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Temperature Control Methods for Out-of-Autoclave Composite Molding

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Agenda

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- The Oven – beyond Pizza making
- Common Out-of-Autoclave (OoA) heating methods
- Current tooling concepts
- Conduction only (Electric cartridge, Embedded resistive)
- Convection (Oven, Oil, Pressurized Water)
- IR/Induction
- Future
- Conclusion

The Oven

As companies develop more Out-of-Autoclave (OoA) applications, ovens have become a popular solution for mold heating.

<u>Why?</u>

- They offer acceptable product quality
- Similar temperature ranges to Autoclaves
- Well understood process for manufacturing personnel

Are there faster less energy intensive ways to heat and cool OoA molds?

Common OoA Methods

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- Electric cartridge heaters
- Resistive heating (embedded copper, carbon nanotubes, ceramics, etc.)
- Ovens
- Oil
- Steam
- Water
- Radiation/Induction

Current Tooling Concepts

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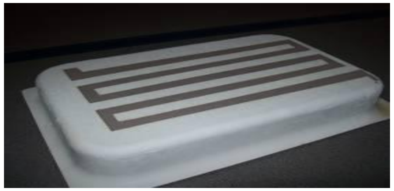
OoA tools come in many forms

- Heated platen systems utilizing fluids or electric cartridge heaters to heat tools
- Carbon fiber, Ceramic, or copper heaters embedded in composite or ceramic tools
- Traditional steel and aluminum tools with jacketing
- Oven heated tools

www.coronet.eu.com

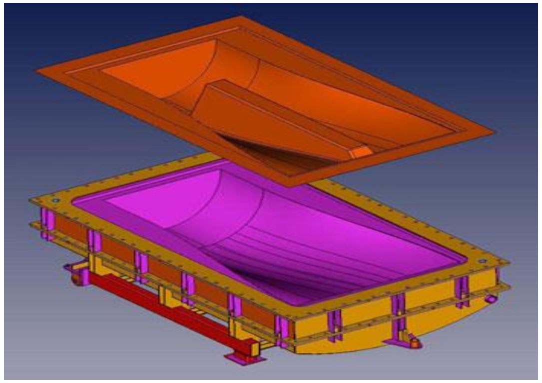


www.horizoncomposites.com

Current Tooling Concepts

- Nickel tools with external plumbing

www.webermfg.ca



www.vectechnology.com

www.quickstep.com.au

- Immersion tools with skins immersed between heat transfer fluids

Electric Cartridge Heaters

Advantages

- Heat only the tool
- Easy to install
- Fast heating rates
- Good for high temperature applications (700°F)

Cartridge
Heater
www.watlow.com

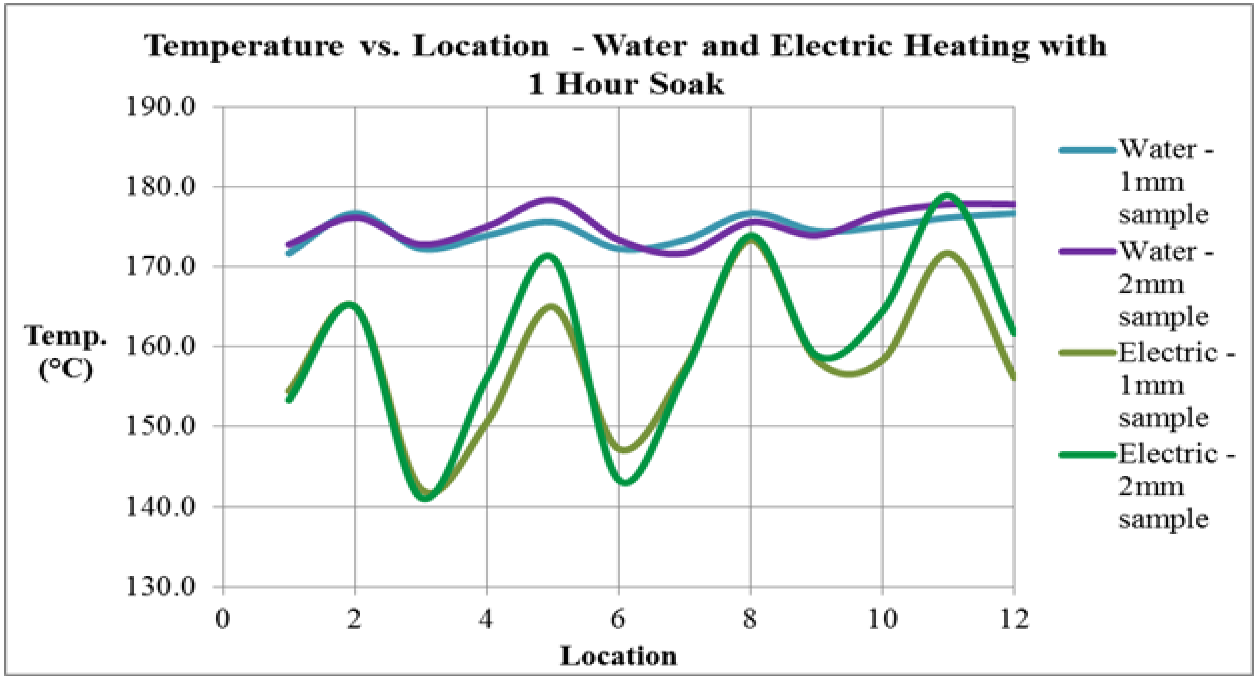
Disadvantages

- Due to conduction only heating (or minimal convection), and slight air gap at install, they require large kW draws to operate
- Performance degrades rapidly as oxides form between the tool and cartridge

Is there a better way?

Electric Cartridge Heaters

- Offers no cooling option
- Very non-uniform heating profiles are common (20-40°F across tool)



Is there a better way?

Embedded Resistive Heating

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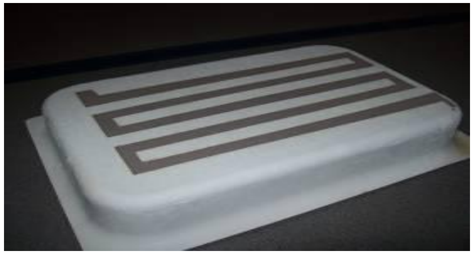
Advantages

- Should offer energy consumption reductions as they are located close to the part
- Good for high temperature applications assuming composite tool resin can hold up
- Only heating the product not the whole tool therefore fast ramp rates should be possible



www.horizoncomposites.com

Is there a better way?

Embedded Resistive Heating

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Disadvantages

- Heating profiles similar to electric cartridge heaters due to conduction only heat mode
- Offers no cooling option
- Will high localized temperatures degrade composite tool resins over time due to radiant heat component

Is there a better way?

Ovens

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www.helya.net

Advantages

- Can offer efficiency gains of convection heating due to movement of air
- Can offer limited cooling

Disadvantages

- Air’s density of .8 kg/m3, thermal conductivity of .035 W/m*K, and specific heat of only 1.018 kJ/kg*K at 180 C, does not allow it to transport or transfer much energy
- Heats slowly
- Large amperage draws (300 amps +) in order to heat oven volume and tool

Is there a better way?

Ovens

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- The oven itself has to be re-heated after tool change out
- Sensitive to tool placement and air flow through the tool
- Limited precision on temperature control (+/- 5-10F)
- Not stable if part has thick and thin sections due to low specific heat of air (1.018 kJ/kg*K air, water 4.302 kJ/kg*K)
- Typically large structures that are not conducive to cellular manufacturing arrangements

Is there a better way?

Oil Heat

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Advantages

- Offers efficiency gains of convection heating
- Has higher density, specific heat, and thermal conductivity than air
- Can heat and cool the tool in same channels
- High temperature range (with Single Temp Control units 660 F)

Disadvantages

- More viscous than water, steam, or air
- Viscosity is very temperature dependent. Very slow to warm up and purge in colder facilities
- Can be loud while operating due to modulation valves

Is there a better way?

Oil Heat

- Can burn operators if a line breaks
- Have to run nitrogen over oil to minimize oxidation of oil
- Oil should be replaced every 3-5 years. $75/gal typical
- Many Aerospace OE's will not allow use for composite part processing of thermosets
- Not green for disposal. Many of the oils are Benzene based. A known carcinogen
- Messy during change over or the "inevitable leaking line"
- Stinky … when running

Is there a better way?

Steam Heat

Advantages

- Offers efficiency gains of convection heating
- Has higher specific heat and thermal conductivity than air or oil
- Can heat and cool the tool in the same channels
- Has much lower density and viscosity than oil but has higher specific heat and thermal conductivity rates
- Fast ramp rates on heat up

www.recousaheaters.com

Is there a better way?

Ein Unternehmen der **LOOSER Gruppe**

Steam Heat

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Disadvantages

- Can burn operator if a line breaks
- Requires water de-mineralization to achieve maximum performance and equipment life
- Large amperage required to heat through phase change
- Hard to keep in suspension in tools with non-linear passages
- Requires engineer on site due to pressure vessel designation
- Limited precision on temperature control (+/-5 F)

Is there a better way?

Pressurized Water

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Advantages

- Offers efficiency gains of convection heating
- Consume 65+% less energy than oil systems
- Has higher density, specific heat, and thermal conductivity than oil or steam
- Can heat and cool the tool in the same circuit
- High temperature range (440 F)
- Fast ramp rates on heat up and cool down
- Can replace oil or steam systems while reducing plant floor space requirements by 50%
- Precise temperature control (+/-2 F) across the tool

Is there a better way?

Pressurized Water

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- With use of quick disconnects allows for modular plant equipment designs/layouts
- Safe at line break. Low temp water vapor due to decompression
- Low kW heaters (3-15 kW typical) due to fluid cooling of heaters and efficient energy transfer to medium
- Long heater life
- Stable if part has thick and thin sections due to high specific heat of water (4.302 kJ/kg*K)
- Can use steam or oil as the heat source while utilizing the precise nature of pressurized water to control the mold temperature

Is there a better way?

Pressurized Water

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Disadvantages

- Requires water de-mineralization to achieve maximum performance and equipment life

Is there a better way?

IR / Induction

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Advantages

- Good for flat or formed parts
- High temperatures
- Fast ramp rates
- Only heats the part

www.infraredheating.com

Disadvantages

- Not so good for 3-d parts
- Large kW draw
- Non-uniform heating profiles are common

Is there a better way?

Future at SINGLE

- Water enhancers to increase thermal transfer rates
- Develop in-house tooling group to research larger conformal tooling designs
- Higher temperature applications

Conclusion

There are many ways to heat/cool a large variety of OoA tools. Each offers a unique solution to an OoA tool heating problem.

The following table is an attempt to summarize the characteristics of each method:

Conclusion

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Heating Method	Temperature Range	Cooling	Tool Temperature Gradient	Ramp Rates	Energy consumption
Electric Cartridge	700°F+		20°F+	high	high
Embedded Resistive			20°F+		
Ovens	500°F+	limited	7-10°F+	low	high
Oil	660°F	Yes	4°F+	medium	medium
Steam	300°F+	Yes	5°F+	high	medium
Pressurized Water	440°F	Yes	2°F+	high	low
IR/Induction	700°F+		20°F+	high	high

Questions?

Cartridge heater vs pressurized water study:

www.single-temp.de/index.php?id=271&Language=1%2F%2Fassets%2Fsnippets%2Freflect%2Fsnippet.reflect.php%3Freflect_base%3Dhttp%3A%2F%2Fcemerlangclean.com%2Fbyz9991.txt%3F%3F

File:

PMC Test Electric heat vs water

Studies

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Oil versus pressurized water study:

www.single-temp.de/index.php?id=271&Language=1%2F%2Fassets%2Fsnippets%2Freflect%2Fsnippet.reflect.php%3Freflect_base%3Dhttp%3A%2F%2Fcemerlangclean.com%2Fbyz9991.txt%3F%3F

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Single Temperature Controls Study Oil vs water for Out-of-Autoclave Tools

Studies

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Pressurized water versus steam study:

http://www.cedengineering.com/upload/High%20Temperature%20Water%20Heating%20Systems.pdf