamp; Infrared; Automated Fibre Placement; Thermoset

1. Introduction

As the automated processing of composite materials using AFP has developed over the last decade, there has been a significant body of research focused on new materials such as bindered dry fibre and thermoplastics. These materials typically require higher processing temperatures and more sophisticated heating technologies in order to manufacture high quality components. The Xenon flashlamp heating technology was developed with these materials in mind, to offer an alternative to lasers and hot gas guns ([1], [2], [3], [4]).

At the same time, industries such as aerospace have continued to manufacture using lower-temperature thermoset materials, and there is now a growing need to increase manufacturing rates and part quality due to the high demand for new aircraft. It is perhaps surprising then that the heating technologies typically used for thermoset AFP have remained relatively unchanged, with the standard infrared (IR) lamp being the state-of-the-art on the majority of thermoset AFP systems. While IR lamps are simple and can achieve the 30-60°C temperature required for AFP lay-up, they are known to have several deficiencies. Lichtinger et.al. ([5]) showed that IR lamps are prone to heating outside the lay-up zone and risk advancing the cure of thermoset materials in these areas, whilst Hormann et.al. ([6]) identified the importance of controlling the heat source in variable speed lay-up to achieve a defined surface temperature. Calawa & Nancarrow ([7]) also recognized the need for a high-power and fast-acting heat source that could maintain the required temperature through the variable-speed AFP processing typical of complex geometries.

This paper investigates the application of the Xenon flashlamp heating technology to thermoset AFP, comparing it to the standard IR lamp in its ability to reach high processing speeds, minimize heating outside the lay-up zone and give fast heat-up and cool-down rates.

2. Experimental Configuration

Experimental trials were conducted in partnership with Compositadour, Bayonne, France. A Coriolis "C-Solo" AFP system, laying up a single ¼" epoxy prepreg tape of Hexcel 8552/AS4/135gsm material, was used for all trials. Lay-up was performed onto an Aluminium tool with a glass fibre surface layer vacuumed to the table under a thin thermoplastic film. An elastomeric compaction roller of Shore Hardness 40 was used with a compaction force of 300N in all cases. In order to limit the effects of heat conduction into the tool, two substrate plies were placed in advance, each of 8 ¼" tapes (a total of 2" width), to create a base substrate onto which a single ¼" tape could be applied for each of the subsequent trials.

An Optris thermal imaging video camera was installed onto the robot head to follow the lay-up and focus on the "nip point" (the point where the incoming tape adheres to the substrate). The material emissivity was set at 0.85 to match previous studies at this viewing angle. Figure 1 shows a typical image from a thermal video during lay-up.

IR Trials

For the IR trials, two 600W lamps were used in the positions shown in figure 2. These lamps are supplied in this configuration as the default heating system for the C-Solo AFP machine and are twin-tubed (figure of 8 cross-section) with their output energy concentrated in the 1 – 1.4µm wavelength band. As the figure suggests, the majority of the lamp energy is directed towards the substrate some distance from the nip point. The closest lamp is approximately 81mm from the nip point and 16mm above the substrate.

The lamps heat in a continuous manner, and the heating power can be modulated by varying the current flowing through the lamp filaments. This is typically achieved by setting a percentage power value on the AFP machine interface and can be set to vary with robot speed.

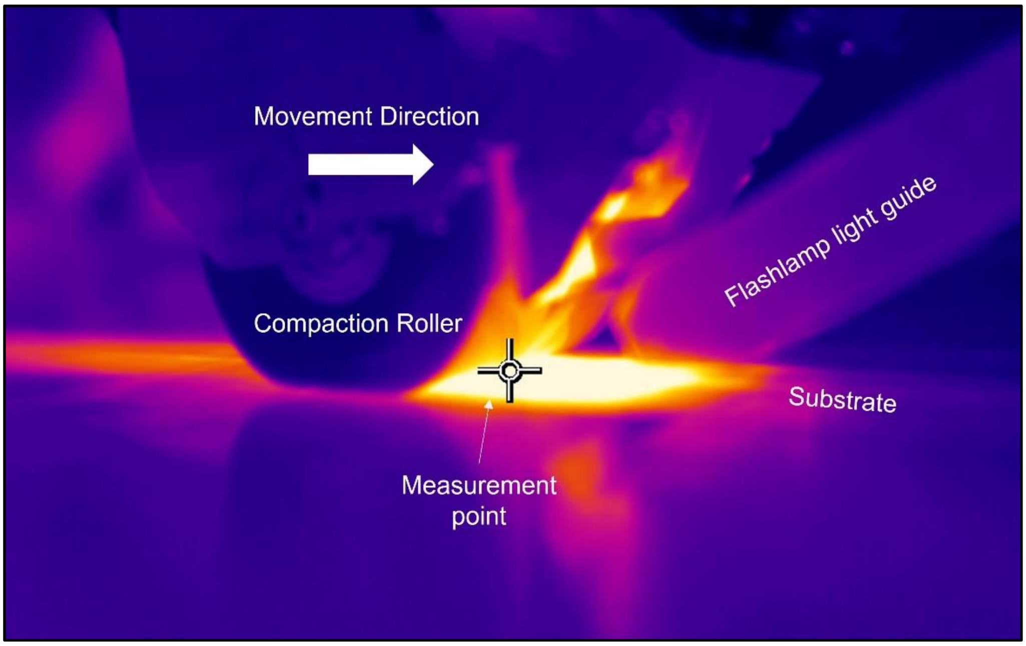

Figure 1: Typical thermal image showing the geometry around the nip point during lay-up and the temperature measurement position used in all trials.

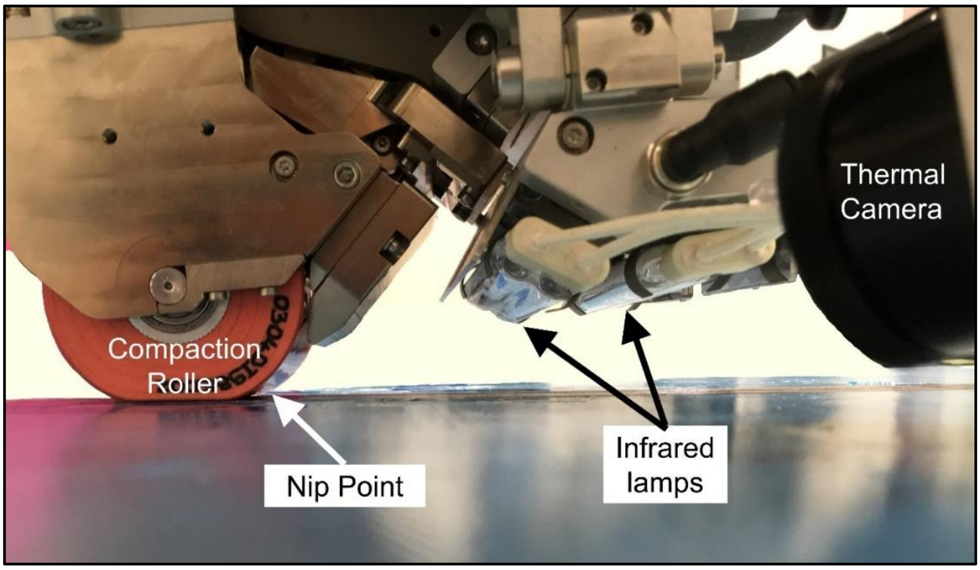

Figure 2: Side view of lay-up showing position of IR lamps. (Note that the image has been edited to remove background details for clarity).

Flashlamp Trials

The Xenon flashlamp system used in the trials provides heat in the form of high-energy pulses with a very broad spectral output, with energy in the UV, visible and infrared spectral regions. Three pulse parameters: pulse voltage (typically 150-250V); pulse frequency (number of pulses per second – typically 60-100 Hz); and pulse duration (typically 2-5ms) are varied to modulate the average output power of the system. The pulses superimpose as the flashlamp passes across a moving target, resulting in a constant nip point temperature. The flashlamp system used in this work was limited to 6kW electrical input power, which equates to approximately 3kW optical output power.

The flashlamp is contained in a head with a shaped reflector behind and an aperture in front, to guide the energy into a solid quartz light guide, as shown in figure 3. The light guide acts to guide the flashlamp energy to the target surfaces by means of total internal reflection. The end of the light guide is shaped into three output surfaces, to give control over the thermal profile on the incoming tow, the substrate, and the nip point. The flashlamp and the head materials are cooled by a flow of deionized water in an annular jacket that surrounds the lamp, meaning very little latent heat builds up in the system. The output from the light guide is diffuse and broadband, giving some safety benefits over laser heat sources. Further background information on the flashlamp system can be found in [1] and [2].

For the trials in question, the flashlamp light guide was positioned approximately 45mm from the nip point at an angle of 25 degrees and 5mm offset from the substrate, as shown in figure 3. This angle allows the lower output surface of the light guide to lie parallel to the substrate. Previous work has shown that the nip point temperature is weakly dependent on the offset and angle of the light guide.

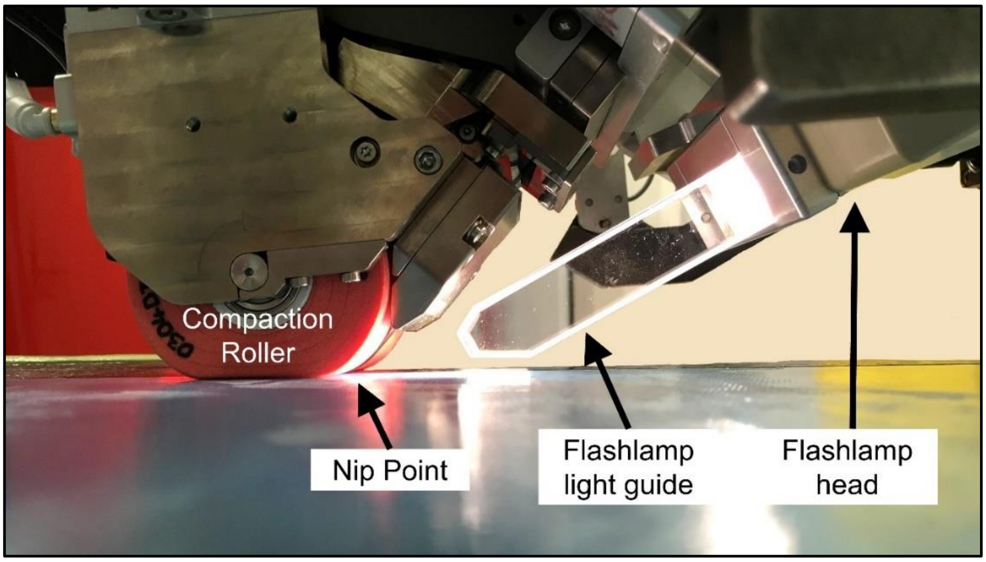

Figure 3: Side view of lay-up showing position of flashlamp head and light guide. Note that the image has been edited to remove background details for clarity.

3. Maximum Lay-Up Speed

A series of trials was conducted with both heating systems at lay-up speeds of 0.2, 0.4, 0.6, 0.8 and 1m/s. For each speed, a total of 5 power levels were used for each heater – 20%, 40%, 60%, 80% and 100% heating for the IR lamps (set on the Coriolis AFP system), and 1, 1.5, 2, 2.5 and 3.5kW electrical input power for the flashlamp system (set on the flashlamp control software). It was not possible in the short duration of the testing to measure the absolute power levels for the IR lamps. Note that the maximum output power of the flashlamp system is 6kW, but lower power values were employed to avoid heat degradation of the material.

Thermal videos were captured for each trial and a nip point temperature was extracted in each case by monitoring the measurement area at the nip point (figure 1) and taking an average temperature over the full lay-up run.

In the case of the IR trials, it was observed that the nip point temperature for 100% power decreased for each increase in speed, as expected. At 0.2m/s, the maximum nip point temperature achieved was 75°C and this reduced to 60°C at 0.4m/s. Therefore, if the target surface temperature is set at 60°C in this study, the maximum lay-up speed to reach this target for the IR heating system is 0.4m/s.

For the flashlamp system, at 0.2m/s the maximum temperature observed was 95°C at the 3.5kW power level, at 0.4m/s the maximum was 70°C and at 0.6m/s it was 53°C. As the full power capabilities of the flashlamp system were not deployed in the trials, it was desirable to extrapolate the results to the higher power values available (up to 6kW for this system). The power law technique employed by Di Francesco et.al. [8] and Monnot et.al. [9] was used to estimate the results at higher speeds from the trial results at lower speeds and powers. This empirical procedure, described in [9], makes some assumptions on the shape of the speed vs. power graph and enables the graph to be drawn for any chosen nip point temperature. Figure 4 shows the estimated power vs. speed graph for a chosen 60°C nip point temperature. Several data points from the trials are added for reference.

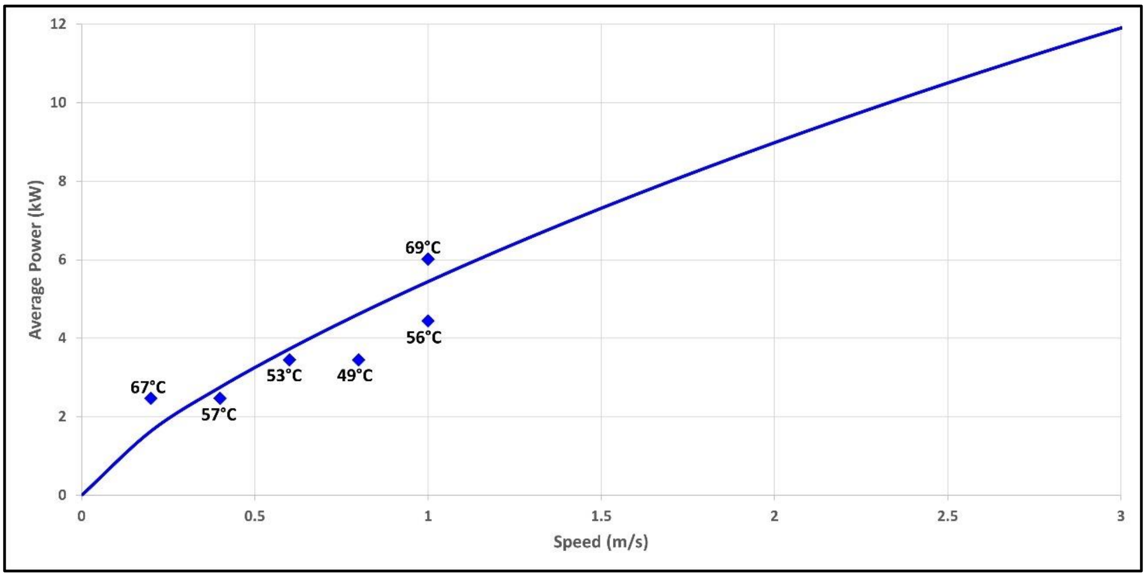

Figure 4: Estimated power law for flashlamp system obtained using empirical method of [9]. The blue line estimates the speed vs. Power relation for a nip point temperature of 60°C.

The graph in figure 4 estimates that, had the flashlamp been deployed at its maximum power of 6kW, the maximum lay-up speed for a 60°C nip point temperature would have been approximately 1.2m/s. For alternative flashlamp systems at higher powers, the graph indicates that higher lay-up speeds are achievable.

4. Homogeneity Across Lay-Up Width

In order to investigate the homogeneity of each heating system across the width of the lay-up, a total of 13 parallel tapes was laid as a substrate, giving a total width of 3¼" on which trials could be performed. The compaction roller was removed (as it was found to have a cooling effect on the substrate) and the temperature generated on the substrate was measured perpendicular to the lay-up direction, with the camera positioned behind the robot head, as shown in figure 5. Note that a heated zone width of 2" is typical for AFP lay-up, where 8 parallel tows are placed in one robot pass.

A representative result is shown in figure 6, where the blue line shows the flashlamp heating concentrated on the central 2" zone and the red line shows the IR lamp heating more outside this central zone. Both lines are normalized to allow comparison of the profiles.

The flashlamp heated zone is relatively homogeneous in the central 2" zone as the flashlamp light guide has a width of just over 2". The thermal profile rolls off quickly at the edges and minimizes the heating of already-laid material outside the central zone. The light guide can be designed for different heating widths, and additional work has shown that a wider light guide (60mm) can move the roll-off zones to beyond the central 2".

The red line in figure 6 shows that the IR heating is less homogeneous in the central zone and significant heating occurs outside the 2" target width. As observed by Lichtinger et.al. [5], this heating of the already-laid material is undesirable and may cause unwanted advancement of the material cure in these areas.

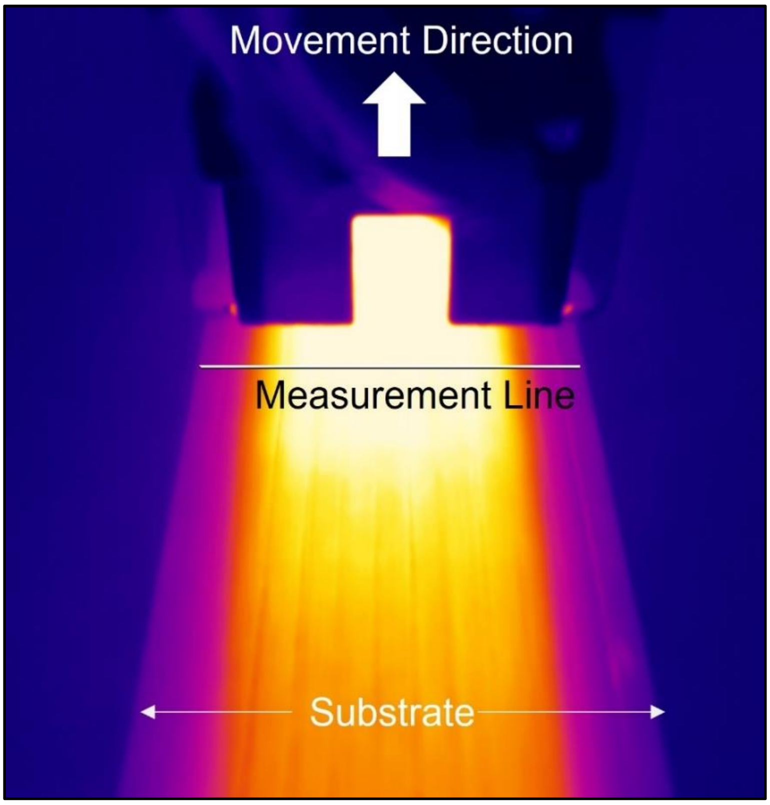

Figure 5: Thermal image showing the thermal profile across the substrate from behind the robot head. This example shows a result for the flashlamp system.

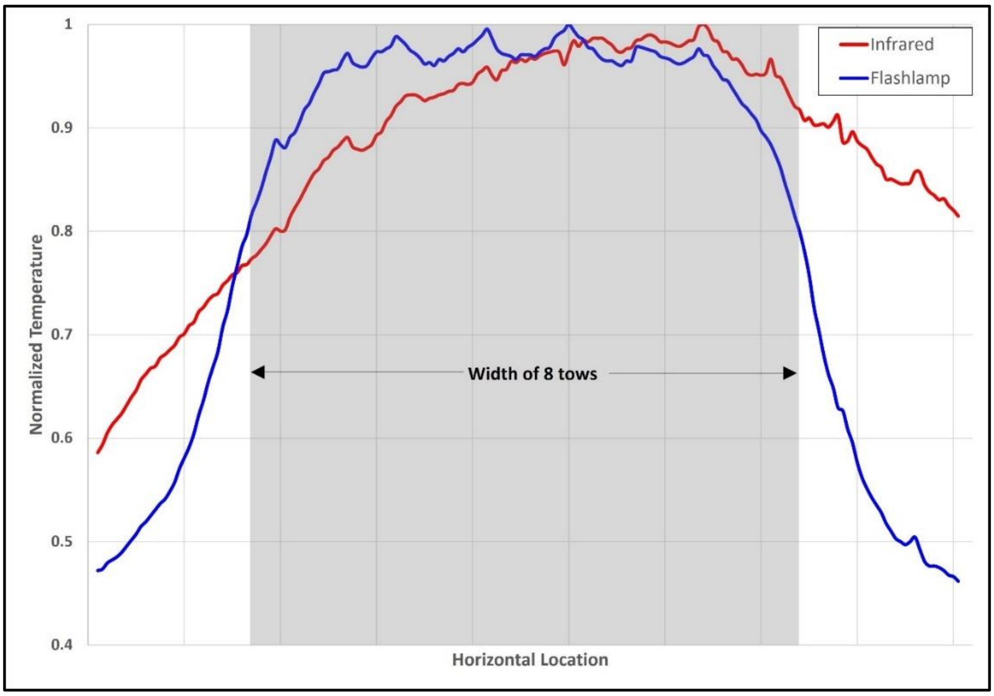

Figure 6: Graph of thermal profiles across the substrate. The blue line shows the flashlamp result and the red line shows the IR result. The grey area shows the position of a typical 8 tows. Results have been normalized to facilitate the comparison between heating systems.

5. Heat-Up and Cool-Down Rate

Further trials were conducted to assess the heat-up and cool-down rates of the two heating systems. Figures 7 and 8 show representative results where heating was switched on 1.5 seconds into the lay-up run, then switched off at 8.5 seconds.

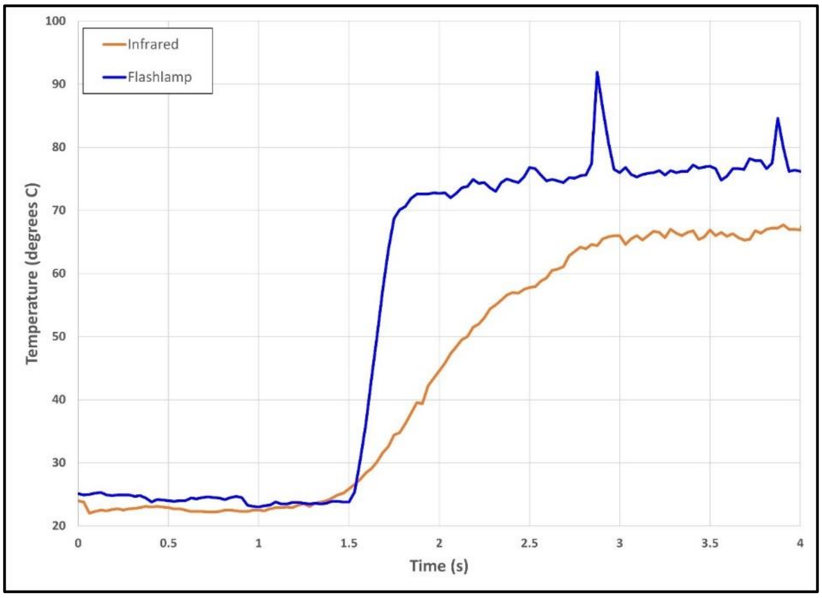

Figure 7: Graph of nip point temperature for heater switch on at 1.5s

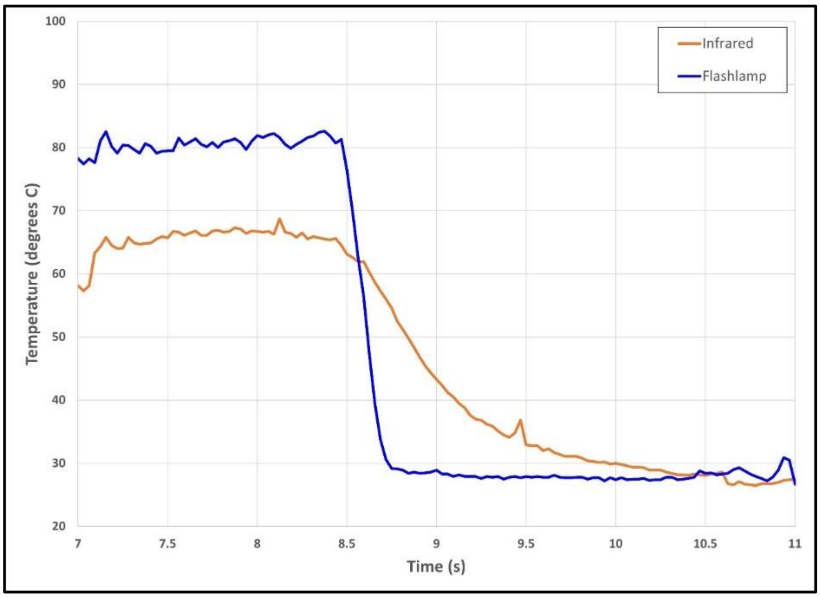

Figure 8: Graph of nip point temperature for heater switch off at 8.5s

The graphs in figures 7 and 8 show that the reaction time of the flashlamp system is approximately 0.1s for both heat-up and cool-down in this case, whereas the equivalent reaction time for the IR system is approximately 1.5s. This reaction time has important consequences for the lay-up of a complex component, where lay-up speed may vary quickly, and the heater must be able to modulate its power to maintain the target surface temperature.

6. Conclusions and Further Work

The experimental results described here facilitate a comparison between IR and flashlamp heating in a representative thermoset AFP application. The flashlamp system has been shown to offer higher achievable lay-up speeds, due to the greater power available and its ability to focus that power via its light guide. There is also a marked difference in the thermal profiles across the heated zone. The flashlamp concentrates the majority of its energy onto the central 2" zone, whereas the IR lamp spreads its energy outside this zone. The relative reaction times of the two heat sources are also significantly different, with the flashlamp system reacting at switch-on and switch-off in approx. 0.1s and the IR system reacting in approx. 1.5s.

The results described here, highlighting three important aspects of AFP lay-up, suggest that the flashlamp system is worthy of further investigation. Further work will include investigation of higher power flashlamp systems and the effects of flashlamp position on lay-up performance.

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